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CULTURAL ROOTS OF TECHNOLOGY: AN INTERDISCIPLINARY STUDY OF
AUTOMATED SYSTEMS FROM THE ANTIQUITY TO THE RENAISSANCE

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muta cantare, insensata vivere, immobilia moveri
Cassiodorus*, Variae,* I, 45, 10

Contents

1 Introduction

People (and scholars) have been fascinated by automata since Antiquity: automata have often been related to the idea of creation, suggesting that man could build another being, though artificial, by means of his competence and knowledge, forcing or imitating natural laws.

Human interest about automata however seems not to be constant along the centuries: we witness an increase in the number of studies, and quotations, mainly in periods in which big and rapid technological development is in action, while in technological stagnation periods, references inevitably decrease.

This study covers the part of the automata history that ranges from the Antiquity to the Renaissance, due to the strong interdependence of design and content, recurring during the considered centuries, as it will be more widely discussed in 1.2.3.

1.1 Literature Review

A main question must firstly be faced, related to the word used to refer to automata.
The etymology of the term passes through the Latin automatus, transliteration of the Greek adjective αὐτόματος, coming from the determinative adjective αὐτὸς (self) and the verbal adjective ματὸς (having in mind, acting) 1. It was at first used to refer to any event or human behaviour that was spontaneous, without external intervention; only later, during the Hellenism, its use was extended to those mechanical devices, which perform, after a user's input, a finite number of default actions, typically, but not necessarily in a periodic sequence.
It follows that in classical literature we find the words automatus / αὐτόματος (and derived) used in contexts where no automata are involved (Homer, Ilias, II 408; Hesiod, Works and Days, 102-105; Aristophanes, Acharnians 976; Petronius, Satyricon, L and CXL), and, on the other side, we have descriptions of automata, where the term is not present (Homer, Ilias, XVIII 468-473; Odyssey, VII 91-94; any instance in Philon's or Heron's Pneumatics; Gellius, Attic Nights, X 12, 9-10; Palaephatus, On Incredible Tales, 5). Only in few cases we have a description where an automaton is referred to as automatus / αὐτόματος (such as Homer, Ilias, V 749-752; XVIII 372-377; Heron's Automata; Sextus Empiricus, Outlines of Pyrrhonism A115).
During the Middle Ages, and in the early Renaissance, the word is fully discarded; whenever what we call an automaton is described, it is referred to considering rather its look and behaviour: so we have singing birds, moving or drinking (anthropomorphic or theriomorphic) statues, opening doors, and many more; or the skills of his builder, so we have *ingenium*, *engiens*, *ingegni*. Only after the 16th-century translations of Heron's *Automata*, the word returns in use and it appears in Italian, French, and other vernaculars (*automati*), too.

1.1.1 Monographic Studies

The first written references to such objects in Greek literature, are in Homer's, Plato's, and Aristotle's works, where automata are not always associated with human figures, but can consist in automated devices or systems, such as tripods or plectra. In the last decades, ancient Greek works

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1 Due to the meaning of the verb μάω (cfr. Sanscrit *matah*, Latin *mens*, Lithuanian *mintas*), the adjective is strictly connected with thought and will, more than with action, intended here as an effect of thought and/or will.

have been studied by some scholars [1-11], in order to highlight "important references to specific autonomous systems and mechanisms of very advanced technology, such as automata and artificial intelligence, as well as to almost modern methods of design and production", as stated in the volume abstract [12] about science and technology in Homeric epics. These studies represent one of the most effective attempts to break the deadlock of the absence of technical literature at Homer's times (7th century BC), by means of the study of literary sources, conveniently supported by technical analysis and historical evidence. Such an interdisciplinary approach, though between written and figurative sources, was also used by Amedick [13], leading to interesting results. D'Arrigo, in the 1950s, studied Archytas' dove from an engineering point of view [14-15], trying to demonstrate that the Greek philosopher could have a suitable knowledge to build such a device. Berryman [16] has recently studied most of these literary references, denying the possibility that they represent the true mechanical automata.

Ancient writers mention talking statues, especially dating back to the Egyptian world: apart from traditional collections of references to these ancient sources [17], studies of this acoustic phenomenon have recently been made by Pettorino [18-21].

In Alexandria, during the Ptolemaic kingdom (305-30 BC), and shortly after, we witness the greatest progress of such researches in a scientific and technological perspective: Ctesibios (3rd century BC), Philon (3rd century BC), and Heron (1st century AD) wrote significant treatises, which would pave the way both to the persistence of such engineering knowledge in Byzantium, and to the spread of mechanical studies in the Arabic world. The first written studies about this period and works date back to the 16th century, when, within the the courts of Ferrara and Urbino, a remarkable work of editing and translation of Heron's treatises, both in Latin and in vernacular, was performed: in 1501 edition of Giorgio Valla's encyclopedic work about sciences was included at chap. XV a long excerpt from a Latin translation of *Pneumatics* [22-23]; Federico Commandino edited the Latin text of the *Pneumatics* in 1575 [24]; Giovan Battista Aleotti edited and translated the *Pneumatics* into vernacular in 1589 [25-26], and Bernardino Baldi edited the *Automata* in vernacular [27]; two years later, the *Pneumatics* was edited in vernacular by Alessandro Giorgi as well [28]. These translations will be studied in chapter 2.5.2.3. As evidenced by some contemporary essays, the common goal of Renaissance scholars was to make this text available to themselves [29], or to their contemporaries [30-37] both interested in mechanics from the theoretical point of view and responsible for the construction of automatic devices at the courts of Italian lords (mainly in Ferrara, Urbino, Mantua, Florence, Milan) during religious, or civil festivals [38-41], or in their country villas, like Pratolino near Florence, or Tivoli near Rome [42]. In order to have accurate critical edition and historical analysis of ancient works by Heron and Philon, we must wait until the end of the 17th century when the first Greek edition was made in France [43]; later, in the 19th century Prou wrote an essay about *Automata* by Heron [44], and respectively Schmidt [45-46] and Carra de Vaux [47] censed the manuscripts housed in European libraries. Schmidt made the critical edition of the Greek texts by Heron, having a large number of manuscripts, and added an appendix containing a transcription of a Latin translation of *Pneumatics* by Philon. He also identified two families of manuscripts corresponding to two versions of the work: the second one, as a result of a later revision, is therefore referred to as a Pseudo-Heron. From this second version, comes one of the most important Latin translations, that is Giovanni Francesco Burana's version, dating from the 15th century. Carra de Vaux was however struggling with the much more complex tradition of

Philon, characterized by the absence of a complete Greek manuscript and by the presence of several Arabic and Latin versions, so he proceeded to make a double critical edition (in Greek and Arabic) and compared the resulting text with the Latin transcription of Schmidt. Apart from some isolated studies in the middle of the 20th century [48-49], since the Seventies we have seen a renewed interest in the topic of ancient Greek technology [50-76], culminating with the work by Russo [77], entirely dedicated to the Alexandrian age, with Micheli's philosophical research [78], and with Cambiano's studies about machines and automata [79-82]. A special quotation pertains to Lucentini's paper [83], dating back to 1962: it probably represents the only historical and thematical study about automata made by a novelist in order to study the evolution from the classical to the romantic automaton idea; the article also contains a chrestomathy (i.e. an anthology) of some literary passages in which automata appear.

During the Roman period, we apparently witness a total absence of interest in the automata theme; nearly no scholars or engineers seem to be interested in building or at least in describing these devices, except for some references in Vitruvius' work [84-86]. It is hard to say whether it depends on an actual lack of interest or on the triviality of the subject, due to the presence of automata in daily life and made possible by highly developed skills of mechanics, as the Antikythera mechanism suggests [87-88]; as a matter of fact, we have some late references to the persistence of automata use in public ceremonies (like Caesar's funeral, see Appianus, *Roman History*, II, 147), in private banquets (Petronius, *Satyricon*, LX), and in religious rituals related to oracles (Macrobius, *Saturnalia convivia*, I, 23 ,14). We are likely in front of a problem very similar to the age-old question of the Greek origin of the novel, marked by a deep difference between ancient and modern cultural categories [89-94]: it is possible that we are trying to apply a modern category to a variety of different classical categories. Similarities between ancient descriptions and the contemporary idea of automaton are evident and undeniable, but, even due to the inconsistent use of a precise term to define them, we should try to distinguish among various kinds of devices (stand-alone/integrated; big/small; described/designed; and so on), that are very different under many respects (for instance, aim, arrangement, material, energy source). A most evident example is Heron's work: he mainly used his designs and machines to show evidence of physical laws, by means of mechanics; he probably never thought of the devices described in the *Pneumatics*, as automata: the "narrative" part of the device is usually meant to impress the audience (other engineers, or, more probably, students), in order to attract their curiosity, and to prompt them to understand how the device works. The study of the continuity between Greece and Rome in technological studies is another interesting issue emerged from historical literature [95-101, 85, 102-119].

In the Early Middle Ages, in Western literature, technical descriptions disappear and give way to narrations of autobiographical or historical episodes in which there is a mechanical precision device, however mainly designed to the measurement of time (Cassiodorus's *Variae* and Eginardus' *Annales Regni Francorum*), or a musical instrument, typically an organ (*Annales Regni Francorum*), as shown in [120-122]. In Byzantium, natural heir of Greek mechanical tradition, we can't find any reference to mechanical treatises devoted to automata, though some interesting devices (a throne of Solomon's replica, for instance) are described in histories of the emperors, set in the Imperial Palace, the Magnaura, also studied by several scholars [123-131]. These works were composed by the emperors themselves (Constantine Porphyrogenitus), by their historians (Georgius

Monachus, Symeon Magister, or the so-called Theophanes Continuatus), or by foreign ambassadors, like Liutprandus of Cremona, or Arabic voyagers [132-134].

In the same centuries, in the Arabic world, from Baghdad to al-Andalus, mechanical culture and practice underwent an extraordinary development, due partly to the translations of Greek treatises (Aristotle's, Philon's and Heron's), and partly to a self-interest for the construction of such devices, for the caliph's fun and/or with practical purpose. Manuscripts of Banu Musa's (800-860), of al-Jazari's (1136-1206), and of al-Muradi's (11th century) works are housed in European and Middle-Eastern libraries, as witnesses both of the extraordinary level of development of these studies, and of the interest in their contents. Banu Musa's and al-Jazari's works were however brought to public attention and published only in the 1970s by Hill (1922–1994), a British engineer and historian of science and technology, who not only edited the manuscripts with the help of another historian, al-Hassan, but rebuilt in several occasions the rich landscape of Arabic medieval engineering and technology, also in its relationships with the Ancient and Medieval European technical culture and tradition [135-146]. Losano was involved as well in the history of automata, starting right from al-Jazari's treatise: he analyzed in particular the work genesis and the relationship with the previous tradition [147-148], extending over time the subject considered from Arabic automata to the general history of automata [149-150]. In Lebanon and in Turkey, new editions of Banu Musa's treatise have been carried out since the 1980s [151-152]. Cigola's studies about Arabic automata focused both on historical environment and on drawings and representations [153-155]. Studies about al-Muradi's manuscript, began in the 1980s: Hill was sorry for its poor state of preservation [156, 141], regretting that it would never be read, but recently technological progress has made it possible, thanks to the group Leonardo3 and to a team of philologists at the University of Milan (Jolanda Guardi, Alba Fedeli, Hocine Benchina) [157], though several less complete studies were already in progress mainly in Spain [158-168]. In recent times the above mentioned approach consisting in the use of literary sources, has been extended even to Arabic literature [169]. Also deserving of mention are several studies carried out by some scholars [170-177] with the aim of writing a non-Eurocentric history of Medieval technology, and of giving more emphasis and attention to the Arabo-Islamic mechanical culture. Many recent works on the subject are available at websites like http://www.history-science-technology.com, or www.muslimheritage.com, whose ambitious claim is "Discover 1000 years of missing history".

Probably fascinated by the stories of travelers in the Eastern lands or by Crusaders' tales [178-179], Medieval poets and writers (Benoît de Sainte Maure, Thomas of Britain, Alexandre de Bernay, Wolfram von Eschenbach, and many more), living at the French, German, and English courts, included in their romances many automata, whose design and implementation were however attributed not to scientists or engineers, but to magicians or necromancers. Some philological and historical studies have led in the last century to the census and to the analysis of these quotations [180-194], and the Medieval landscape of relationships between science and magic has been considered by Federici Vescovini [195]. As some well-known legends recount, even Gerbert d'Aurillac (945-1003), later pope Sylvester II, and the philosopher Albertus Magnus (1193/1206-1280) would have built talking human shaped automata, probably with the help of sorcery, though no positive historical evidence exists, as respectively shown among others by LaGrandeur, Flusche and Oldoni [196-198]. In the same years, however, the interest in hydraulic questions (and consequently for Philon's and Heron's works) was significantly growing just in a religious

environment: Benedictine, and later Cistercian, monasteries, where the monks needed to build efficient pipe systems, in order to improve fields irrigation, were probably the main way of technological diffusion in medieval Europe [199-204]. Due to their need for technical knowledge, they searched for ancient sources on the subject and began studying and copying Latin treatises taken from Arabic translations of Philon's *Pneumatics* (whose title would become *De spiritualibus/spiritalibus/subtilibus/specialibus ingeniis; De inani et vacuo; De conductibus aquarum*, wrongly attributed to Aristotle) [205-206]. During the 12th and 13th centuries, a feverish activity of translations of Greek scientific works, preserved only in Arabic version, began both in Spain and in Southern Norman Italy, as studied mainly by Haskins [207-212]. We have no incontrovertible news about translations dealing with our subject, so we can neither exclude that these translations (maybe partial) were actually made [2], nor assert that the mechanical knowledge transmission was strictly oral and only occurred in the workshops. There really was a European tradition in the field of mechanics, as shown by Long [214], though it was not evidenced by technical writings, but, for instance, by travelers' accounts. The work of the French architect Guillaume Boucher at the Court of the Khans have remained almost completely unknown, if he hadn't been quoted by the Flemish Franciscan missionary and explorer William of Rubruck in his report to King Louis IX (*Itinerarium fratris Willielmi de Rubruquis de ordine fratrum Minorum, Galli, Anno gratia 1253 ad partes Orientales*), studied by Olschki [215] and by Baltrušaitis [216] in the field of gothic art history. Such skills in mechanics would justify the existence of the so-called "merveilles" (automata) of the garden of the castle of Hesdin, in Artois, Northern France, [217-219], and of a unique Latin manuscript of mechanics, written for the king of Denmark [220], though not dealing with automata. Villard de Honnecourt's (ca. 1200-1250) sketchbook of drawings (Bibliothèque Nationale de France, MS. Fr. 19093) is another example of how the design of technical objects had developed in the 13th century: on several occasions, scholars have examined this author's work from a mechanical, artistic, and historical point of view [221-225]. Many general studies have also been carried on about medieval technology: one of the most important scholars on the field was Lynn T. White jr. (1907-1987), an American historian, who, since the 1940s, has focused his interest on topics, such as Medieval technology and inventiveness; he considered them crucial both for the development of Western technological supremacy, and for the importance they had together with Christianity, in the making of modern exploiting attitude towards the environment [226-234].

However, it is only in the 15th century that new sources are added to the late Medieval wealth of knowledge: mechanics was already applied to entertainment, as witnessed by the work of Giovanni Fontana [235], where also references to Arabic sources are made. The Council of Ferrara-Florence (1438-1445), the fall of Constantinople in the hands of the Turks in 1453, and the subsequent flight of many Greek scholars to the West, led to a copious flow of manuscripts of ancient Greek works in European libraries, and to a revival of studies in many fields, mechanics included. One of the most fascinating figures in such a landscape, as indicated, among others, by Keller [236], is definitely Cardinal Bessarion, whose collection of Greek manuscripts was given to the Serenissima and became the first germ of the Biblioteca Marciana of Venice: among them stands Gr. 516, the oldest known Greek manuscript of Heron's *Pneumatics* and *Automata*, copied in Greece in the 13th century by the scribe Andreas Telountas from Nauplion [46]. This manuscript was probably the

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[2] As Hill assumes [213] that "versions the book of al-Jazari and works by ither Islamic engineers may exist."

source of the Latin and vernacular translations made at the end of 16th century and introduced above. Bessarion wanted in his entourage the German scientist Johannes Müller from Königsberg (1434-1474), better known as Regiomontanus, who took part to Bessarion's travels in Italy, and later retired in Nürnberg with the intention to publish critical editions of ancient texts he passionately copied from Bessarion's manuscripts, also studied by Malpangotto [237], or during his travels in Eastern Europe. It is not probably a coincidence that some later sources (like Pierre de la Ramée, or Johann Wilhelm Baier) refer to him as automata builder [238-239]. The relationships between the new stream of ancient sources coming from Byzantium, and the beginning of the Renaissance have been deeply considered by Setton [240-241], and for minor aspects by Field and Wright [242]; De Gandt and Derenzini considered the influence of the pseudo-Aristotelian *Mechanics* upon mechanics development [243-244]. Many studies have been carried on various aspects of the Renaissance: Sarton and Benoit [245-246] investigated particularly the connection with medieval sciences; Eamon [247] studied the dependence of Renaissance science and technology on magic; Canestrini and Ceccarelli investigated the machines theme in the 15th century [37, 248]; Long's research interest in this subject consisted in the social contextualization of technology [249-251], while Parlato [252], Aracil [253], and Marr [254-255] focused straightforwardly on automata during the Renaissance; Fagiolo studied [256] the automata presence in Mannerist art; Galluzzi [257-258, 34, 259] concentrates on the Renaissance engineers, as Gille had already done some decades before [260]: Leonardo, among others; da Vinci's works have also been related with the sources pretending he was an automata builder, by several scholars [261-271].

At the end of the 16th century, after the massive above mentioned wave of Latin and vernacular translations, works about automata, showing a new mindset, and a different awareness of the subject, gradually appear (see 2.5.8.4). Due to the global effect on knowledge availability and dissemination [272-273], implied by the introduction of movable type printing, and to a profound change of mentality, mechanics is no longer conceived as a way to deceive natural laws, and turns into a truly scientific discipline; automata, in particular, finally lose their supernatural or magic traits [274], mostly becoming collectibles to be preserved by gentlemen in a Wunderkammer (cabinet of curiosities) and shown to friends [275-277], or working like an amusement park.

Western historiography of Chinese ancient and Medieval automatics deserves a separate consideration: it consists almost solely in the monumental, and well documented Needham's work [278], dating back to the middle of the 1960s; however, being a general survey, it briefly touches the subject, and merely refers to some sources. As far as we know at this time, no systematic comparative studies between Eastern and Western automatics have been made, apart from a very general one [279].

1.1.2   General Studies

General studies include both research on the history and evolution of automata from ancient times to the moment in which the study has been carried out, and diachronic inquiries on a particular kind of automaton, or on a precise theme, or about automata but under a specific point of view.

Probably the most famous and complete study about automata history has been carried on by the Swiss scholar Alfred Chapuis (1863-1942), who, alone or in collaboration with others [3], has been studying the subject and updating his results for 30 years, since the late 1920s [281-285]. Though his works mainly focus on clocks or jewelry with automata, he is the first to perform a reconstruction of automata history, retrieving information and iconographic documents, that will then be largely reused by almost all those who will disseminate on this issue, too often without any source reference. Being the study of human movement reproduction mechanisms his main center of attention, in his reconstruction he starts from jointed statuettes of Egyptian Middle Kingdom[4], probably the oldest artifact imitating some arms' movements; he briefly reviews the literary sources of the miracles performed by moving or talking statues and by masks (by quoting Loukianoff, [286] referring to item JE 66143) in Antiquity (chap. I), then he immediately focuses on the Hellenistic, Arabic, Renaissance (chap. II) instances; while describing later production, Chapuis abandons the chronological approach, and organizes his analysis based upon automata types or behavior [5]. Even though Chapuis' contribution is only for a small part focused on the considered subject, we must remark that for at least 30 years it has been the only diachronical study on automata from a technological point of view, spreading in Europe. Chapuis, in his essay dedicated to automata in the works of imagination [282], passes quickly through all the early references (already present, for example, in [287]) and pays more attention to 19th-century literature, an epoch certainly featuring great vivacity around the themes of automata and artificial life. Since the end of the 1950s, we have however witnessed an increase in publications about the subject, evidenced by the appearance of papers, books, and encyclopedia entries [288-293, 149, 294, 79, 295-298]. In addition to this literature production focused on automata history, we also see a new interest in the more general themes connected with technology history (or philosophy), such as engineering or machine history [299-300, 140, 301-303, 249, 304, 250-251, 305, 16, 214, 306-311] [6], nowadays the subject of a series of volumes published by Springer and edited by Ceccarelli and Paipetis (History of Mechanism and Machine Science). In addition, the Society for the History of Technology (SHOT), concerned both with the history of technological devices and processes, and with technology in history, has been publishing an outstanding journal on the topic (*Technology and Culture*), since 1958.

The spread of science fiction novels (and later movies) dating back to the end of the 19th century, arose curiosity about automata history and the need for the popularization of such contents, as evidenced in [312-325], and in the hundreds of websites on the Internet. Due to the broad variety of audience, possibly lacking in historical and/or mechanical knowledge, and almost certainly bored

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[3] Like the French watchmaker and collector Alfred Gélis, or the Swiss Edmond Droz, professor at École de méchanique in Neuchâtel, as well as a collaboration with the Swiss (and later French) architect Le Corbusier about clockworks results from his correspondence [280].

[4] Housed at Metropolitan Museum in New York: some wooden examples, dating back to 12th-13th dynasties (20th-18th century BC), coming from Memphis region, are now visible on museum website (www.metmuseum.org).

[5] As it is evident even from chapters titles : III. De quelques horloges monumentales à automates. IV. Horloges d'appartement anciennes et pièces d'orfèvrerie avec automates. V. Les automates dans les pendules riches. VI. Les horloges en bois et les pendules de fantaisie. VII. Tableaux mécaniques. VIII. Les jouets mécaniques. IX. Montres et tabatières à automates. X. Les oiseaux chantants. X J. animaux mécaniques. Devins. Magiciens. Escamoteurs, etc. XIII. Musique automatique. Automates musiciens. XIV. Androïdes écrivains et dessinateurs. XV. Automates marchants, parlants. XVI. Automates de fantaisie. XVII. Vitrines animées. XVIII. Mécanique truquée (Théâtres. Pseudo-automates. Demi-automates). XIX. Des Robots et de l'Automatisme

[6] Perhaps this was encouraged also by the long wave of the French Annales school, which has carried at the heart of historic interest even the material culture (*histoire totale*).

by detailed descriptions of mechanisms or by accurate historical reconstructions, in such works authors paid more attention to audience amusement or to the need for amazing readers with unexpected interpretations, than to facts and sources exactness, so that sometimes narrated events are confused, altered or referred to obscurely. Usually these writers refer only to the most common sources, without adding any original content, apart sometimes from drawings, representing the imagined appearance of automata. Some of these papers, though by different authors, living in different countries and writing in different languages, are quite identical in content: a possible explanation for the oldest works can be the very difficult access to sources, and the non-scientific needs of their audience, which made such plagiarism permissible, according to them. An example can be found in the tradition about ancient oracles, which were believed to be linked to automata: an episode is quoted in Pausanias' *Description* (9.39.10-11) dating back to the 2nd century AD, quoted by the contemporary Maximus of Tyre's *Dissertations* (XIV, 1); it is later cited in Clavier's book written in 1818 [326] and quoted by Salverte in 1829 [327], whose work is summarized in 1830 in an English journal [328], and largely taken in an article [314] in the late 1920s, without any reference. The most interesting issue of such reconstruction is that Clavier added the following personal inference to the description of the descent to the oracle through a narrow hole: "il est vraisemblable que à l'aide de quelques mécanique, ce trou s'élargisseoit subitement lorsque les genoux y étoient entrés; autrement le corps n'auroit pas pu être entraîné avec autant de rapidité que le dit Pausanias, puis que le plus difficile restoit à passer" [7]. What looked likely to Clavier, is attributed directly to Pausanias in the subsequent references.

If we examine general studies in order to identify authors' aims, a variety of approaches appears: automata, like other subjects, have often been studied to validate an author's philosophical or historical thesis, emphasizing (and sometimes overemphasizing) or, on the contrary, underestimating one or some features. Some scholars highlighted the continuity of automata and robots, considered their likely heirs, by neglecting the relevance of differences [329-330, 297, 331-332, 325]; engineering historians, on the contrary, are sometimes primarily interested in verifying whether the studied descriptions can or cannot be actually implemented, regardless of historical issues [267, 333, 269, 157]; an opposite approach is followed by scholars with a humanistic background, who privilege literary and, generally speaking, written sources, neglecting design principles or even designs "*stricto sensu*"; other researchers remark the idea of creation, in a way implicit in any automata, focusing obviously on anthropomorphic or zoomorphic ones, imitating life [8], or, at least, some behaviors of living beings [334-337]; in Descartes' work *Treatise about man* (*Traité de l'homme*, 1648), however, automata are used epistemologically as a metaphor to describe the physiology of human and animal body [9], and, in *Passions of the Soul* (*Passions de*

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[7] "It is likely that, by means of some mechanisms, this hole could suddenly become larger, when the knees had entered, otherwise the body would not have been drawn as quick as Pausanias says, and the most difficult part [of the body] had not passed yet."

[8] Sometimes called "machinic", "mechanical", or "artificial" life.

[9] « Je suppose que le corps n'est autre chose qu'une statue ou machine de terre que Dieu forme tout exprès pour la rendre la plus semblable à nous qu'il est possible […] en sorte qu'elle imite toutes celles de nos fonctions qui peuvent être imaginées procéder de la matière, et ne dépende que de la disposition des organes. Nous voyons des horloges, des fontaines artificielles, des moulins et autres semblables machines qui, n'étant faites que par des hommes, ne laissent pas d'avoir la force de se mouvoir d'elles - mêmes en plusieurs diverses façons […]. Ainsi que vous pouvez avoir vu dans les grottes et les fontaines qui sont aux jardins de nos rois, que la seule force dont l'eau se meut en sortant de sa source est suffisante pour y mouvoir diverses machines, et même pour les y faire jouer de quelques instruments, ou prononcer quelques paroles, selon la diverse disposition des tuyaux qui la conduisent.»

l'âme, 1649), the philosopher equates the two possible states (working/not working) of machines to men's (alive/dead) states [338-339] [10]. Thematic researches have been carried out by Battisti [340-343], who studied automata as artistic objects, or, to use his own words, as "statue in movimento" (moving statues).

A final observation must be made about the difficulties of finding and verifying sources: internet penetration and the presence of large online archives (www.archive.org; http://www.perseus.tufts.edu, www.jstor.com, http://archimedes.mpiwg-berlin.mpg.de, www.edit16.it, just to quote the most used ones), repositories, and data bases have undoubtedly allowed to proceed with more precision and speed than before, by immediately and/or repeatedly checking remote sources and texts of past centuries, even existing in a few specimens, and by crossing references.

From the brief overview of general studies above, the need for multidisciplinary skills, or for the establishment of a research team skilled on many fields, is clear for those who are approaching these studies; unfortunately the history of technology is often considered as a minor discipline, and investigation is confined by scholars out of their leading researches, or teaching activity, and therefore carried out solo. This necessarily leads to a fragmented and discontinuous trend of studies.

1.2 Research Question Definition

Over the past few decades, many projects have been carried out in order to even virtually build (according to given requirements), to rebuild or to restore "historical" automata (by John Gaughan, an American manufacturer of equipment for magicians, whose works are visible on Youtube [11]; by Leonardo3 group [269, 344]; by Mark Rosheim [265]; by Istituto e Museo di Storia della Scienza, now Museo Galileo, in Florence).

Such devices rise fascinating questions about the purpose of those particular reconstructions: is it a pure and sterile antiquarian interest or a sincere desire to learn from them something otherwise hopelessly lost? And what is the legitimate limit in the "interpretation" of drawings and/or implementation? In the meanwhile, as shown in 1.1, a large number of studies has been made, in order to collect references and texts about automata, dating back to different periods.

"I suppose that the body is nothing but a statue or a machine of earth, that God has purposely made as similar as possible to us [...] so she utters all of our functions that can be imagined to proceed from the matter, and depend only on the organs disposition. We see that clocks, artificial fountains, mills and other similar machines which are made only by men, do not fail to have the strength to move - even in different ways [...]. As you may have seen in the caves and springs that are the gardens of our kings, that the only force that moves the water leaving its source, is sufficient to move various machines, and even to make them play some instruments, or pronounce a few words, by varying the arrangement of the leading pipes."

[10] AT XI : « […] Jugeons que le corps d'un homme vivant diffère autant de celui d'un homme mort que fait une montre, ou autre automate (c'est-à-dire autre machine qui se meut de soi-même), lorsqu'elle est montée et qu'elle a en soi le principe corporel des mouvements pour lesquels elle est instituée, avec tout ce qui est requis pour son action, et la même montre ou autre machine, lorsqu'elle est rompue et que le principe de son mouvement cesse d'agir.»

"Let us […] conceive that the body of a living man differs as much from that of a dead one, as a watch or any other automaton (that is any kind of machine that moves of itself) wound up, having in itself the corporeal principle of those motions for which it was instituted, with all things requisite for its action, and the same watch or other engine when it is broken and the principle of its motion ceases to act."

[11] http://www.youtube.com/watch?v=ZQCt6rglRdU; it is interesting to remark the presence of an archer and of a peacock, among other automata. His works has also been presented on the New York Times (online edition) http://www.nytimes.com/2008/05/18/fashion/18magic.html?_r=1&ref=design

Such a dichotomy in the state of art of studies thus emphasizes the need for an interdisciplinary approach that integrates the results achieved in the two research fields, in order to restore unity to the studies, without compromising either the historical or the technological aspects.

A first step in this direction had already been made in 1970, when Otto Mayr, a German engineer, studied the origins of feedback control in a work, now become a classical essay [290]; his investigation paved the way to a new method of studying the history of science as history of ideas. Such an interdisciplinary approach has been recently followed by other studies, predominantly, but not only carried out by Greek scholars, as shown above.

The milestone in this approach - directly related to computer science - is however the work of Donald E. Knuth (1938-), who, shortly after Mayr's book, extended his interests to the history of science, in order to analyze algorithms in ancient and Medieval sources [345]. His attention focused on the Babylonians and al-Khwarizmi, in whose artifacts and works he found the first instances of the main subject of his studies in computer science, even though in a different context.

Based on these considerations, it seemed interesting to delve into a technological topic, such as automata, which has proven over time to be structurally interdisciplinary, involving from time to time technical drawing, art, religion, stage design, mythology, philosophy, mechanical engineering, clockwork, magic, computer science, literature; furthermore most people consider it as a precursor of robotics; the huge number of sources and references made it necessary to choose a limited historical range, as shown in 1.2.3.

1.2.1 What is an Automaton?

As already discussed in 1.1.1., not only the concept, but also the word "automaton" has been used inconsistently since Antiquity and, in some periods, like the Middle Ages, it is even completely missing, even though most (probably all) modern readers would identify such devices as automata.

This inconsistency is even more evident if one looks for a definition suitable to include all or most of the historical automata. Unfortunately, we have to cope with the absence of a uniform definition suitable to be applied to such different historical and literary sources, in order to identify single machines or devices as automata, as Mayr [346] could do with feed-back control, by using the definition given in 1951 by the American Institute of Electrical Engineers. It is therefore necessary to identify the descriptive traits most commonly attributed to automata, and to eventually update them, when necessary, during the historical reconstruction.

Some of these definitions, taken from contemporary common, otr thematic dictionaries, are the following:

Dictionary	Definition
Webster (1913)	Any thing or being regarded as having the power of spontaneous motion or action.
	A self-moving machine, or one which has its motive power within itself; - applied chiefly to machines which appear to imitate spontaneously the motions of living beings, such as men, birds, etc.
Feldhaus (1914)	Eine selbstbewegliche Figur. (A self-moving figure)

Dictionnaire de l'Académie française (1992-)	Machine qui a en soi les ressorts de son mouvement. (Machine which has in itself the resources for his movement.) Imitation d'un corps animé renfermant un mécanisme qui le met en mouvement. (Imitation of a living body including a mechanism that sets it in motion.) Mécanisme, machine automatique capable d'exécuter un programme déterminé d'opérations. (Mechanism, automatic machine capable of executing a given sequence of operations.)
Collins (2003)	a mechanical device operating under its own hidden power
Longman (2003)	a machine, especially one in the shape of a human, that moves without anyone controlling it
Wordnet 3.0 2003-2008	a mechanism that can move automatically
	device consisting of a piece of machinery; has moving parts that perform some function
Diccionario Manual de la Lengua Española Vox. (2007)	Aparato provisto de un mecanismo interior que le permite ciertos movimientos (Device provided with an internal mechanism that allows certain movements) Máquina electrónica fabricada para realizar automáticamente movimientos y acciones propios de un ser animado. (electronic machine manufactured to automatically perform movements and actions of an animate being)
Cambridge (2008)	A machine which operates on its own without the need for human control
Diccionario Enciclopédica Vox 1 (2009)	Máquina que imita la figura y los movimientos de un ser animado. (Machine that mimics the shape and movements of an animate being.)
Larousse Online (accessed 2010)	Machine qui, par le moyen de dispositifs mécaniques, pneumatiques, hydrauliques, électriques ou électroniques, est capable d'actes imitant ceux des corps animés. (Machine which, by mechanical, pneumatic, hydraulic, electrical or electronic means, is capable of mimicking acts like those of animated bodies) Machine et mécanisme automatiques, utilisés par exemple pour la peinture et le soudage dans l'industrie automobile. (Machine and automatic mechanism, used for example for painting and welding in automotive industry)
Treccani On-line (s.d.)	Macchina che riproduce i movimenti (e in genere anche l'aspetto esterno) dell'uomo e degli animali. Machine that mimics the movements (and usually the outer appearance) of man and animals.
Ефремова (2007)	Устройство, самостоятельно, без непосредственного участия человека выполняющее какие-л. действия или операции в соответствии с заранее заданной программой. A device carrying out, independently, without direct human intervention,

	some actions or transactions in accordance with a predetermined program.
Britannica	any of various mechanical objects that are relatively self-operating after they have been set in motion
Oxford (2010)	a moving mechanical device made in imitation of a human being
	a machine which performs functions according to a predetermined set of coded instructions

By a simple count of the occurrence of the most significant terms, words like "machine", "mechanical" and "mechanism" take large numerical precedence over the others, highlighting the fact that the most noticeable trait of these devices is their mechanical nature, followed by the ideas of "motion" and generic "operation"; "imitation" appears as a less important trait.

Most of the other terms occur only once, indicating that these are the most variable terms, or at least perceived as not essential in definitions. In Fig. 1, a graph, summarizing the above, is presented (for occurrences equal to or greater than 3).
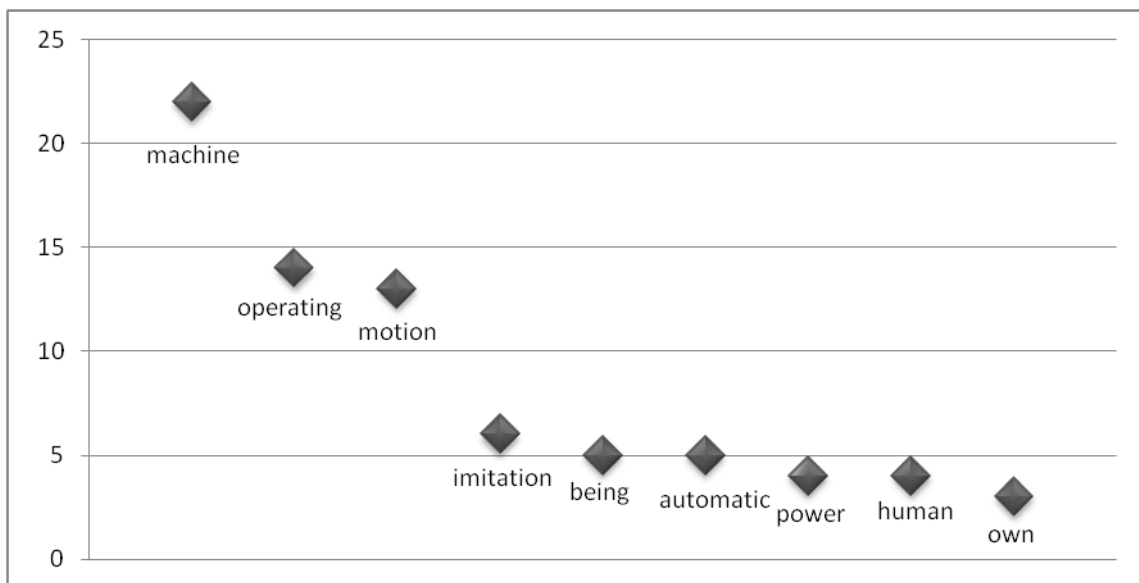

Fig. 1: Terms occurrence in automaton definitions (values ≥ 3)

Another study of definitions can be performed by grouping terms in categories emerging from a thematic analysis, as it is usually done in social sciences researches based upon content analysis [12].

The features of "automaton" concept appear more various, as shown in Fig. 2: they are mainly associated with the ideas of "mechanism" and "self", though relationships between some other categories can be found. For instance, complementary categories like "generic action" and

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[12] Such analysis can be defined as a "way of discerning, examining, comparing and contrasting, and interpreting meaningful patterns or themes" [347]. Thereby the more suitable approach seems to be the Qualitative Content analysis: within such approach "meaningfulness is determined by the particular goals and objectives of the project: the same data can be analyzed and synthesized from multiple angles depending on the particular research or evaluation questions being addressed" [347]. Content analysis has been defined as a systematic, replicable technique for analysis text content by categories based on explicit rules of coding [348-350]. A broader definition by Holsti [351] defines it as "any technique for making inferences by objectively and systematically identifying specified characteristics of messages". According to Stemler [352], it can be a useful technique for discovering and describing the focus of individual, group, institutional, or social attention.

"movement" emphasize the idea of "activity", while "imitation", "shape", and "life" categories highlight the concept of "simulation".
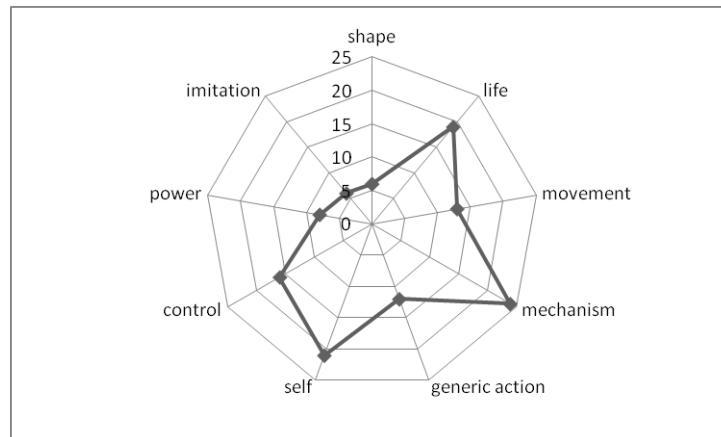

Fig. 2: Emerging categories in automaton definitions

As we can see, it is a multifaceted concept, not necessarily attributable to a single object behavior and activity, but more often to a system, with respect to both components of the mechanism, and to a possible multiplicity of interacting automata present together in the same context.

To better represent such complexity, we have chosen to refer to automata as to "automated systems" in the title of this work.

1.2.2 Automata Features and Need for Classification

Strictly connected with the need for concept definition, classification can be an interesting means to understand how scholars have been referring to automata along time. Unfortunately, taxonomies were generally not possible for many reasons: firstly, because features attributed to objects called automata are not the same in all periods; then, because scholars' points of view are not uniform, based on different skills, knowledge and investigative purposes; finally, because the scholars' interest has often focused more on external descriptions, on technical issues, on specific implementations or on individual designers than on automata in themselves.

One of the rare essay of taxonomy has been made by Pugliara [67], who, while studying animated and self-moving ancient statues, identifies 4 categories:

1. *perfect copies of livings*: descriptions of art objects emphasize the skills of the artist who can make them look so realistic, that anyone can think they have their own souls (e.g. Myron's cow cycle in *Anthologia Palatina*, IX, 713-742 and 793-798);

2. *statues able to lose immobility*: images to which sources attribute potential and unexpected behaviors, produced by inexplicable magic, or by a miracle (e.g. Galateia and Pygmalion; Plutarch, *Camillus*, VI, and *Coriolanus* XXXVIII: a Juno's statue would have talked to Camillus at the presence of many people, while in the second episode, a statue of Fortuna would have spoken to the Roman women as well).

3. *simulacra artfully speaking*: statues that charlatans, initiates, priests, and magicians make move or speak, through devices able to produce the desired temporary effect in a spellbound and naive audience (e.g. *Diodorus* IV, 51: Medea would have build a statue of Artemis,

filled with all sorts of magic potions, which would have been able of protecting the town of Iolco).

4. *self-moving statues* (explicitly called "automi"): simulacra are designed and built as self-moving, fitted with hidden mechanisms that, after a human input, allow a movement of at least some parts of it, or the emission of sound, by means of techniques based upon scientific laws. The term "automa" is then referred both to anthropomorphic and to zoomorphic figures, and, finally, to systems (such as fountains, clocks, hydraulic equipment, theaters), within which the builder had put a mechanism for "automatic" motion.

Pugliara also states that in the first three types of statues the illusion of movement prevails, while the last type is the only one in which the movement, though possibly partial, is real. The author also draws the difference between "animated" statue (the first three types), where the artist's purpose is mimetic perfection celebrating nature power (φύσις), and "self-moving" one, where the builder's aim is to show his extraordinary technical skills (τέχνη).

In some cases, automata are studied as part of a broader context, as the history of technology, in which they are placed, for instance, by Bedini [298] as the first step of the development of mechanisms able to mimic actual, enhanced, or dreamed human skills; Belardi [307] studies the term etymology in connection with the concept of machine in ancient Greece; Maitre [345] emphasizes the importance of feedback, performing the same (or higher) function as the senses in humans, in order to discriminate between mechanization and automation.

Rather than identifying some arbitrary criteria for automata classification, we have preferred to point out some dimensions referable to automata descriptions:

- *Built/imagined automata*: along this dimension are located the various kinds of automata, depending on whether they were actually implemented (or at least completely designed, and thus implementable) or only figured out by the imagination of a writer or a poet. In some rare case, it will be evident that both features are referable to the same automaton.

- *Static/moving automata*: perhaps the oldest sorting, made by Heron himself in the prologue of his *Automata*. Though movement is always present, the author distinguishes moving automata, that is self-moving statues posed on a moving structure, from static automata, for instance, a kind of miniature theater, where scenes take automatically place, but only parts of the scene (i.e., ships, men, dolphins) are moving.

- *Useful/useless automata*: this is undoubtedly a dimension far from the mindset of those who described or designed automata during the considered period; some scholars [353-355, 140, 97, 356-357] emphasized such feature, mainly while comparing Greek or Western automata with the Arabic ones. As a matter of fact, we must remark that, at first sight, most of ancient automata actually don't have practical use for everyday life. In addition, the massive presence of the theme of wonder (θαῦμα), and the substantial lack of information on the actual implementation of automata by Heron and by other technicians, have often led to think that they may not be considered useful, not even by their designers, in spite of what Heron writes in his *Pneumatics* [13]. We should however pay attention not only to the literal

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[13] Pneumatics I. Proemium 15-20: "διὰ γὰρ συμπλοκῆς ἀέρος καὶ πυρὸς καὶ ὕδατος καὶ γῆς καὶ τῶν τριῶν στοιχείων ἢ καὶ τῶν τεσσάρων συμπλεκομένων ποικίλαι διαθέσεις ἐνεργοῦνται, αἱ μὲν ἀναγκαιοτάτας τῷ βίῳ τούτῳ χρείας παρέχουσαι, αἱ δὲ ἐκπληκτικόν τινα θαυμασμὸν ἐπιδεικνύμεναι." "As a matter of fact, by means of the mixture of air,

meaning of the word θαῦμα, but also to the author's true aim, as stated by Tybjerg [76] for Heron: the Greek author has probably undersized his interest in the practical usefulness of his works, in the belief that his research would appear of lower quality, because of the ancient culture preference for abstract studies. Another interesting remark can be added, pertaining the pseudo-Aristotle's *Problemata mechanica*, also known as *Mechanics*, a content technically connected with automata; the treatise's first sentence is precisely "Θαυμάζεται τῶν μὲν κατὰ φύσιν συμβαινόντων, ὅσον ἀγνοεῖται τὸ αἴτιον, τῶν δὲ παρὰ φύσιν, ὅσα γίγνεται διὰ τέχνην πρὸς τὸ συμφέρον τοῖς ἀνθρώποις" [14]; as we can see, the author immediately emphasizes the function given to wonder, both as a preliminary motivation indispensable to any research, and as an attitude that must attend to the investigation work itself [15] [79]. As Ferrari [55, 58] has very well stated, however, the *Pneumatics* paved a new way in mechanics: as a matter of fact, specific devices, not related to everyday use, were made both for principle validation purposes, and to provoke wonder; and then, we might add, taking into account the physicians-to-be, that is the main recipients of works about pneumatics, to stimulate the desire to understand (and possibly imitate) devices operation. In any case (demonstration issues, or stimulation to learning), usefulness can't be excluded.

- *Things/Beings*: it appears that, over the centuries, poets, writers, designers, and engineers described and/or designed and implemented, even for different purposes:
  - man-made artifacts (that is things, like tripods, or vessels) that spontaneously perform the function they were built for, without any human intervention, in some cases after an initial input;
  - representations of living beings (plants, animals or humans) capable of performing at least one of the actions they do in the environment (e.g., to rustle, to sing, to care for the offspring, to shoot an arrow, to talk).
- *Simulacra/Automata*: De Solla Price [358] defines automata as "mechanisms designed by ingenious artificers to simulate the natural universe" and makes a distinction between "simulacra" (simulating devices) and "automata" *stricto sensu* (self-moving devices), corresponding to the two traits of automata, both useful to illustrate the gradualness of the study of living beings in mechanical terms, by constantly adding more complex features.
- *Seriousness/fun*: in presenting the two main fields of activity (mathematics and mechanics) of Archimedes, Plutarch (*Marcellus*, 14, 3-4) emphasizes their own polarity (σπουδὴ/παιδιὰ, serious/funny subject), pointing out that the genius of Syracuse had almost reluctantly built machines only at the invitation of the local tyrant Hieron II, as proven by the total lack of writings on the subject [359, 80].
- *Duty/entertainment*: Sherwood [184], while introducing his works about Medieval automata in literary sources, divides automata into "machines assum[ing] human shape and

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fire, water and earth and combining three or four principles, varied arrangements can be made; they both provide the most necessary needs of our life and show an astonishing wonder."

[14] "Source of wonder are both phenomena that occur naturally whose cause is unknown, and, on the contrary, phenomena, that happen thanks to intervention and skills of man, for his own advantage."

[15] Such a view of wonder is present both in Plato's *Theaetetus* (155 d) and in other works by Aristotle (*Metaphysics* A 2, 982 b; *Rhetoric*, 11, 1371 a 31-b 9; *Poetics* 1448 b 4, 4-19); in particular in the passage from the *Rhetoric*, Aristotle says that wonder is inherent in the desire to learn, and both are source of pleasure. Equally delightful, as the philosopher says, is imitation, since, by matching model and result of imitation, we feel pleasure and learn something.

perform[ing] certain specified duties; such as, defending the entrance to a castle, guarding a bridge or a treasure" and "others, in the likeness of birds or beasts, [which] are intended merely for entertainment".

- *Input visibility/invisibility*: the purpose of the automata builders is generally to hide the device operation to spectators, so, whenever the event which serves as input is visible, it is camouflaged or placed in a context that prevents audience from immediately inferring the relationship of *post hoc ergo propter hoc* between cause (e.g., fire ignition) and effect (door opening), which would negate the element of surprise.

These dimensions allow us to approach in a less superficial way the automated systems studied in this work, highlighting common and uncommon features.

1.2.3 Historical Period Definition

As stated by Randell about the origins of computer programming, a subject related with automata, "One of the difficulties of discussing the historical origins of a subject is to decide where to begin" [360], since this involves the identification of an event or a figure considered crucial for the theme; we could add that, in our case, it is much harder to decide where to end, given the impossibility to cover the whole subject history until nowadays.

If for the beginning it is relatively easy to decide to start with the oldest sources, as most of the historians have already done, it is much more difficult to identify a moment that could represent a real break in the history of automata, and, generally speaking, in disciplines connected with our subject. We have chosen to end with the Renaissance for several reasons, both intrinsic and extrinsic to automata theme.

Firstly, the Renaissance is a historical, and cultural moment in which a new attitude towards automata appears: the supernatural element, in some way native in their design and implementation since Antiquity, becomes less and less important, and it almost [16] vanishes, replaced by science and technology. This is due to a renewed interest in the knowledge of the ancients, aimed at a deeper and correct understanding, not at its adaptation to Christianity, as it had happened during the Middle Ages. The Renaissance introduces the beginning of the passage from supernatural to technological wonder which will be completed with the baroque, when some devices will become even the subject of poems, beginning from Italy, with the poet Giovan Battista Marino (1569-1625), or his follower Ciro di Pers (1599-1663).

Secondly, after the Renaissance, designers' focus will permanently move from the dimension that we previously defined as simulacra/automata, that is from external appearance, to the application of mechanical principles to the imitation of living beings' physiology (see Descartes' idea of animals, or Vaucanson's duck).

The connotation of the word mechanics changes profoundly: associated by the Greeks with the idea of deception (of natural laws), and during the Middle Ages often connected with a not always orthodox esoteric knowledge, it becomes (at least partly) free from such negative nuances. The so-

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[16] Statues that are told to weep or bleed, object of great popular veneration during the Baroque mainly in Italy and in Spain, were never referred to as automata, though the term was at that moment commonly used and their behavior essentially similar.

called restorers of mathematics (as Maurolico, Commandino, Tartaglia, for example) often insist on the nobility of mechanics, due both to its mathematical foundation, and to the distinction between scientific knowledge of the principles (typical of scientists) and work based exclusively upon experience, without any theory comprehension (characteristic of craftsmen) [361].

In this period, the most powerful kings, churchmen, and lords in European countries adored to be surrounded by *mirabilia*, which were kept in the so-called *Wunderkammer* and became sometimes the first part of large collections [277]: the predilection for the uncommonn, for aesthetic appreciation and for wonder, combines with the need to understand natural phenomena halfway between art and science.

Finally, after the introduction and the spread of printing with movable type, the dissemination of classical texts and of their interpretations or comments became much easier and possibly quicker than before, thanks, in particular, to the translations into the vernacular languages [362].

In Chapuis' avant-propos to "Automata dans les oeuvres d'imagination" [282], referring to theory of three stages by the French philosopher Auguste Comte (1798-1857), the author states that they are present even in the history of automata, as from the early automata until Renaissance, they are witnessing events of mystery and wonder; later, during the 18th century, they are a useful tool for scholars to try to recreate life ("machinisme utilitaire"); then from the time when designers could rely on the use of electricity, automata were also equipped with devices in order to make them perceive, and to increase their resemblance to humans, or at least with some of their faculties. It was not a crucial point in our decision, although the chronological coincidence seems striking; as we could see, by considering a wider range of sources, such distinction doesn't fit any more.

1.2.4   Method

In order to study automata from Antiquity to the Renaissance, not as a phenomenon historically done and finalized, but as a proto-history of robotics, it is manifest that, while the analysis of specific implementations could show designers' expertise, strictly connected with their mechanical skills and knowledge, it would not sufficiently highlight design features in a more abstract way (what we now call the "rationale"); in addition, the study of literary, or, better, non technical, sources, that are totally lacking in technical details, would merely contribute to create an atmosphere of past times, and would represent only a catalogue of curiosities. For this reason, we decided to focus more on describing design principles than on specific implementations.

1.2.4.1 Milestones

Donald Knuth was probably coping with analogous issues in 1972, when he decided to approach for the first time algorithms in Babylonian tablets [345] and to consider them as a remote moment of computer science evolution, since he writes: "One of the ways to help make computer science respectable is to show that it is deeply rooted in history, not just a short-lived phenomenon. Therefore it is natural to turn to the earliest surviving documents which deal with computation, and to study how people approached the subject nearly 4000 years ago"; specific implementations (such as cuneiform notation, sexagesimal number system) are not essential, in his eyes. To adapt his idea to our context, it is enough to replace "computation" with "robotics", and shorten the term from 4000 to 2700 years ago.

As outlined by De Solla Price [363] in the 1960s, the interconnection between a branch of philosophical thought (the mechanistic philosophy) and the making of automata has been often discussed; by analyzing the history of technology (since Egyptian times), he states however that "contrary to the popular belief that science proceeds from the simple to the complex, it seems as if mechanistic philosophy - or mechanicism, to use the appropriate term coined by Dijksterhuis [17] - led to mechanism rather than the other way around. We suggest that some strong innate urge toward mechanistic explanation led to the making of automata, and that from automata has evolved much of our technology, particularly the part embracing fine mechanism and scientific instrumentation. When the old interpretation has been thus reversed, the history of automata assumes an importance even greater than before": paving the way to an interdisciplinary research about the subject, he also admits sources traditionally discarded in the study of automata.

1.2.4.2 Recent Studies

In more recent times, in the history of computer science field, Randell, in his reconstruction of a "partial chronology" of the origins of computer programming [360], has followed exactly the same path in the study of works by men like Babbage, who in a strictly chronological sense cannot be considered a computer programmer, though Babbage's efforts have undoubtedly been connected with the same issue: finding a "means for specifying a sequence of choices, among a set of possible machine actions, in such a way that the machine could carry out the sequence completely automatically". Randell was not so interested in compiling an exhaustive chronological catalogue of distinguished scholars and works: he rather wanted to "provide at least some brief explanations of the nature and the extent of the intellectual and technical achievements that were involved in a few selected developments", dating back, in the pegged cylinder case, directly to Heron of Alexandria.

In the last few years, mainly concerning Greek ancient technology [7-8], we have witnessed a substantial renovation of the studies: the work of Homer is thoroughly analyzed as a historical source from a technological point of view, even facing practical issues related to automata, such as energy supply and automatic control; the importance of this new approach is twofold: first, literary contents are no longer complementary and ancillary, but they become true historical sources; and secondly, such literary sources are subjected to a more complex analysis, which takes into account not only the feasibility (not always provable), but the overall landscape of technological knowledge of the considered ages.

1.2.5   Facing Cross-Historical, and Interdisciplinary Comparison Issues

As we have already pointed out, a careful search for any sources is fundamental, in order to reconstruct both the technical knowledge, and possibly the social perceived presence of automata.

Providing a historical reconstruction as wide and accurate as possible can certainly help to understand links of similarity and cause among characters and events, though far in time and space. However, especially as regards the prehistoric and medieval periods, sources often appear very different in importance and tradition, and by scarcity. They also are not uniform, because of their inherent variety, and therefore difficult to compare in several respects.

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[17] A Dutch historian of science (1892-1965), who studied both Ancient and Renaissance figures of scientists.

This need to ensure as much uniformity and consistency as possible in sources data gathering, with the aim of subsequent comparisons and analysis, suggested to uniformly organize information about automata in a data base, where a large amount of data (text, source reference, images, biographical information about the author, historical data about the device, for example) related to each instance could be stored. Data base entries have been designed to contain, where reachable [18], both the original author name and texts in the language of the culture in which they appeared, and in English translation, for reasons of accessibility. Wherever no English version was available, it has been specially made. In the following pages, the text of the source is given whenever its length makes it reasonable (< 10 lines), unless it can be found in the database at the following address (http://www.cyberprof.it/automata/). To witness the research in the contents of the database, (possibly multiple) tags referring to the most common subthemes (walking statue, bird, opening door, and so on) have been added to any single entry. Emerging classes have been linked to every single entry only at the end of the collection.

A second data base has been designed and implemented in order to collect data about manuscript containing Greek texts of ancient engineers, and their Arabic and Latin translations. The creation of a database was necessary, since it was essential to keep track of data not only on individual manuscripts, but also, where known, on owners, translators and copyists. We decided to store data in the same information structure as one of the most famous online databases of scientific manuscripts: www.jordanus.org. Our data base was gradually populated thanks to critical editions by Schmidt, whose distinction between older and newer *recensio* of Heron's works was used as a classification standard also for Latin translations, and by De Solla Price; libraries catalogues; on- and off-line manuscripts data base; specific essays, and direct examination of manuscripts, as it will be widely shown in 2.5.2.

1.2.6 Representing behavior and design principles: animation vs. UML

Since, as we have repeatedly stated, the focus of our attention is not so much on specific automata implementation, but rather on their design and behavior, the problem of a faithful representation as uniform as possible arises: a different approach, based on a standard, (natural) language-independent representation of automata behavior, should be used.

The first solution considered was to represent the design and behavior principles of individual automata through animation; it could grant:

- (natural) language independence, thus immediate comprehensibility
- a complete behavior representation
- attractiveness
- abstraction of implementation.

On the other side, an animation:

- can't fully explain all details, and possibly needs some captions
- is not always culturally independent

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[18] If the author's name was unknown, instead of leaving blank author name field, that would be common to many entries even not related to each other, we preferred to insert a descriptive name, like "French anonymous", sometimes followed by the century.

- is based on a picture, which is strongly subjective, mainly for literary sources
- can't fully show design principles
- is still a stand-alone instance, that cannot be generalized

Based on these remarks, we considered more fitting (for our purpose) to model automata behaviors with UML diagrams (http://www.uml.org/). The diagram that can better represent the temporal sequence of actions and (possible) interaction among actors and any automated system is the sequence diagram, which shows how and in what order processes work with each another. In case of very complex behavior, it will be useful to represent the system with an activity diagram, too.

While the historical reconstruction made it possible to place the various automata in the moments when they were invented or implemented, the classification has allowed the identification of the recurrence in different epochs also of automata with similar characteristics and behaviors.

But we thought it might be interesting an evolutionary analysis of the automaton idea, in the framework of memetics; as a matter of fact, by using the most significant features (appearance and behavior) that have already emerged, a kind of DNA of the automaton idea could be drawn, characterized by the presence or by the absence of specific traits. This analysis is presented in chapter 4.

2 Automated Systems from the Antiquity to the Renaissance

Before coping with historical problems, it is useful to spend some words about an apparently minor question, set by Rossi and others [74] in recent years. Can the aim of an automata history be the study of the origins of robotics? In their work, the above scholars remark that differences between automata and robots are so definite [19], that automata history can only be a tribute to "scientists/engineers/craftsmen" of the past centuries for their skills, often underestimated: the authors moreover conclude that "automata are interesting examples of the development of human knowledge and of human ability to invent new things. It may be excessive to think that in some of these machines science and technology joined art and poetry; while admitting the excess, we embrace the thought."

Even though we largely agree with Rossi and colleagues, we have to remark that, from our point of view, focused on design and ideas, rather than to actual implementations, the above mentioned differences appear as pertaining to objects which could be set at the extremes of a continuum, or, at least, at two distant moments in the historical evolution of the same idea, characterized by tremendously dissimilar technology levels.

We would like to add some words about ancient automata and their (real or supposed) lack of utility, since many scholars insist on such an issue since Antiquity [80]; in addition to what we remarked in 1.2.2, we will see that this is not a constant for all automata or periods, and that ancient treatises, which are full of "useless" devices designs, were meant as an introduction to more serious subjects, such as ballistics or poliorcetics, and were therefore far from being useless.

2.1 The Myth of Ancient Egyptian Automata

Chapuis [284] and De Solla Price [363] quote the most ancient instances of devices that can be considered as proto-automata: they are the wooden Egyptian articulated statuettes, dating back to the 12th-13th dynasty (20th-18th century BC) now housed at the Metropolitan Museum in New York. Their main feature is the fact that their arms can perform some movements, similar to the human ones: such movements however are not automated, but need someone to move the arm, fixed to the body by means of a pivot.

Another essay to imitate a human behavior (and this time without evident external participation) had been made by building statues able to emit a (musical) sound. Probably the best known example, located in Egypt, even though in the Roman period, are the colossal statues of massive stone of Pharaoh Amenhotep III (though later referred to as Memnon [20]) near Thebes, quoted by the Greek Strabo (65 BC - 25 AD) in his *Geography* (XVII, I, 46) in the 1st century BC; according to the hearsay, after an earthquake in 27 BC, the only one statue that was still entire could produce a musical tone as soon as it was struck by the rays of the rising sun, probably due to increasing temperature and humidity. Strabo refers he had actually heard the sound, but also that he absolutely could not identify the source [21]. Some years later, Pausanias visited the country and reported that the

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[19] As the authors explicitly point out, such differences involve fundamental features, such as re-programmability, almost absent in automata; the multi-degree of freedom, heavily limited in automata; the need for utility, very rare in automata.
[20] The son of Eos, the goddess of dawn. Mennu, however, is the Egyptian word for the funerary temple of the pharaon.
[21] "It is believed, that once a day a noise as of a slight blow issues from the part of the statue which remains in the seat and on its base. When I was at those places with Ælius Gallus, and numerous friends and soldiers about him, I heard a

tune could still be heard [22]. Greek and Roman visitors used to inscribe a sentence or their own names on the statue legs [364-366]; such graffiti date from 65 to 196 AD [367]; soon after that time the statue, after a restoration sponsored by the emperor Septimius Severus (145-211), would cease to give forth musical sounds, and, therefore, its fame vanished, but its name will be used later to refer to an automaton, the *memnonium*, that produces music using solar energy [368].

Pettorino [18-21] makes four assumptions about the origin of the phenomenon:

1. Temperature range (natural event)
2. Presence of cavities (natural event)
3. Contrivance present in a specific part of the statue (artificial event: mirror activating levers that pressed a keybord)
4. Stories, or collective illusion

He immediately rejects the first two hypothesis: such a phenomenon would have happened also elsewhere; but we have no news about another similar occurrence. The fourth one has been discarded by historians, since such an agreement among witnesses of so different ages appears impossible. The third hypothesis, that of a hidden device, is the one Pettorino considers most likely, since the time when most witnesses live, is the same as Heron's: a suitable technology was available since two centuries [23].

Such an assumption would also explain, according to the author, why after Septimius Severus' restoration sound would have ceased, since, as we are referred by the historian AElius Spartianus, the emperor personally visited this place [24] and it was likely in such occasion that any trick was made to disappear. We are obviously still in the field of hypotheses, since no evidence has been found at the moment.

The subsequent level of complexity is also present in ancient Egypt: talking statues (or, better, giving out sounds that could be interpreted as words uttered by a divine voice) worked by means of a trumpet hidden in hollows leading down from the mouth. In the 1930s, the Egyptologist Loukianoff [286] studied a statue housed at the Egyptian Museum in Cairo (catalogue #66143), the bust of Re-Harmakhis of Lower Egypt: such artifact was a large white limestone bust of the god, and shows an orifice where the priests could speak in order to amplify and alter the sounds of their voices, simulating the God's tone of voice. Frankfurter [369] says that the statue was carved in the Roman period, inferring such date from the armor style, and suggests considering it as a chapter of the universal history of religious hoax [370]. Charles Boreux, who was curator at Louvre Museum, in 1929 studied [371] a painted wooden mask of the jackal god of the dead (Anubis) preserved in the same museum; this very small item (17.8 x 11 cm) was alleged to be a divinatory mask, used in order to deceive an audience, since its lower jaw is movable. Later studies on this object (N 4096 is its catalogue number at the Musée du Louvre), that put it correctly in relationship with other

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noise at the first hour (of the day), but whether proceeding from the base or from the colossus, or produced on purpose by some of those standing around the base, I cannot confidently assert, for, from the uncertainty of the cause, I am disposed to believe anything rather than that stones disposed in that manner could send forth sound." (Translation by Hamilton and Falconer, 1903-1906)

[22] "Every day at the sunrise it sends forth a sound that can be compared to a harp or a lyre with a broken string".

[23] See *infra* 2.3.2.1, where a similar device alleged to Ctesibius is quoted.

[24] Ælius Spartianus, *Septimius Severus, Historia Augusta* 17, 4: […] *fuisse Severus ipse postea semper ostendit. nam et Memphim et Memnonem et piramides et labyrinthum, diligenter inspexit*; since then he always showed to be severe, as he visited both Memphis, and Memnon, and the pyramids and the labyrinth.

contemporary finds dating back to the end of the 1st millennium BC, led to exclude that it could be used for such a purpose, due to the presence of holes on the edge and on the ears of the mask. They were probably used to fasten it to a pseudo-canope (an imitation of a vase containing the entrails of the dead): if so, the represented god would be Douamoutef, a protecting sprite [372].

Even though in ancient Egyptian inscriptions, in literature or in archeological finds, we have no actual evidence of automata in Egyptian culture, we should face the fascinating question of animated or living statues, that is statues where the soul of the god/goddess is thought to be resident [373-376]. At the end of the 19th century [373], another Egyptologist Maspero, while admitting to having no extant instances, believes that these statues were certainly fitted with devices that allowed the movement, so that the faithful were certain to have received a response from the god depicted in the statue. He also gives a careful description of these no longer extant statues, adding legends referred to renown places and kings, that would confirm his conjectures: for instance, as it would result in an unknown inscription, queen Hatshepsut would have sent a naval expedition on the incense route through the Red Sea, due to a message from Amon-Ra, heard in the Karnak temple. Even if we admit the existence of this written source, however, it would be an official text, intended to justify, in the eyes of the subjects, an uncertain and costly initiative, promoted (so much the worse) by a woman. It seems enough to establish that the content is not conclusive. Maspero adds even that arms and head were openly moved by priests, and the faithful were fully aware of their role as intermediaries. While such statues have absolutely nothing to do with automata, studies about this topic have probably suggested to some superficial readers the idea that, in Egyptian tombs, temples, and pyramids, actual automata were commonly used. If we also consider De Solla Price's remark that animism is at the very root of animation [300], we can explain why for such a long time people have continued to believe in Egyptian automata; moreover such legends have gradually become so likely that in some works, scholars give also a picture of such automata, that would be described in necessarily unquoted hieroglyphical inscriptions [296].

As an explicit connection between Egyptian and Greek culture, we have a Greek papyr [25] on a certain Philotas, a priest at the sanctuary of Apollinopolis (now Edfu), who claimed to be able to restore fertility to the Thebaid, ravaged by drought: this was clearly some kind of hydraulic knowledge [100].

2.2 The Greek World

When we are talking about ancient Greece, it is essential to highlight the geographical discrepancy which exists between the current and the ancient concept. The Greek world in fact, though with ups and downs along the centuries, included in addition to what we currently call Greece: the Black Sea and the Turkish coasts (Ionia), the Libyan coasts, a large part of Southern Italy (Magna Graecia), the Mediterranean coasts of France and Spain, and, after the Macedonian expansion of the 4th century BC, even Egypt and the Middle East. Such a wide geographical extension has never corresponded to political unity, at least until the Alexandrian age. Greek politics was mainly characterized by the so-called particularism: the individual cities were separate administrative units, almost always at war with each other. Nonetheless, from the civilizing point of view, ancient

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[25] It is housed at the library of Warsaw university (P. MN 140153) and it dates back at the late 3rd century BC (http://papyri.info/ddbdp/sb;6;9302/); image visible at http://www.papyrology.uw.edu.pl/papyri/pmn140153.htm. About hydraulics in Ancient Egypt, see also [377].

Greeks felt part of a larger community, that included all Greek citizens. The most significant evidence of this spirit were the Pan-Hellenic games (Olympic, Pythian, Nemean, and Isthmian games), during which the cities entered into armistice.

From the cultural point of view, the Greek world was substantially united, and produced a corpus of works in the fields of literature, art, philosophy, mathematics, and science, which is still largely at the basis of Western culture.

2.2.1 The Golden Age Theme: αὐτόματος βίος

As we already said in 1.1, when the word αὐτόματος first appears in the Greek language, its meaning is far from the reference to a mechanical device; it rather alludes to any event that happens spontaneously, without external agency, such as either a human being who does something unsolicited, or an unanimated object that begins moving, or performing some actions, by itself. These two main meanings are attested both in Greek and, later, in Latin literature, even though sometimes the idea is uttered without explicit use of the word αὐτόματος / *automatus* [378-380]:

- Referred to men behavior:
  - Homer in *Iliad* (II, 408): αὐτόματος δέ οἱ ἦλθε βοὴν ἀγαθὸς Μενέλαος (And unbidden came to him the good Menelaus, at the war-cry);
  - Aristophanes in *Wealth* (1189-1190): ὁ Ζεὺς ὁ σωτὴρ γὰρ πάρεστιν ἐνθάδε, / αὐτόματος ἥκων. (*Zeus the saver is coming there spontaneously*);
  - Plato in *Theaetetus* (180c): Theodorus describes to Socrates the spontaneous succession of philosophical schools [26];
  - Petronius in *Satyricon* (L): *Plausum post hoc automatum familia dedit* (At this the slaves burst into spontaneous applause).
- Referred to concrete or abstract objects:
  - Homer in *Iliad* (XVIII, 372-379; 468-473): Hephaestus' automated tripod and bellows (see 2.2.2.2);
  - Hesiod in *Works and Days* (ll. 102-105): diseases spread like a ghost all over the world [27];
  - Herodotus in *Histories* (VIII, 37, 2): self-moving weapons [28];
  - Thucydides in *History of the Peloponnesian War* (VI, 91, 7): οἷς τε γὰρ ἡ χώρα κατεσκεύασται, τὰ πολλὰ πρὸς ὑμᾶς τὰ μὲν ληφθέντα, τὰ δ᾽ αὐτόματα ἥξει (Whatever property there is in the country will most of it become yours, either by capture or surrender);
  - Aristophanes in

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[26] τοιούτων ἕτερος ἑτέρου μαθητής, ἀλλ᾽ αὐτόματοι ἀναφύονται ὁπόθεν ἂν τύχῃ ἕκαστος αὐτῶν ἐνθουσιάσας, καὶ τὸν ἕτερον ὁ ἕτερος οὐδὲν ἡγεῖται εἰδέναι. Pupils of one another, but they grow up of themselves, each one getting his inspiration from any chance source, and each thinks the other knows nothing. Translation by H.N. Fowler (1921)

[27] νοῦσοι δ᾽ ἀνθρώποισιν ἐφ᾽ ἡμέρῃ, αἳ δ᾽ ἐπὶ νυκτὶ / αὐτόματοι φοιτῶσι κακὰ θνητοῖσι φέρουσαι / σιγῇ, ἐπεὶ φωνὴν ἐξείλετο μητίετα Ζεύς. / οὕτως οὔτι πῃ ἔστι Διὸς νόον ἐξαλέασθαι. Of themselves diseases come upon men continually by day and by night, bringing mischief to mortals silently; for wise Zeus took away speech from them. Translation by Hugh G. Evelyn-White (1914)

[28] θῶμα μὲν γὰρ καὶ τοῦτο κάρτα ἐστί, ὅπλα ἀρήια αὐτόματα φανῆναι ἔξω προκείμενα τοῦ νηοῦ. Marvellous indeed it is, that weapons of war should of their own motion appear lying outside in front of the shrine. Translation by A.D. Godley (1920)

- *Acharnians* (l. 976): αὐτόματα πάντ᾽ἀγαθὰ τῷδέ γε πορίζεται (All good things flow towards him unsought);
- *The Assemblywomen* (ll. 730-745): the character speaks to furnishings [29];
- *The Wasps* (ll. 936-939): the character calls a plate, and more kitchen tools as witnesses [30].
- *Wealth* (l. 476): ὦ τύμπανα καὶ κύφωνες, οὐκ ἀρήξετε; (Oh! cudgel and rope's end, won't you come to my help?)
- Crates in
  - *Beasts* (fr. 16 and 17): the two fragments respectively refer to kitchen tools and to courses, able to work and cook by themselves; to bathroom objects (water, basin, sponge, sandals) working by themselves [31]. In the first one, we also have two dialogues: the first is between character A and B; the second, between character A and a fish which is not yet cooked on both sides, so it can't put itself in the plate.
- Plautus in *The Forgery* (I, ii, 54-63): a παρακλαυσίθυρον (paraklausithyron), a topos or lyrical poetry where the lover wants to enter the girl's room, but the door is closed, so he is forced to remain outside, speaking about his feelings. In Plautus' comic version, the character begs the door bolts to open and to let him in.

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[29] χώρει σὺ δεῦρο κιναχύρα καλὴ καλῶς / τῶν χρημάτων θύραζε πρώτη τῶν ἐμῶν, / ὅπως ἂν ἐντετριμμένη κανηφορῇς, / πολλοὺς κάτω δὴ θυλάκους στρέψασ᾽ἐμούς. / ποῦ᾽σθ᾽ἡ διφροφόρος; ἡ χύτρα δεῦρ᾽ ἔξιθι, / νὴ Δία μέλαινά γ᾽, οὐδ᾽ἂν εἰ / τὸ φάρμακον / ἔψουσ᾽ἔτυχες ᾧ Λυσικράτης μελαίνεται. / ἴστω παρ᾽αὐτήν, δεῦρ᾽ἴθ᾽, ἡ κομμώτρια. / Φέρε δεῦρο ταύτην τὴν ὑδρίαν ὑδριαφόρε / ἐνταῦθα. Σὺ δὲ δεῦρ᾽ἡ κιθαρῳδὸς ἔξιθι, / πολλάκις ἀναστήσασά μ᾽εἰς ἐκκλησίαν / ἀωρὶ νυκτῶν διὰ τὸν ὄρθριον νόμον. / ὁ τὴν σκάφην λαβὼν προΐτω· τὰ κηρία / κόμιζε, τοὺς θαλλοὺς καθίστη πλησίον, / καὶ τὼ τρίποδ᾽ἐξένεγκε καὶ τὴν λήκυθον. / τὰ χυτρίδι᾽ἤδη καὶ τὸν ὄχλον ἀφίετε. Come hither, my beautiful sieve, I have nothing more precious than you, come, all clotted with the flour of which I have poured so many sacks through you; you shall act the part of Canephorus in the procession of my chattels. Where is the sunshade carrier? Ah! This stew-pot shall take his place. Great gods, how black it is! It could not be more so if Lysicrates had boiled the drugs in it with which he dyes his hair. Hither, my beautiful mirror. And you, my tripod, bear this urn for me; you shall be the water-bearer; and you, cock, whose morning song has so often roused me in the middle of the night to send me hurrying to the Assembly, you shall be my flute-girl. Scaphephorus, do you take the large basin, place in it the honeycombs and twine the olive-branches over them, bring the tripods and the phial of perfume; as for the humble crowd of little pots, I will just leave them behind.

[30] αὐτὸς καθελοῦ• τοὺς μάρτυρας γὰρ ἐσκαλῶ. / Λάβητι μάρτυρας παρεῖναι τρύβλιον / δοίδυκα τυρόκνηστιν ἐσχάραν χύτραν, / καὶ τἆλλα, τὰ σκεύη τὰ προσκεκαυμένα. Get it yourself. I go to call the witnesses; these are a plate, a pestle, a cheese knife, a brazier, a stew-pot and other half-burnt utensils.

[31] Fr. 16: (A) ἔπειτα δοῦλον οὐδὲ εἷς κεκτήσετ' οὐδὲ δούλην. / ἀλλ᾽αὐτὸς αὑτῷ δῆτ' ἀνὴρ γέρων διακονήσει; / (B) οὐ δῆθ᾽, ὁδοιποροῦντα γὰρ τὰ πάντ᾽ἐγὼ ποιήσω. / (A) τί δῆτα τοῦτ᾽αὐτοῖς πλέον; (B) πρόσεισιν αὖθ' ἕκαστον / τῶν σκευαρίων, ὅταν καλῇ τις «παρατίθου τράπεζα· / αὐτὴ παρασκεύαζε σαυτήν. μάττε θυλακίσκε. ἔγχει κύαθε. / ποῦ 'σθ᾽ἡ κύλιξ; διάνιζ᾽ἰοῦσα σαυτήν. / ἀνάβαινε μάζα. τὴν χύτραν χρῆν ἐξερᾶν τὰ τεῦτλα. / ἰχθὺ βάδιζ᾽.» «ἀλλ᾽οὐδέπω 'πὶ θάτερ᾽ὀπτός εἰμι.» / «οὔκουν μεταστρέψας σεαυτὸν ἁλὶ πάσεις ἀλείφων;» (A): "And so no one will own a slave neither male nor female, and each one will serve to himself, even the old men?". (B): "Nothing at all, because I will make all objects automated." (A): "What advantage will they take?" (B): "All furnishings will come, if someone calls, 'Come, table, set by yourself. Knead, little sack. Pour, jug. Where is the cup? Go and wash yourself. Rise, cake. The pot should serve the beets. Fish, come.' 'But I am not cooked on the other side', 'What are you waiting for? Turn and sprinkle yourself with salt and oil.' "

Fr. 17: ἀλλ᾽ἀντίθες τοι. 'γὼ γὰρ αὖ τραπέμπαλιν / τὰ θερμὰ λουτρὰ πρῶτον ἄξω τοῖς ἐμοῖς / ἐπὶ κιόνων, ὥσπερ διὰ τοῦ Παιωνίου, / ἀπὸ τῆς θαλάττης ὥσθ᾽ἑκάστῳ ῥεύσεται / εἰς τὴν πύελον. ἐρεῖ δὲ θὔδωρ «ἀνέχετε». / εἴθ᾽ἀλάβαστος εὐθέως ἥξει μύρου / αὐτόματος ὁ σπόγγος τε καὶ τὰ σάνδαλα. "But so do a comparison; in fact, at the opposite, I first will bring the hot water home by an aqueduct, like those crossing the paionion so that from the sea hot water will flow for anyone in the tub; and the water will say, "stop". And then just a vase of alabaster filled with perfume will arrive by itself, and sponge and sandals." For a complete philological analysis of the passage, see [381].

- Propertius in *Elegiae* (I, 16): another παρακλαυσίθυρον, whose main character is the door, which regrets the past, when passioned lovers were begging to enter, while now only drunk people sit down near the door itself.

We must observe the massive presence of playwrights in our list; it suggests that the theme was used in comedies mainly because it well fits with the upside-down reality typical of this genre. As shown by Fraenkel [382], due to the general naivety of the audience, such wit (inverting social structures, that is, in our case, describing automatic working of everyday objects) was certainly successful in amusing the spectators.

It is however noteworthy that some other passages, taken from the same authors' works, are also linked with the recurrent theme of the αὐτόματος βίος [32] in the Golden Age [382]. As a matter of fact, such idea of automated behavior included however also nature: if it was nice to think to everyday tools working spontaneously, it would be equally (or even more) pleasant to imagine to get food and everything that would be useful for life, without being forced into hard works. The natural forces, often mysterious to Greek man, could be very well represented as having an autonomous ability to meet human material needs, with or without gods' intervention; or, on the contrary, to hinder his life. Poets imagined that, in a distant past, nature spontaneously supplied everything men needed or wished: the myth of the golden age is thus deeply linked to the idea of αὐτόματος. The first instances of such happy state are already in the oldest texts: Homer's and Hesiod's.

In the *Odyssey*, several passages allude to such imaginary existence:

- VII 113-132: while presenting Alcinous' palace, Homer [33] describes the king's wonderful orchard where trees are always covered with fruits, thanks to two springs, granting water all all year round.
- IX 109-114: the Cyclops' faith is so strong that they don't seed or plant anything, trusting in gods' help, according to Ulysses' account [34].

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[32] Literally "automated life", the term was first used by Plato in his *Statesman* (see *infra* in the chapter) referring to life at the Chronos' age, when men received spontaneously from nature everything they needed.

[33] ἔκτοσθεν δ᾽αὐλῆς μέγας ὄρχατος ἄγχι θυράων / τετράγυος· περὶ δ᾽ἕρκος ἐλήλαται ἀμφοτέρωθεν. / ἔνθα δὲ δένδρεα μακρὰ πεφύκασι τηλεθόωντα, / ὄγχναι καὶ ῥοιαὶ καὶ μηλέαι ἀγλαόκαρποι / συκέαι τε γλυκεραὶ καὶ ἐλαῖαι τηλεθόωσαι. / τάων οὔ ποτε καρπὸς ἀπόλλυται οὐδ᾽ἀπολείπει / χείματος οὐδὲ θέρευς, ἐπετήσιος· ἀλλὰ μάλ᾽αἰεὶ / Ζεφυρίη πνείουσα τὰ μὲν φύει, ἄλλα δὲ πέσσει. / ὄγχνη ἐπ᾽ὄγχνῃ γηράσκει, μῆλον δ᾽ἐπὶ μήλῳ, / αὐτὰρ ἐπὶ σταφυλῇ σταφυλή, σῦκον δ᾽ἐπὶ σύκῳ. / ἔνθα δέ οἱ πολύκαρπος ἀλωὴ ἐρρίζωται, / τῆς ἕτερον μὲν θειλόπεδον λευρῷ ἐνὶ χώρῳ / τέρσεται ἠελίῳ, ἑτέρας δ᾽ἄρα τε τρυγόωσιν, / ἄλλας δὲ τραπέουσι· πάροιθε δέ τ᾽ὄμφακές εἰσιν / ἄνθος ἀφιεῖσαι, ἕτεραι δ᾽ὑποπερκάζουσιν. / ἔνθα δὲ κοσμηταὶ πρασιαὶ παρὰ νείατον ὄρχον / παντοῖαι πεφύασιν, ἐπηετανὸν γανόωσαι· / ἐν δὲ δύω κρῆναι ἡ μέν τ᾽ἀνὰ κῆπον ἅπαντα / σκίδναται, ἡ δ᾽ἐτέρωθεν ὑπ᾽αὐλῆς οὐδὸν ἵησι / πρὸς δόμον ὑψηλόν, ὅθεν ὑδρεύοντο πολῖται. / Τοῖ᾽ἄρ᾽ἐν Ἀλκινόοιο θεῶν ἔσαν ἀγλαὰ δῶρα. "But without the courtyard, hard by the door, is a great orchard of four acres, and a hedge runs about it on either side. Therein grow trees, tall and luxuriant, pears and pomegranates and apple-trees with their bright fruit, and sweet figs, and luxuriant olives. Of these the fruit perishes not nor fails in winter or in summer, but lasts throughout the year; and ever does the west wind, as it blows, quicken to life some fruits, and ripen others; pear upon pear waxes ripe, apple upon apple, cluster upon cluster, and fig upon fig. There, too, is his fruitful vineyard planted, one part of which, a warm spot on level ground, is being dried in the sun, while other grapes men are gathering, and others, too, they are treading; but in front are unripe grapes that are shedding the blossom, and others that are turning purple. There again, by the last row of the vines, grow trim garden beds of every sort, blooming the year through, and therein are two springs, one of which sends its water throughout all the garden, while the other, over against it, flows beneath the threshold of the court toward the high house; from this the townsfolk drew their water. Such were the glorious gifts of the gods in the palace of Alcinous." Translation by A.T. Murray (1919)

[34] Κυκλώπων δ᾽ ἐς γαῖαν ὑπερφιάλων ἀθεμίστων / ἱκόμεθ᾽, οἵ ῥα θεοῖσι πεποιθότες ἀθανάτοισιν / οὔτε φυτεύουσιν χερσὶν φυτὸν οὔτ᾽ἀρόωσιν, / ἀλλὰ τά γ᾽ἄσπαρτα καὶ ἀνήροτα πάντα φύονται, / πυροὶ καὶ κριθαὶ ἠδ᾽ἄμπελοι, αἵ τε

- XV 403-414: men never experience famine or sickness in the mythic land of Syria, where wheat and wine are always at hand [35]. Such a condition becomes however less desirable, if we pay attention to the way population ageing is controlled: Apollo and Artemis slay systematically the most aged tribes.

Hesiod's *Works and Days* is a didactic poem in hexameters, written around 700 BC, which discusses the necessity of work, gives useful advice on agriculture, and presents a farmer's almanac; here we also find quotations of such imaginary life:

- Ll.117-118: the earth spontaneously offers its fruits to men [36];
- Ll. 166-173: heroes living at the ends of the earth on the Islands of the Blest were offered by Zeus a complete harvest three times a year [37];
- Ll. 232-233: a typical topos is probably used for the first time; oaks produce honey and acorns [38].

Even in ancient comedies, we come across the description of hyperbolic situations, in which men appear untroubled by strife or need:

- Pherecrates in
  - *Persians* (fr. 137, 3) imagines a fantastic land, where rivers of black soup, full of various delicacies, flow from sources [39];
  - *Miners* (fr. 113, 1): describes in full detail a banquet where tasteful courses enter by themselves the mouth of the diners, and, when finished, reappear in double quantity;

φέρουσιν / οἶνον ἐριστάφυλον, καί σφιν Διὸς ὄμβρος ἀέξει. "and we came to the land of the Cyclopes, an overweening and lawless folk, who, trusting in the immortal gods, plant nothing with their hands nor plough; but all these things spring up for them without sowing or ploughing, wheat, and barley, and vines, which bear the rich clusters of wine, and the rain of Zeus gives them increase." Translation by A.T. Murray (1919)

[35] "νῆσός τις Συρίη κικλήσκεται, εἴ που ἀκούεις, / Ὀρτυγίης καθύπερθεν, ὅθι τροπαὶ ἠελίοιο, / οὔ τι περιπληθὴς λίην τόσον, ἀλλ᾽ ἀγαθὴ μέν, / εὔβοτος, εὔμηλος, οἰνοπληθής, πολύπυρος. / Πείνη δ᾽ οὔ ποτε δῆμον ἐσέρχεται, οὐδέ τις ἄλλη / νοῦσος ἐπὶ στυγερὴ πέλεται δειλοῖσι βροτοῖσιν• / ἀλλ᾽ ὅτε γηράσκωσι πόλιν κάτα φῦλ᾽ ἀνθρώπων, / ἐλθὼν ἀργυρότοξος Ἀπόλλων Ἀρτέμιδι ξὺν / οἷς ἀγανοῖς βελέεσσιν ἐποιχόμενος κατέπεφνεν. / ἔνθα δύω πόλιες, δίχα δέ σφισι πάντα δέδασται· / τῇσιν δ᾽ ἀμφοτέρῃσι πατὴρ ἐμὸς ἐμβασίλευε, / Κτήσιος Ὀρμενίδης, ἐπιείκελος ἀθανάτοισιν. "There is an isle called Syria, if haply thou hast heard thereof, above Ortygia, where are the turning-places of the sun. It is not so very thickly settled, but it is a good land, rich in herds, rich in flocks, full of wine, abounding in wheat. Famine never comes into the land, nor does any hateful sickness besides fall on wretched mortals; but when the tribes of men grow old throughout the city, Apollo, of the silver bow, comes with Artemis, and assails them with his gentle shafts, and slays them. In that isle are two cities, and all the land is divided between them, and over both ruled as king my father, Ctesius, son of Ormenus, a man like to the immortals." Translation by A.T. Murray (1912)

[36] [...] καρπὸν δ᾽ ἔφερε ζείδωρος ἄρουρα / αὐτομάτη πολλόν τε καὶ ἄφθονον. "For the fruitful earth unforced bare them fruit abundantly and without stint." Translation by Hugh G. Evelyn-White (1914)

[37] ἔνθ᾽ ἤτοι τοὺς μὲν θανάτου τέλος ἀμφεκάλυψε, /τοῖς δὲ δίχ᾽ ἀνθρώπων βίοτον καὶ ἤθε᾽ ὀπάσσας / Ζεὺς Κρονίδης κατένασσε πατὴρ ἐς πείρατα γαίης. / καὶ τοὶ μὲν ναίουσιν ἀκηδέα θυμὸν ἔχοντες / ἐν μακάρων νήσοισι παρ᾽ Ὠκεανὸν βαθυδίνην, / ὄλβιοι ἥρωες, τοῖσιν μελιηδέα καρπὸν / τρὶς ἔτεος θάλλοντα φέρει ζείδωρος ἄρουρα. "But to the others father Zeus the son of Cronos gave a living and an abode apart from men, and made them dwell at the ends of earth. And they live untouched by sorrow in the islands of the blessed along the shore of deep-swirling Ocean, happy heroes for whom the grain-giving earth bears honey-sweet fruit flourishing thrice a year." Translation by H.G. Evelyn-White (1914)

[38] τοῖσι φέρει μὲν γαῖα πολὺν βίον, οὔρεσι δὲ δρῦς / ἄκρη μέν τε φέρει βαλάνους, μέσση δὲ μελίσσας. "The earth bears them victual in plenty, and on the mountains the oak bears acorns upon the top and bees in the midst." Translation by H.G. Evelyn-White (1914)

[39] αὐτόματοι γὰρ διὰ τῶν τριόδων ποταμοὶ, λιπαροῖς ἐπίπαστοί / ζωμοῦ μέλανος καὶ Ἀχιλλείοις μάζαις, κοχυδοῦντες ἐπιβλὺξ / ἀπὸ τῶν πηγῶν τῶν τοῦ Πλούτου ῥεύσονται, σφῶν ἀρύτεσθαι. Of their own accord rivers do flow down every road (though half choked up with spice-cakes) of rich black soup which rolls along within its greasy flood Achilles' fat barley-cake, and streams of sauce which flow straight down from Plutus' own springs.

- Metagenes, in his *Thouriopersians* (fr. 6), imagines that the river Crathis drags huge barley cakes mixed by themselves, while the river Sibaris brings fish stew prepared by itself that flies in the mouth or at the feet of such lucky diners [40].
- Cratinus in *Plouti* (fr. 172) imagines that a deity gives a spontaneous supply of goods [41].
- Teleclides in *The Amphictyons* (fr. 1) longs for the mythical past in which everything people needed, was spontaneous [42].

In the so-called classical period (V-IV century BC) and in Latin literature, we find more instances:

- Aeschylus in *Prometheus Unbound*: the fantastic region inhabited by the Gabii, where the "self-sown" lands gave plenty of food to humans;
- Herodotus in *Histories*
  - (II, 14, 2) describes the Nile's natural cycle of flooding [43];
  - (II, 94, 1) mentions a plant that grows wild in Greece and is cultivated in Egypt [44]
  - (III, 18) refers that, according to an Ethiopian legend, the earth would spontaneously produce meat for the Table of the Sun [45];

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[40] Ὁ μὲν ποταμὸς, ὁ Κρᾶθις , ἡμῖν καταφέρει / μάζας μεγίστας αὐτομάτως μεμαγμένας, / ὁ δ'ἕτερος ὠθεῖ κῦμα ναστῶν καὶ κρεῶν, / ἑφθῶν τε βατίδων, εἰλυόμενον αὐτόσε· τὰ δὲ μικρὰ ταυτὶ ποτάμι᾽ἂν γ'ἐντευθενὶ / ῥεῖ τευθίσιν ὀπταῖς καὶ φάγροις καὶ καράβοις, / ἐντευθενὶ δ'ἀλλᾶσι καὶ περικόμμασι, / τῇδε δ'ἀφύαισι, τῇδε δ, αὖ ταγηνίαις·/ τεμάχη δ'ἄνωθεν αὐτόματα πεπηγμένα / εις τὸ στόμ'ᾄττει, τὰ δὲ παρ' αὐτὼ τὼ πόδε, / ἄμυλοι δὲ περινάουσιν ἡμῖν ἐν κύκλῳ. The river Crathis bears down unto us huge barley-cakes, self-kneaded and self-baked. The other river, called the Sybaris, rolls on large waves of meat and sausages, and boiled rays all wriggling the same way. And all these lesser streamlets flow along with roasted cuttlefish, and crabs, and lobsters; and, on the other side, with rich black-puddings and forced-meat stuffings; on the other side are herbs and lettuces, and fried bits of pastry. Above, fish cut in slices and self-boiled rush to the mouth; some fall before one's feet, and dainty cheese-cakes swim around us everywhere.

[41] Αὐτόματα τοῖσι θεὸς ἀνίει τἀγαθά. Spontaneously a god gave them all goods.

[42] Λέξω τοίνυν βίον, ἐξ ἀρχῆς ὃν ἐγὼ θνητοῖσι παρεῖχον. /εἰρήνη μὲν πρῶτον ἁπάντων ἦν ὥσπερ ὕδωρ κατὰ χειρός· / ἡ γῆ δ᾽ἔφερ'οὐ δέος, οὐδὲ νόσους, ἀλλ'αὐτόματ᾽ ἦν τὰ δέοντα· / οἴνῳ γὰρ ἅπασ'ἔρρει χαράδρα, μᾶζαι δ'ἄρτοις ἐμάχοντο / περὶ τοῖς στόμασιν τῶν ἀνθρώπων ἱκετεύουσαι καταπίνειν, / εἴ τι φιλοῖεν τὰς λευκοτάτας · οἱ δ'ἰχθύες οἴκαδ'ἰόντες /ἐξοπτῶντες σφᾶς αὐτοὺς ἂν παρέκειντ'ἐπὶ ταῖσι τραπέζαις. / Ζωμοῦ δ'ἔρρει παρὰ τὰς κλίνας ποταμὸς κρέα θερμὰ κυλίνδων· / ὑποτριμματίων δ'ὀχετοὶ τούτων τοῖς βουλομένοισι παρῆσαν, / ὥστ'ἀφθονία τὴν ἔνθεσιν ἦν ἄρδονθ'ἁπαλὴν καταπίνειν. / λεκανίσκαισιν δ'ἀνάπαιστα παρῆν ἡδυσματίοις κατάπαστα· / ὀπταὶ κίχλαι μετ'ἀμητίσκων εἰς τὸν φάρυγ'εἰσεπέτοντο, / τῶν δὲ πλακούντων ὠστιζομένων περὶ τὴν γνάθον ἦν ἀλαλητός, / μήτρας δὲ τόμοις καὶ χναυματίοις οἱ παῖδες ἂν ἠστραγάλιζον· οἱ δ'ἄνθρωποι πίονες ἦσαν τότε καὶ μέγα χρῆμα γιγάντων. I will tell you now the life which I have prepared for men. First of all the lovely Peace everywhere was always by, Like spring water which is poured over the hands of feasted guests. The earth produced no cause for fear, no pains and no diseases. And everything a man could want came forth unasked for to him. The streams all ran with rosy wine, and barley-cakes did fight With wheaten loaves which first could reach a hungry man's open month. And each entreated to be eaten, if men loved dainty whiteness. Fish too came straight unto men's doors, and fried themselves all ready, Dished themselves up, and stood before the guests upon the tables. A stream of soup did flow along in front of all the couches, Rolling down lumps of smoking meat; and rivulets of white sauce Brought to all such as chose to eat the sweetest forced-meat balls. So that there was no lack, but all did eat whatever they wanted. Dishes there were of boiled meat too, and sausages likewise and pasties; And roasted thrushes and rissoles flew down men's throats spontaneously. Then there were sounds of cheesecakes too crushed in men's hungry jaws: While the boys played with dainty bits of tripe, and paunch, and liver.

[43] ὁ ποταμὸς αὐτόματος ἐπελθὼν ἄρσῃ τὰς ἀρούρας, ἄρσας δὲ ἀπολίπῃ ὀπίσω, τότε σπείρας ἕκαστος τὴν ἑωυτοῦ ἄρουραν ἐσβάλλει ἐς αὐτὴν ὗς. The river rises of itself, waters the fields, and then sinks back again. Translation by A.D. Godley (1920)

[44] ἀλείφατι δὲ χρέωνται Αἰγυπτίων οἱ περὶ τὰ ἕλεα οἰκέοντες ἀπὸ τῶν σιλλικυπρίων τοῦ καρποῦ, τὸ καλεῦσι μὲν Αἰγύπτιοι κίκι, ποιεῦσι δὲ ὧδε. παρὰ τὰ χείλεα τῶν τε ποταμῶν καὶ τῶν λιμνέων σπείρουσι τὰ σιλλικύπρια ταῦτα, τὰ ἐν Ἕλλησι αὐτόματα ἄγρια φύεται. The Egyptians who live around the marshes use an oil drawn from the castor-berry, which they call kiki. They sow this plant, which grows wild in Hellas, on the banks of the rivers and lakes. Translation by A.D. Godley (1920)

[45] ἡ δὲ τράπεζα τοῦ ἡλίου τοιήδε τις λέγεται εἶναι, λειμὼν ἐστὶ ἐν τῷ προαστείῳ ἐπίπλεος κρεῶν ἑφθῶν πάντων τῶν τετραπόδων, ἐς τὸν τὰς μὲν νύκτας ἐπιτηδεύοντας τιθέναι τὰ κρέα τοὺς ἐν τέλεϊ ἑκάστοτε ἐόντας τῶν ἀστῶν, τὰς δὲ ἡμέρας δαίνυσθαι προσιόντα τὸν βουλόμενον. φάναι δὲ τοὺς ἐπιχωρίους ταῦτα τὴν γῆν αὐτὴν ἀναδιδόναι ἑκάστοτε.

- o (III, 100) refers that Indians eat a given variety of wheat that grows spontaneously [46];
- Plato in *Statesman* (271e-272b) coins the term αὐτόματος βίος to indicate the artlessness and genuineness of the men who lived under Cronus' reign [47];
- Lucretius in *De rerum natura*, V, 772-1457: the author does not believe in a mythical golden age when man lived happily. So, he devotes hundreds of verses to dispel such myth on the basis of rationalistic Epicurean philosophy.
- Virgilius in his *Eglogae*, IV: The poet celebrates the imminent return of the reign of Saturn (Chronos), following the birth of a "divine child", who would put an end to a tragic epoch marked by civil wars, to start a new golden age.
- Ovid in *Metamorphoses* (I, 89-90): *Aurea prima sata est aetas, quae vindice nullo, / sponte sua, sine lege fidem rectumque colebat.* (The golden age flourished first; loyalty and honesty were spontaneously honored, without executioners and without laws,)

The theme of αὐτόματος βίος, even in the form of the Golden Age theme, passed through Greek and Latin literature, and survived, often identified with a life away from civilization, in close contact with nature, in the major European literatures until at least the 18th century.

It shows how for centuries the idea of automatism was visibly present in the collective imagination: we are however dealing, rather than with a rigorously designed automatic mechanism, with a kind of "black box", whose outputs were observed and expected; on the contrary, physical principles (easily attributable to the helpful force of nature or to gods) and working features were ignored. We can model the only automata in Crates' fr. 16 and 17, where at least a control is implied, and some sequences of actions are described (see Fig. 3 and Fig. 4).
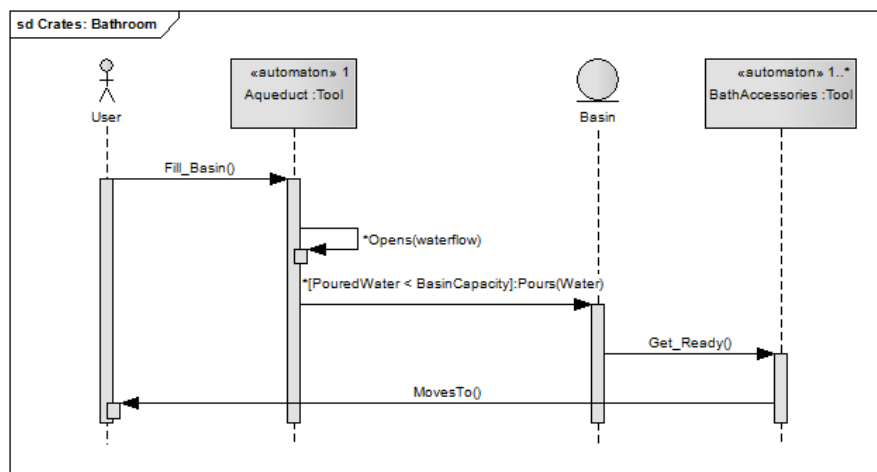
Fig. 3: UML Diagram of Crates' fr. 16

Now the Table of the Sun is said to be something of this kind: there is a meadow outside the city, filled with the boiled flesh of all four-footed things; here during the night the men of authority among the townsmen are careful to set out the meat, and all day whoever wishes comes and feasts on it. These meats, say the people of the country, are ever produced by the earth of itself. Translation by A.D. Godley (1920)

[46] καὶ αὐτοῖσι ἐστὶ ὅσον κέγχρος τὸ μέγαθος ἐν κάλυκι, αὐτόματον ἐκ τῆς γῆς γινόμενον [Indians] have a grain growing naturally from the earth in its husk Translation by A.D. Godley (1920)

[47] τὸ δ᾽οὖν τῶν ἀνθρώπων λεχθὲν αὐτομάτου πέρι βίου διὰ τὸ τοιόνδε εἴρηται. But the reason for the story of the spontaneous life of mankind is as follows. Translation by H.N. Fowler (1921)
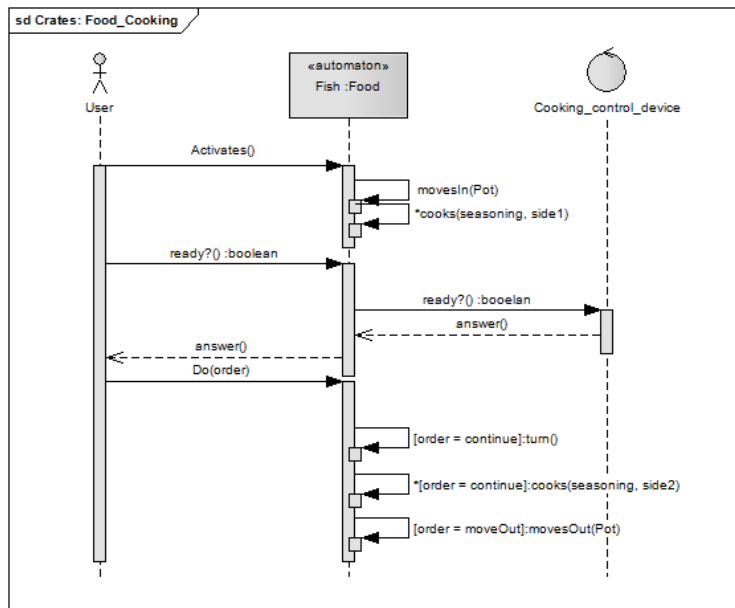
Fig. 4: UML Diagram of Crates' fr. 17

2.2.2 Automata in Greek Mythology and Literature

Greek mythology consists of a large collection of tales composed to explain the origin of the world by telling the life and adventures of a large number of deities, demigods (heroes), monsters and other creatures. It represents therefore a first essay to understand world phenomena and to investigate their causes, though in a poetical way. Mythology became essential in Greek literature, representing an inexhaustible source of plots and characters for epics, lyric poetry and also for the tragedy. Later, Romans would simply adopt the Greek pantheon and match many Greek gods with Italic deities.

Literature can therefore be considered an important historical source about automata; Iliad and Odyssey, for instance, show an already complete and mature notion of automaton: they are material entities capable of performing certain movements in various ways with specific functions [78]. Not all automata quoted in Greek literary texts are however due to a god: sometimes a man is so skillful to be comparable with deities.

2.2.2.1 Daedalus

Descendant of the Athenian royal line of Cecrops, Daedalus, in Greek Δαίδαλος, that literally means "artful" [48], was a mythical skilled craftsman and artisan; the origin of his legend probably dates back to the 5th century BC [383-384].

Pliny the Elder attributed [49] to him carpentry and its principal tools, like the saw, the axe, the plumb line, the auger, the glue, and the isinglass. According to Ovid (Ovid, *Metamorphoses,* VIII 152-763)

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[48] Pausanias, *Description of Greece*, IX, 3, 2: ὅτι οἱ πάλαι τὰ ξόανα ἐκάλουν δαίδαλα· ἐκάλουν δὲ ἐμοὶ δοκεῖν πρότερον ἔτι ἢ Δαίδαλος ὁ Παλαμάονος ἐγένετο Ἀθήνησι, τούτῳ δὲ ὕστερον ἀπὸ τῶν δαιδάλων ἐπίκλησιν γενέσθαι δοκῶ καὶ οὐκ ἐκ γενετῆς τεθῆναι τὸ ὄνομα. Because the men of old time gave the name of daedala to wooden images, my own view is that this name was given to wooden images before Daedalus, the son of Palamaon, was born at Athens, and that he did not receive this name at birth, but that it was a surname afterwards given him from the daedala. Translation by W.H.S. Jones, H.A. Ormerod (1918).

he would have formerly caused the death of Talos, son of his sister Perdix [50], out of resentment, by throwing him from the Athenian citadel, but Athena would have changed the boy into the partridge (in Latin, *perdix*): this professional envy was provoked by the brilliant invention made by Talos, who, using a fishbone as model, would have built the first saw [51].

Daedalus would have also been the first who carved statues of the gods [6]; their beauty was such as to induce those who had seen them, to believe that statues could not only move, but also see or speak.

The mythical sculptor is mentioned as one of Socrates' ancestors in Plato's *Euthyphrones* [52], where Socrates refers to his works as to moving statues. Even Aristotle refers that people believe that Daedalus' statue would be able to move, in *Politics*, 1.1253b. Many other sources repeat that they showed such an extraordinary feature [385-386, 384].

A more detailed description about these statues is given by Plato in *Meno* [53]: statues would run away, if they weren't fastened; and such a legend is later explained both in *Scholia to Meno* [54], by

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[49] VII, 198 […] *fabricam materiariam Daedalus et in ea serram, asciam, perpendiculum, terebram, glutinum, ichthyocollam* […]. Daedalus [invented] carpentry and, in particular, saw, axe, plumb line, auger, glue, and isinglass.

[50] According to other versions of the myth (Hyginus, *Fabulae*, 274), Perdix would have been his nephew's name.

[51] […] *natalibus actis / bis puerum senis, animi ad praecepta capacis; / ille etiam medio spinas in pisce notates / traxit in exemplum ferroque incidit acuto / perpetuos dentes et serrae repperit usum; / primus et ex uno duo ferrea bracchia nodo / vinxit, ut aequali spatio distantibus illis / altera pars staret, pars altera duceret orbem. / Daedalus invidit sacraque ex arce Minervae / praecipitem misit, lapsum mentitus; at illum, / quae favet ingeniis, excepit Pallas avemque / reddidit et medio velavit in aere pennis, / sed vigor ingenii quondam velocis in alas / inque pedes abiit; nomen, quod et ante, remansit / non tamen haec alte volucris sua corpora tollit, / nec facit in ramis altoque cacumine nidos: / propter humum volitat ponitque in saepibus ova / antiquique memor metuit sublimia casus.* "Twelve years old, his mind ready for knowledge. Indeed, the child, studying the spine of a fish, took it as a model, and cut continuous teeth out of sharp metal, inventing the use of the saw. He was also the first to pivot two iron arms on a pin, so that, with the arms at a set distance, one part could be fixed, and the other sweep out a circle. Daedalus was jealous, and hurled the boy headlong from Minerva's sacred citadel, claiming that he had fallen. But Pallas Minerva, who favors those with quick minds, caught him, and turned him into the partridge, masking him with feathers in mid-air. His inborn energy was transferred to swift wings and feet, and he kept his mother's name, Perdix, from before. But the bird does not perch above the ground, and does not make its nest on branches or on high points, but flies low on whirring wings over the soil, and lays its eggs in a sheltered place."

[52] Sophroniscus, Socrates's father, was a sculptor; [11ξ] Δαιδάλου τὰ ὑπὸ σοῦ λεγόμενα. καὶ εἰ μὲν αὐτὰ ἐγὼ ἔλεγον καὶ ἐτιθέμην, ἴσως ἄν με ἐπέσκωπτες ὡς ἄρα καὶ ἐμοὶ κατὰ τὴν ἐκείνου συγγένειαν τὰ ἐν τοῖς λόγοις ἔργα ἀποδιδράσκει καὶ οὐκ ἐθέλει μένειν ὅπου ἄν τις αὐτὰ θῇ· νῦν δὲ σαὶ γὰρ αἱ ὑποθέσεις εἰσίν. ἄλλου δή τινος δεῖ σκώμματος• οὐ γὰρ ἐθέλουσι σοὶ μένειν, ὡς καὶ αὐτῷ σοι δοκεῖ. [11c] are like works of my ancestor Daedalus, and if I were the one who made or advanced them, you might laugh at me and say that on account of my relationship to him my works in words run away and won't stay where they are put. But now-well, the statements are yours; so some other jest is demanded; for they stay fixed, as you yourself see.

[53] [97d] […] ὅτι καὶ ταῦτα, ἐὰν μὲν μὴ δεδεμένα ᾖ, ἀποδιδράσκει καὶ δραπετεύει, ἐὰν δὲ δεδεμένα, παραμένει. Socrates: That if they (i.e. Deadalus statues) are not fastened up they play truant and run away; but, if fastened, they stay where they are.

[54] Δαίδαλος ἄριστος ἀγαλματοποιὸς ἐπιγεγονὼς πρῶτος ἀναπετάννυσί τε τὰ τούτων βλέφαρα, ὡς δόξαι βλέπειν αὐτὰ, καὶ τοὺς πόδας, ὡς νομίσαι βαδίζειν, διίστησι. καὶ διὰ τοῦτο δεδέσθαι, ἵνα μὴ φύγοιεν, ὡς δῆθεν ἐμψύχων ἤδη γεγονότων αὐτῶν. Daedalus, become an extraordinary sculptor, first opened their eyes, so that it seemed that they could see, and split their feet, so that they seemed to walk. And so they had to be tied up, so that thay couldn't run away, becase they were animated.

Zenobius (2nd century AD), in *Proverbia* III, 7 [55], and by Philostratus the Elder (3rd century AD) in *Imagines* I, 16 [56], where moreover they are believed to see, or to speak.

Since we are obviously not dealing with automata [16], some remarks may be made, in order to explain the origin of this description. The first point concerns the news of the separation of the legs: it surely refers to a precise moment in the history of Greek sculpture, the archaic phase, in which the figures were represented standing with their legs near one another, in total immobility; such hieratic attitude was also reinforced by the almost total absence of any form of glance, which would explain why in two texts appears the reference to the opening of the eyes. Daedalus would therefore represent the personification of an important transition moment in ancient Greek sculpture, when statues legs began to be separated, and eyes were vividly carved[57], as the Greek writer Palaephatus [58] in the 4th century BC already tried to explain in his *On Incredible Tales* [385]. Secondly, the reference to the alleged ability to speak is probably derived through the centuries from contamination with stories related to sacred statuary. Finally, the idea that they were tied up is probably hyperbolic, born from the high degree of realism shown by these statues, so similar to humans that they would like to move. This does not exclude, however, that some sculptors (whether or not Daedalus) attempted to simulate some form of sudden movement, which would require binding the statue, until the moment it should have to move. Such a supposition is suggested by a passage by Aristotle referred to the technique by which the movement would be given to a wooden statue of Daedalus, the Aphrodite [59]: according to the playwright Philippus, he would have simply covered it with quicksilver. The passage is quoted by Aristotle, in order to quip on Democritus' atomistic theory. Although, of course, a comedy is not an incontrovertible source and this technique cannot produce a statue capable of actual movement [16], we must remember that the quicksilver will be used both by Heron (2.3.2.3), and by Arabic engineers (2.4.3), in order to show at least a sudden movement. The latter remark prevents us from considering the quotation tout court as a hoax.

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[55] ὁ Δαίδαλος καὶ τοὺς ὀφθαλμοὺς αὐτοῖς ἀνεπέτασεν, ὡς καὶ δόξαν κατασχεῖν ὅτι καὶ ἔμψυχά ἐστι, καὶ κινοῦνται καὶ φθέγγονται. φασὶ γοῦν τινὰ τῶν δαιδαλουργῶν ἀνδριάντων δεδέσθαι τοῦ ποδός, ὡς μὴ ἀποδράσοι. Daedalus had even opened their eyes, so that it seemed as if they were alive, and moved and spoke; people said that some of the statues of Daedalus had one tied foot, as to prevent their escape.

[56] ἐργαστήριον μὲν τοῦτο πεποίηται τῷ Δαιδάλῳ, περιέστηκε δὲ αὐτὸ ἀγάλματα, τὰ μὲν ἐν μορφαῖς, τὰ δὲ ἐν τῷ διορθοῦσθαι, διαβεβηκότα ἤδη καὶ ἐν ἐπαγγελίᾳ τοῦ βαδίζειν. This is the workshop of Daedalus and about it are statues, some with forms blocked out, others in a quite complete state in that they are already stepping forward and give promise of walking about.

[57] It must pointed out that Greek statues were also painted, in order to increase their realism and, in the case of the eyes, to give expression to their glance.

[58] 5, About Daedalus: Λέγεται περὶ Δαιδάλου ὡς ἀγάλματα κατεσκεύαζε δι᾽ ἑαυτῶν πορευόμενα· ὅπερ ἔμοιγε ἀδύνατον εἶναι δοκεῖ, ἀνδριάντα δι᾽ ἑαυτοῦ βαδίζειν. Τὸ δὲ ἀληθὲς τοιοῦτον. Οἱ τότε ἀνδριαντοποιοὶ καὶ ἀγαλματοποιοὶ συμπεφυκότας ὁμοῦ τοὺς πόδας καὶ τὰς χεῖρας παρατεταμένας ἐποίουν. Δαίδαλος δὲ πρῶτος ἐποίησε διαβεβηκότα τὸν ἕνα πόδα. Διὰ τοῦτο δὴ οἱ ἄνθρωποι ἔλεγον· "ὁδοιπορῶν τὸ ἄγαλμα τοῦτο εἰργάσατο Δαίδαλος, ἀλλ᾽ οὐχὶ ἑστηκός.» ὡς καὶ νῦν λέγομεν· «μαχόμενοί γε ἄνδρες γεγραμμένοι εἰσὶ καὶ τρέχοντες ἵπποι καὶ χειμαζομένη ναῦς." οὕτω κἀκεῖνον ἔλεγον ὁδοιποροῦντα ποιεῖν ἀγάλματα. Daedalus, people say, has built statues moving by themselves; the fact that the statues in human form walk alone, seems to me impossible. The truth is the following: the sculptors of ancient statues of humans and gods made them with feet parallel and hands along their sides. On the contrary, he for the first time carved them in the act of moving a foot. So people say, "Daedalus made this statue in motion, not static." Even now as we say, "people say that men fight, that horses run and a ship is in the midst of the storm", so people say that he has made moving statues.

[59] φησὶ γὰρ τὸν Δαίδαλον κινουμένην ποιῆσαι τὴν ξυλίνην Ἀφροδίτην, ἐγχέαντ᾽ ἄργυρον χυτόν· [Philippus, the comic poet,] tells that Daedalus endowed the wooden Aphrodite with motion, simply by pouring them in quicksilver. Translation by R.D.Hicks, 1907

In spite of their identical name (Talos), Daedalus' nephew and the brazen giant, who, according to a legend, patrolled three times a day the shores of Crete, preventing foreigners from entering, are not the same character. The latter had been built by the god Hephaestus and consisted in a kind of automaton, which could throw large stones hurled by the force of arms against the enemies of king Minos. It would have been beaten by Medea by means of magic, as referred by Apollonius of Rhodes (3rd century BC) in his *Argonautica* (IV, 1638-1693), who, however, presents him as a demigod "of the race of bronze"; the giant was hit in his weak spot and fell heavily to the ground without being able to raise, but covering the island with his blood. The possible interpretation of the myth refers to a volcano, which would menace the island, and prevent foreigners from landing on the shore: red blood would be erupted lava. Otherwise, it could be a reference to the "lost wax" technique of casting, that consists in gradually replacing with molten metal the mold wax as it melts; wax then flows through orifices.

2.2.2.2 Automata in the Iliad

Hephaestus (Vulcan, for the Romans) was a Greek god, son of Zeus and Hera. He was the god of technology, that is blacksmithing, and metallurgy, and in addition of fire and volcanoes, so he was worshipped in the manufacturing centers of Greece, predominantly in Athens. According to myths, his appearance was ugly, as they imagined him in his workshop working hard all alone, or, at best, assisted by the Cyclops. In the Greek world, the blacksmith god plays a fundamental role both in forging special objects for the gods (lightning for Zeus, bow and arrows for Eros, and many more) and in equipping heroes of their wonderful armors (Achilles, and Aeneas), and in building artificial items, as told in the Iliad and Odyssey.

The first instance of automaton referred to Hephaestus in the Iliad (XVIII, 372-379) are the automatic tripods: Thetis comes to the forge of Hephaestus, determined to ask a new armor and a shield for her son Achilles, though she knows of his terrible fate. Homer presents the god feverishly working on twenty golden tripods for the banquet of the gods, and gives a brief description of their operation [60]: they have golden wheels that allow them to automatically (αὐτόματοι) enter and exit the banquet hall at his wish (see Fig. 5), and to their completion only a decorative element is missing: elaborately forged ears to be fixed with rivets. Homer describes the tripods as a wonder (θαῦμα) to behold, but restricts the running explanation in only two lines, so that we can think that the poet avoided a too detailed description to give greater verisimilitude to this passage, as for a god, as Hephaestus is, building such objects is not only possible, but also easy. This impression is confirmed by the next automaton that also appears in the episode of Thetis and Hephaestus: the golden maidens (XVIII, 417-425) [61], who come immediately to serve the god. They are real robots,

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[60] τὸν δ᾽ εὗρ᾽ ἱδρώοντα ἑλισσόμενον περὶ φύσας / σπεύδοντα• τρίποδας γὰρ ἐείκοσι πάντας ἔτευχεν / ἑστάμεναι περὶ τοῖχον ἐϋσταθέος μεγάροιο, / χρύσεα δέ σφ᾽ ὑπὸ κύκλα ἑκάστῳ πυθμένι θῆκεν, / ὄφρά οἱ αὐτόματοι θεῖον δυσαίατ᾽ ἀγῶνα / ἠδ᾽ αὖτις πρὸς δῶμα νεοίατο θαῦμα ἰδέσθαι. / οἳ δ᾽ ἤτοι τόσσον μὲν ἔχον τέλος, οὔατα δ᾽ οὔ πω / δαιδάλεα προσέκειτο• τά ῥ᾽ ἤρτυε, κόπτε δὲ δεσμούς. Him she found sweating with toil as he moved to and fro about his bellows in eager haste; for he was fashioning tripods, twenty in all, to stand around the wall of his well-built hall, and golden wheels had he set beneath the base of each that of themselves they might enter the gathering of the gods at his wish and again return to his house, a wonder to behold. Thus much were they fully wrought, that not yet were the cunningly fashioned ears set thereon; these was he making ready, and was forging the rivets. Translation by A.T. Murray (1924), as the following ones from Iliad.

[61] ὑπὸ δ᾽ ἀμφίπολοι ῥώοντο ἄνακτι / χρύσειαι ζωῇσι νεήνισιν εἰοικυῖαι. / τῇς ἐν μὲν νόος ἐστὶ μετὰ φρεσίν, ἐν δὲ καὶ αὐδὴ / καὶ σθένος, ἀθανάτων δὲ θεῶν ἄπο ἔργα ἴσασιν. / Αἳ μὲν ὕπαιθα ἄνακτος ἐποίπνυον• αὐτὰρ ὃ ἔρρων / πλησίον, ἔνθα Θέτις περ, ἐπὶ θρόνου ἷζε φαεινοῦ, / ἔν τ᾽ ἄρα οἱ φῦ χειρὶ ἔπος τ᾽ ἔφατ᾽ ἔκ τ᾽ ὀνόμαζε. but there moved swiftly to

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being equipped with what we would now call artificial intelligence, with a natural language processing system, with a voice synthesizer, and with servomechanisms to act, even using strength. Again, Homer spends very few words (just over one line) to describe the automaton behavior.
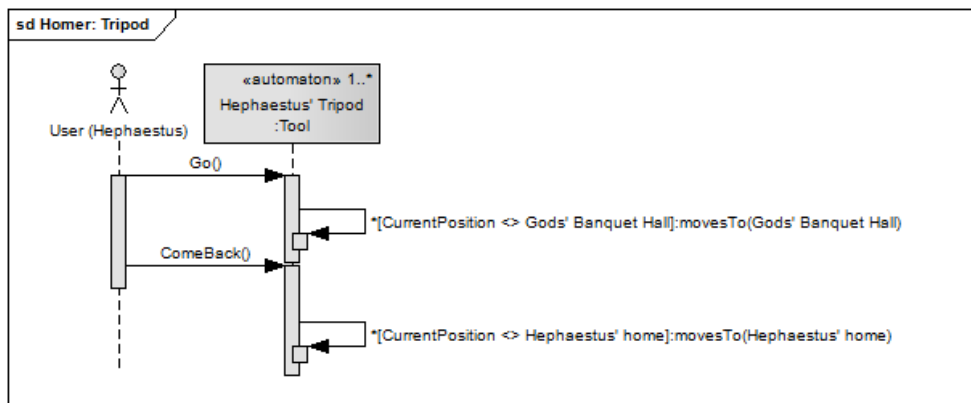

Fig. 5: UML Diagram of Hephaestus' Tripods

Maidens are not the only automated presence in Hephaestus's workshop, as he has an automated plant, which allows him to focus only on the most challenging part of the work (design), and not to worry about the frequency of his twenty bellows operation, self-regulating in relation to the work demands (XVIII, 468-473) [62].
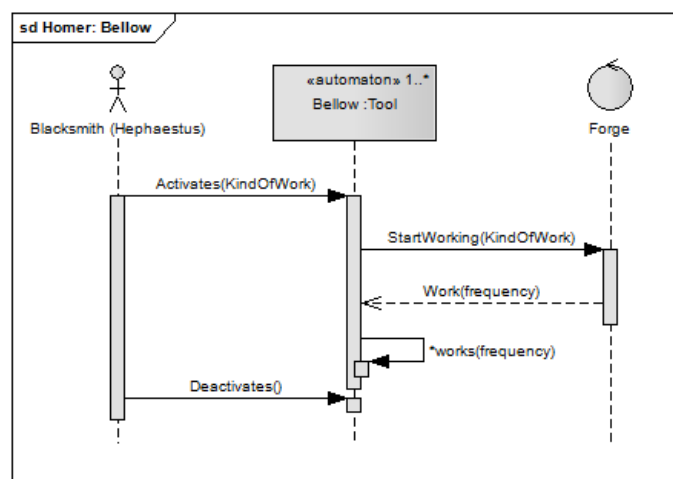
Fig. 6: UML Diagram of Hephaestus' Bellows

As we can see, some characteristics commonly attributed to ancient automata are present: they are masterpieces of craftsmanship (for merely aesthetic reasons, a little resistant metal, such as gold, is even used), and therefore a source of wonder. The automata of Hephaestus are, however, certainly

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support their lord handmaidens wrought of gold in the semblance of living maids. In them is understanding in their hearts, and in them speech and strength, and they know cunning handiwork by gift of the immortal gods. These busily moved to support their lord, and he, limping nigh to where Thetis was, sat him down upon a shining chair.

[62] ὣς εἰπὼν τὴν μὲν λίπεν αὐτοῦ, βῆ δ᾽ ἐπὶ φύσας· /τὰς δ᾽ ἐς πῦρ ἔτρεψε κέλευσέ τε ἐργάζεσθαι. / Φῦσαι δ᾽ ἐν χοάνοισιν ἐείκοσι πᾶσαι ἐφύσων / παντοίην εὔπρηστον ἀϋτμὴν ἐξανιεῖσαι, / ἄλλοτε μὲν σπεύδοντι παρέμμεναι, ἄλλοτε δ᾽ αὖτε, / ὅππως Ἥφαιστός τ᾽ ἐθέλοι καὶ ἔργον ἄνοιτο. So saying he left her there and went unto his bellows, and he turned these toward the fire and bade them work. [470] And the bellows, twenty in all, blew upon the melting-vats, sending forth a ready blast of every force, now to further him as he laboured hard, and again in whatsoever way Hephaestus might wish and his work go on.

useful [7], and perfectly reliable. We are probably, as it has been said, "at the summit of ancient Greeks' technophilia" [8].

Another automated system whose authorship is however indirectly attributed by Homer to Hephaestus, is quoted in the Iliad: the gates of the Olympus (V, 749-752) [63]; when Hera returns back from Troy to Olympus in her chariot, the doors, that are controlled by the Hours, open spontaneously. The role of the Hours appears as indicative: it seems to imply some time-dependent control (see Fig. 7).
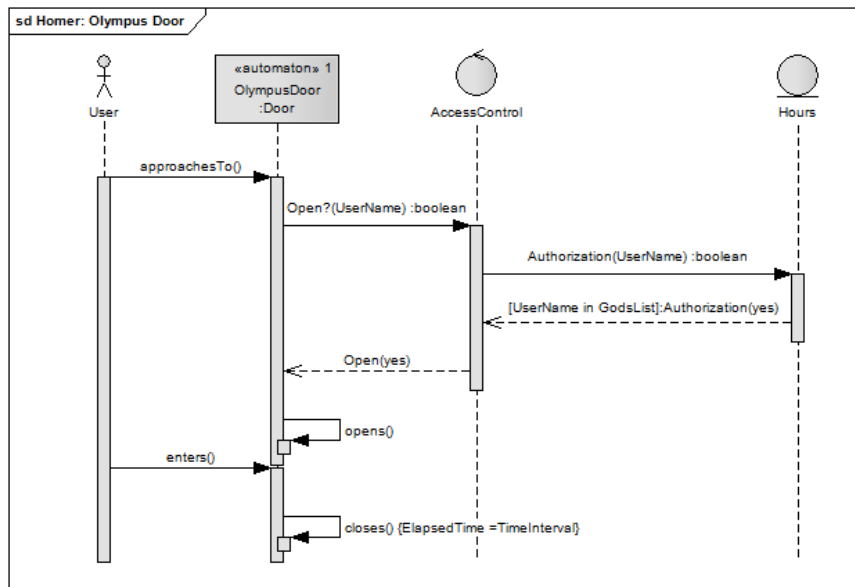
Fig. 7: UML Diagram of Olympus Doors

2.2.2.3 Automata in Odyssey: Watch Dogs, Ships, and a Trap

Some automata, though fewer in number, are also present in the other Homeric poem, the Odyssey. While Odysseus enters the palace of Alcinous, he notes, near the golden door of the palace, the watch dogs: they were built by the skillful Hephaestus in gold and silver, immortal and ageless, in order to protect Alcinous' royal palace (VII 91-94) [64]. The passage, as usual, is very concise, and it also presents some ambiguity: Homer says, in effect, only that dogs are cast in metal. For this reason, Faraone, based upon philological and literary remarks [1], thinks that Alcinous' dogs cannot be regarded as automata, but as wonderful statues made by a god; accepting this interpretation, it becomes however puzzling how they could somehow do the job they were built for by Hephaestus, being, moreover, without any apotropaic function, characteristic of horrible and disgusting figures. In addition, we must cite the golden (or bronze) watchdog built by Hephaestus for Rhea, to protect Zeus [65], and later reused. An Oxyrhynchus papyrus contains a fragment (LIII, 3711) about a lion

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[63] Ἥρη δὲ μάστιγι θοῶς ἐπεμαίετ'ἄρ' ἵππους· / αὐτόμαται δὲ πύλαι μύκον οὐρανοῦ ἃς ἔχον Ὧραι, / τῇς ἐπιτέτραπται μέγας οὐρανὸς Οὔλυμπός τε / ἠμὲν ἀνακλῖναι πυκινὸν νέφος ἠδ'ἐπιθεῖναι. And Hera swiftly touched the horses with the lash, and self-bidden groaned upon their hinges the gates of heaven which the Hours had in their keeping, to whom are entrusted great heaven and Olympus, whether to throw open the thick cloud or shut it to.

[64] χρύσειοι δ᾽ ἑκάτερθε καὶ ἀργύρεοι κύνες ἦσαν, / οὓς Ἥφαιστος ἔτευξεν ἰδυίῃσι πραπίδεσσι / δῶμα φυλασσέμεναι μεγαλήτορος Ἀλκινόοιο, / ἀθανάτους ὄντας καὶ ἀγήρως ἤματα πάντα. On either side of the door there stood gold and silver dogs, which Hephaestus had fashioned with cunning skill to guard the palace of great-hearted Alcinous; immortal were they and ageless all their days. Translation by A.T. Murray (1919), as the following from Odyssey.

[65] Quoted by later written sources, it is connected with the figure of Tantalus, who would have stolen (or made Pandaraeus steal) it. Julius Pollux, a grammarian of the 2nd century AD, in his *Onomastikon* V, 39, speaks of a "[Dog]

made by Hephaestus as well, where the god would have put φάρμακα (phàrmaka, drugs) [66]; so it could be argued that the dogs of Alcinous had unspecified defensive capabilities, possibly chemical. The second automaton of the Odyssey [67] are the ships of the Phaeacians, capable, according to Homer, to sail the seas without a pilot, or steering-oars, since they would have been able to follow smoothly the known courses, and to prevent the effects of bad weather, crossing the sea, and hidden in the fog (VIII 555-563) [68]. This is the second representation of a form of artificial intelligence in Homeric poems; the ships should be equipped with what today we would call automatic pilot, with radar and sonar to detect obstacles, and perhaps even with a satellite view for weather conditions. The detail that perhaps doesn't affect modern readers, is the fact that Phaeacians' ships sailed across the sea; it should be noted that the conventional navigation of the ancients, mostly along the coasts (cabotage), was very time consuming, so a ship that could go across the sea, would have been very efficient.

The last device in the Odyssey is a trap prepared by Hephaestus to catch Aphrodite and Ares in the act of adultery, binding them to the bed; in spite of the vagueness of Homer's word about device working, one can easily imagine that the weight of the bodies on the bed activates the laces, and inextricably binds the two lovers (VIII 272-284) [69].

Greek mythology depicts Hephaestus as not new to such traps, since he had also built a chair with fetters that is quoted by Pausanias (1.20.3) as a corrective gift, sent by the god to Hera, guilty of having thrown him down from Olympus [70].

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that Hephaestus had forged with the bronze from Dermonesos, after having infused the life, he had given to Zeus and this last to Europe, and she to Minos and Minos to Procris, and Procris to Cephalus". ὃν Ἥφαιστος ἐκ χαλκοῦ Δημονησίου χαλκευσάμενος. ψυχὴν ἐνθείς, δῶρον ἔδωκε Διὶ κἀκεῖνος Εὐρώπῃ, αὕτη δε Μίνῳ καὶ Μίνως Πρόκριδι καὶ Πρόκρίς Κεφάλῳ. His contemporary Antoninus Liberalis, in his Μεταμορφώσεων Συναγωγή, (Collection of Transformations), refers to the mother of Zeus and to tha goat that would have nursed him: Τὴν αἶγα δὲ Ῥέας βουλῇ κύων χρύσεος ἐφύλαττεν. A golden dog watched the goat by will of Rhea.
[66] The Greek word has a double meaning: poison/medicine.
[67] This automaton authorship is not referred to Hephaestus.
[68] εἰπὲ δέ μοι γαῖάν τε· τεὴν δῆμόν τε πόλιν τε, / ὄφρα σε τῇ πέμπωσι τιτυσκόμεναι φρεσὶ νῆες· / οὐ γὰρ Φαιήκεσσι κυβερνητῆρες ἔασιν, / οὐδέ τι πηδάλι᾽ ἔστι, τά τ᾽ ἄλλαι νῆες ἔχουσιν· / ἀλλ᾽ αὐταὶ ἴσασι νοήματα καὶ φρένας ἀνδρῶν, / καὶ πάντων ἴσασι πόλιας καὶ πίονας ἀγροὺς / ἀνθρώπων, καὶ λαῖτμα τάχισθ᾽ ἁλὸς ἐκπερόωσιν / ἠέρι καὶ νεφέλῃ κεκαλυμμέναι· οὐδέ ποτέ σφιν / οὔτε τι πημανθῆναι ἔπι δέος οὔτ᾽ ἀπολέσθαι. And tell me thy country, thy people, and thy city, that our ships may convey thee thither, discerning the course by their wits. For the Phaeacians have no pilots, nor steering-oars such as other ships have, but their ships of themselves understand the thoughts and minds of men, and they know the cities and rich fields of all peoples, and most swiftly do they cross over the gulf of the sea, hidden in mist and cloud, nor ever have they fear of harm or ruin.
[69] Ἥφαιστος δ᾽ ὡς οὖν θυμαλγέα μῦθον ἄκουσε, / βῆ ῥ᾽ ἴμεν ἐς χαλκεῶνα κακὰ φρεσὶ βυσσοδομεύων, / ἐν δ᾽ ἔθετ᾽ ἀκμοθέτῳ μέγαν ἄκμονα, κόπτε δὲ δεσμοὺς / ἀρρήκτους ἀλύτους, ὄφρ᾽ ἔμπεδον αὖθι μένοιεν. / αὐτὰρ ἐπειδὴ τεῦξε δόλον, κεχολωμένος Ἄρει, / βῆ ῥ᾽ ἴμεν ἐς θάλαμον, ὅθι οἱ φίλα δέμνι᾽ ἔκειτο, / ἀμφὶ δ᾽ ἄρ᾽ ἑρμῖσιν χέε δέσματα κύκλῳ ἀπάντῃ, / πολλὰ δὲ καὶ καθύπερθε μελαθρόφιν ἐξεκέχυντο, / ἠΰτ᾽ ἀράχνια λεπτά, τά γ᾽ οὔ κέ τις οὐδὲ ἴδοιτο, / οὐδὲ θεῶν μακάρων· πέρι γὰρ δολόεντα τέτυκτο. / αὐτὰρ ἐπειδὴ πάντα δόλον περὶ δέμνια χεῦεν, / εἴσατ᾽ ἴμεν ἐς Λῆμνον, ἐϋκτίμενον πτολίεθρον, / ἥ οἱ γαιάων πολὺ φιλτάτη ἐστὶν ἁπασέων. And when Hephaestus heard the grievous tale, he went his way to his smithy, pondering evil in the deep of his heart, and set on the anvil block the great anvil and forged bonds which might not be broken or loosed, that the lovers might bide fast where they were. But when he had fashioned the snare in his wrath against Ares, he went to his chamber where lay his bed, and everywhere round about the bed-posts he spread the bonds, and many too were hung from above, from the roof-beams, [280] fine as spiders' webs, so that no one even of the blessed gods could see them, so exceeding craftily were they fashioned. But when he had spread all his snare about the couch, he made as though he would go to Lemnos, that well-built citadel, which is in his eyes far the dearest of all lands.
[70] λέγεται δὲ καὶ τάδε ὑπὸ Ἑλλήνων, ὡς Ἥρα ῥίψαι γενόμενον Ἥφαιστον, ὁ δέ οἱ μνησικακῶν πέμψαι δῶρον χρυσοῦν θρόνον ἀφανεῖς δεσμοὺς ἔχοντα, καὶ τὴν μὲν ἐπεί τε ἐκαθέζετο δεδέσθαι, θεῶν δὲ τῶν μὲν ἄλλων οὐδενὶ τὸν Ἥφαιστον ἐθέλειν πείθεσθαι, Διόνυσος δὲ— μάλιστα γὰρ ἐς τοῦτον πιστὰ ἦν Ἡφαίστῳ—μεθύσας αὐτὸν ἐς οὐρανὸν ἤγαγε. One of the Greek legends is that Hephaestus, when he was born, was thrown down by Hera. In revenge he sent as a gift a
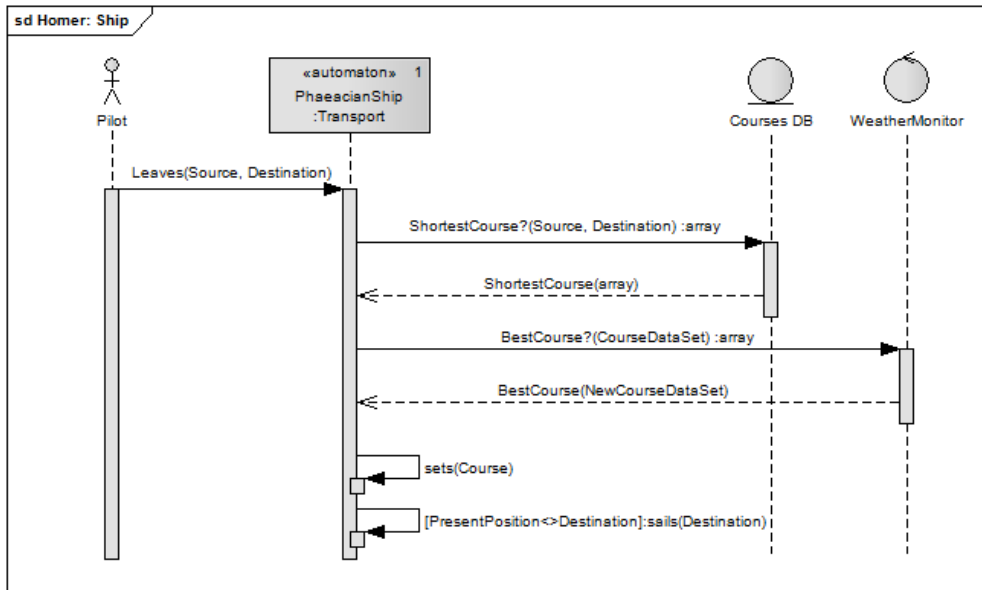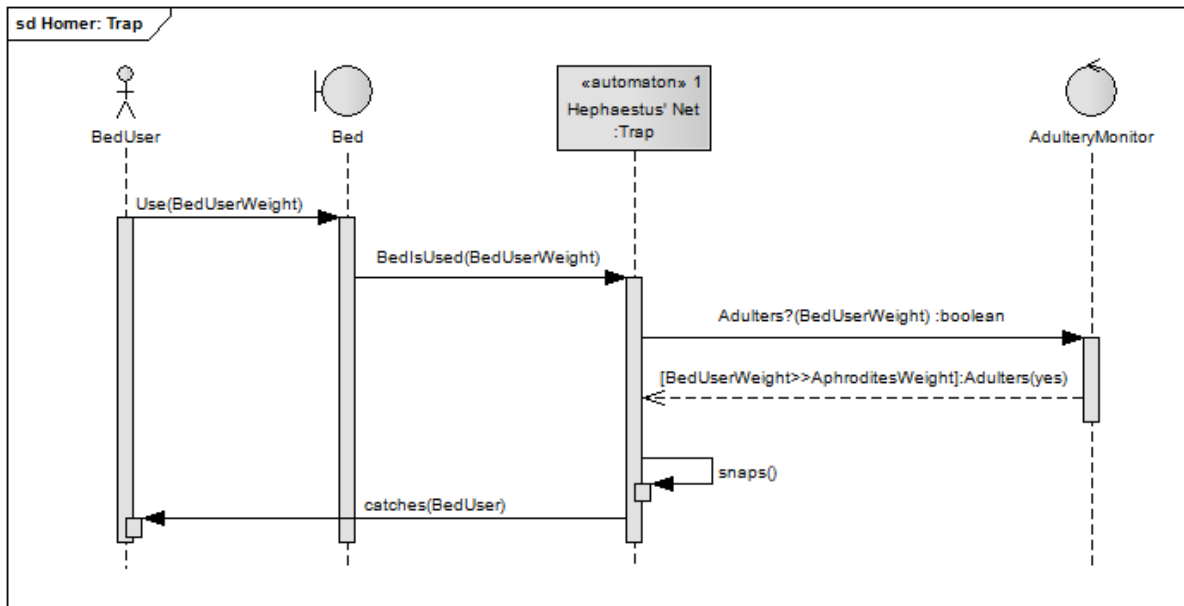
Fig. 8: UML Diagram of Phaecian Ships

Fig. 9: UML Diagram of Hephaestus' Adultery Trap

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golden chair with invisible fetters. When Hera sat down she was held fast, and Hephaestus refused to listen to any other of the gods save Dionysus—in him he reposed the fullest trust—and after making him drunk Dionysus brought him to heaven. Translation by W.H.S. Jones, Litt.D., and H.A. Ormerod (1918)
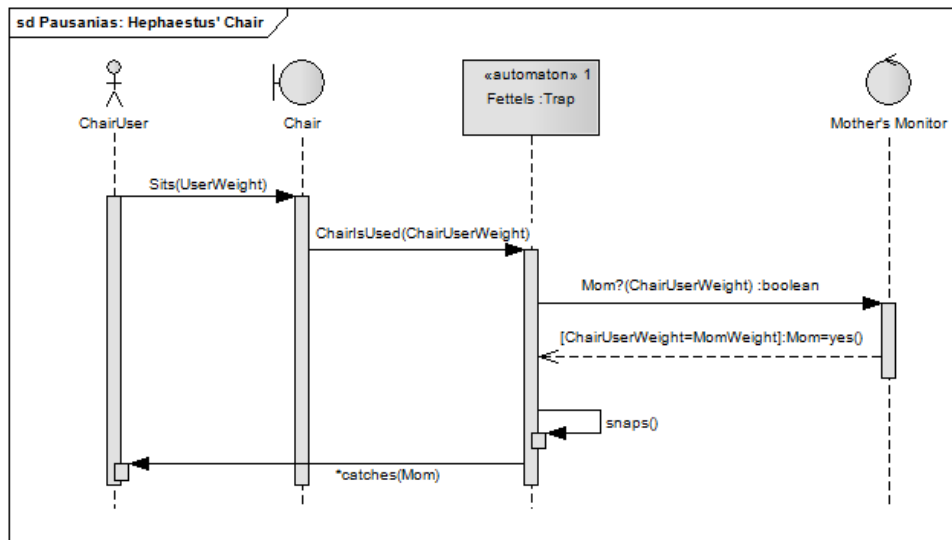
Fig. 10: UML Diagram of Hephaestus' Chair Trap

Kalligeropoulos and Vasileiadou [7], as well as presenting Homeric automata in detail, raised two major questions about energy source, and operation control. If the first problem [71] pertains more to the specific automata implementation than to design logic, the second one instead comes fully into our question. The two scholars remark that "the control process is a contradictory process. The simple, straight logic that goes from the cause to the result does not suffice. In the control process the desired result - output - determines the cause - input, which results in this output." Then they briefly review some aspects of the philosophy of Heraclitus, Socrates, and Plato, who would have helped to create the notions of contradiction, and control. We believe that, even if it is a very evocative and potentially fruitful combination of ideas, a thorough study of all available (philosophical, and possibly technical) sources is mandatory, before making well-substantiated hypothesis. As a matter of fact we should also remember that Homer's biography is still very controversial, so it is very difficult to determine when and why references to automata appeared in both poems.

2.2.3   Philosophy and Automata

In the 5th and 4th centuries BC we witness a gradual emergence of the approach rational in the analysis of reality: two very different philosophical systems are conceived first by Plato and then by Aristotle in order to provide a uniform interpretation of the world and of man.

Even the automata come in view of these authors. Aristotle, in particular, is believed to be the author of a treatise on mechanics, which in Middle Ages would become the only basis of knowledge on the subject.

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[71] The proposed solution is based on analysis of the work of pre-Socratic philosophers, especially the so-called physiologists, who sought the origin of all things in an element.

2.2.3.1 Archytas of Tarentum (4th century BC)

Archytas of Tarentum was a Greek mathematician, and a philosopher, living during Plato's lifetime [387]. He was the last outstanding figure in the early Pythagorean school [72] and a leading political man in his country. Biographical information about him are scant and often contradictory; just to give an idea, we quote the Stanford Encyclopedia of Philosophy: "our knowledge of Archytas' life and work depends heavily on authors who wrote in the second half of the 4th century, in the fifty years after Archytas' death.". We include him in our history, as he could have contributed to the advances of optics and to the mathematical foundations for the science of mechanics.

He was extremely popular among the Romans [73] and just the work of a Roman, the *Attic Nights* by Aulus Gellius (125-180), is the principal source about an automaton (X, 12, 9-10) [74] that Archytas would have built. The passage refers to a quotation from the work of the Greek Academic philosopher Favorinus of Arelates (now Arles), who flourished in the second half of the 1st century AD. The automaton working description is extremely concise: Favorinus simply says that the "wooden flying dove, […], when rested, did not rise anymore"; Gellius adds that the "dove built by Archytas from wood with rational mechanics studies has risen in flight, of course suspended to cables and driven by compressed air hidden inside". It is really hard to believe that Gellius has only paraphrased the words of his source, since he has probably added his or others' comments, in order to make the story less improbable. This has been for centuries the fate of Archytas' dove, which has systematically been the protagonist of attempts to rebuild its working, and to explain how such a little volume of compressed air could make the bird fly.

One of the most interesting is Schmidt's one [388]: the philologer who edited some of Philon's and Heron's works, tried to use the Alexandrian engineer's designs and some other indirect archeological evidence (see *infra* notes 76, and 77), in order to formulate a hypothesis. He assumes that the dove of Archytas was not a stand-alone device, but part of a system (a tree, for instance, or a basin), as the birds in Heron's, or Philon's automata would have been [75].

Through a hidden tube, compressed air would have entered into the hollow dove, and then the air flux would have been interrupted by a control valve. The dove, suspended (by means of a cord and

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[72] Based upon Plato's and Cicero's witnesses (respectively, Fr. 1 of *Archytas*, and *De oratore.* III 34. 139), and upon most later sources; Aristotle refers to him as to an independent philosopher [387].

[73] Mainly Roman authors of the first century BC (Propertius *Elegies*, IV 1 b.77; Varro in B8; Cicero, *De re publica,* I 38.59, I 10.16; *De finibus bonorum et malorum,* V 29.87; *Tusculanae disputationes,* IV 36.78, V 23.64; *De amicitia,* XXIII 88; *De senectute,* XII 39-41).

[74] IX. *Sed id, quod Archytam Pythagoricum commentum esse atque fecisse traditur, neque minus admirabile neque tamen vanum aeque videri debet. Nam et plerique nobilium Graecorum et Favorinus philosophus, memoriarum veterum exsequentissimus, affirmatissime scripserunt simulacrum columbae e ligno ab Archyta ratione quadam disciplinaque mechanica factum volasse; ita erat scilicet libramentis suspensum et aura spiritus inclusa atque occulta concitum. X. Libet hercle super re tam abhorrenti a fide ipsius Favorini verba ponere: ponere* Ἀρχύτας Ταραντῖνος, τὰ ἄλλα καὶ μηχανικὸς ὤν, ἐποίησεν περιστερὰν ξυλίνην πετομένην. ὁπότε καθίσειεν, οὐκέτι ἀνίστατο. Μέχρι γὰρ τούτου … But what the Pythagorean Archytas is said to have commented and done, is no less worthy of admiration and must not seem trivial. Indeed the most noble Greeks and the philosopher Favorinus, respectful of the ancient memories, wrote with absolute assurance that the image of a dove built by Archytas from wood with rational mechanics studies has risen in flight, of course suspended to cables and driven by compressed air hidden inside. I would like to refer the very words of Favorinus on a subject so far from credible: "Archytas of Taranto, being among other things also mechanic, built a wooden flying dove, that, when rested, did not rise anymore. For without this …

[75] In Alexandrian automata [387], thanks to air forced through a pipe, birds mainly sing (Heron, *Pneumatics*, I 14-15), drink (Heron, *Pneumatics*, I 28-30), or rotate (Heron, *Pneumatics*, I 15); only one design represent a bird, whose wings raise, when a predator approaches to his nest (Philon, *Pneumatics*, 40, 42). Counterweights are also commonly used, in order to reproduce a sudden movement.

a pulley) to a hidden counterweight, would then have been placed on a low branch of the tree, or on the edge of the basin. At the valve opening, the air would have made the dove's wings flap and lift the dove off the branch upwards by the counterweight. The dove would have perched on an upper branch (or a perch on the wall), once the counterweight had fallen to the ground; this last detail would explain why Favorinus remarked that the dove did not rise anymore: most likely the whole apparatus needed to be reset.

Schmidt admits that, accepting such a reconstruction, we should also admit that Archytas would have anticipated at least by a century the works of the Alexandrian engineers, or, at least, some of their solutions. This is not in itself impossible, but certainly difficult to prove: therefore the historian searched some primary or secondary sources in order to prove his assumption. He quotes, for instance,

- the eagle by Cleotas, quoted by Pausanias (*Description of Greece*, 6.20.12), used to indicate the start for horse races at Olympic games [76];
- a passage by Pliny the Elder (*Natural History,* XXXIV, 75), where the Roman historian refers to a brazen statue of Apollo, carved in the 6th century BC by the sculptor Canachus of Sicyon, for the temple of Miletus [77]. The statue would have had in its right hand a stag, that by means of a rope could seem to walk, or, better, to move legs.

Both these examples are loosely connected with the dove, and they are therefore not conclusive proof of the ability of the philosopher of Tarentum. In addition, if we compare this hypothetical reconstruction to the other object whose design is attributed to Archytas (the so-called clapper, a kind of rattle) [80] [78], we are forced to admit a formidable technical disparity between the two.

If exemples quoted by Schmidt are not conclusive, they are at least not the only ones. According to Polybius (200-118), the orator Demetrius of Phalerum (350-280 BC) had been critizised by his Athenian political opponent Demochares (355-275), for his entrance into the theatre followed by a mechanical slobbering snail (probably a kind of carnival float), during the Great Dionysia held in

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[76] δὲ ἐπὶ τῷ βωμῷ χαλκοῦς κεῖται τὰ πτερὰ ἐπὶ μήκιστον ἐκτείνων. ἀνακινεῖ μὲν δὴ τὸ ἐν τῷ βωμῷ μηχάνημα ὁ τεταγμένος ἐπὶ τῷ δρόμῳ· ἀνακινηθέντος δὲ ὁ μὲν ἐς τὸ ἄνω πεποίηται πηδᾶν ὁ ἀετός, ὡς τοῖς ἥκουσιν ἐπὶ τὴν θέαν γενέσθαι σύνοπτος, ὁ δελφὶς δὲ ἐς ἔδαφος πίπτει. And a bronze eagle stands on the altar with his wings stretched out to the fullest extent. The man appointed to start the racing sets in motion the mechanism in the altar, and then the eagle has been made to jump upwards, so as to become visible to the spectators, while the dolphin falls to the ground. Translation by W.H.S. Jones, and M.A.Ormerod (1918)

[77] *Canachus Apollinem nudum, qui Philesius cognominatur, in Didymaeo Aeginetica aeris temperatura, cervumque una ita vestigiis suspendit, ut linum subter pedes trahatur alterno morsu calce digitisque retinentibus solum, ita vertebrato dente utrisque in partibus, ut a repulsu per vices resiliat.* Canachus executed a nude Apollo, which is known as the "Philesian": it is at Didymi, and is composed of bronze that was fused at Ægina. He also made a stag with it, so nicely poised on its hoofs, as to admit of a thread being passed beneath. One fore-foots, too, and the alternate hind-foot are so made as firmly to grip the base, the socket being so indented on either side, as to admit of the figure being thrown at pleasure upon alternate feet. Translation by J.Bostok (1855)

[78] In Greek πλαταγὴ; philologists and historians have long debated the nature of this object, whose sole purpose is however to produce a sound to entertain children [387]. It is quoted by Aristotle in *Politics* 8, ἅμα δὲ καὶ δεῖ τοὺς παῖδας ἔχειν τινὰ διατριβήν, καὶ τὴν Ἀρχύτου πλαταγὴν οἴεσθαι γενέσθαι καλῶς, ἥν διδόασι τοῖς παιδίοις, ὅπως χρώμενοι ταύτῃ μηδὲν καταγνύωσι τῶν κατὰ τὴν οἰκίαν· οὐ γὰρ δύναται τὸ νέον ἡσυχάζειν. αὕτη μὲν οὖν ἐστι τοῖς νηπίοις ἁρμόττουσα τῶν παιδίων, ἡ δὲ παιδεία πλαταγὴ τοῖς μείζοσι τῶν νέων. At the same time also boys must have some occupation, and one must think Archytas's rattle a good invention, which people give to children in order that while occupied with this they may not break any of the furniture; for young things cannot keep still. Whereas then a rattle is a suitable occupation for infant children, education serves as a rattle for young people when older. Translation by H.Rackham (1944).

308 [79]. Even if we assume that Demochares was speaking allegorically, the use of the mechanical "contrivance", which doesn't appear as an oddity neither to Polybius, nor to Demochares is interesting. Rehm, however, [389] tried to reconstruct the snail operation, by assuming that it was large enough to contain some men who moved in a wheel (similar to the one currently used as a pastime for hamsters), pushing the whole device.
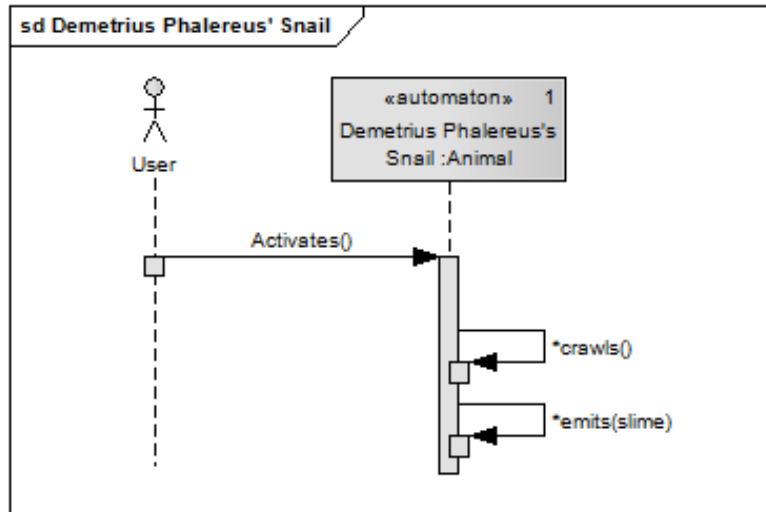

Fig. 11: Demetrius Phalereus' Snail

Another interpretation, rather fanciful, has been given by D'Arrigo [14-15], based on another Latin source; the writer Marcus Terentius Varro (116-27 BC) in his work about agriculture (*Rerum rusticarum libri III*) quotes to his wife Fundania a list of Greeks authors who had written in some way about plant cultivation: among them, even Archytas is referred (I, 1, 8). D'Arrigo assumes that Archytas might have been inspired by the fruits of some plants (plantain, dandelion, salsify, lettuce), whose shape allows them to remain suspended in the air for some time. As we can see, this assumption is unprovable.

2.2.3.2 Plato, and Aristotle

Though we have no direct reference to automata in Plato's works, Brumbaugh [390], and later De Solla Price [363] remark that "By the time of Plato it seems likely there existed artifacts, perhaps even with simple animation, simulating the geometrically-understood cosmos. […] much of Plato's imagery seems to derive from models that were more than mental figments. Certainly by the time of Eudoxos (ca. 370 BC) we find a geometrical model of planetary motion having every appearance of relation to an actual mechanism of bronze rings." [80]

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[79] *Histories*, XII, 13, 10-11. [10] ἐπὶ γὰρ τῷ πολλὰ καὶ λυσιτελῶς πωλεῖσθαι κατὰ τὴν πόλιν καὶ δαψιλῆ τὰ πρὸς τὸν βίον ὑπάρχειν πᾶσιν, ἐπὶ τούτοις φησὶ μεγαλαυχεῖν αὐτόν: [11] καὶ διότι κοχλίας αὐτομάτως βαδίζων προηγεῖτο τῆς πομπῆς αὐτῷ, σίαλον ἀναπτύων, σὺν δὲ τούτοις ὄνοι διεπέμποντο διὰ τοῦ θεάτρου, διότι δὴ πάντων τῶν τῆς Ἑλλάδος καλῶν ἡ πατρὶς παρακεχωρηκυῖα τοῖς ἄλλοις ἐποίει Κασσάνδρῳ τὸ προσταττόμενον, ἐπὶ τούτοις αὐτὸν οὐκ αἰσχύνεσθαί φησιν. And he tells another story of Demetrius, that "He was not ashamed to have a procession in the theatre led by an artificial snail, worked by some internal contrivance, and emitting slime as it crawled, and behind it a string of asses; meaning by this to indicate the slowness and stupidity of the Athenians, who had yielded to others the honour of defending Greece, and were tamely submissive to Cassander." […] Translation by E.S. Shuckburgh (1899)
[80] Quotation is from De Solla Price's paper.

As a matter of fact, the philosopher, in *Laws* (1, 644 d-e) [81], while discussing about the relationship between man and gods, describes the former as a θαῦμα, literally "wonder", but in this specific meaning referred to a toy, source of wonder for children because of its unpredictable behavior. The toy Plato alludes to, is probably a puppet, since he adds that gods made us for mysterious purposes (it could be either for their own pleasure, or for some serious reason), and now we live in the world, affected by contradictory feelings, in a body made of antagonist sinews, or cords. Their working can lead us to opposite actions, that is to good, or to evil. Some scholars also suggest that the Allegory of the Cave as well, taken from *Republic* (VII, 514a-520a), could be connected with a puppet show [79].

A secondary source (Athenaeus, *Deipnosophistae*, IV, 174 b), interpreted by Diels [299] and Schmidt [391], refers to a nightly clock [82], Plato would have built, because of his repugnance to sleep.

In the usual absence of direct sources, we can only remember that the basis of Platonic philosophy is the dualism between the world of ideas, perfect, motionless and unchanging, and the world of things, misleading, subject to motion and time. The idea of Plato as an inventor seems poorly compatible with this view.

Aristotle can be considered as the first philosopher to have been seduced by the idea of automation to the point of figuring out some possible manufacturing, or, at least, useful, applications, as evidenced in *Politics* I, 1253b [83]. The passage is quoted by almost all those who have studied

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[81] περὶ δὴ τούτων διανοηθῶμεν οὑτωσί. Θαῦμα μὲν ἕκαστον ἡμῶν ἡγησώμεθα τῶν ζῴων θεῖον, εἴτε ὡς παίγνιον ἐκείνων εἴτε ὡς σπουδῇ τινι συνεστηκός· οὐ γὰρ δὴ τοῦτό γε γιγνώσκομεν, τόδε δὲ ἴσμεν, ὅτι ταῦτα τὰ πάθη ἐν ἡμῖν οἷον νεῦρα ἢ σμήρινθοί τινες ἐνοῦσαι σπῶσίν τε ἡμᾶς καὶ ἀλλήλαις ἀνθέλκουσιν ἐναντίαι οὖσαι ἐπ᾽ ἐναντίας πράξεις, οὗ δὴ διωρισμένη ἀρετὴ καὶ κακία κεῖται. Let us suppose that each of us living creatures is an ingenious puppet of the gods, whether contrived by way of a toy of theirs or for some serious purpose-for as to that we know nothing; but this we do know, that these inward affections of ours, like sinews or cords, drag us along and, being opposed to each other, pull one against the other to opposite actions; and herein lies the dividing line between goodness and badness.

[82] λέγεται δὲ Πλάτωνα μικράν τινα ἔννοιαν δοῦναι τοῦ κατασκευάσματος νυκτερινὸν ποιήσαντα ὡρολόγιον ἐοικὸς τῷ ὑδραυλικῷ οἷον κλεψύδραν μεγάλην λίαν. καὶ τὸ ὑδραυλικὸν δὲ ὄργανον δοκεῖ κλεψύδρα εἶναι. ἐντατὸν οὖν καὶ καθαπτὸν οὐκ ἂν νομισθείη, ἐμπνευστὸν δὲ ἂν ἴσως ῥηθείη διὰ τὸ ἐμπνεῖσθαι τὸ ὄργανον ὑπὸ τοῦ ὕδατος. but it is said, that Plato showed a sort of notion of the invention, making a nightly clock like the hydraulic organ; being very like an enormous hour-glass. And, indeed, the hydraulic organ does seem to be a kind of hour-glass. It cannot, therefore, be considered a stringed instrument, and one to be played by touching. But perhaps it may be called a wind instrument, because the organ is inflated by the water. Translation by C.D.Yonge (1854).

[83] ἐπεὶ οὖν ἡ κτῆσις μέρος τῆς οἰκίας ἐστὶ καὶ ἡ κτητικὴ μέρος τῆς οἰκονομίας (ἄνευ γὰρ τῶν ἀναγκαίων ἀδύνατον) καὶ ζῆν καὶ εὖ ζῆν, ὥσπερ δὲ ταῖς ὡρισμέναις τέχναις ἀναγκαῖον ἂν εἴη ὑπάρχειν τὰ οἰκεῖα ὄργανα, εἰ μέλλει ἀποτελεσθήσεσθαι τὸ ἔργον, οὕτω καὶ τῷ οἰκονομικῷ. τῶν δ᾽ ὀργάνων τὰ μὲν ἄψυχα τὰ δὲ ἔμψυχα (οἷον τῷ κυβερνήτῃ ὁ μὲν οἴαξ ἄψυχον ὁ δὲ πρῳρεὺς ἔμψυχον· ὁ γὰρ ὑπηρέτης ἐν ὀργάνου εἴδει ταῖς τέχναις ἐστίν)· οὕτω καὶ τὸ κτῆμα ὄργανον πρὸς ζωήν ἐστι, καὶ ἡ κτῆσις πλῆθος ὀργάνων ἐστί, καὶ ὁ δοῦλος κτῆμά τι ἔμψυχον, καὶ ὥσπερ ὄργανον πρὸ ὀργάνων πᾶς ὑπηρέτης. εἰ γὰρ ἠδύνατο ἕκαστον τῶν ὀργάνων κελευσθὲν ἢ προαισθανόμενον ἀποτελεῖν τὸ αὑτοῦ ἔργον, <καὶ> ὥσπερ τὰ Δαιδάλου φασὶν ἢ τοὺς τοῦ Ἡφαίστου τρίποδας, οὕς φησιν ὁ ποιητὴς αὐτομάτους θεῖον δύεσθαι ἀγῶνα, οὕτως αἱ κερκίδες ἐκέρκιζον αὐταὶ καὶ τὰ πλῆκτρα ἐκιθάριζεν, οὐδὲν ἂν ἔδει οὔτε τοῖς ἀρχιτέκτοσιν ὑπηρετῶν οὔτε τοῖς δεσπόταις δούλων. Since therefore property is a part of a household and the art of acquiring property a part of household management (for without the necessaries even life, as well as the good life, is impossible), and since, just as for the particular arts it would be necessary for the proper tools to be forthcoming if their work is to be accomplished, so also the manager of a household must have his tools, and of tools some are lifeless and others living (for example, for a helmsman the rudder is a lifeless tool and the look-out man a live tool-for an assistant in the arts belongs to the class of tools), so also an article of property is a tool for the purpose of life, and property generally is a collection of tools, and a slave is a live article of property. And every assistant is as it were a tool that serves for several tools; for if every tool could perform its own work when ordered, or by seeing what to do in advance, like the statues of Daedalus in the story, or the tripods of Hephaestus which the poet says 'enter self-moved the company divine,'-if thus

mechanics in the ancient world, who have often questioned the causes of the scarcity of objects of this kind either in sources or in finds. The text shows, according to some, that, just in the 4th century, the use of machines was considered, at least in theory, as an alternative to human work: such a remark would require to seek the causes of the lack outside the field of technology (e.g., abundance and low cost of slaves; aristocratic attitudes towards manual work, considered unworthy of a free man, that would lead to a conscious rejection of the mechanics, as focused by Aymard [392]; philosophical culture devoted more to ethics than to machines and to technology [100], as also shown by Seneca, *Epistulae morales ad Lucilium*, 90, 25-26); according to others, however, Aristotle would be in the tradition of myth of αὐτόματος βίος: these passage would be a paradox, just like in comedies studied above (2.2.1), written in order to demonstrate the necessity of slavery.

Cambiano [79] believes that Aristotle's reference is to actual automata, and focuses on what Aristotle says in aside "when ordered, or by seeing what to do in advance", which goes at the heart of the problem of a proto-AI. The automaton is a tool, exactly as slaves are, but to be actually similar to a slave, the automaton must be able to reproduce at least a minimal appearance of intelligence, consisting in the understanding of a command [84]. According to Cambiano, if we accept Aristotle's authorship for the *Mechanics*, automata were the acme of technical objects, that, hiding their mechanical nature, were explicitly intended to appear different from themselves; they would be a class of objects possessesing in itself its motion principle, and the highest product of a technique that would best imitate nature by trying to leave no visible trace of itself in the objects of his production.

On other occasions, in *On the Movement of Animals* (I, 7), and in *On the Generation of Animals*, (2,1), Aristotle uses automata as an analogy, to describe respectively the features of self-motion and of reproduction in animals [79, 78, 16] [85]; these texts have been used to prove, or to disprove, the mechanistic inclination of Aristotelian zoology [393-394, 16]. Both passages nevertheless represent significant evidence for us, since any interpretation you want to give the two texts, automata have been chosen to give explanation of the functioning of living beings. This shows that the automata

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shuttles wove and quills played harps of themselves, master-craftsmen would have no need of assistants and masters no need of slaves. Translation by H. Rackham (1944)

It is worth mentioning that, if we exclude the possibility that Aristotle is referring to some form of automation actually existing in his time, we must recognize to him an important insight in identifying the relevant production field (textiles) in which the mechanization of work would start, 2000 years after his words. He probably noticed that movements of weavers (and of musicians) are essentially periodical, which would have been easier to reproduct.

[84] This is also made evident in our UML-morales by the use of entities like sensors or monitors, or by behaviors, like access to a data base.

[85] "The movements of animals may be compared with those of automatic puppets, which are set going on the occasion of a tiny movement; the levers are released, and strike the twisted strings against one another; or with the toy wagon. For the child mounts on it and moves it straight forward, and then again it is moved in a circle owing to its wheels being of unequal diameter (the smaller acts like a centre on the same principle as the cylinders).";

"It is possible, then, that A should move B, and B move C; that, in fact, the case should be the same as with the automatic machines shown as curiosities. For the parts of such machines, while at rest, have a sort of potentiality of motion in them, and, when any external force puts the first of them in motion, immediately the next is moved in actuality. As, then, in these automatic machines the external force moves the parts in a certain sense (not by touching any part at the moment, but by having touched one previously), in like manner also that from which the semen comes, or in other words that which made the semen, sets up the movement in the embryo and makes the parts of it by having first touched something though not continuing to touch it. In a way it is the innate motion that does this, as the act of building builds the house. Plainly, then, while there is something which makes the parts, this does not exist as a definite object, nor does it exist in the semen at the first as a complete part."

operation was known to a reasonable level of detail at least among the recipients of Aristotle's works.

2.2.4 Oracles

As we have seen in Greek Archaic and Classical culture, the correctness of the statement of De Solla Price "It seems that by the beginning of Greek culture the process of natural exaggeration in mythology and legend had produced at least the concept of simulacra able to do more than merely talk and move their arms." has been verified [363].

However this should not imply that automata were missing from the liturgy, especially the oracular one. We are informed by the Greek satirical writer Lucian of Samosata (120-190), in his *The Syrian Goddess* (36-37), that Greek oracles were still in activity during the 2nd century AD [86]. Although, given the satirical nature of the text, we cannot rely on the details of the description, just for the same reason, we have to think that the consultation of oracles was still common at the time, or making them the subject of satire would not have made sense. The grammarian and philosopher Macrobius, in the 5th century AD, i.e. long after the beginning of the Christian era, also refers to processions with self-moving, or talking statues in Antium and Heliopolis, in his *Saturnalia* (*Saturnalia Convivia* I, 23, 14) [87].

2.3 The "Thauma Connection": from Alexandria to the Roman Empire

One of the most challenging questions about this historical period pertains to lost technology, given the perishable nature of the materials with which it was implemented.

In addition, due to a sort of contempt for the objects of daily use , their descriptions in literature are extremely rare, almost entirely absent referring to our topic. Even the word μηχανὴ (mechanics) implies both a denotative and an ethical meaning [69, 395]: though it literally refers to a branch of

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[86] First I will speak of the oracle. There are many oracles among the Greeks, and many, too, among the Egyptians, and again in Libya and in Asia there are many too. But these speak not, save by the mouth of priests and prophets: this one is moved by its own impulse, and carries out the divining process to the very end. The manner of his divination is the following: When he is desirous of uttering an oracle, he first stirs in his seat, and the priests straightway raise him up. Should they fail to raise him up, he sweats, and moves more violently than ever. Should they fail to raise him up, he sweats, and moves more violently than ever. When they approach him and bear him up, he drives them round in a circle, and leaps on one after another. At last the high priest confronts him, and questions him on every subject. The god, if he disapproves of any action proposed, retreats into the background; if, however, he happens to approve it, he drives his bearers forward as if they were horses. It is thus that they gather the oracles, and they undertake nothing public or private without this preliminary. This god, too, speaks about the symbol, and points out when it is the due season for the expedition of which I spoke in connection therewith. I will speak of another wonder, too, which he performed in my presence. The priests were raising him aloft, but he left them on the ground, and was born aloft himself alone.

[87] *Vehitur enim simulachrum dei Heliopolitani ferculo, uti vehuntur in pompa ludorum Circensium deorum simulachra: et subeunt plerumque provinciae proceres, raso capite, longi temporis castimonia puri, ferunturque divino spiritu, non suo arbitrio sed quo deus propellit vehentes: ut videmus apud Antium promoveri simulachra Fortunarum ad danda responsa.* For the statue of the god of Heliopolis is borne in a litter, as the images of the gods are carried in the procession at the Circensian games, and the bearers are generally the leading men of the province. These men, with their hair shaved, and purified by a long period of abstinence, go as the spirit of god moves them and carry the statue not of their own but whithersoever the god directs them, just as at Antium we see the images of the two goddess of Fortune move forward to give their oracles.

physics, it still alludes to a tricky attitude [88]. Nonetheless, as De Solla Price [300] clearly states, "the technology was there, and it has just not survived like the great marble buildings, statuary, and the constantly recopied literary works of high culture". [97]

Though we deal with two different languages and cultures (the Alexandrian and Roman one), we must call attention to the substantial Alexandrian-Roman technological continuity, due to historical reasons: the Egyptian reign simply passed in the Roman hands, becoming part of the empire. One of the most interesting sources about automata in this period ranging from the 3rd century BC and the 2nd CE are out of doubt the *Deipnosophists* (*Banquet of the learned*) by the Greek grammarian Athenaeus of Naucratis (3rd century CE), featured by Egyptian origin, Greek culture and language, Roman era. They are still portrayed as a courtly pastime [396], used during the same public ceremonies as the ones described by Theocritus in his *Syracusans*, where two women from Syracuse see in Alexandria a show for the queen.

2.3.1 Antikythera

One of the very few objects that testify the level of technology of the ancient Greek world is undoubtedly the one found by chance near the island of Antikythera in Greece at the beginning of the 20th century. Nearly 50 years after its discovery, De Solla Price began a systematic study of this find [87], followed, during the century by other teams of scholars [397-399, 88]. Although the reconstructions differ in many significant details, they all agree on the nature of the object: it is a device to calculate the positions of the planets, an artifact of precision mechanics, which can well demonstrate the level of technology attained in the 1st century BC.

The Antikythera mechanism is probably the best preserved artifact, that can be usefully quoted for our aim, but it is not the only one: while Taub describes some astrolabes [400], King [401] quotes

- a pocket Roman sundial, graduated with an hourly scale with the latitudes of 30 provinces of the Empire, in order to calculate the time depending on where you are, housed in Oxford;
- a 5th century geared sundial (housed in London) with a mechanism to indicate the weekday.

We therefore, even without numerous archaeological finds, can see that the mechanics had finally reached and maintained a good level and there were the skills to realize complex objects like automata.

2.3.2 The school of Alexandria

At the end of the 3rd century BC, as traditionally alleged, pharaon Ptolemy I Soter (the Savior) undertook in Alexandria the construction of the Library and the Musaeum (literally, shrine of the Muses, daughters of Zeus and patrons of arts and sciences), where scientists could study in full freedom, sponsored by the king, for the prestige of the court; their studies didn't need an actual and immediate applicability to practical purposes, as demonstrated by the composition of the research team: 30 grammarians / philologists, 25 doctors, 17 philosophers, 11 historians / biographers, 11 astronomers, 15 mathematicians, 4 physicists (mechanics), and 2 geographers [402].

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[88] As a matter of fact, one of the first mentions of the root of this word is found in Homer's works, referring to the character of Odysseus (πολυμήχανος, polymechanos, meaning a man who can perform many tricks).

Both the Byzantine chronicler Georgius Syncellus (9th century), and the poet Johannes Tzetzes (ca.1110-1180) refer that the Greek statesman Demetrius of Phalerum would have been responsible for the collection of books from all over the world in Alexandria, thanks to the royal funds, and would have placed them in two libraries. The king would however have been Ptolemy II Philadelphus (brother/sister-loving) [403]. Sources are very late, and therefore potentially not reliable, and it would certainly have been an irrelevant detail, if only Demetrius had not been quoted as the protagonist of another episode on automata (see *supra* 2.2.3.1).

2.3.2.1 Ctesibius

He lived in Alexandria around 270 BC, as an epigram by the poet Hedylos [89] quotes his singing cornamuse made for a statue of Arsinoe, sister and wife of Ptolemy II Philadelphus [404]. Other sources that would fix his life's date one century later are controversial and led to the assumption (controversial as well) of a second Ctesibius [405].

The Roman architect Vitruvius (80-15 BC) is our main source about him [90]: he would have got a book by Ctesibius about his inventions, containing some news about his life; the Alexandrian scholar would have been the son of a barber, and in his father's shop he would have built an adjustable mirror controlled by a counterweight, producing a loud noise, while operating. By observing its operation, Ctesibius would have begun studies about pneumatics [91], in collaboration with the Peripatetic philosopher Strato of Lampsacus (335-c. 269) [406] .

He invented:

- An air-powered catapult
- An air pump with valves, connected to a keyboard and rows of pipes (water organ) [92]
- A force pump for water [93]
- A water clock [94]; a clepsydra with constant flow; he made up his work in gold to avoid rust or verdigris or in precious stone to guard against wear; the water flowed into a cylindrical container and lifted a float, which carried a pointer to mark the hours; thanks to a rack turning a toothed wheel he made the clock work with *parerga*, like whistling birds moving puppets, and ringing bells.

Unfortunately, nothing of his written or invented works still survives.

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[89] Referred by Athenaeus in *Deipnosophists* XI, 497 d: Ἡδύλος δ’ἐν Ἐπιγράμμασι περὶ τοῦ κατασκευασθέντος ὑπὸ Κτησιβίου τοῦ μηχανοποιοῦ ῥυτοῦ μνημονεύων φησί· “ζωροπύται, καὶ τοῦτο φιλοζεφύρου κατὰ νηὸν / τὸ ῥυτὸν εὐδίης δεῦτ’ἴδετ’Ἀρσινόης, / ὀρχηστὴν Βησᾶν Αἰγύπτιον’ὃς λιγὺν ἦχον / σαλπίζει κρουνοῦ πρὸς ῥύσιν οἰγομένου, οὐ πολέμου σύνθημα, διὰ χρυσέου δὲ γέγωνεν κώδωνος κώμου σύνθεμα καὶ θαλίης, / Νεῖλος ὁκοῖον ἄναξ μύσταις φίλον ἱεραγωγοῖς / εὗρε μέλος θείων πάτριον ἐξ ὑδάτων. / ἀλλ’εἰ Κτησιβίου σοφὸν εὕρεμα τίετε τοῦτο, / δεῦτε, νέοι, νηῷ τῷδε παρ’ Ἀρσινόης.” but Hedylus, in his *Epigrams*, mentioning the rhytum made by Ctesibius the engineer or machinist, speaks thus- Come hither, all ye drinkers of sheer wine,- Come, and within this shrine behold this rhytus, The cup of fair Arsinoe Zephyritis, The true Egyptian Besa, which pours forth Shrill sounds, what time its stream is open'd wide,- No sound of war; but from its golden mouth It gives a signal for delight and feasting, Such as the Nile, the king of flowing rivers, Pours as its melody from its holy shrines, Dear to the priests of sacred mysteries. But honour this invention of Ctesibius, And, o youths, to fair Arsinoe's temple. Translation by C. D. Yonge (1853)
[90] *De architectura* X, vii, 5; see *infra* footnote 107
[91] *De architectura* I, i, 7: *item qui Ctesibii aut Archimedis et ceterorum qui eiusdem generis praecepta conscripserunt leget, sentire non poterit nisi his rebus a philosophis erit institutus*.
[92] *De architectura* X,viii;
[93] *De architectura* VII, *Introduction*, 14
[94] *De architectura* IX,viii,4-7

2.3.2.2 Philon of Byzantium

Very little is known about his life and works, apart from some minor news [95] [408]. We however have extant fragments of a work about mechanics, whence it is possible to find some clues:

- He refers to Ctesibius' catapult as to a recent invention: he possibly was a contemporary of his;
- He studied the catapults, by travelling between Alexandria and Rhodes: he probably was wealthy or had a wealthy patron (possibly the Ariston, whose name is the receiver of the treatise [409])

It is possible, according to Drachmann [408], to reconstruct the contents of his main work about *Mechanics*

1. Introduction
2. On the lever (Μοχλικὰ)
3. On the building of seaports (Λιμενοποιικὰ)
4. On catapults (Βελοποιικὰ): it survived complete, and contains references catapults, possible hint of alleged Philon's travels.
5. On pneumatics (Πνευματικὰ): it survived complete
6. On automatic theaters (Αὐτοματοπιικὰ)
7. On the building of fortresses (Παρασκευαστικὰ): it survived complete, and it is considered as originally composing book 5, together with the following
8. On besieging and defending towns (Πολιορκετικὰ): complete
9. On stratagems

2.3.2.2.1   Philon's Pneumatics

Its preliminary chapters include a number of experiments almost certainly taken from Ctesibius; the rest of the book consists of "pneumatic toys", as Drachmann says "apparatus for parlor magic".
Philon's devices, that would be imitated during the following centuries, are mostly: 31, 40, 58, and 59, referring to Carra de Vaux' progressive numeration [47]. The other ones, as we will see also in Heron's work, are often basic devices, and are distributed in the treatise according to a criterion of increasing complexity, though mostly using the same principles, and the same basic structure. We preferred to focus on Heron's devices, when identical, and we modeled them, as we have the Greek description, as near as possible to the original. A special mention deserves however other devices #10-29, concerning "wonderful vessels", also present in Heron's and in Banu Musa's works.

As we will see for Heron, devices often need to be activated by someone (therefore called Activator, in our diagrams) who is not the final recipient, and possibly acts secretly, not to show any hints about working principles.

The first device here considered (#31) serves automatically guests with water and pumice stone (a surrogate of soap) for washing hands. It will be used also by al-Jazari, though with some major differences (see *infra* Fig. 100).

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[95] Vitruvius includes him in the list of ancient inventors (VII, intro, 14); Heron mentions an automated theater by him (*Automata*, XX, 1,3); Eutocius cites his work on the duplication of the cube [407], pg. 60
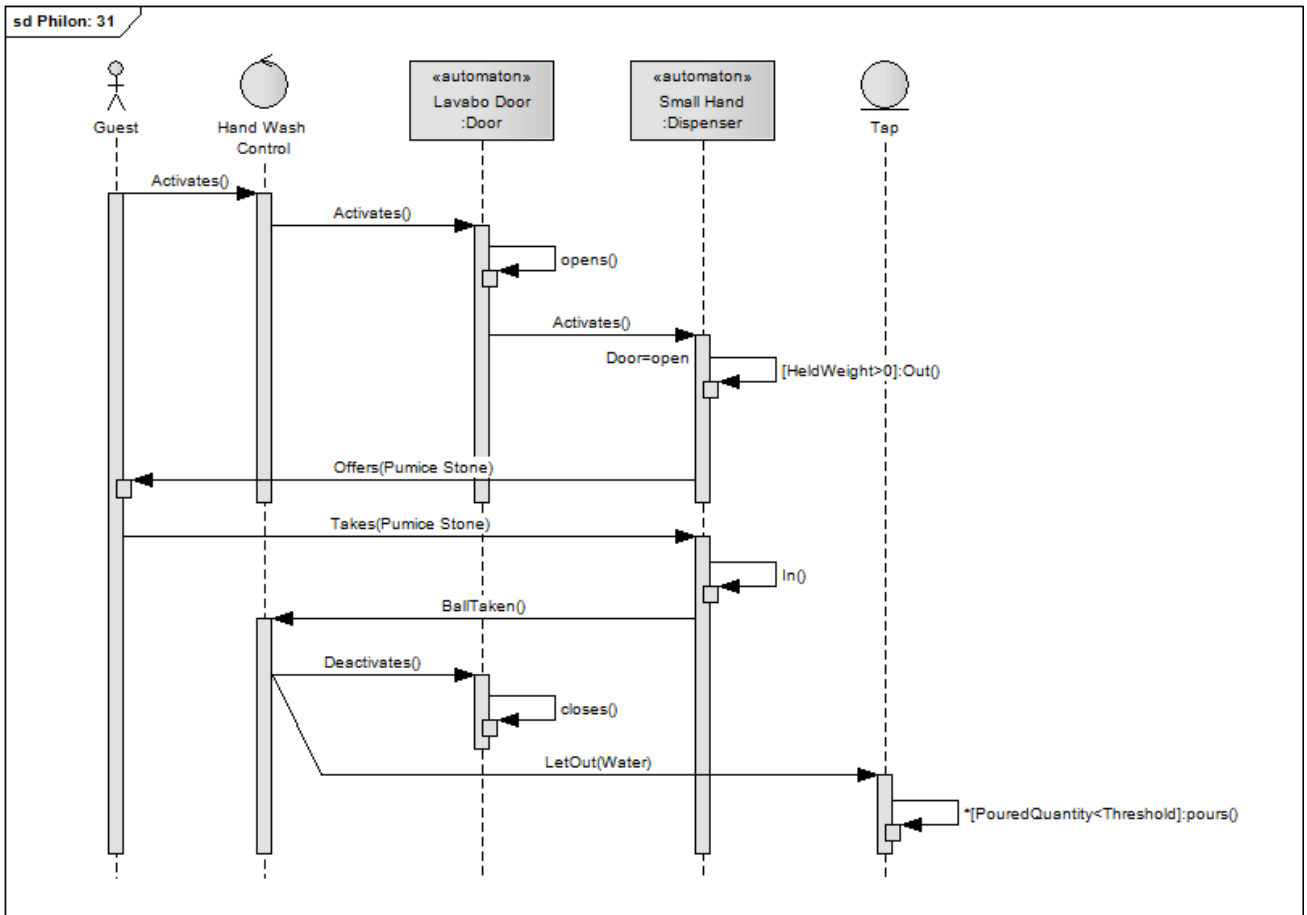
Fig. 12: UML Diagram of Philon's Design #31
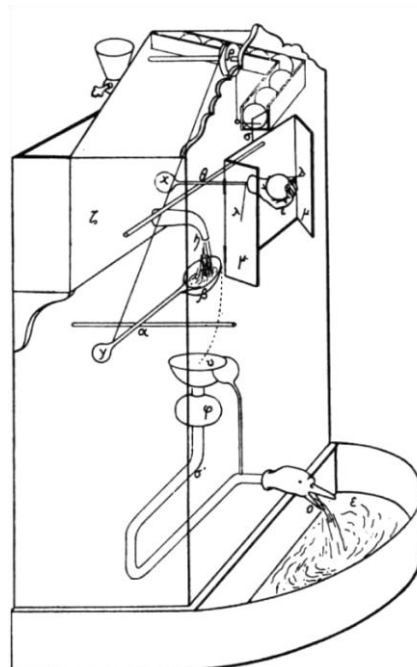
Fig. 13: Philon's Device #31 by Carra de Vaux

The second device here considered (#40) represents a vessel, where a scene is played by a bird, defending his chicks in the nest from a sudden snake's attack [96].
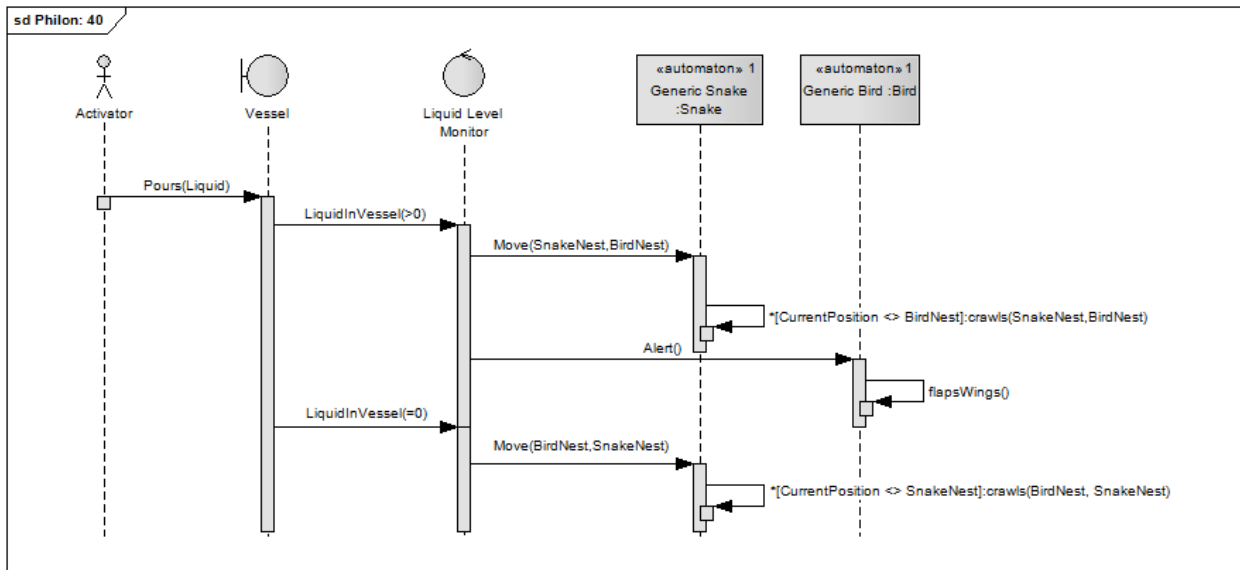
Fig. 14: UML Diagram of Philon's Design #40
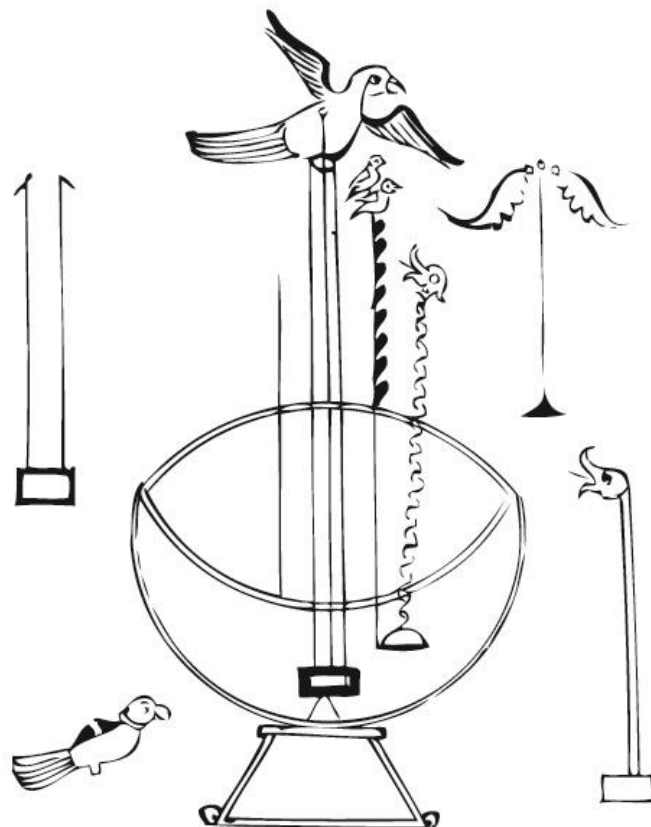
Fig. 15: Philon's Device #58; darwing based upon Aya Sofia MS.

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[96] See *supra* note 75.

The third one (#58) represents singing birds on the lip of a brazier. The effect is got thanks to a hidden cause: steam produced from heating water inside the vessel.
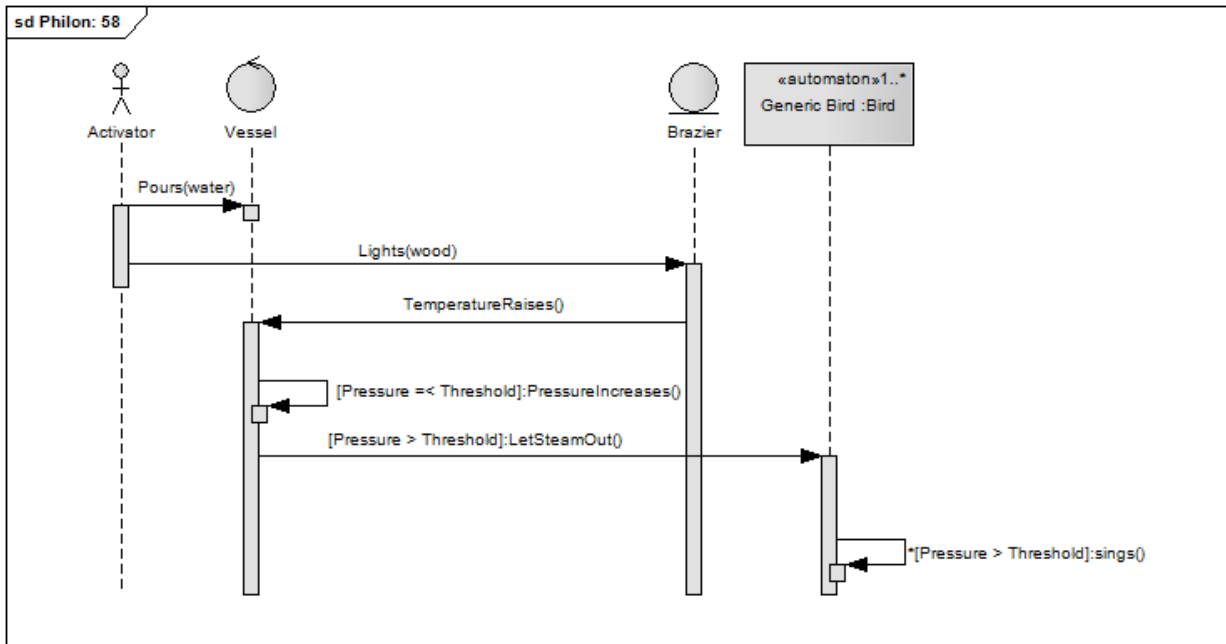
Fig. 16: UML Diagram of Philon's Device #58

Fig. 17: Philon's Device #58 by Carra de Vaux

The fourth one (#59) is the most complex, and involves the presence of mythic characters. It should be placed in a temple, near running water from a cave or a steep rise, as Philon recommends in order to have an unlimited quantity of available running water. The builder should also provide a system to drain surplus of water. It is the rare case of a user (or we could say a visible activator) who contributes to the operation of the device only after it is already working, and alters the system state, preventing the water to escape through the pipes hidden in the dragon. Here the human automaton works mainly as a cork, while the theriomorphic one as a pipe.
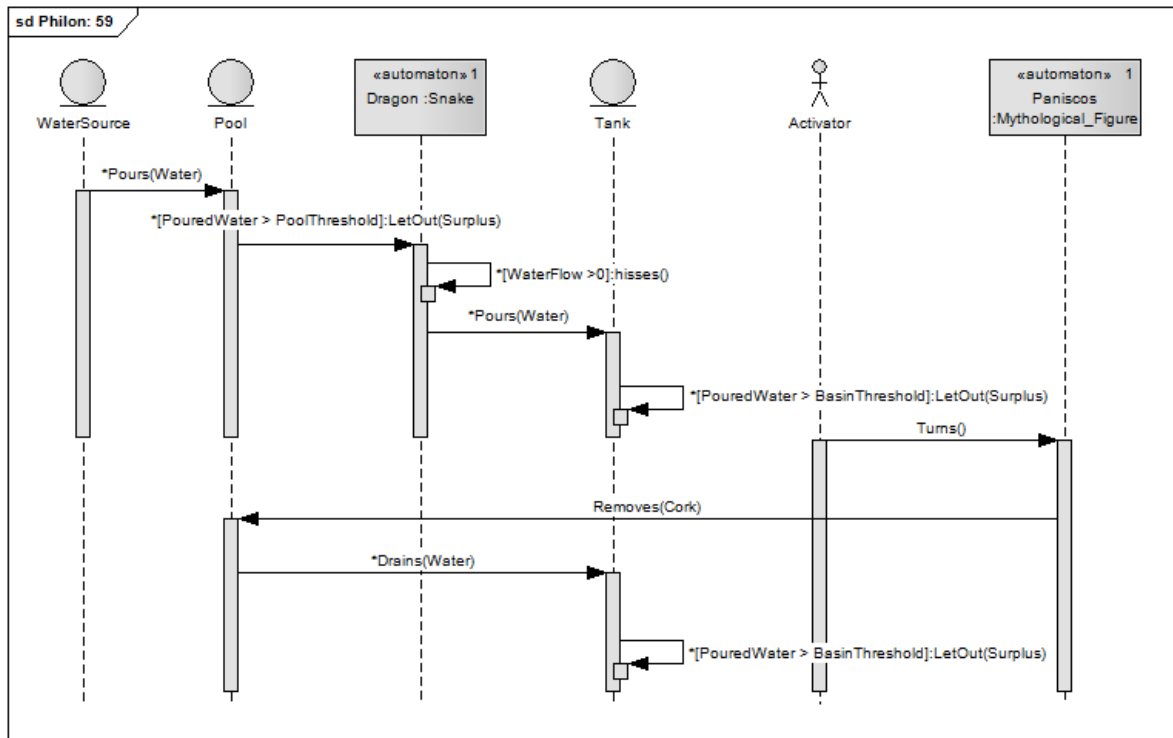
Fig. 18: UML Diagram of Philon's Device #59
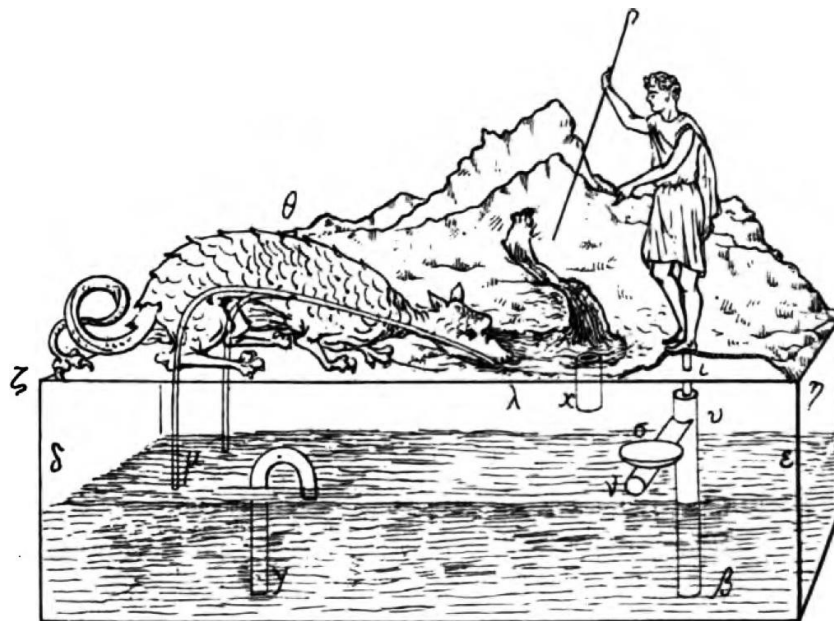
Fig. 19: Philon's Device #59 by Carra de Vaux

2.3.2.3 Heron of Alexandria

Apart from the names of his works, we don't know anything about him [410]. *Mechanics* survived only in Arabic and the *Optics* only in Latin. The first source that mentions him is Pappus (330 AD), who quotes from his mechanics; he quotes Archimedes (212 BC) so we have the terminus ante quem and the post quem. The range has been shortened by Neugebauer [411], who showed that Heron could have referred to a real eclipse of the moon in the problem of determining the distance between Rome and Alexandria in his *Dioptra*, ch. 35. This would have happened in 62 AD.[97]

His works, according to what is known at the moment, pertain to two main fields:

1. *Mathematics*
   a. *Definitiones*
   b. *Geometrica*
       i. *Metrica*
       ii. *Stereometrica*
2. *Mechanics*
   a. *Automata*
   b. *Baroulkos* or the lifter of weights. It is the name given by Pappus to an extract from *Dioptra* 37 and *Mechanics* I, 1
   c. *Belopoiika*, about throw weapons
   d. *Catoptrica*, only in Latin version; how to arrange mirrors for illusions
   e. *Cheirobalistra*, fragment of a dictionary about catapults
   f. *Dioptra*, that contains a description of instruments for surveyors;
   g. *Mechanics*: preserved only in Arabic version; it is deeply different from *Pneumatics*; ordered consisting of an introduction, a theoretical part and a practical part
   h. *De mensuris*
   i. *Pneumatics*

2.3.2.3.1 Heron's Automated Systems: Pneumatics

Heron's *Pneumatics* is the oldest work, conserved in original Greek manuscripts, describing amazing applications of pneumatic and hydraulic control principles, operating and moving without human involvement. The most famous is the *eolipile*, a turbine in which an escaping steam jet makes a ball fixed on a pivot revolve.

The *Pneumatics* is of interest in the history of scientific theory no less than in the history of technology: in the introduction, Heron even discusses about *vacuum*, that, for him, has the characteristic of discontinuity in nature, though a continuous vacuum can be artificially obtained in different uncomplicated ways. Heron states that a discontinuous vacuum separates the particles of all matter. For instance, according to Heron, air consists of microscopic particles divided by vacuum: that's why air can be compressed, and can expand and contract [413, 362].

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[97] Another indirect evidence (as far as we know, at the moment, never considered) that allows to date Heron's life to the 1st century AD and namely under Nero's reign, can be found in Pneumatics I, 21, where a pentadrachm (a five drachms coin) is quoted. This small coin was last produced during the reign of Nero, made upon the coins of Cleopatra VII, and, like them, it was marked with an E (that is 5). A specimen is catalogued as RPC 5251 [412].

The work includes the description of a set of some 70 devices, ordered by increasing difficulty of implementation [98], moved by water, air, or steam pressure; they can emit sounds, adorn public spaces, surprise the audience, or supply the needs of the users.

Due to the big number of devices, and also to the relative redundancy (some of them show minimal variations with each other in their apparent behavior), we decided to single out the most interesting ones and to focus on their modeling. Our selection of Heron's automated systems ranges between the two books of *Pneumatics* (I 12, 15, 16, 17, 21, 29, 30, 31, 32, 34, 37, 38, 41; II, 3, 4, 10), and the *Automata* (moving / static devices). Schmidt's numeration is here used.

Selection criteria have been the following:

- Exclude basic devices (like vessels), that are also part of more complex ones:
    - Book I: # 1-11; 13; 18-19; 22-27; 35.
    - Book II: # 1-2; 6-9; 11-14; 16-20; 22-29; 33-35.
- Exclude relatively redundant instances:
    - Book I: # 14 (→15); 20 (→21); 28 (→29); 33 (→21); 36 (→37); 39(→38); 40 (→41).
    - Book II: # 5(→4); 9 (→10); 15(→10); 21 (→ I, 12); 30, 31 (→ I, 17); 32 (→ I, 15); 36, 37 (→ I, 29).
- Exclude musical instruments:
    - Book I: # 42-43.
- Include device with anthropomorphic, or zoomorphic figures:
    - Book I: # 12; 15; 21; 29-31; 37; 41.
    - Book II: # 4; 10.
- Include devices whose behavior is similar to other (possibly not Heronian) automata behavior:
    - Book I: # 16-17; 32; 34; 38; 41.
    - Book II: # 3.

As already shown for Philon, devices often need to be activated by someone (therefore called Activator, in our diagrams) who is not the final recipient, and possibly acts secretly not to show any hints about working principles.

We don't have any evidence that such devices were actually implemented, at least once in the Alexandrian times.

Heron's I-12 device shows a scene that could be usual in front of a temple: two worshippers are intent on a sacrifice, and, when it is done, they pour water on the altar, to extinguish the fire. The two figures are completely static: it appears that at a certain moment water flows from their cups. The device is interesting not due to its (quite simple) working, but because it shows how much care Heron took in suggesting to his readers what an application in a dramatic (and therefore wonderful) context could be. Another remarkable issue of this device stands in its aim: we could either imagine that the spectators are aware of the cause-effect relationship, though ignoring the exact device

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working, or they aren't; in any case, Heron's aim is obviously to make them wonder, by maximizing the distance between the input and the possible range of its outputs (see also I, 38).
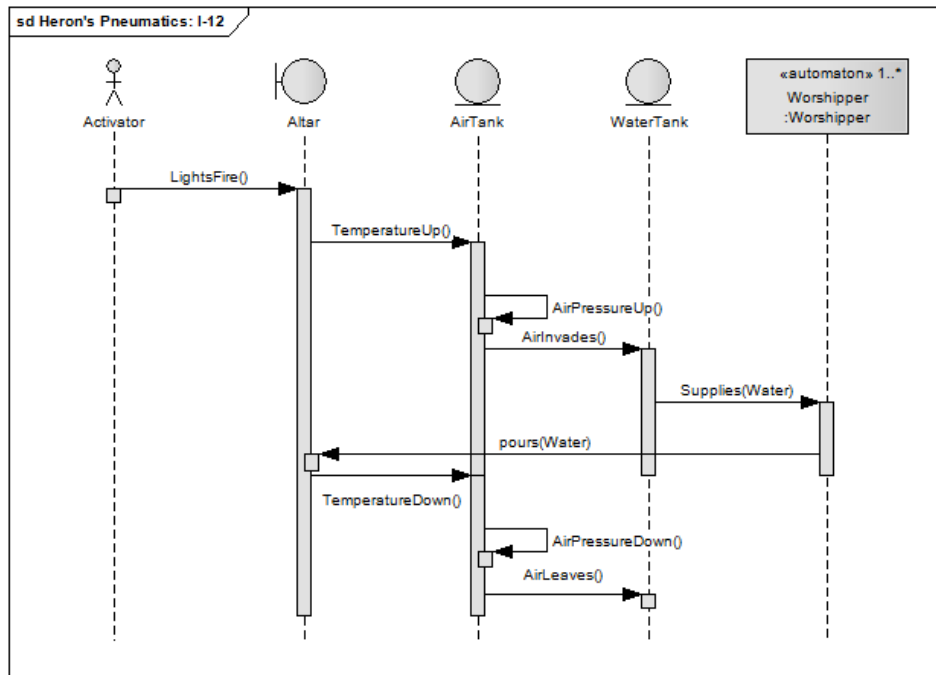
Fig. 20: UML Diagram of Heron's Pneumatics Device I-12
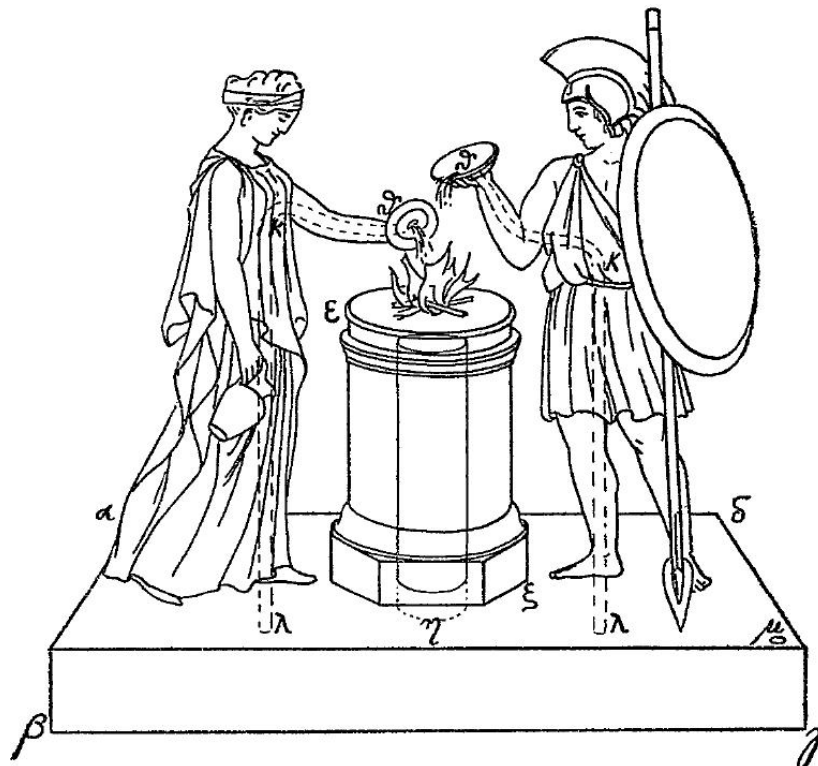
Figura 21: Heron's Device I-12 by Schmidt

Heron's I-15, very similar to Philon's #58, shows an instance of a very common device both in technical and in literary texts. Its working is quite simple, and can produce the most various sound effects due to a different structure (mainly diameter) of the terminal pipe, hidden in the metal bird. This is the reason why the sound here reproduced is blackcap's chirruping, as Heron explains in I-16 description [99].
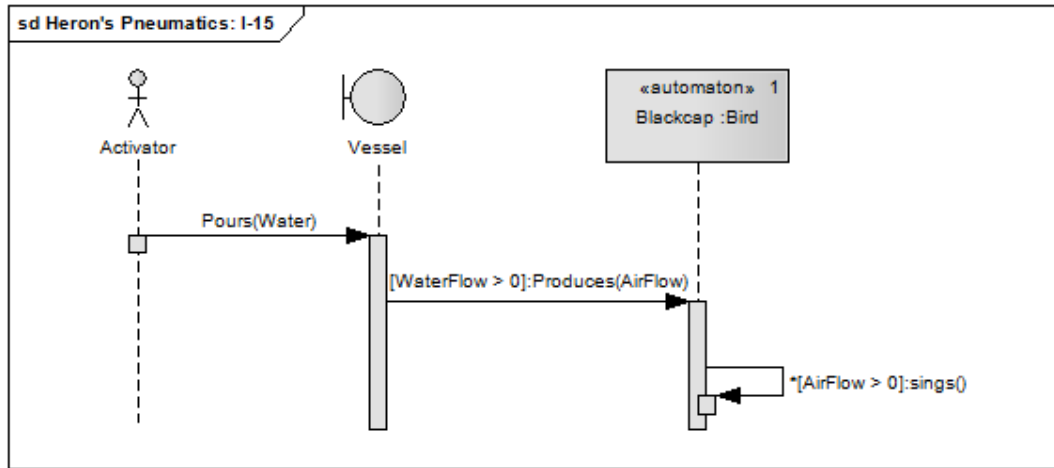
Fig. 22: UML Diagram of Heron's Pneumatics Device I-15
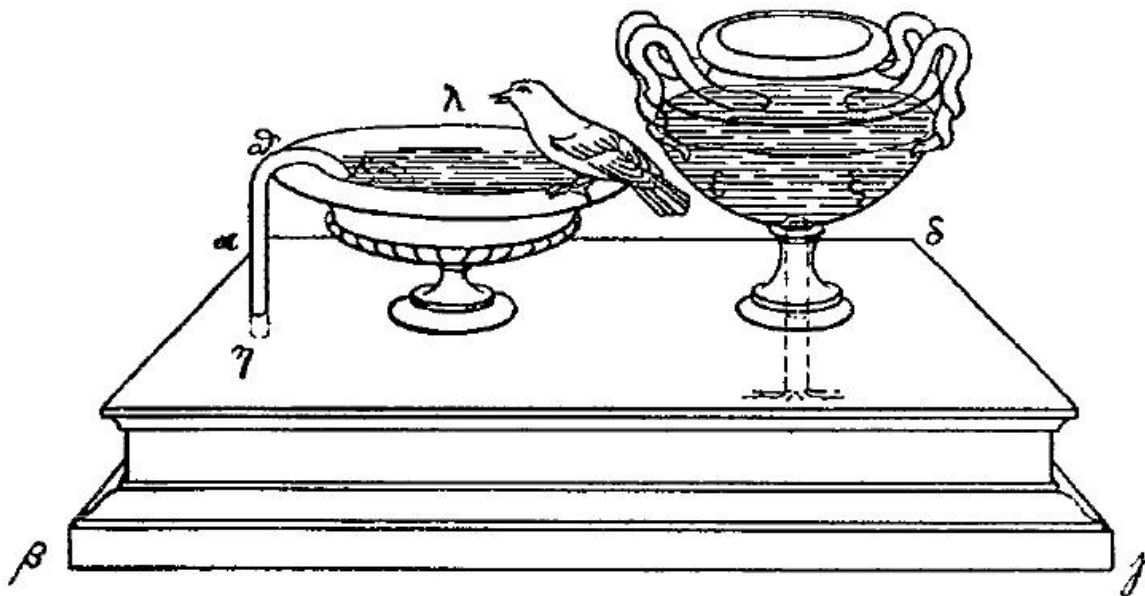
Fig. 23: Heron's Device I-15 by Schmidt

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[99] Αἱ μὲν οὖν φωναὶ γίνονται διὰ τῶν συρίγγων· διάφοροι δὲ τοῖς ἤχοις γίγνονται, τῶν συρίγγων ἤτοι λεπτοτέρων γινομένων ἤτοι καὶ παρεκτεινομένων εἰς μῆκος ἢ καὶ συστελλομένων καὶ τοῦ βαπτιζομένου μέρους εἰς τὸ ὕδωρ ἤτοι πλείονος ἢ ἐλάττονος γινομένου, ὥστε διὰ τοιούτου τρόπου ὀρνέων πλειόνων διαφόρους γίγνεσθαι φωνάς. These sounds are produced through pipes; but the quality of the sounds will vary as the pipes are more or less fine, or longer, or shorter; and as a larger or smaller portion of the pipe is immersed in the water: so that by this means the distinct notes of many birds can be produced.

Heron's I-16 is a variation of Philon's #59, where the turning of the "guardian" (here an owl, instead of the Paniscos), is automatic, not triggered by the activator. Its diagram is therefore much more complicated, and involves a counterweight. As usual, each kind of bird can easily be made chirrup its own way, as described above.
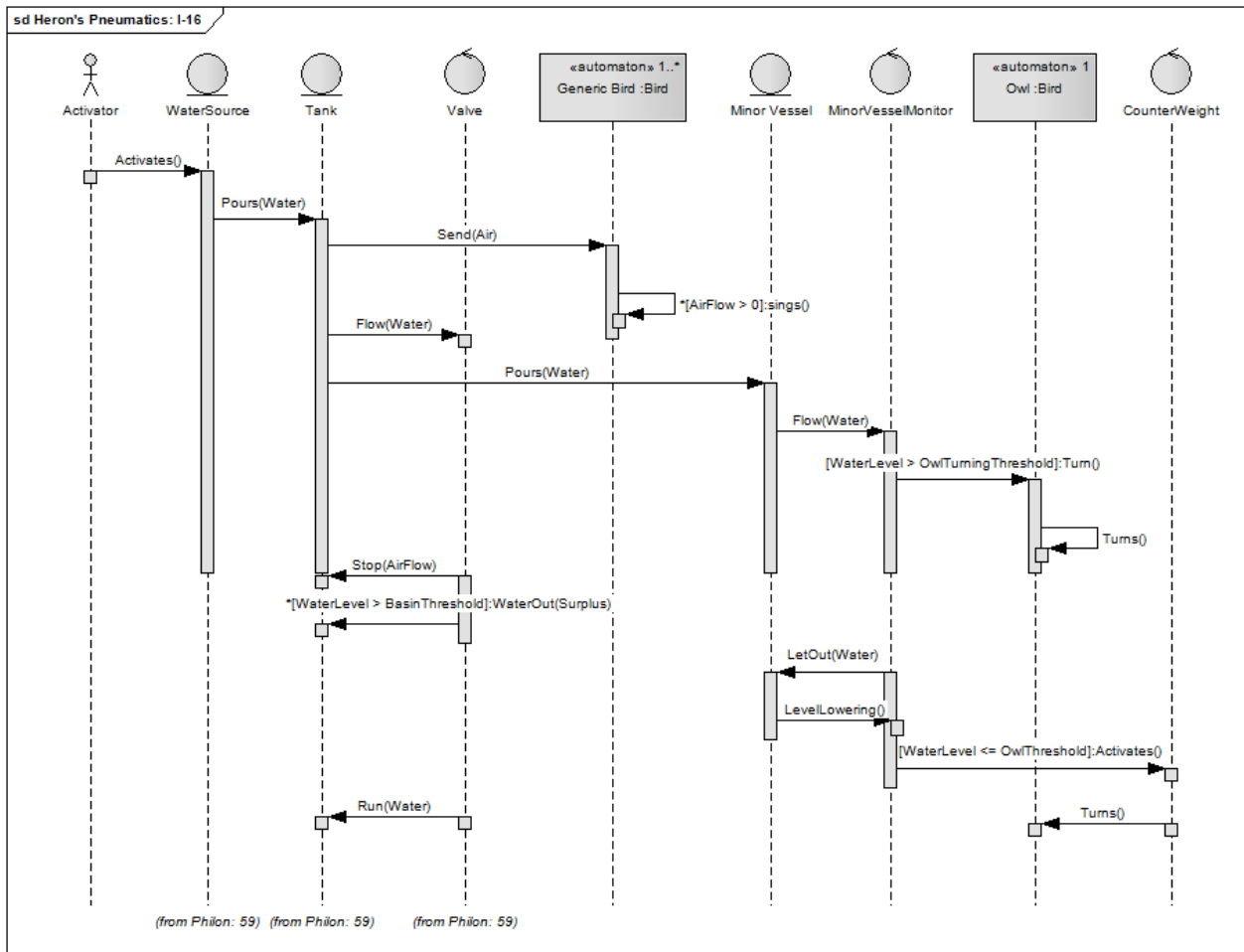
Fig. 24: UML Diagram of Heron's Pneumatics Device I-16
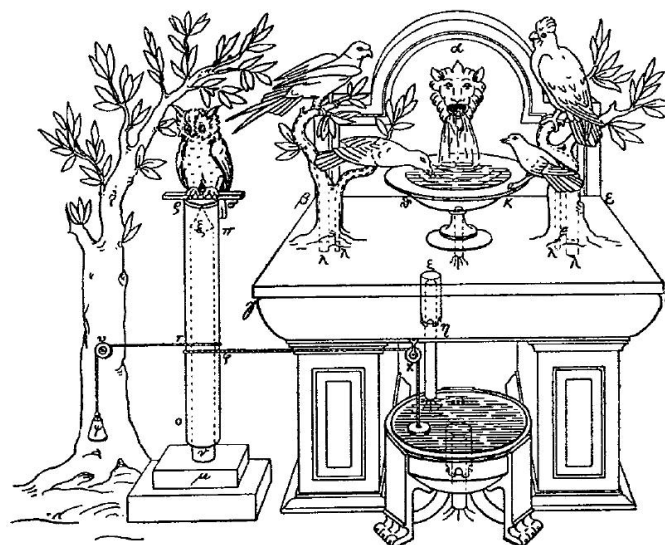
Fig. 25: Heron's Device I-16 by Schmidt
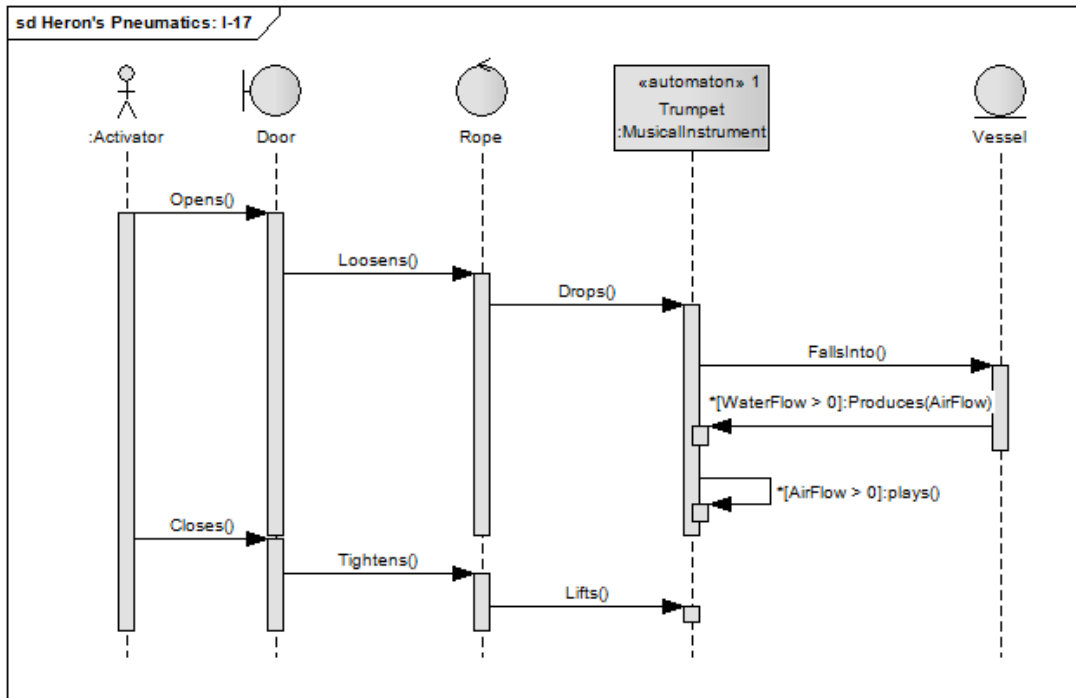
Fig. 26: UML Diagram of Heron's Pneumatics Device I-17
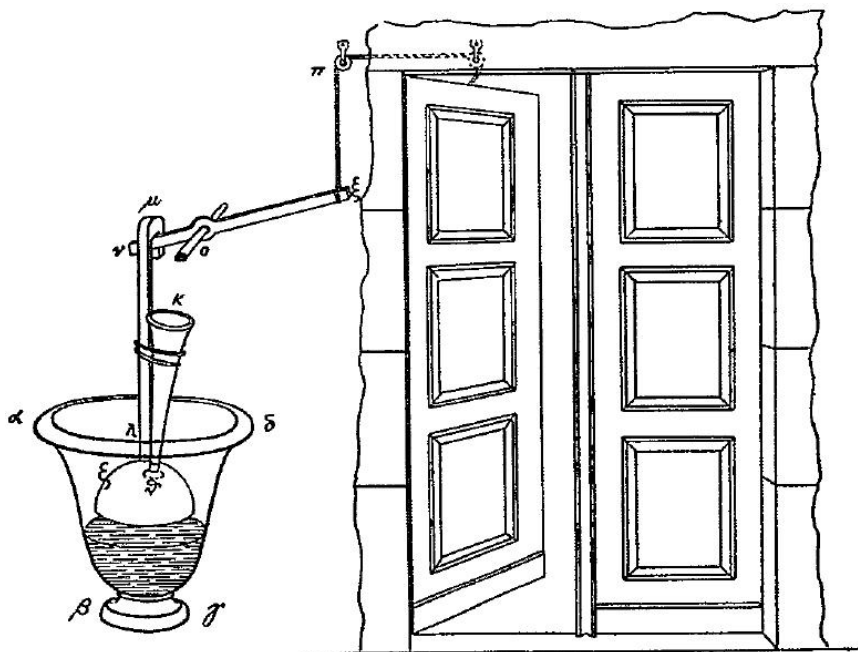
Fig. 27: Heron's Device I-17 by Schmidt

Heron's I-17 shows a useful implementation of the sound produced by an air flow forced in a musical instrument: what we would call a door bell, though it refers to a temple door. The aim is then to attract the attention of the worshippers, standing outside the sanctuary, and not of someone behind the door, in the building.
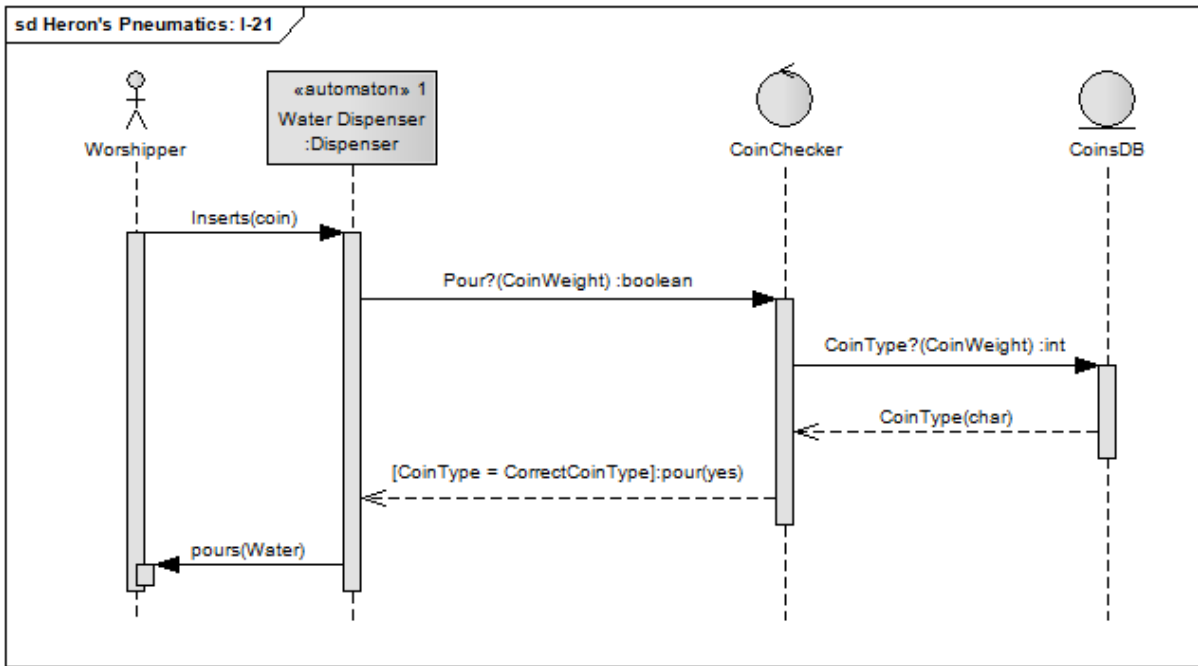
Fig. 28: UML Diagram of Heron's Pneumatics Device I-21
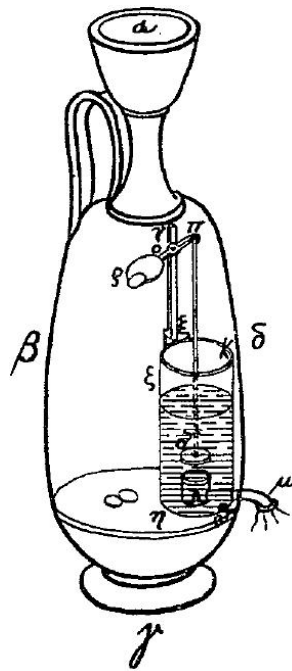
Fig. 29: Heron's Device I-21 by Schmidt

This is one of the most renown among Heron's devices, mainly due to its similarity with modern vending machines. Heron however still imagines a religious context for his device: dispensed water is used to wash hands before entering the temple, as quoted also in description of I, 32 (see *infra*). In addition, Heron doesn't consider the case of a worshipper who can drop the correct amount, though with more than one coin of five drachms, as such coins existed [414].
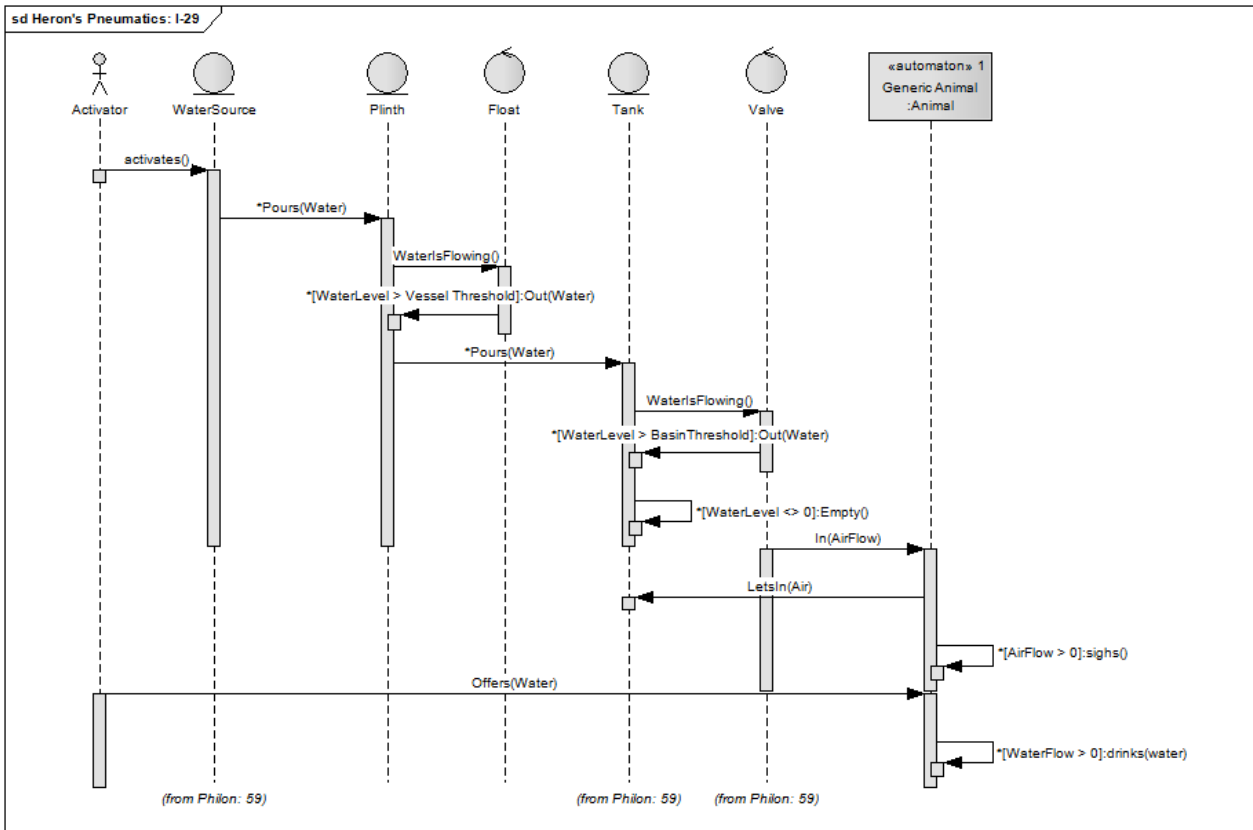
Fig. 30: UML Diagram of Heron's Pneumatics Device I-29
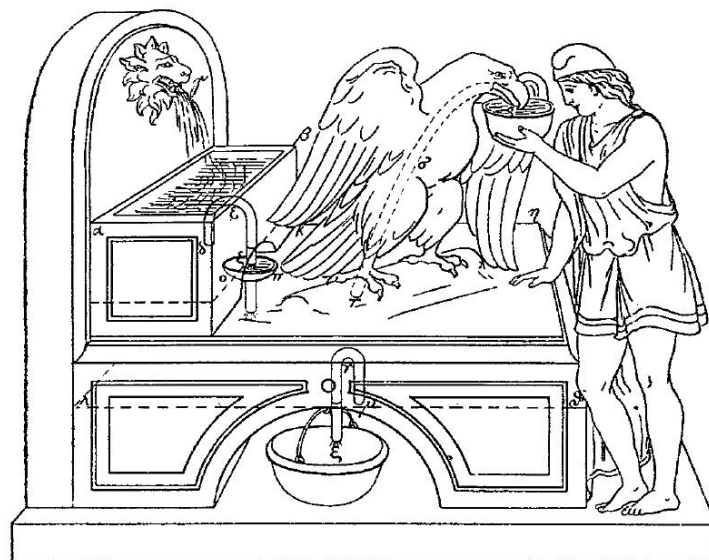
Fig. 31: Heron's Device I-29 by Schmidt

Heron's I-29 is again a variation of Philon's #59; the animal drinks at certain times only, on a liquid being presented to it by a user; in addition, the narrative content is different, due to the absence of a guardian, and to possible involvement of a user.
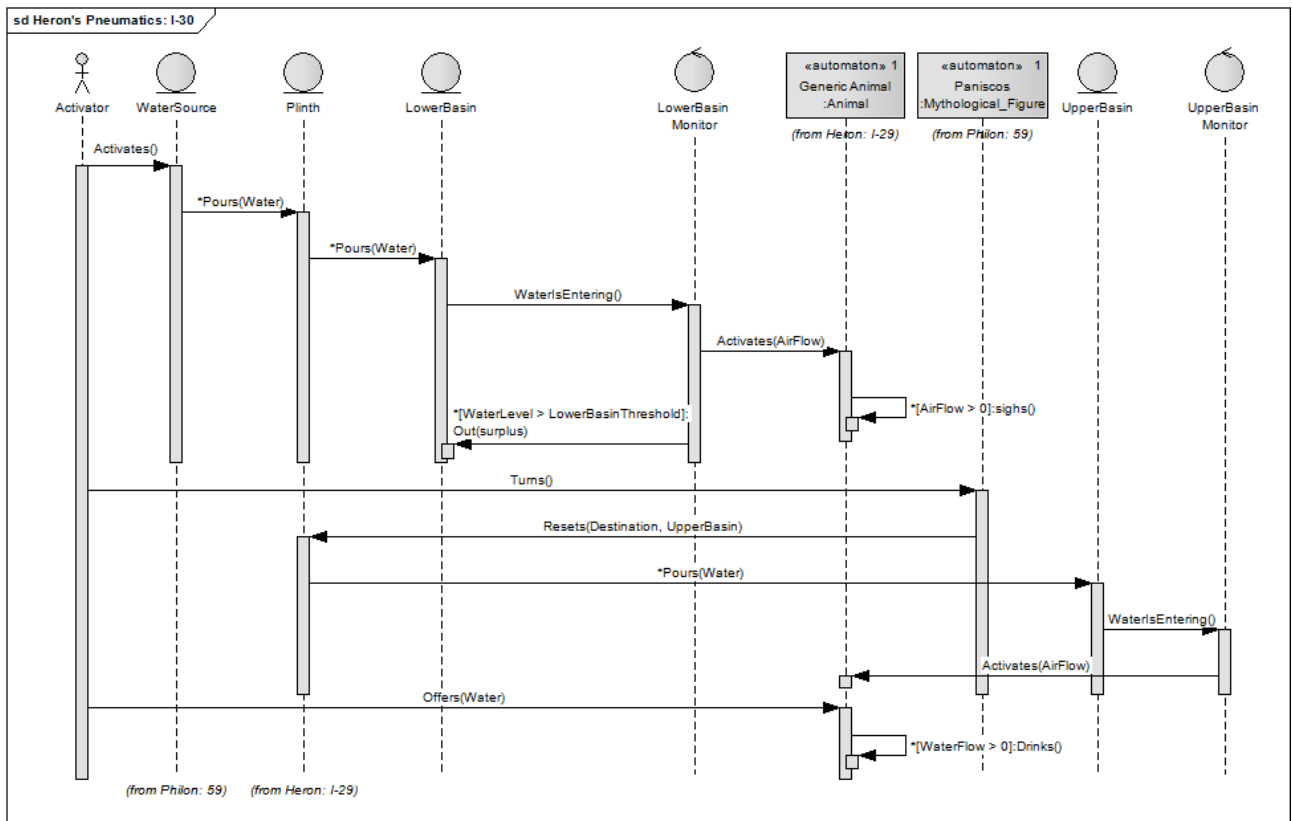
Fig. 32: UML Diagram of Heron's Pneumatics Device I-30
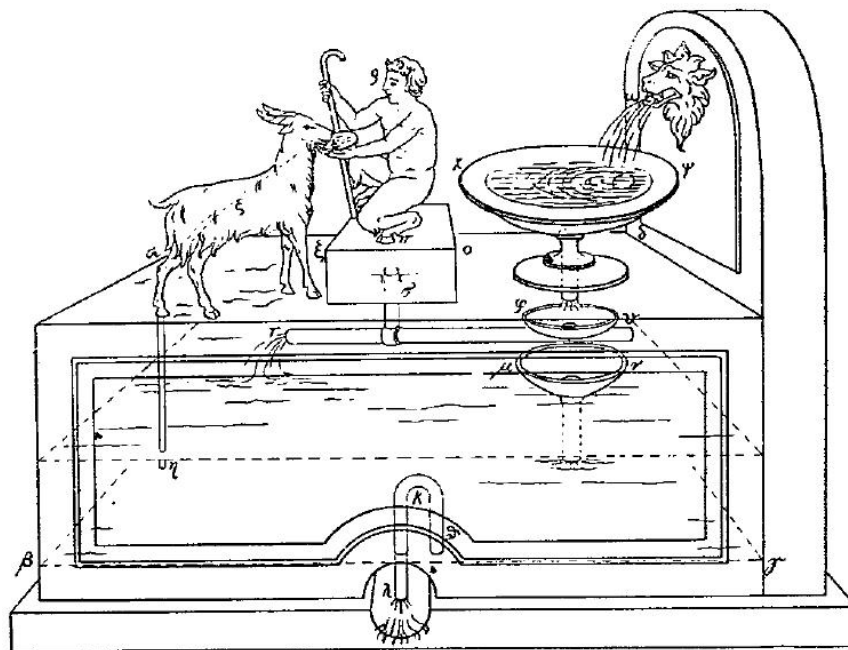
Fig. 33: Heron's Device I-30 by Schmidt

Heron's I-30 is again a variation of Philon's #59; even here, the dramatic content is different, due to the presence of a turning Paniscos, drawing water from the source, and watering the animal, which may drink whenever a liquid is being presented to it.
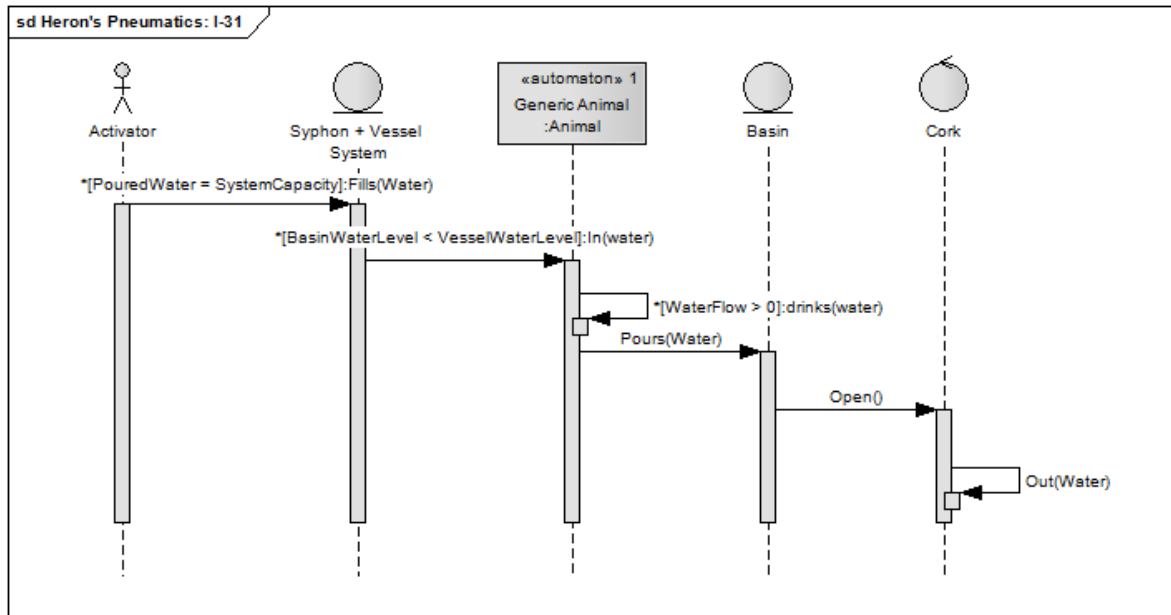
Fig. 34: UML Diagram of Heron's Pneumatics Device I-31
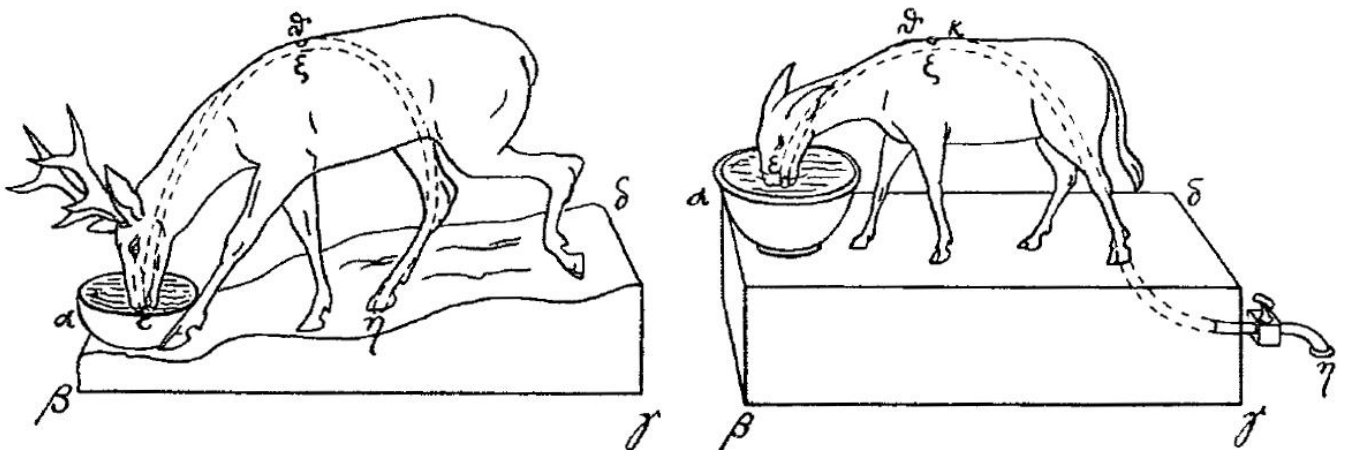
Fig. 35: Heron's Device I-31 by Schmidt

In I-31, again a variation of Philon's #59, Heron presents two instances, essentially identical, apart from the fact that in the first solution, the animal will continue watering itself, while in the second one it will drink all the water, until some water will be available in the vessel hidden in the pedestal. Water can be let out by means of a cork. This lets the animal drink any quantity that may be presented to it.
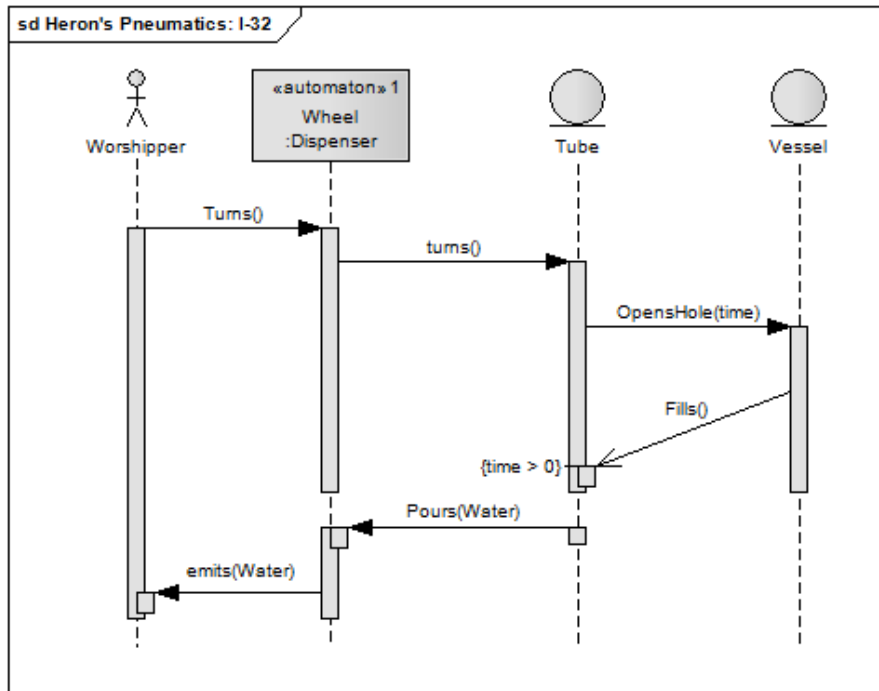
Fig. 36: UML Diagram of Heron's Pneumatics Device I-32
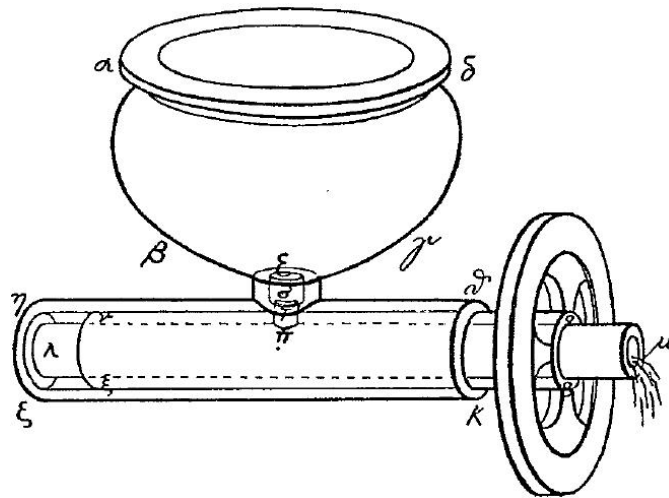
Fig. 37: Heron's Device I-32 by Schmidt

In the description of I-32, Heron mentions Egyptian temples, in whose entrance a similar device was quite common, according to him [100]. This is the only passage where a reference to possible implementations is made. As a matter of fact, Heron simply quotes them and their diffusion, without referring to his own designs, and works. Such a statement can validate Pettorino's assumption about the presence of a contrivance in the Memnon statue.

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[100] Ἐν τοῖς Αἰγυπτίων ἱεροῖς πρὸς ταῖς παραστάσι τροχοὶ χάλκεοι ἐπιστρεπτοὶ γίνονται πρὸς τὸ τοὺς εἰσερχομένους ἐπιστρέφειν αὐτοὺς διὰ τὸ δοκεῖν τὸν χαλκὸν ἁγνίζειν· ἔστι δὲ καὶ περιρραντήρια πρὸς τὸ τοὺς εἰσερχομένους περιρραίνεσθαι. In the porticoes of Egyptian temples revolving wheels of bronze are placed for those who enter to turn round, from an opinion that bronze purifies. There are also vessels of lustral water, from which the worshippers may sprinkle themselves.

In I-34 we have the first instance of self-trimming (or unexstinguishing) lamp, that will be presented by tha Banu Musa (see Fig. 72), and will appear also in Medieval romances, in complex contrivances attributed to Virgil (see Fig. 121). Also in the work *Ecclesiastic History* by the Greek historian Sozomenus (400-450) an instance of such lamp is quoted, as used by the emperor Theodosius II (401-450) in his palace, in order to lighten the labors of his servants [101].

The mechanism allows the wick to be pushed by an internal gear, so that the lamp doesn't exstinguish, until oil is enough.
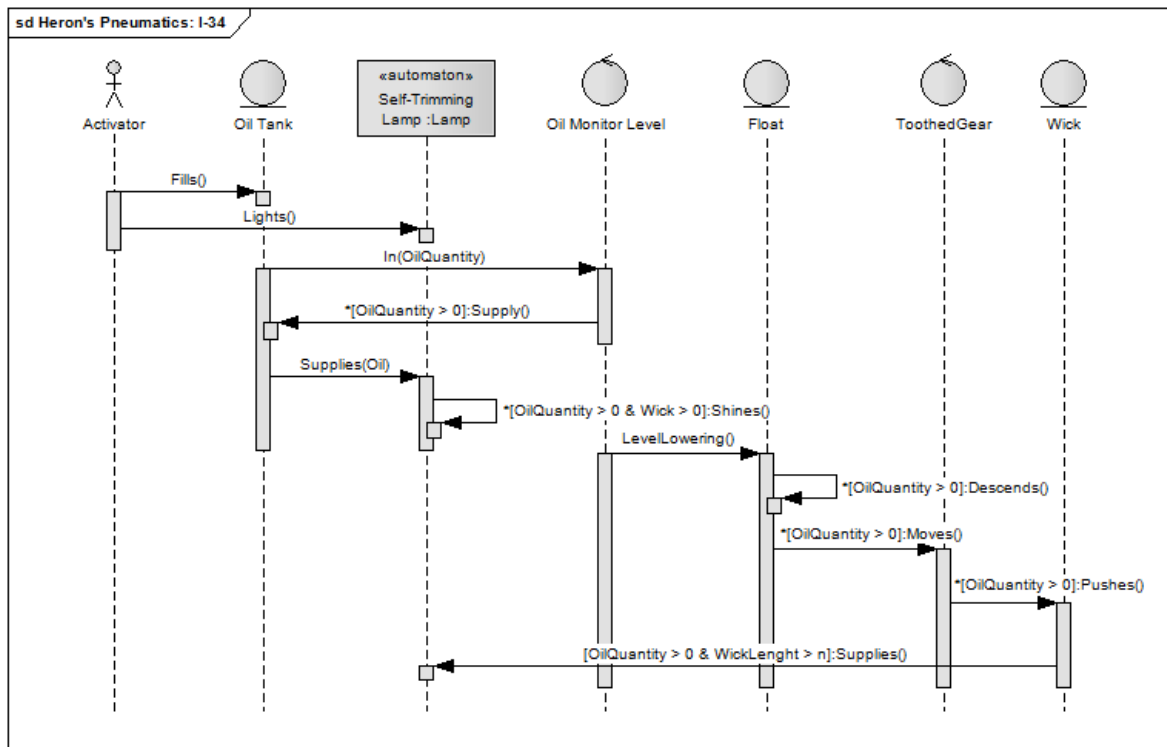
Fig. 38: UML Diagram of Heron's Pneumatics Device I-34
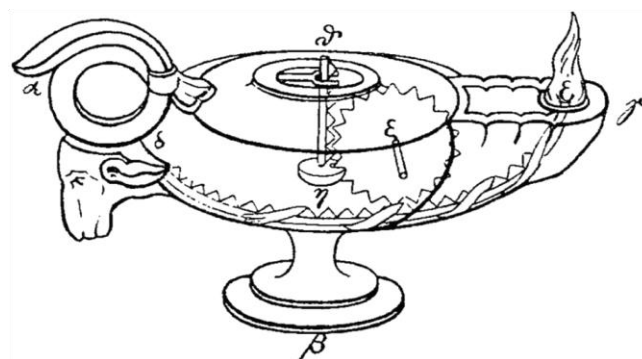
Fig. 39: Heron's Device I-34 by Schmidt

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[101] Prol. 8. Address to the Emperor Theodosius by Salaminius Hermias Sozomen, and Proposal for an Ecclesiastical History. […] Διακονεῖν δὲ σοι λόγος πρὸς τὴν τούτων εἴδησιν λύχνον, ἔκ μηχανῆς τίνος αὐτομάτως τῇ θρυαλλίδι ἐπιχέοντα τὸ ἔλαιον, ὡς ἂν μηδὲ εἰς τῶν περί τὰ βασίλεια ἐντοῖς σοῖς πόνοις ταλαιπωρεῖν ἀναγκάζοιτο, καὶ τὴν φύσιν βιάζηται, πρὸς τὸν ὕπνον μαχόμενος· […] It is a saying, that there serves thee for the study of these works, a lamp which causes the oil to flow automatically into the wick, by means of some mechanism, so that not one of the servants in the palace should be compelled to be taxed with thy labors, and to do violence to nature by fighting against sleep.
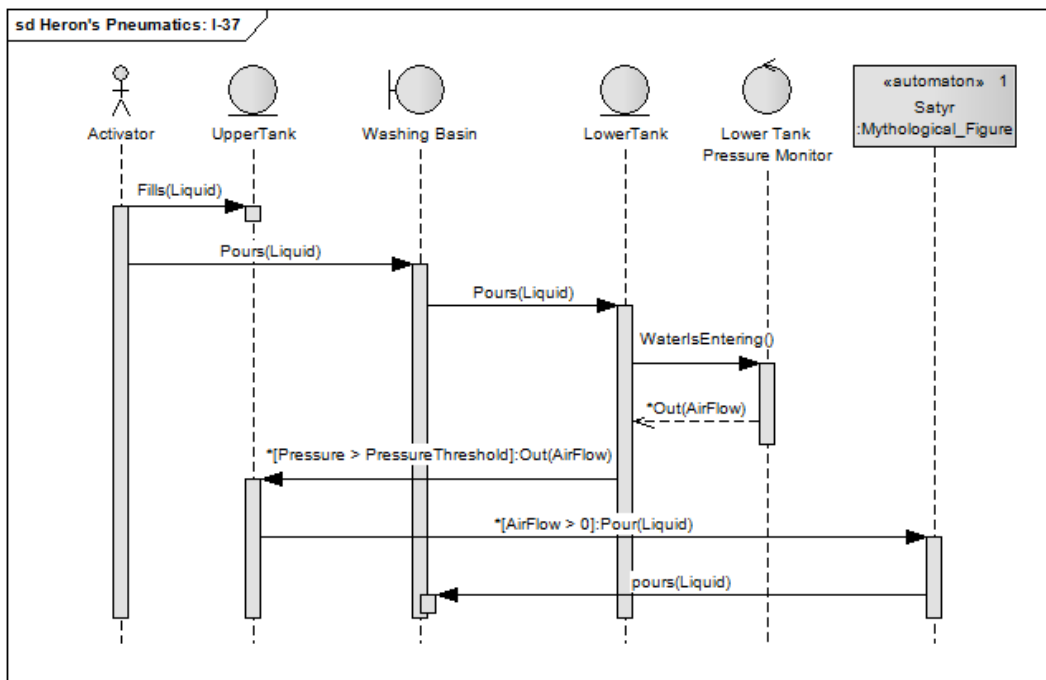
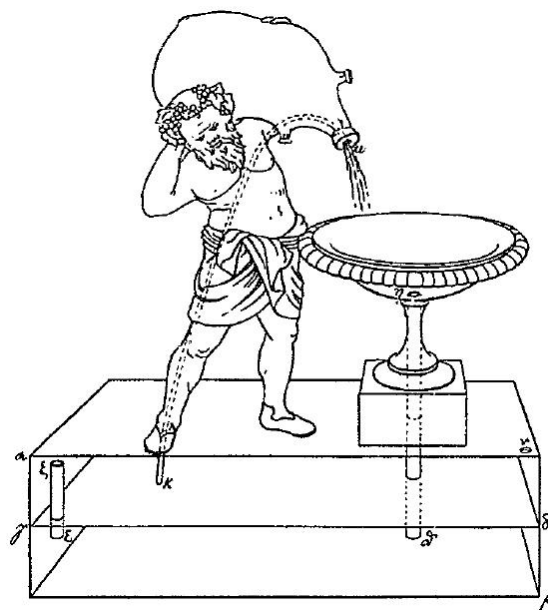**Fig. 40: UML Diagram of Heron's Pneumatics Device I-37**

Fig. 41: Heron's Device I-37 by Schmidt

In I-37, a satyr is pouring water from a wine-skin into a full washing-basin, whose content never overflows. As the choice of a satyr is obviously due to the use of wine, the device had been possibly designed for the table, as a wine fountain.
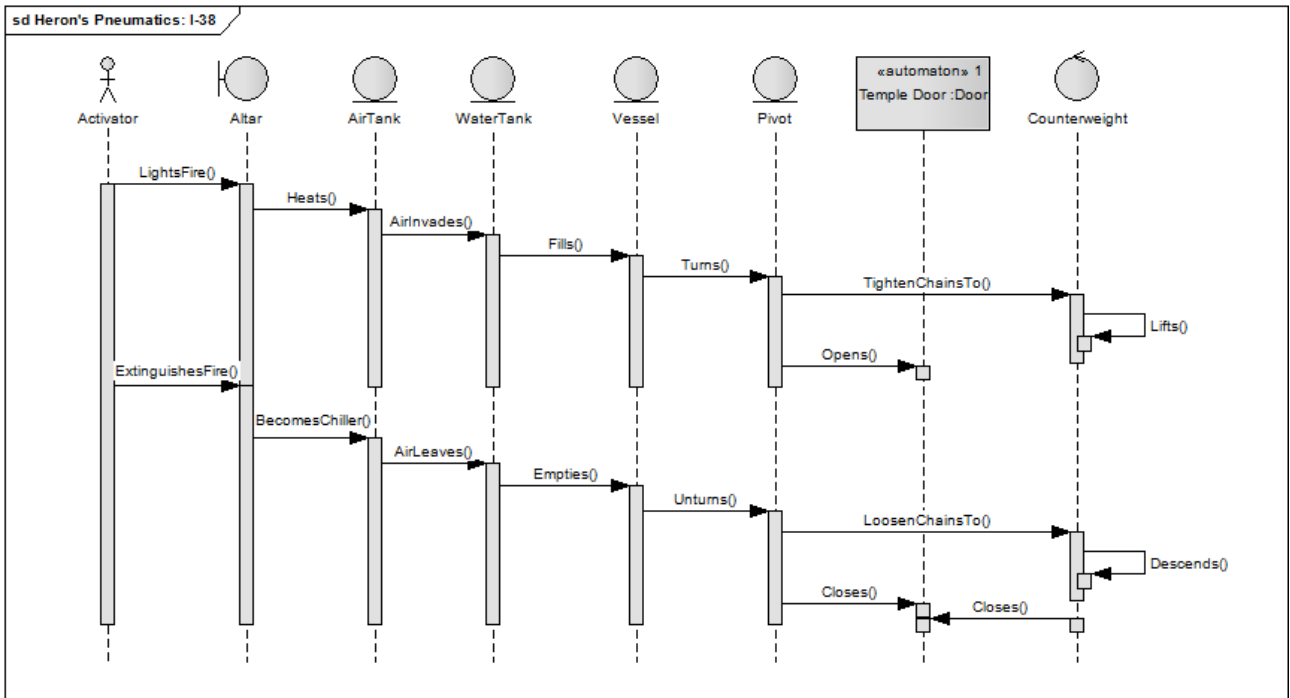
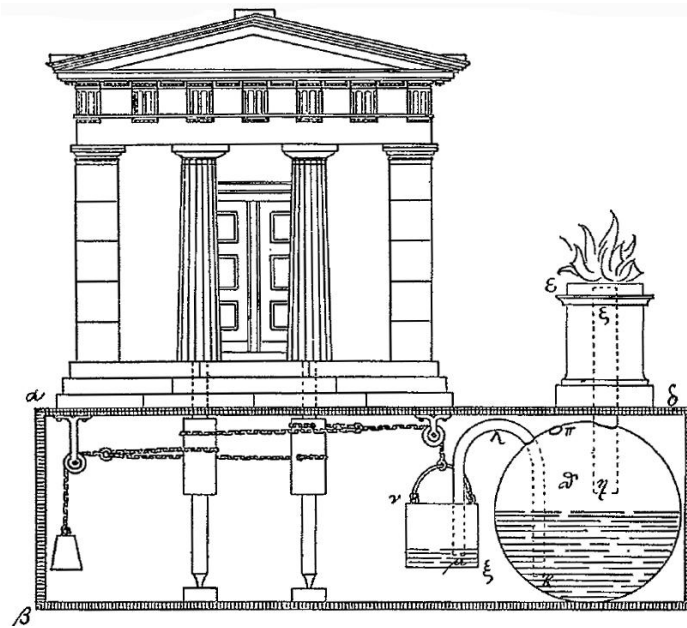**Fig. 42: UML Diagram of Heron's Pneumatics Device I-38**

Fig. 43: Heron's Device I-38 by Schmidt

In I-38, one of Heron's most famous devices (temple doors opened by fire on an altar), we have a combination of design principles taken from other devices, in order to build a completely different one. The activator, who, in this case, acts openly, lights a fire on an altar: this action leads to the unforeseeable effect of opening the temple doors. The aim of making the audience wonder is quite evident, as seen above in I, 12. A similar device will be described by the French writer Honoré d'Urfé (1568-1625) in his novel *Astrée* (1627) [415, 107].
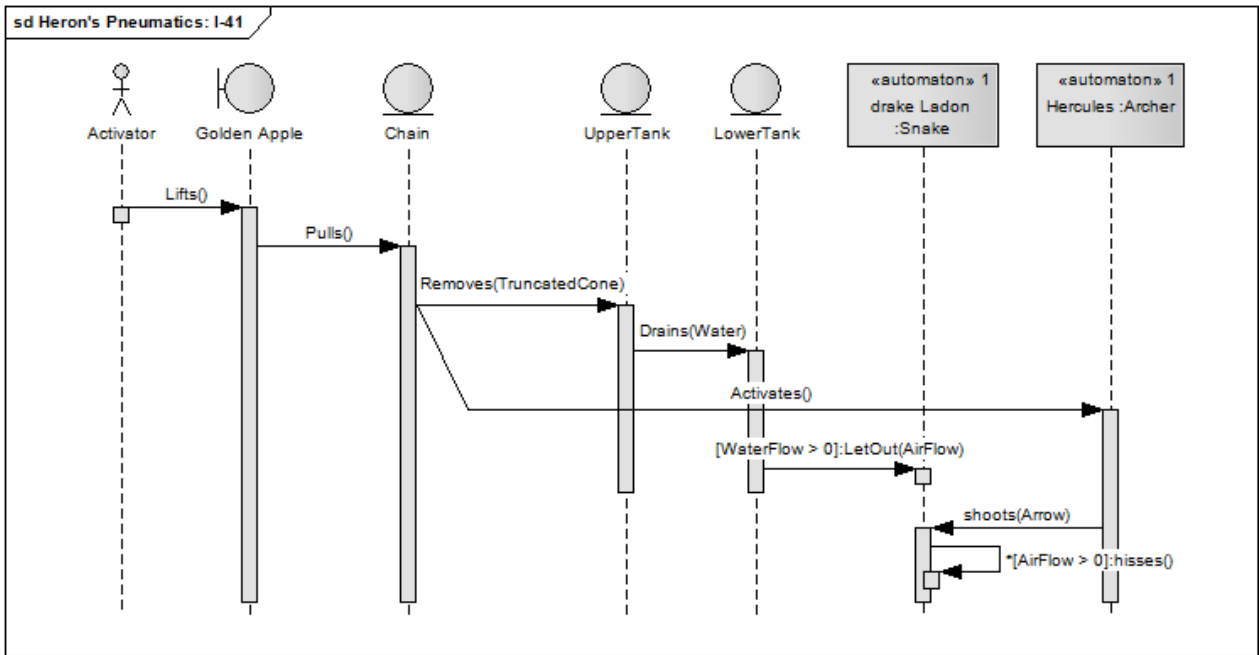
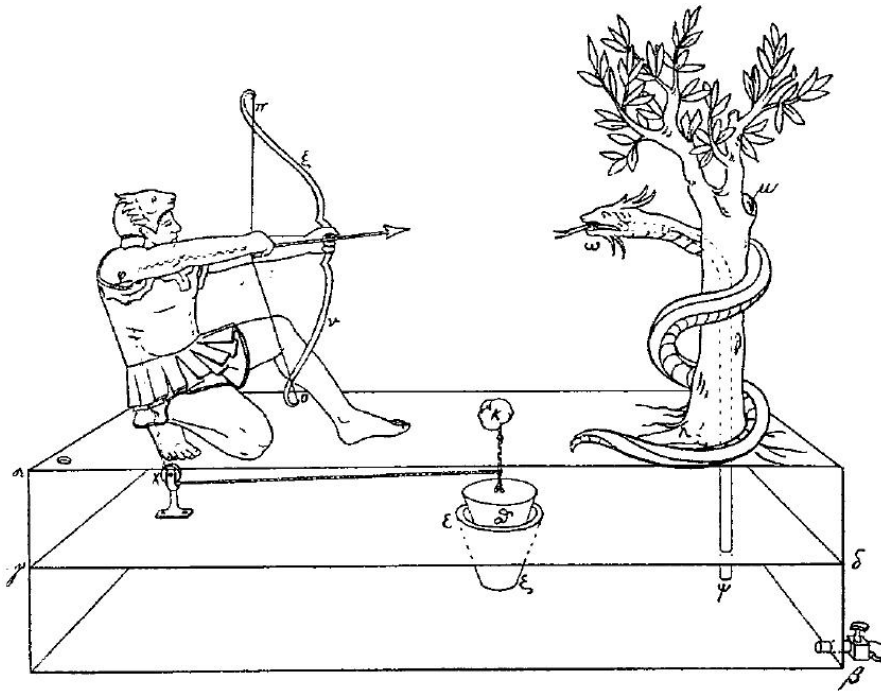**Fig. 44 UML Diagram of Heron's Pneumatics Device I-41**

Fig. 45: Heron's Device I-41 by Schmidt

On an apple being lifted, Hercules shoots a dragon which then hisses. Here the myth of the golden apple of the Hesperides' garden is probably performed. The user, acting as the hero in his Labours, picks up the apple, and immediately the guardian, the drake Ladon, appears ready to attack him; so Hercules must shoot an arrow against the snake.
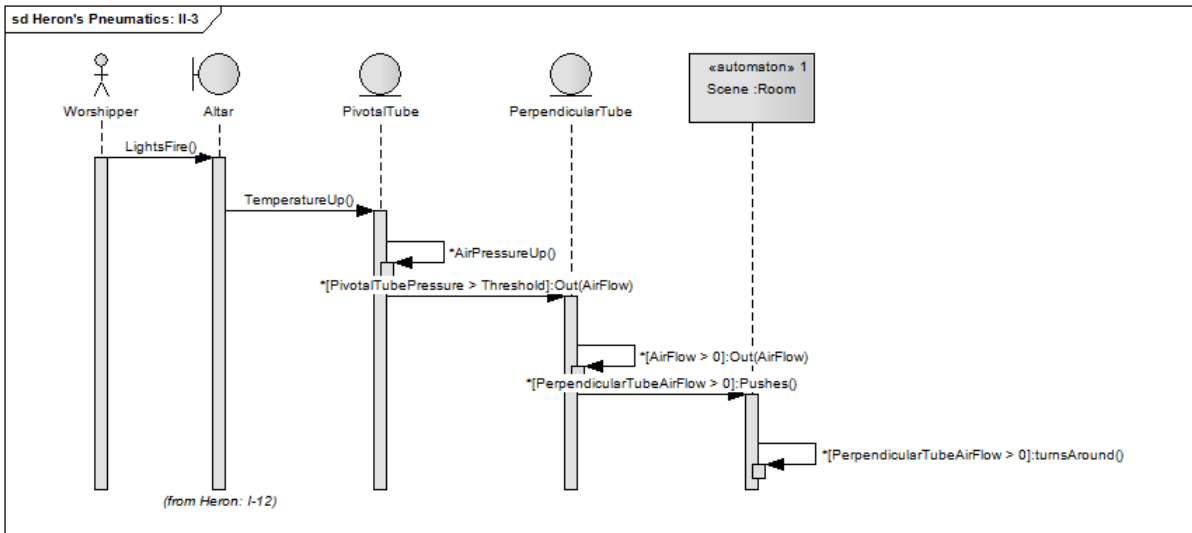
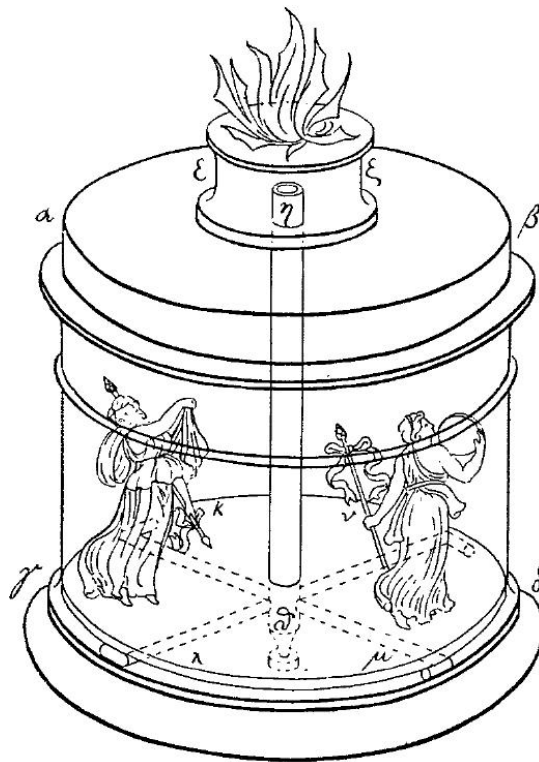**Fig. 46: UML Diagram of Heron's Pneumatics Device II-3**

Fig. 47: Heron's Device II-3 by Schmidt

II-3 shows an altar, working like a small theater. Figures are static, and jointed to the cylinder structure, that on the contrary is pivoting on his main axis: this gives the illusion of their movement. In order to accomplish the desired result, the altar must obviously be made of a transparent material, that is glass or horn, as Heron warns. The possible presence of flaws in the glass, not so rare in Antiquity, would have even increased the realism of the scene.
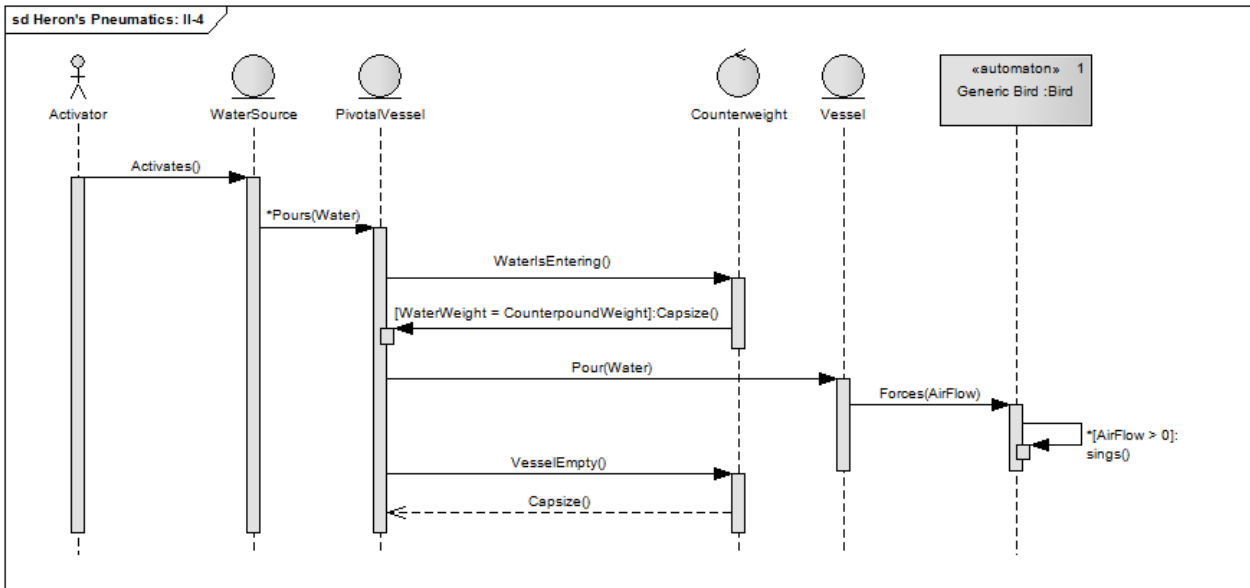
Fig. 48: UML Diagram of Heron's Pneumatics Device II-4

Fig. 49: Heron's Device II-4 by Schmidt

In II-4 Heron tests himself with a new difficulty in making birds sing: they should sing at intervals; he obviously needs an intermittent stream of water. In the following device, he even uses more birds, singing one after another at intervals, by splitting the pedestal vessel in n parts (where n is the same number of the birds), each one containing the same structure.
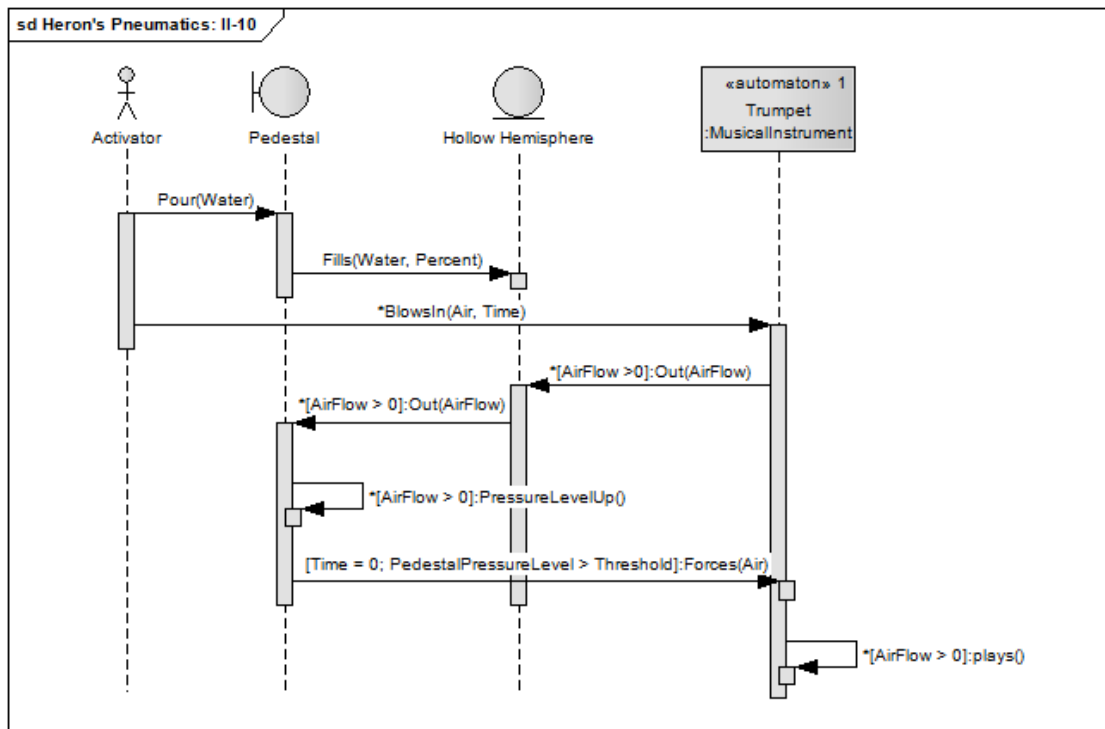
Fig. 50: UML Diagram of Heron's Pneumatics Device II-10
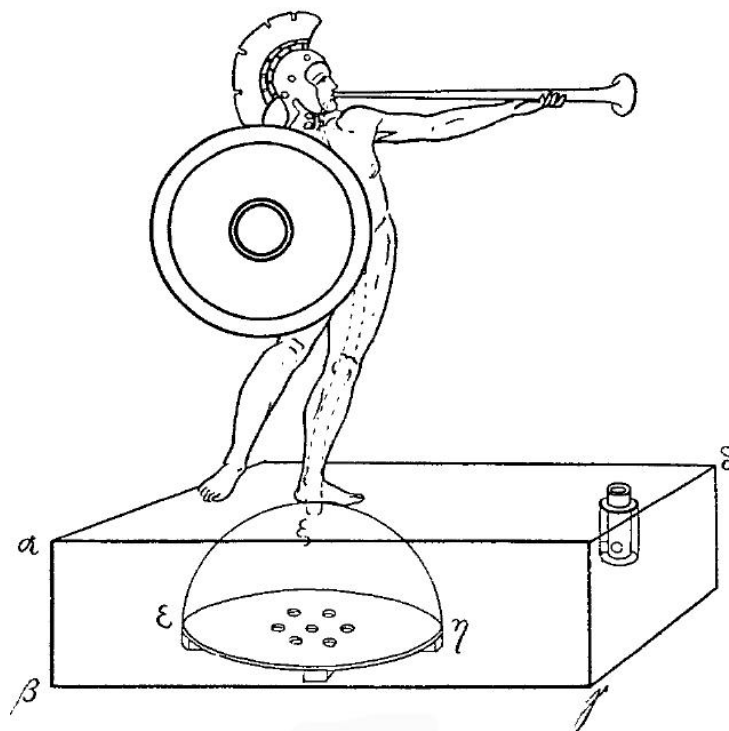
Fig. 51: Heron's Device II-10 by Schmidt

The actual working part of the system is the trumpet, not the bugler; and, in addition, the activator plays a more active role, by blowing air into the trumpet. This is why it is difficult in this instance to speak about spectator's wonder, unless we suppose that the activator arranged the statue behind a curtain. This is more probably the case of the learner's wonder, used by Heron to stimulate curiosity in his readers.

2.3.2.3.2 Heron's Automated Systems: Automata

The *Automata* deals with the mechanics of solids; it contains descriptions of two kinds of automata, borrowed from Philon's work on the subject, according to Heron: the moving and the static ones. The main feature of both moving and static automata is their small dimensions, in order to avoid the suspect that someone was hidden in the device, and moved the different parts, as Heron openly says. The major difference between the two categories lies in their capability (or absence of capability) of moving into the space, since motion is referred to the whole device, in addition of the motion of distinct parts. Recently Sharkey [416], an English scholar, a firm believer in ancient Greek technology, coined for them a pun, by joining the words "rope" and "robot": ropebots.

A moving example of automata made by Heron is a Dionysian procession taking place around a canopy, where each character plays his own role, and the whole structure moves around, thanks to counterweights.

An instance of static automata is an automatic tiny theater, capable of performing a whole show with automatic curtains, scene changing, and acting puppets, even with appropriate sound effects.
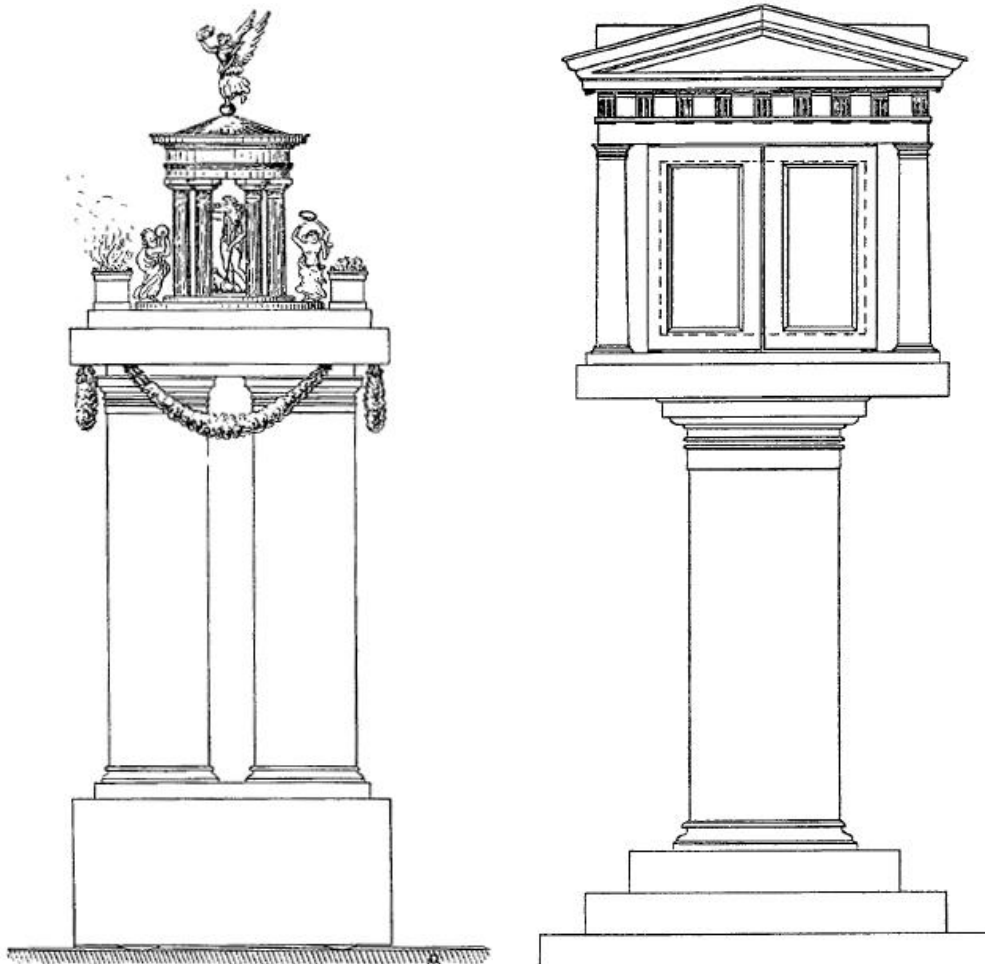

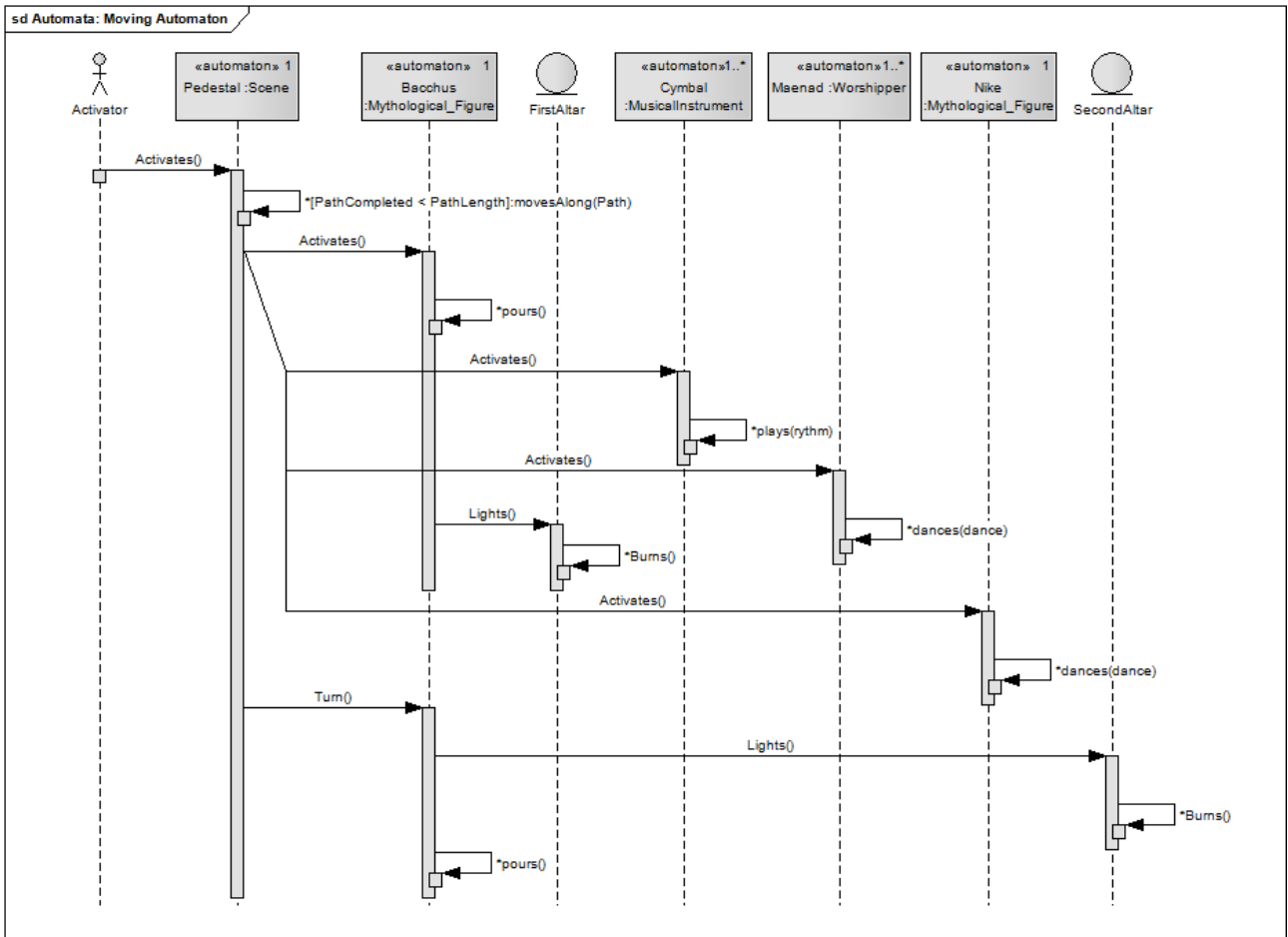**Fig. 52: Heron's Moving and Static Automata by Schmidt**

Fig. 53: UML Diagram of Heron's Moving Automaton from Automata
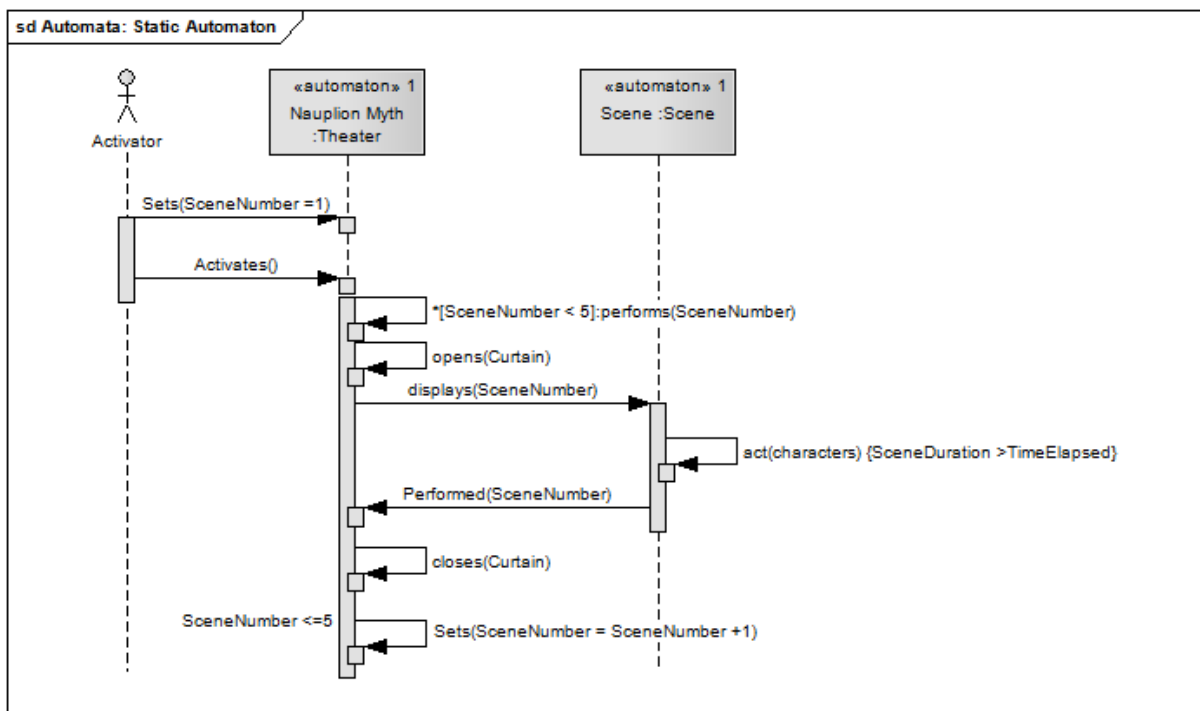

Fig. 54: UML Diagram of Heron's Static Automaton from Automata

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The design of the moving automaton shows that, after an initial activator's input, the device will work of itself: all system parts are only working at the same time, even though independently. Such a device will be a source of inspiration for feasts during the Renaissance, as it will be shown in 2.5.3.3.

In addition, as Walther [52] Randell [360], and Sharkey [416] showed, the design of the moving automaton is interesting from the programming point of view: Randell says that Heron "described mechanisms involving the winding of a rope to and fro over the surface of a cylinder, from peg to peg, in such a way that when the cylinder was turned the rope wound and unwound irregularly, causing various other devices to perform a small sequence of actions." Such a precursor of the pegged cylinder can be considered a first form of programming language, even though with many objective limits.

In our opinion, even the static automaton shows programming features: the theater actually performs a sequence of actions (what we could call a routine), and the scenes as well, at their turn, run subroutines, as the diagram shows. We have a main process (theater), starting sub-processes (scenes); when the sub-process ends, control returns to the main one.

An interesting interpretation of the static automaton has been given by Russo [77]: due to the fact that Heron, in the introduction to *Automata*, remarks that in static automata design

- characters are figures painted on a board, and appear moving;
- scenes are made up by figures and quickly appear one after another;
- the interval between two contiguous curtain opening must be very small;
- a complex system can control both timing of door opening, and the scenes succession;

and in some other passages he refers that "an early automaton playlet merely showed, by way of motion, a face with blinking eyes" [102], and static automata can also show a character in motion, or appearing/disappearing [103], and considering that Heron is trying to imitate what Philon had done, though the latter's books on the subject are at his time no longer available; Russo assumes that possibly the first instances of this kind of automata were optical illusions, such as stroboscopic movement. Though such a suggestive hypothesis can't be definitely verified at the moment, due to the absence of other incontrovertible sources, we must remark that it can't moreover be falsified, due to the same reason.

Cambiano [82] remarks that we are dealing with a "tragedy without words", underlining the relationship between Heron's show and tragedies performed in actual theatres.

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[102] Automata, XXII [1] Οἱ μὲν οὖν ἀρχαῖοι κέχρηνται ἁπλῇ τινι διαθέσει. ἀνοιχθέντος γὰρ τοῦ πίνακος, ἐφαίνετο ἐν αὐτῷ πρόσωπον γεγραμμένον. τοῦτο δὲ τοὺς ὀφθαλμοὺς ἐκίνει καμμύον τε καὶ ἀναβλέπον πολλάκις. […] The Ancients used a simple scene. When the scene was open, the image of a face appeared on it; and it moved the eyes, opening and closing several times.
[103] Automata, I [5] καὶ τῶν φαινομένων δε ζῳδίων τῶν γεγραμμένων ἐν τῷ πίνακι ἓν ἕκαστον ἐν κινήσει δύναται φαίνεσθαι, ἐὰν ἀπαιτῇ ὁ μῦθος, οἷον ἃ μὲν πρίζοντα, ἃ δὲ σκεπαρνίζοντα, ἃ δὲ σφύραις ἢ πελέκεσιν ἐργαζόμενα, ψόφον ποιοῦντα καθ'ἑκάστην πληγὴν καθάπερ ἐπὶ τῆς αληθείας. [6] Δύνανται δὲ καὶ ἕτεραι κινήσεις ὑπὸ τὸν πίνακα γίγνεσθαι, οἷον πῦρ ἀνάπτεσθαι ἢ ζῴδια ἐπιφαίνεσθαι πρότερον μὴ φαινόμενα καὶ πάλιν ἀφανίζεσθαι. […] Each of the figures that appeared designed on the scene could appear in motion, if the story demanded it; for example, some could saw, others use hatchets, others work with hammers or axes, while they produced a noise similar to real one. There could be other movements on the stage, for example, you could light a fire or to make figures appear suddenly and disappear again.

2.3.2.4 A Lost Tradition

Some more names and texts related to our topic emerge from Arabic engineers' works ranging from the 8th to the 13th century. In a 19th-century manuscript, now housed at the New York Public Library (Indo Spencer Pers. Ms. 2 - *Risala-i Hakim Muhammad Yasin*) [417], we have both a pseudo-Archimedes' treatise about pneumatics and the description of an automated flute player, whose design is alleged to an Apollonius of Byzantium. They have been noticed by Hill, while working to the critical edition of Banu Musa's treatise. The mention by Hill however has been largely misunderstood, to the point that it led some scholars [418, 116] to state that in the very work of the Banu Musa a reference would be made to a now lost treatise (entitled *On the Fluteplayer*), written by the mathematician Apollonius of Perga, and dating to the 270-240 BC.

An Arabic treatise about water clocks (the so-called *clepsydrae*) is also attributed to Archimedes [419-422]; Hill, who collated several manuscripts, concluded that the treatise shows Hellenistic and Byzantine tradition, as well as contents from the Arabic-Islamic tradition, as the clock has some resemblance with Iranian and Indian techniques, but it also reproduces the clock described by Procopius of Gaza (see *infra* 2.4.2).

2.3.3 The Pervasive Technology of the Roman Age

Scientific and technologic realizations in Ptolemaic Egypt were considerable. When Octavian established Rome as the leading force in the Mediterranean sea, by defeating the Egyptian fleet at Actium (31 BC), all this knowledge became directly available to the Romans [109].

As a matter of fact, Roman patricians in general knew quite well the Greek language at an early age, thanks to the cultured Greek slaves chosen to educate Roman children (the so-called *paedagogi*), and also thanks to study visits in major Greek cities, including Alexandria. Evidence of this Philhellenism is given by Marcus Porcius Cato, the Censor, (234-149 BC), with his fierce opposition to such Hellenization of Rome [104], or by the famous couplet by Horace (65 BC- 8 AD), taken from *Epistles* (Book 2, #1, ll. 156-157): "*Graecia capta ferum victorem cepit / et artis intulit agresti Latio*" (Greece, though captive, took her wild conqueror captive, and brought arts into the savage Latium). This last example tells us that the process of Hellenization of Roman culture had a sudden acceleration just after the conquest of Egypt.

This is also confirmed by the research on the topic of our interest, as the first quotations in Latin texts of devices pertaining to our theme date back to the 1st century AD. This is unlikely to be a coincidence: it is far more plausible that the contact with the School of Alexandria, and the Alexandrian culture overall, played a major role [95, 97, 101, 104, 116].

Anyway, we are forced to admit both that the number of such sources is tremendously modest, and that the almost total absence of technical works is also remarkable. In addition, we don't have any archaeological findings, useful to definitely demonstrate the presence of automata in ancient Rome.

This lack of automata and of technological treatises on the subject of mechanics could lead to the idea that technology was underestimated in Rome. On the other hand, archeological sources undoubtedly show that Romans were technically skillful in many other topics: agriculture, breeding,

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[104] See, for instance, *Praecepta ad Marcum filium*, written after 180 BC, for the education of his son Marcus Licinianus; according to Cato, it was not appropriate to entrust a greek teacher, as it was customary in aristocratic Roman families.

building (bridges, and road construction; invention of *opus coementicium*), hydraulics, nautical science, surgery (invention of new instruments), construction of war machines, glyptography, glass blowing, just to quote the most popular ones [96, 100, 103, 105, 113]. We could notice that the Romans were undoubtedly skilled navigators, but on the other hand we have no news about the existence of treatises on navigation [105]: all our knowledge on the topic is derived from the works of Roman historians, and from archaeological findings. In the case of automata, the absence of findings can be explained with the decay of the materials they were built with, and with the fact that they were built expressly for the occasion, without thinking of a long duration. It is different in the case of pneumatic devices that require plumbing facilities, made of more durable components. Amedick [13] followed precisely this line of research, examining Philon's and Heron's designs and comparing them with artifacts found throughout the Mediterranean area, especially in the area near Naples perfectly preserved because of the rain of ash of Vesuvius in 79 AD. She found remarkable similarities between some of the pneumatic devices of both the authors and some findings, such as, for instance, a water spring in Pompeii [106] (see *supra* Fig. 19), and the Hydra fountain (see *supra* Fig. 45 and *infra* Fig. 55), originally near the cruciform pool of the gymnasium at Herculaneum. These are suggestive indications that such a topic may be subject to further iconographic research, to identify many more examples of potential citations of pneumatic devices.

Fig. 55: the Hydra fountain at Herculaneum

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[105] The late *Periplus Maris Erythraei* [423], dating back to the 2nd century AD, is probably the only exception; the work is a kind of portolano, written for Roman-Egyptian merchants, interested in navigation along Red-Sea coasts and harbors; its language is Greek. The text is available online in English translation at the address http://www.fordham.edu/halsall/ancient/periplus.html.

[106] The "House of the Camillo" was a laundry, fully functional at the time of the eruption, since bodies of the workers have been found. In the courtyard there was a bathtub with running water, issuing from a dragon or serpent of bronze, which is now sadly lost [424]. Some other Roman villas in Pompei had complex hydraulic facilities (House of Iulia Felix; Villa of Loreius Tiburtinus).

At the moment, all we know about automatic devices, and the underlying technological culture in ancient Rome, must be conjectured from some written sources [112, 117-118]. The most important and detailed one is undoubtedly the *De architectura* by Vitruvius (80-15 BC), a large treatise in 10 books about all useful knowledge for a perfect architect, dedicated to Augustus. In the 9th book, Vitruvius describes the technical advances attributable to Ctesibius [107]: he appears well informed on the Alexandrian engineer's work, that he describes completely, though superficially [111]. Such brevity doesn't allow us to understand if Vitruvius knew the argument only outwardly (which seems unlikely), or if he decided to treat it briefly, being a topic known to many people, and perhaps not attributable to an architect. No references are made to Philon or to Heron. In the 10th book, Vitruvius focuses on mechanics, applied both to civil, and to military purposes [99, 84, 425]; we find again mentions of Ctesibios' designs, related however only to the organs. A later quotation of automata (2nd century AD) is made by the Greek philosopher Sextus Empiricus in his *Outlines of Pyrrhonism*: when he speaks about the wonder aroused by self-moving devices, he however refers to the Archimedean celestial sphere [108].

The analysis of literary texts provides a larger number of examples, although, unfortunately, often indirect. In Rome, puppets called *neurospastes* or *petauristarii*, or even *sigilla* were well known and used in many situations, even the official ones. They are quoted both by the Roman writer Petronius (ca. 27-66) in his *Satyricon* (LX, 1), and by the Greek historian Appianus (95- ca. 165), in his *Roman History* (II, 147): in the first passage [109], the main character is afraid of a new horrific surprise consisting in some unpleasant surprise from his host Trimalchio; in the second passage [363], Appianus describes a macabre scene of Caesar's funeral, during which, as secretly requested by Antony, a self-moving wax statue of Caesar was used in order to make it show the twenty-three bleeding wounds, to instigate the people of Rome against those who had killed Caesar. It had to be

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[107] IX, viii, 4-5: *4. Ergo Ctesibius cum animadvertisset ex tactu caeli et expressionibus spiritus <sonitus> vocesque nasci, his principiis ydraulicas macinas primus instituit. item aquarum expressiones automatopoeetasque macinas multaque deliciarum genera, et his etiam horologiorum ex aqua comparationes explicuit. primumque constituit cavum ex auro perfectum aut ex gemma terebrata. ea enim nec teruntur percursu aquae nec sordes recipiunt ut obturentur.*
5. namque aequaliter per id cavum influens aqua sublevat scaphium inversum, quod ab artificibus phellos sive tympanum dicitur. in quo conlocata est regula versatili tympano denticulis aequalibus perfecta. qui denticuli alius alium inpellentes versationes modicas faciunt et motiones. item aliae regulae aliaque tympana ad eundem modum dentata una motione coacta versando faciunt effectus varietatesque motionum, in quibus moventur sigilla, vertuntur metae, calculi aut ova proiciuntur, bucinae canunt, reliquaque parerga. Ctesibius having thus observed that by the compression and concussion of the air, sounds might be produced, he made use of the discovery in his application of it to hydraulic machines, to those automata which act by the power of inclosed water, to lever and turning engines, and to many other entertaining devices, but principally to water dials. First he made a perforation in a piece of gold or a smooth gem, because these materials are not liable to be worn by the action of the water, nor to collect filth, by which the passage of the water might be obstructed: the water flowing through the hole equably, raises an inverted bowl, called by the workmen phellos, or the tympanum, with which are connected a rule and revolving drum wheels with perfectly equal teeth, which teeth, acting on one another, produce revolutions and measured motion. There are other rules and other wheels, toothed in a similar manner, which acted upon by the same force in their revolutions, produce different species of motion, by which figures are made to move, cones are turned round, stones or oviform bodies are ejected, trumpets sounded, and similar conceits effected.
[108] A [115] Τά γε μὴν αὐτομάτως κινούμενα τῶν κατασκευασμάτων θαυμαστότερά ἐστι τῶν μὴ τοιούτων. τὴν γοῦν Ἀρχιμήδειον σφαῖραν σφόδρα θεωροῦντες ἐκπληττόμεθα, ἐν ᾗ ἥλιός τε καὶ σελήνη κινεῖται καὶ τὰ λοιπὰ τῶν ἀστέρων, οὐ μὰ Δία ἐπὶ τοῖς ξύλοις οὐδ'ἐπὶ τῇ κινήσει τούτων τεθηπότες, ἀλλ'ἐπὶ τῷ τεχνίτῃ καὶ ταῖς κινούσαις αἰτίαις. Artifacts that are capable of automatic movement evoke more wonder than static ones; for example, when we carefully look at the Archimedean sphere, where the sun and the moon, and other celestial bodies are moving, we wonder, not, by Zeus, admiring components or their movement, but the technician, and the origin of the movement.
[109] *Consternatus ego exsurrexi et timui ne per tectum petauristarius aliquis descenderet.* I leaped to my feet in consternation, fearing that some rope-walker would fall down.

an quite impressive scene, as the Roman people immediately burned the curia where the dictator had been slain, at least according to Appianus. We have some doubts about the plausibility of the anecdote, especially due to the uniqueness of the source; the fact is presented, however, as so ordinary (it is impossible to believe that nobody realized that it was a statue), to give the impression that this was not a rare case, in any case at the time of Appianus, i.e. under Trajan's reign.

Another example is given by a Greek biographer of the 4th century, Eunapius of Sardis, who, telling the life of the sophist Maximus of Ephesus, refers an episode occurred in a temple of Hecate, due to a certain Eusebius: a statue of the goddess would have first smiled, then laughed and at the end lit the torches held in its hands [110].

Some instances of automated, or apparently automated devices [111] are described by:

- The historian Suetonius (71-135), who, in his *The Twelve Caesars,* refers about:
  - Emperor Claudius' habit of brutally punishing the manufacturers of malfunctioning automata (Claudius, 34, 2): *Bestiaris meridianisque adeo delectabatur, ut et prima luce ad spectaculum descenderet et meridie dimisso ad prandium populo persederet praeterque destinatos etiam levi subitaque de causa quosdam committeret, de fabrorum quoque ac ministrorum atque id genus numero, si automatum vel pegma vel quid tale aliud parum cessisset.* (He took such pleasure in the combats with wild beasts and of those who fought at noonday, that he would go down to the arena at daybreak and after dismissing the people for luncheon at midday, he would keep his seat and in addition to the appointed combatants, he would for trivial and hasty reasons match others, even of the carpenters, the assistants, and men of that class, if any automatic device, or pageant, or anything else of the kind, had not worked well.)
  - the so-called *coenatio rotunda*, a rotating room in Nero's Domus aurea (Nero, 31, 2): *praecipua cenationum rotunda, quae perpetuo diebus ac noctibus uice mundi circumageretur* (The main dining room was round and was always revolving day and night as the world does.) [428]
- The philosopher Seneca (3 AD-65) describes two costly, and unnecessary habits of contemporary Roman patricians during their banquets: he refers to real facilities to spread perfumes from the ceiling, and to the revolving ceilings of dining rooms (*versatilia cenationum laquearia*) that were built so as to show different figures every time a new course was served on the table [112].

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[110] *Lives of the Sophists*, Maximus 89-90

[111] Giardina [426] quotes an interesting Indian source about Roman automata, taken from an anonymous cosmographic Burmese treatise, entitled Lokapaññatti, which dates back to 11th-12th century, but compiled on more ancient Sanskrit texts; it tells of a man from Pataliputta who acquires the secret of these machines and returns back in his country from a place identified with Rome, where many inhabitants were skilled in building automated machines [427]; Giardina considers such machines as an allegorical image of slaves, moving and working with great regularity. Either we do take or don't take into account the source reliability and its interpretation, it is nevertheless clear that, at least in the imagination of Indians, Rome was characterized by great technical ability in the field of automata.

[112] Epistulae morales ad Lucilium, XIV, 90, 15: *Hodie utrum tandem sapientiorem putas qui invenit quemadmodum in immensam altitudinem crocum latentibus fistulis exprimat, qui euripos subito aquarum impetu implet aut siccat et versatilia cenationum laquearia ita coagmentat ut subinde alia facies atque alia succedat et totiens tecta quotiens fericula mutentur, an eum qui et aliis et sibi hoc monstrat, quam nihil nobis natura durum ac difficile imperaverit, posse nos habitare sine marmorario ac fabro, posse nos vestitos esse sine commercio sericorum, posse nos habere usibus nostris necessaria si contenti fuerimus iis quae terra posuit in summo? Quem si audire humanum genus voluerit, tam supervacuum sciet sibi cocum esse quam militem.* Whom do you believe wiser? Who has found a way to spray, at great

- Such devices are quoted also by Petronius, who satirically describes the costly and tacky dinner offered by the parvenu Trimalchio [113]; and shortly after, a figure of Priapus, made of pastry, becomes a device for the spray of crocus perfume, with all the inconveniences one can imagine, as a simple touch is enough to activate it (see Fig. 56).
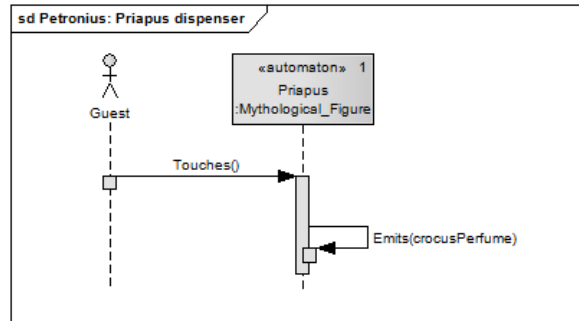

Fig. 56: UML Diagram of a Perfume Dispenser by Petronius

In Athenaeus of Naucratis' *Deipnosophistae*, dating to the 2nd century AD, the author cites the description[114] of a procession, composed by some wagons, pulled by several men, where statues of Dionysus and deities associated with him were placed. The second wagon is mainly interesting to our purpose, since there was a statue of Nysa [i.e. Dionysus' nurse], "of eight cubits high, in a sitting posture, clothed in a box-coloured tunic embroidered with gold, and it was also clad in a Laconian cloak; and this statue rose up by mechanism, without any one applying his hand to it; and it poured libations of milk out of a golden bottle, and then it sat down again; and in its left hand it bore a thyrsus wrapped round with turbans, and it was crowned with a garland of ivy-leaves, made of gold, and with gorgeous bunches of grapes inlaid with precious stones; and it had a parasol over it; and on the corners of the wagon were fastened four golden lamps" [115].

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heights through invisible ducts, perfume, which fills or drains the channels with a sudden flush, and can build ceilings revolving during dinner so that different images follow one another and the ceiling changes as many times as the course? or who demonstrates to himself and to others that nature does not force us to anything too strenuous and difficult, that we can have homes without the stonemason and the blacksmith, that we can dress without importing silk, that we have the necessary goods for our needs, if we are satisfied by what the land produces? If humanity wants to listen, they must understand that the chef is as useless as a soldier.

[113] [LX] *Repente lacunaria sonare coeperunt totumque triclinium intremuit. Consternatus ego exsurrexi et timui ne per tectum petauristarius aliquis descenderet. Nec minus reliqui conuiuae mirantes erexere uultus , expectantes quid noui de caelo nuntiaretur. Ecce autem diductis lacunaribus subito circulus ingens, de cupa uidelicet grandi excussus, demittitur, cuius per totum orbem coronae aureae cum alabastris unguenti pendebant.* The ceiling commenced suddenly to creak and then the whole dining-room shook. I leaped to my feet in consternation, for fear some rope-walker would fall down, and the rest of the company raised their faces, wondering as much as I what new prodigy was to be announced from on high. Then lo and behold! The ceiling panels parted and an enormous hoop, which appeared to have been knocked off a huge cask, was lowered from the dome above; its perimeter was hung with golden chaplets and jars of alabaster filled with perfume. (Traslation by M. Ryan - 1905)

[114] We actually have three narration level, as Athenaeus quotes the narrator, who is a character taking part to the banquet (Masurius), who at turn cites the now lost *History of Alexandria*, book IV, by the Greek historian Callixines of Rhodes.

[115] V, 198 f: μετὰ δὲ ταύτας ἤγετο τετράκυκλος πηχῶν ὀκτὼ πλάτος ὑπὸ ανδρῶν ἐξήκοντα, ἐφ᾽ἧς ἄγαλμα Νύσης ὀκτάπηχυ καθήμενον, ἐνδεδυκὸς μὲν θάψινον χιτῶνα χρυσοποίκιλον, ἱμάτίον δὲ ἠμφίεστο Λακωνικόν. ἀνίστατο δὲ τοῦτο μηχανικῶς οὐδενὸς τὰς χεῖρας προσάγοντος καὶ σπεῖσαν ἐκ χρυσῆς φιάλης γάλα πάλιν ἐκάθητο. Εἶχε δὲ ἐν τῇ ἀριστερᾷ θύρσον ἐστεμμένον μίτραις. Αὕτη δ' ἐστεφάνωτο κισσίνῳ χρυσῷ καὶ βότρυσι διαλίθοις πολυτελέσιν εἶχε δὲ σκιάδα καὶ ἐπὶ τῶν γωνιῶν τῆς τετρακύκλου κατεπεπήγεσαν λαμπάδες διάχρυσοι τέτταρες". Translation by C. D. Yonge (1853)
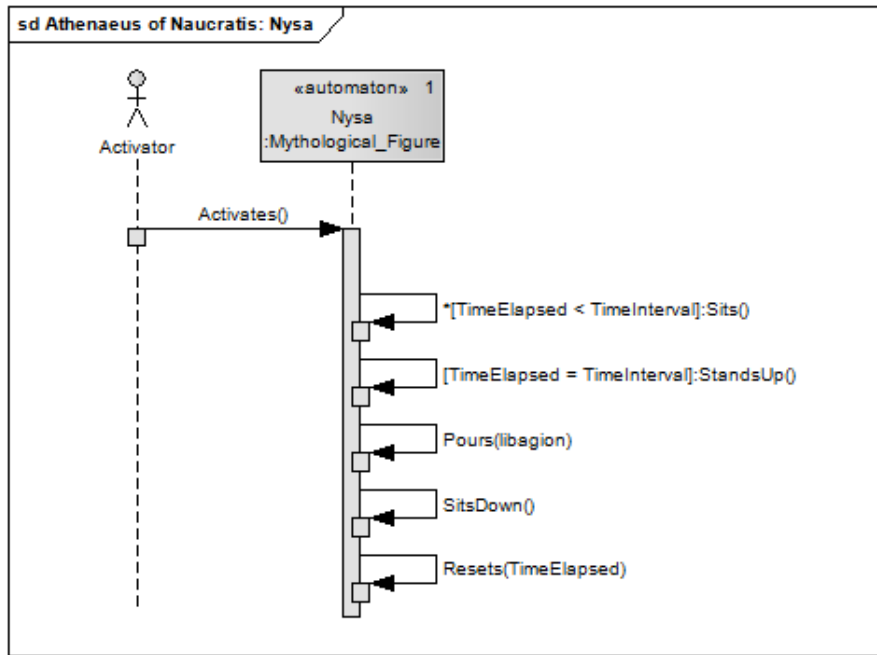
Fig. 57: UML Diagram of Nysa statue by Athenaeus

We found a quotation of automata also in the novelistic biography *Life of Apollonios of Tyana* by Flavius Philostratus (170-243): the main character was a Greek Pythagorean philosopher, who lived in the 1st century AD in Cappadocia, and was even believed to perform miracles. In a passage of the biography (5, 12), Flavius Philostratus refers about a journey to India, where Apollonius would have seen automata [116]. Due to its idealistic tone, the story would not be very remarkable, if the quoted automata were not tripods and dumb waiters. We are most likely dealing with a narrator's invention, which proves, however, that, in the 2nd century AD, Homeric and Alexandrian automata were still known [83].

Lucian of Samosata (120-190) was a Greek writer living in the 2nd century AD, who is famous for his satirical *Dialogues*, where he ridiculed the most evident vices of his time. Among such vices he includes credulity, that he condemns in the dialogue entitled *The Lover of Lies*, that will be quoted several times, though with slight variations, over the centuries, as it includes the famous episode of the apprentice sorcerer. From our point of view, it can be considered another example of αὐτόματος βίος, though, for the first time, strictly connected with magic, not with religion or myth.

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[116] ἰδὼν δὲ παρὰ τοῖς Ἰνδοῖς τοὺς τρίποδας καὶ τοὺς οἰνοχόους καὶ ὅσα αὐτόματα ἐσφοιτᾶν εἶπον, οὔθ᾽ ὅπως σοφίζοιντο αὐτά, ἤρετο, οὔτ᾽ ἐδεήθη μαθεῖν, ἀλλ᾽ ἐπήνει μέν, ζηλοῦν δ᾽ οὐκ ἠξίου. And when among the Indians he beheld their tripods and their dumb waiters and other automata, which I described as entering the room of their own accord, he did not ask how they were contrived, nor did he ask to be informed; he only praised them, but did not aspire to imitate them.
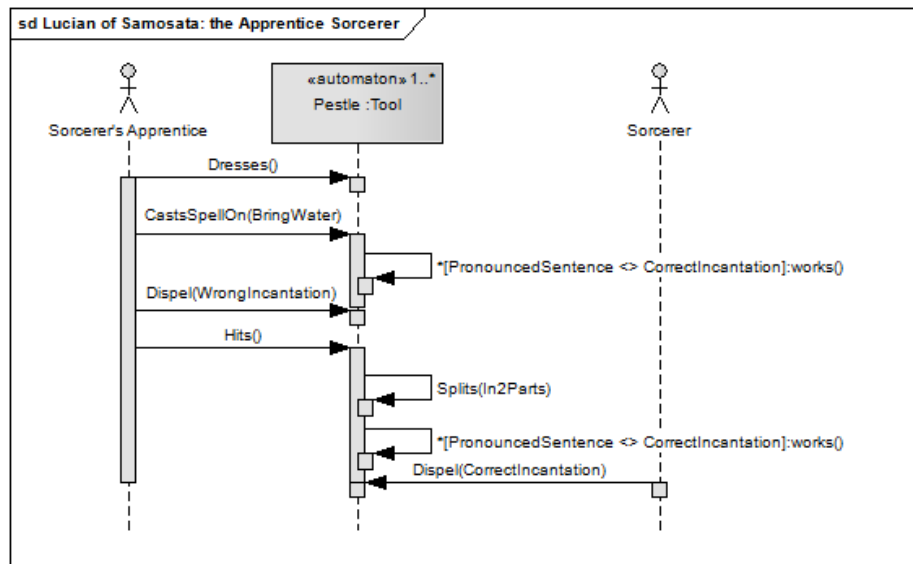
Fig. 58: UML Diagram of Lucian of Samosata's Apprentice Sorcerer

The apparent discontinuity between Alexandrian and Roman technology has always stimulated the interest of scholars who have sought to explain it with unusual approaches as well. An interesting point of view about the so-called Roman rejection of Alexandrian technology is contained in Morley's analysis of Roman history of technology [119]. As he states, "as it has often been pointed out by historians of technology, innovation is always less important than the adoption of innovation At first it seemed more than likely that Hero's device [i.e., the eolipile] would suffer a similar fate. The ancients, particularly the Romans, were always willing to innovate or adopt the innovations of others when they suited their purposes; for example, in the development of urban water supplies, in agriculture, and in military affairs. Their initial failure to adopt steam power is not a sign of their ignorance or primitiveness, but simply a clear indication that their values and attitudes differed markedly from our own." He remarks that any decision about the adoption of an innovation was taken by an emperor, and, among other crucial problems (such as the pressure on the Northern and Eastern borders, for instance), the massive introduction of the steam engine has probably been overshadowed, even due to its lack of cost-effectiveness [117]. If we accept such a counterfactual historical reconstruction, we are forced to admit that, though Romans were probably skillful in the use of steam power (in all its applications), they simply chose not to employ it.

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[117] Beginning from a kind of steam-operated railway from Ostia to Rome, for the supply of goods, during Nerva's, and Trajan's reigns.

2.4 Early and Late Middle Ages

When the Roman Empire was split into two parts by the emperor Diocletian, around the 300, Rome continued to be the capital of the Western Roman Empire and the town of Byzantium, later Constantinople, became the capital of the Eastern part; its Greek cultural origin was emphasized, as contrasting with the Latin West, where the level of knowledge lowered much faster than in the Greek East. For example, it should be remarked that throughout the last centuries of the Western Roman Empire, and still after the fall (476 AD), during the Early and Late Middle Ages, the primary scientific text was the *Naturalis Historia* of Pliny the Elder (23-79): an erudite collection of hearsays and curiosities. In the Byzantine empire, on the contrary, Greek science survived, at least partly. Scholars continued studying the ancient scientific texts, and commented them, even without innovating with new scientific studies. "Much of what is known today about Greek science is due to this tradition", Vasileiadou and Kalligeropoulos state [429].

When the works by Philon and Heron came into the hands of Arabic and Byzantine scholars, they were not only subject to a thorough theoretical study, but they also brought to the actual implementation of devices. While in the Byzantine empire no translation of these texts was required, in the 9th century, Qusta ibn Luqa, author of many translations of scientific works from Greek into Arabic, provided a version of Heron's *Mechanics* to the Arabic scholars in Baghdad.

The social structure of the Byzantine and the Arabic empires was fundamentally identical to the Alexandrian one: the king (pharaon, emperor or caliph) was the undisputed arbiter of cultural life; for his impressive palace, wonderful automata were constructed for the double purpose of amusing the king and his court, and of arousing the admiration of the audience, mainly ambassadors of foreign peoples.

Since the last centuries BC, in the Far East, a new culture has begun implementing automata, possibly due to news reported after travels to the West along the Silk Road: the Roman Empire has been importing a huge quantity of spices, incense, and silk, at least since the 1st century AD (see note 112).

2.4.1 China

The only Western work that traces the major issues of history of science and technology in China is Needham's Science and Civilization in China [278]; in this seven-volume book, the author faces also the question of automata in ancient China, quoting some instances in the second volume. Some fifteen years ago, Chen studied again the subject, focusing exactly on the oldest works by Chinese scholars about physics of motion, acoustics, astronomy and scientific thoughts, and included automata [430]. Chinese works are however not our only sources about automata in the Eastern lands, as in the 13th-14th centuries, the European friars William of Rubruck, and Odoric from Pordenone made detailed descriptions of automated, or apparently automated systems in their travel accounts, though referred to the Tartars (see *infra* 2.4.4.3).

The first attractive example is quoted in the *Master Lie* (列子−Lie Zi) , a 4th century BC Taoist work by Lie Yukou (列圄寇/列禦寇) [118]. It is set at the time of the king Mu of Zhou (周穆王; living in the second half of the 10th century BC): a moving automaton, that could sing and dance, and be pleasant with king's concubines, built by a certain Yan Shih (偃師), has been presented to the king, whose jealous reaction is to order the builder to destroy it, unless the builder is killed. Once the automaton has been brutally taken into pieces, and his content ("leather, wood, glue and lacquer, variously coloured") has become visible, the monarch enjoys himself in disassembling it, as in the automaton Yan Shih had reproduced all the internal organs of a human body, giving to each of them the control on the different systems of the body, though in a very unrealistic way: the liver, for instance, controlled the eyes, and the kidneys motion. At the end, the automaton is reassembled, and the engineer is also enthusiastically invited by the king to follow him to the royal palace on a royal chariot, with his automaton. What is however not always quoted in studies that refer to this episode is that Lie Yukou adds some partly obscure words: "Now, Pan Shu, with his cloud-scaling ladder, and Mo Ti, with his flying kite, thought that they had reached the limits of human achievement. But when Yen Shih's wonderful piece of work had been brought to their knowledge, the two philosophers never again ventured to boast of their mechanical skill, and ceased to busy themselves so frequently with the square and compasses." It seems that he warns philosophers not to overestimate their own works, as in the past other scholars had done more remarkable inventions.

If the episode could be anyhow proved, it would obviously be the oldest instance of automaton, but the kind of work (philosophical), the final moral warning, the absence of other quotations, and the chronological gap between episode, and narration lead us to be cautious.
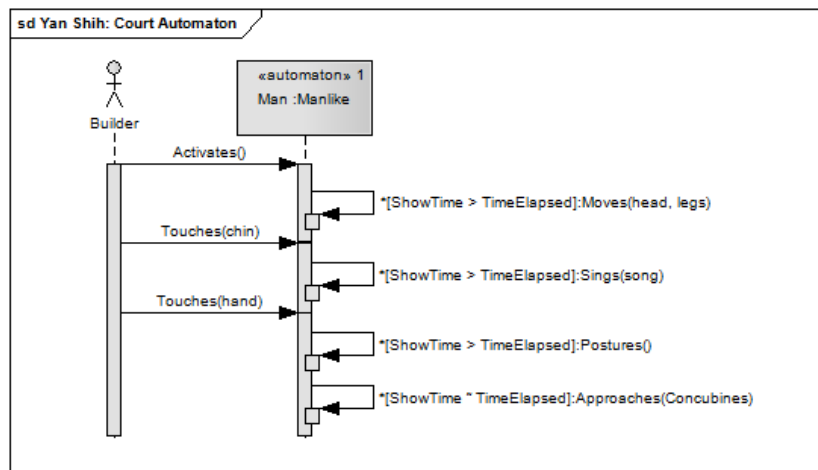

Fig. 59: UML Diagram of Yan Shih's Court Automaton

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[118] The work (chapt. 1-6 and 8) was translated into English by Giles [431], and fully by Graham [432], and by Wong [433], as well.

Another example is taken from the work *Miscellaneous Records of the Western Capital* (西京雜記 -Xi Jing Za Ji) [119], that in 1st century AD collects anecdotes about the Han dynasty (206 BC-220 AD). The author describes a brazen music band, probably dating back to the end of the 3rd century BC, since he refers that it was found in the treasury of Qin Shihuangdi (秦始皇), who died in 210 [430] [120].

Its working is far less automated than the previous one, since the activator must work for the whole show, by blowing into a tube, and pulling a rope. Obviously by increasing the number of "musicians", and consequently of activators, the performance would have been more various, therefore the anonymous used a 12-element band. We can also consider the band as a set of parallel couples of activator-"automaton" systems, all working together in the same place.
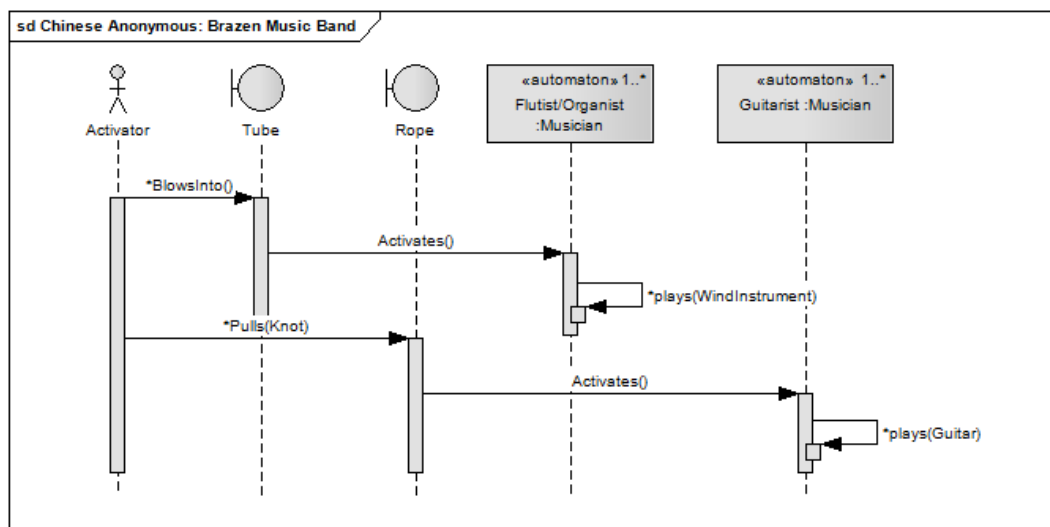

Fig. 60: UML Diagram of Chinese Brazen Music Band

Another quotation dates back to the 3rd century AD, when the historian Chen Shou (陳壽) in his *Records of Three Kingdoms* (三國志 - San Guo Zhi), refers to a wooden puppet automated theater, built by an anonymous craftsman, and enhanced by a skilled man, called Ma Jun (馬鈞). It was a gift made to the emperor, and it could only perform some static scenes; so the sovereign asked Ma Jun, possibly the court engineer, to make puppets move, and he did it. The result must have been astonishing for the audience: thanks to a water wheel, the wooden puppets not only could move, but also sing and dance, and, at a given moment, when a given puppet appeared on the stage, some other puppets began playing musical instruments (flute, and drums) [121]. In another occasion, Ma Jun would have built a wooden structure, shaped like a mountain, where figures acted like jugglers: they danced on balls, threw swords, hanged upside down on ropes ladders.

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[119] The identity of the author and even the date of the work in Needham/Chen's appear different from what is referred in histories of Chinese literature; the latter indicate Liu Xin (劉歆) as author, and date the work to the 6th century AD. See for instance, Knechtges [434], and Chan and Lo [435].
[120] The same emperor, in whose tomb in 1974 the terracotta army was found.
[121] As far as we can imagine, the similarity to Heron's *Automata* is high.
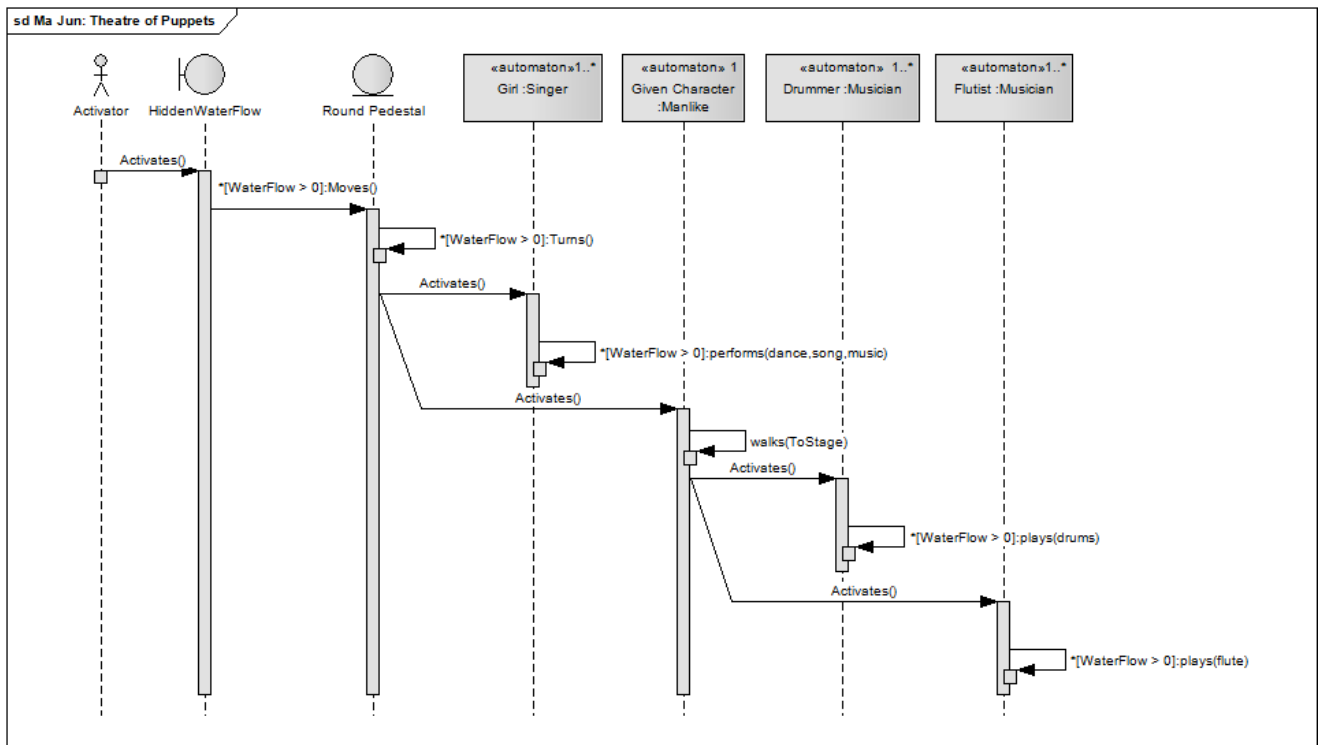
Fig. 61: UML Diagram of Ma Jun's Wooden Puppet Theater

Needham and Chen refer that in Wang Jia's (王嘉) *Researches into Lost Records* (拾遺記 -Shi Yi Ji), dating to the 4th century, a mechanical moving man is mentioned, made of jade (this last detail is given only by Chen). Since no other detail is given, its modeling is impossible.

Engineer Huang Gun (黄滚), in his *Illustrated Manual of Hydraulic Elegances* (Shui Shi Tu Jing), dating to the 7th century AD, describes his own design; in the palace gardens pools, seven small boats sailed with a very curious crew, made of wooden statues (the "hydraulic elegances"), "consisting of singing girls, musicians playing actual instruments, dancers and tumblers, oarsmen busy rowing, cup-bearers, and wine-pourers all moving simultaneously as if alive". In particular, the author describes the working of the cup-bearer and the wine-pourer automata at each stop of the boat in front of the emperor's guests, as shown in Fig. 62.
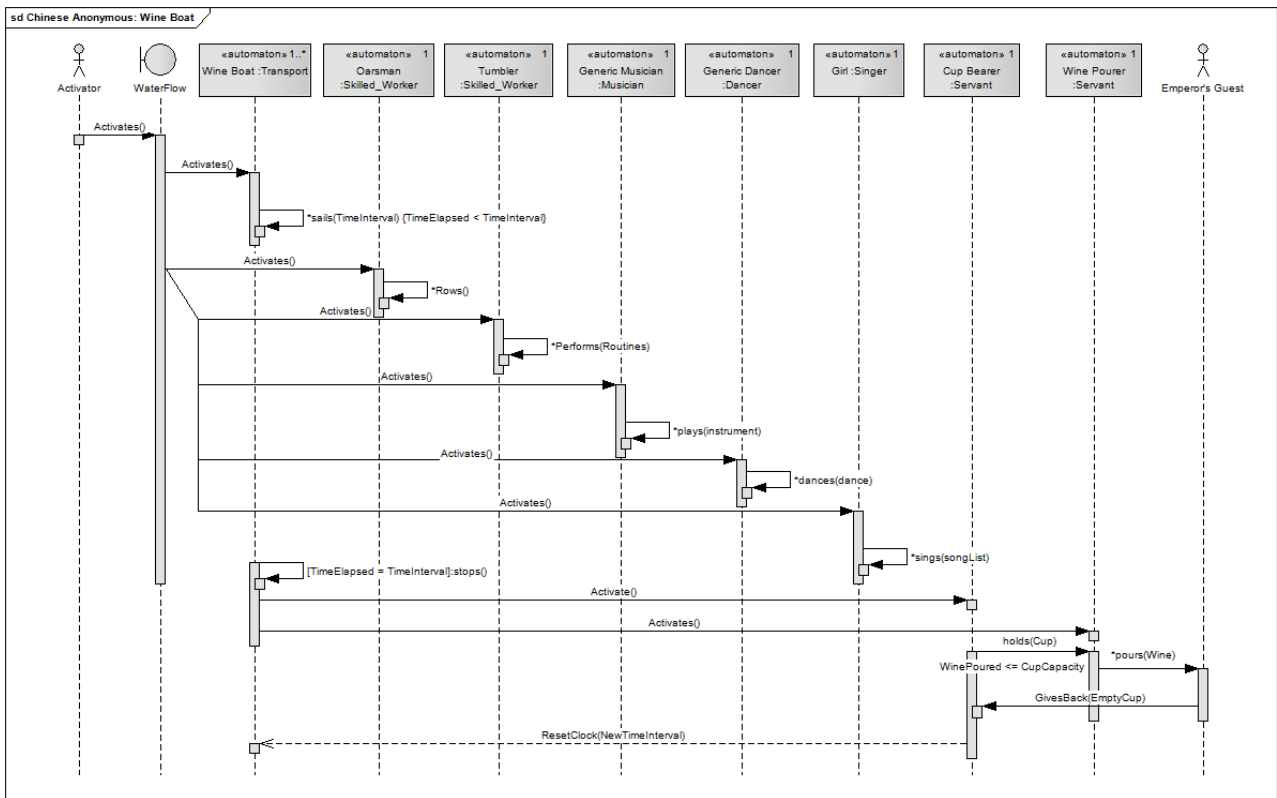
Fig. 62: UML Diagram of Chinese Wine Boat

Needham and Chen also quote another automated system dating to the 7th century: the Kuan Wen Hall Library entrance. This library, made of 14 rooms, was near the emperor's palace. His engineers had equipped its entrance with a device comparable to our automatic doors, though extended not only to some of them (every third door had it), but also to shelf doors. The activator of the trigger, hidden in the floor, was obviously not the emperor Sui Jangdi, but a servant, who had to walk on a given tile.
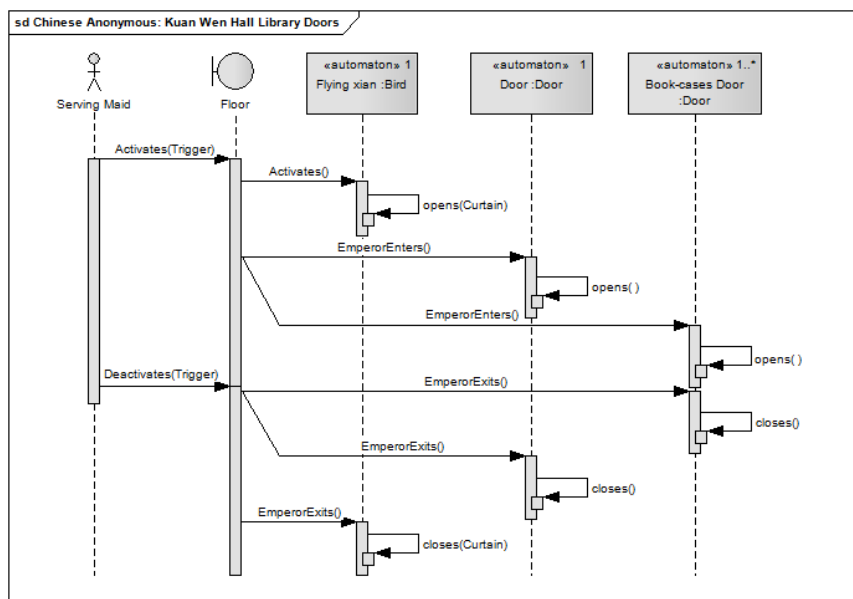

Fig. 63: UML Diagram of Kuan Wen Hall Library Doors

Apart from Yan Shih's, we are dealing with automata that display more evident similarities to the older Western tradition, mainly to Heron's work, due to the presence of mechanic principles, besides the pneumatic ones. Though we can't exclude an independent development of the topic, it is well-known that merchants travelled along some important trade routes (such as the Silk Road, for instance) to the West, and contacts with Western engineers are absolutely possible [122].

If we accept as correct at least the dates when these devices would have been built, we must however face another problem: all these instances are far older than the Arabic analogous automata by al-Jazari.

Therefore, we must alternatively assume that:

- Chinese engineers have designed such automata, influencing the Arabs [430, 441];
- A Greek, or Roman, practical tradition, now lost, influenced Chinese engineers, and
  - Consequently reached the Arabs
  - Independently reached the Arabs

2.4.2   Byzantium

The oldest source about automata in the Byzantine empire can be found in a rhetorical work entitled *Clock Description* (Ἔκφρασις ὡρολογίου), written in the first quarter of the 6th century CE and attributed first to Choricius of Gaza, a Greek sophist and rhetorician, flourished between the 5th and the 6th century [442], and later to his master Procopius of Gaza (465-528), a Christian sophist philosopher [443-444]. The work belongs to the genre of the *ekphrasis*, consisting in a detailed description of an artwork [445]: in this case the subject is the clock standing in the market place of Gaza, featured by the presence of many automata.

The *Description* is attested by one only witness, the ms. Vat. gr. 1898 (ff. 327v-328v.); the fasciculum is dating back to the 13th century, and contains only the first part of the work, enough however to get a quite clear idea of the clock structure and of the automata operation. The manuscript was first studied in 1841 [446] by cardinal Mai (1782-1854) and later other critical editions were given by Boissonade in 1846 [442], by Diels in 1917 [443] and by Amato in 2009 [444].

The clock stood near the royal palace, in a corner of the market place of Gaza, housed in a small building and protected from the crowd by a low marble barrier surmounted by spiked iron gates.

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[122] Pliny the Elder in his *Naturalis Historia* (VI, xxii, 54; XII, xli, 84) refers about a people, called Seres (note that *sericus* is the Latin word for *silken*), more than once and to the silk trade as so fascinating Roman people that they spent millions of sesterces.
In addition, many more or less justified claims were made about direct contacts between Rome and China, both in the form of Roman embassies (by Antoninus Pius or his successors) [436-437], and as mercenaries or prisoners of war, captured after the battle of Carre (53 BC) and deported in China [438-440].
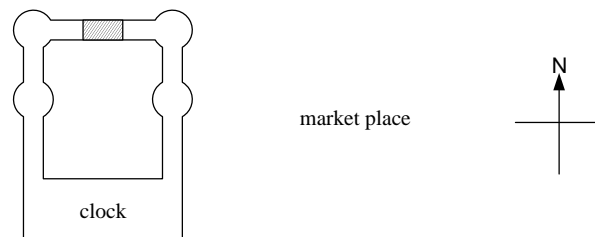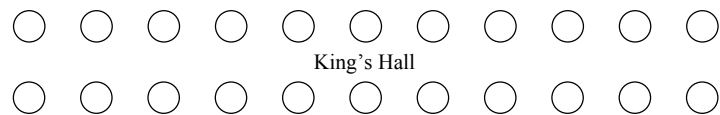
Fig. 64: The clock in the market place of Gaza

Its structure was the following (see also Fig. 65):

- At the uppest level, there is a carved threatening Gorgon's face, whose eyes move at the hour.
- At the middle level, there are two overlying rows composed by 12 doors; the upper doors operation (working during the night hours) is not shown in the work, while the lower level description is given in detail. Several automata are involved:
    - a statue of Helios (the god of Sun), portrayed with a spiked crown, is holding a sphere in its left hand and a wand in the right; it moves from the extreme left (considering a front watch) to the extreme right in 12 hours.
    - over each door there is an eagle (so 12 eagles overall) holding a crown in its claws.
    - 12 triumphant Hercules' statues (one behind each door), holding each one a different symbol of the 12 labors of the hero.

At the hour Helios is near one of the doors and gives a signal with the wand as to make it open; a Hercules' statue comes out from the door; the eagle drops the crown in his head; then Hercules returns back and the door closes.

- The lowest level is at turn made up by two levels: one is the ground level, where three aedicules stand, and the second is made up by statues placed on the roof of the aedicules themselves.
    - At the upper level:
        - In the left part, a statue of a shepherd passes a pastoral from the right to the left hand (and probably vice versa) at the hour.
        - In the central part, there is a statue of Pan hopelessly in love with Echo, surrounded by satyrs. At the hour, the god lifts his head as if looking for the nymph, while the satyrs mock him. It is not clear from the description whether the satyrs actually move or they are still statues.
        - In the right part, a Diomedes' statue blows in a trumpet at the hour as many times as the corresponding number of hours, but, not to annoy people, the number of blows can be at maximum 6; so instead of 7 blows Diomedes plays again only once. The second series of six runs at a higher volume.

90

- At the lower level, there are three statues of Hercules in the aedicules:
  - The one in the middle is dressed with the Nemean lion's skin, holds a tympanum, called the *Lion*, and strikes it at the hour, with the same rules as Diomedes. It is surrounded by two statues of servants, who are in a hurry to prepare a bath for their master and to bring home the grocery shopping. Even in this case it is not clear whether they are actually moving or they are only carved in a very realistic way.
  - At one side, Hercules is pointing with his bow: from the author's description it is not easy to understand whether this is an actual automaton or simply a statue. It appears quite unlikely that the archer could be an automaton, or it would have needed to be reset at each hour; in addition, no prey is described.
  - At the other side, a third Hercules is standing, but the description is missing since the text is not complete.

Though we are not dealing with a historical work, rather than with a rhetorical one, we can consider trustworthy its content. As a matter of fact, both Procopius and his pupil Choricius described other artworks in their writings: their goal was to show their skills in representing with words what had been built to be seen, and their audience could judge the excellence of their works only by comparing the text with the described object. It seems therefore unlikely that the clock or even its operation were fictitious. In addition, we must say that, in another ekphrasis, the author describes a cycle of Gazean frescoes, that has been used without hesitation by art historians and historians tout-court to reconstruct the appearance of the town at the beginning of the 6th century [447, 445].

We must also consider the strong resemblance with analogous Arabic clocks (see *infra* 2.4.3.1 and 2.4.3.5) by the Banu Musa and al-Jazari, though dating some centuries later than this one. All the philologists who made the critical edition agreed in dating the composition to the beginning of the 6th century, due to linguistical and stylistical reasons: the *ekphrasis* is therefore a key witness, being the only one, as far as we know at the moment, that can shed some light on the history of clocks and of automata during the transition between the Hellenistic, and the Arabic technological culture.

The description has been associated with another one by the Roman rhetorician Cassiodorus (see *infra* 2.4.4.1.1), mainly because they are almost contemporary [448]. We refer to the relating paragraph for a deeper analysis.
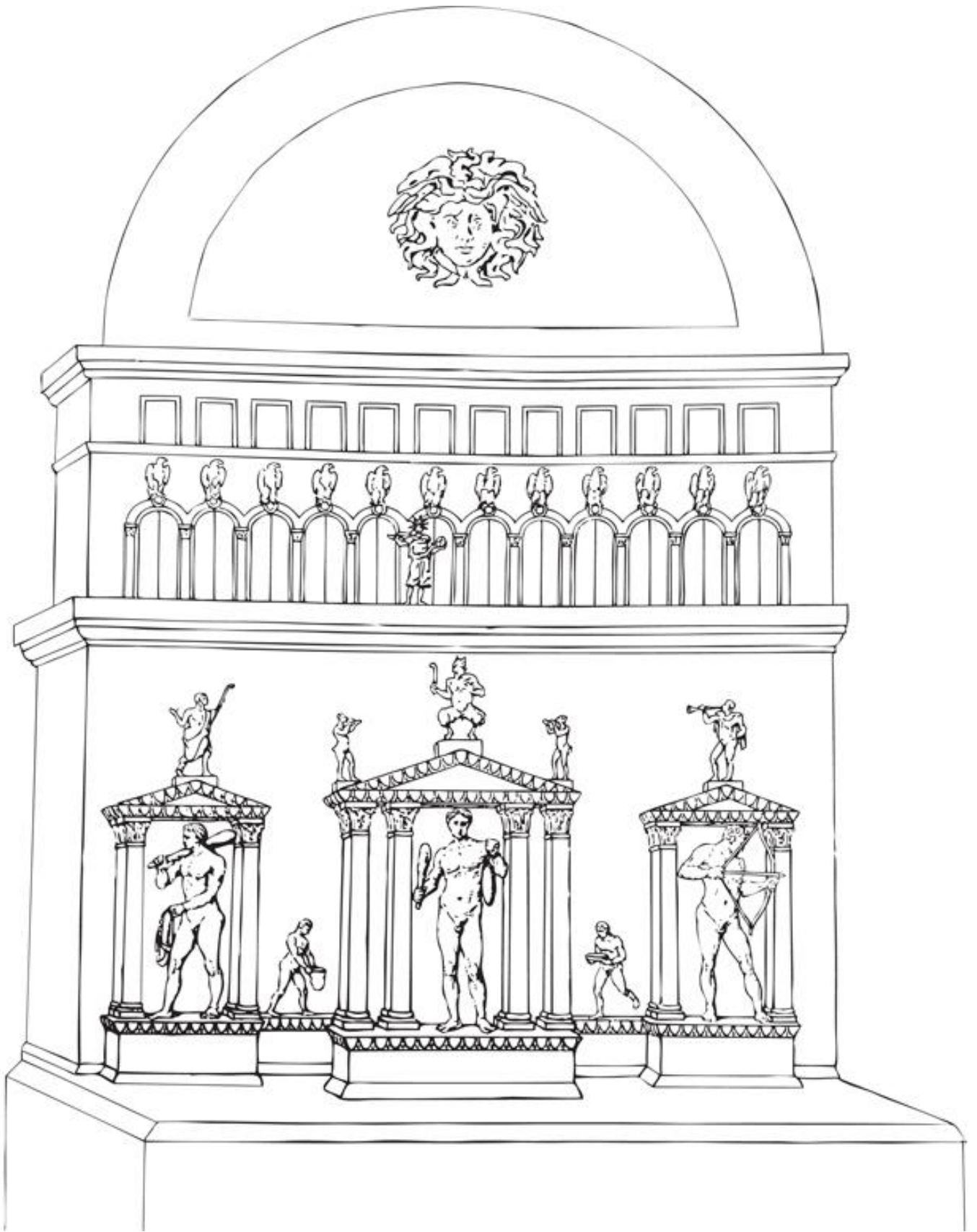
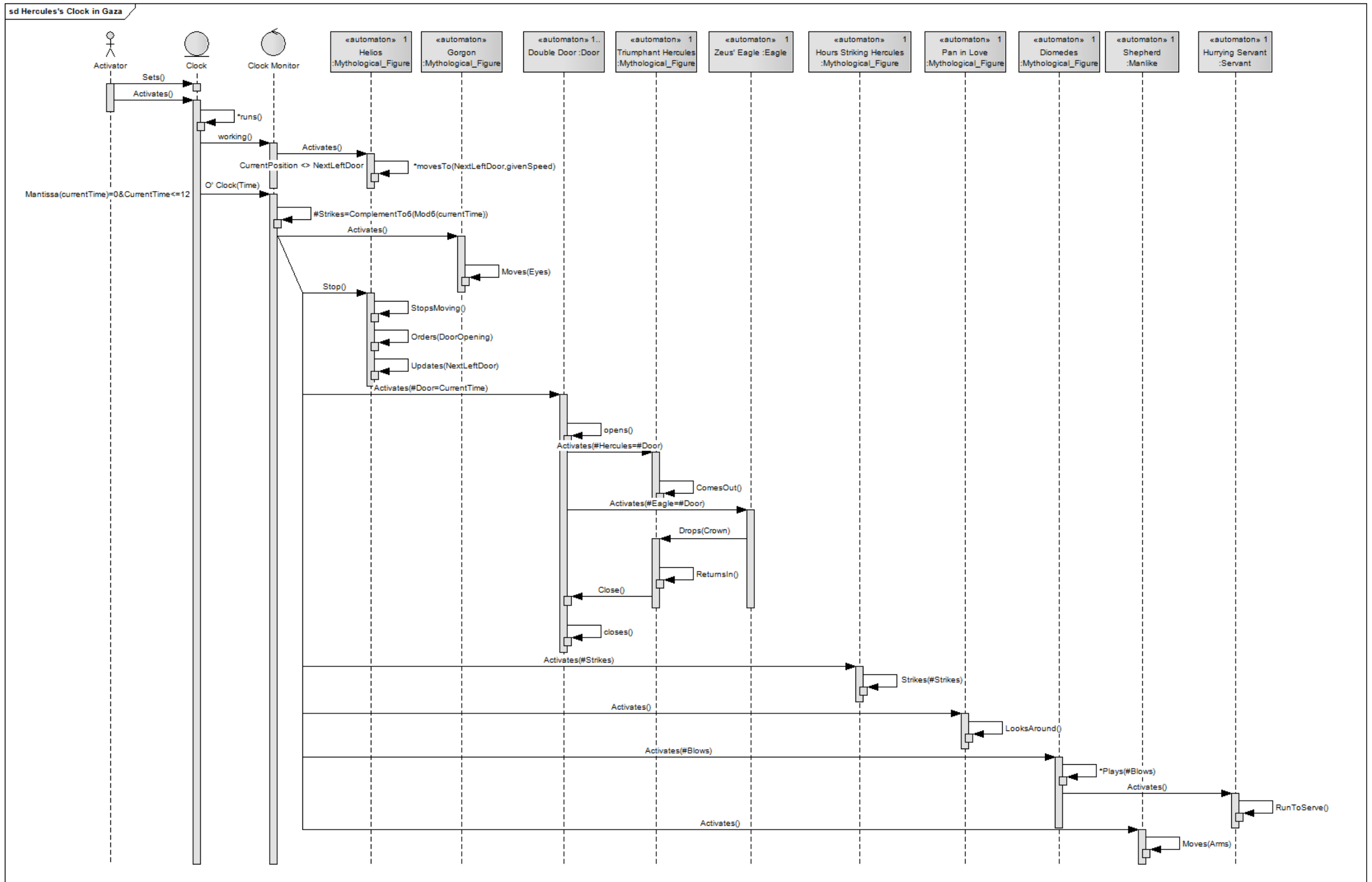**Fig. 65: the Gaza clock (reconstruction taken from Diels, 1917)**

Fig. 66: UML Diagram of the Gaza Clock

At the magnificent court of Byzantium, the natural heir of Hellenistic tradition, but also of the splendour of the Eastern world, automatic devices were largely used in the imperial Great Palace, in the Magnaura [130]. Interestingly, even in this case, the sources are not technical and no name of architect or engineer, who built automata in Byzantium, was handed down.

The oldest source [131] aboute the palace is a historical work by Georgios Monachus (9th century), who, in his *Lives of the New Emperors*, in the 5th chapter, devoted to emperor Theophilus' reign (813-842), refers that "Being lover of fine elegance, Theophilus built, thanks to a master goldsmith, an exceptionally cultured and industrious man and relative of the patriarch Antony, what is called the Pentapyrgion, and two large organs of solid gold studded with various worked precious stones, and also a golden tree, where birds harmoniously sang due to some devices" [123]. It is the first time these automata are mentioned. Also Leo Grammaticus quotes them, and Symeon Magister (10th century), in his *Annals*, wrote that "[…] the emperor Theophilus, lover of refined elegance and luxury, built the Pentapyrgion and two large organs of solid gold studded with various worked precious stones, and also a golden tree, where birds sang harmoniously due to some devices, which lead air through hidden pipes", adding also a technical detail [124]. The fact that the second text quotes the first one nearly word by word shows that Symeon used largely Georgius' *Lives* as a source, but added an important detail about automata operation.

The emperor Constantine VII Porphyrogenitus (913-959) composed the *Ceremonies at the Imperial Court* (Ἔκθεσις τῆς βασιλείου τάξεως), a compilative work. The main content is a detailed description of the ceremonies from the court's point of view; in II,15 he relates what usually happened during a typical audience granted by the emperor: after the ritual bowing, the postulant heard a roar coming from the lions on either side of the throne, while birds, resting on the trees that surrounded the throne, began to sing harmoniously. Subsequently, the lions, in perfect synchrony with the various moments of the ceremony, departed from their starting position and then returned back to it; both lions and birds gave up producing any cries at the end of the ceremony [123, 130] [125].

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[123] Φιλόκοσμος δὲ ὢν ὁ αὐτὸς Θεόφιλος κατεσκεύασε διὰ τοῦ ἄρχοντος τοῦ Χρυσοχόου λογιωτάτου πάνυ ὄντος καὶ συγγενοῦς Ἀντωνίου πατριάρχου τό τε Πενταπύργιον καὶ τὰ δύο μέγιστα ὄργανα ὁλόχρυσα, διαφόροις λίθοις καὶ ἐλίοις χαλλύνας αὐτά, δένδρον δὲ χρυσοῦν, ἐν ᾧ στρουθοὶ ἐφεζόμενοι διὰ μηχανῆς τινος μουσικῶς ἐκελάδουν.

[124] Ὁ τοίνυν βασιλεὺς Θεόφιλος φιλόκοσμος ὢν κατασκευάζει ἐξ ἀρχῆς τὸ Πενταπύργιον, καὶ τὰ δύο μέγιστα ὄργανα ὁλόχρυσα μετὰ διαφόρων λίθων, καὶ δένδρον χρύσεον, ἐν ᾧ στρουθοὶ ἐφεζόμενοι διὰ μηχανῆς τινος μουσικῶς ἐκελάδουν, τοῦ πνεύματος διὰ κρυφίων πόρων εἰσπεμπομένου.

[125] καὶ δὴ τούτου εἰσελθόντος, πίπτει ἐπ'ἐδάφους προσκννῶν τοὺς δεσπότας, καὶ εὐθέως αὐλοῦσι τὰ ὄργανα• εἶτα εἰσέρχεται καὶ ἵσταται ἀπὸ διαστήματος τοῦ βασιλικοῦ θρόνου, καὶ εὐθέως παίουσι τὰ ὄργανα• ἰστέον, ὅτι, τοῦὶ φίλου ἀποκινοῦντος πρὸς τὸν βασιλέα, εἰσέρχονται οἱ προκριτώτεροι τούτου ἄνθρωποι, καὶ προσκυνοῦντες ἵσταιται ἔνδον τῶν δύο συρτῶν βήλων• καὶ ποιοῦντος τοῦ λογοθέτου τὰς συνήθεις ἐρωτήσεις εἰς αὐτόν, ἄρχονται βρυχᾶσθαι οἱ λέοντες καὶ τὰ ὄρνεα τὰ ἐν τῷ σέντζῳ, ὁμοίως καὶ τὰ ἐν τοῖς δένδρεσι, ᾄδειν ἐναρμονίως• τὰ δὲ ζῷα τὰ ἐν τῷ θρόνῳ ἀπὸ τῶν ἰδίων βαθμῶν ἀνορθοῦνται. καὶ ἐν τῷ ταῦτα οὕτως τελεῖσθαι εἰσάγεται τὸ τοῦ ἐθνικοῦ κανίσκιον ὑπὸ τοῦ πρωτονοταρίου τοῦ δρόμου, καὶ πάλιν μετ'ὀλίγον παίουσι τὰ ὄργανα, καὶ οἱ λέοντες ἠρεμοῦσι, καὶ τὰ ὄρνεα τοῦ ᾄδειν παύονται, τά τε θηρία τοῖς ἰδίοις τόποις ἐγκαθέζονται. καὶ δὴ μετὰ τὴν συμπλήρωσιν τοῦ κανισκίου ὑπὸ τοῦ λογοθέτου προτραπεὶς ὁ ἐθνικὸς προσκυνήσας ἐξέρχεται, καὶ ἐν τῷ τοῦτον ἀποκινῆσαι ἐξελθεῖν τά τε ὄργανα αὐλοῦσιν καὶ οἱ λέοντες καὶ τὰ ὄρνεα τὴν ἰδίαν ἕκαστον ἀποπληροῦσι φωνήν, καὶ τὰ θηρία πάντα τῶν ἰδίων βαθμίδων διανίστανται. καὶ ἐν τῷ ἐξιέναι τὸν ἐθνικὸν τοῦ βήλου παίουσι τά τε ὄργανα, καὶ τὰ ὄρνεα καὶ τὰ θηρία τοῖς ἰδίοις τόποις ἐγκαθέζονται. While the logothete is posing the usual questions to the ambassador, the golden lions begin to roar and the golden birds on the golden trees surrounding on the holy throne begin to sing in harmony. The wild beasts of the throne begin to rise upward on foot. While doing this, is carried by the protonotary of the court the gift bag of the ambassador, which he offers on behalf of his master. Shortly after playing the organ, lions stop roaring, birds (stop) to sing and wild beasts sit down on their pedestals. After finishing to show the contents of the bag, the ambassador is

A very similar ritual is also described by the bishop Liutprandus of Cremona (920-972), in his *Antapodosis*, a report about his stay at the court of Byzantium as an ambassador of Berengarius II (900-966), who was eager to be accredited as king of Italy by the emperor of the Eastern Roman Empire; Liutprandus was formally received by Constantine Porphyrogenitus, in 949, and stayed for some time in the city, taking part in court ceremonies [449, 132] [126].

The reason of the difference between the descriptions made before and during Constantine's reign, can probably be found in another contemporary chronicle (*Annals*) by Theophanes Continuatus: the author explains that "since missing the opportunity to obtain money with which a loyal army fairly fights against the enemy, [the emperor Michael II] gave that famous golden plane tree and two golden lions and many griffins, all of solid gold, and even the golden organ and other furnishings of the treasury (for a total weight of not less than 200,000 in gold), in order to coin money for the imperial tax" [127]. Here griffins appear mentioned for the first time, and lions are even there, but no mention is done of the birds [128]. We can suppose that the golden devices were melted, and subsequently rebuilt, depending on imperial finances status, maybe several times; such a habit could explain the discrepancy between the descriptions.

The presence of a tree near a king's throne [450] dates back to the Sumeric epic of Gilgamesh; a golden plate tree and a golden vine are also cited in Herodotus' *Histories* (VII, 27), as a gift to the Persian emperor Darius by the king of Lydia, Pythius, grandson of the renown Croesus [451-452]. Singing birds are likely to have been inspired by Philon's, and Heron's *Pneumatics*, exactly as in the Arabic world, but, given such lack of technical Byzantine sources, one could also suppose that the Byzantine engineers were inspired by Arabic designs or models, possibly seen in Baghdad [453-454, 441], where the caliph al-Muktadir had such devices at least in 917, as referred, for instance, by Ibn al-Jawzi, in his *Muntazam* [455], and later, in 1750, by de Marigny [456] in his *History of Arabs*.

Concerning the lions, the iconographic source for the Byzantine engineers has been the throne of Solomon, as described in the Bible (Kings, I, x, 18-20; Chronicles, II, ix, 17-29), though no reference is here made to any motion.

These automata show perfectly how the intellectual resources of the Byzantines (in this case, their competence in the fields of mechanical engineering) could be used as *instrumentum regni*, and they also demonstrate the effort that was made both in the imitation of nature, and in showing the emperor as a God's epiphany.

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called by logothete and renders homage to the king. While he gets up and moves to the exit, pneumatic organs sound and lions and birds make noise, each in its own way, and wild beasts rose on their hind legs. Once the ambassador has gone out beyond the veil, the organs play and the birds stop their singing, and the birds and beasts returned to their positions.

[126] Full souce text is in the data base, due to its length.

[127] ἦλθεν δὲ ὁ τῆς διανομῆς τῶν βασιλικῶν δωρεῶν καιρός, καὶ χρημάτων πόρος οὐκ ἦν δι᾽ ὧν τὰ στρατεύματα φιλοτιμούμενα τὰς τῶν ἐχθρῶν παρατάξεις ἀμύνονται, τήν τε χρυσῆν ἐκείνην καὶ πολυθρύλητον πλάτανον καὶ τοὺς δύο χρυσοῦς λέοντας, πρὸς δὲ καὶ τοὺς δύο γρῦπας ὁλοχρύσους ὄντας καὶ σφυρηλάτους, καὶ τὸ ὁλόχρυσον ὄργανον, ἀλλὰ καὶ ἕτερα ἔργα τῆς βασιλικῆς ἐκθέσεως, ὁλκὴν ἔχοντα τῶν διακοσίων οὐκ ἔλαττον κεντηναρίων, χωνεύσας χωράξαι δέδωκεν ἐν τῷ βασιλικῷ ταμιείῳ.

[128] Brett [131] insists on the problem of the tree, that for the first time is quoted as a plane tree, but we think that it could also be a minor question, since some details are added, or excluded from version to version. The most remarkable is the name (Leo) of the clock master who would have made a clock for Theophilus: it is quoted only in a chronicle of the 12th century by Constantine Manasses (ca. 1130-1187). In other chronicles, neither the fact that a clock was there, is mentioned.

Following this idea, we decided to model Liutprandus' description. Travellers like him are responsible for the transmission of these accounts to the West, that will stimulate the imagination of Medieval Western poets and writers, as we will see in 2.4.4.5.
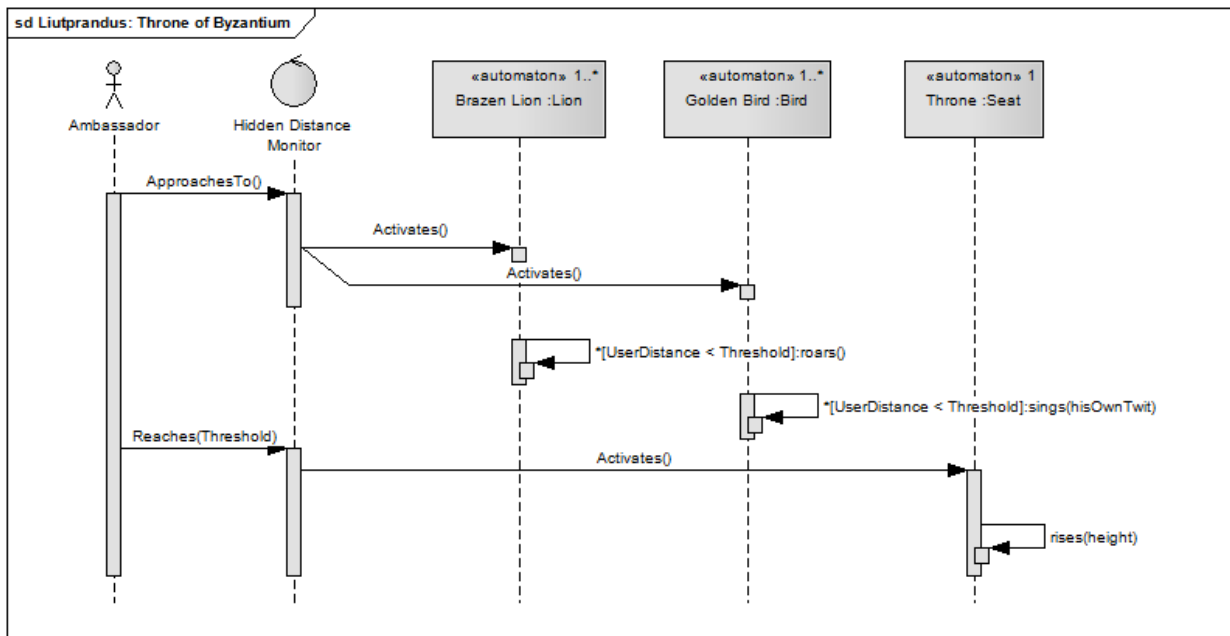

Fig. 67: UML Diagram of Liutprandus' Description of Byzantium Throne

As a matter of fact, when the crusader Robert de Clari, in 1204, took part in the sack of Byzantium, he wrote in his account (*The Accounts of those who took Constantinoples - Li estoires de chiau qui conquisent Constantinoble*) that the city was still amazing: "And all these marvels which I have related to you, and still many more which we cannot relate to you, did the Franks find in Constantinople when they had conquered it."

Though he doesn't refer to the throne, he however describes the famous hippodrome, that was run-down: "All along one side of this place was a wall which was surely fifteen feet high and ten wide; on this wall were statues of men, women, horses, oxen, camels, bears and lions as well as many kinds of beast, cast in copper, which were so well made and so naturally shaped that there was no master craftsman in Christian or pagan lands who knew how to sculpt or shape statues so skilfully as these statues were crafted. And in the past they used to play by magic. But they no longer play at all. And the Franks looked at these Games of the Emperor in amazement when they saw them." He obviously refers to the statues set in the *spina*, whose appearance has recently been virtually reconstructed together with the whole hippodrome, thanks to the *Byzantium 1200* project, a non-funded and non-profit project aimed at creating computer reconstructions of the Byzantine monuments located in Istanbul, Turkey, as they appeared in the year 1200 AD (http://www.arkeo3d.com/byzantium1200/hipodrom.html).

2.4.3   Arabo-Islamic World

As we already pointed out in 0, when the Arabs met the Greek technical culture, they began a feverish activity of translation. The quality of such translations was not always fulfilling, since the

linguistic distance between the languages is formidable [457], and translators were rarely experts in the field studied in the text they were to translate.

The caliphs, particularly al-Mansur (754-775; محمد بـ ن عـ بد الله جعـ فر ابـ و) and Harun al-Rash'id (786-809; الرشيد هلرون), encouraged and supported scholars, doctors and scientists in their task of propagation of classical culture. Translations got greater importance during the reign of the son of Harun, al-Mamun (813-833; الـمأمون عـ بد الله ابـ وجعـ فر), who increased the library built by his father, turning it into a real research center, the Bayt al-Hikma (الحكمة بـ يت; House of Knowledge), where mostly Nestorians worked. The caliphs and their viziers, especially Barmakids (الـ برامكة), in the role of patrons made possible the creation of a unique cultural workshop; they were however primarily concerned with works whose content could be immediately put into practice, such as treatises on medicine, astrology, logic and mathematics. However, soon the interest of Islamic scholars included the philosophic works by Plato and Aristotle. These texts, already available in Syriac (the literary and liturgical language of the Nestorians), were then translated into Arabic; whenever the work was not available in Syriac, it was translated either directly from the Greek into Arabic, or through the mediation of the Syriac language. On several occasions, some scholars were sent to Byzantium to obtain copies of Greek works otherwise unavailable, or even copies of originals held only in hopelessly damaged versions [210]. Today the comparison between Greek and Arabic translation manuscripts frequently puzzles the reader for the differences in content: it must be remembered that often the Greek copies we received were made after the work of translation into Arabic, and that Arabic translators already faced many difficulties in finding well preserved manuscripts [458, 174].

Exactly as we will see in the European context, such translations were copied, and spread in all along the Arabic speaking countries, from East to West, that is to Northern Africa, and to Spain. Thanks to the Arabic translation, we can read the *Pneumatics* by Philon, preserved only in 4 copies of the 14th century, now housed in Turkey, and in England [129].

2.4.3.1 Banu Musa

The Banu Musa ibn Shakir (بـ ن الـ حـ سن موسى بـ نو, literally "sons of Moses, son of Shakir") were three brothers living in 9th century in Baghdad, and working in the House of Knowledge: their names were Muhammad (محمد), Ahmad (أحمد), and al-Hasan (الـ حـ سن). Though their research subjects did not always coincide, the three brother are usually mentioned together as Banu Musa.

Their *Book of Ingenious Devices* (الـ حـ يل كـ تاب; Kitab al-Hiyal) was a large work on various mechanical devices, that circulated starting from the middle of the 9th century, and was attributed from some sources[130] to Ahmad. As a matter of fact, in the work, after an initial mention of the three brother, only Ahmad is constantly quoted. In the late 1970s, the work has been translated and studied by Hill [139], whose edition is still the main one.

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[129] Two manuscripts are at the Soliman Library in Istanbul (Süleymaniye Kütüphanesi, Ayasofya 2755, ff. 92v-144v, and 3713, ff. 1r-6r; 80r-86v); the second one includes all the *Mechanics*. As it can be argued from the press mark, they were before housed at the Library of St. Sophia. A third manuscript is now at the Bodleian library in Oxford (954 Marsh 669, ff. 49r-92v), and a fourth one is at the British Library (Or. 9649).
[130] *Fihrist* by ibn al-Nadim (10th century), and by ibn al-Qifti (13th century).

Starting from the comparison of the content of the four extant manuscripts [131], and continuing with the analysis of a fragment housed in the Leiden library (Or. 168) Hill could reconstruct the plan of the work, that included more than 100 designs.

We chose to model the most interesting ones to our aim, by applying the same criteria as for Philon, and Heron, as in the *Book of Ingenious Devices* the goal of describing the devices working prevailed, and rarely attention is put to the setting component.

In the 5th model, two basins (*Jam*) are presented: by one is the figure of a small wild animal, by the other the figure of a lion. When water is poured into the small animal's basin he drinks nothing: when the lion's basin is filled both he and the other animal drink. The operation is quite easy, since everything depends on drains and a valve, while animals have only a decorative function. The presence of the activator is necessary for both phases.

Device #5 shows also a remarkable resemblance with Philon's #33 and #34, when respectively a horse and a bull are drinking (see *infra* Fig. 69).
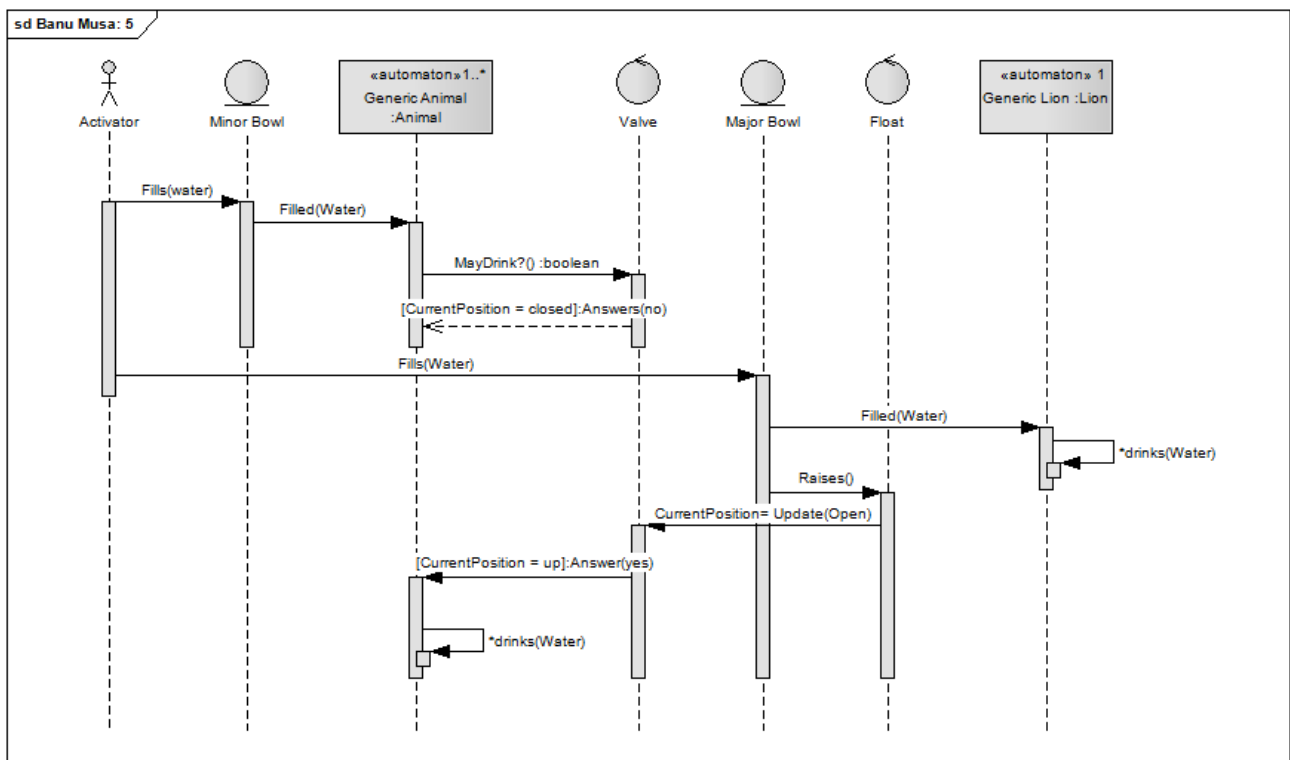

Fig. 68: UML Diagram of Device #5 by Banu Musa

[131] They are preserved in the Vatican State, BAV, Vatican 317; in Berlin, Staatsbibliothek, No. 5562; in Gotha, Forschung- und Landesbibliothek, Arab 1349 (a second part of this manuscript Arab 1349a was not considered by Hill); and in Istanbul, Sarayı Kütüphanesi, A3474.
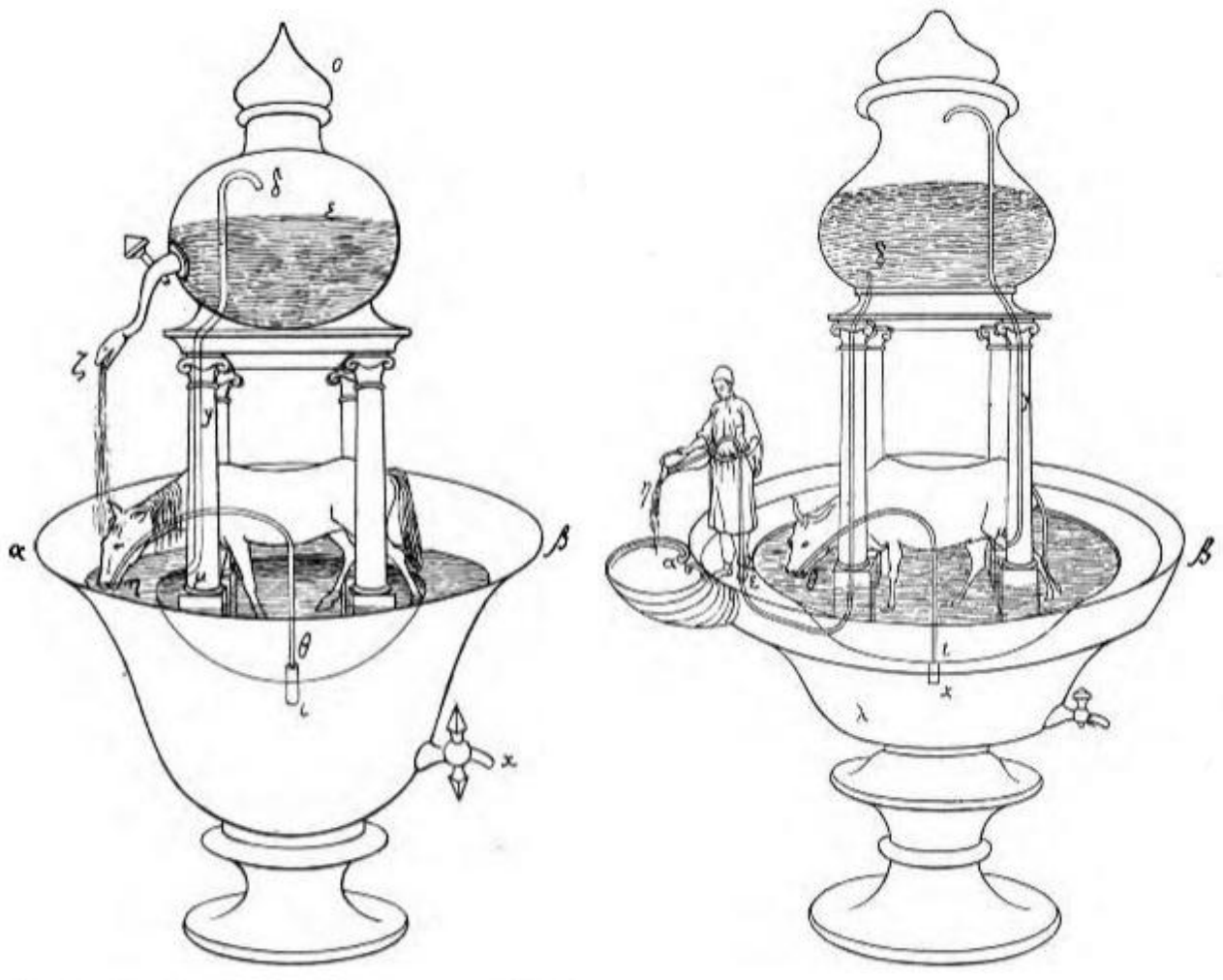
Fig. 69: Devices #33 and #34 by Philon from Carra de Vaux

In the 6th model, we have a basin (*ijjana*): the figure of a bull is placed by the basin with his muzzle in the water it contains and one then hears a sound simulating the sound of a thirsty bull. Exactly what happens in Philon's #59, when the dragon plays the bull's role (see *supra* Fig. 19).
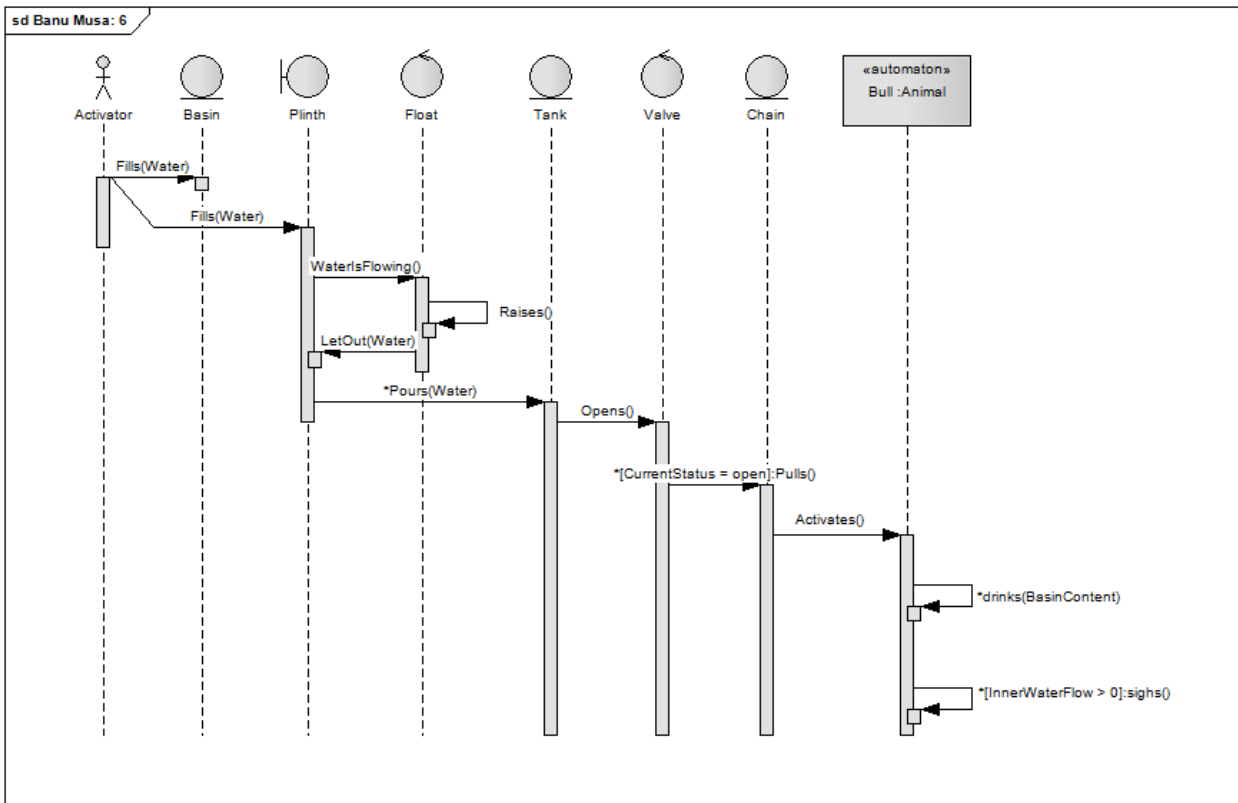

Fig. 70: UML Diagram of Device #6 by Banu Musa

In model #14, a pitcher (*ibriq*) is designed; by pouring one or two ounces of wine in, the adept can deceive his audience that the pitcher is full: he can also fill it completely and make them believe it to be empty; he can dispense from it as much or as little as he desires.
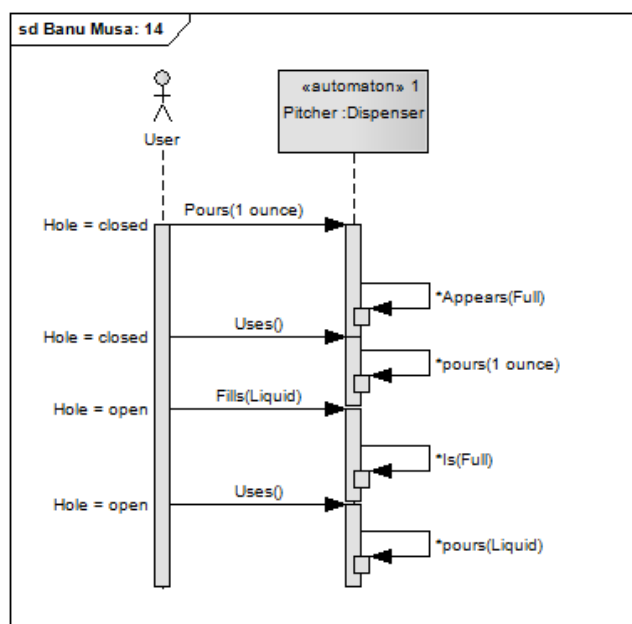

Fig. 71: UML Diagram of Device #14 by Banu Musa

The last presented diagram shows an unexstinguishing lamp, here called the "Lamp of God"; oil level is maintained constant and wick comes out by itself. As we have seen, this automaton pertains to Heron's tradition, and appears to have been historically witnessed by the 5th-century historian Salminius Hermias Sozomenus, who in his *Ecclesiastical History* (Prol. 8.) refers that the noble emperor Theodosius II (401 – 450) used such lamps in order to prevent his servants to stay up late only to supply them (see Fig. 39).
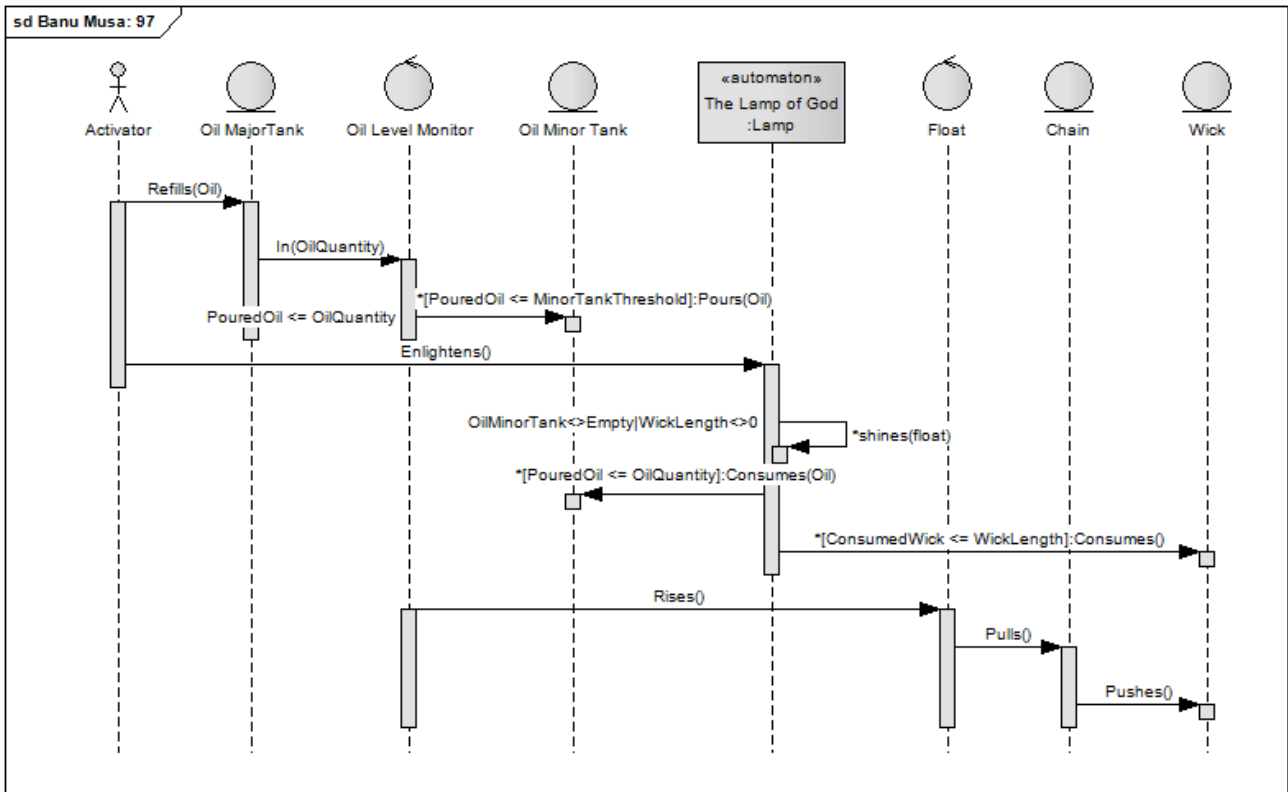
Fig. 72: UML Diagram of Device #97 by Banu Musa
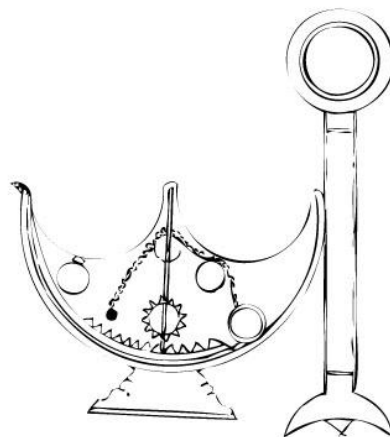
Fig. 73: Device #97 by Banu Musa (drawing based on Hill)

As it is evident also by the analysis of the other designs the debt of the Banu Musa with the Greek tradition is out of discussion, they (or better Ahmad) however, as Hill states, "Compared with the Greek works, they [i.e. these devices] contain far less theory and a much greater degree of engineering inventiveness", meaning with these words that that it was not just a quotation from the others' works, but the result of the application and creative work of Ahmad. Hill, in any case,

recalls the lack of technical sources between the Alexandrian world and the Banu Musa, both the West and in Persia, so that it is impossible to reconstruct with certainty any tradition the book belongs to.

2.4.3.2 Arabic Medieval Literature

2.4.3.2.1 One Thousand and One Nights

In the same century when the Banu Musa were working at their treatises, the long process of composition that would lead to the final version of the tales collection, entitled *One Thousand and One Night* (وليلة لـ يلة ألـف كـ تاب), was beginning. Harun al-Rash'id is a main character in many tales, and, curiously, the first reference to the collection is by ibn al-Nadim, in the 10th century, the same historian, who also quoted the work by Banu Musa: he also adds that the origin of the compilation is Persian.

The frame-story is centered on the Persian king Shahryar, who, betrayed by one of his wives, decides to systematically kill them after the wedding night. The beautiful Scheherazade, who has just married the king, plans a trick to escape her fate: she tells the king a story every night, delaying the final to the next night. She continues for a thousand and one nights, and, at last, the king, fallen in love, saves her life. All the stories are then told by Scheherazade, at a first narration level, but along the collection even some characters at turn tell other tales [459-461].

For our purposes, some stories differ from others [169]:

- Prince Ahmad and fairy Peri, where three brothers (princes Ahmad, Ali, and Husayn) travel around the world and buy at the bazaar magical objects at tremendous price: among them, we must recall a flying carpet, that can bring the traveler immediately wherever he wants, and, as a curiosity, a spying tube, in order to see what happens around him, for a wide range (hundreds of miles), by applying a glass at each end [132].
- The Third Calender's Story, whose plot is very intricate; nonetheless, the narrator tells us he has met a man of brass, that could perfectly work as a ship pilot.
- The Enchanted Horse, where three automata are quoted, obviously related with magic [462]. Sabour, king of Persia, was one of the richest and the wisest kings. He had three beautiful daughters and a son. Twice a year, he opened his palace to his people: on this occasion, "one day, as he sat on his throne of kingship, during one of these festivals, there came in to him three sages, cunning artificers and past masters in all manner of crafts and inventions, skilled in making rarities, such as confound the wit, and versed in the knowledge of [occult] truths and subtleties"; the three sages (an Indian, a Greek, and a Persian) respectively offer to the king
  1. "a figure of gold, set with precious stones and jewels of price and holding in its hand a golden trumpet", that, placed near a city gate, can show enemies, who try to enter, by blowing in its trumpet;

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[132] Even though it looks like a true spy-glass, we are more probably dealing with an enhanced version of a device that was common among Arabic astronomers: an observation tube that allows to focus on one star, or constellation in the sky, without interferences from other light sources.

2. "a basin of silver, in whose midst was a peacock of gold, surrounded by four-and-twenty young ones of the same metal"; basically a clock that can also mark the arrival of the new moon;

3. "a horse of ebony wood, inlaid with gold and jewels, ready harnessed with saddle and bridle and stirrups such as befit kings", that, "if one mount him, […] will carry him whither he will and fare with its rider through the air for the space of a year and a day".

The king offers them whatever they desire, so the three sages choose to marry the kings' daughters, who however are reluctant; and then the story continues to the happy end.
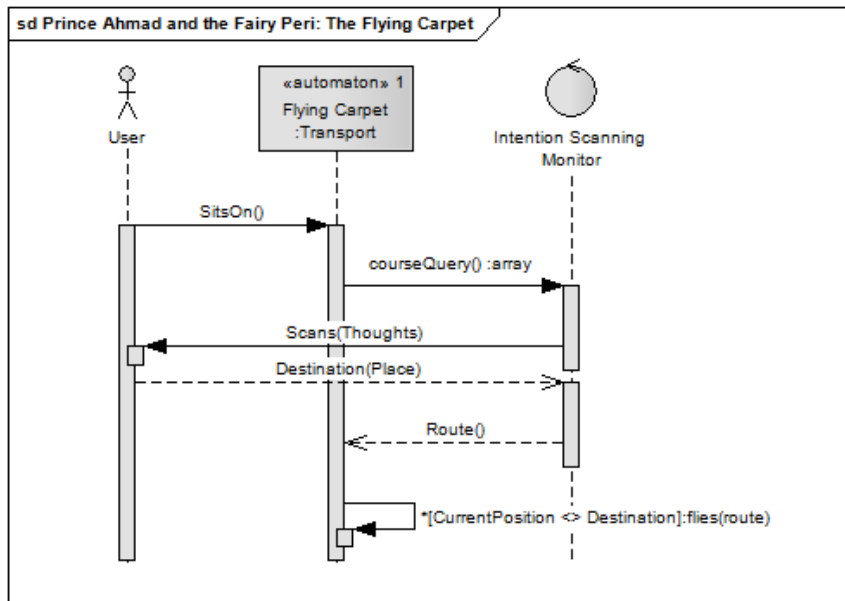
Fig. 74: UML Diagram of The Flying Carpet from One Thousand and One Nights
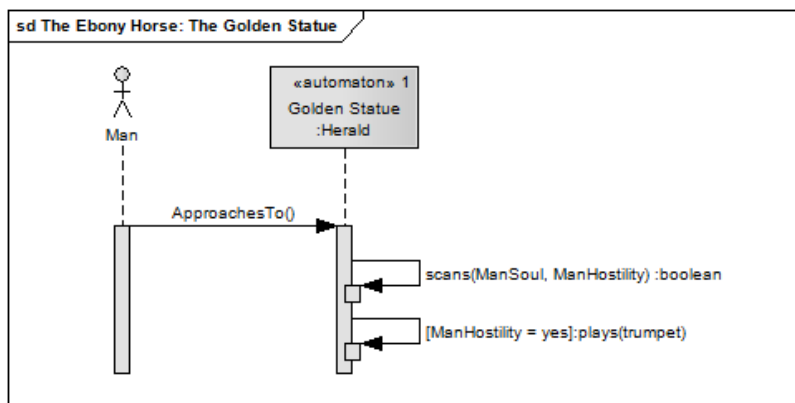
Fig. 75: UML Diagram of The Golden Statue from One Thousand and One Nights
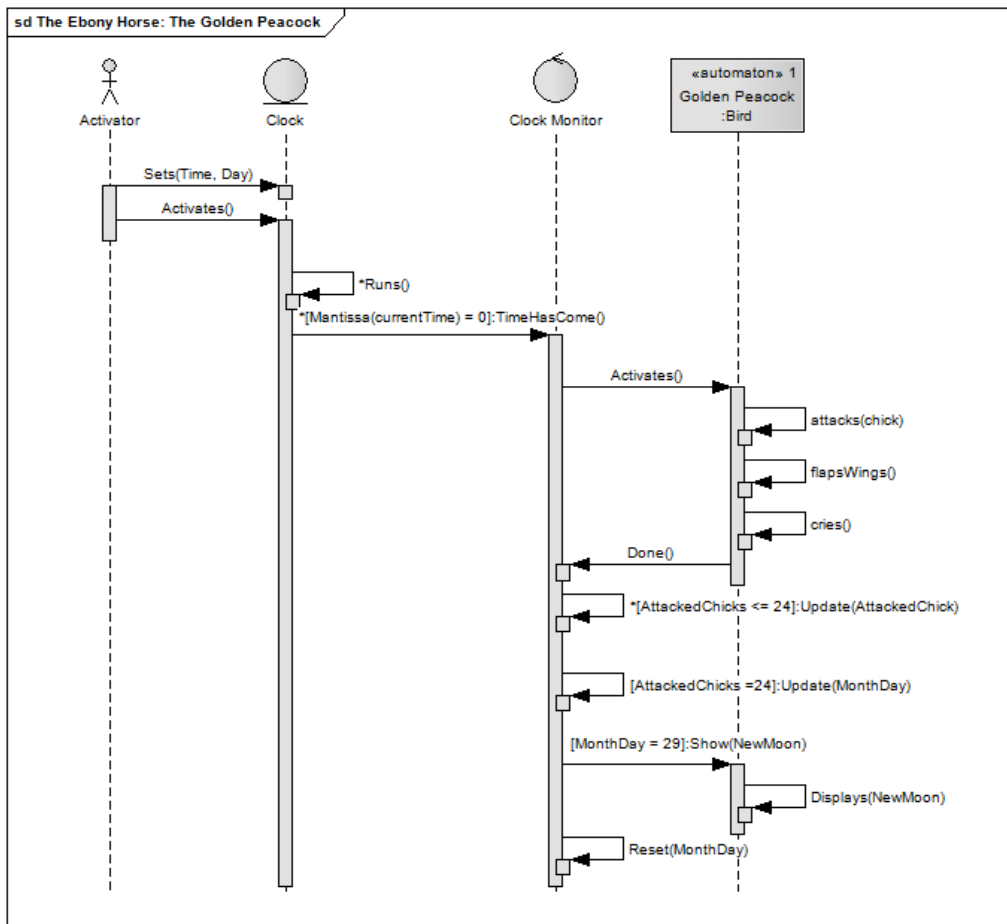
Fig. 76: UML Diagram of The Golden Peacock from One Thousand and One Nights
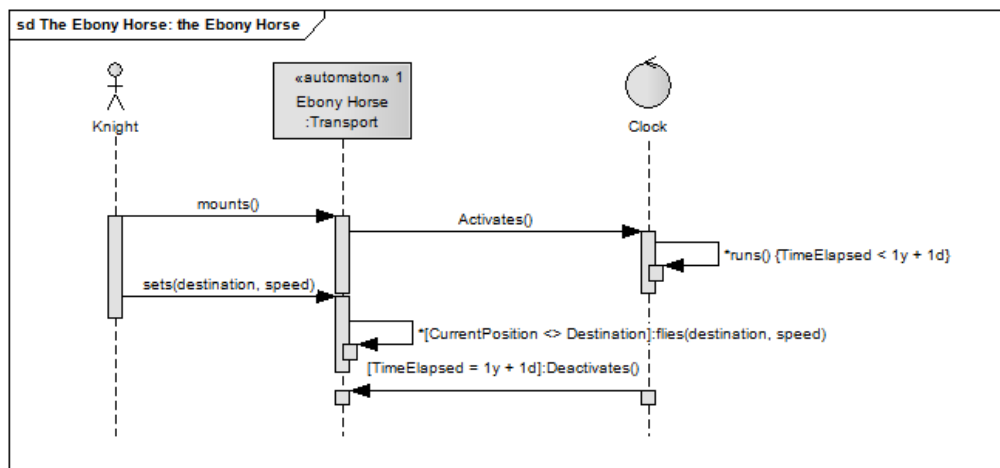
Fig. 77: UML Diagram of The Ebony Horse from One Thousand and One Nights

This last tale will be resumed, as we will see in 2.4.4.5, in Western literature of chivalry [463], but both its Eastern matrix, due to the presence of the peacock-clock (see 2.4.3.5) and the Greek influence, because of the automaton trumpeter, are instantly recognizable. Geoffrey Chaucer, on the contrary, narrates a similar, but not identical episode (see *infra* 2.4.4.5.2).

2.4.3.2.2 Al-Masudi (896-956)

He (المسعودي) was one of the most famous and prolific writer of the 10th century, mainly dealing with world history, and religion. His historical work *The Meadows of Gold and Mines of Gems* (الجواهر ومعادن الذهب مروج - Muruj adh-dhahab wa ma'adin al-jawhar) starts from *Genesis* to arrive until the late Abbasid Caliphate.

In a passage, the author tells an Egyptian saga that dates back to the 7th century: the greedy ruler Abd el-Aziz, in search of treasures, learns of a golden cock, studded with precious stones, set on a column of gold, priceless. He organizes the expedition, and the excavations bring to light the cock, but the site proves to be a death trap, ready to kill raiders [464], since, as soon as the workers try to get the cock, they are horrendously chopped by hidden swords, while the cock cries atop the column, where it is set.
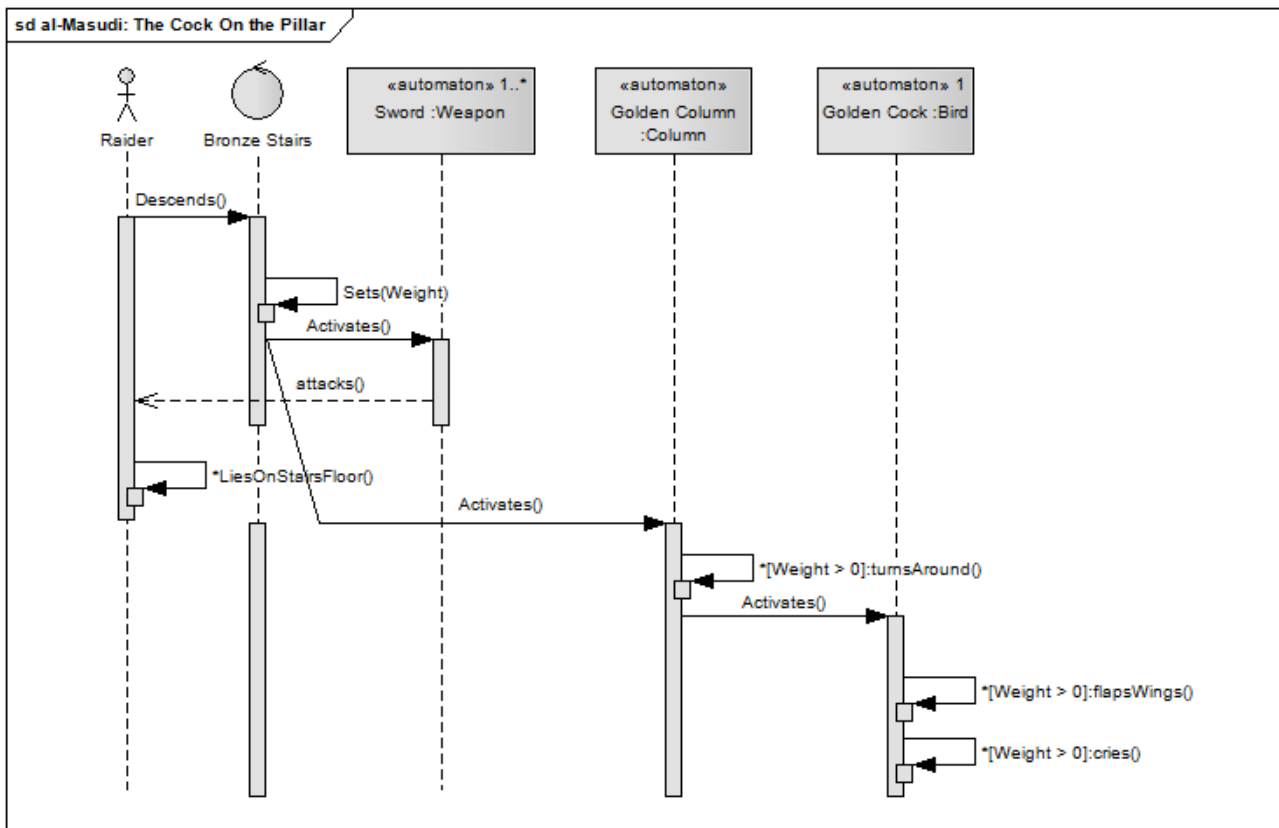
Fig. 78: UML Diagram of al-Masudi's "Cock on the Pillar" Episode

2.4.3.3 A Water Clock in Damascus

The 13th-century tecnician Ridwan ibn al-Sa'ati in his book about the history of water clocks [465] entitled *Book on the Construction of Clocks and Their Use* (*Kitab 'amal al-sa'at wa-l-'amal biha*), dating back to 1203, refers that a man called Hormuz would have been the inventor of the water clocks used by his father, when he built the Damascus clock. He also adds that "the design [of Hormuz] continued in the land of Fars [a region of Persia] for a long time, and was transmitted from there to the land of the Greeks, and its construction spread out in the land until it was transmitted to Damascus, where it was constructed up to the days of the Byzantines and after that in the days of Banu Umayya, according to what is mentioned in the histories. This clock attributed to Hormuz

continued to be reproduced by one man after another on this pattern, and it was in the shape that we described above" [133].

The account by Ridwan therefore connects the tradition of the water clocks with both Mesopotamic and the Hellenistic culture.

2.4.3.4 Al-Muradi

As early as the 7th century, the Spanish region of al-Andalus was the subject of several attempts at conquest by the Arabs, first rejected by the Visigothic kings; in 711, however, the Arabic troops, led by Tariq ibn Ziyad (زياد بـ ن طارق), they landed in Gibraltar, defeated the Visigothic army and then succeeded in penetrating up to Toledo. In less than 10 years nearly the whole Spain fell into Arabic hands. The Arabic language and culture so penetrated the region, which has been for centuries an important center of scientifical, and technological culture [141, 467].

In the 11th century the Arabic astronomer al-Zarqali (1029-1087), whose name was later latinized as Arzachel, was an outstanding scholar, born in Toledo, but working in el-Andalus; he built an astrolabe [468], which took its name (al-Safihah Zarqalia, the plate of al-Zarqali) and wrote a treatise on the construction of the equatorium; he demonstrated the motion of solar apogee with respect to the fixed stars and determined the extent of such motion; he compiled the Toledan astronomical tables, thanks to his observations in Toledo between 1061 and 1080; he corrected geographic measures present in Ptolemy's works (estimate of the length of the Mediterranean Sea) and would have built a water clock capable of determining the hours during day and night, and indicating the days of the lunar months [143], as expected in Islamic calendar.

In such an environment [134], it is not difficult to imagine that other technicians were trained and designed more or less complex devices. One of them was al-Muradi: the biography of this engineer is unfortunately completely unknown. The only information we have about him comes from a heavily damaged manuscript housed at the Biblioteca Medicea Laurenziana in Florence (Or. 152), in which the only extant copy of his treatise entitled *The Book of Secrets in the Results of Ideas* (*Kitab al-Asrar fi natayij al-Afkar*) is preserved. The scribe is probably the scientist Isaac ibn Sid, who wrote it at the 12th-century court of Alphonse X the wise [158, 156], but the draft of the treatise dates back more probably to the 10th -11th century, as other members of the al-Muradi family are quoted in documents of those years; in addition, many references to the town of Cordova suggest The poor conditions of the manuscript have led someone (Hill, for instance) to despair that it could be recovered; other scholars however attempted to reconstruct the automata designed by Andalusian engineer: an automaton model for the measurement of blood collected in a drain is visible at the Museum for the history of Arabic technology in Istanbul; the clock with gazelles has been reconstructede by a group of researchers from Barcelona [168]; recently a virtual three-dimensional reconstruction of almost all automata has been been made by Leonardo3.

The number of al-Muradi designs is far smaller than Banu Musa's or al-Jazari's, they are, nonetheless very interesting, mainly because of their originality, and obviously of the worth of the design. We will follow here the reconstruction by Leonardo3, as it appears far more precise and

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[133] Quotation from Hill [466].
[134] A water clock was also built on the banks of the Tagus river in Toledo in 1085 [465].

complete, since there are some differences from the one done by Vernet and Casals of Universidad de Barcelona in 1998 [168].

The first figure always stimulated the interest of scholars, in spite of the poor state of preservation of the manuscript, as a story is told: four gazelles are quietly drinking from a brook, while a man, previously hidden in a nearby pit, comes out and (probably) calls a young woman; as soon as she appears on the balcony, three snakes come suddenly out, threaten the two human beings, who return to their default positions, and scare the gazelles, that stop drinking.

In the figures #2, 4, and 5, fight scenes are presented: in #2, menacing knights and soldiers holding weapons frighten a young woman; in #4 two rams are fighting and a nosy man turns to look at them; in #5 we have a true duel among many soldiers. In #3, we have an everyday life scene: a blind man has a short walk with his dog, while in #13 we have a setting, that will become traditional though with minor differences: after a brief scene where a man with an astrolabe and two girls move on a balcony, two serpents spit a ball, to strike the hour.
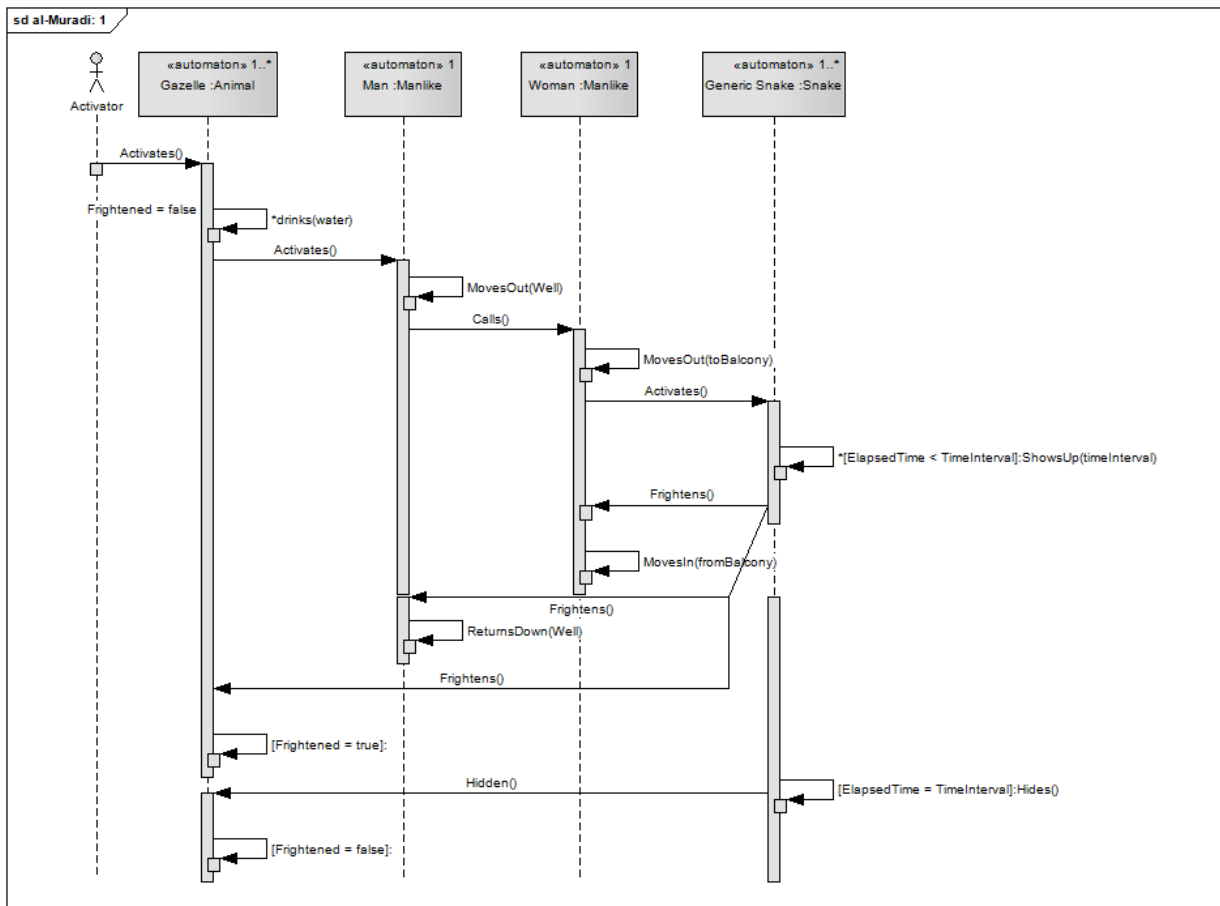
Fig. 79: UML Diagram of al-Muradi's Figure #1
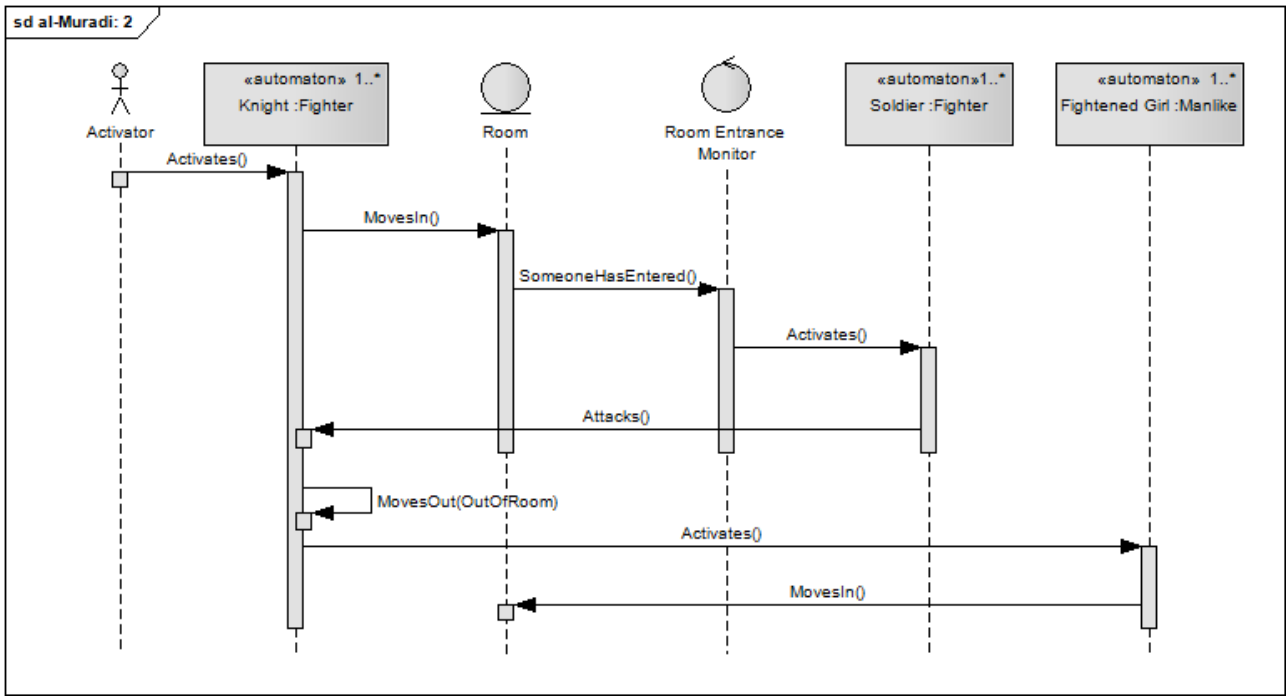
Fig. 80: UML Diagram of al-Muradi's Figure #2
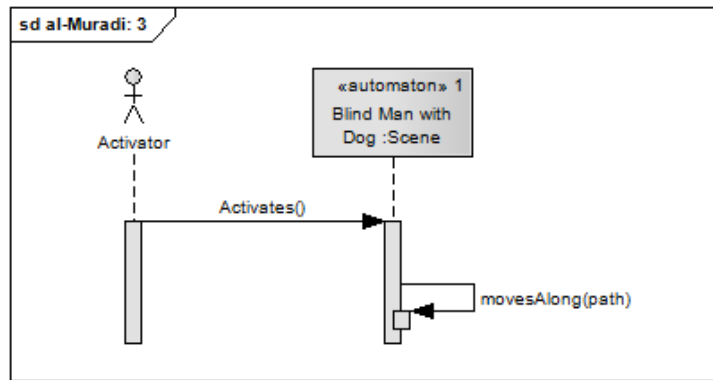
Fig. 81: UML Diagram of al-Muradi's Figure #3
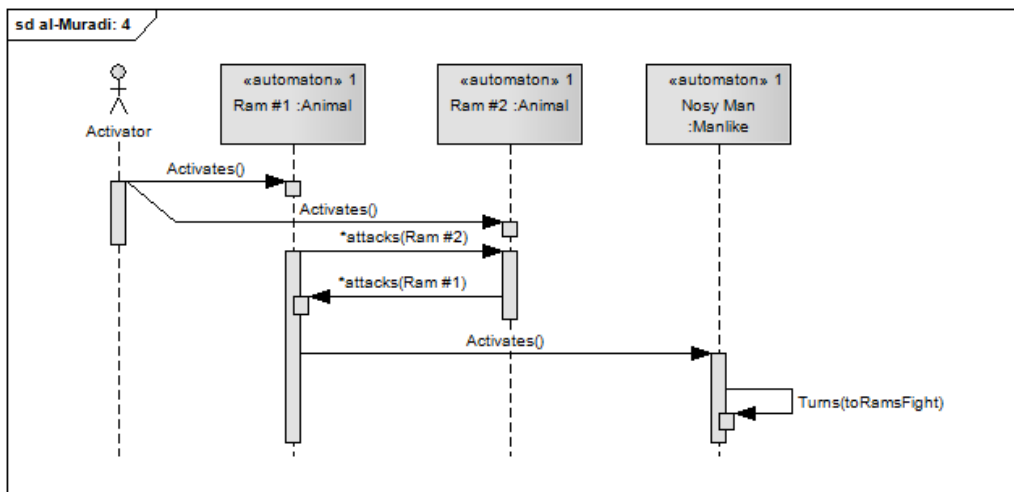
Fig. 82: UML Diagram of al-Muradi's Figure #4
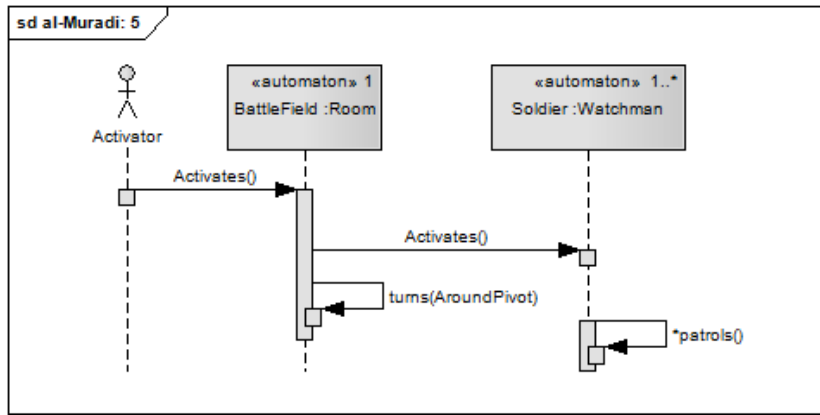
Fig. 83: UML Diagram of al-Muradi's Figure #5
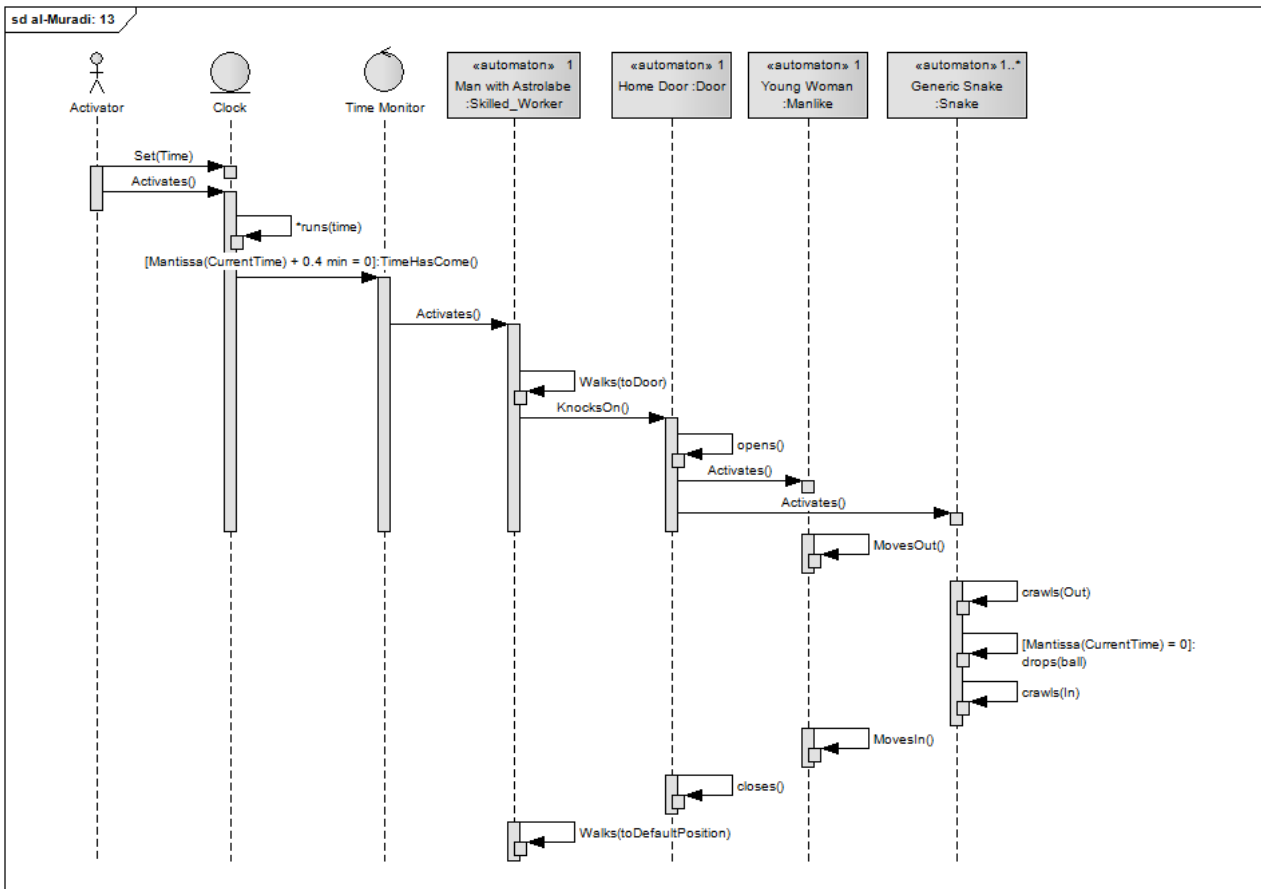
Fig. 84: UML Diagram of al-Muradi's Figure #13

2.4.3.5 Al-Jazari (1136-1206)

All is known about al-Jazari's life is contained in the introduction of his work, whose complete title is *Kitab fi Ma'rifat al-Hiyal al-Handasiyya* [213]. He refers to be in the service of Nasir ad-Din, the Artuquid king [135] of Diyar Bakr, where he has been for 20 years.

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[135] A Turcoman dynasty that had become vassal of Saladin in 1181. [213]

2.4.3.5.1 Al-Jazari's Kitab al-Hiyal

The work, usually dated to 1206, is a summary of al-Jazari's technical knowledge, characterized by the methodical reorganization of the previous engineering tradition, and by creative innovation. As stated by Hill [135], the text had been handed down in ten Arabic manuscripts; there is no news of a Latin translation, even late [136]. In chronological order, they are the following:

City	Library	Ms.	Century	Date	Origin
Istanbul	Sarayı Kütüphanesi	No. 3472	13th	-	-
Oxford	Bodleian Library	Ms. Graves 27	14th	1341	-
Istanbul	Süleymaniye Kütüphanesi	Aya Sofya No. 3606 [137]	14th	1354	Egypt
Paris	Bibliothèque Nationale	Arabe 2477	15th	1485	
Leiden	Bibliotheek der Universiteit	No. Or 656	16th	1561	
Oxford	Bodleian Library	Ms. Frazer 186	17th	-	
Paris	Bibliothèque Nationale	Arabe 5101	18th	-	Persia
Paris	Bibliothèque Nationale	Suppl. pers. 1145 and 1145a	19th	1874	
Dublin	Chester Beatty Library	Ms. 4187	-	-	
Leiden	Bibliotheek der Universiteit	No. Or 117	-	-	

In Oxford, a later (dating back to 1496) copy of Ms. Graves 27 is also preserved [469]; and in Berlin, Staatsbibliothek, MS Orient fol. 3306, a copy not included in Hill's census, made however later than the 16th century. Some dismembered drawings from his work are also preserved in New York, at the Metropolitan Museum of Art, and Washington, at The Freer And Sackler Galleries [136].

The work contains fifty designs, distributed into 6 categories [138], as follows:

1. "On the construction of clocks from which can be told the passage of the constant and solar hour by means of water and candles"
2. "On the construction of vessels and figures suitable for drinking sessions"
3. "On the construction of pitchers and basins for phlebotomy and ritual washing"
4. "On the construction of pools of fountains which change their shape and of machines for the perpetual flute", probably written to improve the results of the Banu Musa, lacking of creativity

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[136] Hill also quotes a 14th century manuscript, now lost, dating to 1315. As far as we know, a detached folio is preserved at Metropolitan Museum of New York, representing the elephant-clock; it has been possible to know the name of the scribe (Farkh ibn Abd al-Latif), and to assume that the probable place of origin is Syria (https://www.metmuseum.org/toah/works-of-art/57.51.23); some other drawings from the same manuscript are also preserved in Washington DC at The Freer And Sackler Galleries - Smithsonian Museum of Asian Art. Here two more drawings taken from the Aya Sofya 3606 manuscript are housed; they represent the falconeer of al-Jazari I, 4 (see *infra* Fig. 85 and Fig. 90), and the pourer servant of II, 7 (see *infra* Fig. 96 and Fig. 97).

[137] In 1910 some miniatures removed from this manuscript were found in some USA public and private collections and studied by Riefstahl [469]. Some of them are now housed at the The Freer And Sackler Galleries in Washington DC.

[138] Categories from 1 to 4 include 10 designs, while 5 and 6 include only 5 designs.

5. "On the construction of machine for raising water from standing water which is not deep and from a running river"
6. "On the construction of different, dissimilar things".

Descriptions are systematic, and nearly all follow the same scheme: a general description of the device, and many subsections, rich of drawings, to describe its operation very carefully, since he can't use dynamic representations [470]. One could say that neither Philon, nor Heron could, but we are now dealing with devices that are thought to work by themselves possibly for a long time, not only for few minutes.

As we can immediately see from the work contents, al-Jazari focuses both on fine, and on useful technology, devoted to the court of the sultan: in his effort to prepare an actual show for his sovereign, he designed basic devices, that could be combined together to create more complex ones (or, we should better say, systems), capable to accomplish simple tasks, such as the most famous ones: the orchestra boat, and the elephant.   To our goal, what characterizes the work of al-Jazari, in addition to his indisputable technical qualities, is also his ability to imagine realistic settings for his devices: he goes so far as to suggest using one of his devices (II, 6) to make a joke to the sultan's guests. Probably, his inclination to imagine dramatic and suggestive scenarios, was indirectly the cause of the fate of his manuscripts, sometimes dismembered because of the beauty of their drawings.

We chose to model 10 of al-Jazari's designs, selected with the usual criteria.

Device I, 1 is "a water-clock from which can be told the passage of the solar hours": at each hour strike, birds drop balls into a cymbal, while a complicated mechanism makes some doors open, close, and change color. If however the hours are the sixth, the ninth, or the twelfth, a small music band composed by a drummer, a cymbalist, and a flutist, plays. This device resembles very much the Gaza clock (see *supra* 2.4.2) due both to its structure and operation, as Fig. 89 shows.

In device I, 2 "at daybreak a man is at the end of a frieze and moves smoothly until he is behind the first of the twelve battlements, whereupon the falcon leans forward and casts a ball from its beak onto a cymbal in a vase, and six musicians (trumpeters, cymbalists, and drummers) play".

Device I, 4 is probably the most famous, and at the same time, the most complicated; it is called "the elephant water clock from which can be told the passage of the constant hours". It is a complete elephant (possibly its scale is 1:1, as some contemporary reconstructions show); between its shoulders sits a rider, armed with an axe and a mallet; on the elephant's back is a dais, where a sitting scribe is writing; in front of him, two bronze vases are set. Over his head, two snakes are grasping an axle with their claws, while their heads are tilted backwards, with the mouth open. One of them is upside down. In the upper part of the the dais, is a man sitting on a balcony, who is keeping closed the beak of one of the two falcon heads, set at his sides, with one hand. Atop the dais, a dome, surmounted by a bird.

When activated, the scribe writes, moving its pen on the sheet; when the half an hour strike arrives, the bird whistles, the man frees the beak of the falcon, that drops a ball into the snake mouth. The snakes at turn descend to drop the ball into a vase. At this point, the riding man hits the elephant, and the ball falls into a cymbal, suspended under the elephant. Now, the device is ready to reset, as at the next strike the falcon and the snake involved will be the other two (the two on the right, for instance).

Fig. 85: al-Jazari's Elephant at ibn-Battuta Mall in Dubai

Device I, 6 is "the water clock of the peacocks": a peahen turns (180°), while her chicks cry loudly at each half an hour. It appears as a very elegant device, since al-Jazari suggests to build it on a pool.
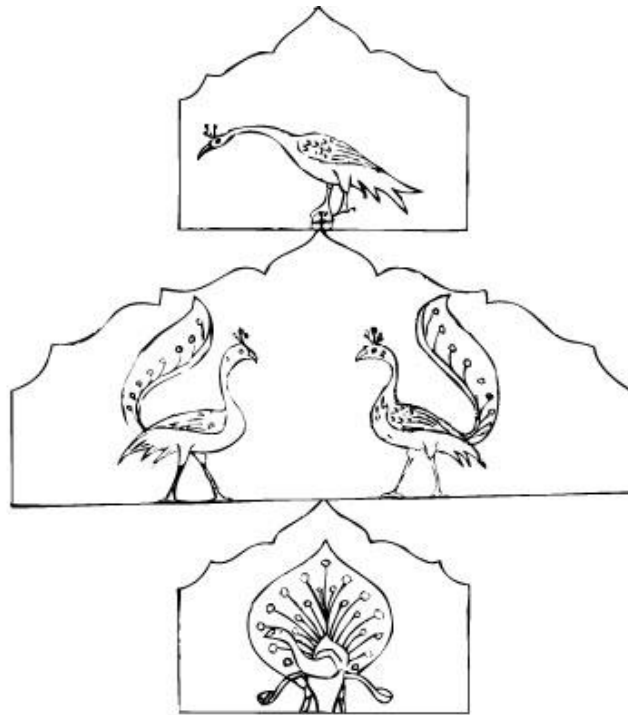

Fig. 86: al-Jazari device I, 6 (drawing based on Hill)

Device II, 4 is "a boat which is placed on a pool during a drinking party"; though complicated, this system is composed by many subsystems working in parallel. A boat sails in a pool for not less than 7, 5 hours, since it has to stop every half an hour, for 15 times. The crew is composed by some figures (possibly static), representing the court, and by automata: a sailor, working only when the boat sails; an orchestra, that plays whenever the boat stops; and a couple of servants (a cup bearer and a wine pourer) that serve the sultan's guests. Al-Jazari admits that he had been requested by his king to design such a device for feasts. This design has been enthusiastically described by Sharkey, as "a veritable boatload of programmable robot musicians effectively a floating jukebox designed to entertain nobles as they drank and lounged at royal pool parties". [416] But the English scholar goes further, underlining the programmability of the musical automata, whose played rhythm can be varied by only rearranging the pegs on the underlying cylindrical beam. Since he defines as programmable any device that can take a set of written or hard-wired instructions, that can be changed without taking the machine itself apart, al-Jazari's music players can be defined programmable.

Device II, 6 is "the figure of a boon-companion who drinks the king's leavings". It is a knelling figure that can drink only a certain quantity of liquid, presented to it, since over the maximum it lets the water out, and, obviously, wets whoever is carrying it.

Device II, 7 is "a standing slave holding a fish and a goblet". Here we have an example of the narrative creativity of the designer: the liquid is poured from a fish into a goblet, and then served to the guest. It must be however pointed out that a similar device is described also in Philon #30, where a servant pours a liquid (see Fig. 97).

Device I, 10 is "a slave girl who emerges from a cupboard at intervals, holding a glass which contains wine". In this device the automated part is the cupboard that opens automatically, since the slave girl is only a dressed puppet, that can hold a goblet.

Device III, 7 is "the basin of the reckoner for blood letting": we have a group of similar useful devices. Their usefulness however is not without elegance. Al-Jazari, as usual, has thought of a dramatic context: while blood quantity is measured by the device, three figures work like a display, by indicating units and tens of blood. Blood limit is 120 dirham (units).

Device III, 9 is "the basin of the peacock for washing the hands"; another useful device, made to wash hands automatically. Water flows as long as the user wants; then he can use a perfume, and a towel; all served by the device.

Device VI, 5 is "a boat clock": it is completely different from the previous boat, since it sinks in an hour. When the boat is to be completely sunken, the sailor plays his pipe, alarming the user.
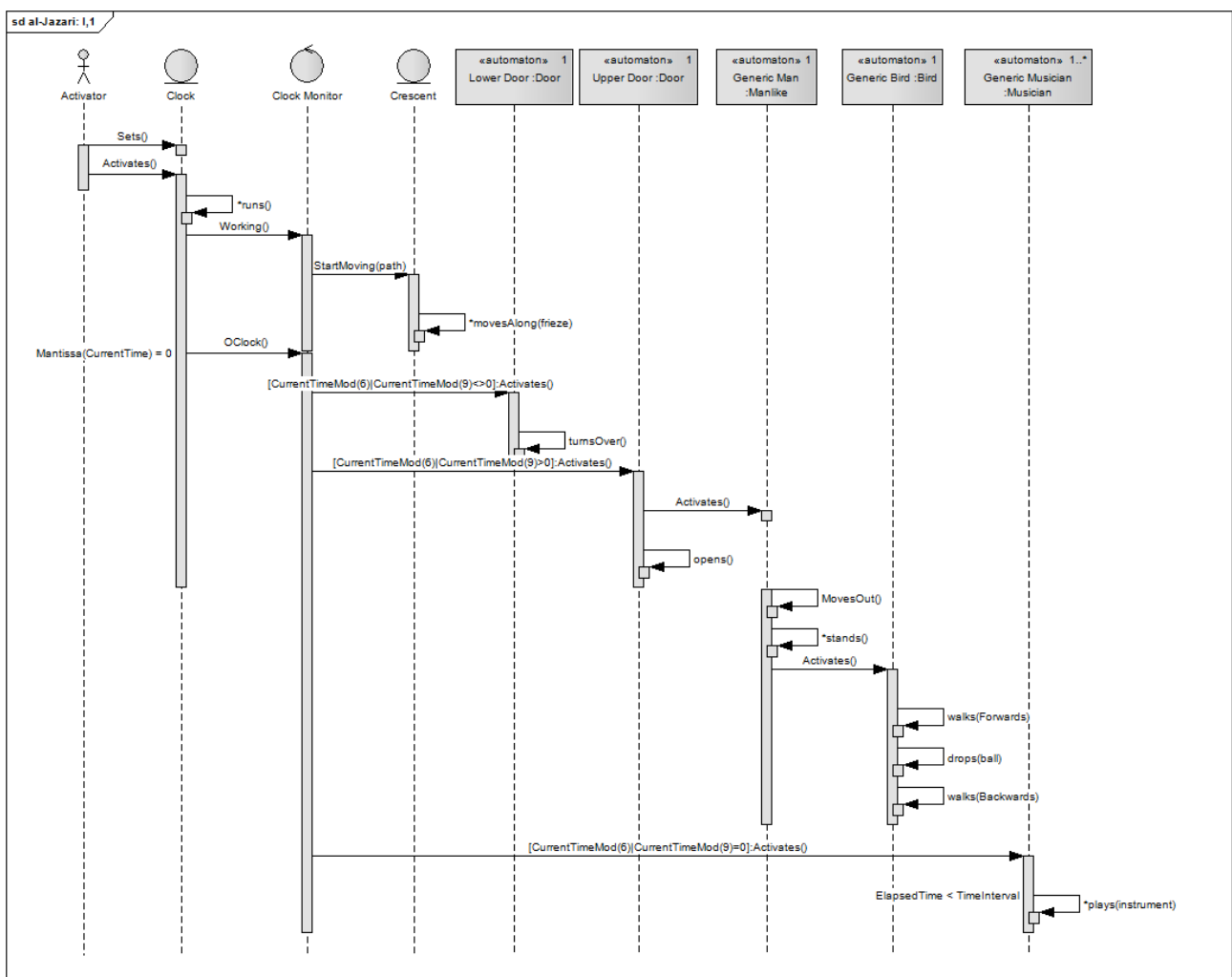
Fig. 87: UML Diagram of al-Jazari's I, 1
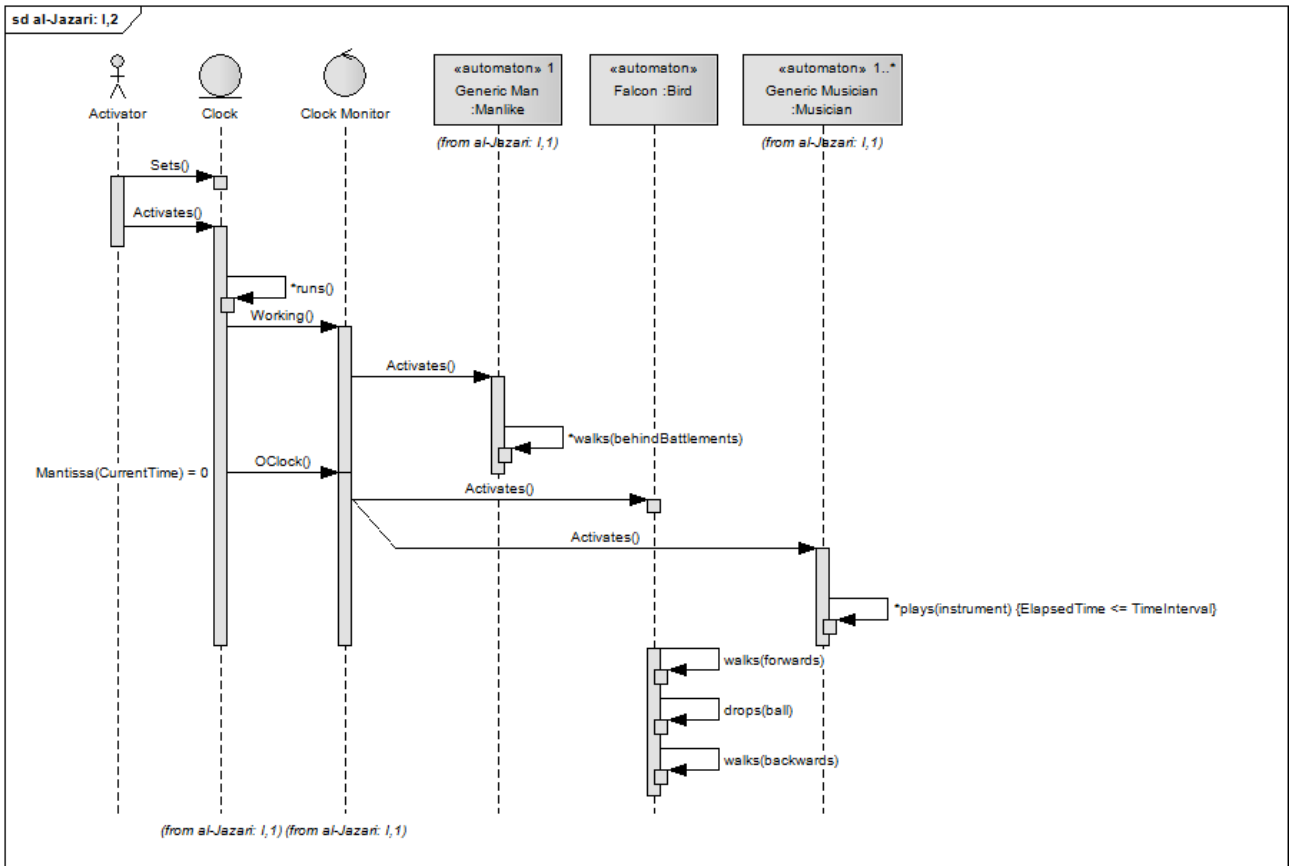
Fig. 88: UML Diagram of al-Jazari's I, 2

Fig. 89: al-Jazari's I, 2
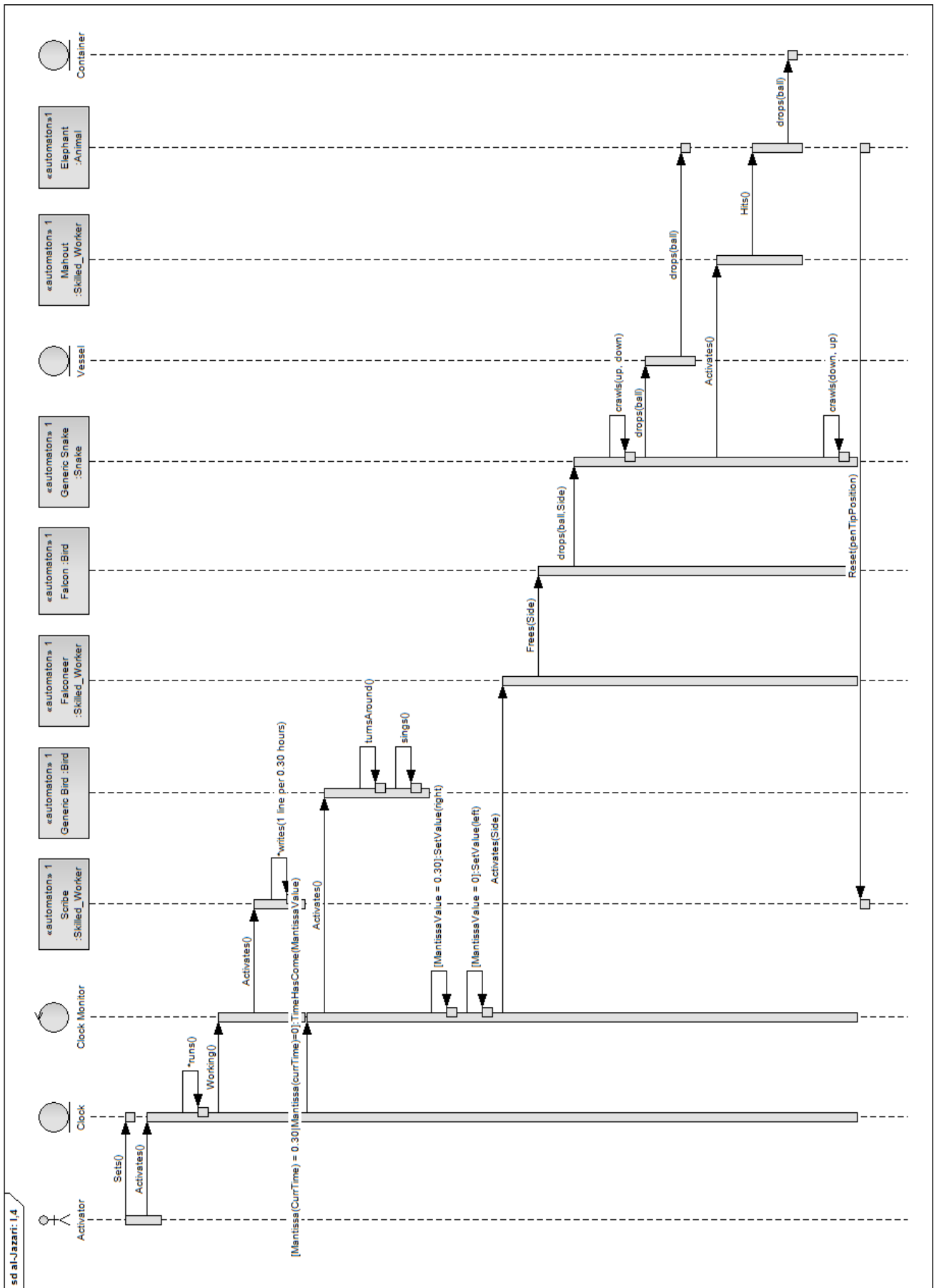
Fig. 90: UML Diagram of al-Jazari's I, 4

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Fig. 91: al-Jazari's I, 4 (from New York leaf of manuscript)

117
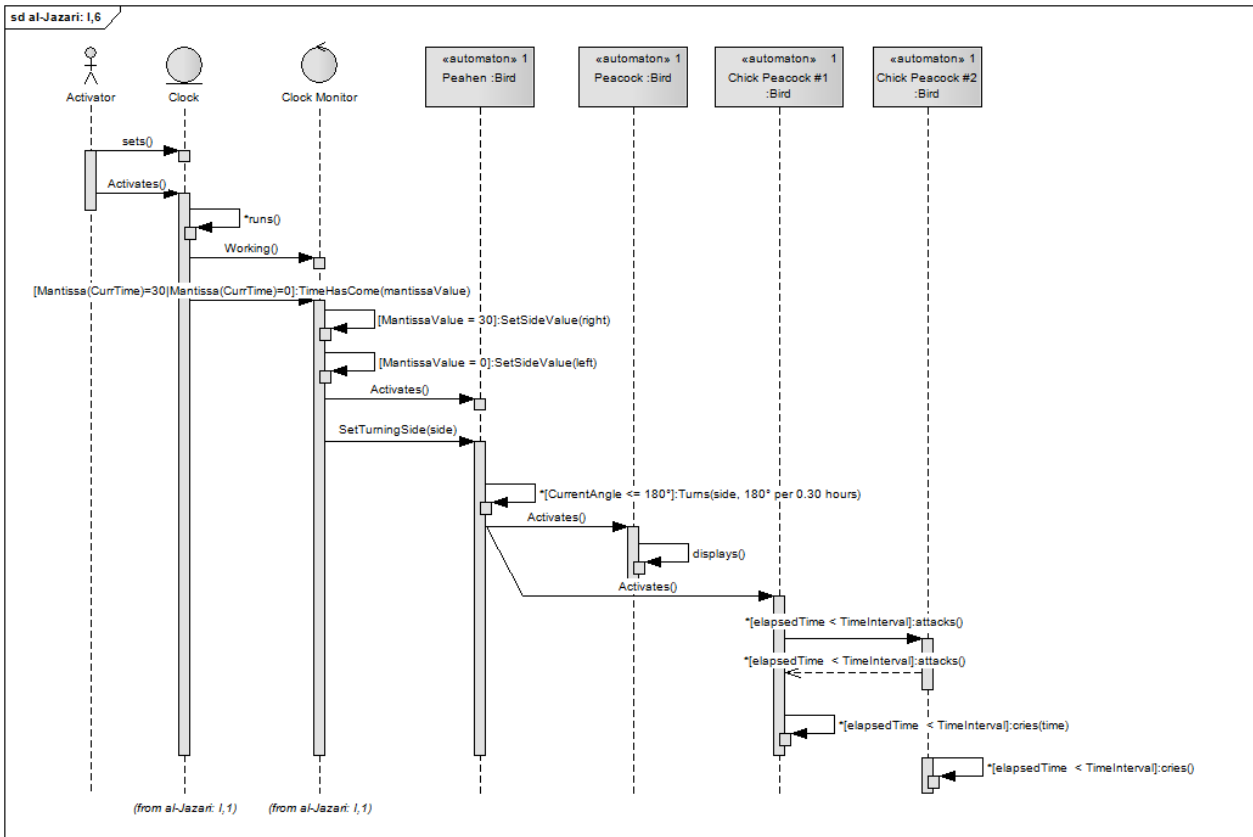
Fig. 92: UML Diagram of al-Jazari's I, 6
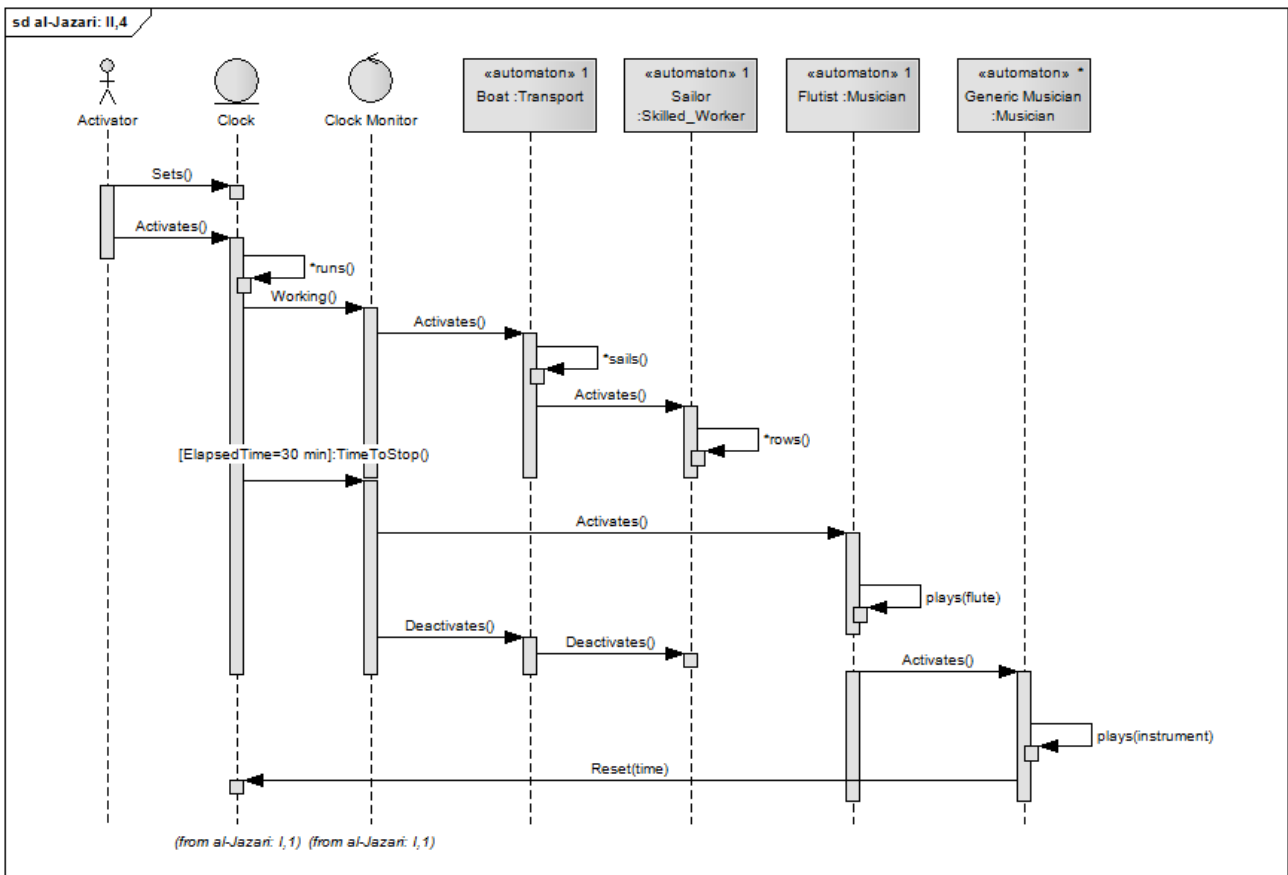
Fig. 93: UML Diagram of al-Jazari's II,4

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Fig. 94: UML Diagram of al-Jazari's II, 6

Fig.a 95: al-Jazari's II, 6 (drawing based on Hill)

Fig. 96: UML Diagram of al-Jazari's II, 7

Fig. 97: Philon's device #30 by Carra de Vaux

Fig. 98: UML Diagram of al-Jazari's II, 10

Fig. 99: UML Diagram of al-Jazari's III, 7

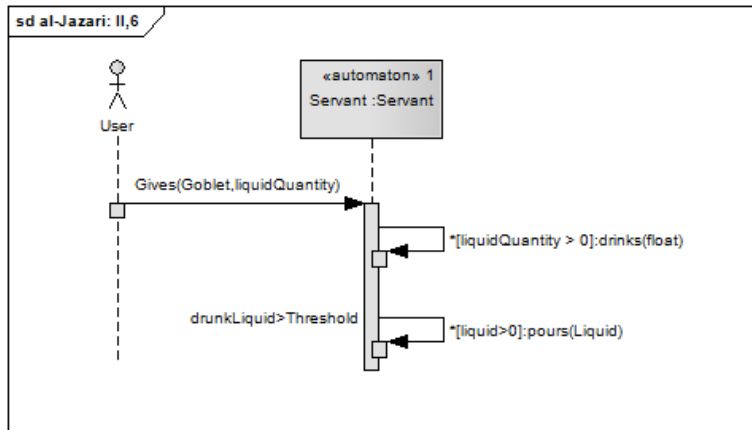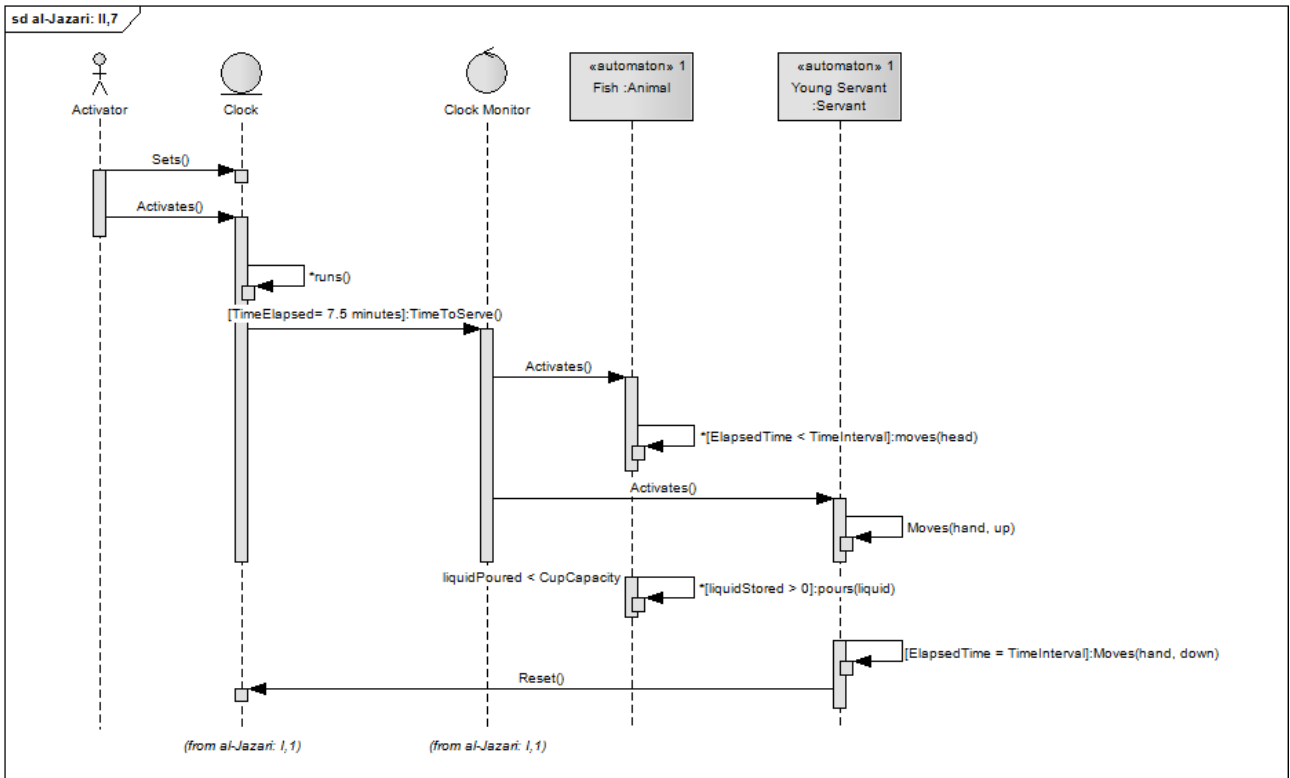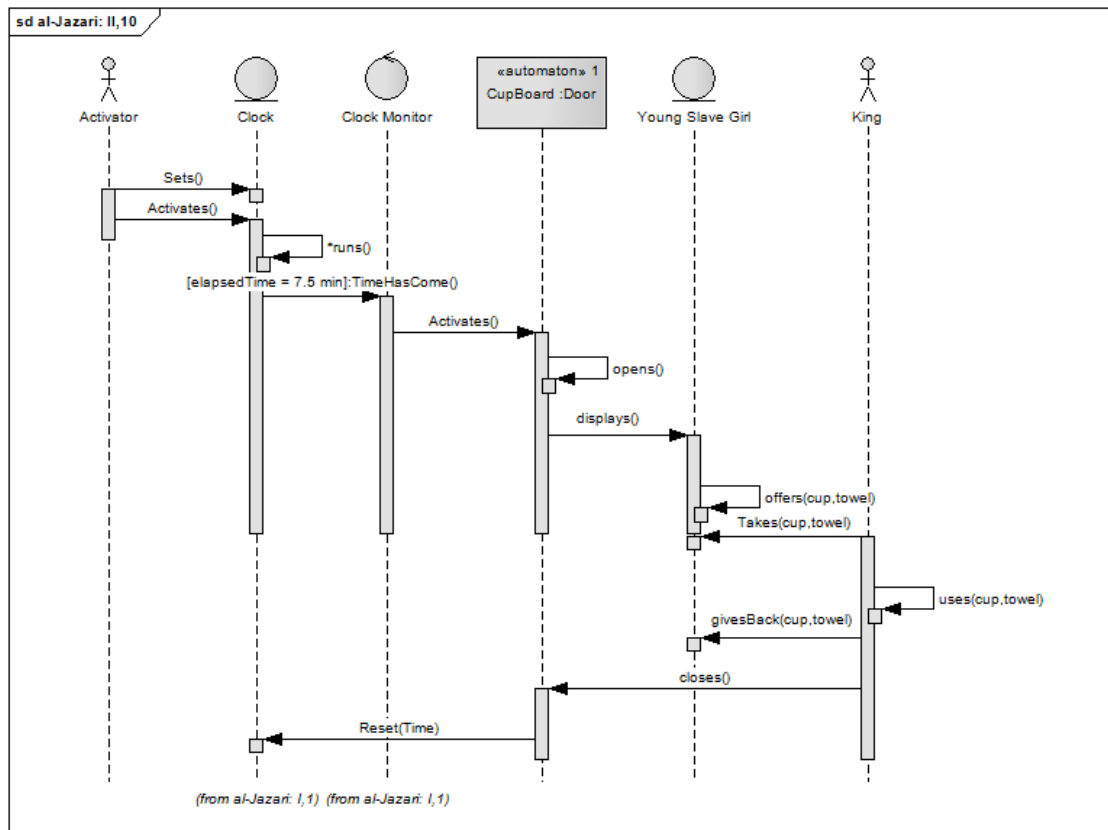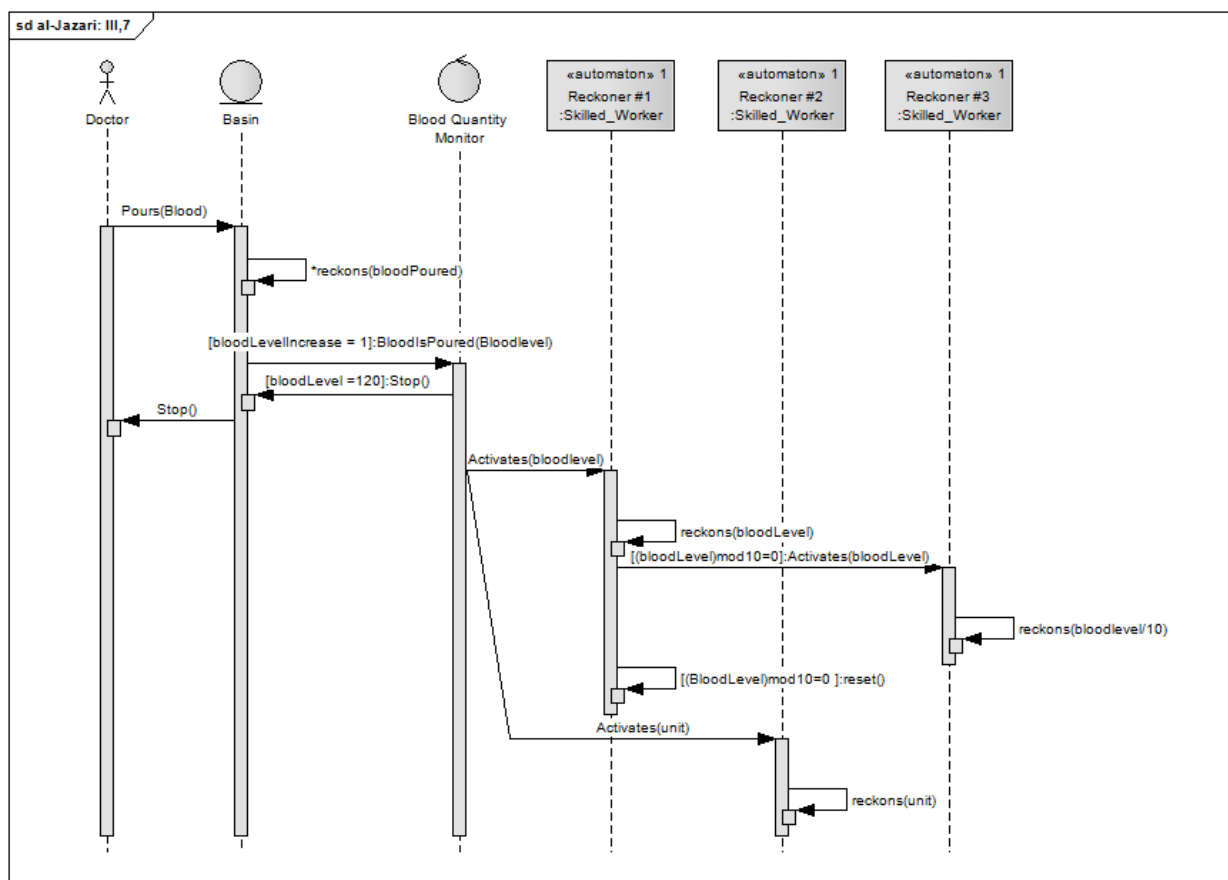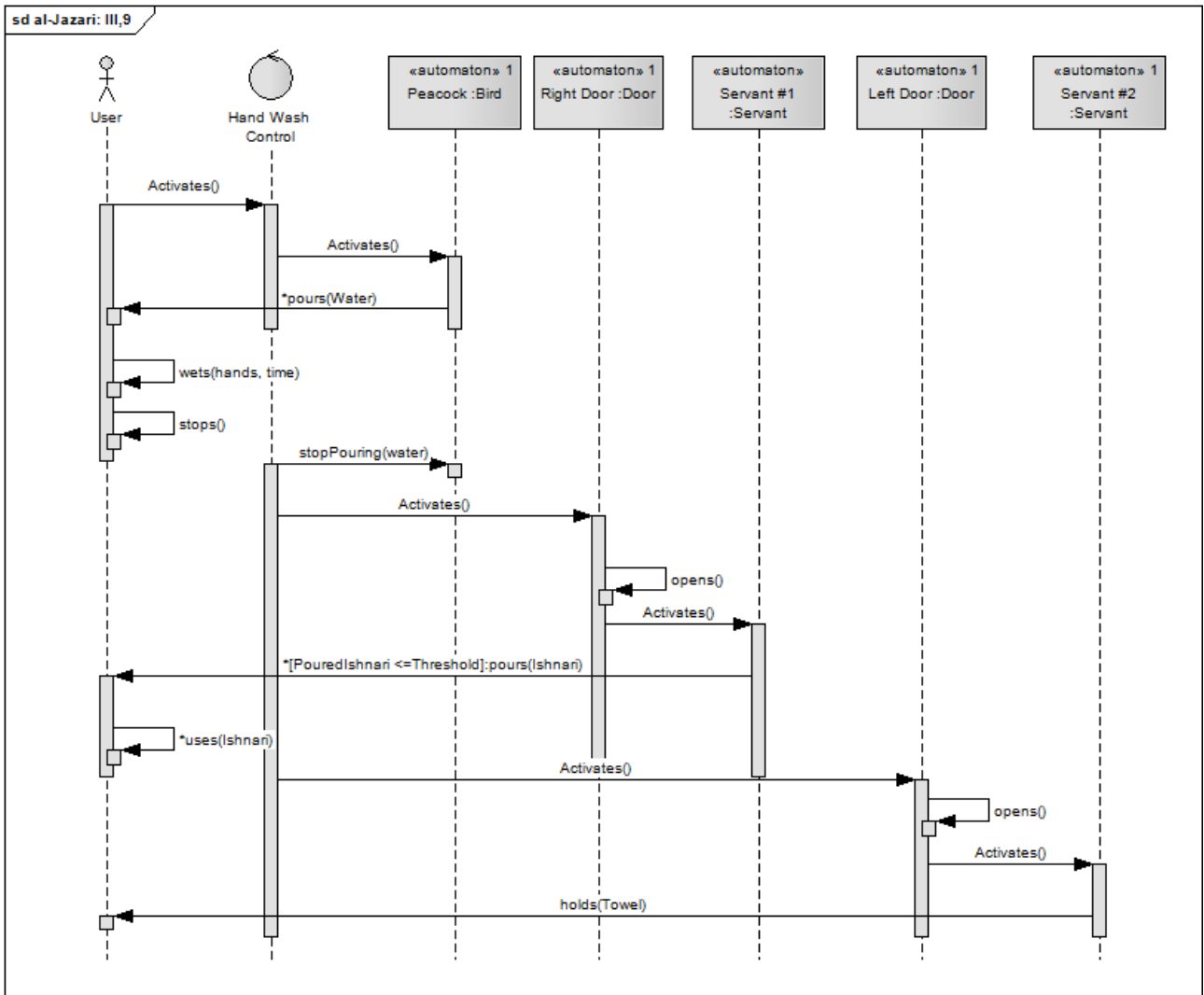**Fig. 100: UML Diagram of al-Jazari's III, 9**
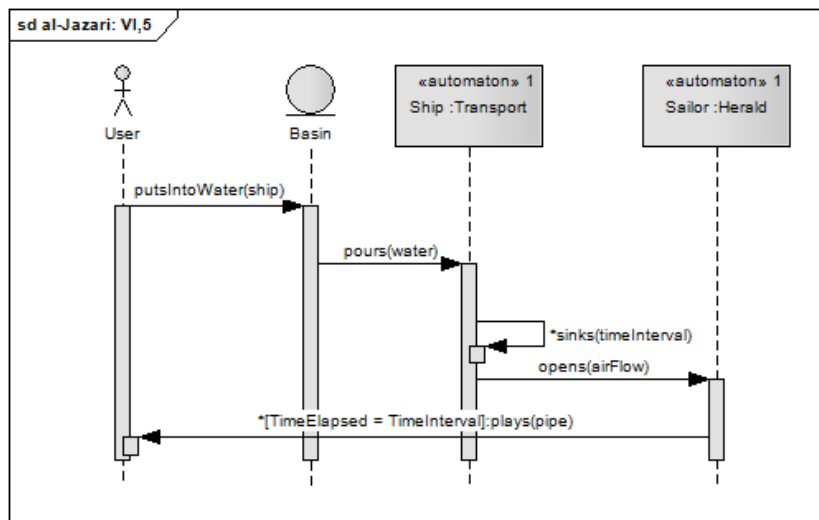
Fig. 101: UML Diagram of al-Jazari's VI, 5

Fig. 102: al-Jazari's VI, 5 (drawing based on Hill)

2.4.3.6 Some final observations

One could ask how Arabic scholars and engineers, as the Banu Musa, al-Muradi, and al-Jazari, could work at the same time at useful and useless devices, and moreover why they tend to use terms like "ingenious device", or "trick", as if they would emphasize the aesthetic, or, better, [471] component of their designs, and not to stress on their utility. Saliba [173] tried to answer such an aged question about applied mechanics, by considering it in its natural context, that is Medieval Islamic society. He states that this question is posed in the wrong way, for some reasons; firstly, such a distinction between "frivolous toy" and "useful machine" can't historically apply, as it doesn't pertain to the actual requests of the market ("a free-market demand for either could give rise to a higher production irrespective of the utility concerned - if utility is to be understood as generating further production"); then, we must consider that, even when utility doesn't appear as a design goal, "in these toys [i.e. constant-level water basins by Philon enhanced by the Banu Musa] some real technological advances could also be made"; and lastly, such attitude of the Islamic engineers for mere entertainment must not be overemphasized: Saliba quotes as an instance Philon's and Heron's singing birds, that never appear in Islamic scholarly tradition, but were used at court, as it is referred in *Muntazam* by Ibn al-Jawzi [455] [139], probably made by common craftsmen; and in public places [140].

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[139] Vol. 6, p. 144; In the year 305 H. (AD 917) there came a messenger from Byzantium seeking a treaty and an exchange of prisoners. The messenger was a young man accompanied by an older man and some twenty servants. They were received in posh surroundings for a few days until they were brought to the caliphs palace to which he passed by the review of the armed forces of 160,000 knights and infantrymen, followed by several kinds of slaves and servants. The messenger almost descended by the house of the doorkeeper which had already impressed him to think that it was the caliph's house. He was advised that it was only the doorkeeper's house. Then he was brought to the Vezir's house which he had not doubted that this time it was the caliph's house. He was told that it was only the Vezir's. When he finally arrived at the caliph's palace, he was taken around the palace to watch the festive decorations, the domesticated wild animals eating from peoples hands, and some hundred lions or so with their trainers. Then he was brought into the house of the tree which wus placed in the midst of a pool that had clear water, and which had eighteen branches and each branch had several branchlets adorned with birds of every kind made of silver and gold, and most of the branches were made of silver while others were of gold. [The branches] were swaying with their multicolored leaves, and each kind of these birds wus chirping. [emphasis added]. Only &r that, he was taken into the glorious room (lit. paradise)

Recently, some scholars focused on some issues of al-Jazari's automata, in order to demonstrate his role as a precursor of modern automation:

- Their programmability (see *supra* al-Jazari II-6) [416]
- these devices are an instance of "untoward automation", involving "deliberate and elaborate programming for untoward behaviour in automated devices" [470], so as to simulate real life;
- automatic control [177].

Nonetheless, we must recall that neither Banu Musa's, nor al-Muradi's, nor al-Jazari's works were ever translated in a European language in the Middle Ages, as far as we know at the moment; so, if we want to prove they had an influence on European technology, we should also find evidence of a practical tradition handed down in craft shops, possibly in Spain [472].

2.4.4 Europe

Although it has been discarded the idea of a period when ancient culture had been totally abandoned, medieval Europe is still considered a difficult time to study, especially due to the insufficiency or inaccessibility of sources. If we consider that the sources we have on technical knowledge in the Roman world of late antiquity are scarce, it is not surprising that we are dealing with an even more desolate period: a kind of "no-man's land", to quote Cracco-Ruggini [473]. Such a decay has been studied by Lawan [474] and by Mannoni [475], who pointed out the main features and scenarios of technological change in the early medieval transition.

Although many aspects of continuity with the ancient world were still present, a substantial decline has to be highlighted: Roman technologies became actually rarer or disappeared altogether, in some areas of the empire. Automata probably lost that miraculous role that had featured them in the courts of the Hellenistic and Roman rulers and aristocrats, mainly due to their high costs. No new use of such old products could be imagined.

We also witness "an adoption of apparently simpler solutions to everyday problems", probably due to the disappearance of Roman technologies and to the consequent resurgence of indigenous peoples' ones. Automata were maybe forgotten or replaced by tricks or puppets activated by servants. The adoption of techniques from other manufacturing trades or cultures would probably have come later, when the Western and the Arabo-Islamic culture would have restored their contacts, though we have no evidence of consequences in the production.

The absence of continuity in research would likely result in on-demand problem solutions. It appears unlikely that such a feature can deal with automata, given their nature of useless objects. They couldn't be replaced by other devices also due to the limited availability of specialized labour (engineering).

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which was also heavily decorated with gold silk, where he finally met the caliph who was attended by his translator and Vezir. (Translation by Saliba, 1985)

[140] "The same source, *Muntazam*, vol. 10, p. 148, also reports that during the time of celebrations several automata were usually set up in public places, each bazaar group of craftsmen exhibiting their own automata. This kind of festivities called *taliq*, literally "mounting up", was celebrated when a monarch assumed power or when an heir was announced, or the like."

Then, the disappearance of the previous culture involved the fading of strictly related technologies. The close relationship between automata and many religious and recreational aspects of the pagan world has certainly affected their abandonment. Such objects lost their only use, that was to astonish a courtly audience: the prestige of the court of Rome, and later of Milan, or of Ravenna was strongly decreased, and vanity was considered as a sin. Demand for such a product disappeared, so production simply ceased, though we cannot exclude that technical ability was retained in the field of pneumatics or hydraulics, related to organ building.

2.4.4.1 Before Year 1000

After the great season of Hellenistic engineering and during all the early medieval centuries in the Eastern Roman Empire or in the territories under Arabic domination, the sources related to automata decrease dramatically and are limited in Europe to secondary references. No designs or technical descriptions are available, at least until the 13th century.

2.4.4.1.1 Theodoricus' Clocks

Anyway, secondary sources can testify at least the existence of mechanical precision devices, demonstrating that even in Roman-barbarian kingdoms the technical skills required for such objects were not completely lost, and the landscape was still the same as in the Late Empire Era (see *supra* 2.3.3). For instance, in Cassiodorus' *Variae*, the official correspondence of the Ostrogothic court in Ravenna, a letter (XLV, 6) addressed to the philosopher Boethius is preserved; Theodoric says that the Burgundian king has repeatedly asked him for two water clocks and for craftsmen (probably as maintenance men); he comments the episode with revealing words: the reason why the Burgundian king insisted so much, is that he considers as a "*miraculum*" (wonder) an object that for Theodoric is instead "*cottidianum*" (daily) [476] [141]. Although we can suppose that Theodoric overemphasized his acquaintance with these devices, it is clear that at the beginning of the 7th century in Europe there were still craftsmen capable of building a water clock. Theodoric continues extolling the great culture of Boethius, who composed scientific works and is also expert in mechanics [142], in order to ask him to send the two clocks. The King then defines mechanics as the art that makes "sing dumb things, live inanimate things, move motionless things", and the mechanician "is almost Nature's comrade, opening her secrets, changing her manifestations, sporting with miracles, feigning so beautifully, that what we know to be an illusion is accepted by us as truth." [143] Even though no

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[141] [2] *Burgundionum itaque dominus a nobis magnopere postulavit, ut horologium, quod aquis sub modulo fluentibus temperatur et quod solis immensi comprehensa illuminatione distinguitur, cum magistris rerum ei transmittere deberemus: quatenus impetratis delectationibus perfruendo, quod nobis cottidianum, illis videatur esse miraculum. Merito siquidem respicere cupiunt, quod legatorum suorum relationibus obstupescunt.* The Lord of the Burgundians has earnestly requested that we would send him a clock which is regulated by water flowing under a modulus, and one which is marked by embracing the illumination of the immense sun, with craftsmen: therefore, obtaining and enjoying these delectable items, the Burgundians will marvel at things that for us are everyday things. This is the reason why they rightly want to watch what, based on their ambassadors' tales, makes them wonder. Translation by Hodgin, 1886.

[142] [4] [...] *Translationibus enim tuis Pythagoras musicus, Ptolemaeus astronomus leguntur Itali: Nicomachus arithmeticus, geometricus Euclides audiuntur Ausonii: Plato theologus, Aristoteles logicus Quirinali voce disceptant: mechanicum etiam Archimedem Latialem Siculis reddidisti.* [...] You have translated Pythagoras the musician, Ptolemy the astronomer, Nicomachus the arithmetician, Euclid the geometer, Plato the theologian, Aristotle the logician, and have given back the mechanician Archimedes to his own Sicilian countrymen. Translation by Hodgin, 1886.

[143] [10] [...] *haec hodie facit muta cantare, insensata vivere, immobilia moveri.* [11] *Mechanicus, si fas est dicere, paene socius est naturae, occulta reserans, manifesta convertens, miraculis ludens, ita pulchre simulans, ut quod compositum non ambigitur, veritas aestimetur.* The mechanician, if we may say so, is almost Nature's comrade,

automata are quoted in the passage, such a description of mechanics is not proportionate to the building of a clock, and it is obvious that the sender is acquainted with history of mechanics, or at least with its mythology [122].

2.4.4.1.2 Charles the Great's Clock

The next quotation of a device linked with automata is probably made by Einhard (Eginardus), a Frankish historian, whose main work *Life of Charlemagne* (*Vita Karoli Magni*) is devoted to the biography of the emperor Charles the Great. He however made also a revision of the *Annals of the Kingdom of the Franks* (*Annales Francorum*, a work covering the history of early Carolingian kings from 741 to 829, called therefore *Annales qui dicuntur Einhardi*), though we have no persuasive evidence of his authorship, as they could have been written at different moments, and edited overall at a later period.

The episode dates back to the year 807, and it is set at the imperial palace in Aquisgrana (Aachen), when a gift from the Persian king Abdella [i.e. Harun al-Rashid] was delivered to the emperor by some monks from Jerusalem; among other wonderful gifts (e.g., silken palli, perfumes, ointments and balms), there was also a clock made of aurichalcum (brass) [144], that resembles the ones we already described, as we have balls dropping into a cymbal, and human figures appearing and disappearing at windows. The historian refers that more details could be given, but he prefers to neglect them.

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opening her secrets, changing her manifestations, sporting with miracles, feigning so beautifully, that what we know to be an illusion is accepted by us as truth. Translation by Hodgin, 1886.
[144] *necnon et horologium ex auricalco arte mechanicam mirifice conpositum, in quo duodecim horarum cursus ad clepsidram vertebatur, cum totidem aereis pilulis, quae ad completionem horarum decidebant et casu suo subiectum sibi cimbalum tinnire faciebant, additis in eodem eiusdem numeri equitibus, qui per duodecim fenestras completis horis exiebant et inpulsu egressionis suae totidem fenestras, quae prius erant apertae, claudebant; necnon et alia multa erant in ipso horologio, quae nunc enumerare longum est.* and even a clock made of aurichalcum, with extraordinary skills in mechanics; the course of twelve hours was moved to an hourglass, when twelve balls bronze, which fell at the stroke of the hour and with their fall hit a tinkling cymbal, put at the bottom; in addition in the same (clock) there were many riders, who went out from twelve windows at the end of each hour and closed twelve windows, which were open before. There were also many other things in the watch itself, too numerous to enumerate. See also [477].
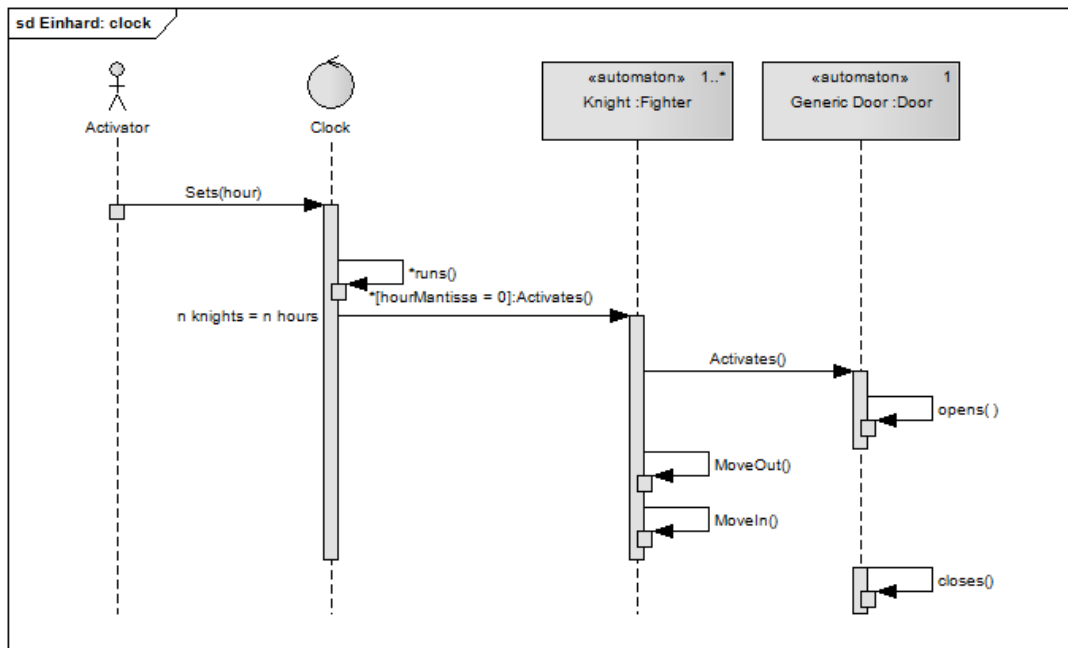
Fig. 103: UML Diagram of Einhard's Clock

We assumed that, due to the number of knights, the number of activated knights at each hour was equal to the number of hours: e.g. at three o'clock three knights performed their show.

As we remarked, historians don't agree with the date of the work; so it is possible that this description has been "enhanced" or even added in a later phase; if not, we would be facing one of the oldest instances of Eastern clocks come to Europe. As stated by Lewis [130], based on [478-480], the origin of this clock could have been the following: "a tradition in the eastern Roman provinces of complex clocks with elaborate jackwork and even gears, dropping balls on the hour, ringing bells and moving little figures. At an early date the idea was passed on to Islam, which developed it with enthusiasm."

2.4.4.1.3   The Great Sorcerer (?) Gerbert d'Aurillac (946-1003)

An important secondary source consists also in legends, flourishing around a controversial historical figure, such as the French Benedictine monk Gerbert d'Aurillac, later Pope Sylvester II, who was ascribed by the English historian William of Malmesbury (1080/1095-1143) the building of a talking head [145]. Since he had been educated in Catalonia [481-482], where he could have studied Islamic science and technology, these hearsays could seem to be genuine [198] [146].

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[145] *Chronicles of the Kings of England* II, §172, where he writes a biography of the pope. "He cast, for his own purposes, the head of a statue, by a certain inspection of the stars when all the planets were about to begin their courses, which spake not unless spoken to, but then pronounced the truth, either in the affirmative or negative. For instance, when Gerbert would say, "Shall I be pope ?" the statue would reply, "Yes." "Am I to die, ere I sing mass at Jerusalem?" "No." They relate, that he was so much deceived by this ambiguity, that he thought nothing of repentance: for when would he think of going to Jerusalem, to accelerate his own death ? Nor did be foresee that at Rome there is a church called Jerusalem, that is, "the vision of peace," because whoever flies thither finds safety, whatsoever crime be may be guilty of."
[146] Catalonia and al-Andalus were, as a matter of fact, an ideal setting for cross-cultural exchanges between Christian, Arabic and Jewish scholars, as shown in the case of astrology by Juste [483].

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In Gerbert's biography, another interesting event is reported [484-485]. During his stay in Rome, the future pope had decided (by sheer greed) to rescue Octavian's treasure, buried, according to a legend, in a cave beneath the Roman Forum; the cave entrance was indicated by a statue. Many others had unsuccessfully tried to find the entrance, being less artful than him: he marked the place where the shadow of a statue's finger fell at noon; at night he made the earth open by means of his magical arts and, attended by a servant with a lantern, he entered a beautiful golden palace, where they found a court of golden automata. The light source was a small carbuncle of the first quality, standing on a base. At the opposite corner of the room stood a young archer, holding a bow and an arrow. Gerbert and his servant soon noticed that, if they tried to take anything, all these automata appeared to rush forward to attack them. So Gerbert guessed what would be the consequences of such an attempt, and decided to give up, but his servant, unable to resist, decided to steal a superb knife. Immediately, the automata cried loudly and began moving, and the archer shot the carbuncle with his arrow, so that all was in darkness; Gerbert ordered his servant to drop the knife, otherwise their lives would have been in danger. He obeyed, and they left the palace, though without any treasure [147].

The story is very interesting from several points of view.

1. First of all, the palace designer had planned the system in order to kill any thieves or at least to give them a moral lesson, not to impress them with the automata's capabilities. We have the description of an actual distributed system made up of automata: they are all running the same task (stop the intruders, if they are stealing something). The actions performed by the automata are not periodical: they begin and end depending on values measured by "sensors". Nothing is said about how the system reverts to its initial state after the departure of the intruders.

2. The system is very similar to Heron I, 41 (see Fig. 45)

3. In a French romance, whose first written version dates to the middle of the 12th century, entitled *Charles the Great's Pilgrimage* (*Le pèlerinage de Charlemagne*), the setting of the emperor's main adventure is the vaulted and circular palace of Hugon [148], emperor of Constantinople, where Charles and his 12 peers are housed as guests in a beautiful bed-chamber, full of precious decorations and refined objects. The light source is a carbuncle, set on a pillar [486]. The front of the palace is decorated with the statues of two smiling young men, holding ivory horns. Whenever a wind comes up, these images blow their horns, producing a loud clear sound, and immediately the palace begins rotating. A carbuncle and a moving room appear also in the 14th-century allegorical poem titled Σοφροσύνη (*Temperance*) by Theodore Meliteniotes [487]. Here we also find an abridged version of a lapidary, a book where stones are put in relation with moral qualities: the carbuncle is a symbol for temperance, a cardinal virtue, related to self-control.

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[147] William however in the following paragraph adds another version of the story, whose main character would have been an Aquitanian monk; at the age of seven, he would have been told an episode that appears very similar to Gerard's one. This tale will be deeper studied in 2.5.5.1, due to its relation with Boiardo's account.
[148] The rotating palace is a gigantic automaton, a perfect synthesis of Eastern richness and technology [185].

4. Last, but not least, remark: Gerbert is told to have designed and built a water organ, during his stay in Reims; recently this alleged building has been proved false by Flusche [197].
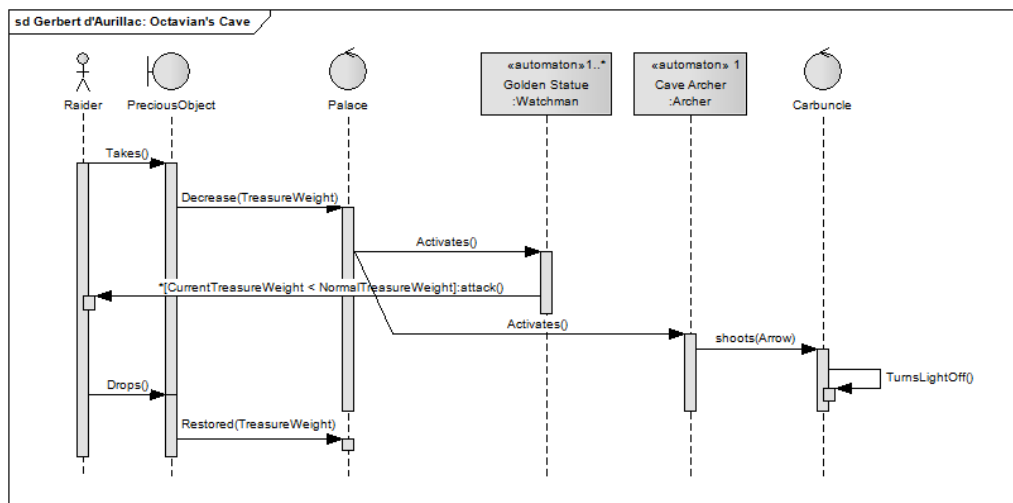

Fig. 104: UML Diagram of Gerbert d'Aurillac in Octavian's Cave

Even taking into consideration that this is a legendary episode, one cannot but be struck by the strong similarity between this system and the Heronian automaton, which may have been the remote source of the story, though it was considered neither in the Arabic written tradition, nor in the Byzantine implementations.

It is therefore reasonable to make two assumptions, not mutually exclusive:

1. this knowledge was transmitted within the workshops by the masters to their apprentices from the Antiquity to the Middle Ages [475], with or without Arabic contribution; it is unfortunately very hard to prove, due to the lack of sources.

2. a Latin cultured tradition, mostly separated from the Arabic one, existed, and flourished, probably in the monasteries; this second assumption could be easier to prove, by means of a census of Latin manuscripts on the subject.

2.4.4.2 Mille et non plus mille, or the "Y1K Debug"

Probably due to an allegorical interpretation of a passage from the Apocalypse [149] by St. John, "in the later ninth and early tenth centuries, large numbers of [European] learned people lived in a heightened atmosphere of mingled hope and fear" [488]. Such an eschatological mind-set was then called *millenarism* or *chiliasm* (from χίλιοι, the Greek word for thousand) and was often linked to

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[149] Apocalypse, 20, 1-8 *I saw an angel coming down out of heaven, having the key of the abyss and a great chain in his hand. He seized the dragon, the old serpent, which is the devil and Satan, who deceives the whole inhabited earth, and bound him for a thousand years, and cast him into the abyss, and shut it, and sealed it over him, that he should deceive the nations no more, until the thousand years were finished. After this, he must be freed for a short time. I saw thrones, and they sat on them, and judgment was given to them. I saw the souls of those who had been beheaded for the testimony of Jesus, and for the word of God, and such as didn't worship the beast nor his image, and didn't receive the mark on their forehead and on their hand. They lived, and reigned with Christ for the thousand years. The rest of the dead didn't live until the thousand years were finished. This is the first resurrection. Blessed and holy is he who has part in the first resurrection. Over these, the second death has no power, but they will be priests of God and of Christ, and will reign with him one thousand years. And after the thousand years, Satan will be released from his prison, and he will come out to deceive the nations which are in the four corners of the earth* […].

heretical positions; it contrasted with the traditional Augustinian attitude, that consisted in awaiting the end of the world in serenity. Although such a phenomenon has been artfully emphasized by Enlightenment historiography on the Middle Ages, we must also admit that direct evidence of millenarism can be found in Medieval culture [489-490]. This attitude did not apply, of course, the Islamic world and Eastern lands in general, since religion played the major role [491-492, 227, 493]. However, we note that the so-called revival of the year 1000 weakly influenced technological knowledge, as this last one was considered far from theological and, in general, cultural speculation. The research and dissemination of technological culture depended mainly on monasteries, that were the proper places for the conservation and application of techniques learned from the ancient world thanks to the manuscripts studied and copied by monks.

2.4.4.2.1 The Benedictines' and Cistercians' Role

St. Benedict's rule, written in 534, contains the famous motto "*Ora et labora*" (Pray and work), meaning that both praying and working were indispensable to save one's soul. Benedictines meant both physical work (what, mainly in the early centuries, implied tilling, weeding, cleaning up and cultivating desolate and inhospitable places, where they built the monasteries), but also the study and the transcription of ancient texts of religious, literary and scientific content. This care for the manual and intellectual work created an actual synergy: thanks to the study of ancient works, they recovered almost forgotten concepts in science and agriculture (see *infra* 2.4.4.2.2), and applied them in their monasteries. In the Benedictine tradition, it was also the Cistercian order (11th century) that wanted a restoration of the primitive severity of St. Benedict's rule, after Cluny experience; the order was born in 1098, deriving its name from the Burgundian monastery of Citeaux (in Latin, *Cistercium*). They engaged in field work, always in strict conformity with the surrounding environment, increasing and strengthening the agricultural economy of the sites, which were always in lowland areas and often needed hard work to be made fertile [150].

Despite historians generally agree in attributing to the Benedictines and to the derivative orders a key role in Medieval technological innovation, a dissimilar opinion has been expressed about the area of Northern Europe: Götlind [201, 203] believes that their role was far from being crucial; Götlind says, for instance, that, differently from earlier continental Cistercian monasteries, grown up in marginal territories, the Scandinavian ones were primarily founded by monarchs and placed in rich, populated areas, to fortify the power of church and reign, and she concludes that original ideas about architecture and water supplies imported from Cistercian monasteries in France and Germany, rarely spread in the surrounding land.

2.4.4.2.2 The Translations of the 12th Century

Between the 11th and the 13th century, there were three main geographical areas where contacts between Arabo-Islamic and Western world allowed the transmission of knowledge across cultures: southern Italy (especially Sicily), Spain, and the Crusaders' kingdoms. Spain was the most important among them for its role in the direct transmission of Arabic culture in the Christian world. From the 8th century most of Spanish land was under Arabic domination, under which, for several centuries, Muslims, Christians, and Jews lived peacefully. In many ways, as Muslim Spain (al-Andalus) had a pulsating Arabic culture, it could provide a vast amount of manuscripts for

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[150] Many areas of Lombardy (Milan, lacus Gerundus) can be quoted as example of drainage, made by Cistercian monks, starting from the 11th century.

translation: Arabic versions of Greek originals, works of great Eastern Arabic and Andalusian mathematicians, astronomers, physicists [494-495]. Bilingual or multilingual Spanish scholars (as Arabic was the lingua franca of educated people) made the work of translation into Hebrew and Latin possible and even easier, but held a monopoly on this activity, which also attracted foreign scientists: they arrived in Spain, learned Arabic, translated the most congenial texts and spread their translations in their lands of origin. The phenomenon of translation in Spain, however, became very large after the beginning of the Reconquista (11th-12th centuries), when the manuscripts passed from the hands of the Arabs to those of Christians. Toledo [496-498], then a first-class cultural center, where the three cultural souls of Spain (Christian, Jewish and Muslim) lived together, fell under Christian government in 1085, and attracted scholars from across Europe, for instance, from Scandinavia and Wales.

Despite the wide diffusion of Arabic culture and technology, that had accompanied the territorial expansion of the 7th-15th centuries, at the time neither the Latin versions of Arabic engineers' masterpieces, nor information in this regard are available, since the lists of the translations carried out in Europe don't include these works. We may assume that the 13th-century (the oldest, so far as it is known at the moment) Latin translation of Philon's *Pneumatics* (Cambridge, Pembroke College, 169) has been made from an Arabic translation: its incipit "*In nomine Dei pii <et> misericordis…*" is common to other Latin translations of Arabic scientific works (e.g., Robert of Chester's version of al-Khwarizmi's *al-jabr w'al-muqabalah*, or Iohannes Hispalensis' *De scientia astrolabii*) [499, 457].

It is equally unlikely that Byzantine technical works existed, since in European libraries no Greek manuscripts are housed dating before the 15th century. Even the oldest copy of Hero's *Pneumatics* (Venezia, Biblioteca Marciana, gr. 516) dates back to the 13th century, but it was brought to Italy from Byzantium by Cardinal Bessarion during the 15th century.

Another part of Europe where an intense activity of translation took place, was Norman Sicily [500]: Greek, and Arabic works were translated into Latin [240, 199, 212]. One of the most renowned translators in the 12th century was the archdeacon of Catania, Henricus Aristippus, whose origins and life are still largely unknown. He translated from Greek into Latin Diogenes Laertius' works, Ptolemy's *Almagest*, Plato's *Meno* and *Phaedo*, Aristotle's *Meteorologica*. In his preface to the translation of the *Phaedo*, he addresses an Englishman who was to return home from Sicily, using the following words: " […] *Habes Heroni philosophi Mechanica pre manibus, qui tam subtiliter de inani disputat* […] " (you have in your hands the *Mechanics* by Heron, who so subtly deals with the void). These words led Rose and Birkenmajer [501-502] to believe that it was the *Pneumatics*, since in the *Mechanics* Hero doesn't speak of void; Haskins [208-209, 503] refused such an inference, because the content of *Mechanics* is known only from Arabic translations, possibly incomplete; moreover, Haskins rejected the subsequent inference by the above mentioned scholars as a risky assumption: according to them, Henricus was referring to his own Latin translation, since other translations of his are quoted in the passage.

Birkenmajer [504] goes further than Rose, stating that he had found evidence of a copy of this translation in the *Biblionomia* (the library catalogue of the French philosopher and poet Richard de Fournival, living in the 13th century), where the *Pneumatics* would be referred to as *Excerpta de libro Heronis de specialibus ingeniis* (excerpts from Hero's book about special devices); "specialibus" is probably a wrong transcription of "spiritualibus" (concerning with void), due to the

fact that the shortening of the two words is identical. Unfortunately, though the library is now part of the Bibliothèque Nationale de France, no evidence of the manuscript is now available, and even the assumptions that it could be Philon's instead of Heron's *Pneumatics,* or a Latin translation of an Arabic compilation from Banu Musa's work, can be neither validated nor rejected [205].

Birkenmajer also argues that, in the 13th century, the Flemish Dominican William of Moerbecke would have translated, among many other works, Heron's *Pneumatics* into Latin; his proof is based on the presence of a treatise entitled *De aquarum conductibus et ingeniis erigendis* in a list of works, owned by St.Thomas, actually translated by the Flemish scholar [502]. Although the evidence is not completely convincing, it is remarkable that the Aquinas, minor character in a legend about Albertus Magnus' automaton, is also quoted as a possible reader of one of Heron's texts.

Another work, entitled *De inani et vacuo* (About void), is both quoted without any reference to the author by the 14th-century philosopher Marsilius of Inghen in his *Quaestiones super VIII physicorum libros* (Questions on the Eight Books of the Physics; IV, 13), and copied in 1466 in a manuscript (Krakow, Biblioteka Jagiellonska, MS 568, ff. 207-211), where it is attributed to Heron.

The Polish manuscript has two interesting issues:

- in the colophon the scribe's name of the antigraph is mentioned (*quem inscripsit Landfridus*); such a name (in the German version, Lantfrid) has been present also in the colophon of a Carolingian manuscript (München, Bayerische Staatsbibliothek, Clm. 14461, f.150) of religious content, copied in the 820s in Freising, and housed in St.Emmeram's abbey library, near Regensburg, at least since 1347. If the scribe were the same, we would have evidence of the connection between a pneumatics tradition in Latin and a Benedictine monastery, a place quite advanced from the technological point of view during the Middle Ages;
- the handwriting is very similar to Regiomontanus', the famous German astronomer and mathematician; in addition, we must say that the manuscript was bound in Germany, and the author of the letters included in the last part of the manuscript was a friend of Regiomontanus': Cristianus Roder de Hamburgo. Regiomontanus is said by the French humanist Pierre de la Ramée to have built an eagle, and a fly, that could fly away and back. Despite the fact that the story told by Pierre is certainly exaggerated, the fact that Regiomontanus may have dealt with an abridged version of *Pneumatics* makes it less improbable (see *infra* 2.5.4) .

Though there is no definitive proof of direct knowledge of *Pneumatics* during the Middle Ages, we, however, have copies of Latin translations from Philon's or Heron's treatises made in the 14th-15th century (see *infra* 2.5.2).

2.4.4.3 Travelers

2.4.4.3.1 William of Rubruck

The Flemish Franciscan William of Rubruck (c. 1220 - c. 1293) in 1253, on king Louis of France's orders, he left from Constantinople on a missionary expedition to convert the Tartars. His account can be considered one of the most important works of medieval geography (*Itinerarium fratris*

Willielmi de Rubruquis de ordine fratrum Minorum, Galli, anno gratia 1253 ad partes Orientales)
[505]. In his journey he visited the Khan's palace at Karakorum [151], where he could see the famous silver tree by master William the Parisian, that is the French goldsmith Guillaume Boucher, known to us only thanks to this source. He would have been taken to Belgrad by the Mongols, and brought to their capital, according to his biography written by Olschki [215].

As we can read in Olschki's description based upon Rubruck's, the tree recalls in a sense the Byzantine and Arabic courtly trees, only due to the precious metals it is made of; it is however absolutely not automated, as any action is performed by servants, playing each one a precise role in order to get the correct result: pouring water in an impressive way for an unsuspecting audience.
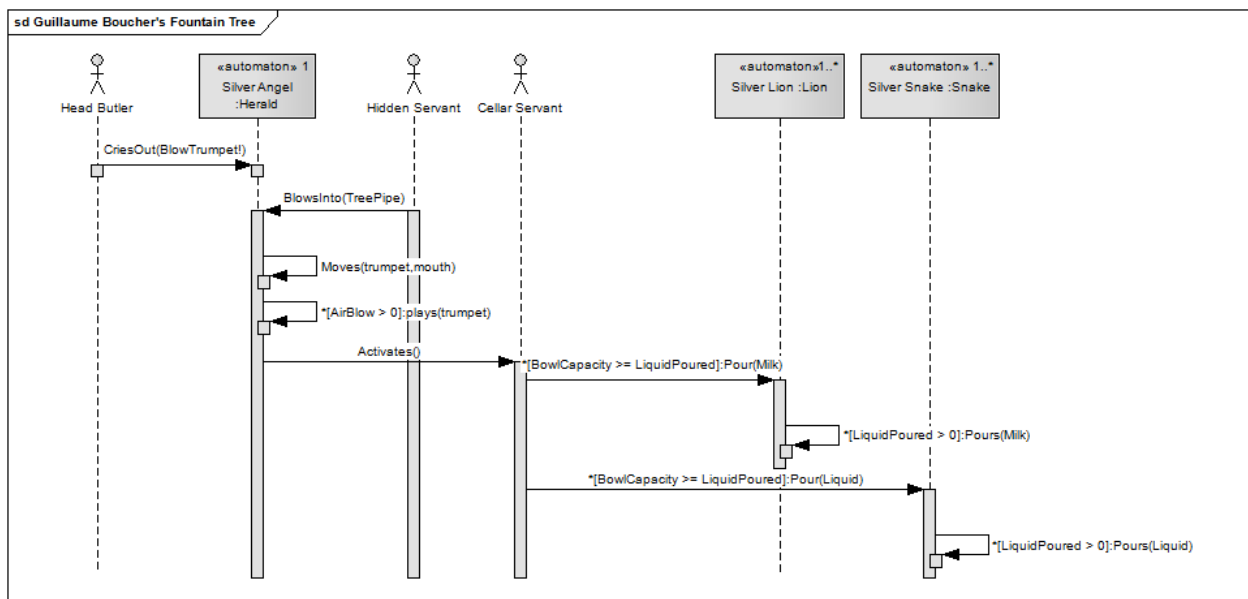

Fig. 105: UML Diagram of Guillaume Boucher's Fountain Tree

As we can easily see from the UML diagram, users are heavily involved in tree working, completely wanting of automation, since automata are only the terminal parts of pipes. Boucher probably tried to imitate the behavior of an automaton described in some text, or requested by the king; since he was more skilled as a goldsmith than as an hydraulic engineer, he only preserved the external wonderful appearance.

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[151] In the entry of this great palace, it being unseemly to bring in there skins of milk and other drinks, master William the Parisian had made for him a great silver tree, and at its roots are four lions of silver, each with a conduit through it, and all belching forth white milk of mares. And four conduits are led inside the tree to its tops, which are bent downward, and on each of these is also a gilded serpent, whose tail twines round the tree. And from one of these pipes flows wine, from another cara cosmos, or clarified mare's milk, from another bal, a drink made with honey, and from another rice mead, which is called terracina; and for each liquor there is a special silver bowl at the foot of the tree to receive it. Between these four conduits in the top, he made an angel holding a trumpet, and underneath the tree he made a vault in which a man can be hid. And pipes go up through the heart of the tree to the angel. In the first place he made bellows, but they did not give enough wind. Outside the palace is a cellar in which the liquors are stored, and there are servants all ready to pour them out when they hear the angel trumpeting. And there are branches of silver on the tree, and leaves and fruit. When then drink is wanted, the head butler cries to the angel to blow his trumpet. Then he who is concealed in the vault, hearing this blows with all his might in the pipe leading to the angel, and the angel places the trumpet to his mouth, and blows the trumpet right loudly. Then the servants who are in the cellar, hearing this, pour the different liquors into the proper conduits, and the conduits lead them down into the bowls prepared for that, and then the butlers draw it and carry it to the palace to the men and women.

2.4.4.3.2 Odoric of Pordenone

In the 14th century, even the Franciscan friar Odoric of Pordenone (1286-1331), in 1322-1323 crossed the whole Asia and reached China on a missionary action. He left us the Latin account of these travels (*The Travels of Friar Odoric - Descriptio fratris Oderici de ordine minorum de partibus infidelium*) [506], and, while describing Gran Khan's royal palace Tumen Amugulang in Karakorum, he doesn't hide his wonder about two automata. The first one is a fountain made of jade and gold and decorated with nets made of pearls, where four golden snakes, one at each corner, are continuously hissing. Around it, many golden vessels are available for courtesans to drink.

The second one is the following: "In this building there are many golden peacocks and, if a Mongol wants to celebrate his king, then he says a few words out loud and claps, then those peacocks open the wings and seem to enjoy. This is diabolical art or human skill on earth." [152]
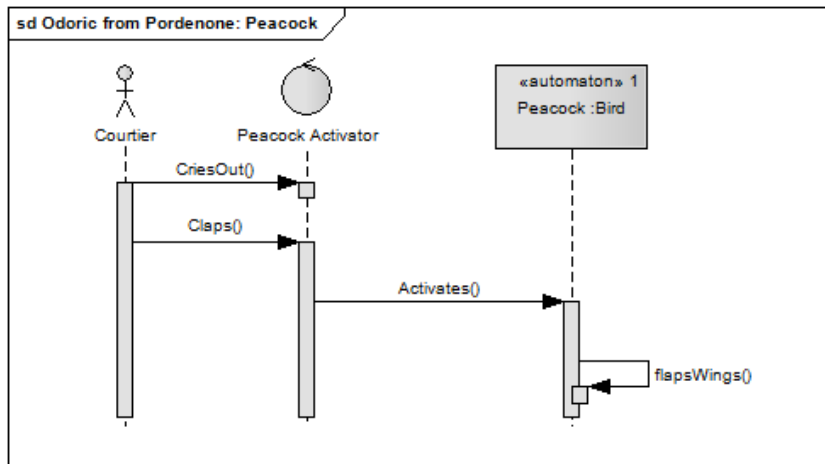

Fig. 106: UML Diagram of Peacock in Odoric from Pordenone's Account

2.4.4.4 Mechanics as Dangerous Knowledge: The Legends

The crucial role played by churchmen is also confirmed by some legends that were born in the first centuries of the new millennium; beside Gerard d'Aurillac, some poets, saints and scholars are involved as main characters in such tales where talking heads [19], or even automata are present [507].

Jacopo da Varagine (1230-1298) in his *Golden Legend* (*Legenda aurea* XVIII) tells the story of saint Macarius (a 4th century Egyptian monk) as a necromancer [153]; he asks the head of a Pagan

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[152] LVI (Preciositas palacii): In hoc eciam pallacio sunt aurei pavones multi, et cum aliquis tartarus vult facere festum domino suo Regi, tunc profert aliquid verbum, vocem iualtando, et manus invicem percudendo, tunc hi pavones alas suas emittunt, et tripudiare videntur. Hoc autem at pato fit arte diabolica, vel forte ingenio humano sub terra.

[153] *Quodam die sanctus Macarius caput defuncti reperit et, dum orasset, interrogavit illud, cuius caput fuerit. Et respondit se fuisse paganum. Et dixit ei Macarius: "Ubi est anima tua ?" Respondit: "In inferno." Cumque requireret, si multum in profundo esset, respondit, quod tantum in profundo esset, quantum distaret terra a coelo. Cui Macarius: "Suntne aliqui te profundiores?" Respondit: "Etiam, Iudaei." Cui iterum ille: "Et ultra Iudaeos suntne aliqui profundiores?" Cui ille: "Profundiores omnibus sunt falsi Christiani, qui Christi sanguine redempti tantum pretium parvi pendunt."* One day, st. Macarius found the head of a dead man and, while praying, he asked it whose head it was. It answered to have been the head of a pagan. So Macarius: "Where is your soul?". It answered: "In hell". Macarius asked whether how deep was it, the head answered as deep as the distance between earth and sky. So Macarius: "Is there anybody in a deeper place?". It answered: "Sure: Hebrews". "And deeper than Hebrews?" asked Macarius; the head answered: "The deepest of all are false Christians, who don't take into consideration the great value of the redeemed blood of Christ."

dead man about hell, and discovers that the deepest of hell is full of false Christians. This is obviously an episode connected with necromancy, though in a Christian background, that is with the moral aim to recall the Christians the importance of faith.

The case of talking heads as emblems of dangerous knowledge is different: the Dominican philosopher Albertus Magnus (1193-1280) would have built an automaton, destroyed by saint Thomas Aquinas (1225-1274); in some later versions, it would have been only a talking head, rather than a complete automaton. The poet John Gower (1330-1408), in his *Confessio Amantis,* mentions a talking bronze head made by Robert Grosseteste (1175-1253), an English cleric and philosopher [154]. A similar episode is also referred about Roger Bacon [155] [196]. Even if we are aware of the legendary nature of these tales, it is interesting to point out that these oracular heads, built by men, that is non-natural, are predominantly related with some of the most innovative European natural philosophers of the time. As shown by Lagrandeur [196], they "are directly or indirectly associated in popular legend with the construction of automata". The author explains such link thanks to "common connections between magic and science in the Middle Ages and the Early Modern era", though "many of the philosophers mentioned above had close contact with knowledge of the occult sciences adapted from Moslem sources and from classical sources recovered through the Moslems". Some of them (at least, Gerbert, Robert and Albertus) were also interested in mechanics, which contributed to the origin of these legends, and to their likeliness. In addition, Bacon left one of the most fascinating descriptions of technology power when in his letter *Letter on Secret Works of Art and of Nature and on the Invalidity of Magic (Epistula de secretis operibus artis et naturae, et de nullitate magiae),* dated between 1248 and 1257, he writes about some astonishing devices that he is familiar with [156]: "*Therefore, I shall now first relate the works of art and of nature to be marveled at, in order then to assign their causes and modes of operation. **There is no magic in them**, as it would seem that every magical power is inferior to and unworthy of these works. First, those things achieved through the design and reasoning of art alone: Now an instrument for sailed without oarsmen can be produced such that **the largest ships**, both riverboats and seagoing vessels, **can be moved under the direction of a single man at a greater velocity than if they were filled with men**. A **chariot can be made that moves at an unimaginable speed without horses**; such we think to have been the scythe-bearing chariots with which men fought in antiquity. And **an instrument for flying can be made**, such that a man sits in the middle of it, turning some sort of device by which artificially constructed wings beat the air in the way a flying bird does. And **an instrument small in size for raising and lowering almost infinite weights**; at times there is nothing more useful than this, for, by an instrument three fingers high and just as wide, or of less size, a man could snatch up*

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[154] Book 4, Ll. 234-249 *For of the grete Clerc Grosseteste / I rede how besy that he was / Upon clergie an Hed of bras / To forge, and make it forto telle / Of suche thinges as befelle. / And sevene yeres besinesse / He leyde, bot for the lachesse / Of half a Minut of an houre, / Fro ferst that he began laboure / He loste all that he hadde do. / And otherwhile it fareth so, / In loves cause who is slow, / That he withoute under the wow / Be nyhte stant fulofte acold, / Which mihte, if that he hadde wold / His time kept, have be withinne.* Now of Grosseteste that noted scholar, He, who wore the cleric's collar, Undertook to forge a head Of brass, that would foretell, he said, Events, to help avert destruction. Seven years on this production He'd worked, but Procrastination Of a miniscule duration, From the time he'd first begun Caused him to lose all he had done. And this can happen too with love: The suitor who is guilty of Delay, without, beneath the wall, At night will often stand there, all Alone and cold, who could have been, If he had been on time, within.
Note that this head talks about past events, not about future.
[155] Robert Green, *Friar Bacon and Friar Bungay*, an Elizabethan comedy dating to 1589, the oldest, as far as we could find [508].
[156] Translation by Mahoney.

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*himself and his friends and raise and lower them from every danger of prison. Moreover, **an instrument could easily be made by which one man could violently draw to himself a thousand men against their will** and attract other things in the same way. And instruments can be made for walking in seas and rivers, right down to the bottom, without bodily danger. For Alexander the Great used these to see the secrets of the sea, according to what Ethicus the astronomer says. These things were all made in antiquity, and it is certain they have been made in our times, unless it be the flying machine, which I have not seen, nor do I know anyone who has, though I do know a wise man who has thought of a way to carry out such a device. Almost infinitely many such things can be made, such as bridges that span rivers without pillars or any support, and machines and unheard-of devices.*" A passage that can be compared with the one taken from Aristotle's *Politics* for its visionary power. For this reason it had the same fate of the former: being quoted nearly by all scholars studying Medieval technology. Bacon's main aim is not to impress his audience with examples of wonderful technological achievements, rather to reconduct such realizations into the field of rational science, excluding any magical component in their building and operation, since they are artificial, i.e. made thanks to an art (=skill).

Also the Roman poet Virgil (70-19 BC), due to a misleading interpretation of one of his work, became the main character of a series of legends, quoted in many sources, as Comparetti and Spargo could largely show [509-510]. As a matter of fact, Virgil would have built

- A group of statues, the so-called *Salvatio Romae*, that would ring bells without human intervention to warn Rome of a revolt in its provinces; in other versions, it is a mirror, where betrayals are shown [157].
- A bronze fly that, when set in Naples, could keep other flies away from the city [158];
- An unexstinguishing fire, protected by an automaton archer [159]
- A calendar, that marked the passing of the seasons: four colossal bronze statues, representing the four seasons, were set on the walls of Rome; the current season statue held

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[157] Adenet le Roi, *Cléomadès*, ll.1691-1698. *A Rome fist, c'est verités, / Virgiles plus grant chose assez; / Car il fist .I. miroir / Per quoi on povoit bien savoir, / Par ymage qu'il y avoit, / Su nus vers Romme pouchaçoit / Ne fausseté ne trayson / De ceaus de leur subjection*. / In Rome, Virgil did, indeed, many of the great things he did as a mirror with which anyone could have known through the image, whether any of the subjects was plotting against Rome some deception or betrayal.

[158] Adenet le Roi, *Cléomadès*, ll. 1699-1706. *Et fist une mousche d'arain / De quoi encor le pris et ain. / A Naples cele mousche mist, / Et de tl maniere la fist / Que, tant com la mousche fu là, / Mousche dedenz Naples n'entra*. And he built a copper fly Used as a bait. He sent that fly to Naples And he made it so That, as the fly was there, no more flies entered Naples. A similar tale is in Gervaise of Tilbury, *Otia imperialia*, 3.10: *Porro in Campania, civitate Neapolitana, scimus Virgilium arte mathematica muscam erexisse eneam, que tante virtutis in se habuit experimentum quod, dum in loco constituto perseveravit integra, civitatem late spatiosam nulla musca ingrediebatur*. Moreover, we know that in Campania, in Naples, Virgil set up by means of magic power a bronze fly, which had within itself such a power that as long as it remained intact in the place where it had been left, no fly could enter the city, although it was far and wide.

[159] Adenet le Roi, *Cléomadès*, ll. 1707-1722. *Encor Virgiles fist un fu / Qui longuement a Romme fu. / Adès et nuit et jour ardoit, / Grant aise à pluseurs gens faisoit. / Devant ce feu ot .I. arcier, / Qui n'ert nè de fer ne d'acier, / Ains ert de coivre; si sambloit / Qu'il vousist traire ou feu tout droit. / En son front escrites estoient / Lettres qui en ebrieu disoient: / "Qui me ferra je trairai jà". / Et un musars passa par là / Qui d'un baston l'arcier féri, / Et il traist el feu: s'estaint si / Que ains puis ne fu ralumés*. Virgil made a fire that long lasted in Rome. It was always burning, night and day, it was a great pleasure to many people. In front of the fire there was an archer, who was made neither of iron nor of steel, but of copper, and it looked like he wanted to hit the fire. On his forehead there were written in Hebrew words that meant "I'll hit if someone touches me". And one that went there, struck it with a club and the statue hit the fire that was immediately extinguished and was never revived.

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a bronze ball, but when the new season was to begin, it threw the ball to the arriving season one [160].

- Another version of the automaton archer, that we could call *Salvatio Neapolis* [161], as it consisted of the same system, aimed however to protect Naples from Vesuvius eruptions.
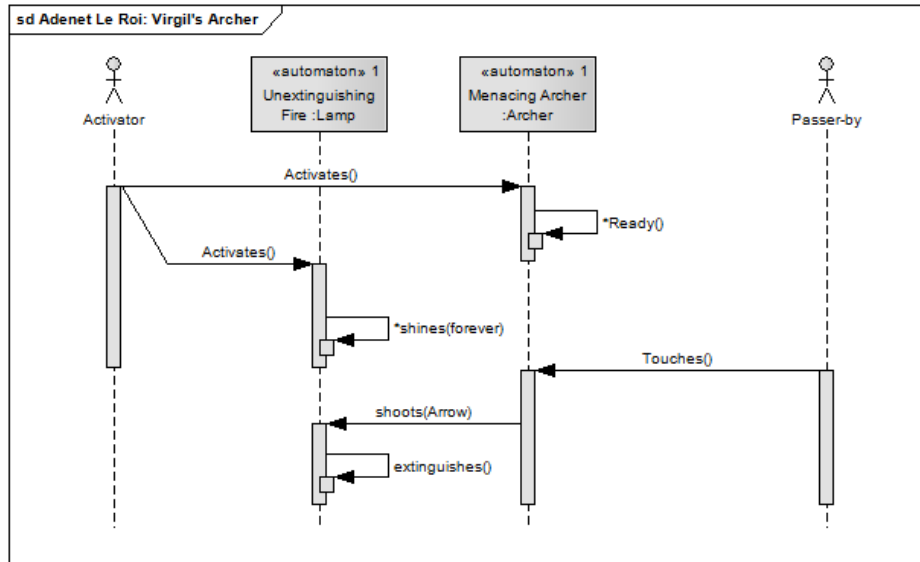
Fig. 107: UML Diagram of Virgil's Archer
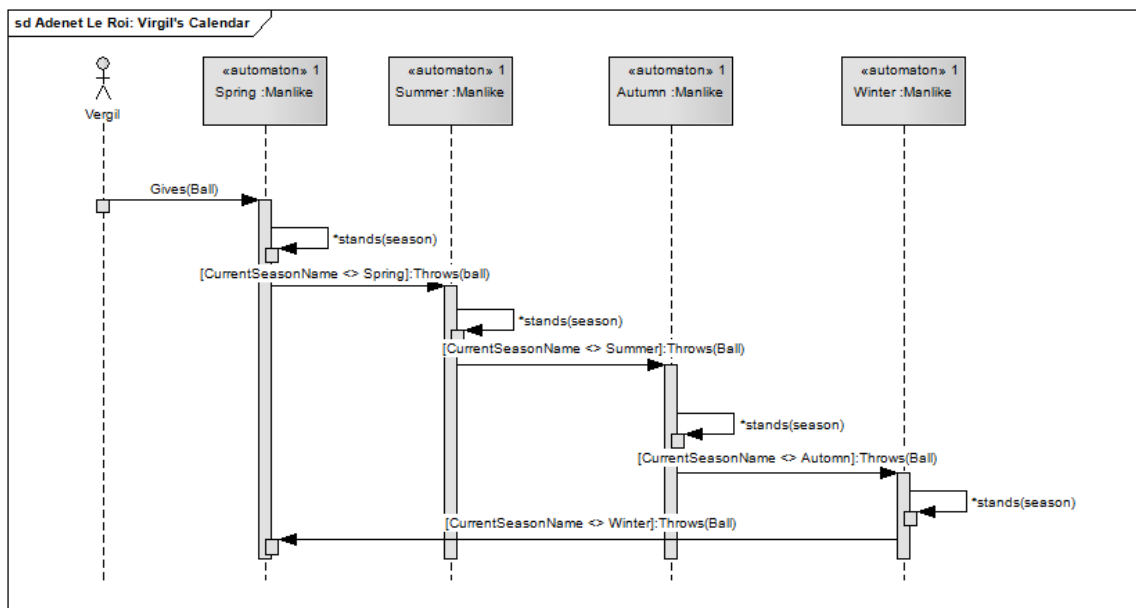
Fig. 108: UML Diagram of Virgil's Calendar

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[160] Adenet le Roi, *Cléomadès,* ll. 1723-1812.

[161] Conrad of Querfurt, *Epistula Conradi cancellarii*, 24-28: *Est ante civitatem Vesevus mons, ex quo ignis, multos involvens cineres foetidos, intra decennium semel solet exhalare: cui Virgilius opposuerat hominem aereum, tenentem ballistam tensam, et sagittam nervo applicatam. Quem quidam rusticus admirans, eo quod semper ballista tensa nunquam percuteret, impulit nervum. Sagitta prosiliens percussit os montis, et continuo flamma prosiliit, nec adhuc certis vicibus cohibetur.* Mount Vesuvius is in front of the city; from it usually once every 10 years lava comes out, which brings many stinking ash; Virgil had built a man of bronze, holding a crossbow with an arrow. A farmer who was watching in amazement as the spring never snapped, touched the string. The arrow was shot and struck the heart of the mountain; so the lava began to erupt irresistibly, and up to now it can not be stopped at certain times.
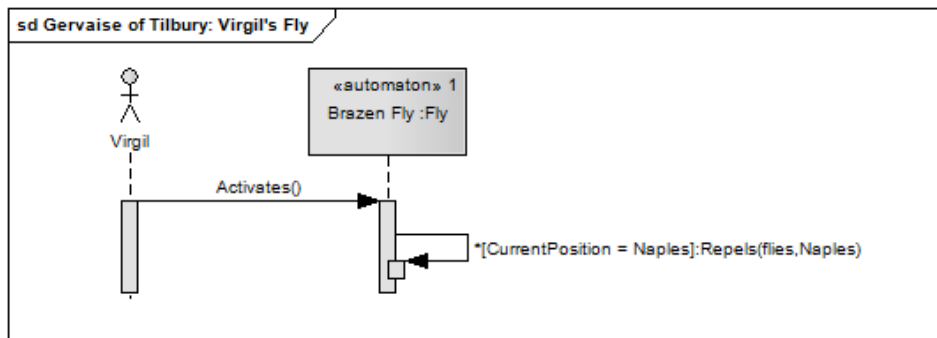
Fig. 109: UML Diagram of Virgil's Fly

Therefore Virgil was believed to be a magician, or rather a true necromancer, able to evoke life, or at least motion, out of lifeless matter, like brass. Both necromancers and automata builders are often mentioned in many romances: whether such works belong to the Matter of Britain (King Arthur's stories) or of France (Charles the Great's stories), or of Rome (the main character is taken from ancient history, such as Julius Caesar or Alexander the Great), references to automata are frequent [511]; they are primarily used as guardians of a strategic place (a tomb, a bridge, a cave, or a castle) and their makers are usually magicians, not technicians.

The reason is easily explained: all mechanical arts were in no esteem throughout the Middle Ages to the point that, for a cultured man, technical practice was considered morally, religiously, and socially dishonorable [195, 512], as the tales about the philosophers can show. On the contrary, knowledge and practice of magic were reserved for a selected group of people, who had chosen to engage in "religiously illicit pursuits, illegitimate knowledge, and trafficking with the Devil" [192]; by attributing the construction of automata to magicians, any moral conflict was avoided.

2.4.4.5 (Cyber)magic in Medieval Literature

2.4.4.5.1 Romances

Chivalric literature, also known as romances, is a collection of stories dealing with the ventures of medieval knights [184]; written in vernacular languages (mostly French), they spread in European courts from the 12th century, as their composition was often required by kings, for prestige reasons. It is, for instance, the case of the Plantagenets' court at the time of the cultivated French queen Eleanor of Aquitaine (1122-1204), who liked to surround herself of French culture and literature, from the period when she was living in Poitiers; and of her daughter Marie, countess of Champagne, born from the first marriage with Louis VII of France [513].

Since these romances can be considered a reasonably homogenous *corpus* of tales, written and spread in two centuries in a quite stable cultural structure, we considered a presentation organized by type more appropriate rather than one following a strictly chronological order, that, in many cases, is far from being sure. Based on the external automata appearance, they can be divided into human beings, animals and objects.

2.4.4.5.1.1   Human beings

Based on their role, they can be grouped as aggressive (guardians, knights or paladins) and peaceful (musicians, jugglers, teachers of courtly virtues), or moving/static.

The two statues of children of the Palace of Constantinople [162] that, when a Western wind is blowing, blow in their ivory horns. They are part of a more complex system (see *infra Palais errant* in *2.4.4.5.1.3*).

In *Floris and Blancheflour*[163], the two lovers' statues, set in their tomb, when activated by wind, seem actually to kiss, and speak to each other.
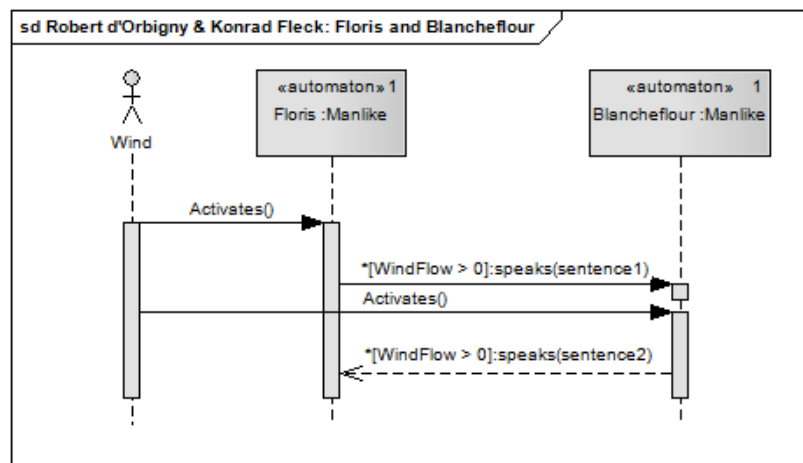
Fig. 110: UML Diagram of Floris and Blancheflour's Tomb

In Tumas de Britanie's *Tristan* a description of the so-called "salle aux images" (Chamber of Statues) is given, where the hero has built a perfuming statue of the beloved Isolde, holding a golden scepter, surmounted by a golden bird flapping its wings. She is protected by two automata, a lion and a warrior and her little dog keeps her company [515]. The same story is told in a Norwegian version of the story (*Tristrams Saga ok Isondar*), dating back to 1225, studied by Kölbing [516].

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[162] French Anonymous, *Charlemagne's Voyage to Jerusalem and Constantinople* 352-359: *De cuivre et de metal tresjetet dous enfanz, Chascuns tient en sa boche un corn d'ivoire blanc, Se galerne ist da mer, bise ne altre venz Qui fiereut al palais de devers occident, Cil corn soneut et boglent et tonent ensement Com tabors o toneires o granz cloche qui pent. Li uns esguardet l'altre ensement en riant. Que ço vos fust viaire que tuit fussent vivant.* Two figures of children made of bronze and metal / Each holds a white ivory horn in his mouth, / If galerne, bise or another wind comes from the sea / of those that come to the palace from the West, / those horns sound and ring and agree / like drums or thunder or a large hanging bell./ They look at each other and smile. / This gave the impression that they were really alive.

[163] Robert d'Orbigny, *Floire et Blanchefloire,* 583-586 *Quant li vens les enfans touchoit, / L'uns baisoit l'autre et acoloit: / Si disoient par ingremance / Tres-tout lor bon et lor enfance.* When a breath of air touched the two youngs, they kissed and caressed each other; so they could express, by means of necromance, all their good and youth.

Konrad Fleck (*Flore und Blanscheflur*, 2018-2048) goes further and imagines also the words said by lovers. [514]
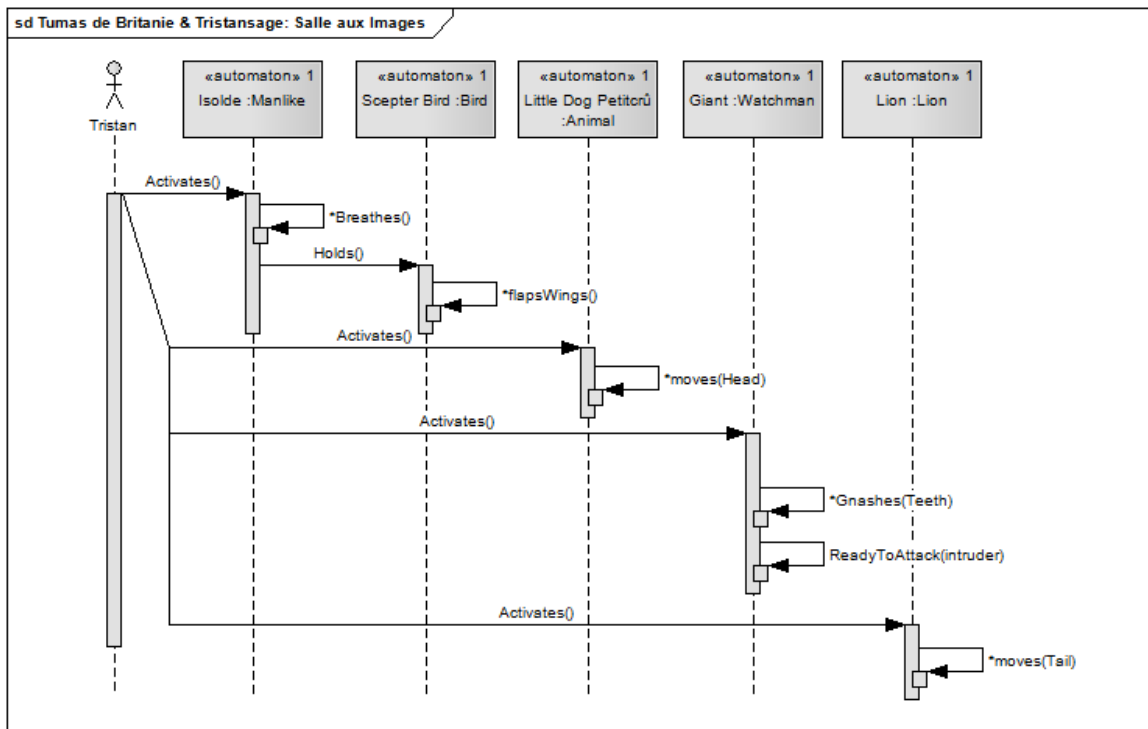
Fig. 111: UML Diagram of Salle aux images

In *Huon de Bordeaux* the main character is told of the presence of two copper statues constantly beating air with their flails in front of the entrance of the castle of Dunostre, and therefore preventing anyone from entering, even larks.
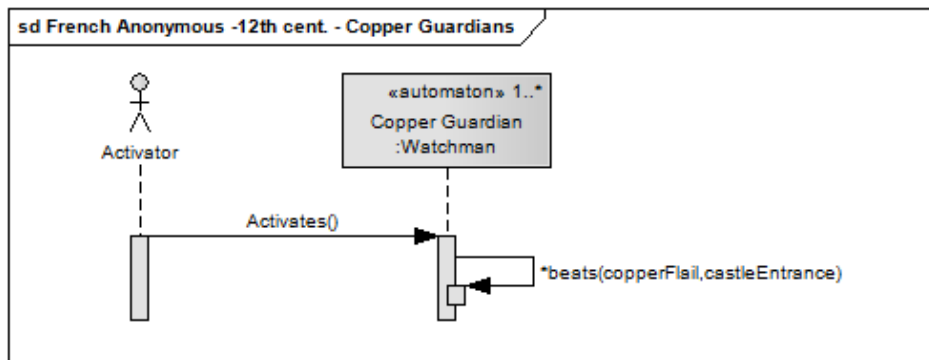
Fig. 112: UML Diagram of Copper Guardians

In *Lancelot do Lac*, a 13th-century prose version of Chrétien de Troyes' *Le Chevalier de la Charette*, two copper knights face Lancelot, while he is entering the castle known as *La Doulourouse Garde*.
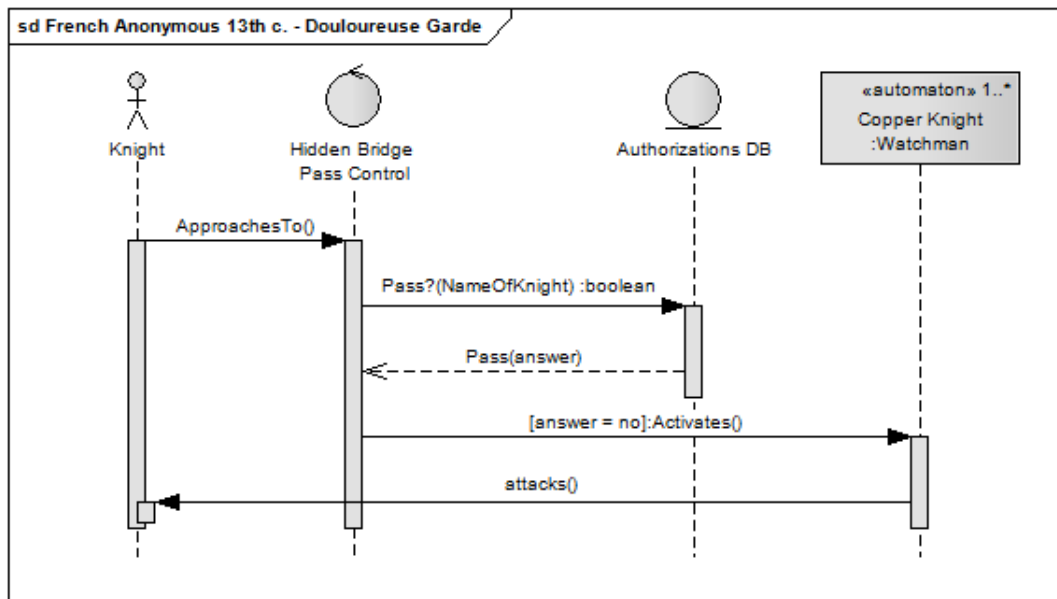
Fig. 113: UML Diagram of Douloureuse Garde

In Adenet Le Roi's *Cléomadès* [164] we have a variant of the story of the ebony horse, taken from the *One Thousand and One Nights* (see 2.4.3.2.1); for the first time, we have the name of the magician who built the automaton: Baldigane. He is one of the three necromancers that are offering their gift to the king, and has built the golden statue of the automated lie detector, a more delicate version of the Arabic one, since it scans men's loyalty, rather than their being true enemies.
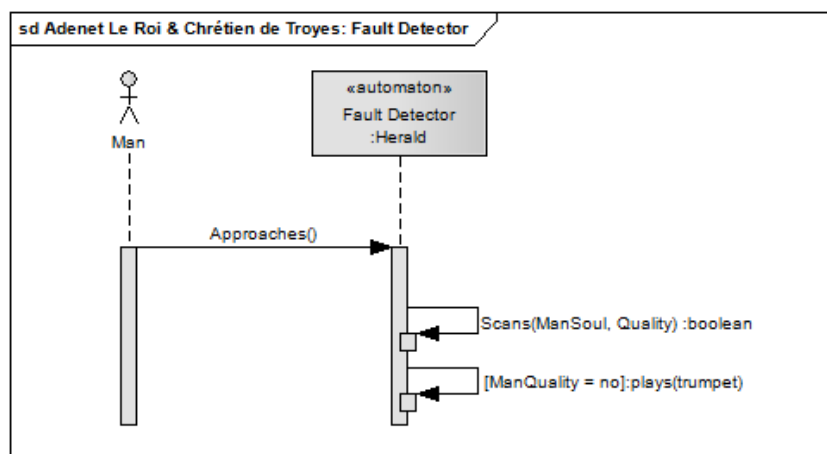
Fig. 114: UML Diagram of Fault Detector

Quite similar are the statues quoted [165] in Chrétien de Troyes' *Perceval*, made to detect betrayal and loss of virginity [517].

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[164] Ll. 1594-1608 *Baldigane ne s'oublia mie, / Ains fist un home de fin or / Qui valoit plus d'un grant trésor; / Une trompe en sa main tenoit / Où mainte riche pierre avoit. / En tel manière ert arrôés / Li tromperas et compassés, / Que qui le trompeéur eûst / Trestout certainement seûs't / Ee, se nus pourchaçast vers lui / Traison ne mal ne anui, / Li tromperas trompait tantost.* Baldigane did not forget, so made a man of gold worth more than a great treasure; it was holding in his hands a trumpet with many rich stones. The trumpeter was made in such a manner and position that who had got the trumpeter certainly could know that no one could have betrayed or hurt or damaged him, without the bugler played the trumpet.
[165] Ll. 13352-13364 ; 13365-13372; 13410-13418;

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In the adespote *Roman de Thèbes* [166], two automated musicians, fascinate the audience with a superb performance.

But the richest and finest automata of romance tradition are the four statues of the "chambre de labastrie" (Alabaster Chamber) [167]. Whoever visits this room, built by three necromancers and decorated with all the precious stones recorded in Medieval lapidaries as inspiring moral virtues, is doing a real training course in courtly life, lectured by four automata, two beautiful girls and two handsome boys:

1. The first one is the younger of the two girls, and teaches fine elegance; she gives a mirror which shows the dress faults of those who are reflected, so that they can correct them immediately.

2. The second one teaches many tricks and also cultural contents; she can play with knives, but she can also show all world wonders, that people rarely can see, such as "ambushes, parliaments, battles, betrayals and assaults, great ships on the high seas, different species of sea fish, fierce battles of champions, horned men and dwarves and the shapes of large abominable flying snakes, marine animals and dangerous monsters".

3. The third one is sitting in an obsidian throne, and teaches the control of passions, such as anger, with the help of musical instruments.

4. The fourth uses perfumes to teach indispensable courtly virtues, by showing to people what they really need. Benoit adds that user's needs remain secret, unaccessible to anybody but the user; we must then assume that more than one user can enter the room together, and that at least this automaton (or the whole learning system) is thought as a multi-instance one, exactly as it happens in many VR-applications, e.g. MMPORG.

In the passage even the figure of a satyr is described, that, swinging its mace similar to the one used to play the pelota, appears to operate another automaton: a flying eagle.
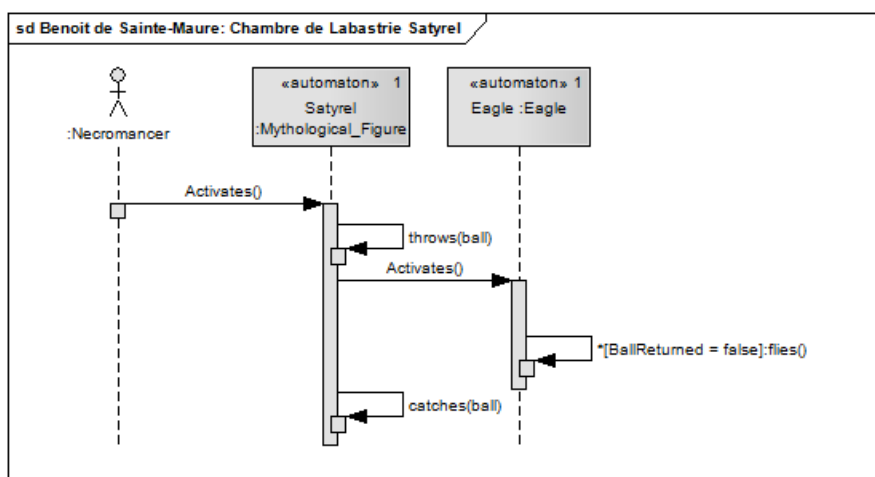
Fig. 115: UML Diagram of the Satirel and Eagle

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[166] ll. 4765-4768 *Une image i ot tresgetee / Que vait cornant a la menée; / Une autre, que toz tens frestele / Plus cler que rote ne viele*. There is a carved statue / which continues to play the horn; / another who always plays the flute / more harmoniously than a rote or a viola.

[167] Whose name is due to the material used for the construction of walls, perfectly transparent to incoming light, but opaque to outside view. Ll. 14681-14709, 14710-14746, 14759-14790, 14862-14910.
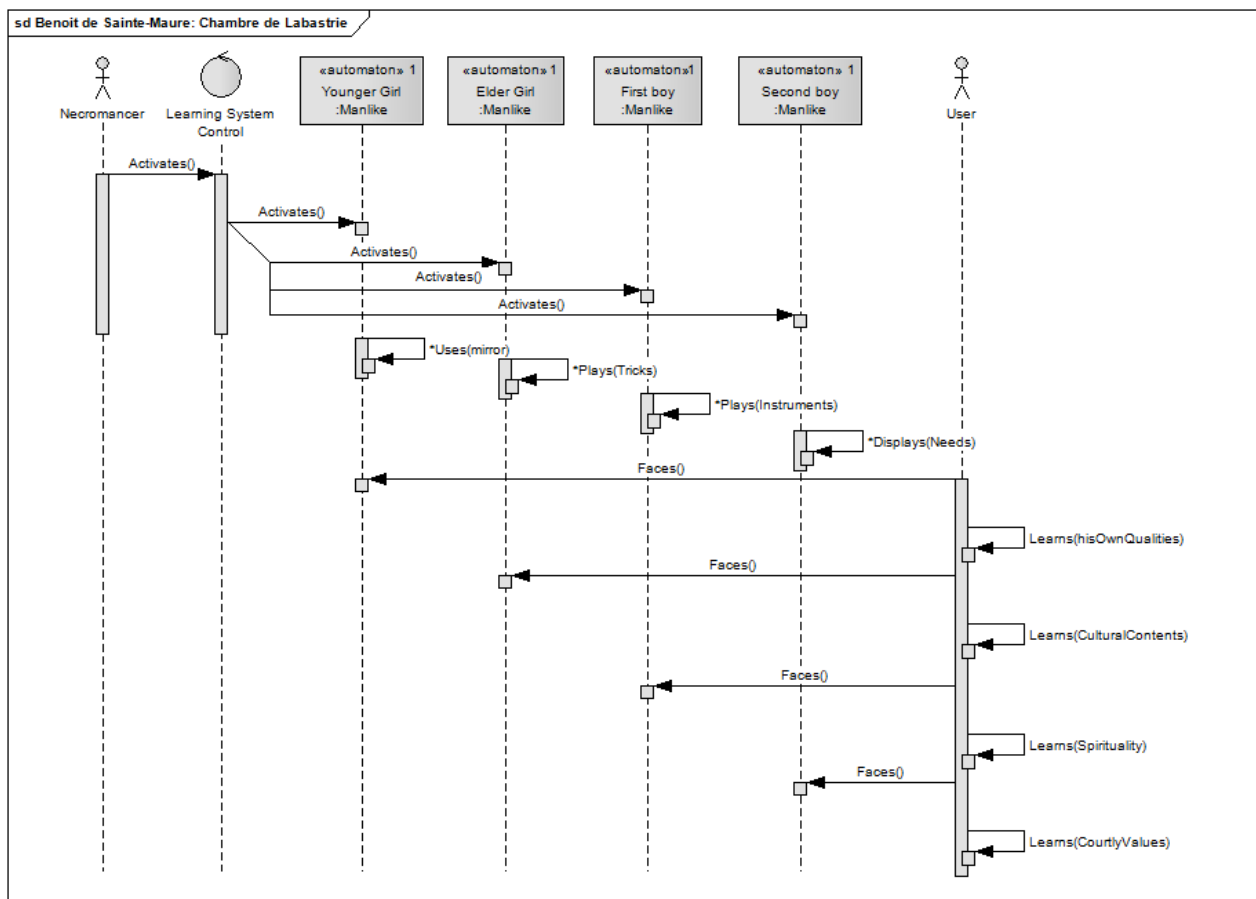
Fig. 116: UML Diagram of the Chambre de Labastrie

2.4.4.5.1.2   Animals

Among animals, the most frequent are certainly birds, perhaps due to the stories of travelers in Byzantium [182], as for the setting on a golden tree, or to their relative ease of construction. They are quoted as musical device in *Aymeri de Narbonne* by Bertrand de Bar-sur-Aube [168], *Heldenbuch Wolfdietrich* by a German Anonymous[169], in *Escanor* by Girart d'Amiens [170], this last built by the magician Esclarmondine. In addition, in Norse mythology we find a golden boar (Gullinbursti or Slidrugtanni) build by the dwarf Brokkr for the chariot of Freyr, god of fertility; the only reference to it are made in the *Snorra-Edda*, a literary text composed at the beginning of the 13th century by the historian, poet, and politician Snorri Sturluson [171].

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[168] 3507-3528

[169] 567-568: *Sy nam in bei der hende und weist in in ein sal, / der was von merbelstain(e) und leuchtet über al, / dar in stund ein lind(e) dy was guldin gar, / als sy der haiden fraissam het gemachtet dar. // Zwen und sibenzig est(e) nam er an der linden war, / dy vogel dy daraufsassen dy waren guldin gar, / sy waren gemacht mit listen und waren innen hol: / wenn sy der wint durch waet(e), ir stimme sungen wol*. He went right and entered a room, that was of marble and shone more than any other, inside there was a lime tree that was of pure gold, as the terrible enemy had done it there. He saw 72 beings on the lime the birds were placed above and were golden they were made with art and were hollow: when the wind blew into them, their singing voices came out.

[170] 15966-15987; 15991-16036

[171] *Skáldskaparmal*, 43: *Þá bar fram Brokkr sína gripi. [...] En Frey gaf hann göltinn ok sagði, at hann mátti renna loft ok lög nótt ok dag meira en hverr hestr ok aldri varð svá myrkt af nótt eða í myrkheimum, at eigi væri ærit ljós, þar er hann fór; svá lýsti af burstinni.* Then Brokkr brought forward his gifts: [...] to Freyr he gave the boar, saying that it could run through air and water better than any horse, and it could never become so dark with night or gloom of the Murky Regions that there should not be sufficient light where be went, such was the glow from its mane and bristles.

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Fig. 117: UML Diagram of Tree with Birds and Angel

In Hue de Rotelande's *Ipomedon* [172], the author presents an instance of a golden eagle, working as a guardian, but activated by wind. It holds a carbuncle in its beak, that enlightens all the land around.
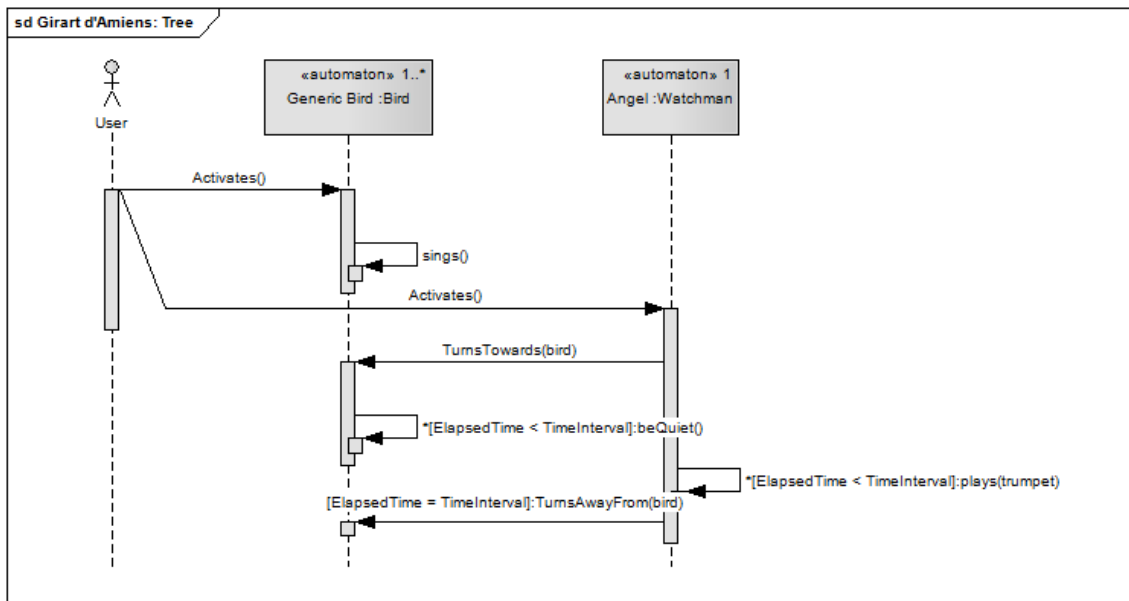
Other automata are presented both in Adenet Le Roi's *Cléomadè*s [173] and in Girart d'Amiens' *Meliacin or the Ebony Horse* [174]; besides the golden guardian, taken from the Arabic tale, as shown above, we have also the ebony horse, that works basically as its Arabic homologous, apart from minor differences, and a completely new instance: a hen followed by her chicks.

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[172] 3291-3304; *Suz Candes est li reis venu, / Li tref real est tost tendu: / El mund un sul si bon n'aveit: / Un aigle par en mount aveit, / Mut par ert bone e ben ovre, / Trestut de fin or tresjete; / Par tel engien ovrez estiet, / Quant li gardeins del tres voleit, / A poi de vent getast teus criz, / Par tut le pais fust oiz. / En sun bec un escarbucle out, / Ke les nuiz tel clarte jetout, / K'el pais veist l'um entur / Si cler, cum s'il fust de grant jur.* To Candez the king has come, the royal standard is immediately hoisted: Worldwide there was only one so beautiful: It had an eagle on top, known to be a fine and good work, made of pure worked gold; This device made what the guardians wanted, in the wind it gave out its cry; it was heard throughout the country. In its beak it had a carbuncle, that during the night shed light, seeing around the country, so brightly, as if it were daylight.

[173] 1587-1593; 1609-1634 ; 2141-2162; *Une geline, ce m'est vis, / De fin or fist Melocandis, / Et trois pucines qui sivoient / Cele geline, et si chantaient / Si doucement que il sanbloit / Chascun qui chanter les ooit / K'ains n'oy si grant mélodie.* A hen, so it seems to me, of fine gold built Melocandis and three chicks that followed this hen, and they sang so sweet that it seemed to all that heard it, to have never heard such a beautiful melody.

[174] The 'cheval de fust' is present all along the tale; the hen's behavior on the contrary is quoted at ll. 272-283. *Si tost com la clef i bouta, / un joel en atraist mout bel: / une geline en un platel / Et avoeques de poucins sis; / mais sachiés que d'or fin massis / furent compost et tresjetés. / Li clers, qui avoit volenté / c'on seust laiens son convine, / a mise a terre la geline / qui tantost se prist a escourre / et commença partout à courre / et li poucinet après li.* As he turned the key, he got a very nice device: a hen on a plate and six chicks with her, but you must know that they were made and engraved in solid gold. A cleric who wanted everybody to know what he had made, put the hen on the ground and she immediately began to move, started running everywhere and the chicks behind her.
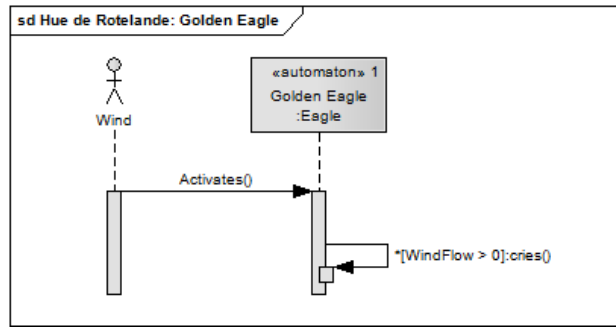
Fig. 118: Hue de Rotelande's Golden Eagle
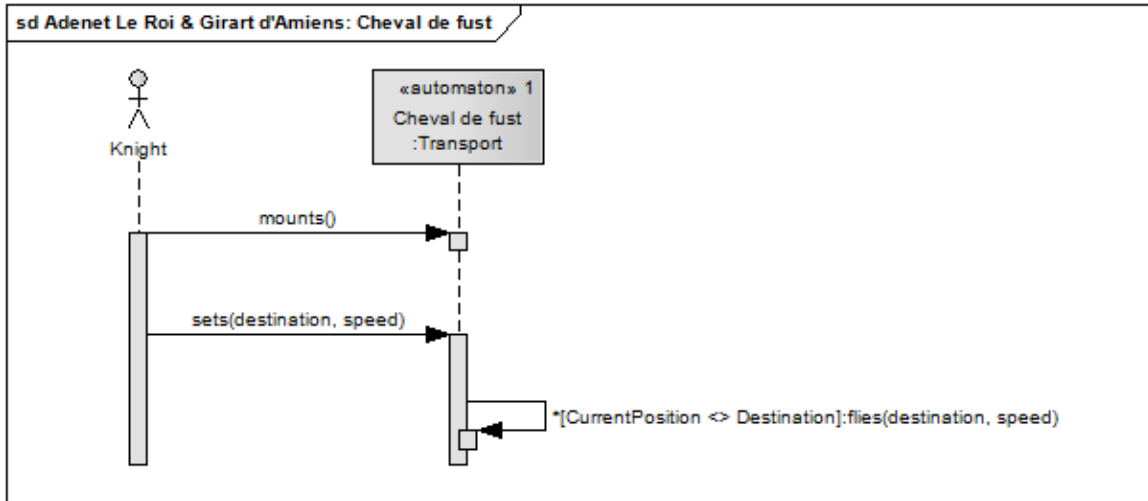
Fig. 119: UML Diagram of Cheval de fust
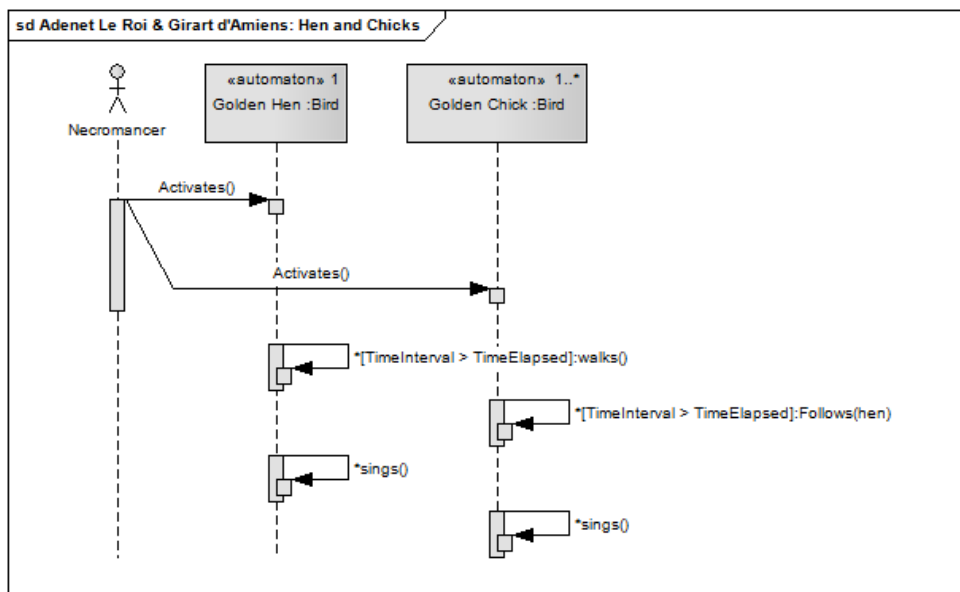
Fig. 120: UML Diagram of Golden Hen and Chicks

2.4.4.5.1.3 Objects

Probably the most interesting automata are objects intended in the broadest sense, since they range from tools to games; from musical instruments to weapons; from furniture to buildings. The first

instance is taken from previous tradition, as it refers to an unexstinguishing lamp [175], guarded by an automaton archer.
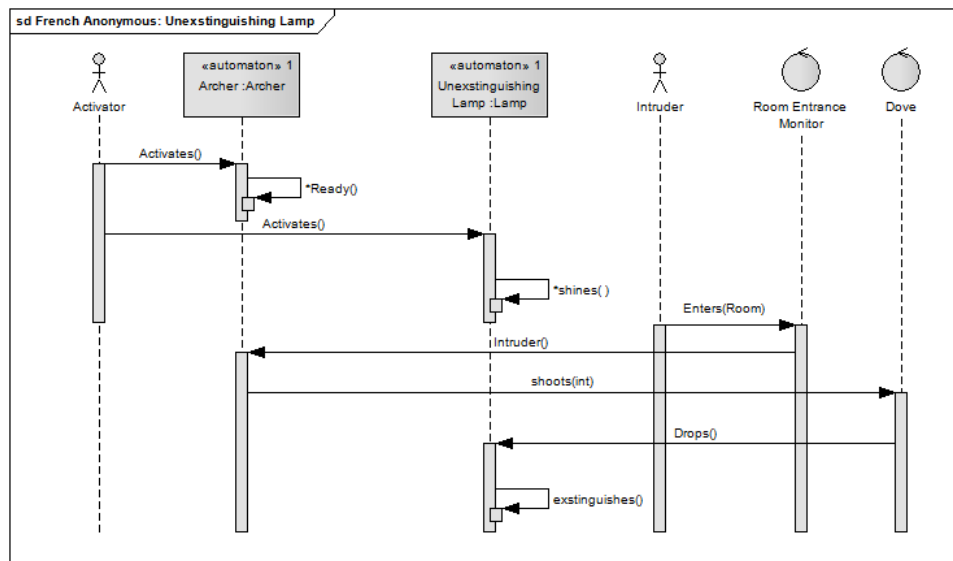
Fig. 121: Unexstinguishing Lamp in Roman d'Eneas

The lives of ancient and medieval knights were made more difficult by the presence of objects designed to test their virtues:

- a goblet [176], that let liquid out only if held in a special way. In this last example we still find, as in al-Jazari, the use of an object apparently common, but automatic, to trick someone; in fact, Huon of Bordeaux is tested by his host, who offers him the filled cup, saying that only honest men can drink from that goblet. Huon, however, looks at the moves made by the host before drinking from this "Tantalus' cup", and passes the test easily, claiming to have discovered the trick.

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[175] Very similar to Virgil's automaton, but interestingly also to lamp with automatic feed in Philon's #20, to Heron's #71 and to Banu Musa's 95. French Anonymous - 12th c. *Roman d'Enéas*, ll.s 7669-7718.

[176] [518] Similar to Philon's # 43-48 (mainly 45); and to Banu Musa's # 14, 15, 24; French Anonymous - 12th c. *Huon de Bordeaux*, ll. 3644-3788. Although this is not an automaton *stricto sensu*, its repeated presence in the tradition of pneumatic devices is an indirect evidence of its spread. It should be noted however that due to the simplicity of the device, it could only be a craft tradition, parallel to the scholars' one. Sherwood quotes an anologous silver cup, made in silver, and housed at Corpus Christi College Museum in Cambridge. Probably the oldest instance is a figurine found in a Boeotian tomb and dating back to the early 6th century BC; it depicts a satyr, on his knees, while holding a jar [519].
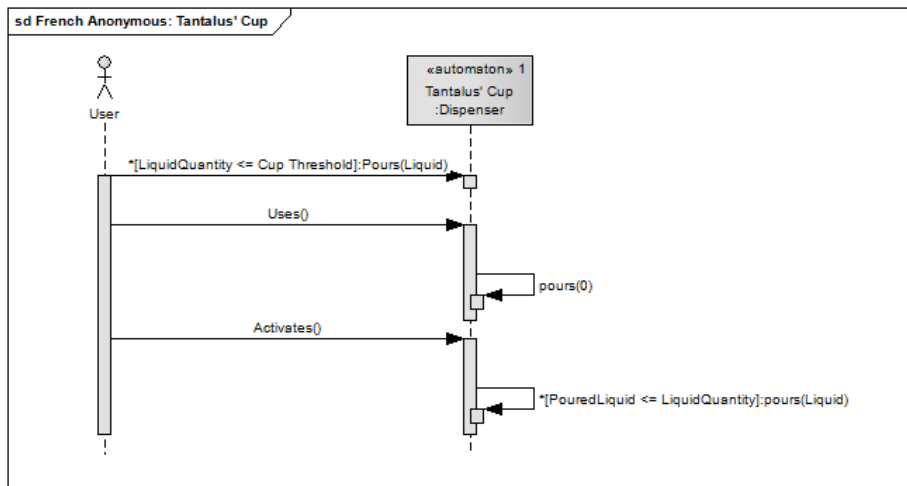
Fig. 122: UML Diagram of Tantalus' Cup

- a pillar on which were placed iron rings for horses, that worked however only for excellent knights [177]; if virtues are not enough, horses are freed.
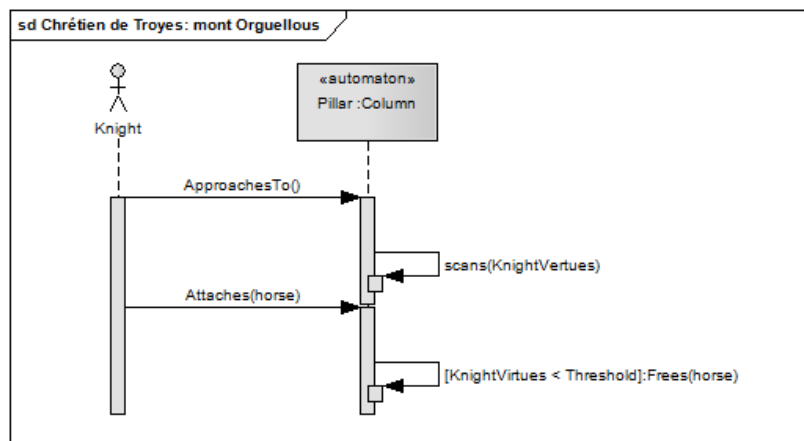
Fig. 123: UML Diagram of Pillar of Mount Orguellous

- a golden seat (the "siège perilous") where only virtuous knights could sit, unless they were either sent to sleep, or imprisoned in an abyss as deep as hell [178]; according to the two versions, the knight sir Perceval succeeds both in sitting and in freeing other knights previously imprisoned by the seat.

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[177] Chrétien de Troyes *Perceval,* ll. 22202-22216; 30616-30669; 33915-34369
[178] French Anonymous - 13th c. *Durmart le Gaulois*, ll. 9504-9609; 9653-9672; Chrétien de Troyes, *Perceval*, Fragment in *Perceval le Gallois* [520], pp. 171-173
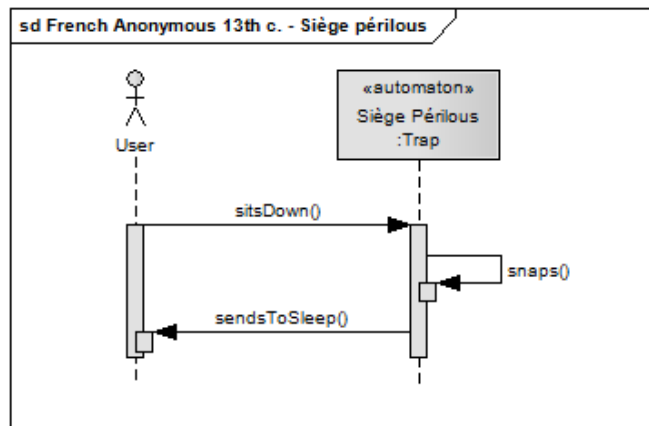
Fig. 124: Siège Périlous
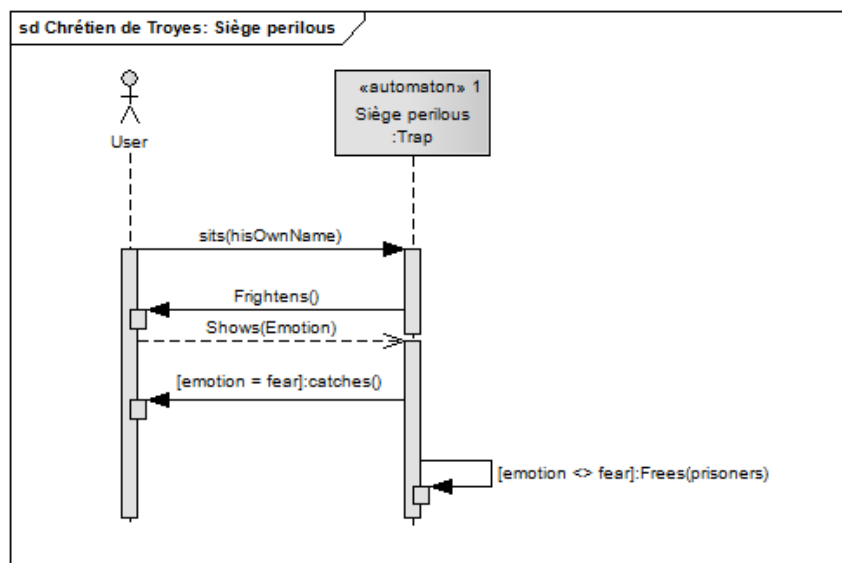
Fig. 125: UML Diagram of Siège perilous

- a moving bed [179] (the "lit merveille"), whirling in a room to prevent crossing; once the knight had jumped over there, one hundred catapults covered him with stones, had he not had the forewarning to bring the shield with himself in his jump. This instance is possibly the source of the passage by Boiardo (see *infra* 2.5.5.1.7).

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[179] Wolfram von Eschenbach, *Parzifal* XI, 561, 21-562, 6; XI, 566, 11-568.
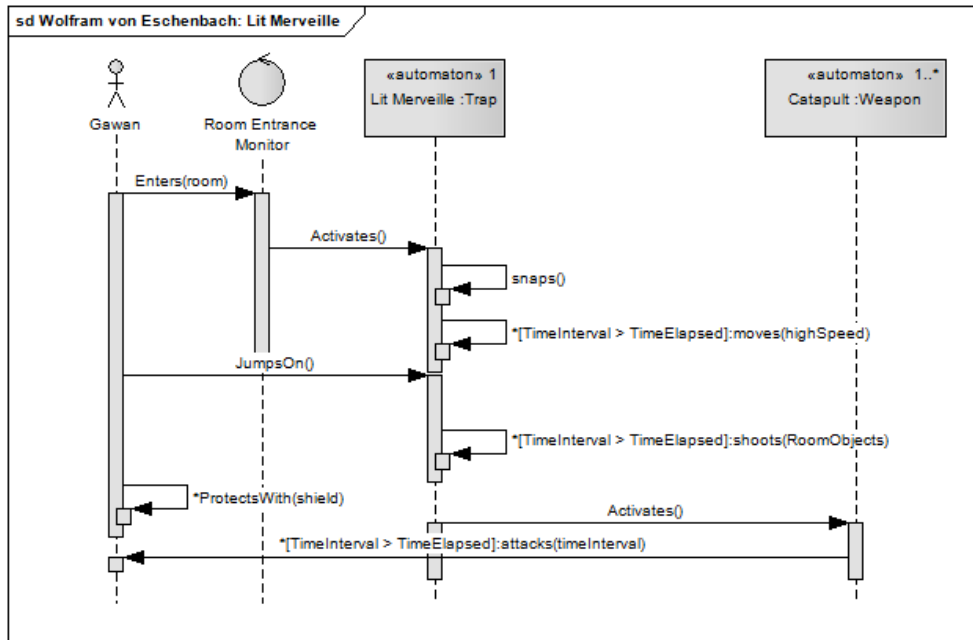
Fig. 126: UML Diagram of Lit merveille

Sometimes, they were also helped, or, at least, entertained by:

- a viola, that could make lions fall asleep [180];
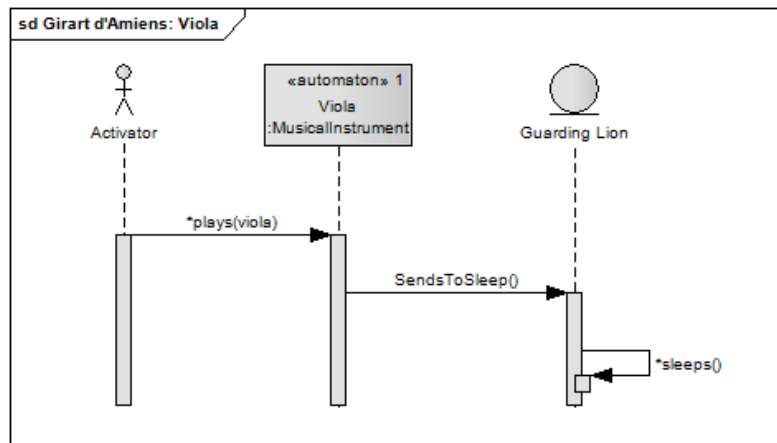
Fig. 127: UML Diagram of Viola

- an unmissing bow (arc-qui-ne-faut), that hit and bound whatever was targeted [181];

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[180] Girart d'Amiens, *Escanor*, ll. 15869-15876
[181] French Anonymous - 12th c. *Huon de Bordeaux*, ll. 3223-3228; Béroul, *Tristan*, ll. 1716-1730 ; see *infra* 2.4.4.6
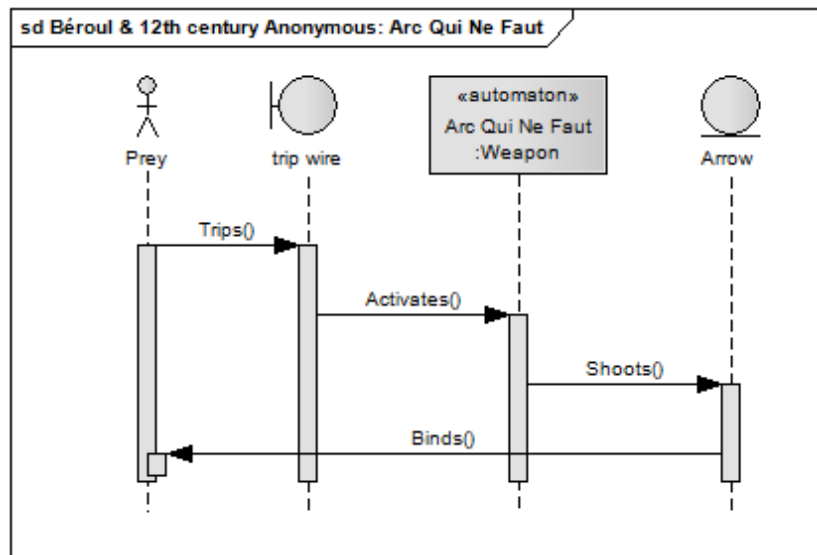
Fig. 128: UML Diagram of Arc qui ne faut

- an automated sign post: the knight didn't need to look at signs, as a wooden hand, by recognizing him, could show the correct direction [182]; such a device results astonishing for its ability to anticipate in some way an implementation that only recently has taken place (satellite-based navigation systems and automatic traffic management) [521].
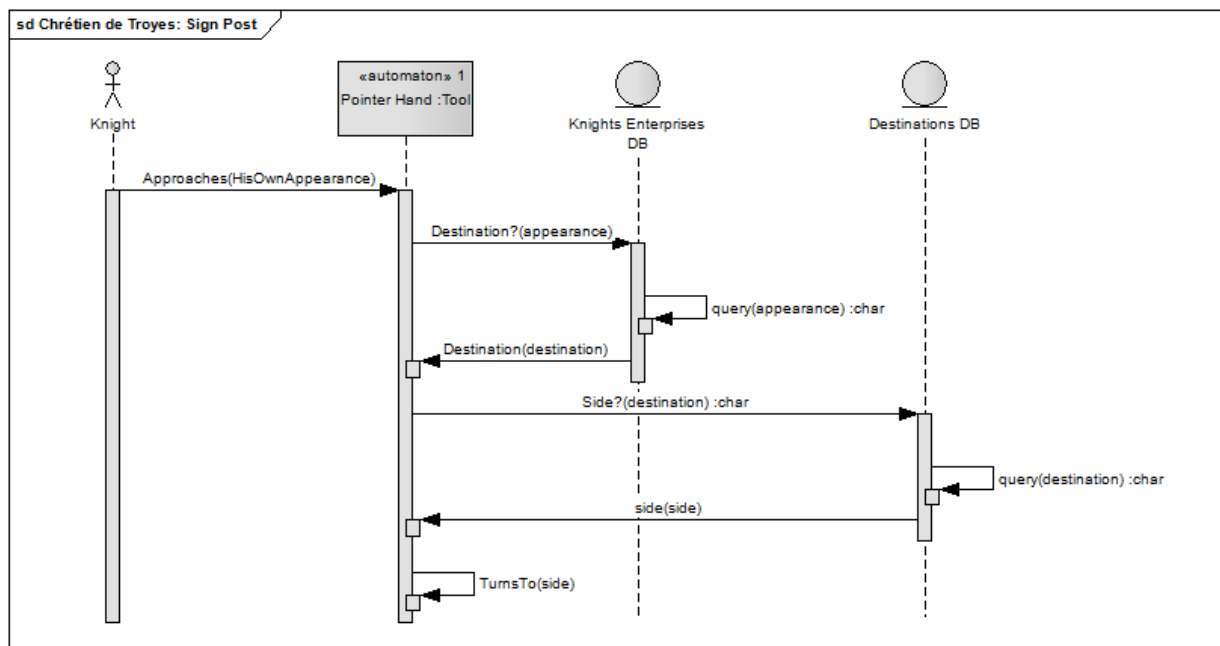
Fig. 129: UML Diagram of Sign Post

- an automated chessboard [183], that can make moves and systematically defeat the human player. It presupposes the existence of a database of moves and games.

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[182] Chrétien de Troyes, *Perceval*, Fragment in *Perceval le Gallois* [520], p. 255
[183] Welsh Anonymous - 12th century, *Peredur fab Efrawg*; Chrétien de Troyes, *Perceval*, ll. 22442-22522. When Perceval uses it, however he can't win a single game, becoming so angry that he tries to destroy the chessboard. [522]
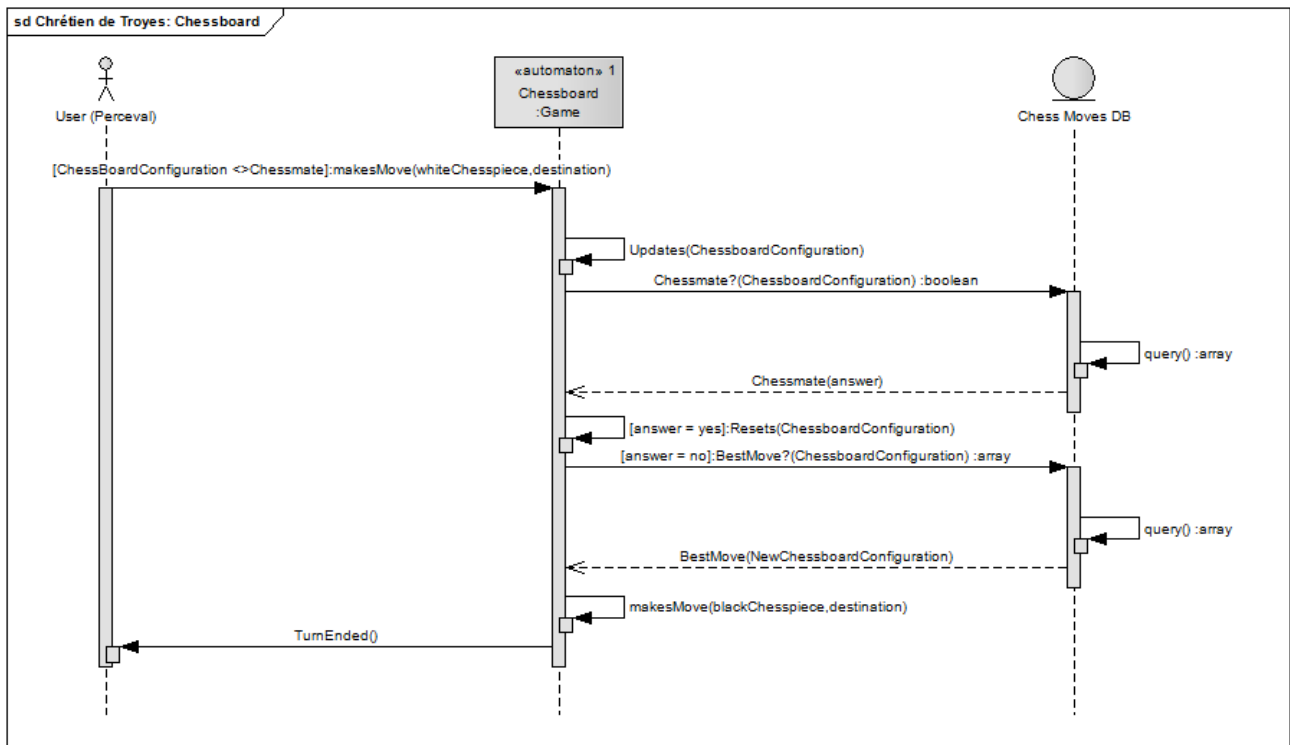
Fig. 130: UML Diagram of Chessboard

In any case, knights couldn't even rely on the stability of buildings and places, as they faced:

- closing city walls [184]; Hercules, because of his pride, is punished by the city walls, that prevent him from entering the city, by closing in front of him.
- rotating castles and palaces [185]; both the palace of Constantinoples [523] and the castle of the Grail [183, 524-525] move, though only the latter for defensive purpose.
- chill boiling fountain [186]; even this last instance is not strictly an automaton, but it appears as an implementation based on pneumatic principles.

2.4.4.5.2 English Narrative and Italian Poetry in 14th century

Closely linked to the theme of magic devices is a sonnet by Dante Alighieri (1265-1321), *Guido, i' vorrei*, taken from the *Rime*, LII. The poet speaks to his friend Guido (Cavalcanti) and discloses his impossible desire: a magician should take Dante himself, Guido, and a third friend, Lapo Gianni, and allow them to leave for a trip on an enchanted ship, in perfect harmony, where they could also enjoy the company of their women. The ship behaviour is very similar to the Phaecians' ships: travelers don't bother to drive the ship, nor about the weather, since all they need is to express their own wish about destination. The ship of Dante's sonnet evokes feelings of joy, peace and friendship, the exact opposite of the terror caused by the "navire" without any crew, inexorably carrying in a mysterious land Guigemar, the protagonist of the homonimous romance by Marie de France [526], living in the late 12th century. A common source could probably have been the *Navigatio sancti Brandani*, a short Latin prose work composed in the 10th century, probably by an

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[184] Gautier d'Arras, *Eracles*, ll. 6186-6189;
[185] Respectively the "*palais errant*" in French Anonymous-12th c. *Charlemagne's Voyage to Jerusalem and Constantinople*, c XIX-XX; and the "*chateau tournoyant*" in French Anonymous - 13th c. *Perlesvaus or Li Hauz Livres du Graal*, quoted all along the poem.
[186] Chrétien de Troyes *Yvain*, ll. 380-454.

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Irish monk, and handed down by a large number of manuscripts. The direct source of Dante's sonnet is, however, a short poem entitled "Mare amoroso" (Sea of Love), dating back to the late 13th century; in the tale, king Arthur, injured, sails to the Isle of Avalon on a vessel full of beautiful women, built by Merlin [527]. Only in Dante's work, however, we have a fully detailed description of the ship behavior.
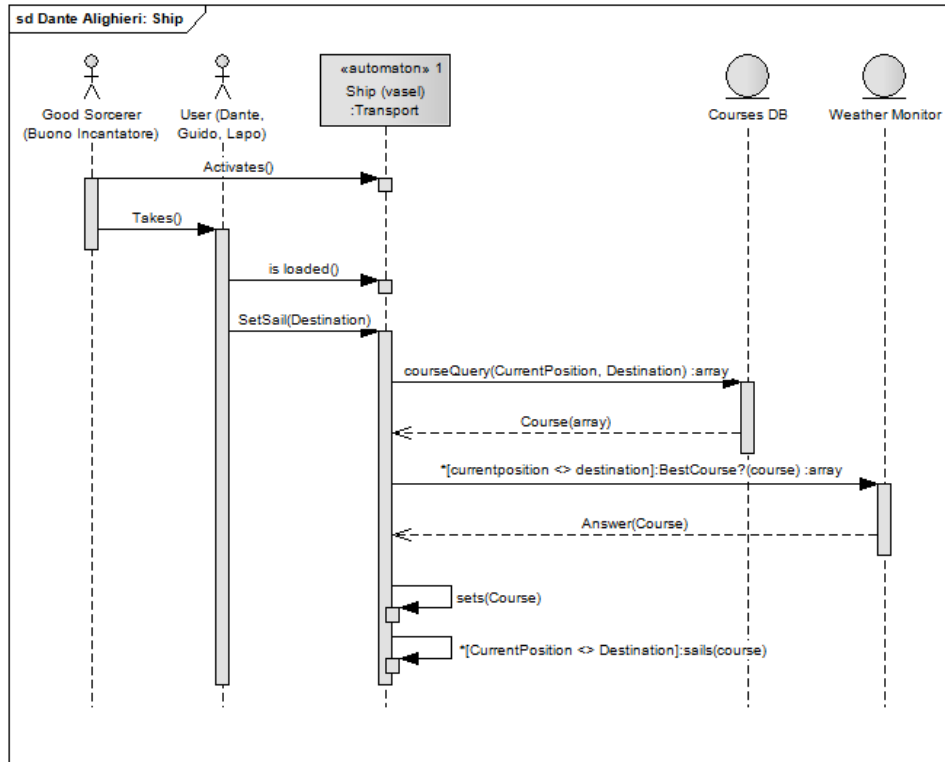
Fig. 131: UML Diagram of Dante, Guido and Lapo's Ship

A major feature of the poetry of Guido Cavalcanti (1259-1300), a leading poet of the Dolce Stil Novo, is dramatization: the expression of feelings and emotions of the poet is entrusted to concrete or abstract objects, speaking to each other or to the public or to the poet's beloved. In Sonetto XVIII, we have a (probably unintentional) appearance of αὐτόματος βίος, since writing tools have recorded (in a log-file or in a Vannevar Bush' memex *ante litteram*) all the poet's experiences, and are therefore able to speak about him, to induce readers to compassion. We have stressed the inadvertence of the quotation as an example of automatos bios, since Guido was certainly influenced by the poetic theory of the Provençal poet Geoffrey of Vinsauf, who recommended the use of prosopopoeia in his *Poetria Nova* [187] [528]; it does not seem likely that he wanted to quote ancient texts, mainly Greek ones.

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[187] II, 2, § 22 "*Prosopopeia est conformatio novae personae, quando scilicet res non loquens introducitur tanquam loquens*". Prosopopaeia is the creation of a new character, when a non speaking object is used as speaking.
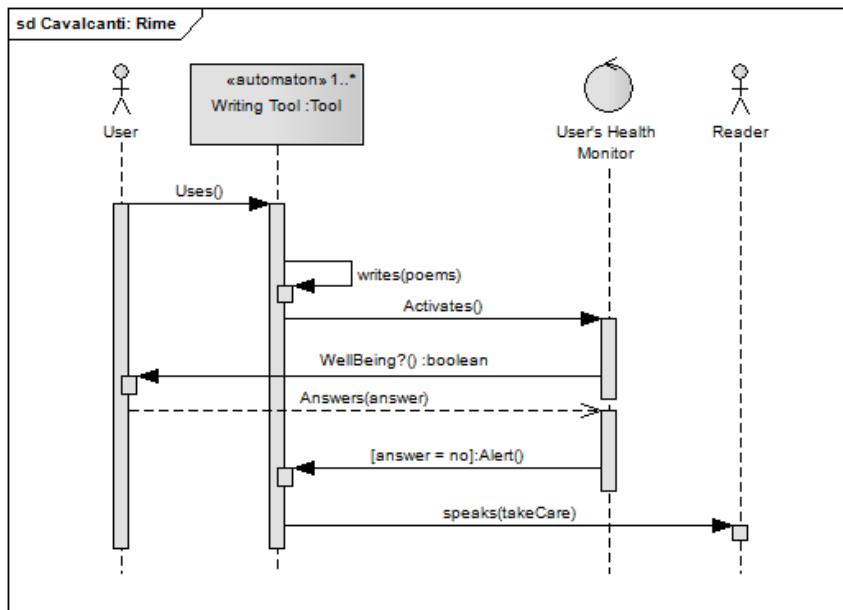
Fig. 132: UML Diagram of Cavalcanti's Writing Tools

In Geoffrey Chaucher's *Canterbury Tales*, written at the end of the 14th century, we also find an open reference to automata, namely a steed of brass, in *The Squire's Tale*, where an Eastern ambassador gives it to the Mongol king. It is yet another quotation from the magical steed of the *One Thousand and One Nights* (see 2.4.3.2.1), or of the cheval de fust (2.4.4.5.1.2), although with a small change related to its speed: it can reach any destination in no more than one day. As recently stated by Lionarons [529], even more attractive than the horse itself is the reaction of the courtiers and of ordinary people who look at this wonder in the courtyard: they say it is a magical thing, even if it is clearly due to mechanics, "an attitude which seems to suggest that the essence of its magic could be that no one quite understands how it works. [...] None of the magic in the tale necessarily involves the supernatural; none is clearly differentiated from the technological. Nevertheless, even if the so-called "magic" is really technology, it is still suspect, precisely because it is based on uncommon knowledge and can therefore be used by the learned to deceive the ignorant."
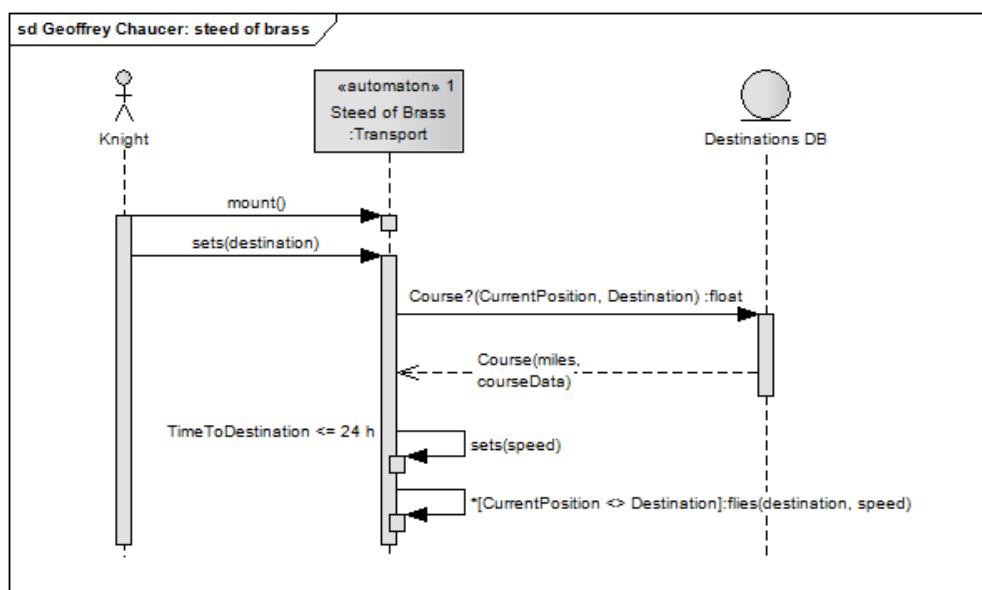
Fig. 133: UML Diagram of Geoffrey Chaucer's Steed of Brass

2.4.4.6 Technicians

Some scholars [188] drastically stated that the accomplishments in the field of mechanics were largely preserved by the Arabs and conveyed through Spain and then to the whole Europe; though we don't have any positive evidence about the manuscript sources of this mechanical renaissance of the 13th century [189], we can agree with their statement as for its visible effects: we witness an increasing presence of automata, that contradict Grau's statement "Medieval evidence of the automaton is almost completely nonexistent" [532]. As White very well stated [512], we can add that scientists were very reluctant as to implementation, for instance to making their own instruments, an action traditionally considered as humiliating. Only the abbot of St. Albans in England, the Benedictine Richard of Wallingford (1292-1336), around 1330 personally designed and made a "geometricum instrumentum", that could show the motions of sun, moon, and tides. His atypical realization may be attributed to a lasting monastic respect for handworking, since probably the most famous portrait of Richard, shows him "with his crosier and mitre tossed aside, hammering at the forge to make his invention". We couldn't find the image White refers to, due to incomplete quotation data; in any case, he forgot to say that all portraits are so realistic that the abbot's face shows even the signs of a terrible disease, that had never stopped his work: leprosy.

In order to draw the landscape of this rebirth of mechanics, Sherwood [184] recalls the presence of treatises on the topic in Latin language, such as translations of the *Book of the Balance*, attributed to Euclid, and of pseudoAristotle's *Mechanics*; or new works on statics by Jordanus (probably Nemorarius), such as *Elementa super demonstrationem ponderis*, and *De ratione ponderis*.

Machines, as Sherwood states, were being improved: mainly the water-wheel, that, though appeared in Europe very early, in the 4th century still needed to be put into practical use. The scholar therefore introduces one of the most important sources for our purpose, though referring to him for the sketch of a water-driven saw: the French architect Villard de Honnecourt.

2.4.4.6.1 Villard de Honnecourt

We know very little about his life. His place of origin, Honnecourt, is a small town in Picardy, near a Benedictine abbey. He traveled a lot in France, Switzerland, Germany, Hungary, but he is famous for a collection of annotated drawings, that is fundamental for our knowledge of Gothic architecture: the *Livre de portraiture*, probably only part of the original, including 33 parchment sheets, each written and drawn on both sides. The *Livre* is housed at Bibliothèque Nationale de France (Français 19093) [225], and searchable online (http://classes.bnf.fr/villard/index.htm), along with an interesting study of the *Livre*, carried out by Bechmann [533] in 2001, considering seven facets of expertise: architecture, stereotomy, applied geometry, mnemonics, companionship, the field manager, and inventions and automata.

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[188] Among others, Sherwood [184], and Losano [150]. The former quotes, in the previous paragraphs, the *Libros del saber de astronomia* [530], a translation made in 1276-1277, under the reign of Alphonse X the Wise, king of Castile and León, rather linked with clepsydras and clocks, than to automata; then the scholar entirely relies on Thorndike's authority [491], vol. 1 p. 189.

The latter also generically refers to Latin translations of Arabic works, that would date back to the 12th century in Spain, but, instead of giving further details to eventually identify them, he describes the translation activity in general.

[189] Thorndike is frequently moved by enthysiasm for discoveries, and sometimes gives an emphasis perhaps exaggerated, as it is the case, for instance, of the invention of the mechanical clock about 1271, he infers from a passage in the *Commentary on the Sphere of Sacrobosco* by Robertus Anglicus, found in manuscript housed at Basel library [531].

What are called automata, only appear working of themselves, but they are nonetheless remarkable to our purposes, due to their close resemblance to the devices of chivalric literature:

- f. 9r: *cantepleure* (sing-and-cry) goblet, or Tantalus' cup [190].
- f. 22v:
    1. *par chu … fait om / l'arc ki ne faut* (by this [means] one makes a bow that does not miss)
    2. *par chu … fait om / un angle tenir / son doit ades vers le solel* (by this [means] one makes an angel hold its finger always towards the sun)
    3. *par chu … fait om dorner la teste del aquile / vers le diachene kant list la / vengile* (by this [means] one makes the eagle face the Deacon while the Gospel is being read).

Honnecourt's designs are quite essential, lacking in many details, and require a large dose of intuition, combined with a good knowledge of techniques of the time, to reconstruct the proper functioning, since even captions are usually very short, probably because, as White states [512], "those who compiled them had not been taught to communicate through books".

The cantepleure is another version of Philon's, Banu Musa's and Medieval Tantalus' cup: here we have however the presence of a bird, that appears emphasizing the link with the Greek tradition (see Fig. 35), maybe with some Byzantine flavor. How aware was Honnecourt of this affinity, it is difficult to say.

Sherwood [184] refers of a similar device preserved at Corpus Christi College in Cambridge: "The device consists of a wine goblet with a hollow stem and base. The stem contains a tube, which rises just short of the brim of the cup and is disguised by a tower with a bird perched on top. When the cup is filled with wine, and the thirsty drinker wishes to take a sip, the liquid is siphoned off into the base of the cup, to the delight of the bystanders. In some cases, a hole in the bottom of the goblet causes the wine to pour over the drinker. If, instead of offering a drink to a guest, the host pours the wine gradually into the cup, the bird appears to be drinking it."

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[190] *vesci une cantepleure con / puet faire an .i. henap en / tel maniere, q[u]ens en mi le / henap doit avoir une torete / et ens enmi liu de le torete / doit avoir .i. behot. Qui tiegne / ens el fons del henap. Mais que li / behos soit ausi lons com li henas / est parfons et ens en le torete doit a / voir .iii. travecons par sontre le fons / del henap. Si que li vinc del henap puist / aler al behot, et par deseur le torete doit avoir / .i. oiziel qui doit tenir son biec si bas que quant li henas iert plains quil boive, a dont sen corra / li vins par mi le behot et par mi le piet del henap qui est dobles, et sentendes bien que li oisiaus / doit estre crues.* See here a sing-and-cry as can be made in a goblet, in such manner that in the middle of the goblet there must be a little tower. And in the middle of the little tower there must be a tube that touches the bottom of the goblet, so that the tube is as long as the goblet is deep. And in the little tower there must be three crosspieces across the bottom of the goblet, so that the wine in the goblet can go into the tube. And above the little tower there must be a bird that must hold its beak so low that, when the goblet is full, it drinks. Then the wine will flow through the mid tile of the tube and through the middle of the floor of the goblet, which is double. And understand well that the bird must be hollow. In his *De fugiendis et expetendis rebus* Valla refers to it as to *futilis contructio* (see *infra* 2.5.6.1)

Fig. 134: Villard de Honnecourt Sketchbook f. 9r (detail)

L'*arc ki ne faut* shows a remarkable similarity to the above-cited passages in which Tristan ensures a kill with a similar, and homonymous device. A possible question is whether these are two distinct examples that relate to a weapon that actually existed, or Honnecourt has striven to build the weapon described in the poems; the accuracy of both working descriptions (in Huon, and in Tristan) would favor the first hypothesis.

Fig. 135: Villard de Honnecourt's Sketchbook f. 22v (detail)

In Honnecourt's sketch, are perfectly visible

- the crossbow with adjustable rise
- the arrow tied to the rope, which serves to bind the prey
- the base where the counterweight to improve the range is set (Bechmann estimates up to 100 m).

The last two devices (the angel and the eagle) have an interesting feature [153]: the restoration of the liturgical setting, which, in the Christian, or, better, in the Medieval world, is unprecedented. The attitude of the Church, as seen in the case of natural philosophers, was of distrust rather than of

acceptance; Honnecourt, on the other hand, does not seem to feel the design of such devices inappropriate, probably because, in those centuries, theatrical genres of religious content (miracle, mystery and morality plays) were developing, presenting an account of the life, miracles, or martyrdom of a saint; or biblical subjects, or even personifications of moral qualities. Such an initiative by the church could also have paved the way to the use of some contrivance to increase the participation of the faithful, as we will see in Italy in the 15th century, when the renown architect Brunelleschi was responsible for implementing similar devices [191] (see *infra* 2.5.3.3).
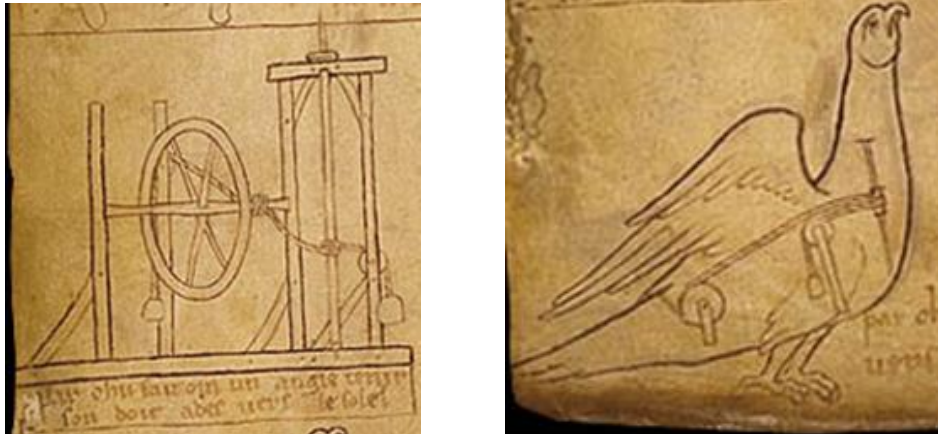
Fig. 136: Villard de Honnecourt's Sketchbook f. 22v (details)

As Cigola [153] has pointed out, the angel, that was most likely created to move about the pole on the left side of the drawing, is not represented, since recipients were experts who did not need guidance on the iconographic or scenographic details, but only on the operation of the device.

The eagle, "probably the oldest image of a western automaton that has come down to us" [153], is instead characterized by a more precise attention to details, probably due to the need to clearly show how to dispose and hide the pulleys and the counterweights within the eagle itself.
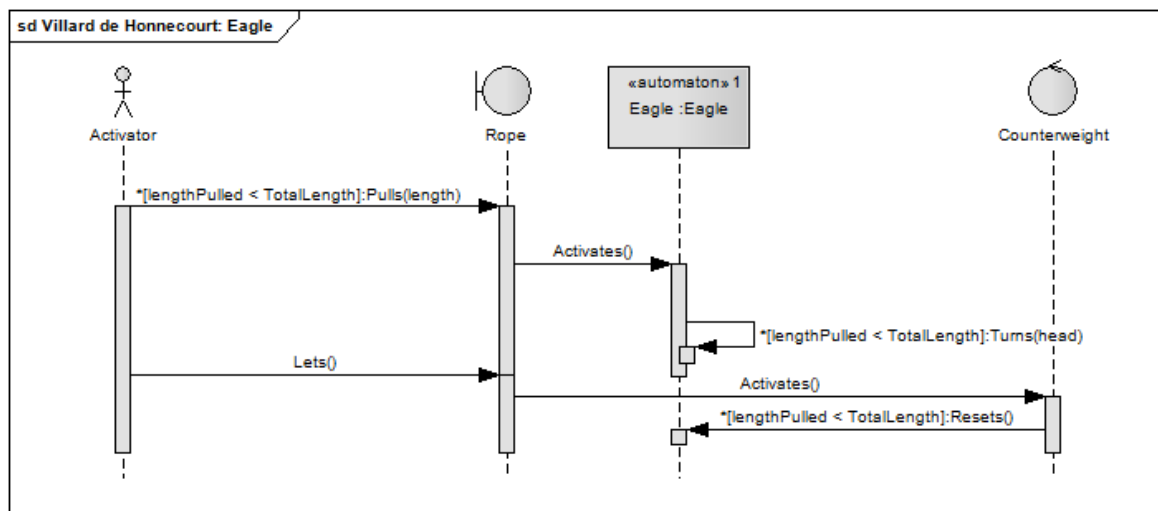
Fig. 137: UML Diagram of Villard de Honnecourt's Automated Eagle

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[191] Such as the "ingegni" for the representation of the Annunciation in Florence in 1439, during the council [534] of the Eastern and Western church, in the SS. Annunziata or in S. Marco; and the other ones for S. Maria del Carmine or S. Felice in Piazza, even in Florence.

2.4.4.6.2 The Hesdin Castle

One of the most interesting examples of automata implementation in the Middle Ages is the whole castle of Hesdin, in Artois. According to the first quotations we have about it, in the castle or in its huge park, the counts of Artois, and later, Philip the Good or the dukes of Burgundy, built and/or maintained a large number of automata, at least until 1470, when we have the last quotation, made by the English writer and diplomat William Caxton (1412-1490), fascinated by the place [535, 218]. Franke [218] has meticulously reconstructed the history of the castle through the research of archival documents and also tried to describe the appearance of some castle automata, looking for similar contemporary works to compare with quotations content.

This castle [535] was along centuries an actual "hortus deliciarum" (garden of delights), where noblemen could rest, surrounded by marvels. The park surrounded a fortified castle of the 11th century, and was conceived by Robert d'Artois at the end of the 13th century. Robert II d'Artois was undoubtedly influenced by a journey in Sicily made in 1270, to bring back to France the remains of king Louis IX (who had died during the seventh crusade), and by his subsequent 5-years stay in Naples and Palermo. When back in Artois, he built a residence and a wonderful park; we have a detailed documentation on the work and of the craftsmen, who worked there, as well as literary evidence.

He first enclosed his possessions, then built a house of delights, the House of the Marsh (Maison du Marais), placed in the middle of pavilions, gazebos, and fountains; and a labyrinth (Maison de Dédale), all in the countryside. Automata spread into the park of Hesdin itself: swans, lions, and later also monkeys, an elephant, boars and a he-goat. The idea of such a garden, where automata and other devices enhanced the beauty of nature, came probably to him from the Arabic culture and the engineers, expert on hydraulics, Robert d'Artois could have met at the court of Naples in his stay. Another possible source are French romances; as a matter of fact, in his library in Hesdin Robert d'Artois housed some of these works (*L'histoire de Perceval le Gallois, L'histoire de Troyes, Le roman de Tristan*) [536].

The first mention of a restoration of such "engiens d'esbattement" (machines for fun) dates back to 1299, in the account-books of Mahaut, Countess of Artois, Peer of France and great-niece of St. Louis; automata had been probably installed by her father, Count Robert of Artois, once . We also know that the name of one of the engineers ("maistre des engiens") who worked at the castle to upgrade and to maintain automata, was Jacques de Boulogne. Throughout the 14th century, we are witnessing frequent maintenance of the automata, placed in the garden (especially some monkeys that suddenly appeared near a bridge, while someone was passing by; some birds, an elephant, a boar and a he-goat): skin, gold, quicksilver, and glass were bought to refurbish them. During the Hundred Years War (1337-1460), the devices in the garden were poorly maintained, and later also destroyed.

In 1419, Philip the Good (1396-1467) came into possession of the castle, and automata were completely rebuilt inside the building. He hired Colard le Voleur (Colard the Thief, *varlet de chambre et paintre de MS le Duc*), who covered the gallery walls with frescoes representing the myth of the Golden Fleece, and fully refurbished automata. He also transformed the ballroom into an entertainment room, the *Salle des Distractions*, where everything was based on water. The *roulotte* was also built by order of Philip the Good. It was a kind of dining room on wheels, open to the outside so that one could look at the beauty of the park while eating [537]. Even though this last

device can't be considered a very automaton, it is remarkable that even in this case we deal with the implementation of a design idea taken from romances (see *supra* 2.4.4.5.1.3).

As we can see, both the position in the castle and the types of automata varied much over the centuries; some of them were intended to surprise an educated audience (the hall that turns on itself to face the sun is a reminiscence of the Grail castle, and the throne next to which there is a golden tree with singing birds is another reference to the throne of Byzantium); others simply were intended to populate the garden (monkeys, elephants); others should entertain the lord against their hapless hosts (like the *Salle des Distractions* that was an amusement park, from the Lord's point of view) and finally the cycle of Jason and Medea (where the show of panels depicting the story was accompanied by the simulation of a real storm[192]) could possibly be considered a first attempt at virtual reality.

Probably the most extraordinary is the *Salle des Distractions*, where even if we deal with automata, they need continuous inputs by the "victims" (users). The plot is quite simple, as the UML diagram clearly shows: the victims enter the gallery, where they are forced to face one after another a group of automata, that

- Criticize (hermit)
- Wet (floor, generic human figures, fountain, guardian)
- Cover with flour (a roof, a generic human figure)
- Make fall (bridge)
- Invite to leave the gallery as soon as possible, only to send to face another automaton (bugler).

The Lord is looking at this from outside, and enjoys the spectacle of his terrified guests [539], prisoners in a sort of Medieval candid camera. One might perhaps ask how rich the social life of such a host could be, after he had subjected many visitors to this treatment, but, as we will later note in 2.5.8.2, wetting one's guests with automata was a common habit in such parks.

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[192] It must be noted that this is again a quotation from romances such as *Huon de Bordeaux* (ll. 3267-3279) and *Yvain* by Chrétien de Troyes (ll. 380-454); and in *Girart de Roussillon,* 15 [538].
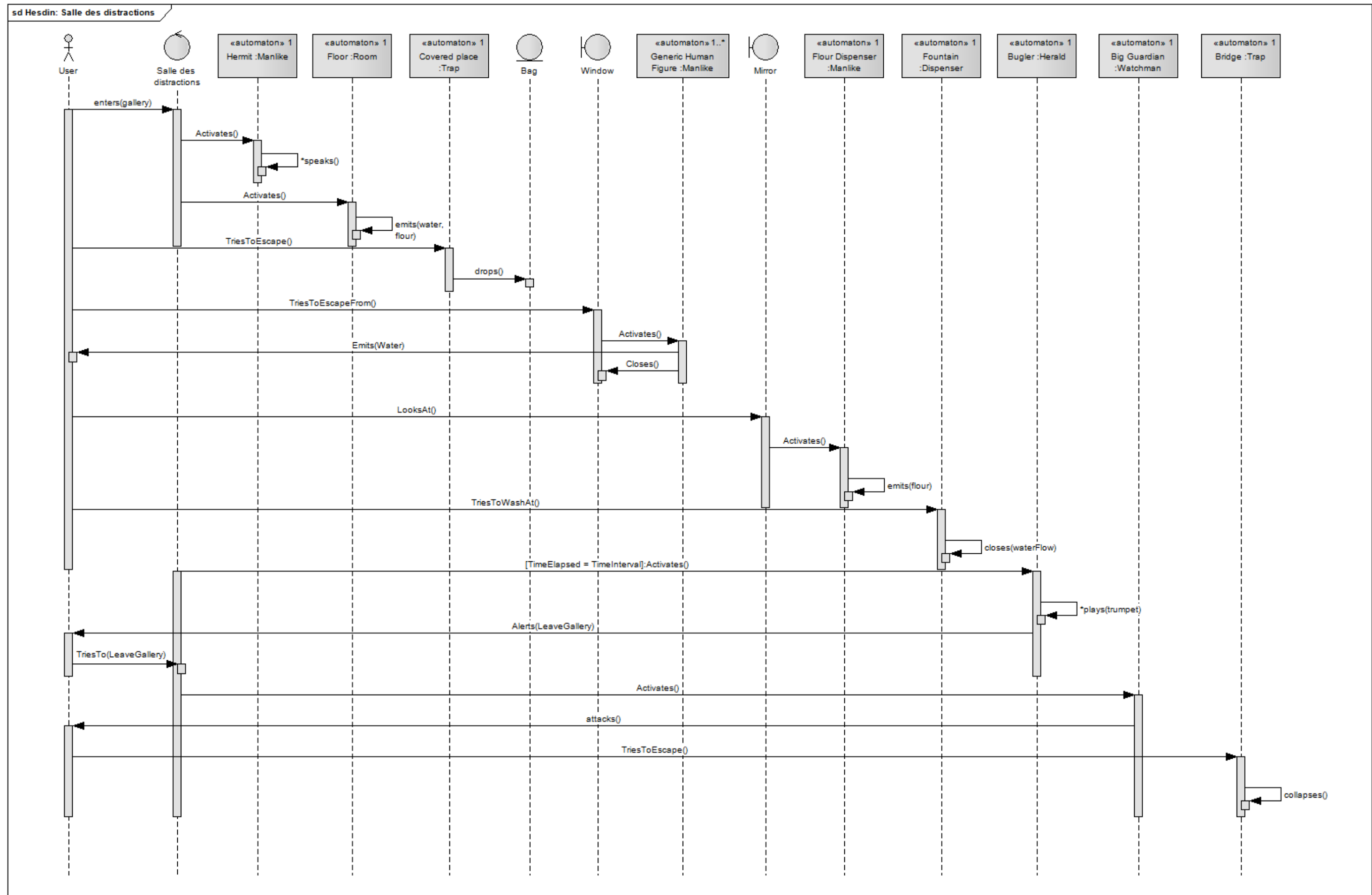
Fig. 138: UML Diagram of the Salle des distractions

2.4.4.6.3   Wine and Water Fountains

Not all Medieval hosts had (luckily) the same habits of the Dukes of Burgundy, since some of them even bothered to offer their guests a memorable lunch or dinner [540], thanks to automata of great value that served as wine or water dispensers, just as at the Arabic courts. These devices, known as wine or water fountains, were placed at the center of the table and pumped the liquid automatically (to the top of the fountain) from a large cup that served as base; then the liquid went down from one floor of the fountain to another through animal (or gargoyle) shaped mouths. The guests had just to put their glass under one of these mouths and this would be filled.

There are however very few examples of these simple devices: the most complete, as it is known at present, is preserved in the Cleveland Museum of Arts (see *infra* Fig. 140). The fact that there is only one example should not mislead: they are fairly common devices, but for their great value (as the trees of the throne of Byzantium) they were often reused for other purposes. As recalled by Fliegel [541], many of them were dismembered and adapted to religious furnishings.
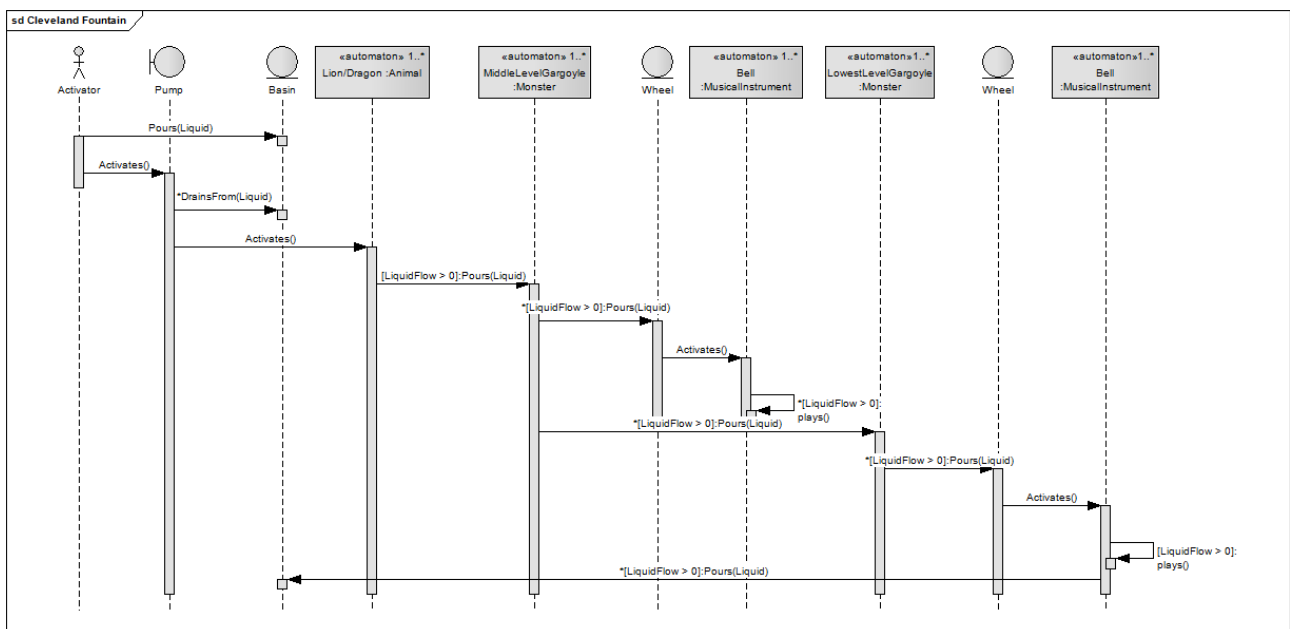
Fig. 139: UML Diagram of Cleveland Wine Fountain

Fig. 140: Cleveland wine fountain

2.4.4.6.4   The First Automata in Tower Clocks

In the late Middle Ages, we witness the spread of tower clocks, which were intended to articulate the life of either religious or civil communities. To exhibit the prestige of the community, automata (mainly characters of the Bible, or saints) were often added to the structure, just like in the Arabic world: on the hour they performed a small show.

We can remark that more or less in the same years when the castle of Hesdin was in activity, one of the oldest mechanical automata appeared in Italy, in Orvieto. In 1347 the Opera del Duomo (Committee on the cathedral works) charged the clockmaker Francesco with building a clock mechanism, which required 285 pounds of iron, three blacksmiths, and eight craftsmen. The following year a bronze automaton was added to the clock as a striking system; it represents a "dottiere", a yard overseer, who was in charge of verifying compliance with working hours, and of forbidding workers to waste time. This is one of the rarest, and oldest, instances of automata (before the Renaissance), due inter alia to a virtually unknown clockmaker [193]. In addition, this is clearly a device which was rather designed for practical purposes than to impress an audience: the automaton had become so familiar to the citizens of Orvieto, and to the yard workers, that it was even given a name: Maurizio (distortion of the word "muriçio", that indicates the yard).

Fig. 141: the Clock in front of the Duomo

One of the most renowned and remarkable automata connected with an astronomical tower clock was the cock of the cathedral of Strasbourg [74], that has a long history, since the clock was completed in 1354, and, after some 150 years, it stopped working until the 16th century, when it was completely rebuilt. The present clock dates back to the 19th century, after a restoration by Jean Baptiste Schwilgué (1776-1856). The clock that is visible nowadays, is the one rebuilt in the 19th century, restored as it was in the 16th-century version. Together with the cock, whose iconography

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[193] Probably the first known name we have in a written source about jacquemarts is that of Andrea del Verrocchio (1435–1488), that famous painter and sculptor, in whose workshop Leonardo was apprenticed. According to Vasari (*Le vite de' più eccellenti pittori, scultori, e archi tettori*, III, Andrea Verrocchio), *è anco di mano del medesimo* [Andrea del Verrocchio] *il putto dell'oriuolo di Mercato Nuovo, che ha le braccia schiodate in modo che, alzandole, suona l'ore con un martello che tiene in mano: il che fu tenuto in que' tempi cosa molto bella e capricciosa.* and was also made by him [Andrea del Verrocchio] the little boy of the clock in Mercato Nuovo, that has such arms that, by lifting them, it strikes the hours with a hammer he holds; and it was considered at those times as a wonderful whim.

is due to the Bible [194], there were other characters: the Magi and the Virgin Mary and Child, in the 14th-century version; at 12 o'clock, the three Magi moved and bowed before the statue of the Virgin and Child, while a carillon was playing, and a cock was crowing and flapping its wings. One can easily see the similarity, except obviously for the religious theme, with the scenes represented in the clocks designed by Arabic engineers.

Fig. 142: the Strasbourg Cock (Strasbourg Museum)
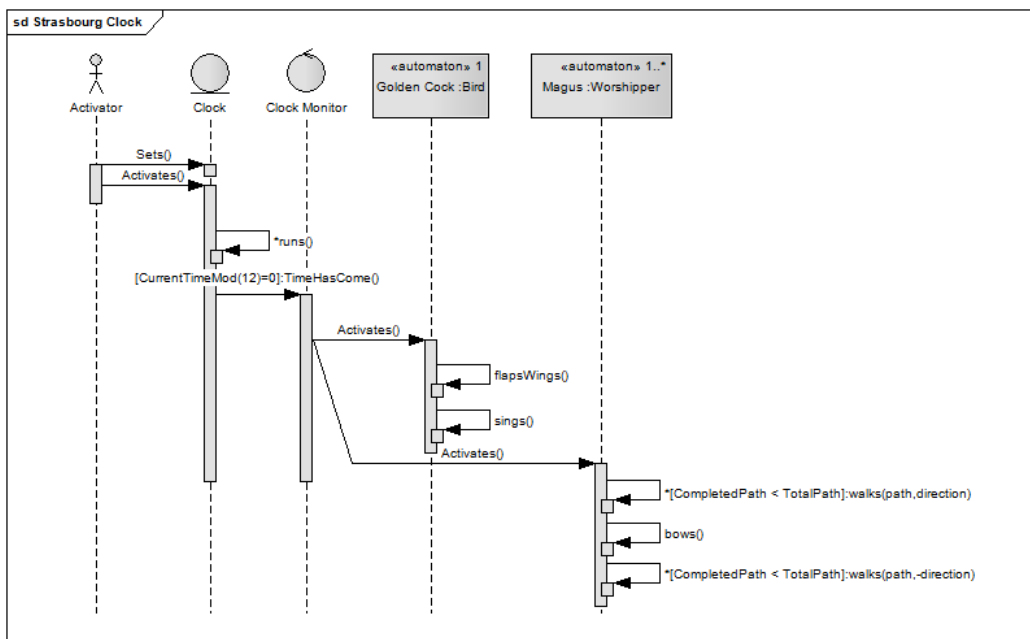
Fig. 143: UML Diagram of Strasbourg Clock

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[194] Gv 13:31-38; Mt 26:30-35; Mr 14:29-31

2.5 The Renaissance

2.5.1 From East to West

During the 15th century two events occurred that strongly influenced the spread of ancient Greek culture in the West, including the texts of *Pneumatics*. The first one was the Ecumenical Council of Basel-Ferrara-Florence (1431-1445), that brought to Europe a number of learned Greek clergimen from the East. They had the appropriate language skills to give Western scholars access to the classical works, which until then were only accessible in Latin translation, often mediated through an older Arabic one. The second event was the fall of Constantinople in the hands of the Turks in 1453, which produced a stream of Greek scholars and manuscripts from East to West, and contributed to the beginning of the Renaissance. The arrival of these resources to the West was welcomed with great interest especially at a time when the culture was freeing itself from the medieval heritage, both in the field of the so-called *humanae litterae* and in the scientific knowledge.

As we have already shown, one of those scholars was cardinal Bessarion (1408-1472), who played a major role both in collecting as many manuscript works as he could, creating a rich library, while he was still alive, and in the foundation of one of the most important Italian libraries, the Biblioteca Marciana in Venice, since in 1468 he donated his own library to the city of Venice [240-241, 35].

He also was a patron, funding the studies of the German astronomer Regiomontanus, for the translation of Ptolemy's *Almagest* from the Greek; and a designer, as we will later see in 2.5.3.1.

2.5.2 Pneumatics and Automata Manuscripts

As Boas [362] has clearly stated, "In the late fifteenth and early sixteenth centuries there were signs of growing interest in Hero's work. All the earliest complete Greek manuscripts date from this period." We made a census as accurate as possible of all Greek, Latin and vernacular manuscripts, in order to reconstruct at least the general diffusion of these texts; the census has not been confined to the works of Heron, but also includes, as far as possible, those of Philon (in Latin).

2.5.2.1 Latin Philon's Pneumatics

In addition to Arabic translations studied by Carra de Vaux, some Latin manuscripts survive where there is at least part of the section of Philon's *Mechanics* devoted to *Pneumatics*.

A Latin fragment [195] of the original text was first edited by Rose [542] in 1870, under the title *Liber Philonis de ingeniis spiritualibus*. With minor alterations and accompanied by a German translation, it was published again by Schmidt [46], in 1899; and in 1905, as we have already seen, Carra de Vaux made the critical edition of the Arabic translation.

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[195] Rose used the following manuscripts: Bayerische Landesbibliothek, Lat. 534 (Q) and Lat. 444 (R); Oxford, Bodleian Library, Ashmole 1471 (S); Paris, Bibliothèque Nationale, Lat. 7295 (T); and Vatican Library, Pal. Lat. 1377 (U).

Due to the wide variety of titles given to the text [196], the only way to identify such tradition is by referring to the incipit *Quoniam tuum …/Quia tuum…*, as the translation of the basmala (*In nomine dei pii <et> misericordis incipit liber Philonij de specialibus ingenijs dixitque*) is sometimes completely or partly missing. An interesting remark pertains the name of the recipient quoted in the incipit (*quoniam/quia tuum, amice mi <u>anitoniane</u>, iamdudum noui desiderium*), that is as variable as the title, since we have:

- Antoniane/Automane
- Arzathom/Arzothoni/argutom
- Marzacio/Marzato/Martalom
- Archateni

While the first one seem of Latin origin, the others are more probably due to a transliteration from Arabic. Marzatom is the Arabic name attributed to Archimedes in an Arabic text about the clepsydra, where the recipient is referred to as Aristun. Carra de Vaux in the Arabic manuscripts found other different instances (Muristos, Ristun, and Aristun) and concluded that the recipient's name had to be the Greek Aristos or Ariston (a friend of Philon's, the recipient of *Belopoiika*), corrupted by increasing malformations of scribes, who probably tried to emendate the mistake. Rose made the same assumption.

The manuscript list is however longer than Rose's one, since it includes in addition:

A. Cambridge, Pembroke College 169, ff. 1-4
B. Firenze, Biblioteca Medicea Laurenziana, Ashburnham 210, ff. 141v-144v
C. Oxford, Bodleian Library, Digby 40, f. 9r-15r
D. Oxford, Bodleian Library, Lyell 36, f. 12
E. Biblioteca Apostolica Vaticana, Pal. Lat. 1369, ff. 140r-143r (source of the following)
F. Biblioteca Apostolica Vaticana, Pal. Lat. 1375, ff. 180r-181r
G. Biblioteca Apostolica Vaticana, Vat. Lat. 2975, f. 212-231; the work appears by a certain Vassor.
H. Biblioteca Apostolica Vaticana, Vat. Lat. 11482, ff. 74r-80r
I. Krakow, Biblioteka Jagiellonska, Clm. 568, ff. 104r-104v, whose authorship is attributed to a Philo Hebraeus
J. Praha, Národní knihovny, 832 (X.B.3), ff. 130-133r
K. British Library, Egerton 2622, ff. 85-88v
L. Génève, Universitätsbibliothek, Ms. lat. 80, ff. 28r-32r
M. Firenze, Biblioteca Nazionale, Convent. soppr. J. IX. 26, 67r-70v
N. Berlin, Staatsbibliothek, Lat. 4° 392, ff. 102

And the following, in Italian vernacular:

O. London, British Library, Add. 34113, ff. 1-9; 21-104
P. Dresden, Sächsische Landesbibliothek, O^b 13, ff. 14v-20r

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[196] As we already have seen in 2.4.4.2.2, the title given to this text is far from being stable along time, due to the use of abbreviations which created confusion at least between *spiritualibus* and *specialibus*.

The Latin manuscripts B, C, D, I, J and K contain only an inner fragment of the text. The other ones can be grouped, based on their incipits, into three families:

α) *Quoniam tuum*: A, L;

β) *Quia tuum*: E, F, G, H, N, and some of Roses's manuscripts (T, U).

Family β can be split into sub-families, due to some *errores separativi* in the surrounding words; we have therefore:

β₁) *Quia tuum amice mi Arzathom*: E, F, U; T (*argutom*); E is reported in catalogues as the antigraph of F and T, and its origin is Southern Germany, in 1444.

β₂) *Quia tuum amice mi Archateni*: H, N.

γ) [*Dixit*]*que tuum amice Marzato*: Q; R, S (*zimite Marzato*); M (*Martalom*); here the possessive adjective *mi* becomes part of the name of the recipient.

The oldest copy, entitled *De subtilibus ingeniis*, dates back to the late 13th century, and is housed at Pembroke College Library in Cambridge. It was probably copied in England or for an Englishman, as in an attached list of herbs many names are given in English, despite the presence of an Arabic charm printed inside the cover, against misfortunes, enemies, the evil eye, and during pilgrimages by sea or land. The manuscript, entitled *Practica Gilberti et Gaufridi*, was later owned by a "magister Walter de Stratton quondam Rector de Teweresham", near Cambridge, who gave it to Pembroke by 1349. Besides the *Pneumatics* and the list of herbs, the manuscript includes a *Liber morborum* in seven chapters, that was copied by Gilbertus Anglicus for Johannes de Caturcio (Cahors, in France).

The two vernacular versions are included in collections of texts about engineering and military technology, unlike the Latin ones, which are usually accompanied by medical (especially about urology) or alchemical works.
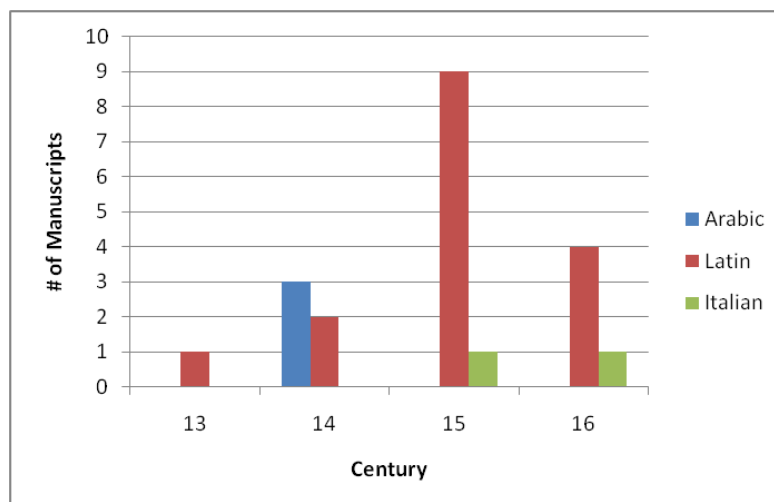
Fig. 144: Philon's Pneumatics Tradition

2.5.2.2 Greek Heron's Pneumatics and Automata

The Schmidt's census of Heron's manuscripts is extremely rich and accurate [46].

Pneumatics	Older recensio (a)	Greek	Complete	13
			Abbreviated [197]	22
			Klasmata	8
			Supplemented	22
			Fragments	7
			Indeterminated	9
			Missing	11
		Latin		4
		Arabic		0
	Later recensio (b)	Greek		6
		Latin		8
Automata	περὶ αὐτοματοποιητικῆς		Better	15
	περὶ αὐτοματοποιητικῶν		Worse	16

He first divides the manuscripts of *Pneumatics* into two groups (recensiones), based on the presence (older) or absence (younger) of some paragraphs of Book II (namely 22, 23, 36); since the second group shows, in addition to the feature mentioned above, even an amount of contents elaboration, Schmidt chose to attribute the authorship to a pseudo-Heron. Drachmann [410] believes that even this second version should be attributed to Heron.

Other manuscripts need to be added to Schmidt's census:

- Automata: Amsterdam, Bibliotheek der Remonstranten, 104
- Klasmata: Wien, Österreichische Nationalbibliothek, Suppl. 21
- Latin Pneumatics: see *infra*.
- Vernacular Pneumatics: see *infra* 2.5.2.4

2.5.2.3 Latin Heron's Pneumatics and Automata

We have one late manuscript of a Latin version of *Automata* (Paris, Bibliothèque Nationale, gr. 2380), entitled *De iis quae per se et sponte faciunt libri II Iosepho Auria interprete*, while we have 17 manuscripts of *Pneumatics* [198].

Based on a comparison of the *incipit*, they can be grouped into the following families:

α) *Quum spiritalis facultas:* 2 manuscripts; the translation is attributed to Ioannes Baptista Gabio, who, according to Schmidt [199], was a translator from Verona. It appears that the Greek

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[197] Abbreviated means that some parts are missing; klasmata contain only the passages that are missing in abbreviated; supplemented means that in their first version were abbreviated, but later they were supplemented with klasmata; indetermined refer to manuscripts Schmidt couldn't personally examine.
[198] Among indetermined manuscripts Schmidt includes also the alleged translation by Henricus Aristippus [46, 205].

source, belonging to the older *recensio*, is an abbreviated version of *Pneumatics* (Biblioteca Ambrosiana, D 313 Inf.), due to the identity both of content and of chapters order.

- Biblioteca Apostolica Vaticana, Vat. Lat. 4575
- Biblioteca Apostolica Vaticana, Barb. X 128

β) *Cum in spiritalis doctrinae tractatione*: 1 manuscript, containing a copy of the only prooemium; the alleged translator is the Portuguese humanist and philologist Cardinal Aquiles Estaço, latinized as Achilles Statius (1524-1581), who bequeathed approximately 1700 printed books and 300 manuscripts to St. Filippo Neri and to his order, an important fund of the Biblioteca Vallicelliana [543].

- Rome, Biblioteca Vallicelliana, R 26

γ) *Quum/Cum apud antiquos*: 13 manuscripts; by means of the title of Paris, Bibliothèque Nationale, Lat. 10261, the translation, made in the 15th century, is attributed to Giovanni Francesco Burana from Verona, "*philosopho et medico praestantissimo*" (great philosopher and physician). The original translation has been made on the later recensio.

The manuscripts quoted by Schmidt are:

- Rome, Biblioteca Corsiniana, Rossi 11 [200]
- Milan, Biblioteca Ambrosiana, I 38 Inf. [201]
- Milan, Biblioteca Ambrosiana, G 78 Inf.
- Oxford, Bodleian Library, Canonici 521
- München, Bayerische Staatsbibliothek, gr. 431
- München, Bayerische Staatsbibliothek, gr. 577, a copy of the previous one.
- Modena, Biblioteca Estense, XVII G G 25, a precious source about Alberti (see 2.5.3.3).
- Paris, Bibliothèque Nationale, Lat. 10261
- Turin, Biblioteca Nazionale Universitaria, H II 27, considered by Schmidt the best one.

And the following must be added to Schmidt's census:

- Paris, Bibliothèque Nationale, Lat. 7226A
- New York, Columbia University, Rare Book and Manuscript Library, X533.H43, owned by the astronomer and mathematician Marcantonio Cadamosto (15-16th century) in 16th century

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[199] He refers to Konrad Gesner's *Bibliotheca universalis*, 406: *Ioannes Baptista Gabia Veronensis, septem tragedias Sophoclis Latinas fecit ad verbum et scholiis illustrauit: Liber impressus Venetiis, anno 1543* Jophannes Baptista Gabia, of Verona, literally translated into Latin and commented seven tragedies by Sophocles; book printed in Venice in 1543.

[200] This manuscript is included by Schmidt into the older *recensio*. He however admits not to have studied it, but to have only some vague references to it; since we found that the incipit is the one of this family, we list it here.

[201] Quoted by Schmidt as J 38 Inf., due to a different notation. It has been studied by Schmidt in [45], together with Milan, Biblioteca Ambrosiana, G 78 Inf. and München, Bayerische Staatsbibliothek, gr. 431; in that study, he refers that the librarians of the Biblioteca Ambrosiana, Giovanni Mercati, and Achille Ratti, who would have later become pope Pio XI, suggested him that the handwriting of J 38 Inf. could be similar to Leonardo da Vinci's, though it isn't a mirror handwriting. Based upon this absence of a crucial element, and on the very poor quality of drawings, not applicable to Leonardo, as young as he could be, we think that it can be considered only a suggestive hypothesis. This however doesn't exclude that Leonardo could have seen and studied the manuscript.

- Biblioteca Apostolica Vaticana, Vat. Lat. 11482
- Rome, Biblioteca Lancisiana, 249

δ) *Cum spirituale negocium*: 1 manuscript; the translator is unknown, but, according to Haskins [209], the translation "not only differs from the Renaissance versions described by Schmidt, but has the close literalness of a mediaeval rendering", and so it can't be excluded that it could be the 12th-century translation alleged to Henricus Aristippus (see 2.4.4.2.2). The only extant copy can be dated to the 16th century, due to paleographic reasons; the codex, in quarto, was severely damaged both by water and by human interventions: some of the drawings and a whole sheet between ff. 30 and 37 were taken away. A recent restoration led to the replacement of the lacking parts of folia and of the binding, while (now apparently loose) folia were bound thanks to strips of gummed paper. It is therefore now impossibile to identify any watermark. Page numbering is threefold: two of them, in red ink, are presumably contemporary to the drafting of the manuscript or of the notes. One type is Dérolez 6 and is located at the bottom about in the middle, the other (Dérolez 1) and is located in the upper left. The third numbering, still in the upper left, is written in pencil and appears to be the most recent one, since it doesn't reveal the absence of the old f. 31. The manuscript is written on paper from f. 1 to 41, ff. 42-44 are on the contrary on cloth.

It appears quite interesting because of the presence of many erasures, quotations of Greek words, and alternative renderings, probably by a second hand. It is then possible that it is a working copy for a new translation, where the translator tried to enhance a previous version (maybe Medieval, and therefore less elegant, in his eyes). In any case, a first hand copied the Latin text which was later annotated by a second, more recent, hand, that added also Greek words. The last two folios are written by the second hand only on the verso and contain some working notes, and quotations taken from Latin technical authors, like Vitruvius.

- Paris, Bibliothèque Nationale, Lat. 7226B

2.5.2.4 Vernacular Heron's Pneumatics and Automata

We also witness during the 16th century to further translation in Italian language.
- Italian Pneumatics:
    - Milan, Biblioteca Ambrosiana, N 237 Sup., 16th century (the translator is unknown)
    - Siena, Biblioteca pubblica, ms. L.VI.44 (translation made in 1582 by Oreste Vannoccio Biringuccio and dedicated to the architect Bernardo Buontalenti [544-545]; completely searchable online) [202]
- Italian Automata: Milan, Biblioteca Ambrosiana, N 237 Sup., 16th century (the translator is unknown)

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[202] http://nausikaa2.mpiwg-berlin.mpg.de/cgi-bin/toc/toc.x.cgi?dir=heron_pneum_109_it_1582&step=thumb
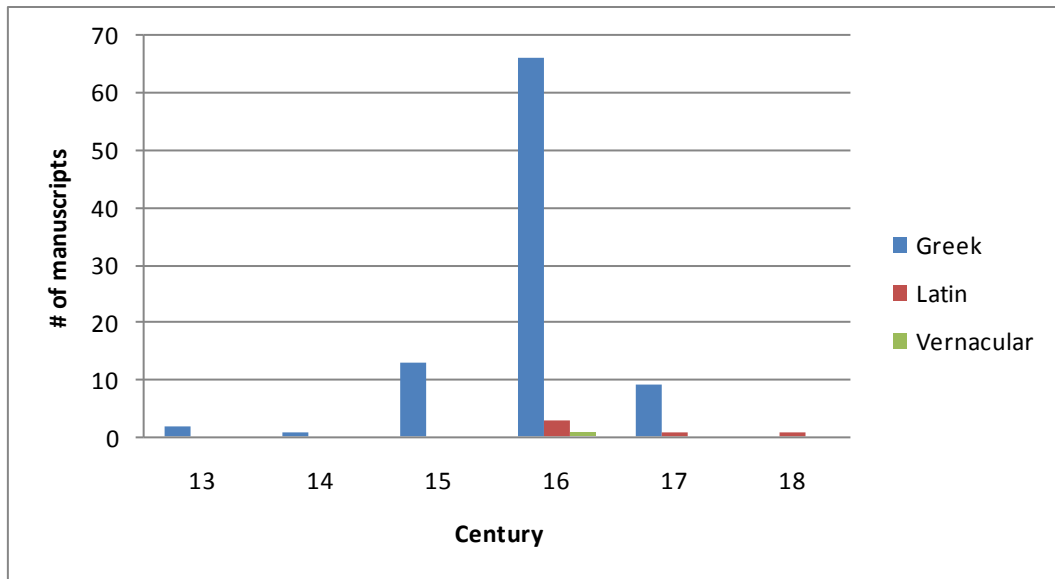
Fig. 145: Heron's Pneumatics Tradition
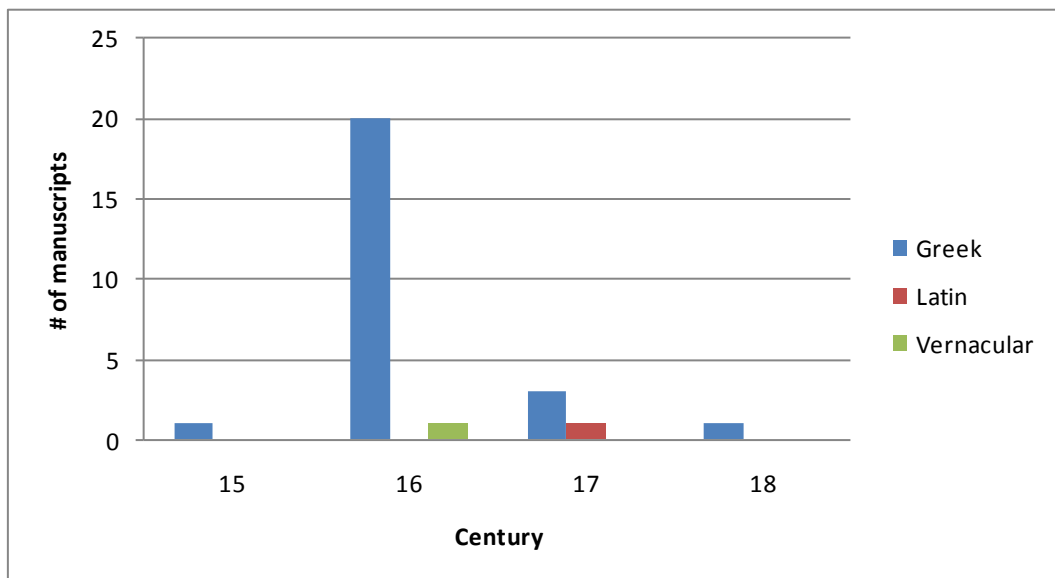
Fig. 146: Heron's Automata Tradition
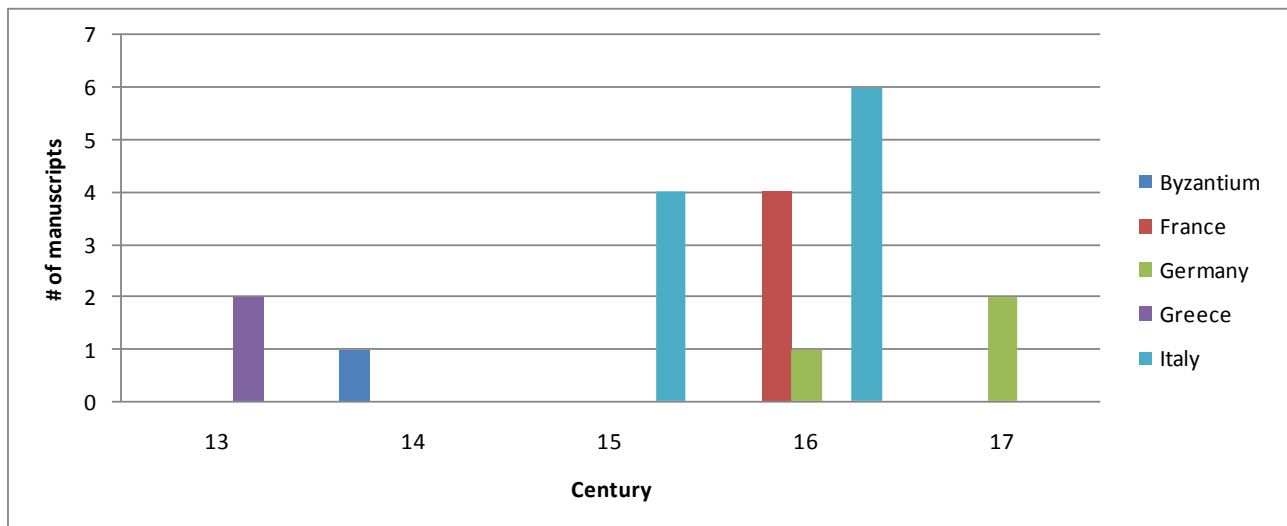
Fig. 147: Heron's Tradition and its Place of Origin

2.5.3 Designed Automata

As Ceccarelli states [37], the "first phase of the Renaissance of Machines can be characterized by a growing community of designers referring to the approaches by Brunelleschi, who is an example and personality of architect being designer and user of machines for architectonic goals; and Mariano di Jacopo, who can be seen as a first professional whose main activity was focused in the development of machines. Both personalities are representative of category of professionals who developed and used machines as results of practical knowledge of tasks and solutions that were available to a very limited community." As we will see in the following paragraphs, these are the eminent figures of technicians, who embodied the innovative trend of the Renaissance, along with restorers of ancient learning, as cardinal Bessarion and the courtly humanists. As a matter of fact, they are in a real dialectic relationship: as Sarton [245] pointed out, Renaissance scientists could be divided into two groups: those who were fluent in Latin and possibly in Greek (the "imitators"), and those who were ignorant of classical languages, but gave great contribution to science.

2.5.3.1 Some Italian Tower Clocks

During the 15th century, other tower clocks were built in Italy: two of them, located in Italy (precisely in Emilia Romagna, at that time in the Papal State) are interesting to our purposes:

- In 1421, the clock master Marchionne Toschi from Brescello (near Reggio Emilia) received a formal commission to build the tower clock in Parma. In one year, the clock was built and put into operation. In 1443 Toschi added an angel coming out from a shrine and playing the trumpet [546].
- In 1444, other two clock masters Giovanni di Evangelista and Bartolomeo di Gnudolo were commissioned to build a tower clock for the town hall in Bologna; the dial, on of Cardinal Bessarion's advice, represented the concept of the universe according to Philolaus from Taranto, that is "a central focus around which revolved the sun, the moon, the earth and the planets and the sky". The clock took seven years of work, and came into operation in 1451. After the restoration due to a strike in 1492, the clock was also equipped with automata: a knight, an angel, and the Magi [547]. The angel appeared on the hour and played the

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trumpet. Then appeared the figures of the Magi who made a complete turn, bowed in front of the static group of the Virgin Mary and Child, and returned back. As we can see, besides minor details, it is identical to the Strasbourg clock.
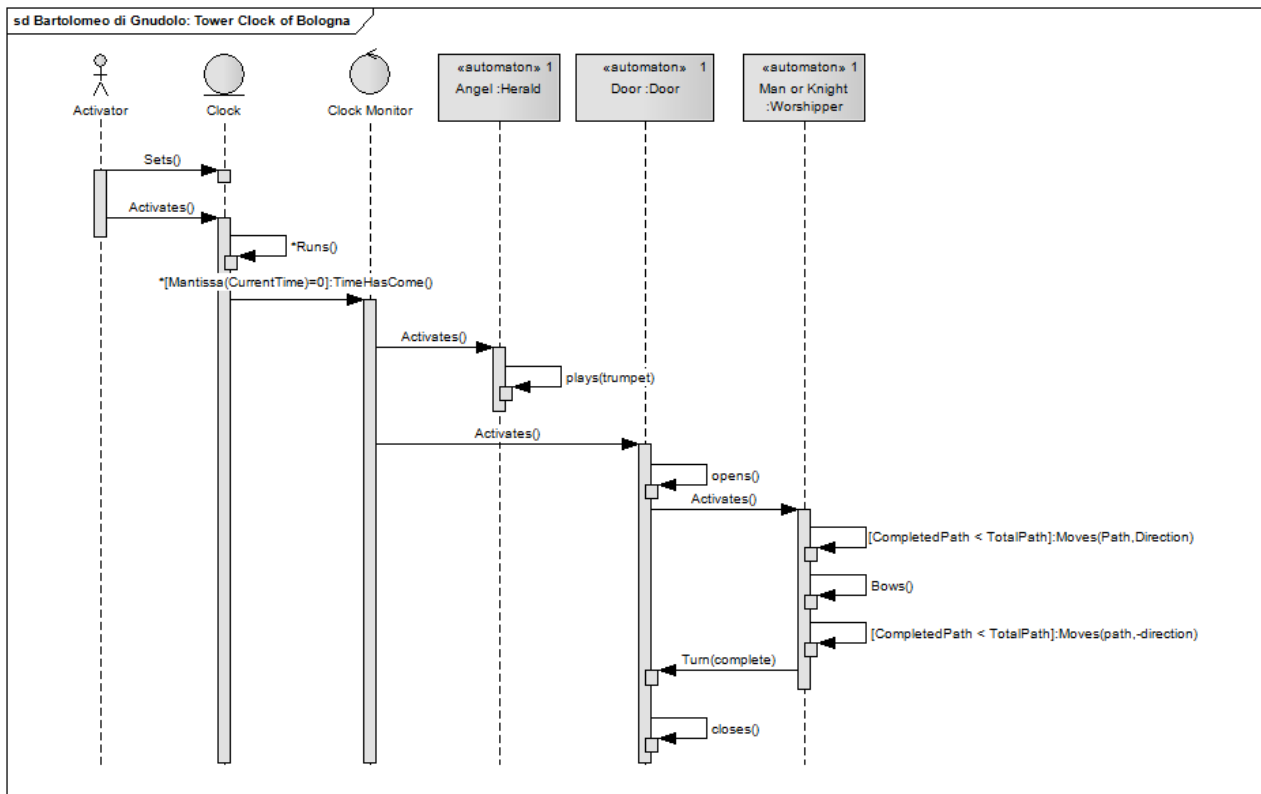
Fig. 148: UML Diagram of Tower Clock of Bologna

2.5.3.2 Giovanni Fontana

During the 14th century, theoretical studies and works about automata increased noticeably. As we have seen in 2.5.2, in the same years, ancient sources, like Heron, were studied and possibly used to create devices that could appear new, and therefore wonderful, not only in the field of automata, but also in military techniques. Giovanni Fontana (1395-1454) was an eminent figure in such a landscape.

He studied medicine at the university (*studium*) of Padua, earning a medical degree; he studied optics, mnemotechnics, and pneumatics. He mainly lived in Venice, apart from some official travels [203]. His main work [204] is *Bellicorum instrumentorum liber* (Book of War Machines), whose manuscript (Cod. Icon. 242) is housed at the Bayerische Staatsbibliothek in Munchen [205] [548].

The Cod. Icon. 242 was written in Venice between 1420 and 1430, and includes 72 parchment leaves with drawings, and encrypted descriptions. It has been housed in the library at least since 1618, as both the *ex libris*, and the catalogue entry state. The manuscript contains a number of drawings of automata, whose aim is obviously to be used within the world of the court: feasts, or entertainment of the lord. It is also evident that these were ephemeral objects, not designed to be

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[203] Between 1420 and 1432, he was sent to the headquarters of the army in Brescia, to bring to Count Carmagnola a message by the Doge of Venice [235].
[204] Besides this work, Birkenmajer quotes some 12 other technical writings.
[205] This one is fully online searchable, (http://daten.digitale-sammlungen.de/~db/0001/bsb00013084/images/).

reused, since it is very likely by the operation design that the use could imply their destruction; anyway, the low cost of materials (wood, cloth, candles, paper) allowed to reconstruct them inexpensively every time they were required.

In the tight captions, Fontana once (28v) refers to al-Kindi (801-873) as a common source, or at least as a source his contemporaries could easily get and consult: "*alkindi fons iste est, quem in suo libelo et alios consimileles declarat. Recure ergo ad ipsum si huius ignoraveris qualitatem.*" [206] It is also very likely that Fontana had consulted at least some Arabic manuscripts or Latin manuscripts made upon Arabic ones: the drawing at f. 63r shows Arabic influence in the decorations. Among medieval writers, the quotations from the works of Isidore of Seville (560-636), Thomas Bradwardine (1290-1349) and Nicolas d'Oresme (1320-1382) seem to show that his mechanical knowledge was still linked to Medieval sources.

At f. 51r, Fontana draws a mechanical device with a skeleton that moves, as if it was rising from its coffin: the first instance of Fontana's taste for the macabre [207]. One of the most interesting designs is however a witch (l. 63v) that moves along an inclined rail (motion depends on this inclination) and is controlled by a cable on a capstan. As evidenced from the drawing of the inner mechanism, the witch can:

- throw projectiles (by means of a spring);
- move her head and bat wings, connected to the arms and to the tail;
- emit light (by means of inner candles) [208];
- emit rockets from mouth and ears.

The horrific aspect of the witch is made even worse, if necessary, by the feet, which look like bird talons; this shows Fontana's almost maniacal attention to every single detail, even to those that have only a scenic purpose. It is curious to remark that bird talons feature links this automaton with another witch of Slavic folklore: the Baba Yaga has a self-moving home with legs similar to bird talons; she moves her home to deceive passers-by who got lost in the wood.

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[206] "This is the fountain by al-Kindi, which he describes in his book along with others like it. Recourse to him if you ignore the operation of this one." It appears that al-Kindi has never worked on pneumatics, so it is likely, even taking into account the appearance of the fountain in the picture, that Fontana is referring to treatises of pharmacology and perfumery, or that the name of al-Kindi was erroneously inserted in place of some others.

[207] *De resurectione mortuorum artifitiosa. Fit archa, ubi mortui de ligno picto fabricati resident, sub qua rote construuntur que membra mobilia mortuorum conmoveant et actus fatian<t> eo modo, sicud in horalogiis figurarum.* Artificial resurrection of the dead. A coffin is built, where the dead, made of painted wood, are sitting; in it [the coffin] are built wheels that move the jointed limbs of the dead, and they make movements, like clock automata.

[208] See also l. 19v: a copper archbishop's miter and a pastoral, projecting light through holes, are depicted; the side effect of the objects heating appears as not considered.
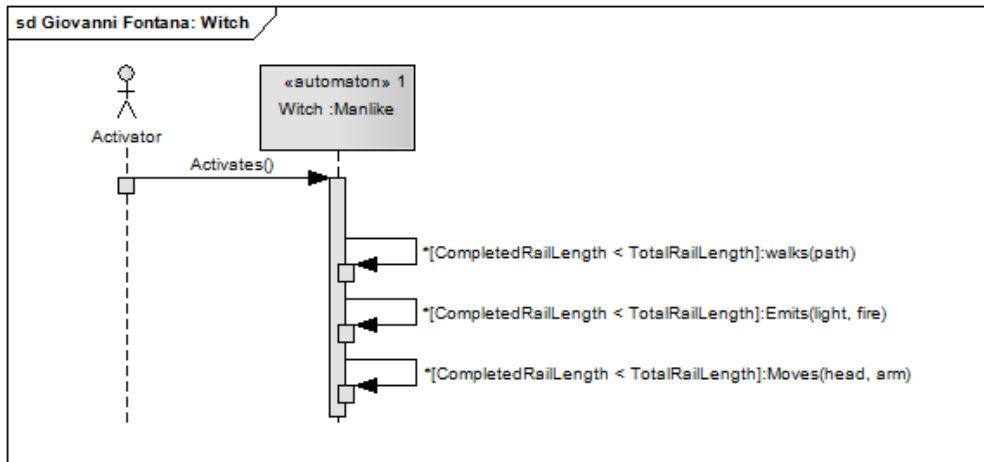
Fig. 149: UML Diagram of Giovanni Fontana's Witch

The working of a devil (ll. 59v and 60r), whose only aim is to frighten the audience, is similar to the witch's one: the figure performs some actions along some time. It moves the horns, the crown, the tongue, and all body joints, like a puppet [209].

Rossi [74] remarks that, at f. 37r, are drawn two "rocket powered objects: a hare (hound) and a bird; the latter reminds us of the dove by Archytas and is used to measure vertical heights. This was obtained by adjusting the charge of power in the rocket: to a given power amount, corresponded a known height; on the same folio a device used to measure the amount of powder is also represented." Birkenmajer [235] quotes an early work by Fontana, never printed, entitled "*Tractatus de pisce, cane et volucre, quem doctissimus ... Johannes Fontana Venetus in adolescentia sua edidit.*", where the author has described three kinds of rockets, working respectively in water, on earth and in air. Grafton [549] provides an interesting interpretation of Fontana's work: he would have produced figures capable of spitting fire in order to demonstrate how they work, that is without any magical or supernatural intervention ("*a deflation of the stories told by magi and theologians alike*").

2.5.3.3 Automata for Feasts and Courts

As we anticipated, according to Giorgio Vasari [210], the renown architect Filippo Brunelleschi (1377-1446), who built the dome of Santa Maria del Fiore in Florence, dealt with "ingegni", that is mechanical systems for public feasts from the second quarter of the 15th century. Art historians [550-551] have attributed to him, or to "il Cecca", a master of his circle, the authorship of the theatre for the representation of the Annunciation in Florence in 1439, during the council of the Eastern and Western church, in the SS. Annunziata or in S. Marco; and the other ones for S. Maria del Carmine or S. Felice in Piazza, even in Florence.

Another famous architect, the Sienese Francesco di Giorgio Martini (1439-1502) is important to us as an indirect source of the spread of classical models; he wrote a famous treatise on architecture,

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[209] *Dyaboli artifitiosi, olim in terrorem aspitientibus opus ingeniosum.* Device of an artificial devil, [made] one time to frighten the audience. Grafton compares such iconography with the frescoes of Santa Francesca Romana's convent in Tor de' Specchi in Rome. The devil is however a rather common subject; a similar one, dating to the 16th -17th century, is preserved at the Museo del Castello in Milan [275-276], where it arrived from the Settala Museum, a wunderkammer of over three thousand pieces of various kinds, collected by the nobleman Manfredo Settala (1600-1680), nicknamed "the Milanese Archimedes".
[210] *Vite de' più eccellenti Pittori, Scultori, Architettori*, III, Filippo Brunelleschi

preserved in manuscript form, among other libraries, at the Biblioteca Medicea Laurenziana in Florence (Ashburnham 361) [211]; at f. 41r, on glass, he portrays a fountain, representing a young woman, very similar to another one in a contemporary manuscript housed at Biblioteca Nazionale di Firenze, Palatino 767, f. 6; in this last manuscript, at f. 2, we find also a fountain with a mechanical drinking bird, very similar to one of Heron's (#29). Also in il Taccola's *De ingeniis* (*About machines*) books I and II, (Munchen, Bayerische Staatsbibliothek, clm. 197), written between 1427 and 1441 [259].

While the activity of copying manuscripts was raging, the main courts, especially the Italian ones, tried to get hold of these specimens: this is the documented case of Florence, where Lorenzo de' Medici (1449-1492) in 1491 commissioned the humanist Poliziano (1454-1494) to buy manuscripts in Venice, and among many others (e.g., Galenus, Aristotle, Hippocrates), as Politianus refers: "*In Vinegia ho trovato alcuni libri di Archimede e di Herone mathematici, che ad noi mancano e uno Phornuto de Deis, ed altre cose buone. tanto che Papa Janni* [212] *ha che scrivere per un pezo*" (In Venice I found some books by the mathematicians Archimedes and Heron, that we haven't got, and one by Phornutus de Deis, and many other good works, so that Papa Janni will have to write for a long while) [552] . The manuscript with Heron's work is likely the Biblioteca Medicea Laurenziana 86, 28, that appears in the Florentine library catalogues just after 1491 [213]. If so, the work by Heron would have been *Pneumatics*.

Another link with a manuscript containing a work by Heron is in a copy of *Pneumatics* (Modena, Biblioteca Estense, XVII G G 25, 16th century), where in the title of I, 37 a reference [214] is made to a work by the polymath Leon Battista Alberti (1404-1472), the *Ludi mathematici*, where the author, while listing various kinds of clocks, describes a fountain that worked exactly as described in the corresponding passage of Heron. The work by Alberti, written around 1450, is dedicated to the marquis of Este, in the same cultural context in which there are constant references to the work by Heron.

As a matter of fact, in 1452, Borso d'Este, marquis of Ferrara, Modena and Reggio, gives hospitality to Frederick III of Habsburg, who is traveling to Rome in order to be crowned as an emperor: in exchange for hospitality, Borso receives the title of Duke as an imperial acknowledgement. One year later, on July 5th, Borso enters Reggio, where his vassals pay homage to him. The ceremonial, designed by the courtier Malatesta Ariosto (?-1476), at the presence of a crowd of reverent subjects, is sumptuous and complicated, as refers the chronicler Giovanni da Ferrara [38]: "*Immediately out of the walls, the duke and his suite are received by a magnificent machine, covered by a canopy. Under the canopy stands Saint Prospero, patron of the town, and, at a lower level, on a moving platform, two figurants dressed like angels, ask the Saint for the scepter and the town keys, in order to give them to the Duke. Behind this machine, a scaffolding, moved by hidden horses and sustaining a throne, proceeds; behind the throne, a tableau vivant is set, representing an allegory of the Justice, surrounded by 4 old lawmakers, by 6 angels sustaining flags and by 2 ranks of armored knights. When Borso finally arrives at St. Peter church, from the top of the church front, a figurant, dressed as St. Peter and held up by a rope covered with wreaths,*

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[211] This manuscript has been consulted by Leonardo da Vinci, since he wrote some edge notes [259].

[212] Possibly a Giovanni di Lorenzo who in 1466 was working with Demetrius Calcondila at the Biblioteca Laurenziana.

[213] The copy is fully online searchable http://teca.bmlonline.it/TecaViewer/index.jsp?RisIdr=TECA0001013502

[214] *De satyrisco utrem in manu inflatum tenente quod Leo Bap. ta Albertus in Ludis mathematicis docuit*; About a satyr holding a goatskin, what L. B. Alberti explained in Ludi mathematici.

flies to the Duke and sets a laurel crown on his head. After the ceremony in the church, the duke is invited to sit on a high golden throne, while, from a near building, three more figurants dressed as angels descend to give him palm branches, symbol of peace." There's no mistaking the similarity to Heron's moving automaton.

Author	Heron	Ariosto
Structure	Canopy	Canopy
Main Character	Bacchus	St. Prospero
Surrounding Characters	2 Maenads	2 Angels
Held Object	Thyrsus	Scepter and town keys
Flying Figure	Nike	St. Peter
Gift	Laurel Crown	Laurel Crown
Procession	--	Allegory of Justice

Although the similarity is not conclusive, we must admit that at the Este's court, two indirect references to works by Heron can be quoted: the one by Alberti, and as we will see in 2.5.5, by Boiardo.

In the Vatican Library a manuscript is housed (Urb. Lat, 899, 124v), containing a report about the feast for the marriage of Costanzo Sforza (1447-1483), lord of Pesaro, with Camilla d'Aragona, in 1475 [553]. The booklet had been commissioned to the humanist Niccolò di Antonio degli Agli and to the painter Giovanni Santi, Raphael's father, by Costanzo as a gift to his brother-in-law Federico da Montefeltro. During the celebrations, many theatrical machines, probably designed by Costanzo himself, were used to impress the audience. None of them however is directly comparable with Heron's works.

2.5.4 Attributed Automata

2.5.4.1 Regiomontanus

One of the first intellectuals who understood the advantages of printing with movable type, was the German mathematician and astronomer Johannes Müller (1434-1474), also known as Regiomontanus, due to his birth in Königsberg. Due to his collaboration with Cardinal Bessarion, who wanted him to translate Greek Ptolemy's *Almagest*, Regiomontanus could collect many scientific manuscripts, that he planned to print; as he died before accomplishing this task, he left a list of the scientific works he hoped to issue [554, 237]; in such list appears "*Heronis inuenta spiritalia*", apparently in Latin [215]. The source could unlikely be the manuscript copied by Regiomontanus, and housed in Kraków, Biblioteka Jagiellonska, Clm. 568, since its title is "*Spiritalia secundum Philonem Hebreum*", unless we assume that Regiomontanus thought that it was a mistake to be corrected. It appears in any case that the author had read at least one copy of a

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[215] Due to the poor knowledge of the Greek language by librarian, Greek titles were often translated into Latin. This habit prevents to understandin which language the work is actually written.

work about pneumatics; one can't but find plausible that some legends flourished about him as an automata builder [216]: the French humanist Pierre de la Ramée (Petrus Ramus), in 1569, in his *Scholarum mathematicarum libri unus et triginta*, describes a fly and an eagle that the German astronomer would have built in Nürnberg for the emperor [217]. They would have taken off, flown, and landed in a given place. Though, exactly in the case of Archytas, and of Gerbert d'Aurillac, the source is not contemporary, and therefore not necessarily trustworthy, it is curious to note that even in this case we have an independent source (here, a manuscript) documenting that the alleged automata builder actually dealt with pneumatics. The same reference is made by the German scientist Baier, who in 1707 wrote an essay with a significant title: *About an eagle and an iron fly that are told once to have flown in Nurnberg thanks to a mechanical contrivance* (*De aquila et musca ferrea, quae mechanico artificio apud Norinbergenses quondam volitasse feruntur*).
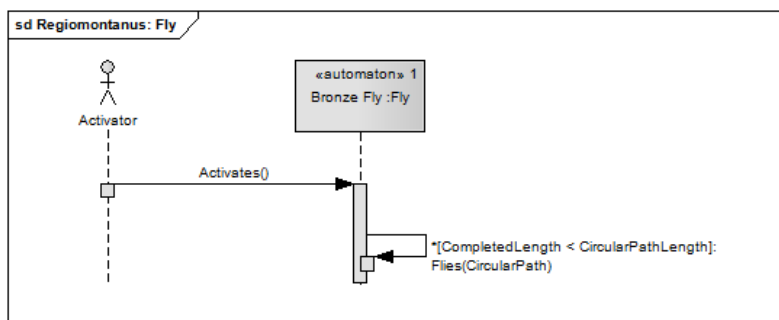
Fig. 150: UML Diagram of Regiomontanus' Fly
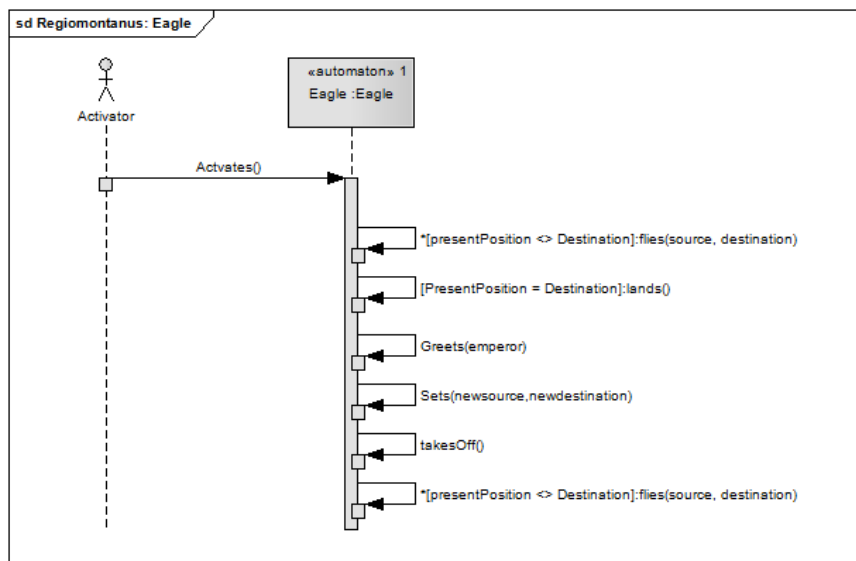
Fig. 151: UML Diagram of Regiomontanus' Eagle

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[216] "The story may have originated from a Nuremberg custom of hanging a large double image of an eagle in a main street whenever the Holy Roman Emperor was there." [274]

[217] *At inter artificum Noribergensium Regiomontani mathematis eruditorum delitias est, muscam ferream ex artificis manu velut egressam convivas circumvolitare, tandemque veluti defessam in Domini manum reverti. Aquila ex urbe adventanti imperatori longissime obviam sublimi aere procedere atque adventantem ad urbis portam comitari.* But among wonders made by engineers from Nurnberg, are the ones by Regiomontanus: an iron fly that, flying from its builder's hand, made a round flight, and then, as if it was tired, returned to his builder's hand. An eagle flied out far from the city to meet the emperor, and and accompanied him as he approached the city.

The episode is quoted also, twenty years later, by Bernardino Baldi in his introduction to the Italian translation of Heron's *Automata* (see *infra* 0).

2.5.4.2 Leonardo da Vinci

Leonardo is alleged to have built automata mainly for feasts and possibly for military purposes, since he as the other Renaissance engineers, like the abovementioned Mariano di Jacopo, nicknamed il Taccola, or Francesco di Giorgio Martini (1439-1502), had the suitable skills [37]. To prove, or disprove that he actually built such ephemeral devices, is a very difficult task.

It is very probable that Leonardo knew the *Pneumatics* by Heron. In Leonardo's largest codex, the Codice Atlantico, preserved in Milan at the Biblioteca Ambrosiana, some quotations from Heron's are made: at f. 219v, Leonardo writes "Herone de aqua". Solmi [555] believes that, if to the hydraulic expertise of Leonardo, and his use of the eolipila for the automatic movement of a revolving spit, we add this quotation, Leonardo's knowledge of Heron is proved. He also adds references to the "cicognola", at f. 80r (that can be compared to Heron's I, 13) and to the drawing of an oil lamp, at f. 41r, virtually identical to I, 34. He could even have read part of this work in Valla's encyclopedia (see 2.5.6.1). We don't have any further evidence.

Even the drawings of Leonardo represent a challenge for scholars, who have sought to understand how he worked, and to identify any projects undertaken and subsequently set aside or hidden in Leonardo's design [556-558, 268]; Leonardo's designing approach was quite chaotic, as he returned several times to the same sheet. Scholars have tried to identify the projects of Leonardo's alleged automata, even by abridging parts from different sheets, with a "hypertextual" analysis [269], and assembling them.

Anyway, if we look at some contemporary sources about his automata, we find mainly two:

- Giovan Paolo Lomazzo (1538-1592), who met one of Leonardo's disciples Francesco Melzi (1491-1570), his source. In his *The Ideal Temple of Painting* (Tempio della Pittura), he exalts the genius of Leonardo with these words: "*More than these writers, is worthy of memory Leonardo da Vinci, who [...] taught the way the birds fly, lions go by the wheels, and make monstrous animals, and with so much talent he drew so monstrous faces that no one else, although many have been excellent in this field, could match with him.*" [218]. And in his *Treatise of the art of painting, sculpture et architecture*, he includes Leonardo in the list of the most remarkable automata builder, along with Daedalus, Vulcan, and Archytas (!). [219]

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[218] Sopra a tutti questi scrittori, è degno di memoria Leonardo Vinci, il qual […] insegnò il modo di far volar gli uccelli, andar i leoni per forza di ruote, e fabricare animali mostruosi, e con tanto ingegno disegnò le faccie mostruose, che niun altro mai, come che molti siano stati in questa parte eccellenti, ha potuto agguagliarlo.

[219] II, i. *Secondo che mi ha raccontato il Signor Francesco Melzo suo discepolo, grandissimo miniatore, soleua fare di certa materia vcelli che per l'aria volauano; & vna volta dinanzi à Francesco primo Rè di Francia, fece caminare da sua posta in vna sala vn Leone fatto con mirabile artificio, & dopoi fermare apprendosi il petto tutto ripieno di gigli, & diuersi fiori.* According to Sir Francesco Melzi, his disciple, a great miniaturist, he used to build some birds, made by a certain matter, who flew through the air; and once in front of Francis I, King of France, he made walk in a room a lion made with an admirable contrivance, and afterwards it stopped, opening the chest completely filled with lilies and other flowers.

- Giorgio Vasari, who, in his *Lives* (IV), in 1550, refers about a walking lion built in Milan for the King of France [220].

Because of this small number of sources, we decided to account for all automata identified by scholars, but to model only the one attested by contemporary sources; and this for two reasons: first, the reconstructions show a too high degree of arbitrariness and the fact that they actually work, does not prove that these were Leonardo's very projects; secondly, such automata, as they were presented in reconstruction, don't add any significant feature to our analysis. As a matter of fact, fromy the point of view of automated systems, the flying bird operates like Fontana's witch, that moves along a rail by gravity laws; the cart is comparable to Homer's tripods, or the old man with the dog by al-Muradi, which have both the same re-programmability; the knight is a typical automaton in medieval romances and in Renaissance poems, as we have seen; the bell-ringer is a jacquemart.

2.5.4.2.1 The lion(s)

In a recently published article, Burke [559] examines a document found at the Biblioteca Nazionale in Florence (Fond. Princ. II.IV.171) pertaining a mechanical lion built by Leonardo in 1509 for the entrance of Louis XII, king of France, in Milan. Atop a gate, the lion, while the king was approaching, stood up on rear legs, opened its chest, drew blue balls filled with golden lilies, and threw them on the ground. Afterwards, it drew its heart and, by pressing, issued again golden lilies (symbol both of France and of Florence). The source agrees substantially with the Vasari, although there is no reference to a lion walking, but only to movements performed in the same place.

Leonardo would have built another mechanical lion that was presented in tribute to the new king Francis I, on the occasion of his solemn entrance into Lyon on July, 12th 1515, by the local Florentine community. Our most detailed source is rather late, since we deal with Michelangelo Buonarroti il Giovane (1568-1646), who, while describing the banquet for the wedding of Maria de' Medici with the French king Henry IV in 1600, quotes Leonardo's device [560]. The technological work of art by Leonardo would have been designed and created in Florence and later sent to Lyon, as a gift presented to the king by the governor of Florence, in name of all Florentines living in that city.

Neither for Louis XII, nor for Francis I, we have historical sources that have recorded Leonardo's work. Unfortunately, these are all our sources; everything else is conjecture, even the reconstruction [40] based on some drawings, not linked to these lions.

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[220] *E per tornare alle opere di Lionardo, venne al suo tempo in Milano il re di Francia; onde pregato Lionardo di fare qualche cosa bizzarra, fece un lione, che camminò parecchi passi, poi s'aperse il petto e mostrò tutto pien di gigli.* And to return to the works of Leonardo, the King of France was in his time at Milan; being Leonardo asked to do something bizarre, he made a lion, who walked several steps, then opened its chest and showed it was all full of lilies.
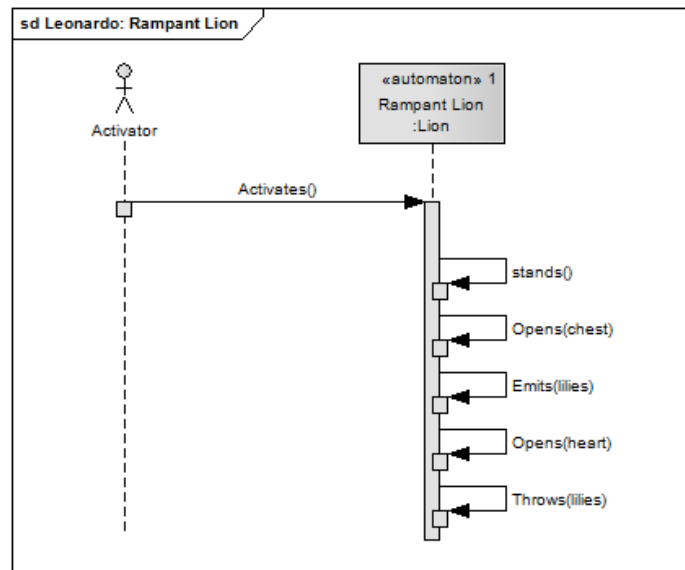
Fig. 152: UML Diagram of Leonardo's Alleged Rampant Lion (Fond. Princ. II.IV.171)
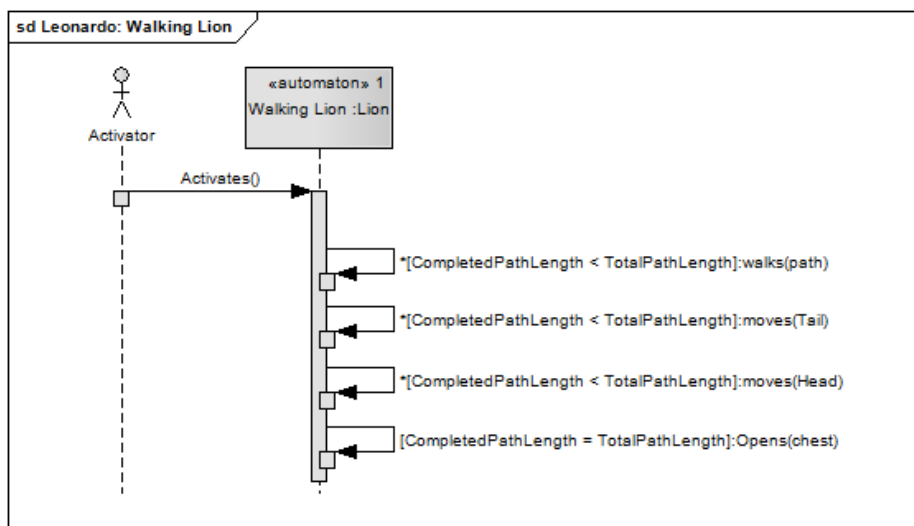
Fig. 153: UML Diagram of Leonardo's Alleged Walking Lion (Buonarroti)

2.5.4.2.2 The Bird

According to the American engineer Rosheim [265], in CA 630v 231 v-c, dating back to 1508, a mechanical flying bird is drawn; possibly made for the French governor of Milan, Charles d'Amboise, for whom Leonardo had designed a suburban villa [556], this bird could flap its wings as it descended along a cable.

2.5.4.2.3 The Cart

According to Rosheim [262], the drawings (CA 812r) by Leonardo let possibly assume that he wanted to make a faithful reconstruction of the automaton described by Homer (i.e. the tripods, see Fig. 5), that could follow a predetermined path (to and from the gods' banquet hall). In order to reconstruct the operation of this device, Rosheim uses parts of drawing in Leonardo's manuscripts, and as many sources as possible: Lomazzo's accounts, Giovanni Alfonso Borelli's *De motu animalium* for Renaissance studies about biomechanics, Japanese automata of the 18th century; he concludes that Leonardo's cart had "two independent sub system for propulsion and guidance" and

it was "propelled, capable of performing a variety of pre-determined movements that could be varied depending on the desired choreography and available space. Starting from a home position the automaton begins to move forward and follows a preprogrammed course, stopping and starting, turning left and right. Special effects at any point could be introduced. The particular program is determined by the number, shape and location of cams on top of the two large cam gears. Each cam represents an individual instruction, or "line of code". The "program" is latent in these cams and is predetermined by the programmer, who might "debug" or modify his "program" with a file!". Even Leonardo3 in the following years tried a reconstruction [269], which is basically in the same direction as Rosheim with regard to the objectives of this study.

2.5.4.2.4   Knight

Scholars found many possible references to a mechanical knight that would have been drawn at CA f. 812r; in 1957, first Pedretti wrote about it [561], then, some twenty years later, even Ladislao Reti, editing the Code of Madrid, referred to a mechanical knight [562]. Since the 1990s, Rosheim [262, 265] worked hard to build a complete physical model; according to him, this automaton can be reconstructed based on drawings present in CA, f. 388 v-a (head and neck); CA 366 v-b (small titled head); Codex Forster MS II, 2, f. 65 r-v (neck/helmut and perhaps face); Windsor, RL 19075v (anatomical cord diagram for human neck); Madrid MS. I f. 91r (mechanical leg). Its date would range between 1495 and 1497. Rosheim supposes that the presence (in Madrid MS. I at f. 142r) of a water wheel of the same type as those later adopted by Buontalenti in Pratolino can suggest that it may have been the power source of the automaton. Rosheim states that the operation of Leonardo's knight is very simple and elegant, since he solved "several design problems with a simple cable system", with such a system, the automaton can asynchronously move its arms, and legs, in order to grab someone with its arms in a bear hug. The advantage of the differential motion would consist in an automatic compensation for one of the arms being out of use. The most interesting (and at the moment mysterious) issue consists in the identification of the power source, that must fit two requirements: occupying a limited space, since it must be put within the body of the automaton, and yielding the strength needed to make it move and possibly fight, or, at least, hold a weapon.

2.5.4.2.5   Bell Ringer

This automaton, dating back to 1510, is also an inferred reconstruction by Rosheim [266], based on the presence, in various Leonardo's manuscripts, of

- parts of devices suitable for the construction of a water clock, like Heron's fountains (Windsor RL 12690)
- drawings and descriptions of human figures that raise heavy hammers, (CA f.206 v-a; f.352 v-a)
- some drawings jacquemarts (Windsor 12641; Windsor RL 12716 and 12688; CA f. 65v, antigraph of Windsor 12480 and 12718)

These devices, especially the fountains, could be related to the design of the suburban villa for the governor of Milan, as reported by Pedretti [556, 563]. If so, we could assume both an external influence on Buontalenti for his fountains in Pratolino (see 2.5.8.2), and a local (Milanese) one, as shown in Taegio's dialog (see 2.5.8.1).
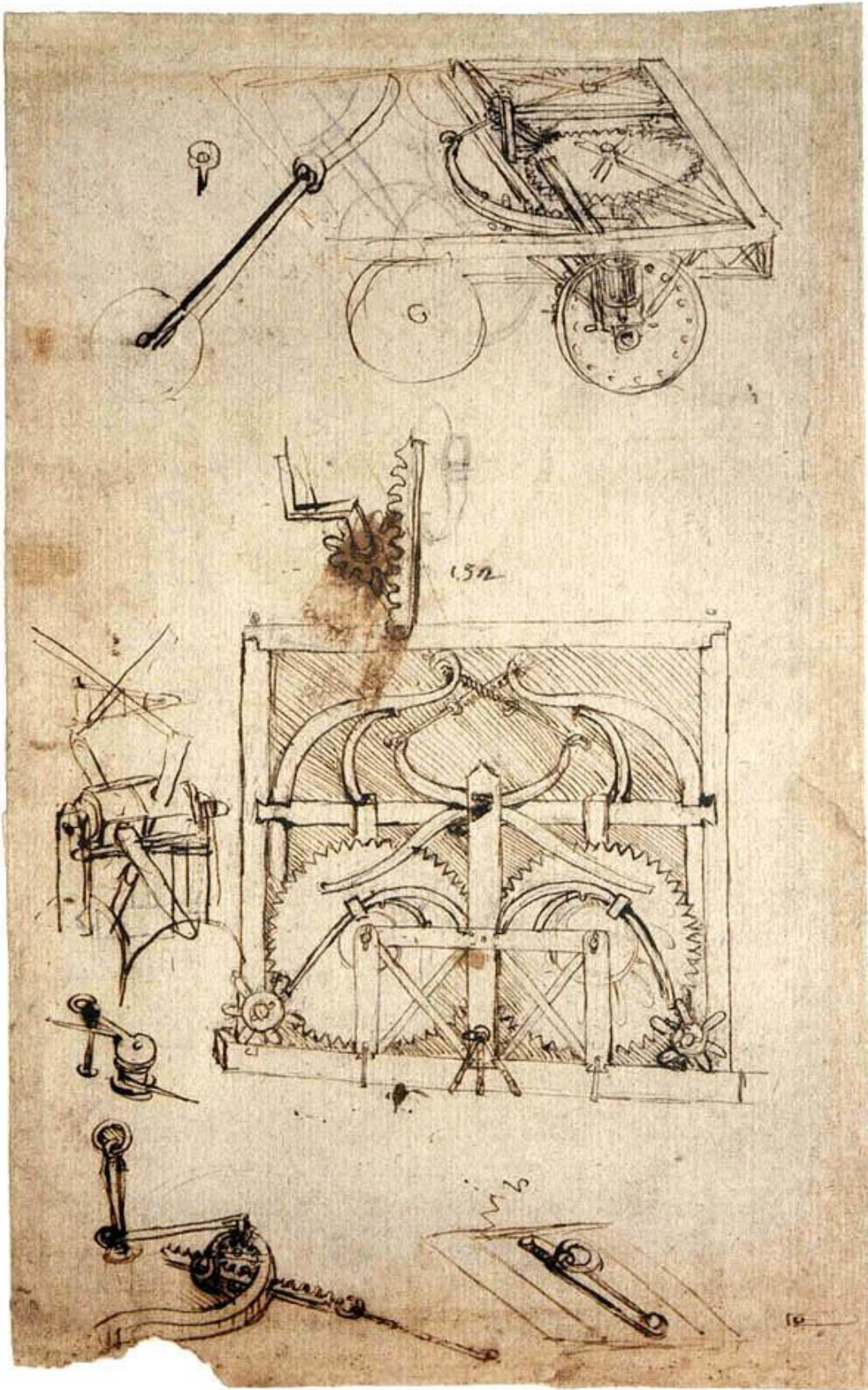
Fig. 154: f. 812r of the Codex Atlanticus

2.5.5 Imagined Automata

Although science fiction (as a mature literary genre) is universally regarded as contemporary, historians have often ventured in search of thematic analogies with the previous literary heritage [185]. So, if we focus our attention on the presence (in literature) of automatic devices, and thus of robotics, we discover that such presence was prominent during the Middle Ages, when their creation was highly related to magic and sorcery, but they didn't disappear during the Renaissance, when technical expertise made it possible to actually build at least some of them.

2.5.5.1 Matteo Maria Boiardo

2.5.5.1.1 Life and Education

Born in Scandiano (Reggio Emilia) in 1441 by Giovanni and Lucia Strozzi, sister of the famous humanist Tito Vespasiano, Boiardo spends his childhood in Ferrara, but in 1451 he is back in Scandiano, where he studies Latin with Bartolomeo da Prato. In 1460 he becomes vassal of Scandiano and returns to Ferrara, where his mother's family is very influent. Counselor of Duke Ercole d'Este, a great patron of arts, Boiardo edits the translation of many classical works and writes vernacular lyrics. At the beginning of the Seventies, following Borso and later Sigismondo d'Este, Boiardo travels to Rome and Naples; in these very years, he begins to work out the idea of writing a poem about a theme which is loved by the court: the stories of Charles the Great's paladins. In this work Boiardo puts an encomiastic motive, by including among the characters the founder of the Este family, Ruggero. In 1476 he settles in Ferrara as "familiare", salaried by the Duke, who, in 1480, makes him captain of Modena, a position he holds for two years. In 1487 he is appointed captain of Reggio Emilia, which he rules justly and sensibly until the day of his death, at the end of 1494, during the passage of defiant French armies led by Charles VIII in Italy, now become a land of conquest.

2.5.5.1.2 Main Work

His main work is the poem *Orlando Innamorato* (*Orlando in Love*) or better *Inamoramento de Orlando*, begun before 1476 and interrupted in 1494, when Charles VIII of France invades Italy. The two first books of the poem are completed in 1483 and given to print both in Reggio and, a few years later, in Venice; unfortunately no copies of the first edition survive. The work had a good success with the public to judge by the many reprints that followed until 1544 and by the spread of some remakes that widely circulated in Italy. There were a good number of continuations of the poem; the most famous of them is undoubtedly the *Orlando furioso* by Ludovico Ariosto. The work is composed by 3 books: the first two are completed between 1476 and 1482 and published in 1483; the third is abruptly interrupted due to Charles VIII's descent in 1494, as written in the last octave; the author dies in the same year. The author aims to synthesize themes taken from either Arthurian (love, magic) and Carolingian cycles (paladins, faith, loyalty), as we can see starting from the title. It's the first time it occurs in a written epic poem [221]. Orlando, once a faithful paladin of Charles the Great, falls in love with the beautiful Angelica, who continuously escapes from him due both to fate and to Merlin's and Morgana's magic. It is probably the longest passage where automata, and their interaction with humans are described in Renaissance literature.

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[221] In oral literature, however, this fusion had already happened, particularly in the "cantari" in octaves, mainly in the 14th century, targeting a popular audience, who listened passionately to the performances of the "canterini" (minstrels).

2.5.5.1.3 The Passage: Book II, Cantare viii, oo. 3-33

In his quest of Angelica, the magician Falerina guides Orlando to Morgana's lake. Although she explains Morgana has enchanted the lake by setting up a guarded bridge to entrap a man who had subjugated her bulls, dragon, and warriors, Orlando does not realize he is the very paladin Morgana seeks. He only reacts when he sees his cousin Ranaldo's armor hanging from a tree, meaning to him that his cousin is dead. So he faces Aridano, the mighty enchanted guardian, he presumes to have murdered Ranaldo; Orlando inevitably falls into Morgana's lake, where he finds another world and, in a wonderful sunny meadow, he kills his enemy. To find his way back to the surface, he enters a mountain cave. Orlando walks along for 3 miles in the dark, then he sees a light and hurries in the light's direction. He discovers that the light comes from a carbuncle posed on the other side of a river; it can be reached by a bridge guarded by two automated warriors. Unfortunately every time he begins to walk on the bridge, one of the guardians destroys the bridge, by hitting it with a pike. Orlando decides to simply jump to the other side; what he right does successfully.

Orlando is now in a big square room (500 feet per side), where he sees a court made up of golden automata. A king, surrounded by his courtesans, is sitting at a table where the food is made of enamel. Near the king are two more identical automata: an archer and a messenger, who is showing a paper, where a warning against greed is written. The room is enlightened by a carbuncle, standing on a base shaped as a lily. Orlando sees 4 doors and tries to escape from the dungeon that way, but beyond the doors the darkness prevents his escape. So he decides to steal the stone, but, as soon as he takes the carbuncle, the archer begins to shoot his arrows to the stone, that falls to the ground and, after an earthquake, returns at its place. Orlando tries a second time to steal the stone, but it appears to be impossible: everything goes as the first time he did. At the end, Orlando decides to use a trick: he protects the carbuncle with his shield; the arrow can't hit the target; and he can escape, preventing the carbuncle from being hit.

We can firstly remark that the automata, although belonging to different classes (guardian and archer), performing different actions, have common features:

- They are all activated by a user's input, non by an activator's one.
- Each automaton can perform only one action.
- They can't react to user's unpredictable behavior, or even to perceive it.
- They are part of a more complex system (the cave), that appears to have overall control, and should be capable of feedback-control.

Since we are dealing with a complex series of crucial decisions taken by Orlando, so we will use also a sequence diagram. We are also coping with two classes of automata with different behaviors, so we will study two activity diagrams, and we will give two versions for each of them: one referring to the expected behavior of the system, and the second, to the failure of the system, due to Orlando's behavior.

2.5.5.1.4 Designed Crossing the River

The strategy implemented by Morgana to prevent intruders from overcoming the obstacles is to stop all their next moves by a deadlock. The only way the intruders can escape the deadlock, is to think creatively and use all their resources in this case their physical ones. If Orlando had not practiced himself enough to make such a long jump, he might not have escaped the cave. Finally, the option

to swim across the river is not feasible, unless intruders leave arms and armor; it is also possible that Morgana has prepared other obstacles in the river itself.
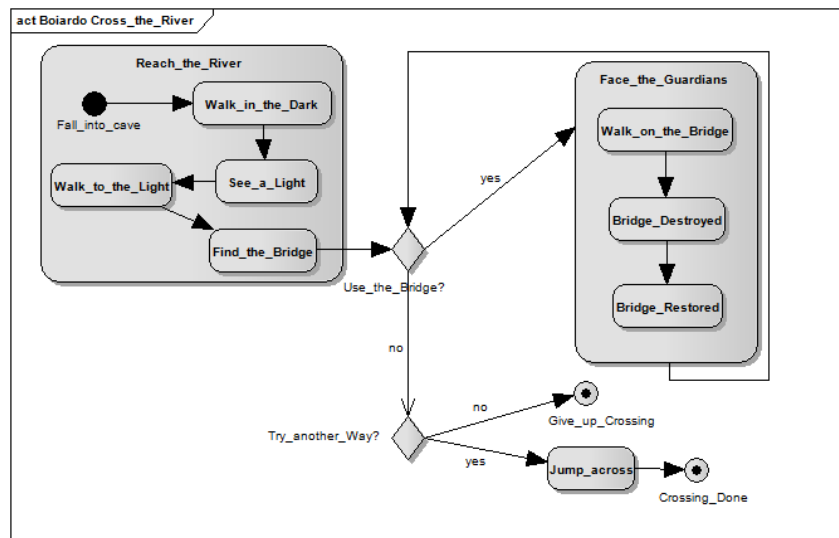
Fig. 155: UML Diagram of Boiardo Designed Cross_the_River (AD)
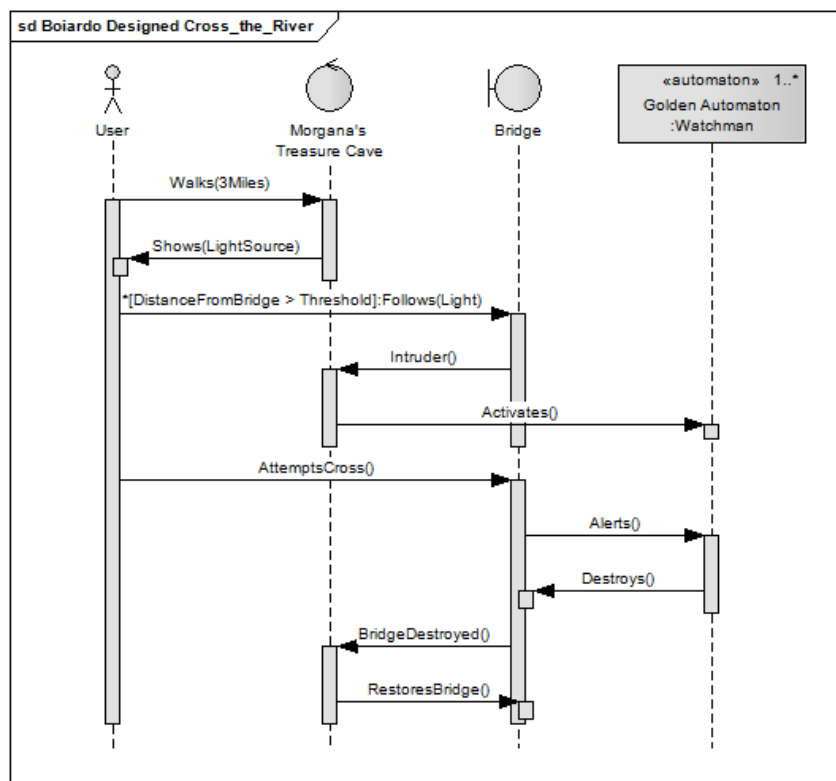
Fig. 156: UML Diagram of Boiardo Designed Cross_the_River (SD)

2.5.5.1.5 Designed Escape From Cave

Orlando, exactly as Gawan in the episode of the "Lit merveille" (see 2.4.4.5.1.3), has luckily got his shield, which allows him to shelter the light source and not to alarm the cave.
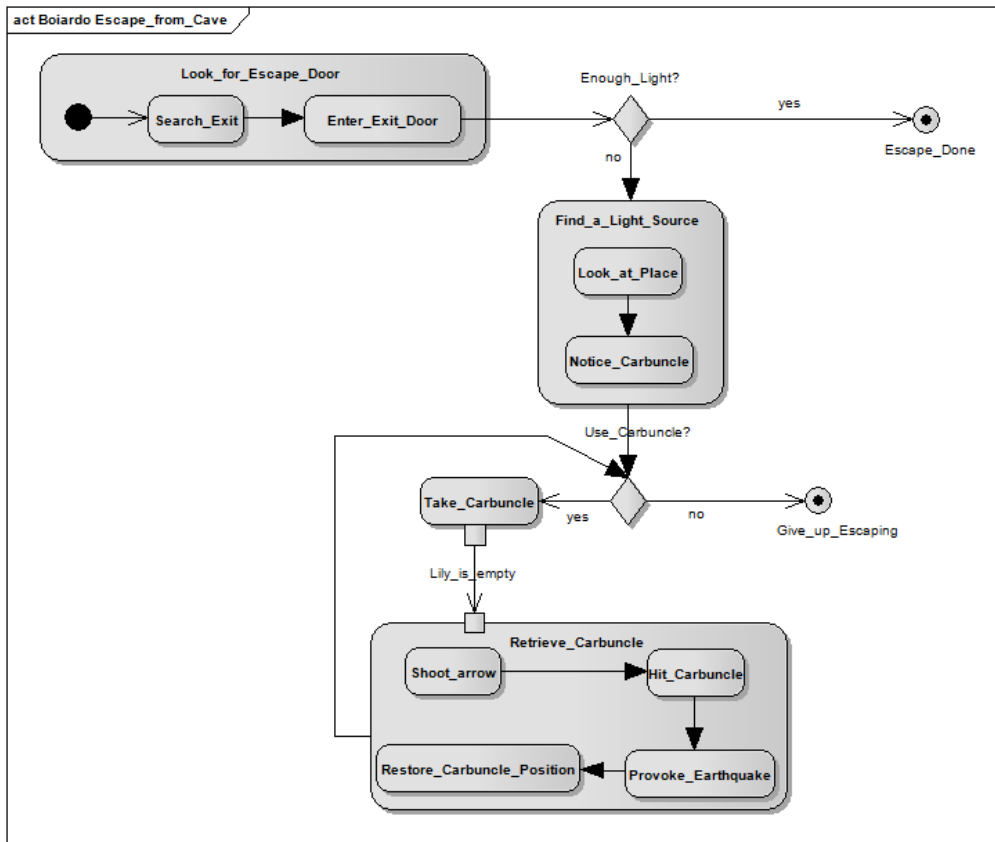
Fig. 157: UML Diagram of Boiardo Designed Escape_from_Cave (AD)
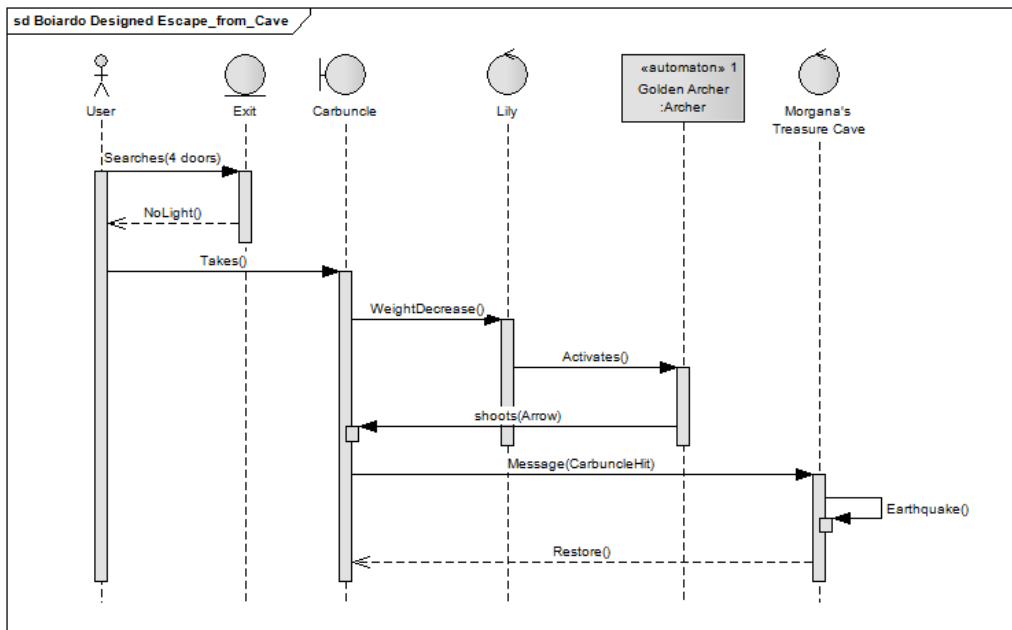
Fig. 158: UML Diagram of Boiardo Designed Escape_from_Cave (SD)

2.5.5.1.6 Actual Cross and Escape
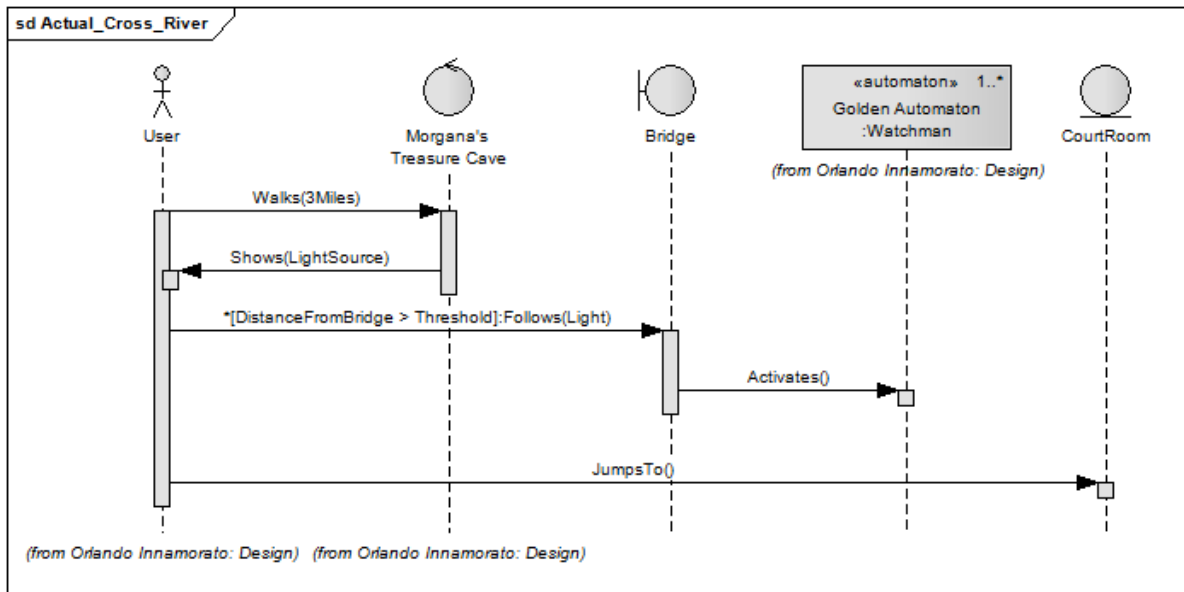
Fig. 159: UML Diagram of Boiardo Actual Cross_the_River (SD)

Since guardians are not programmed to prevent intruders' jump, and no other device is programmed to manage the exception, the deadlock can be avoided. One could ask whether Orlando's behavior could be forecasted, in order to prevent bypassing. Though the system's purpose seems to prevent intrusions, the presence of the next room leads us to believe that crossing the river could be expected; otherwise, the golden room and its moral message would be useless.
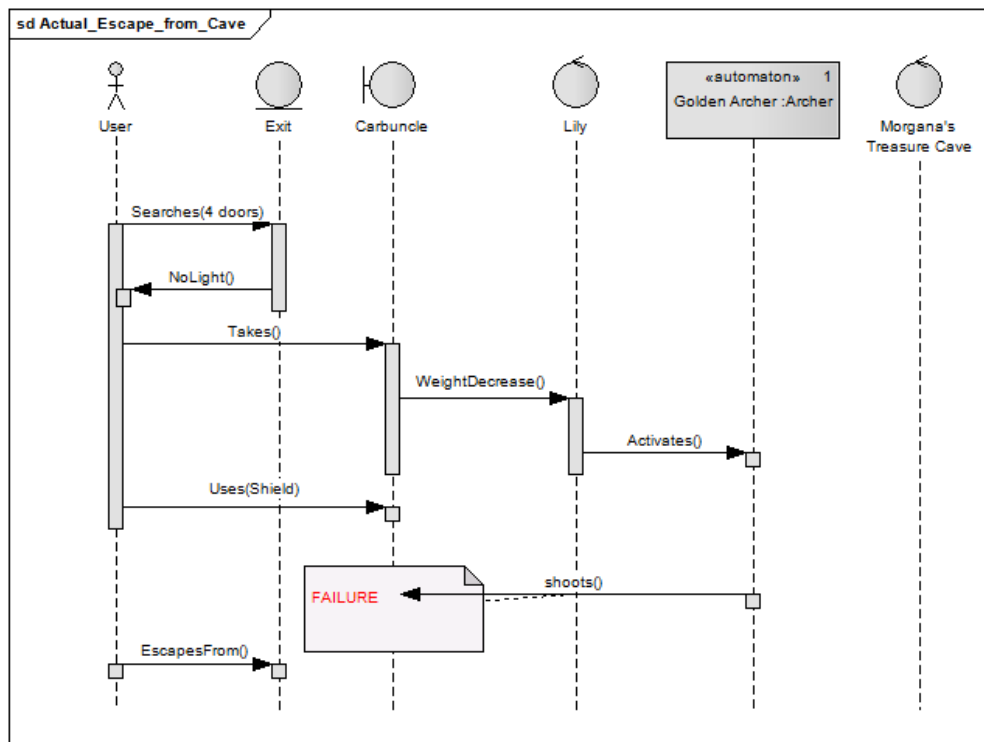
Fig. 160: UML Diagram of Boiardo Actual Escape_from_Cave (SD)

Design faults appear as evident: since the archer can target only the carbuncle, and the other automata are not programmed to prevent Orlando's theft, differently from Gerbert's episode,

another device (e.g., a door or a grating) should be used to stop Orlando's escape, by "capturing the exception". In this case, Orlando's behavior could be unlikely forecasted, since any paladin who arrives here must have fought with the warrior and must have crossed the river by jumping or swimming: it's very difficult that he still has his shield.

2.5.5.1.7   Boiardo's Sources

Boiardo has obviously collected and ingeniously reworked a number of literary sources, creating an episode far more complex than those of chivalric literature. As a matter of fact, the passage suggests a wide collection of readings, possibly including:

- Historiography about Medieval figures of scientists
  - o   William of Malmesbury account on Gerbert d'Aurillac (see 2.4.4.4) . The origin of this design can be found in William of Malmesbury's account in *Chronicle of the Kings of England*, II, 170, where he refers a very similar episode, though not linked with Gerbert d'Aurillac (see *supra* 2.4.4.1.3). The main character in that episode is a monk who told this story to William's source, an Aquitanian Benedictine monk. This part of the episode consists only in the cave episode: the monk, assisted by 12 mates, enters the cave, sees the treasure and tries to cross the bridge guarded by two metal watchman, that immediately rise fog to prevent intrusions. The monk and his mates give up, but some days later, a Hebrew necromancer enters this cave and succeeds in recovering some gold powder. [564]
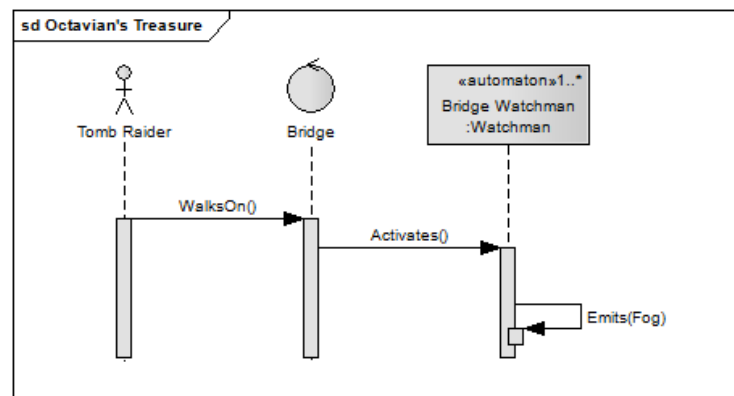
Fig. 161: Octavian's Treasure Raid Account

- French Medieval poems:
  - o   For instance, in the episode entitled *La Doloreuse Garde*, (Sorrowful Guard) in Chrétien de Troyes' Lancelot du Lac, the protagonist must defeat two copper knights watching against intruders and a copper woman [192].
- Didactic Literature:
  - o   In Boiardo, the red light may represent prudence. In Brunetto Latini's *Li livres dou Trésor*, a book cited in an Este's library inventory (so maybe known to Boiardo), a quotation of Cicero explains that prudence "carries a lantern and shows the way to the other virtues [i.e. temperance, prowess, justice]." [565]
- Medieval lapidaries:
  - o   Prudence outshines all other cardinal virtues, each of which has a corresponding gem (the sapphire for temperance, the diamond for prowess, and the emerald for justice).

Prudence is symbolized by the carbuncle, the brightest gem (and the one Orlando takes away). [566]

2.5.6   On the Shoulders of the Giants: the Translations Wave

In the 16th century, when some Greek manuscripts of *Pneumatics* and *Automata* became available, some scholars began planning their printed edition, in order to help dissemination [362]. Nonetheless copies of Greek and Latin manuscripts were constantly made.

2.5.6.1 Giorgio Valla

The oldest printed publication of some parts of Heron's *Pneumatics* is likely the Latin version of the first paragraphs in *De expetendis et fugiendis rebus* (*Things to Pursue and to Avoid*) by the humanist Giorgio Valla from Piacenza (1447-1500), published posthumous in Venice in 1501, by Aldus Manutius. Valla is alleged to have had a copy of the Greek text, that now has been lost.

The work is a big encyclopedia which deals with arithmetic, geometry, mechanics, music, astrology, medicine, natural philosophy, economics, grammar, dialectics, rhetoric, poetry and moral philosophy. The encyclopedia by Valla is humanistic, and, therefore, both the (strictly classical) sources and the method are philological.

In chapter XV, paragraph 1, entitled *De spiritalibus* the author rephrases so closely Heron's words (only a brief summary of the prooemium [222] and the part about siphons), that, starting from the 16th century, he was accused of plagiarism [223]. Anyway, the *De expetendis* is possibly the source of Leonardo da Vinci's knowledge of Heron's works, since, whenever he quotes the Alexandrian engineer, he only refers to devices [224] and never mentions the theory about vacuum [569]. Boas thinks that even the Sicilian mathematician Francesco Maurolico (1494-1575) planned to imitate Valla in quoting from Heron's works, since he refers in his *Cosmographia*, printed in Venice in 1543, to "*Heronis inuenta spiritalia: ac nonnullae machinae hydraulicae a recentioribus inuentae*", as a topic to treat, but unfortunately this part has never been included in the book, in which the only mentions to Heron are likely taken from other ancient authors (Pappus or Proclus).

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[222] *Quod igitur rerum natura inane non admittat, sed continuum, perpetuumque corpus uariis admirandisque motibus comprobatur, quod nimirum ita esse apertissimis ostendemus exemplis mechanicisque rationibus spectandum dabimus ut cum ea quae supra attigimus magis sub animum quam sub sensum haec quae deinceps sumus exposituri magis sub sensum quam sub animum cadere uideantur; nam quae de inani hoc loco prius attingenda statim alicui nobis existimentur ea commodiore loco in physicis rebus putamus recesenda.* Therefore, since nature does not allow void, but it is shown to be continuity and perpetuity of the matter through various and large motions, we will show that it is no wonder that this is true by means of very evident and obvious examples and we will reveal by mechanical demonstrations, that, while things that we explained above, come more under the dominion of the mind than of the senses, the things that we now are to exhibit, seem fall under the dominion of the senses rather than under the reason; in fact we believe that we should study more conveniently among the content of physics the aspects of the void that someone might believe we should have treated in a previous paragraph.

[223] As Boas refers, Gesner in his *Bibliotheca universalis* wrote "*Nos sane obseruauimus Giorgium Vallam a Graecis permulta dissimulantur esse mutuatum, & non pauca perperam in Latinum sermonem transtulisse*", p. 273r [567]

[224] Codex Atlanticus, see Indici per materie ed alfabetico del Codice Atlantico di Leonardo da Vinci, compilata da G. Semenza, Milano, 1939. [568]

2.5.6.2 The late 16th-century printed editions

As clues of the increasing curiosity about Heron, Boas quotes:

- the mathematician and physician Gerolamo Cardano (1501-1576), who in his *De subtilitate rerum* (*The Subtlety of Things*), published in 1550 in Nuremberg, discusses on his view about vacuum, proving significant knowledge of at least part of Heron's contents;
- the French humanist Pierre de la Ramée (1515-1572), who was in possession of a Greek manuscript of Heron's works;
- the Swiss humanist Conrad Gesner (1516-1565), who would have compiled a list of Greek manuscripts of Heron's works housed in Italian libraries [225].

In the last quarter of the century, this increasing attention to Heron's work led to a number of translations into Latin and Italian vernacular.

The Latin edition was first printed in 1575, entitled *Heronis Alexandrini spiritalium liber, a Federico Commandino Urbinate, ex Graeco, nuper in Latinum conversus*. The author was both a humanist and a scientist (physician), and was connected with the court of the dukes of Urbino as a translator of Greek science and as a mathematical tutor. His edition was reprinted in 1583 (in Paris) and in 1680 (in Amsterdam), as evidence of the interest it arose, that will last until the 19th century.

In 1582 the Florentine scholar Bernardo Davanzati Bostichi (1529-1606) completed his translation of the prooemium of *Pneumatics*, under the title *Della natura del voto* (*About void nature*), which he dedicated to the architect and painter Bernardo Buontalenti (see *infra* 2.5.8.2); for the same architect, Oreste Vannoccio Biringuccio translated *Pneumatics*, as we have seen in 2.5.2.4.

A complete Italian translation, based upon Commandino's Latin version, of the *Pneumatics* appeared in 1589, entitled *Gli artificiosi, e curiosi moti spiritali di Erone Alessandrino, tradotti da Gio. Batista Aleotti d'Argenta* [26], whose autograph manuscript is still available in a codex about music, housed at Berkeley Library in New York City, written in 1583 [226]. The author was so fascinated by the topic, that he attached four devices of his own to Heron's, by remarking that the use of water could be replaced by blowing air into the basis; they precisely were:

1. Miliarium (vessel designed to heat water)
2. Miliarium with playing trumpets
3. Hydraulic instrument
4. Organ

The work was so successful, that it was reprinted twice in the following century: in 1647 in Bologna and in 1693 in Paris [227]. In 1589, even Bernardino Baldi (1533-1617), abbot of Guastalla, published in Venice his translation of Heron's *Automata*, entitled *Di Herone Alessandrino De gli automati, ouero, Machine se mouenti libri due* [228].

The last 16th-century Italian translation is the the *Spiritali di Herone Alessandrino, ridotti in lingua volgare da Alessandro Giorgi*, published in Urbino in 1592 and reprinted in Venice three years

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[225] We couldn't find in any of the libraries we visited, the edition of Gesner cited by Boas (1545), but only the most recent one (1555). For this reason, it was not possible to include here the list of manuscripts alleged to Gesner.

[226] Partly searchable online http://app.cul.columbia.edu:8080/exist/scriptorium/individual/CU-MUSI-992.xml

[227] Fully searchable online at http://fermi.imss.fi.it/rd/bdv?bdviewer/bid=000000300236#

[228] Fully searchable online at http://fermi.imss.fi.it/rd/bdv?bdviewer/bid=000000300035#

later. This is a more learned translation than any of the others, not excepting Commandino's, being equipped with critical apparatus and some discussion of the mechanism of various devices, with some references to the work of Giorgi's contemporaries, such as Cardano [229].

2.5.7   Late Renaissance Automata

In those years when these translations were being prepared, engineers continued to design and build automata. The rediscovery of the classics, mainly Aristotle, who had stressed the importance of wonder as a motivation to learning, in a sense made the automata more acceptable from a cultural point of view, attributing to mechanics the scientific dignity that before had been denied and tentatively distinguishing it from magic [247, 570]. Marr [254-255] has reconstructed the attitude towards automata in this period, highlighting that it depended on some issues: "availability of certain types of technical or mathematical education, ownership of printed books, manuscript circulation, and the dispersal of artifact". He also emphasizes that the spread of printed books on the subject has been much lower than found by Boas [362] and Eamon [247]; and in support of his hypothesis, Marr refers that some authors [230] interested in the topic were entirely devoid of copies of these books, adding that most extant copies reveal an Italian origin. We think that the circulation of books, manuscripts, and ideas in the Late Renaissance is so far from being deeply studied, that any assumption can be made and supported by suitable examples.

Despite the growth of studies and publications, the number of documented automata, or of literary references, is rather poor. It does not mean that their spread was necessarily limited: as a matter of fact, in 1530, the Renaissance poet Pier Angelo Manzolli (latinized in Marcellus Palingenius Stellatus, since he was born in La Stellata, near Ferrara) wrote a Latin poem, entitled *Zodiacus vitae*. The twelve books which compose the work are entitled to the twelve zodiac signs, because life, if guided by science, shines like the sun does through the twelve houses of heaven. In Book XI, 846-851, he refers to a Heronian-like device he had witnessed in Rome by 1521: "I saw, during the reign of pope Leon X, while I was in Rome, a potter's work, a statue of a young man, emitting a strong air stream through a narrow mouth opening: because it was keeping in the cavity of the chest some liquid, previously introduced, that, once left free and heated, was emitted out of the mouth, with the appearance of a strong air stream, and was perceptible from a distance." [231]

Around the middle of the century, Bartolomeo Campi, armorer and goldsmith, works for the Dukes of Urbino [571, 255], creating a self-moving silver turtle for the distribution of toothpicks on the table, as Bernardino Baldi is told thirty years later, and promptly refers in his translation of the Automata [232]. In the same years, even the clock maker Giannello Torriano (ca. 1500-1585) from Cremona is working for the emperor Charles V; responsible initially for the building of a copy of

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[229] Fully searchable online at http://fermi.imss.fi.it/rd/bdv?/bdviewer/bid=000000300135#
[230] Like the French scholar Gabriel Naudé (1600-1653).
[231] Vidi ego, dum Romae, decimo regnante Leone, / Essem, opus a figulo factum, iuuenisque figuram, / Efflantem angusto validum ventum oris hiatu: / Quippe cauo infusam retinebat pectore lympham, / Quae subiecto igni resoluta exibat ab ore / In faciem venti validi, longeque furebat.
[232] *Bartolomeo Campi da Pesaro huomo di grande ingegno, mentre seruiua i nostri Prencipi, fece (per quanto mi uien detto) una tartaruca d'argento, laquale caminando per la mensa, mouendo i piedi, la coda, & il capo,se n'andaua nel mezo; doue apertasi, come una cassetta, dalla parte di sopra somministraua gli steccadenti.* Bartolomeo Campi from Pesaro, man of great intellect, while was in the service of our princes, built (as I am told) a silver turtle, that could walk on the table, move the feet, the tail, and the head, arriving in the middle of the table, where, opened atop as a box, served toothpicks.

the Astrarium by Dondi [233], Giannello later (1557-1558) received several commissions of devices for fun: according to a tradition collated at the end of the 17th century, he would have tried to entertain the monarch by building birds that were seen to eat, and almost fly from the hands; statues of human-like warriors, fighting each other, beating the drums, playing the trumpets, and others danced and did some games; barking dogs, that first joked, and caressed, and then bit, and, when lightly beaten on the tail with a small rod, they gave up. On the death of Charles V, Giannello served Philip II, who loved him and for whom he built automata, including a famous "dama que toca y dança" (lady that plays and dances), a puppet higher than a third [of a real one] that, put on a table, danced at the music of a lute, which she was playing, and came back, returning to whence departed", now, according to Bedini [298], housed at Kunsthistorisches Museum in Wien [234].
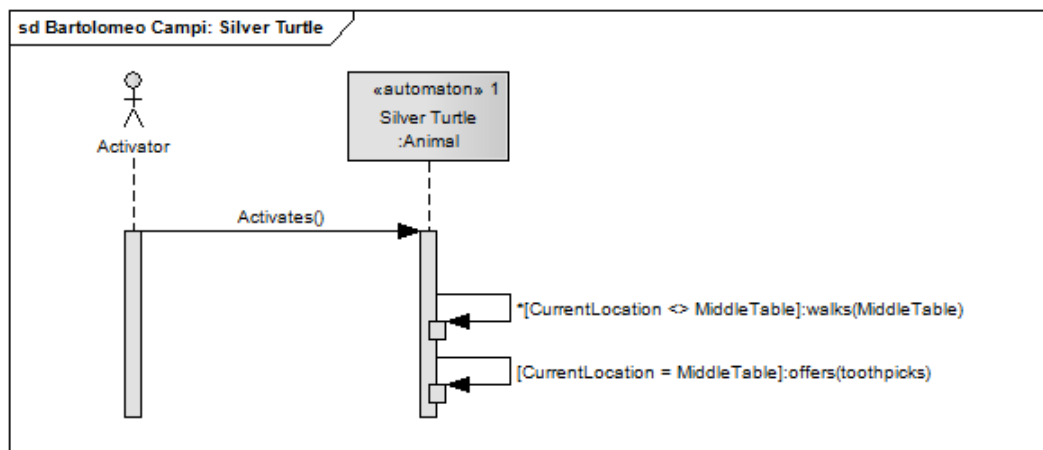
Fig. 162: UML Diagram for Bartolomeo Campi's Silver Turtle

Germany, since the first years of the century, was very active on the front of the production and use of automata: the figure of Hans Bullmann from Nuremberg (?-1535), who would have built androids, would have been very interesting to us, if we only could rely on some more evidence than a late quotation of the 18th century [572]. Around 1560, an anonymous German automata builder, according to Bredekamp [573], would have built for Charles V a monk who prays, saying his rosary, now housed at the Deutsches Museum in München [574]. Another contemporary and nearly identical wooden automaton is housed at the National Museum of American History in Washington, DC. It represents a Franciscan monk dressed exactly as the order rule imposes [574]. The work has been acquired for the museum in the late 1970s by the curator Otto Mayr, who enthusiastically described it as a specimen representing the direct predecessor of the Jacquet-Droz' automata. A legend and some documents in the accession archives, as King refers [574], connect it with Giannello Torriano: it would have been built as an *ex-voto* of the Spanish king Philip II (son of Charles V) for the the healing of his son Don Carlos. Its physical appearance would be similar to the renown Spanish saint Diego de Alcalá (1400ca-1463ca), according to King, who also describes its operation in detail.

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[233] Into two phases: first, he studied the old device, by 1538, and then he rebuilt it, according to the *De revolutionibus orbium coelestium* by Copernic, that is after its printing in 1543 and by 1550, when he presented it to the emperor.
[234] http://www.khm.at/en/kunsthistorisches-museum/collections/collection-of-sculpture-and-decorative-arts/automatons-and-clocks/
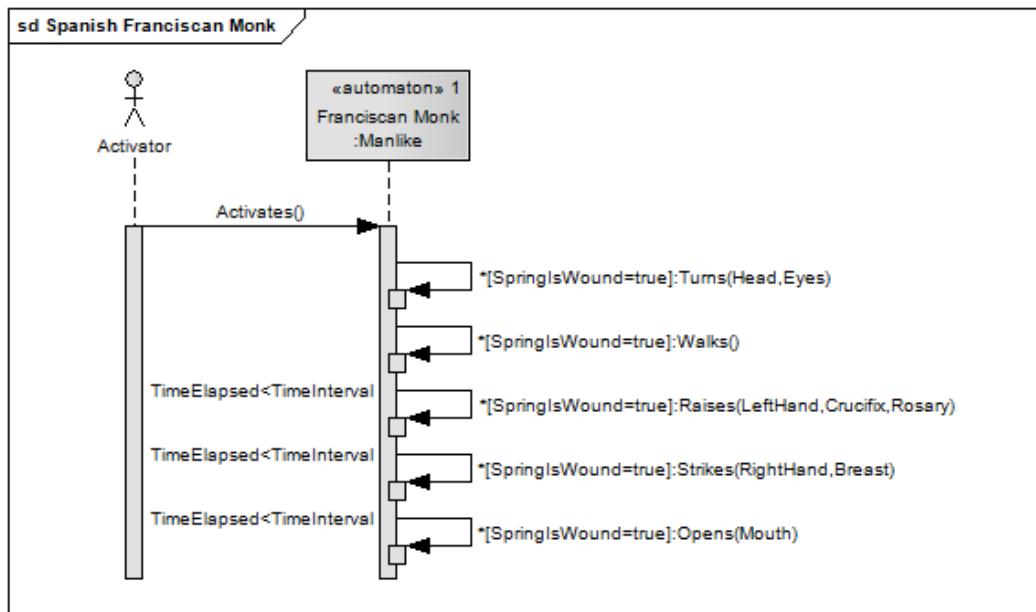
Fig. 163: UML Diagram of the Spanish Franciscan Monk Automaton

2.5.8 From the Courts to the Gardens and Chambers

The situation in the late Renaissance European history, characterized by the widespread presence of noble courts, favored a true revival of pneumatics, applied to fountains in gardens, especially in country houses [256], and, at the same time, the spread among the nobles of collecting rare and valuable artworks, to guard jealously in special chambers and to share only with other sophisticated connoisseurs.

2.5.8.1 Caimo's Garden in Milan

For instance, Milanese lords' interest in rural life (or we should better say the assertion of the need to find it interesting) is well documented in the treatise "*La villa*" written by the architect Bartolomeo Taegio in 1559, in the form of dialogue between two gentlemen; the author listed about two hundred and fifty houses not far from the city center, described as places of calm, surrounded by pleasant gardens, where lords can enjoy literature, hunting, conversations and rest, and manage their estates. The life "in villa" for them is linked to the pleasure of a close relationship with nature, that consists in a special care for the beauty of the gardens, described in great detail by the author. Precisely due to these descriptions, accompanied by detailed drawings, we document the popularity of Heron's pneumatics: two fountain referred to as "machina di Herone", designed by the mathematician Alessandro Caimo for his garden [575]; they by the force of air, or better wind, they pour water almost continually, as it is evident from the drawing, that shows both the internal (functional) structure, and the external (decorative) one. They are very similar, due to the identical subject, to the ones by Francesco di Giorgio and Anonymous quoted in 2.5.3.3.

Fig. 164: Heron's Fountain in Taegio's La Villa

2.5.8.2 The Garden of Villa Medici in Pratolino

In the same years (1558) Oreste Biringucci, also known as Vannoccio, was born in Rome from a noble family; he worked as a scholar, by translating from Latin into vernacular Aristotle's *Mechanics* in 1582, and Heron's *Pneumatics* (this last one for Buontalenti), as evidenced by a letter from Rome, dated December, 28 1582 [576]. In 1583 he was called in Mantua, where he designed decorative works, such as arches and apparatus for feasts.

Bernardo Buontalenti (1531-1608) worked for nearly all his life as an architect at the court of the Medici family in Florence [577], creating works of dramatic effect, and began experimenting in the creation of gardens featuring fountains and caves, often populated by automata: the most famous is the villa of Pratolino, where he has been working from 1569 until 1581. Since the villa of Pratolino had been completed one year before the translation by Biringucci, we must assume that the dedication was a tribute to his expertise in contents taken from Heron's works.

Built as a gift from Francesco I de' Medici (1541-1587) to his mistress and later wife, Bianca Cappello (1548-1587) from Venice, the villa was a kind of permanent exhibition of technics, where to stress the primacy of Florence [341]. Unfortunately, today very little remains of the villa [235], but its appearance can be reconstructed thanks to the descriptions by De Vieri [578], written in 1587, by an anonymous in Ms. 2312 [236], housed at the Biblioteca Riccardiana in Florence; to a report made by the Modenese draughtsman and painter Giovanni Guerra (1544-1618), sent by the pope to visit Pratolino in 1598; and to the lunette by Giusto Utens, as to the Southern part. In the 18th century even Schickard visited the park and made some drawings, now housed at Landesbibliothek in Stuttgart.

The park was divided by two orthogonal axes, which crossed at the villa, ideal center of the park itself: the North/South axis started at the Fountain of Jupiter and ended at the Fountain of the

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[235] A virtual visit of the park is possible at http://pratolino.mpiwg-berlin.mpg.de. Mozilla Firefox ® is the recommended browser. Here the drawings made by Giovanni Guerra are also collected.

[236] Fully searchable online http://nausikaa2.mpiwg-berlin.mpg.de/cgi-bin/toc/toc.x.cgi?dir=Ricc_Ms_2312

Washerwoman, while the East/West axis divided the villa from a large meadow, facing the Giant of Appennino, giant sculpture by Giambologna [578, 256, 579-582].

Fig. 165: The Parco Nuovo of the Villa of Pratolino, lunette by Giusto Utens, (1599)
Museum of Firenze com'era

Only some of the caves were populated by automata, whose operation is well described by De Vieri and the anonymous of the Riccardiana manuscript: they were located mainly in the foundations of the villa, which was very elevated to the plane of the garden, as shown by Utens, in the southern park, the so-called *Parco dei Moderni*.

Just below the villa were obtained six caves. Access to all the four main caves was given through the *Grotta del diluvio* (Cave of the deluge), whose entry was the center of the circular staircase (A) [237]. From this cave on the right, one could go straightforward and enter the Grotta di Galatea (B), or turn right to the *Grotta della stufa* (Cave of the stove - C), or turn left to the *Grotta della spugna* (Cave of the sponge - D), where he could also reach the *Grotta del Cielo*, later splitted into *Grotta del Tritone* (Cave of the triton - E), and the *Grotta della Samaritana* (Cave of the Samaritan woman - F), this last one full of automata; under the two semi-circular staircases that descended from the main balcony, were the *Grotta della donnola* (Cave of the weasel - G) on the left, and the *Grotta dei ranocchi* (Cave of the frogs) on the right (H).

Descending to the garden level, one could see the figure of the Mugnone (the river whose water was used here in Pratolino as automata power source) by Giambologna (1529-1608), and at its sides, two more caves, dedicated respectively to the Fama (Cave of Fame) (I) and to the god Pan (L).

The garden was full of fountains featuring statues with mythological (Jupiter, Juno, Esculapius, Perseus) or prosaic (salamander, farmer, washerwoman) subjects; only in a few number of them there were also automata: the Fontana di Cupido (Fountain of Cupid), the Fontana del Parnaso (Fountain of Parnassus), though this last one is quoted only in Sgrilli's 18th-century description.

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[237] Capital letters refer to the sketch map at Fig. 166
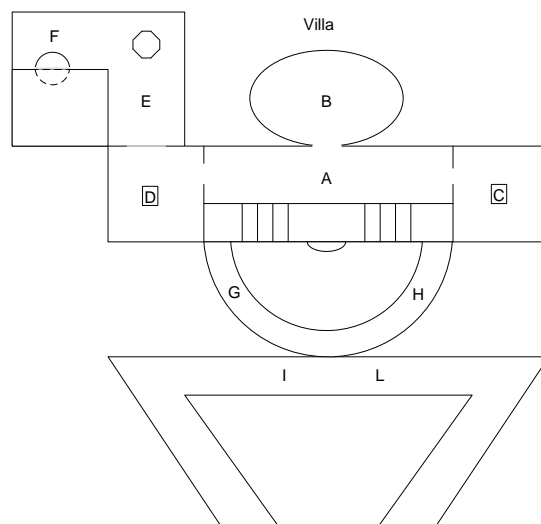
Fig. 166: Sketch map of caves under the Villa at Pratolino

The first cave a visitor would have entered was the Grotta del Diluvio; it is very difficult to definitely reconstruct its appearance, since descriptions don't agree, or are too brief. We chose therefore to present both the model of De Vieri's, and of Sgrilli's description [238], in order to illustrate that probably along centuries the automata were transferred from a cave to another, or some were added; the reasons are probably to be searched in devices wear, or in the need to renew the narrative scheme, avoiding the monotony of an always identical show. The visitor could look at the various automata placed in the wonderfully decorated niches: harpies pouring water, a child turning a globe, some ducks drinking, and some water spheres that showed different objects or scenes, depending on the position of the visitor, who was looking at them [239].

This cave was an entrance to the other caves, and probably a place where to rest; in our descriptions, it is full of fountains, where some automata perform single parallel actions, after a technician's input [240], whose constant presence is mentioned by the sources. As we can see, along years only one harpy, the child and the ducks remained; most harpies and the spheres were removed, and in their place were added some automata whose subject (a miller and a grinder) was taken from everyday life, a topic in perfect tune with the 17th- and 18th-century Arcadian themes of simple living, marked by natural rhythms. The miller peacefully walks behind the ox that turns the millstone, and the grinder spins his wheel, while his assistant brings knife sword to the grinder.

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[238] In the Anonymous' manuscript no description is given.

[239] A comparison can be made with the Banu Musa's fountains water flow, that could assume different shapes, and with the behavior of the second automaton in the Chambre de Labastrie (Fig. 116).

[240] Such technician was called "fontaniere", meaning someone who controls the water flow of fountains.
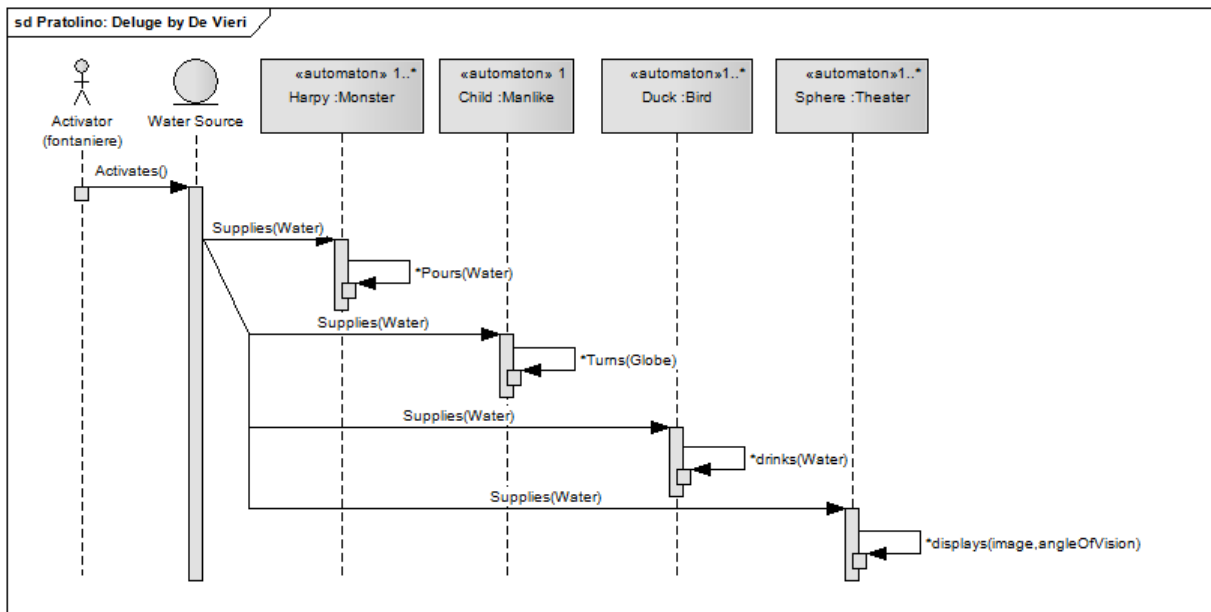
Fig. 167: UML Diagram of the Grotta del diluvio at Pratolino by De Vieri
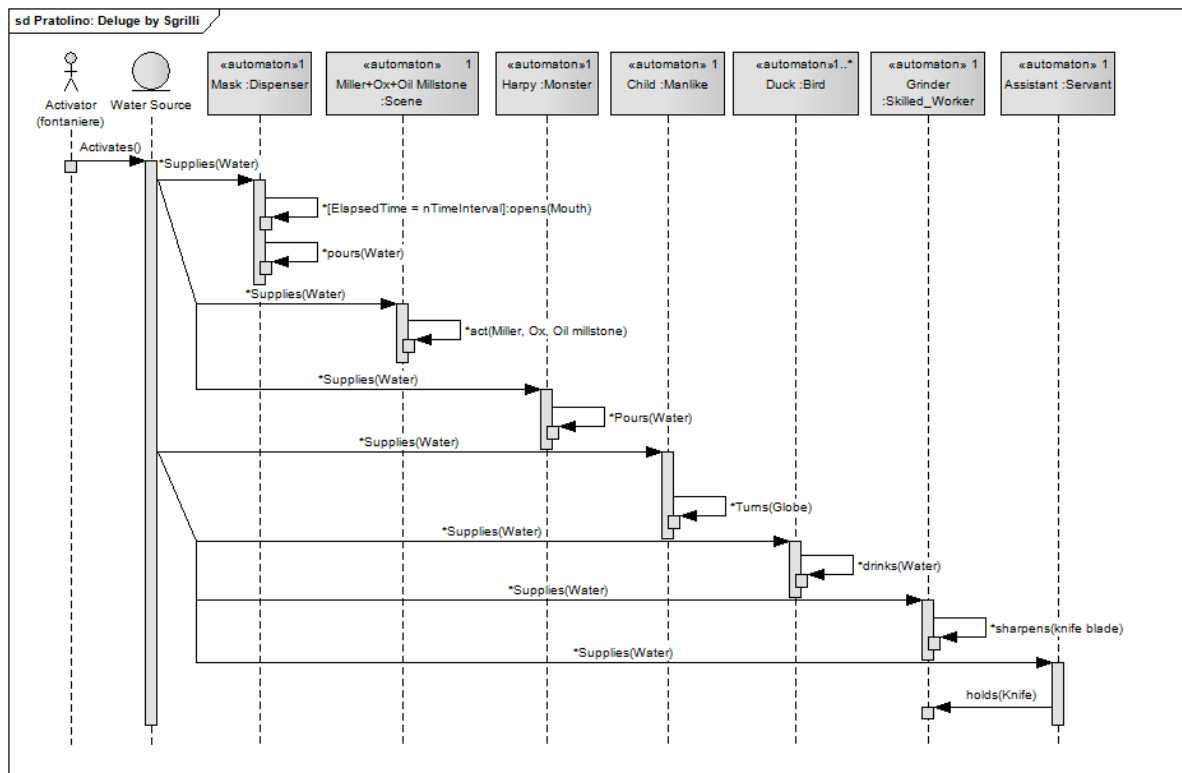
Fig. 168: UML Diagram of the Grotta del diluvio at Pratolino by Sgrilli

The Grotta di Galatea underwent a reorganization as well, because, based on the the description by Sgrilli, in the 18th century, the triton-shaped automaton was separated from the group, and placed in another cave, dedicated to him. Here also, the presence of the fontaniere was essential for the proper operation of the system.

The scene of Galatea has the same iconography used by Raphael in the fresco entitled *Trionfo di Galatea* in the Villa Farnese in Caprarola, near Viterbo (1511), dating to the first part of the century

and therefore possibly known to Buontalenti: the nymph, announced by a triton playing a shell, arrives on a shell, pulled by two dolphins, and is accompanied by other nymphs.
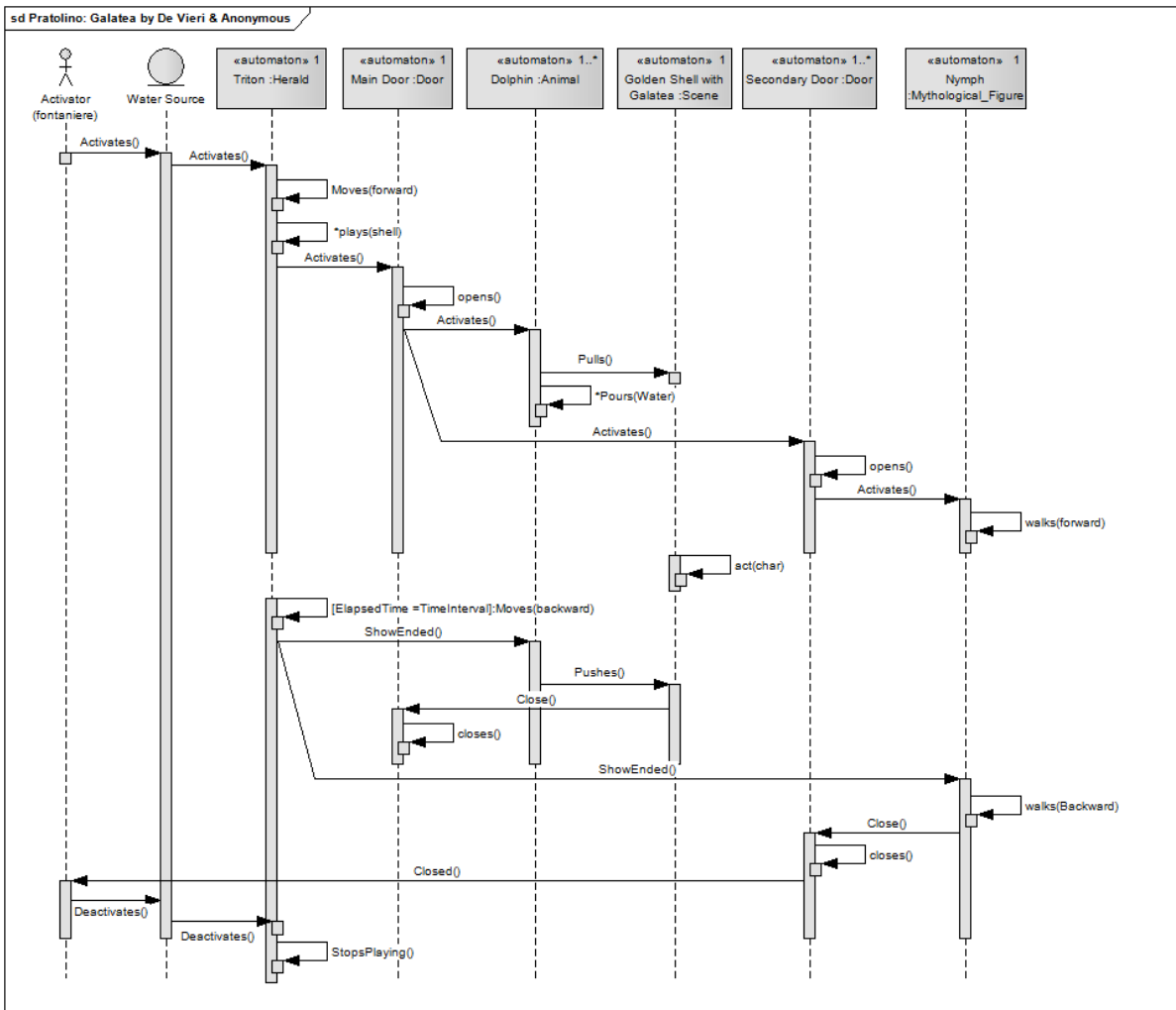
Fig. 169: UML Diagram of the Grotta di Galatea at Pratolino

The Grotta della Stufa should serve as a bathroom, on the model of Roman baths. The 16th-century sources do not speak of the trap that sprays water on visitors, who recklessly activate the trigger, but only of fountains. Again this is likely a subsequent rearrangement.
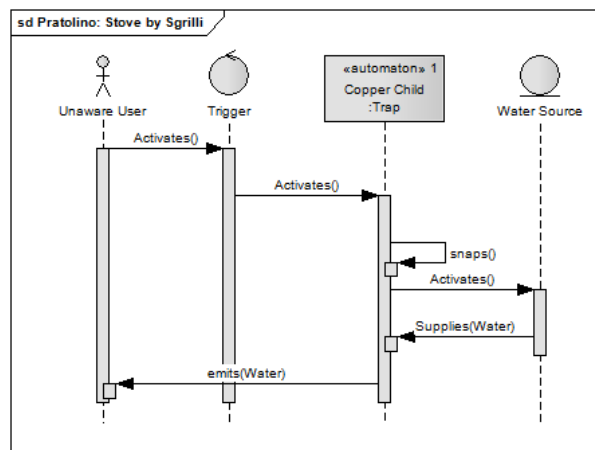
Fig. 170: UML Diagram of Copper Child in Grotta della Stufa (by Sgrilli) at Pratolino

This is the cave that was more than any other subject to change; at first it was known as the Grotta del Cielo and included all the caves, which later were called Grotta della Spugna, Grotta del Tritone, Grotta di Europa, and Grotta della Samaritana. The name of Grotta del Cielo was due to the ceiling mosaic, representing the night sky.

The main part of the Grotta, in the 16th-century descriptions, consisted in a dining room, preceded by a vestibule, decorated with a shepherd that plays surrounded by his animals; guests were then greeted by an automated marble servant, that, on the model of Arabic automata, poured water, holding a towel. They could then sit at the octagonal table, where also they could use running water; meals were automatically served through a wheel, by which courses directly passed from the villa kitchens to the cave.

According to Guerra, Sgrilli [241] and to later sources, guests were also entertained in the meanwhile by some automated scenes, taking place in the grotesques:

1. an assault on a fortress (see *supra* 2.5.3)
2. an idyllic scene with a shepherd, playing the bagpipes
3. a young woman coming out of an automated iron gate, goes to a well to fetch water, and comes back (this scene will later give the final name to the cave)
4. some workshops: the forge by Vulcan, and a mill.
5. a hunting scene
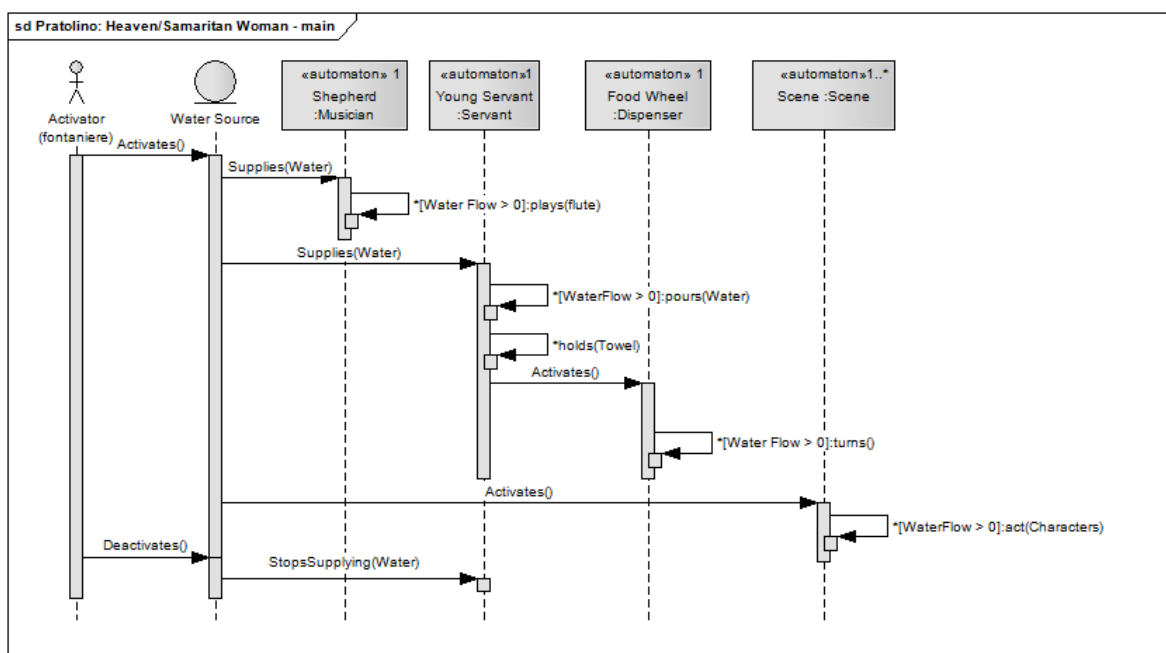
Fig. 171: UML Diagram of the Grotta del Cielo / della Samaritana at Pratolino

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[241] The writer Giovanni Rosini in his historical novel *La signora di Monza: storia del secolo XVII*, dating back to 1829, attributes the authorship of these automata to Buontalenti. The author gives a detailed description of the six main caves, so it likely appears that he had actually visited the villa.

Fig. 172: the Grotta della Samaritana according to Guerra

Sources are almost unanimous on the caves of Fame and Pan. In the first one, Fame is playing a trumpet, while a farmer is offering a cup of water to a thirsty dragon, which recalls one of the devices by Philon (#59); while in the second one Pan stands up, plays his pipes, waits a few moments for the applause, and sits back by his beloved nymph Syrinx. In a later description, at this point, a cuckoo begins to sing.
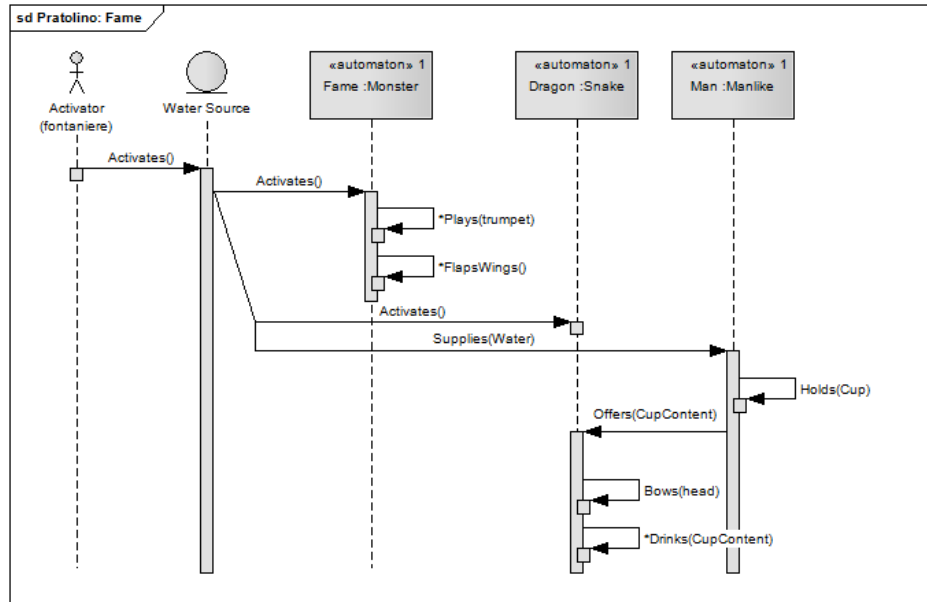
Fig. 173: UML Diagram of the Grotta della Fama at Pratolino

Fig. 174: The Grotta della Fama according to Guerra
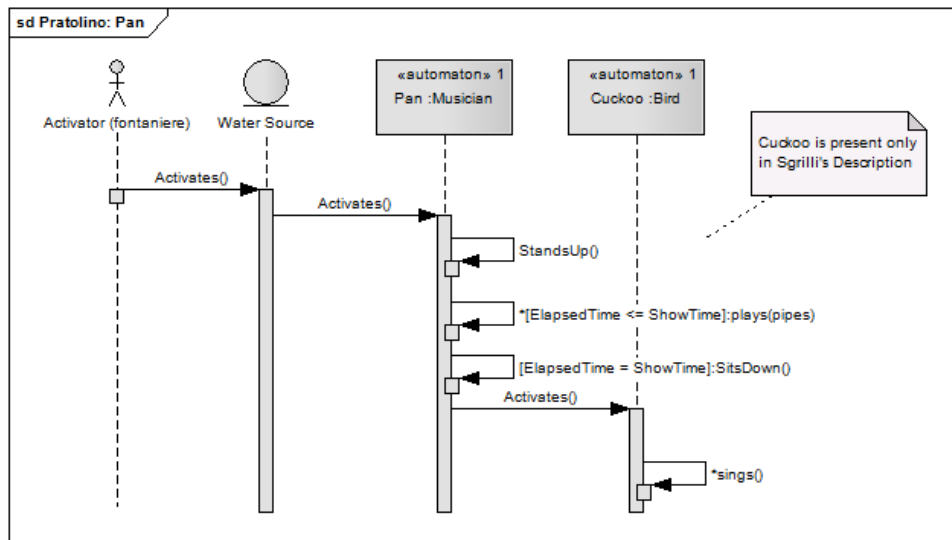
Fig. 175: UML Diagram of the Grotta di Pan at Pratolino

Fig. 176: The Grotta di Pan according to Guerra

The Grotta di Cupido is located in the park outside the building of the villa. It is underground, so visitors accessed via a staircase, where, according to Sgrilli, there were other traps spraying water on unsuspecting guests. In the main room, there was a cupid bronze, rotating on itself, and carrying a flaming torch in one hand, and a bow in the other; at irregular intervals a jet of water came out of the torch, instead of fire. Whether the fire was actual fire or only a carved one, it impossible to say.
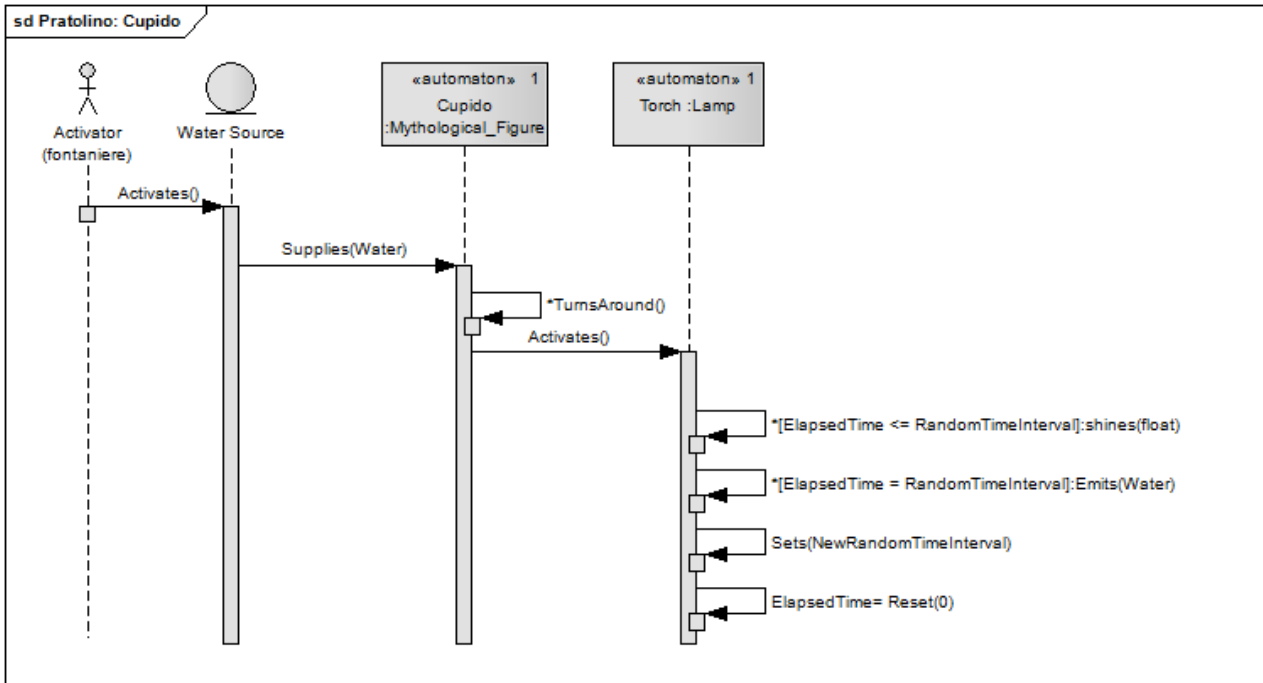
Fig. 177: UML Diagram of the Grotta di Cupido at Pratolino

The last device is described by Guerra and Sgrilli; nothing is referred about it neither by the anonymous nor by De Vieri. We decided to model it because it is linked to the previous tradition, due to the presence of a water organ, and it displays automata, too. The Fontana del Parnaso was outdoors, in the very Southern part of the park. Visitors could however enter its internal part where the organ was hidden, to see how it was operated.

The villa is still accessible to the public, though nothing of the Renaissance facilities survives. Despite the fact that we haven't got almost anything of the villa and its garden of wonders, Pratolino still remains an important example of Renaissance art and technique, based on the revival of the lesson of the ancients and on its systematic, but creative application.

Fig. 178: the Fonte di Parnaso, according to Guerra
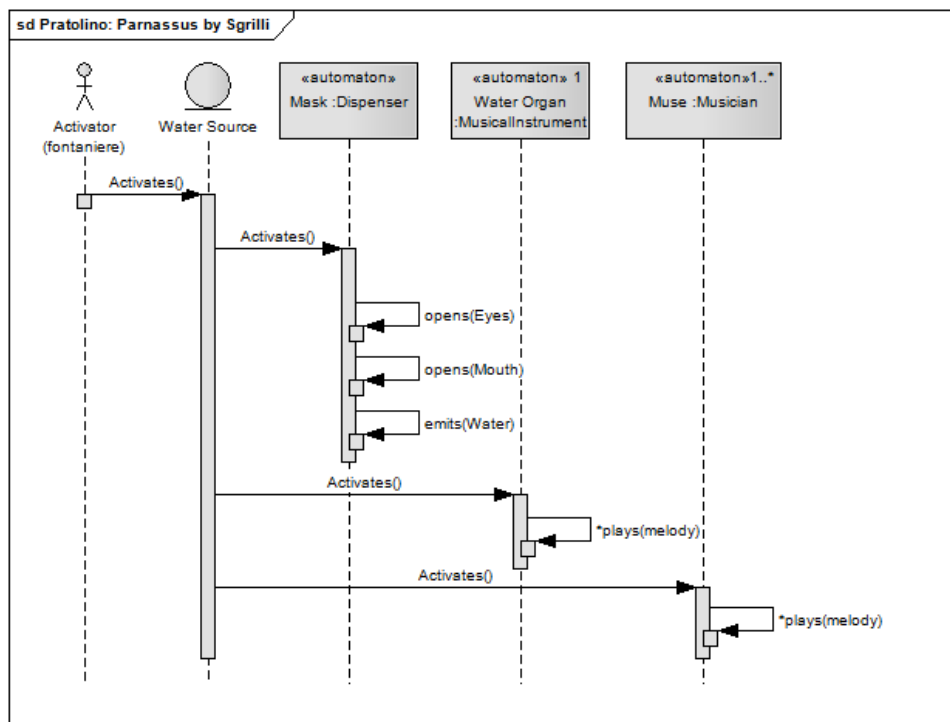
Fig. 179: UML Diagram of the Fonte di Parnaso at Pratolino by Sgrilli

2.5.8.3 The Garden of Villa d'Este in Tivoli

Pratolino, however, was not the only place where a Renaissance villa with a garden full of fountains was built. In Tivoli, near Rome, where in the 2nd century AD the Roman emperor Hadrian had built another jewel of hydraulic systems, Villa Adriana [242], Cardinal Ippolito II d'Este, son of the duke Alfonso I d'Este and Lucrezia Borgia, was sent by the pope to Tivoli as governor for life, and decided to completely reconstruct the residence he had been assigned, so he commissioned the architect Pirro Ligorio (1510-1583) to erect a villa, that could contend with Villa Adriana; in 1549 the construction started, attended by the most prestigious names in hydraulics of the time (the Bolognese Tommaso Chiruchi, and the French organ builder Claude Venard) [583-585], since the gardens were designed to be full of fountains.

The French scholar Michel de Montaigne (1533-1592) recorded in his *Journal du voyage* (Travel Journal) that in Tivoli he had encountered singing birds and an owl, faithfully devised according to Heron's device I-16 [243]; the device is nowadays still extant (Fontana della Civetta) and, after a recent restoration, also working. Also the Fontana dell'Organo still exists, and the organ system built by Claude Venard has been restored. He had implemented a device whereby the water fall produced an air flow through the organ pipes, while simultaneously another pneumatic mechanism lowered keys, producing a melody. [586]

Fig. 180: the Fontana della Civetta

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[242] For a virtual reconstruction, see http://www.villaadriana.com/

[243] *Ailleurs on oit le chant des oiseaus, qui sont des petites flutes de bronse qu'on voit aus regales, & randent le son pareil à ces petits pots de terre pleins d'eau que les petits enfants souflent par le bec; cela par artifice pareil aus orgues, & puis par autres ressorts on faict remuer un hibou, qui, se presantant sur le haut de la roche, faict soudein cesser cete harmonie, les oiseaus étant effraïés de sa presance & puis leur faict encore place: cela se conduit einsin alternativement, tant qu'on veut.* In another place you hear the song of birds, which are little bronze flutes that you see at regals; they give a sound like those little earthenware pots full of water that little children blow into by the spout; and this by a contrivance similar to the organ one, and then by other springs they set in motion an owl, which, appearing at the top of the rock, makes this harmony cease instantly, for the birds are frightened by his presence; and then he leaves the place to them again.

2.5.8.4 From Wonder to Technology and Science

In the following centuries, some other parks [219] were designed with fountains and automata: some examples are represented by the *Chateau neuf* in Saint-Germain-en-Laye, by the *Palace of Coudenberg* in Brussels; the *Hortus palatinus* in Heidelberg, the *Stuttgarter Grotte* in Stuttgart, and in *Hellbrunn*, most of them designed and built by the French engineer Salomon de Caus (1576-1626).
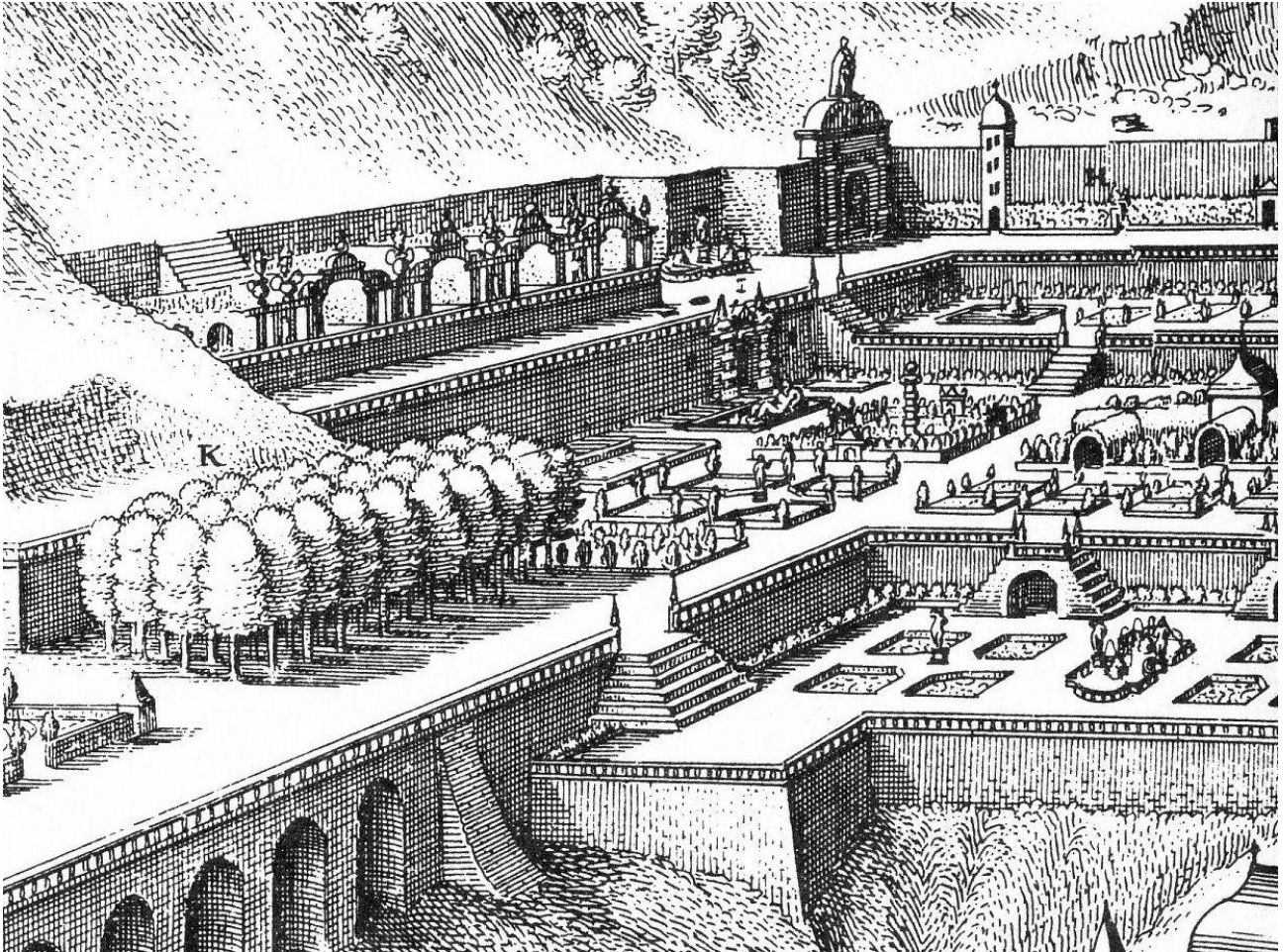
Fig. 181: the Hortus Palatinus in Heidelberg by Matthäus Merian (1593-1650)

The degree of complexity reached by the implementation of such classical instances, required, as it happened in Pratolino and in Tivoli, a continual maintenance, aimed not only to grant full devices efficiency, but also to renew them in order to avoid monotony. Such expensive requirement would lead to the gradual abandonment of these parks. In addition, as we have already pointed out, there was a parallel production of mechanical or pneumatic devices at (relatively) inferior cost, which could therefore enter the private collections of fine gentlemen, who kept them in their *Chambers of Wonders*, just as it had happened in the "studioli" (private studies) of the Renaissance Italian Lords [244].

While the works by the ancients found new life in the gardens and in the Wunderkammer, they were also studied for less noticeable purposes. As Kang has shown [274], Renaissance hermetic

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[244] Federico da Montefeltro in Urbino, Lionello d'Este in Ferrara; Isabella d'Este in Mantua, and Francesco I de'Medici in Florence had commissioned famous artists to design and decorate their studies.

philosophy and automata were strictly linked: for instance, the wandering alchemist, physician, astrologer, philosopher, and courtier, Henricus Cornelius Agrippa von Nettesheim (1486-1535) in his *De Occulta Philosophia* (*Occult Philosophy*) cites the most significant figures of history of ancient automation (Daedalus, Homer, Archytas, Boethius, Apollonius of Tyana), in order to demonstrate that the operation of those devices depends on natural magic principles, whose practice is not evil in itself. Even the English mathematician and astronomer John Dee (1527-1608/9) speaks of *thaumaturgike*, as a form of mathematical magic, and "defends interest in such works from the accusation of diabolical magic". The role played by the Reformation and its consequences are already evident.

Slowly but unquestionably, the idea of automaton was preparing to permanently lose any relationship with wonder, to assume the connotation, all positive, of perfect and fail-safe device. In the 17th century, mechanistic natural philosophers and political theorists used it as a figurative object to depict "the clockwork universe, the state, as well as the human body. Robert Boyle, for instance, in *A Free Enquiry into the Vulgarly Received Notion of Nature* (1686), praised God for having "framed so great and admirable automaton as the world," while Thomas Hobbes, in *Leviathan* (1651), described man as a rational automaton before characterizing the state as *an Artificiall Man*." [274]

Perhaps the only one that for a moment showed to regret the aura of magic and wonder surrounding ancient automata, was the philosopher Tommaso Campanella (1568-1639), who, in his treatise *About the Sense of Things and Magic* (*De sensu rerum et magia*) in 1604, wrote: "What is done by the scientists by imitating nature or helping her with unknown arts, not only to the low plebs, but also to the community of men, it seems magic. So that not only the aforementioned sciences, but all the others are useful for magic. Make a dove fly like the alive ones, was a magic trick by Archytas, and at the time of Emperor Ferdinand in Germany, a German man made fly of themselves an artificial eagle and a fly, but, until the art is not explained, you always speak of magic; after, it is trivial science." [245]

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[245] § 241-242: Tutto quello che si fa dalli scienziati imitando la natura o aiutandola con l'arte ignota, non solo alla plebe bassa, ma alla comunità degli uomini si dice opera magica. Talché non solo le predette scienze, ma tutte l'altre servono alla magia. Magia fu d'Archita fare una colomba che volasse come l'altre naturali, e a tempo di re Ferdinando imperatore in Germania, fece un tedesco un'aquila artificiosa e una mosca volare da se stessa, ma, finché non s'intende l'arte sempre dicesi magia: dopo è volgare scienza.

3 Classification Issues

The implementation of the UML diagrams has imposed a reflection on the nature and characteristics of individual automata, since the purpose of classification had suggested the idea to use a functional (and therefore simplified) representation: the identification of classes has been made both synchronically, during the study of the instances in their historical background, and diachronically, when the general framework of class model was established.

Classes have emerged, thanks to the thorough analysis of both behavior and appearance of individual automata: we have taken into account not only the actions performed by the automaton, but also the appearance of the automaton itself. In fact, while doing the same action (e.g., pouring some liquid), a mask-shaped fountain, and a human figure representing a servant are conceptually different, due to the presence or absence of the life component, that is crucial in representation. In some cases, the decision of modeling the automaton as belonging to a class or to another one has been made in order to preserve as many features as possible. Appearance, in particular, needed to be recorded in some way, at least in classes instance name, unless it would be lost, since behavior rarely implies a specific look: here we have flying horses and eagles; manlike and animals attacking; musicians, heralds and instruments playing. In another case it was necessary to introduce the intermediate category of monster between human and animal, to respect the intentions of the authors' narrative. Humans and gods have been grouped into the manlike class.

We have identified two classes of actors:

- user (the end user of the device), that has a limited recurrence, since the end users are mainly spectators of the device performance, so they are not directly involved in device operation.
- activator, i.e. namely whoever predisposes the device for operation. Users are not necessarily aware of their intervention, though they can sometimes imagine that device operation needs an input.

Classification has been also useful to identify undoubtedly those items that were not automata *stricto sensu*, since their behavior depends on activator's repeated inputs; the presence in a diagram of more than one activator, or of an activator that continues performing an action, are relevant clues of lack of automation (see, for instance, Fig. 60 and Fig. 105).

As it was logical to expect, the source type has influenced the detail level of the working description; where it was possible to study directly the design, the individual components of the system were included in the diagram; on the contrary, where the description was rather brief, we included the essential components and built the framework for the rational operation of the automaton. But the modeling of those devices whose behavior was not even briefly described, has been impossible; although this statement may seem obvious, it has involved the abandonment of modeling such devices, as the handmaidens of Hephaestus, probably the first example of artificial intelligence that man has imagined. While the extreme vagueness of description may suggest a wide variety of behaviors, it however offers no contents for modeling.

The modeling of automata that correspond to animals shows a substantial coherence between animals' natural behavior and corresponding automata's one; birds sing and fly; lions menace and roar; snakes hiss and crawl; sometimes they appear as trained animal, capable of performing actions

they were trained to do: rampant lions near the throne of Byzantium, and falcons dropping balls in cymbals in Arabic clocks are among the most interesting examples.

Objects modeling has made three types of behavior emerge:

1. actions coherent with object purpose, and enhancing usual behaviour, such as unexstinguishing lamp (Fig. 72) , arc qui ne faut (Fig. 128), chessboard (Fig. 130).
2. unexpected actions, that is incoherent or even opposite to object purpose, such as the torch that sprays water in the Grotta di Cupido in Pratolino (Fig. 177), or dangerous columns and furniture (Fig. 123, Fig. 125, Fig. 126)
3. imitation of human actions, such as objects that speak (Fig. 3, Fig. 132), take decisions (Fig. 8, Fig. 131,) or regulate their proper working (Fig. 6)

From a historical point of view, the widespread presence of Greek (firstly) and Arabic (later) traditions makes the chronological distribution of various classes of automata rather homogeneous: one cannot demonstrate the prevalence of one or more classes in some periods than in others.

A careful study of the chronological distribution in terms of numerosity of automata is heavily conditioned by the existence (and by the availability) of the sources and by their size: it goes without saying that automata of Alexandrian and Arabic engineers, who left a significant written heritage, are the most numerous; unfortunately nothing (or little) can be said about other periods less rich of sources, sometimes only circumstantial, or *ex silentio*, as we have seen for the Roman age. The Antikythera mechanism demonstrates how our knowledge and beliefs about Greek technology are at all times liable to be annihilated by new discoveries. In this sense, not even a distinction between mechanical and pneumatic automata seems to affect their history: they both appear to be uniformly present during all periods.

From our analysis, however, it results that also imagined automata, especially in medieval times, should be revisited in relation to the actual technical achievements of the period: the cases of arc-qui-ne-faut, and of Tantalus' cup, present both in romances and in the Honnecourt's sketchbook (the only example of technical work of those years), show that the authors of the romances took a cue from the technical innovations of their time, while blanketing them of magic and wonder.

Finally, from a strictly quantitative point of view, the frequency of different classes is as follows:

Class	Instances	Class	Instances
Door	137	Transport, Snake, Eagle	16
Bird	120	Scene, Monster	14
Tool	52	Musical instrument, Weapon	13
Manlike	38	Singer, Herald	9
Musician	30	Trap	8
Mythological Figure	26	Dancer, Worshipper	7
Skilled Worker, Animal	23	Dispenser	6
Fighter	22	Archer, Lamp	5
Servant, Watchman	20	Theater	4
Lion	18	Column, Fly, Room	2
		Food, Game, Seat, Walls	1

Results show that the most present objects are doors, and the most reproduced animals are birds: the fact that they were (relatively) easier to build, has had an impact. Although the manlike automata

are confined only to the fourth place, it should be noted that, when summed with musicians', skilled workers', fighters', servants', singers', dancers', archers' and worshippers' instances, they would stand at the forefront, demonstrating that the key interest was the reproduction of a human figure, able to make at least some precise actions.

Here we have a model of classes with four emerging abstract classes (Living Being, Daily Life Item, Entertainment, Environment) that can be used to logically organize the actually used classes. They significantly correspond to the three existing disciplines and/or applications derived from ancient automata: robotics, automatics, show business.

Class	Instances
Living Being	423
Environment	144
Daily Life Item	102
Entertainment	32
Total	**701**
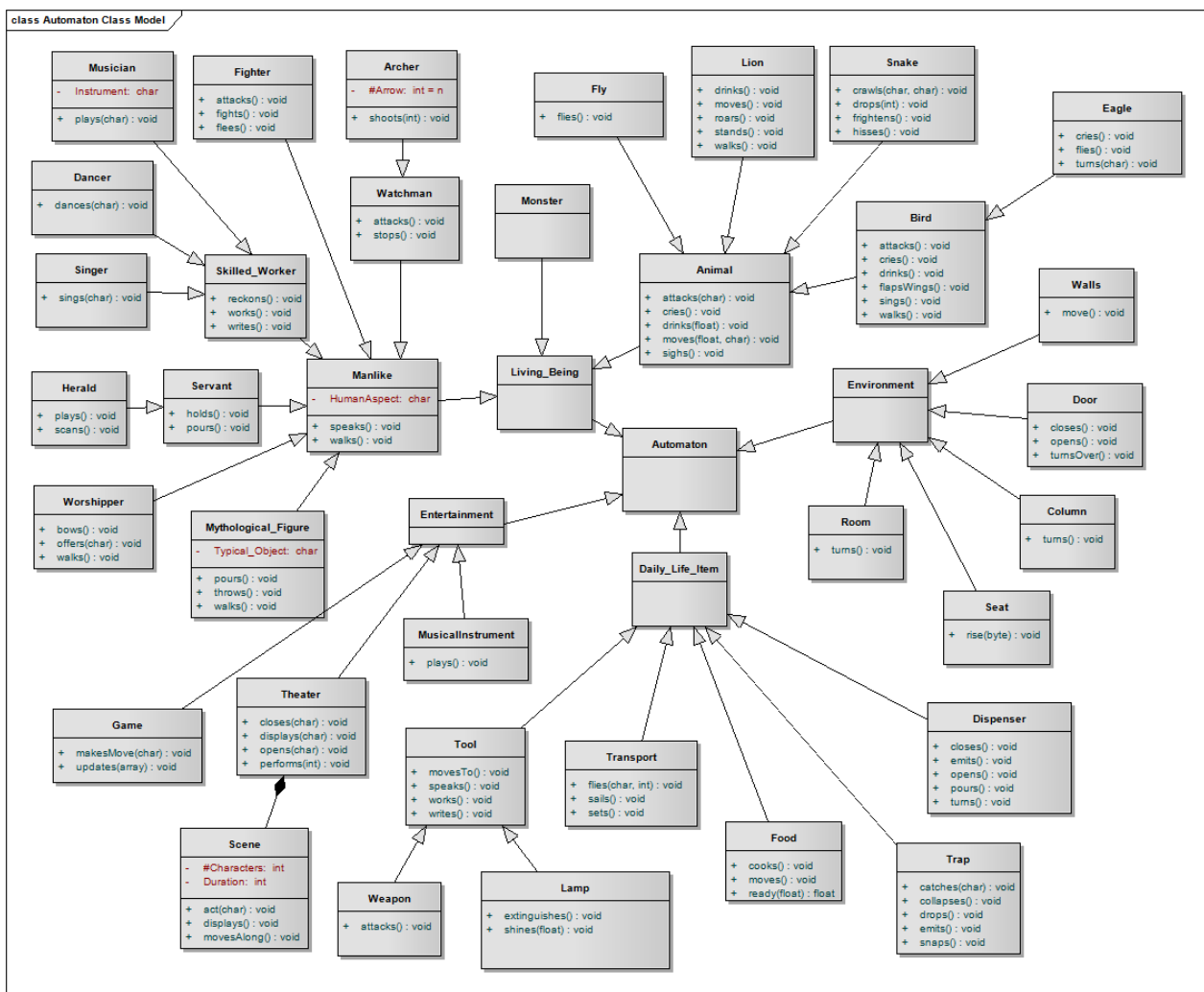
4 The Automaton Meme

A UML-based representation allows, as shown above, to achieve some important goals:

- Separation of contextual cultural components from genotypic components
- Study of how the idea of automaton is instantiated in the specific implementation
- Identification of an automaton meme

Once collected and organized the sources, the study in this final step will provide the analysis of the evolution of the idea of automaton.

Goals of the memetic study are therefore:

- deconstruct the automaton meme
- discover its components

4.1 Meme and memetics

Generally speaking, a meme is a recognizable information entity, related to human culture, that is replicable by a mind or by a symbolic memory support (e.g. a book, a drawing) to another mind or support. In more precise terms, a meme is a self-propagating unit (namely a *replicator*) of cultural evolution, analogous to what the gene is for genetics.

As a matter of fact, the word was coined upon the term *gene* altered with the Greek root (μιμέμη) meaning "imitation" by the ethogist Richard Dawkins and first used in his essay *The Selfish Gene* [587], published in 1976, based on the idea that inheritance, replication, mutation and selection mechanisms, described by Darwin, occur in the cultural field, as well [246]. And like in biology, the presence of these elements leads to the emergence of spontaneous evolutionary effects, though the direction memes arise in is different from the biological one. In his work, Dawkins describes the meme as residing in the human brain, influencing the environment in which it is, thanks to the action of the single men (i.e. *vehicles*), and propagating by means of cultural transmission.

This definition has created a great debate among sociologists, biologists and scientists from other disciplines, because Dawkins gave only a brief explanation of how the information units of replication can control human behavior and finally culture. Therefore, even about the meaning of the term "information unit" there is no general agreement among scholars.

The question was revived in 1999, when the psychologist Susan Blackmore published the book entitled *The meme machine* [589] [247], in which the author introduces the concept of generalized replicator, thus freeing the analogy with genetics from unnecessary constraints, that had let to many critics. She poses the question in rather simple terms: gene and meme have in common only the fact of being replicators, for every other aspect (e.g., copy mechanisms, sources of variation, fidelity, storage), differences outweigh similarities.

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[246] Such an assumption is synthesized by Dawkins as "Darwinism is too big a theory to be confined to the narrow context of the gene". In Blackmore's words [588] the mechanism is clearly explained: memes "show heredity (they are copied from person to person), variation (for example through errors in transmission or memory, and through recombination), and they are selected (people choose what to copy and from whom)".
[247] With a foreword by Dawkins.

In any case, the challenging position of Dawkins had already led to the formation of a rather lively and firm opposition front: just to quote a colorful example, again in 2001 Benítez-Bribiesca [590] defines memetics as a "dangerous idea, that poses a threat to the serious study of consciousness and cultural evolution", since the absence of a persistent information storage and of a defined copying mechanism prevents from any analogy with biological studies. Furthermore he adds that also gene replica mechanisms need a high precision degree, what can't be granted in the case of memes.

Such a position, expressed more than 25 years after Dawkins' work publishing, neglects, however, the explicit studies and improvements by memetics scholars, especially on the issues considered as the most critical, being extremely vague or subject to interpretation, such as criteria for the selection. As Blackmore clearly states [588], though memes are often quoted, memetics finds it hard to be counted among the scientific disciplines, since "there is no thriving science of memetics, and no specialist journals or conferences. Perhaps memetics is just plain wrong; perhaps it is currently too difficult to test its predictions; or perhaps its implications are too scary or unappealing for people to accept" [588]. In any case memetics differs from other theories about human evolution under the respect of the idea of culture, that is not intended "as an adaptation of benefit to early hominids and their genes, but as a parasitic second-level replicator that appeared when our ancestors became capable of imitation". Imitation and not innovation (intended as adoption of a new tools, capacities or habits) would be at the very root of evolution, limiting both the scope of human creativity in the selection among different opportunities to imitate, and the self to a chimera.

It is clear that such a conception can be upsetting, or even insulting to many historians of culture. In any case, from the standpoint of the history of automata, and more than ever for the considered period, imitation (more or less conscious) turns out to be a cornerstone of their propagation.

4.2   Memetics and History of Culture

At the beginning of the 21st century, some scholars who were working on the topic, tried to put order in the uncertainty that characterized the field, by drawing involved academics together at a conference [591]; although the meeting has led to important results, scholars have failed to converge precisely on the approach to meme, leaving unchanged the question, which can be summarized as follows, by using a scheme proposed by Jouxtel [592] and here translated at Fig. 182.

The four approaches presented are the following:

1. Logical meme: meme is here considered as an instruction, a life rule (if … then …) valid for an agent. In such a conception, which is halfway between psychology and AI, the agent can be either a human or a machine, but necessarily individual. Main scholars leading to this approach are Lynch [593], Brodie [594], Hofstadter [595].
2. Symbolic meme: meme is here considered as unifying element of a community, in a standpoint between philosophy, history, politic sociology, study of religions. The main scholar leading to this approach is Bloom [596].
3. Practical meme: meme is here considered as a collective rule, a law, a scheme, a model, valid within a community. This acception is shared by disciplines like anthropology, economics, social sciences and history of technologies, so that the artifact becomes a social

transmitter. Main scholars leading to this approach are Dawkins [587], Blackmore [589], and Dennett [597].

4. Neuronal meme: meme is here considered as an electrical scheme that spontaneously replicates in different parts of the brain. This is the newest acception of meme (proposed by Aunger [598]), based upon psychology and neurosciences; it could lead to a physical evidence of memes, thanks probably to functional magnetic resonance imaging.

```
                          idea
                           |
                           |
          (1)              |              (2)
          logic            |           symbolic
                           |
intrahuman ————————————————+———————————— interhuman
                           |
          neuronal         |           practic
          (4)              |              (3)
                           |
                           |
                         matter
```
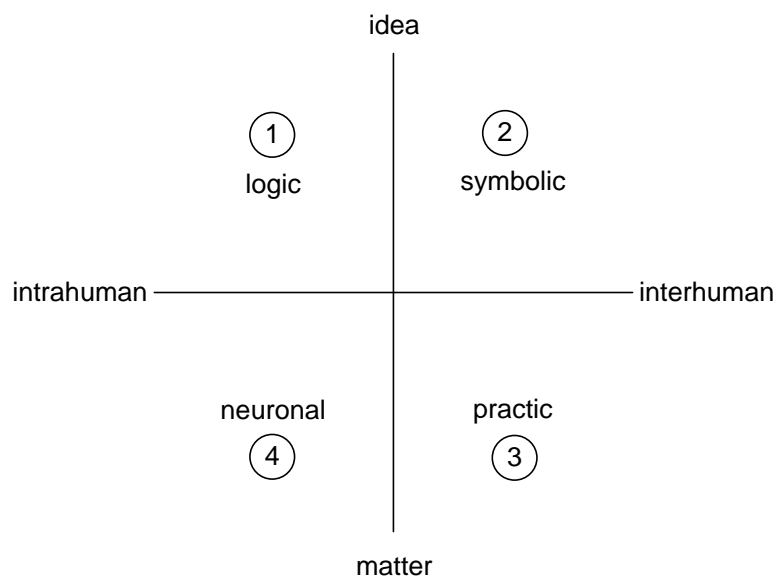
Fig. 182: Approaches to Meme (translated from Jouxtel, 2005)

Approaches 2 and 3 seem the most suitable for our theme, since they give emphasis on the very features that we have highlighted as typical of automata, as they are generally intended (see *supra* 1.2.1), and also for the attention to artifacts, as automata actually are.

4.3 Survival of the Automaton Meme

One of the most interesting studies that is arguably focused on content relevant to our topic, has been carried out by Heylighen, who has in particular analyzed the role of knowledge in transmission principles and in the identification of selection criteria [599]. His approach goes well with the two approaches mentioned above as relevant to the memetic study of automata, and can explain the survival of the automaton meme. The reason why the automaton idea could so long survive and arrived until nowadays can be directly found by applying Heylighen's considerations to our domain.

He points out that such criteria can be described as fitting either individual or social issues; we match such a list with our object features:

1. Individual fitness
   a. Distinctiveness: "some change must follow or precede the appearance of the distinguished phenomenon"; whenever someone decides to describe, design or build an automaton, an emphasis is put on the technological excellence of the

culture that has made their creation possible. A self-operating device is always innovative, and therefore separated from the previous production.

b. Invariance: "The change following or preceding the phenomenon must not be unique, but share some properties with changes associated with similar phenomena". The idea of imitating appearance and behavior of things or of living beings connects automata with similar occurrences.

c. Survivance/reproduction: "monitoring and controlling the basic variables determining whether or not the organism can survive" and "tell the organism how to find a mate and successfully produce offspring". If we are dealing with individuals, automata can survive thanks to maintenance, that can be very costly, as we have repeatedly seen in our historical outline; so technical competence and funds are critical variables, the same that are needed in order to grant automata reproduction. Nonetheless, as we have also pointed out, the idea of automaton can faultlessly survive even through verbal descriptions or technical drawings.

2. Social fitness

a. Ease of expression: due to the traits of simulation and activity, typical both of automata and of human behavior, the idea is out of doubt easy to express. Different is the case of technical production, which requires specific skills of expression (symbology, coherence and consistency), but at the same time is destinated to a competent audience and in any case uses the iconic means, that is an agile vehicle for the transmission of knowledge.

b. Motivation to expression: "the individual should be motivated to imitate that particular behavior". In any environment we consider, references to automata and thus their knowledge are a matter of prestige.

c. Conformity: "the more people already agree upon or share a particular idea, the more easily a newcomer will in turn be infected by the meme". As we have seen in Fig. 1, the words used to give a definition of automaton, even taken from different sources, converge in a very limited number of semantic fields.

d. Consensus: "people agree about an idea because they independently came to the same conclusion". We could repeat the same statement as at the previous point, by highlighting the cultural variety of our sources.

Paraphrasing Heylighen's example, we could say that using or not using automata can lead to different results, rather stable, invariant over time, ways of observing, or circumstances. The idea of automaton can be easy to learn, and is not incoherent with previously established knowledge (their appearance is well known and the work they can do is always done in the same way as before). It has many advantages that may contribute to increase personal and social prestige, what means faster reproduction and higher spread rates. The idea of automaton is pretty conspicuous or salient, and hence easy to imitate. Automata structure and operation can also be uttered formally, e.g. by means of geometry and mechanics, so that the idea can be unequivocally conveyed even to people who have never really met such an object. Even without any symbolic representation, the concept of automaton is relatively uncomplicated to express in natural language or by demonstration. People who are fascinated by automata, are in general also motivated to convince others about the appeal of the idea. And once the idea has spread, people would like to rely on such a device, both as a

narrative instance and as an actual object, "so that newcomers will tend to quickly conform to that consensual pattern of behavior".

4.4 Our Study

The object of our analysis, as stated from the beginning, was the idea of automaton (derived from the design principles) typical of the various cultures that have flourished in the considered time interval, rather than its specific implementations. About cultural artifacts evolution [600], it would be reasonable to wonder whether it occurred in a strictly Darwinian model [601], based on natural selection law, thus leading to reduced importance of efforts in individual adaptation, or, given the cultural and not biological framework of that evolution, in this process we assist to an addition of whatever peculiarities the cultural context required. In other words, the question is to determine whether the automaton meme has evolved according to a Lamarckian [248] or a Darwinian model. Since memetic scholars tend to use either one or the other model, according to their thought framework, we have decided to identify a criterion in previous studies on subjects related or similar to ours. A good example comes from a study about the evolution of music, by Molino [603]; music shares with automata many features, such as the co-presence of an immaterial (design) and a material (implementation/execution) component; the need for technical skills; the fascination aroused by the author / performer, and the consequent prestige; the use of a symbolic language to their description; the need for constant introduction of new (albeit minimal) variations, in order to guarantee that the audience can't predict the final effect. The author recalls that, while in biology the Darwinian model that postulates the mutation as randomly generated, can be easily accepted, it is not suitable in areas such as science and technology in which it is more correct to speak of directed variations, since "their development occurred by means of problems to which successively more satisfying solutions were given by trial and error". Therefore, even in our evolutionary cultural history or phylomemetics, we should better refer to two "systems of transmission and transformation of cultural information", common to many domains of culture.

4.4.1 Foreword

In the following paragraphs, such an approach will be applied for the construction of the automaton phylomemetic tree, based on the technique used by Situngkir [604-606], focusing on the importance of phylomemetic visualization to approach the cultural diversity. Even though the context considered by Situngkir is Indonesia, geographically well-defined, the cultural complexity of that environment, makes it compatible with the cultural diversity found in our excursus, widely ranging in time and space. In addition, the object studied by the Indonesian scholar (tradition-inspired buildings) shows several common features with automata: the design / construction dialectic, enabling subsequent improvements or other changes; the presence or the absence of functional components of utility; the occurrence of an aesthetic component.

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[248] Some studies refer to it as to Spencerian [602]

4.4.2 Building a Binary Table

The first step to build the phylomemetic tree was to identify features and characteristics (allomemes) of the automata, thanks to sources data base, and UML diagrams. We used as a reference [599] and chose to include data to:

- Uniquely identify the single automaton at a glance; we avoided Id#, since it would have been impracticable to understand the tree once generated.
- Show its belonging to a class, or to more than one class; since a class represents both its appearance and its behavior, we had to consider that an automaton could have the aspect of an animal (and therefore was also a living being) and be also a vehicle, that is a daily life object; or that it could be a Manlike (and Living Being), but as a musician or a dancer, it belonged also to the class of of Entertainment;
- Show which generic (common to most class instances) or specific (done by this only automaton) actions were performed. Some more general behavior descriptions were included, in order to fully represent some similarities that natural language description could hide. A movement in a given direction is different from a generic movement, since it requires a different algorithm and a constant position calculation. The fact that it consists in sailing, walking, running or even flying is less relevant. We introduced a superclass (moves in a given direction), to mark affinities, without losing information.

Once collected the allomemes, we draw a binary table, containing: in each row, the instance dataset; and, in columns, the allomemes:

- Automaton unique name
- Class Name
- English Author Name [249]
- English Title
- Classes [250] (39 columns, including classes and superclasses names, taken from the class model)
- Performed Actions (87 columns, taken from classes and instances)

4.4.3 Building a Distance Matrix

From the binary table we built the distance matrix among the automata [606]. In this step, thanks to the comparison between two items, we can calculate the Hamming distance between two automata. Since our entries are constituted by finite binary strings, the hamming distance is measured as the numbers of different bits,

$$d_{i,j} = q + r$$

where q = number of columns containing the value 1 for the i-th row and 0 for the j-th row and r = number of columns with value 0 for the i-th row and 1 for the j-th row.
Or, in a more formal way,

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[249] English Author Name and English Title have been introduced only to debug purposes, and later not considered.
[250] Belonging to the class / performing the action are represented by the value "1" in the corresponding cell, while an empty cell means that the automaton doesn't belong to the class or doesn't perform that action, in accord with [599].

$$d_{i,j} = \left[\sum_{i=1}^{n} |x_{ik} - x_{kj}|^p \right]^{\frac{1}{p}}$$

it is a particular case of the Minkowski distance, with $p = 0$ (since values are binary); n is the number of rows; *i, k* and *j* are the indexes.

The used software package is SPSS 17 ®. The generated matrix is obviously symmetric, with all 0 values on the main diagonal.

4.4.4   Generation of the Philogenetic Tree

This distance matrix can now be used to draw the phylomemetic tree by using the dendrogram techniques. Following the guidelines shown in [604], we chose the UPGMA (Unweighted Pair Group Method with Arithmetic mean) algorithm, a bottom-up data clustering method, commonly employed in genetics. In such a technique, the evolutionary rate is assumed as constant: this issue well fits to our data about automata, which show widely different characteristics, a distribution not constant over time, and unpredictable similarities.

The algorithm checks the content of the distance matrix and constructs the tree. A remarkable feature of this technique is that the tree it constructs imitates a species tree, with the same branch lengths for two (*tax,* or Operational Taxonomic Units) after their disjointing. Since the assumed constant rate of evolution, the produced tree is generally a rooted tree, though the root can be removed for certain purposes.

The elaboration of distance matrix has been carried on with Molecular Evolutionary Genetics Analysis (MEGA) software version 4.0. This software requires the input of a triangular matrix; this implied the setting to 0 of the remaining values.

Fig. 183: Philomemetic Tree

4.4.5 Main issues of the Automaton Philomemetic Tree

The tree must be read starting from the central area, where is the root (in our case, the idea of automaton).

We will proceed counterclockwise.

The first branch (or clade), that is the nearest instance, appears to be a couple composed by Fontana's Witch and Gaza Helios; although, at first glance, this may be unexpected, since the two automata differ in appearance and for most of their behavior, it should be noted, however, that these are the only two manlike who are designed to move in a predetermined direction and to automatically perform a series of actions (i.e. without any further interaction with the user / activator) after the initial input. They share therefore most of the automata traits we highlighted in the first chapter (see supra 1.2.1).

The second branch connects Fontana's Witch and Gaza Helios with Regiomontanus' Eagle that shares the same behavior as the others but it is not a manlike, rather a living being.

The third branch separates the chessboard from the general set of automata: the distinctive feature is that it can reset, i.e. return to its initial state, when all pieces are orderly disposed on the chessboard, in order to begin a new game. No other automaton shows the same characteristic; it can be easily understood concerning designed and actually implemented automata, given the difficulty of achieving this behavior; it is rather unusual as regards imagined automata. One could probably assume that this choice is precisely in the nature of the game of chess, in which repeated challenges usually take place between the players. In this case, the play component would take precedence over admiration for the item uniqueness: this is also confirmed by the reaction of the player, who, after losing three games, gets furious and tries to physically destroy the board, a quite common reaction even among contemporary players of video games.

The next clade leads to the distinction between inanimate objects (the superclasses are daily life items, environment and entertainment) and living beings, including animals and manlike instances.

From this point on, most branches don't isolate a single element from the rest of the set, but rather identify homogeneous subsets and in fact we find that the objects, for example, appear not only linked on the basis of the main purpose they were made for, but also of design details. Even in homogeneous groups, such as the one of the flying transport, some specific design differences, where present, are highlighted in the clades. As we can see at Fig. 184, the flying carpet (Fig. 74), that has a behavior similar to the flying horses is however distinct, because of its nature of object; the horses are one step more complex and thus more evolved than the carpet. At turn, the steed of brass is distinct from the other two for a (minor) detail: as shown in diagrams (see Fig. 77, Fig. 119, Fig. 133), since destination must be reached by 24 hours, in the Steed of Brass tale, speed calculation is needed; this is not necessary for the other flying horses (Cheval de Fust and Ebony Horse), as the user can set speed by himself.

The choice of using both the Darwinian and the Lamarckian approaches is the basis of this result, showing clearly the details of specific instances, in addition to persistent traits.
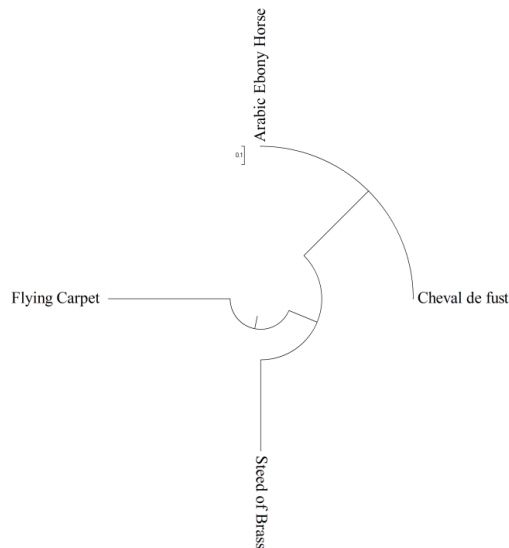
Fig. 184: Clades of Flying Transport

Even in the case of Watchmen with a subclade of the Archers, we can make similar remarks. They include watchmen, who defend without using a bow (Fig. 111; Fig. 112; Fig. 156), and archers, at turn disposed on two different clades: three are activated by a user's input on a specific object of the room (apple, golden knife or carbuncle), while the other two are activated by the presence of an intruder in the room. In the first case, they are protecting a treasure, in the second one, they are preventing the tomb violation, that happens in the very moment the intruder enters the room.
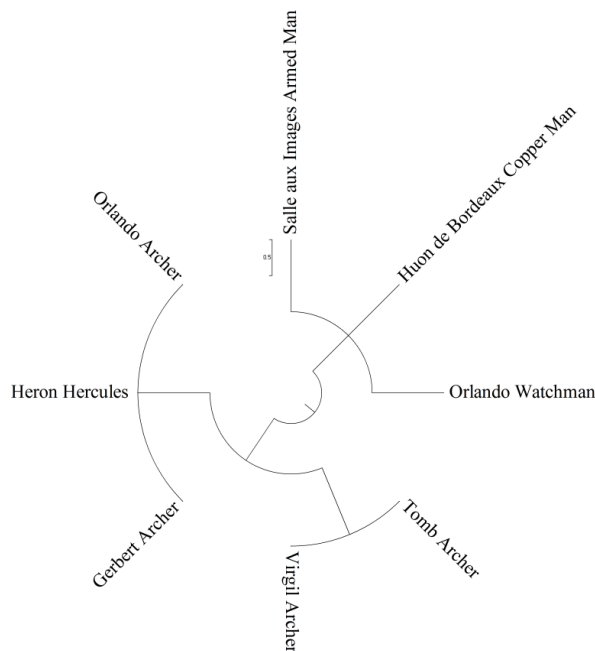
Fig. 185: Clades of Watchmen and Archers

Since the highlighted difference does not affect the behavior of automata, which is identical, but rather the context they operate in, the two clades have the same length. We emphasize only that the Heronian automaton does't actually represent an intruder shot by an archer, but rather can be explained as a dramatization of one of the 12 labors of Hercules, where the role of Hercules is

played partly by the user (who steals the golden apple), and partly by the figure of Hercules, slaying the dragon Ladon. In any case, the knowledge of the myth of the 12 Labors is not needed for a proper understanding of the automaton operation, which, at a strictly narrative level, can be interpreted as an attack on who picks up the apple.

As we have seen, the phylomemetic tree synthetically expresses what has been revealed by the analysis of the individual automata, but also adds important details about their similarities and differences, since it is aimed to see the rooted unity among cultural objects in their features, while focusing on their peculiarities.

In this sense, the memetic approach applied to the history of artifacts and ideas can make a valuable contribution to historical disciplines, bringing out new points of view and original connections among studied objects. For this reason, even in the field of archeology, there are some applications of the method in question [607].

The method displays however two main limits: the strong dependence on the identification of the allomemes and therefore on the specific research point of view, and the need for a large number of examples to issue a meaningful analysis.

5   Conclusions and Future Work

5.1   Goals of the Thesis

This work aimed at studying automata with a multidisciplinary approach, that is under a historical, a computer-science, and a memetic point of view. In particular, our research has been focused on:

- collecting and studying primary and secondary sources about automata as accurately and widely as possible, in order to reconstruct the main streams of protocybernetic systems history;
- translating of the verbal description of the automaton operation into a graphical one, applying systematically a uniform (UML-based) description of the automata instances, in order to classify them and their operation details;
- exploring the possibility of an evolutionary study of automata, in the field of memetics.

To demonstrate the correctness of our sources, and the validity of our modeling, we collected all the sources (and their English translation) in an open data base, fully searchable online (http://www.cyberprof.it/automata), where they are also linked with their own UML-model, whenever given details made it possible to draw it. This allows to anyone to systematically verify the correspondence between the source and the model and possibly to give a critical contribution to the work, in a 2.0 style.

The particular contributions and conclusions of the work are presented in the next section.

5.2   Conclusions and Contributions of this Thesis

5.2.1   Sources Collection and Study

The first objective of this phase was to report on the state of the art about historical studies on the topic. This has resulted, in a first stage, the need for collecting the largest possible number of studies on the subject, in order to identify and collect their sources.

It soon became clear that we needed to keep track separately of the complex manuscript tradition of the works of the Hellenistic and Arabic engineers and of any Latin translations of their work, in order to have further informations about the spread of their works. The catalogue was based initially on the pivotal work by Schmidt, but was then expanded and further integrated through a survey, facilitated by computerization of many databases of manuscripts and by studies made during the 20th century about some of them. We could extend Rose's list of manuscripts of Philon's Pneumatics Latin translation: other 14 codices contain at least part of this work; and other two exhibits an Italian vernacular version. But probably the most important contribution of our *recensio* is the identification of four different Latin translations of Heron's *Pneumatics*, all made probably in Italy, though in different regions. As regards the Arabic manuscript tradition of al-Jazari's work, we showed that some folios housed at The Freer And Sackler Galleries in Washington are presumably part of the 14th-century Egyptian manuscript Aya Sofya 3606, now housed at Süleymaniye Kütüphanesi in Istanbul; and that a Syrian 14th-century manuscript, considered lost by Hill, is partly

preserved both at the Metropolitan Museum of New York and at The Freer and Sackler Galleries in Washington.

A deep study of the secondary sources revealed the need for a new multifaceted approach that extended the catalogue of sources also to non-European works or not directly linked with European culture; such an approach should not simply lead to uncritical collection of curious anecdotes, maybe even fictionalized by the compiler, rather to a historical study aimed, on one hand, at the survey of the works in the background of the historical moment when they were conceived, on the other hand, at finding similarities among different periods, designers and devices; our approach should not consider plausible or crucial a source at the sole condition that the contents are correct (or can be interpreted or integrated so that they become correct, as Leonardo da Vinci's work happens) from a mechanical point of view. This decision has undoubtedly resulted in an extra burden: as a matter of fact, it was necessary to seek the greatest possible number of direct and indirect citations in various kinds of works, and also to read the texts in the original language, where available. It however led to the identification of as many automata instances as possible, in the considered period, regardless of their actual implementation, and to an overall picture of their presence (at least as an idea) all around the known world. Moreover we could reconstruct, as far as possible thanks to the sources, the history of the first automata or, it would be more correct to say, the history of protocybernetics, since our survey did not address the specific implementations (and therefore the strictly mechanical aspects) rather the underlying design principles of those built or imagined devices.

Some interesting contributions have emerged thanks to this detailed research:

- We discovered sometimes a total lack of evidence on certain clichés about the automata . No evidence could be found of Egyptian automata built before the Alexandrian era; as we have shown in 2.1, scholars studied animated statues (used in temples) whose arms and head were openly moved by priests, and the faithful were fully aware of their role as intermediaries. While such statues have absolutely nothing to do with automata, studies about this topic have probably suggested to some superficial readers the idea that, in Egyptian tombs, temples, and pyramids, actual automata were commonly used. If we also consider De Solla Price's remark that animism is at the very root of animation, we can explain why for such a long time people have continued to believe in Egyptian automata; moreover such legends have gradually become so likely that in some works, scholars give also a picture of such automata, that would be described in necessarily unquoted hieroglyphical inscriptions.
- Reconsideration of some historical figures was necessary: Gerbert d'Aurillac, Albertus Magnus, Robert Grosseteste, Roger Bacon, and Regiomontanus, according to the traditions concerning them, have been repeatedly described as involved in the construction of automata, though without conclusive proofs given by primary sources. It is therefore very unlikely that these people have dealt with the actual construction of automata, but we were also able to identify the reasons of the formation of the myth, related to their studies in mechanics and engineering. For one of them (Regiomontanus), the possession of a manuscript of *Pneumatics* by Philon (Krakow, Biblioteka Jagiellonska, MS 568, ff. 207-211) demonstrates the undoubted interest of the author for the topic.

- Through the analysis of a purely literary subject, such as the automatos bios, we have noticed that it also underlies the very idea of automaton and of automation, especially in the Greek-Roman world, but also in the Middle Ages. Such a theme showed evident design issues, since it implies that the object has a sensor to measure its own state and mechanisms to keep or alter it. We are however dealing, rather than with a rigorously designed automatic mechanism, with a kind of "black box", whose outputs were observed and expected; on the contrary, physical principles (easily attributable to the helpful force of nature or to gods) and working features were ignored.

- The analysis of the Byzantine *ekphrasis* by Procopius of Gaza has made it possible to find a clue of the tradition in which al-Jazari stands some six centuries later, in continuity with the Hellenism: the strong similarity between the Gaza clock and some clocks by al-Jazari is astonishing; in addition, this is one of the rare extant sources linking the two cultures and it has never been studied related with automata history.

- The self-trimming or unexstinguishing lamp is an actual leitmotiv: we witnessed its presence during the Hellenism, in late Antiquity, in the Arabic world (Banu Musa) and again in Medieval romances. This is a topic apparently pertaining to magic (an ordinary object working differently from expectation), therefore its design is attributed to a magician.

- Despite the rather deep-rooted idea that the Roman world has been a time of decline for science and technology, we wanted to reiterate the fact that the Roman technology actually existed, given that there were activities related to it (such as navigation) and probably it has not been lucky enough to be subject of specific treatises or of treatises survived until today in some form. A complete description of the operation of a Roman automaton is unfortunately missing, however we have found many references to automated devices cited also by authors who do not show any admiration for them (like Seneca). The testimony of Cassiodorus on technical skills in building clocks in the 6th century shows that even after the fall of Western Roman Empire fine mechanical skills had survived. This is why we decided to use a passage from the *Variae* as a motto of this work, "*muta cantare, insensata vivere, immobilia moveri*" sums well up the salient features of ancient automata.

- Although it has been discarded the idea of a period when ancient culture had been totally abandoned, early medieval Europe is still considered a difficult time to study, especially due to the insufficiency or inaccessibility of sources, to the point that it can be considered a kind of "no-man's land". Such a decay has been studied by Lawan and by Mannoni, who pointed out the main features and scenarios of technological change in the early medieval transition, that we could systematically apply also to our topic to explain the absence of automata. As a matter of fact, although many aspects of continuity with the ancient world were still present, a substantial decline has to be highlighted: Roman technologies became actually rarer or disappeared altogether, in some areas of the empire. Automata probably lost that miraculous role that had featured them in the courts of the Hellenistic and Roman rulers and aristocrats, mainly due to their high costs. No new use of such old products could be imagined. We also witness "an adoption of apparently simpler solutions to everyday problems", probably due to the disappearance of Roman technologies and to the consequent resurgence of indigenous peoples' ones. Automata were maybe forgotten or replaced by tricks or puppets activated by servants. The adoption of techniques from other

manufacturing trades or cultures would probably have come later, when the Western and the Arabo-Islamic culture would have restored their contacts, though we have no evidence of consequences in the production. The absence of continuity in research would likely result in on-demand problem solutions. It appears unlikely that such a feature can deal with automata, given their nature of useless objects. They couldn't be replaced by other devices also due to the limited availability of specialized labour (engineering). Then, the disappearance of the previous culture involved the fading of strictly related technologies. The close relationship between automata and many religious and recreational aspects of the pagan world has certainly affected their abandonment. Such objects lost their only use, that was to astonish a courtly audience: the prestige of the court of Rome, and later of Milan, or of Ravenna was strongly decreased, and vanity was considered as a sin. Demand for such a product disappeared, so production simply ceased, though we know that technical ability was retained in the field of pneumatics or hydraulics, related to organ building.

- Most Chinese automata display evident similarities to the older Western tradition, mainly to Heron's work, due to the presence of mechanic principles, besides the pneumatic ones. Though we can't exclude an independent development of the topic, it is well-known that merchants travelled along some important trade routes (such as the Silk Road, for instance) to the West during the Roman age, and contacts with Western engineers are absolutely possible. In addition, we witness a significant similarity to al-Jazari's work (mainly the band). If we accept as correct at least the dates when these devices would have been built, we must however face another problem: all these instances are far older than the analogous automata by al-Jazari. Therefore, we must alternatively assume that (1) Chinese engineers have designed such automata, influencing the Arabs; (2) a Greek, or Roman, practical tradition, now lost, influenced Chinese engineers, and consequently or independently reached the Arabs. In any case, China was not excluded from contacts with the Middle East and Europe in the field of mechanics.

- Despite the wide diffusion of Arabic culture and technology, that had accompanied the territorial expansion of the 7th-15th centuries, at the time neither the Latin versions of Arabic engineers' masterpieces, nor information in this regard are available, since the lists of the translations carried out in Europe don't include these works. We however assumed that the 13th-century (the oldest, so far as it is known at the moment) Latin translation of Philon's Pneumatics (Cambridge, Pembroke College, 169) has been made from an Arabic translation due to its *incipit* "In nomine Dei pii <et> misericordis…" common to other Latin translations of Arabic scientific works (e.g., Robert of Chester's version of al-Khwarizmi's *al-jabr w'al-muqabalah*, or Iohannes Hispalensis' *De scientia astrolabii*).

- We decided to call (cyber)magic in Medieval literature the study of the presence of automated devices, whose operation is attributed to the magic; in this case, as for automatos bios, the contribution of the analysis of literary texts was fundamental, because not only well-known examples of automata, taken from the previous tradition, appeared, but also other (very innovative) ones, that however anticipates some contemporary systems. This is the case of (1) an actual training system, based on the courtly pedagogy values, implemented by three necromancers in the so-called Chambre de Labastrie, where four automata provide a four-step progressive training; (2) a fail-safe bow (arc-qui-ne-faut), a weapon that maintains the pointing of the target without any error; (3) a sign post, which

automatically and spontaneously indicates the correct direction to each rider approaching to the crossroad.

- Two sonnets of two great Italian poets of the 13th-14th century are to confirm the fact that the automatos bios theme was still extant in the late Middle Ages; in *"Guido, i' vorrei"*, taken from the *Rime*, LII, Dante Alighieri speaks to his friend Guido (Cavalcanti) and discloses his impossible desire: a magician should take Dante himself, Guido, and a third friend, Lapo Gianni, and allow them to leave for a trip on an enchanted ship, in perfect harmony, where they could also enjoy the company of their women. The ship behaviour is very similar to the Phaecians' ships, quoted by Homer, though probably Dante didn't know directly the passage: travelers don't bother to drive the ship, nor about the weather, since all they need is to express their own wish about destination to a kind of autopilot. Again, a major feature of the poetry of Guido Cavalcanti (1259-1300), a leading poet of the Dolce Stil Novo, is dramatization: the expression of feelings and emotions of the poet is entrusted to concrete or abstract objects, speaking to each other or to the public or to the poet's beloved. In Sonetto XVIII, we have a (probably unintentional) appearance of αὐτόματος βίος, since writing tools have recorded (in a log-file or in a Vannevar Bush' memex *ante litteram*) all the poet's experiences, and are therefore able to speak about him, to induce readers to compassion. We have stressed the inadvertence of the quotation as an example of automatos bios, since Guido was certainly influenced by the poetic theory of the Provençal poet Geoffrey of Vinsauf, who recommended the use of prosopopoeia in his *Poetria Nova*; it does not seem likely that he wanted to quote ancient texts, mainly Greek ones, that he hardly knew even in Latin translation.

- The presence of several automata in two episodes of the poem Orlando innamorato by Boiardo has made it possible for us to reconstruct a complex system of sources. The episode of the Automata Cave (Book II, Cantare viii, oo. 24-33) had already been carefully studied by some scholars, who had traced it in the biography of Gerbert d'Aurillac by Willam of Malmesbury, but they had not noticed the presence of other automata in a previous episode (Book II, Cantare viii, oo. 3-23) and therefore they had not identified the source, which is another passage of the same work by William of Malmesbury. In this research, we became aware of the similarity of the archer's behavior to the system described in Heron's *Pneumatics* I, 41, that could have been at turn the source of William's account. In addition, we realized that Boiardo had not only described the system operation, but also the way a system failure could be issued; so we tried to relate it to other passages in the poems of chivalry in which a similar event is described: an unexplored link with the episode of the Lit merveille in Wolfram von Eschenbach's *Parzifal* emerged.

- To place the figure of Boiardo in his historical context, we have studied the relationship between the court of Ferrara and the 15th-century tradition of Heronian works, in order to understand whether Heron's treatises were known, and we made some interesting discoveries: (1) a manuscript containing a work by Heron is in a copy of Pneumatics (Modena, Biblioteca Estense, XVII G G 25, 16th century), where in the title of I, 37 a reference 215 is made to a work by the polymath Leon Battista Alberti (1404-1472), the *Ludi mathematici*, where the author, while listing various kinds of clocks, describes a fountain that worked exactly as described in the corresponding passage of Heron. The work by Alberti, written around 1450, is dedicated to the marquis of Este; (2) in 1452, Borso

d'Este, marquis of Ferrara, Modena and Reggio, gives hospitality to Frederick III of Habsburg, who is traveling to Rome in order to be crowned as an emperor: in exchange for hospitality, Borso receives the title of Duke as an imperial acknowledgement. One year later, on July 5th, Borso enters Reggio, where his vassals pay homage to him. The ceremonial, designed by the courtier Malatesta Ariosto (?-1476), at the presence of a crowd of reverent subjects, is sumptuous and complicated, as it is described by the chronicler Giovanni da Ferrara. There's no mistaking the similarity to Heron's moving automaton, as the following table synthesizes:

Author	Heron	Ariosto
Structure	Canopy	Canopy
Main Character	Bacchus	St. Prospero
Surrounding Characters	2 Maenads	2 Angels
Held Object	Thyrsus	Scepter and town keys
Flying Figure	Nike	St. Peter
Gift	Laurel Crown	Laurel Crown
Procession	--	Allegory of Justice

Although the similarity is not conclusive, we must admit that at the Este's court, two indirect references to works by Heron can be quoted.

This work approach differs from existing ones: the main conclusion regarding the collection of sources and the historical reconstruction is that the use of such a multidisciplinary approach has allowed us to extend the consideration to a wider range of sources, and to enjoy greater resourcefulness in analyzing them. Furthermore, the inclusion of literature in our analysis has proved to be a useful option to draw our attention on ages, figures and backgrounds that otherwise would not have been analyzed and that displayed interesting features from a historical point of view.

5.2.2 Modeling and Classification

The implementation of the UML diagrams has imposed a reflection on the nature and characteristics of individual automata, since the purpose of classification had suggested the idea to use a functional (and therefore simplified) representation: the identification of classes has been made both synchronically, during the study of the instances in their historical background, and diachronically, when the general framework of class model was established.

Classes have emerged, thanks to the thorough analysis of both behavior and appearance of individual automata: we have taken into account not only the actions performed by the automaton, but also the appearance of the automaton itself. In fact, while doing the same action (e.g., pouring some liquid), a mask-shaped fountain, and a human figure representing a servant are conceptually

different, due to the presence or absence of the life component, that is crucial in representation. In some cases, the decision of modeling the automaton as belonging to a class or to another one has been made in order to preserve as many features as possible. Appearance, in particular, needed to be recorded in some way, at least in classes instance name, unless it would be lost, since behavior rarely implies a specific look: here we have flying horses and eagles; manlike and animals attacking; musicians, heralds and instruments playing. In another case it was necessary to introduce the intermediate category of monster between human and animal, to respect the intentions of the authors' narrative.

The main advantage of applying a uniform (UML-based) description of the automata operation was to involve the identification of the underlying algorithm; it allowed to highlight the design principles and what we could call the "implicit objects" (entities, control objects, interfaces, data bases), indispensable for a suitable function. The need to define the role of actors (or activators) in the sequence of operations has been particularly useful: the greater the number of actors / activators in a sequence diagram, the lower the degree of autonomy (from inputs) of the system. In some cases (Rubruck or some Chinese instances), we have immediately evidence that the system is not an actual automaton, since it needs a continuous human intervention. We have also tried to preserve as much as possible the parameters given in the description; this has led to highlighting an interesting historical detail, linked to the figure of Heron, whose biography is controversial. An indirect evidence (as far as we know at the moment, never considered) that allows to date Heron's life to the 1st century AD and namely under Nero's reign, can be found in Pneumatics I, 21, where a pentadrachm (a five drachms coin) is quoted. This small coin was last produced during the reign of Nero, made upon the coins of Cleopatra VII, and, like them, it was marked with an E (that is 5).

Classification, implicit in the UML modeling, has helped us to focus attention on factors closely related to appearance (generally described) and to the actions performed by automata, highlighting similarities and differences with other automata. So we could proceed with the construction of superclasses that generalize the basic classes, to connect them to what we called the abstract superclass automaton. In this process of generalization we found that they significantly correspond to the three existing disciplines and/or applications derived from ancient automata: robotics, automation, show business. This last consideration was crucial for us in deciding to proceed with a study on the evolution of automata.

5.2.3 Evolutionary Study

The last phase of our work was to explore the possibility of an evolutionary study of our topic, considering analogous studies.

One of the most interesting studies that is arguably focused on content relevant to our topic, has been carried out by Heylighen, who has in particular analyzed the role of knowledge in transmission principles and in the identification of selection criteria. His approach can explain the survival of the automaton meme. The reason why the automaton idea could so long survive and arrived until nowadays can be directly found by applying Heylighen's considerations to our domain. He points out that such criteria can be described as fitting either individual or social issues; we matched such a list with our object features:

1. Individual fitness
    a. Distinctiveness: "some change must follow or precede the appearance of the distinguished phenomenon"; whenever someone decides to describe, design or build an automaton, an emphasis is put on the technological excellence of the culture that has made their creation possible. A self-operating device is always innovative, and therefore separated from the previous production.
    b. Invariance: "The change following or preceding the phenomenon must not be unique, but share some properties with changes associated with similar phenomena". The idea of imitating appearance and behavior of things or of living beings connects automata with similar occurrences.
    c. Survivance/reproduction: "monitoring and controlling the basic variables determining whether or not the organism can survive" and "tell the organism how to find a mate and successfully produce offspring". If we are dealing with individuals, automata can survive thanks to maintenance, that can be very costly, as we have repeatedly seen in our historical outline; so technical competence and funds are critical variables, the same that are needed in order to grant automata reproduction. Nonetheless, as we have also pointed out, the idea of automaton can faultlessly survive even through verbal descriptions or technical drawings.
2. Social fitness
    a. Ease of expression: due to the traits of simulation and activity, typical both of automata and of human behavior, the idea is out of doubt easy to express. Different is the case of technical production, which requires specific skills of expression (symbology, coherence and consistency), but at the same time is destinated to a competent audience and in any case uses the iconic means, that is an agile vehicle for the transmission of knowledge.
    b. Motivation to expression: "the individual should be motivated to imitate that particular behavior". In any environment we consider, references to automata and thus their knowledge are a matter of prestige.
    c. Conformity: "the more people already agree upon or share a particular idea, the more easily a newcomer will in turn be infected by the meme". As we have seen in Fig. 1, the words used to give a definition of automaton, even taken from different sources, converge in a very limited number of semantic fields.
    d. Consensus: "people agree about an idea because they independently came to the same conclusion". We could repeat the same statement as at the previous point, by highlighting the cultural variety of our sources.

Paraphrasing Heylighen's example, we could say that using or not using automata can lead to different results, rather stable, invariant over time, ways of observing, or circumstances. The idea of automaton can be easy to learn, and is not incoherent with previously established knowledge (their appearance is well known and the work they can do is always done in the same way as before). It has many advantages that may contribute to increase personal and social prestige, what means faster reproduction and higher spread rates. The idea of automaton is pretty conspicuous or salient, and hence easy to imitate. Automata structure and operation can also be uttered formally, e.g. by means of geometry and mechanics, so that the idea can be unequivocally conveyed even to people who have never really met such an object. Even without any symbolic representation, the concept of

automaton is relatively uncomplicated to express in natural language or by demonstration. People who are fascinated by automata, are in general also motivated to convince others about the appeal of the idea. And once the idea has spread, people would like to rely on such a device, both as a narrative instance and as an actual object, "so that newcomers will tend to quickly conform to that consensual pattern of behavior".

Using Situngkir's method, we obtained our complex philomemetic tree (Fig. 183). The tree must be read counterclockwise starting from the central area, where is the root (in our case, the idea of automaton). The first clade, that is the nearest instance, appears to be a couple composed by Fontana's Witch and Gaza Helios; although, at first glance, this may be unexpected, since the two automata differ in appearance and for most of their behavior, it should be noted, however, that these are the only two manlike who are designed to move in a predetermined direction and to automatically perform a series of actions (i.e. without any further interaction with the user / activator) after the initial input. They share therefore most of the automata traits we highlighted in the first chapter. The second branch connects the first two automata with Regiomontanus' Eagle that shares the same behavior as the others but it is not a manlike, rather a living being. The third branch separates the chessboard from the general set of automata: the distinctive feature is that it can reset, i.e. return to its initial state, when all pieces are orderly disposed on the chessboard, in order to begin a new game. No other automaton shows the same characteristic; it can be easily understood concerning designed and actually implemented automata, given the difficulty of achieving this behavior; it is rather unusual as regards imagined automata. One could probably assume that this choice is precisely in the nature of the game of chess, in which repeated challenges usually take place between the players. The next clade leads to the distinction between inanimate objects (the superclasses are daily life items, environment and entertainment) and living beings, including animals and manlike instances. From this point on, most branches don't isolate a single element from the rest of the set, but rather identify homogeneous subsets and in fact we find that the objects, for example, appear not only linked on the basis of the main purpose they were made for, but also of design details. Even in homogeneous groups, such as the one of the flying transport, some specific design differences, where present, are highlighted in the clades. The choice of using both the Darwinian and the Lamarckian approaches is the basis of this result, showing clearly the details of specific instances, in addition to persistent traits.

Some other interesting contributions arise from memetic analysis. First of all its independence from historical background: in any clade we consider, we can find associated automata of different periods and in addition clades are not chronologically or culturally ordered. It means that the automaton is a memeplex whose traits vary with little correlation with time. Secondly, if we consider the first and the last clades, it leaps immediately at us that the two automata of the first clade are actually implemented automata, while the others are mainly imagined ones, demonstrating that the idea of automaton evolves more rapidly than the technical possibilities of implementation: in other words, the oldest instances, taken from literary sources, are not the simplest ones from the design point of view, as it is manifest from their UML sequence diagrams. Lastly, starting from Renaissance, as we have seen, the idea of automaton becomes an explanatory model for many sciences: we can assume that the mutation rate is perturbed by external factors, like a new mindset, and the evolution of the memeplex is likely to be different, too.

5.3 Future Work

This research may continue in two main directions:

- Historical-chronological, that is the continuation of the chronological reconstruction and classification of automata in subsequent periods, identifying appropriate turning points, since the amount of instances to study at each step risks to become huge. A result of the memetic analysis could be the identification of future lines of development of robotics.
- The second one is closely linked to the knowledge representation on the topic, which could lead to the development of an organized and compete taxonomy or even to an ontology.

A possible application of the UML-based representation of literary texts may educational, applying such a method in introductory courses of robotics or artificial intelligence or even, in high schools, for a first approach to algorithms.

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