Methodological Flaws in Cognitive Animat Research

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Abstract

In the field of convergence between research in autonomous machine construction and biological systems understanding it is usually argued that building robots for research on autonomy by replicating extant animals is a valuable strategy for engineering autonomous intelligent systems. In this paper we will address the very issue of *animat* construction, the rationale behind this, their current implementations and the value they are producing. It will be shown that current activity, as it is done today, is deeply flawed and useless as research in the science and engineering of autonomy.

Keywords: Animats; Cognitive science; Methodology; Cognitive Systems; Robots.

Introduction

Animats are robots mimicking animals (Taubes, 2000; Webb & Consi, 2001; Guillot & Meyer, 2008). We have seen robot dogs, flies, lizards, tuna and even humans. This is a very common thread in robotics and is widely considered valuable research.

We are all enjoyed and mesmerised when a robot gecko climbs a crystal wall or when a robotic dog barks asking for some play. All these *animal* activities address our very inner empathic mechanisms, triggering emotional reactions toward these robots. But the question we want to address here is not if they are cute or not but if this animat construction work is producing anything of scientific or technical value. Is animat construction scientific or technological research following a sound methodology?

In this paper we will try to analyse the real value of animat construction and its contribution to the advancement of knowledge in several fields: mainly biology, engineering, and psychology but also philosophy and physics.

What is an Animat?

The first thing to do is to answer the simple question: *What is an Animat?* This is the Wikipedia definition of *Animat*:

> *Animats are artificial animals, a contraction of anima-materials. The term includes physical robots and virtual simulations. Animat research, a subset of Artificial Life studies, has become rather popular since Brooks' seminal paper* "Intelligence without representation". *The word was coined by S.W. Wilson in 1991, in the first proceedings of the Simulation of Adaptive Behaviour, which was also called* From Animals to Animats.

Wilson article (genetic algorithm, connectionism, cogann ref, 1990) proposed animat construction as a good strategy to advance in artificial intelligence research. This was full in line with the philosophical argument by Dennett some years before (Dennett, 1978). Today, this pure AI plan has been tinted in the colours of post-modern robotics —embodiment, situatedness, enaction— and current research is more focused in solving bodily robotics problems that AI ones.

In this line of analysis we can read another description by the very researchers involved in this activity nowadays. This definition comes from the Animat Lab in France[1]:

> *Animats are artificial animals endowed with sensors and actuators that are co-ordinated by control architectures. They are autonomous because they have needs and motivations to satisfy in order to survive, and because they rely on as few human interventions as possible. They are adaptive because they are able to learn or evolve, thus enhancing their chances of surviving or fulfilling their mission. They are situated because their adaptive capacities stem from the sensorimotor loops that are generated during their permanent interactions with an environment possibly changing, unpredictable and threatening.*

A Cognitive stress

Notice the words in the former text: *autonomous - needs - motivations - survive - adaptive - situated - learn - evolve*. They fully target sophisticated *cognitive competences*. As control engineers we would like to be able to endow our machines with these capabilities. They would make our systems —cars, electrical networks, mobile phones, nuclear reactors, etc.— much more robust in the performance of their mission and hence more safe and dependable.

Unfortunately, these technologies are not available as technological assets. Animat research is apparently addressing these issues —see the text before— but we question the real results this activity is producing. Results are lacking basically because the research methodology is flawed. There are also opinions in favor of this kind of research and a recent issue of the journal *Adaptive Behavior* (August 2009, Vol. 17, No. 4) is fully dedicated to the *animal vs. animat* question.

The Character of Animat Research

Research Objectives

A lot of work in bio-inspired robotics research is dedicated to the construction of animats. As in any kind of research it

[1] Find it at `http://animatlab.lip6.fr`.

is very important to be clear about the objectives —both long and short term— that the research is pursuing.

From the same Animat Lab mentioned before we can read the following research statement:

> *The animat approach [. . .] aims at designing artificial systems, not as intelligent as Man, but as adaptive as animals. At a fundamental level, it contributes to enhance knowledge on animal autonomy. At an applied level, it raises the question of the decisional autonomy of robots interacting with unprepared environments.*

In summary the objectives of animat research are dual: i) enhance knowledge on animal autonomy and ii) capacitate decisional autonomy of robots for unprepared environments.

Research Approach

As we will see later, the concrete production of results in the biological side —the claimed knowledge on animal autonomy— requires a basic dialogue between ideas and observations.

This is a basic stance of all scientific activities that try to capture the rules that rule the world. In the case of animat research, and concerning their potential contributions to animal science, the observations of interest are those of animals and animats are postulated as a form of reified theories —some would use the term *models*— about how the animal behaviour is generated.

The value of a theory is demonstrated not only in its capability of matching some observed phenomena (n.b. for all datasets a model can be built that matches the dataset) but in how the theory extends in the realms beyond the original datasets making reliable predictions about the outcome of experiments in those realms (Hull et al., 1940).

Animats as theories do not have this capability. When placed outside the context where they were developed —Skinnerian boxes, Y-shaped labyrinths, vertical glass walls— they behave in ways certainly different for animals.

In a sense, it can be argued that the animat is the reification of a theory of the animal in that particular context. Other parameterisations, organisations or modules would be needed for matching other different experimental environments. This means that the animat-as-theory model fails in a core aspect of science: parsimony (Cassimatis, Bello, & Langley, 2008).

The same can be said concerning the second major research objective: decisional autonomy of robots in unprepared environments. This is a technical objective and as such it is not a question of addressing certain observed data —as was the case with animal modelling— but a question of attaining data, i.e. obtaining certain pre-specified behaviours that constitute the well known requirements set for any engineering activity.

Apparently, animat research is contributing to this by postulating behaviour-oriented architectures that are robust in relation with environmental changes. For the same reason mentioned before, this objective is not fulfilled and animat architecture cannot systematically be transferred into robot implementations as to provide robust behaviour in unstructured environments.

In the best case, animats get to reproduce experimental data (form biology or ethology). But science does not advance by replication or mimicking, rather it is through the understanding of the general principles in which animats, animals or humans are settled in.

Animat Examples

The Gecko Project

Kim's Stickybot[2] is a cute gecko-inspired robot that can climb glass walls. It is so cute that it appears in Time Magazine Best Inventions 2006.

This is what Time Magazine says about this robot:

> *Real geckos skitter up walls, thanks to millions of tiny hairs on the bottom of each toe. These hairs, called setae, cling fast as the creature pulls up, then gently detach when it's time to take the next step. Such was the inspiration for Stickybot, a mechanical lizard with its own adhesive feet. The hundreds of sharply tapered synthetic fibers that pad the bot's four appendages replicate the gecko's fancy footwork, including an elegant toe-curl release, to climb glass, tile or whiteboard at a rate of 4 cm/sec.*

But Time Magazine recognises the real value of the robot. It is listed in *Best Inventions 2006*, section *Toys*.

It may be argued that the Stickybot project can contribute to knowledge about the mechanisms of gecko adhesion, hence producing worthy science. This is right; but for this we don't need the robot gecko, just the adhesive toes.

We can compare the work on the Stickybot project with Ron Fearing's Gecko Project. This last is inspired by the same gecko's competence in walking and run at any orientation. But this project is focusing on how the very specific *nano-structures function in a hierarchical combination*. This is an quote from Fearing's project website[3]:

> *Geckos have the remarkable ability to run at any orientation on just about any smooth or rough, wet or dry, clean or dirty surface. The basis for geckos' adhesive properties is in the millions of micron-scale setae on each toe of the gecko form a self-cleaning dry adhesive. [. . .] Our interdisciplinary team of biologists and engineers has been working since 1998 developing models for how the natural nano-structures function in a hierarchical combination of spatulae, spatular stalks, setal stalks, setal arrays, and toe mechanics, and developing nanofabrication processes which allow large arrays of hair patches to be economically fabricated.*

There is no robot gecko here. Only fabrication of adhesives that mimic the micro-functional structure of gecko's

[2] http://www-cdr.stanford.edu/˜sangbae/Stickybot.htm
[3] http://robotics.eecs.berkeley.edu/˜ronf/Gecko/

setae. Using these adhesives they are able to fabricate *adhesive tape* and test it in laboratory settings. Fearing's experiments enable the rigourous determination of adhesion properties —with numbers— of their adhesives(Lee, Fearing, & Komvopolous, 2008). Kim's experiments just produce videos, Time Magazine recognition and IEEE Transactions awards (Kim et al., 2008).

Psikharpax

Meyer's Psikharpax project[4] aims at producing an artificial rat equipped with control architectures and mechanisms that reproduce as nearly as possible those that have been widely studied in the natural rat.

Psikharpax is a 50 cm-long robot equipped with many allothetic and idothetic sensors: a two-eyed visual system, an auditory system with two electronic cochleae, a whisker-based haptic system, a vestibular system reacting to linear and angular accelerations of its head, an odometry system monitoring the length of its displacements —by wheels—, and capacities to assess its current energy level.

Its control architecture also exploits internal needs —such as hunger, rest, or curiosity— and according to their builders it is planned to be endowed with background emotions —such as calm, tension, or well-being— and primary emotions —like fear, disgust, or surprise.

Psikharpax and a virtualization of it have been used in the european research project ICEA to investigate models of the rat brain architecture concerning the integration of autonomic, emotional and cognitive aspects[5].

The Amazing Androids of Hiroshi Ishiguro

A case of special importance in the animats world is the case of human-like robots. We have discussed about this research with some colleagues building androids but it is still unclear for us what are the motivations behind this work. What is the business case for humanoid robotics? Are humanoids the future factory workers, human replacements or surrogates, colleagues, friends, vehicles for human-centric research, or just pure hubris ?

A paradigmatical —stricking we would say— example of this kind of work are the androids and ginoids of Hiroshi Ishiguro. These robots try to be maximally realistic in their appearance. The purpose of his research —as stated by Ishiguro— is not robotics, but the search of answers to some basic questions —What is human, What is mind and What is consciousness— by building a robot[6].

Android Science (MacDorman, 2006) is a term used to situate this research on realistic humanoids in a context of tangible scientific purposes. Proponents of this activity define android science as the discipline of investigating real humans using androids (Ishiguro, 2006). Realistic androids enable realistic and repeatable experimentation in human-human interaction.

This experimentation is apparently going to contribute to answer some basic questions about humans. But reading the may texts about this research we cannot find any new, concrete contribution to human physiology, psychology or philosophy of mind. At the end, this work seems more a matter of media impact than anthropology, and Ishiguro robots play very well this game, aptly competing even with the provocative real dolls[7].

Another, may be more serious, example of humanoid research is the European iCub robot[8]. iCub is a robot imitating a 3.5 year old child. The purpose of this work is to establish a research platform for cognitive robotics research —learning, epigenesis of mind, interaction, development, sensorimotor control, etc.— by leveraging the required level of physical competence (the upper body has 38 degrees of freedom). iCub does not come with a pre-built mind but nevertheless their authors consider it to be a milestone in cognitive systems research (Metta, Sandini, & Vernon, 2010). They think so because cognitive science is badly in need of common baselines to enable theory and implementation comparison.

Having a common platform for research has been demonstrated a good strategy in many fields. In domains where there is an enormous variety of application possibilities —both at the system and context levels— the specification of a base system and a set of application benchmarks is the way to measure real advance and have progression. The iCub design is licensed using open source models (Courtney et al., 2009) but this is not enough. Real benchmarking specifications are missing. Mere descriptions of biological scenarios —e.g. monkey grasping action or child language learning in manipulation tasks— are not research-grade benchmarks. Solid, concrete specifications and measurable requirements are needed. In this precise sense, the Robocup specification —win a football match— is a much more solid benchmarking exercise.

An Analysis of Animat Research

It would take a whole volume to perform a detailed analysis of the claimed contributions of animat research to the many areas of knowledge relevant to cognitive science. Contributions from concrete aspects of a particular animat are available throughout the whole spectrum of animat research. However, the argument of this paper is that this contribution does not exist at all from the perspective of the *whole animat*; i.e. building whole iguanas does not contribute to science.

Animats are not good engineering

Animats are not good engineering because they ignore the basic dogma of engineering: fulfil requirements.

Engineering is the practice of the artificial (Simon, 1996). Engineering activities are basically centred about designing a

[4] Extract from *Scholarpedia:Animat*.

[5] http://www.iceaproject.eu

[6] http://spectrum.ieee.org/static/special-report-robots-for-real

[7] http://www.realdoll.com

[8] http://www.robotcub.org/

system that will fulfil requirements when built. In a sense, the design causes the requirements to be satisfied.

In general cognitive systems, the lack of analytical models make impossible the reversion of the causal process —i.e. compute the design from the requirements. The alternative is the use of exploratory, forward-going approaches, where potential designs are proposed, evaluated against requirements and eventually accepted.

However, the enormous variety of aspects to be taken into account in a full animal and the wildly exploratory approaches used in animat construction make impossible also a minimally rigourous forward engineering process.

Animats are not good biology

Animats are not good biology because their technical hacks pervert any modelling relation.

Webb (Webb, 2007) analyses two differing approaches to biological knowledge from the construction of machines: "building models of specific animal systems and assessing them within complete behaviour-environment loops; and exploring the behaviour of invented artificial animals, often called animats, under similar conditions." She recognises that the animat path has obvious problems —"how can we learn about real biology from simulation of non-existent animals?"— but she concludes that animat research is relevant to biology because it can be considered as model building and evaluation (but still have to "to demonstrate that they can usefully account for observations made on real biological systems").

This question of robot realisation as modelling is tricky, however, because the modelling relation —i.e. the isomorphism between the animal and the animat— is lost. This is specially relevant at the cognitive modelling level (Sanz et al., 2009), where the understanding of animal innards is minimal except for some simple model animals.

Animats are not good psychology

Animats are not good psychology because rigourous experimental settings are lacking.

When addressing a simple cognitive task performed by a machine in a rigourous setting similar to those of experimental psychology, the impression that many people get is of triviality. Imagine a servo-controlled pan-and-tilt camera following a blue dot in a well illuminated screen in front of the camera, and all this in a totally dark room. This is a well solved problem in machine vision today. The problem is that for animat builders this may seem too trivial.

The inclusion of a body, movement, hunger and predators make the vision problem much more real. However, in the case of finding a working solution, it will not be easy to identify the chains of causality of relevance for a psychological theory of perception.

Animats are not good philosophy

Animats are not good philosophy because they neglect expliciting their core conceptualisation and assumptions.

The quote from the Animat Lab in the first section of the paper included some words —e.g. autonomous, needs, motivations, survive, adaptive, situated, learn, evolve— that are crucial concepts in philosophy of mind. However, not much work is dedicated in animat research to precisate or avoid undefined terms.

Animats are not good physics

Animats are not good physics because there is no mathematical theory where to match systematic quantitative measurements.

Physics does not work by impressions, experiences and human observations of videotaped happenings of machines. Mathematics constitute the cornerstone of physics but they seem to be used only in virtual, simulated, point-sized animats. The Stickybot work described before is good at this but only at the mechanical level (Kim et al., 2008). Cognition is, in general, devoid of mathematical models of complete functioning.

Hence, what are they good for ?

Animats seem to be just toys to mesmerise youngsters, journalists and general population. This helps appearing in the media, be popular and, eventually, get public funds.

Let us quote Wikipedia again:

> ***Mesmerize*** *may refer to the act of animal magnetism. Animal magnetism (French: magnètisme animal), in its most common usage today, refers to a person's sexual attractiveness or raw charisma. But the term originally signified a magnetic fluid or ethereal medium residing in the bodies of animate beings, as postulated by Franz Mesmer.*

Sharkey (Sharkey & Sharkey, 2006) analyses this problem —in the context of larger scale potential development of robotics— and concludes:

> *The Natural Magic of robotics and AI can create an illusion of sentience and thinking in artifacts by exploiting the cultural myth of the thinking robot and the human predisposition to zoomorphism.*

Assessment of Animat Technology

Passino (Passino, 2004) is quite clear about what is the proper stance concerning the use of bio-inspired technology. He does this analysis by mentally evaluating the possibility of using a Homer Simpson-inspired nuclear plant controller . Passino says:

> *The goal is not emulation of substandard human behavior; it is to design the best control system possible.*

Consider for example a fictional recreation of Passino mental experiment. A bio-inspired animat, Wowwee's Homersapien robot, is controlling the rod insertion process in a nuclear reactor. We all now this is going to fail, but not because the idea is flawed but because Homer —the original one— is flawed. Were it the case that we used a real human, well trained, competent, nuclear technician as model for our bio-inspired robot, nobody would doubt that this was a good strategy.

However copying humans is not, in general, a good strategy. This is so for two basic reasons:

1. Humans sometimes make mistakes —Chernobyl or Bhopal are there as hard proofs.

2. Our copy of the human is different from the human. This is so because i) we do not have complete information about humans' design; and ii) our copy process is not rigourous. The copy will behave differently —esp. when addressing unexpected situations.

Bioinspiration is a good way to have inspiration but not necessarily a source of a general, complete and solid design. The design of the system must be sound and this implies that if it is bio-inspired, some extra work is needed. Additional rigourous functional/behavioural analyses shall be done.

This however is not easy, because analysis shall be done against a backdrop of objectives. In the world of animat construction, researchers do not always have clear ideas about what it is what they are investigating. Is it about better robot construction competences? Is it about modelling the animal they are copying? Is it about the empathic experience of the human that is perceiving the animat? All these motivations and objectives can and become awfully merged in the argumentations and analyses around animat technology (see for example the collection of texts around the uncanny valley hypothesis (Mori, 1970).

Conclusions and Prospects

Animat research is a great pretender and a big scientific failure. However, it is not a failure in the media. Starting with Wensley's Televox, animated machines have always leveraged the human inclination to natural magic (Sharkey & Sharkey, 2006).

Animat research is suffering the methodological pathology of *biologism* (Sanz, 2003), i.e. the chauvinist idea that biological systems are better that their artificial counterparts. This is not just a question of romantic perception of the power of nature, it is an example of the systematic use of the fallacy of evolution: that evolution produces optimal solutions. Not only this is obviously false —see theoretical results about hill climbing in non-linear landscapes— but it is also misguided in this context of natural vs. artificial.

Evolution does not produce solutions to problems (e.g. does not produce a solution for the problems of climbing glass walls or building 3D maps in total obscurity). Evolution produce systems that survive (as individuals and/or as species), hence it is producing systems —not solutions— that are sufficiently viable in a particular environment. This implies that animats —animal inspired robots— will only realise sub-optimal solutions to both natural and artificial problems.

Bear in mind that this is not a critique of bioinspiration nor a failure to recognise the obvious fact that we learn solutions to many problems from nature. What I'm questioning here is not the path *animal* $\rightarrow$ *technology* but the detour through a biomimetic robot *animal* $\rightarrow$ *animat* $\rightarrow$ *technology*. Building an animat to investigate a nature-inspired technology is more a sidetrack than a detour.

We would like to catalog the real contributions to engineering —or biology, or psychology— produced by means of creating an animat. But it is not easy to find an idea that has gone from an animat to a medicine or engineering textbook. It may well be the case that someone believes having done so, but please, before asking for the reward think for a moment to decide if the idea came from the *animat* or from the *real animal* (i.e. decide if it was or not necessary to build the animat to produce the idea).

Prospects for animal-inspired cognitive science

This is a paper about the concrete topic of the so called "animat research", not about general bio-inspired robotics. It is trying to pinpoint the critical issue of having the rigour and repeatability that are critical for science and engineering —especially in the worlds of artificial intelligence (Madhavan, Tunstel, & Messina, 2009). It is not arguing that animats are useless; they are not. What is useless for science is how this work is done today in general. Experimental rigour is lacking and all this potentially valuable work is lost in a collection of robots and happenings around them. The only remaining products are media appearances and pretended scientific publications, not solid science or usable technologies.

We suggest that we should try to avoid the animat chauvinistic detour and focus on the technological matches that provide generalised solutions to problems. Investigating the dynamics of perceptual categories is a worthy task. Doing this with a half-meter long robotic rat with stiff whiskers is an unnecessary effort that is not only expensive but that is producing unnecessary interferences within the experimentation process. The experimental apparatus is too complex to distil solid theoretical models.

Building animats the way they are built today is a waste of time and money both from a scientific and technical research perspective. This kind of activity should be left to student training activities in robotics, developments in the toy industry, science fairs and media events.

The strategy for animal-inspired cognitive science should be as follows:

1. Identify a problem yet to be solved.
2. Theoretically characterise it.
3. Gather animal data.
4. Propose a theoretical hypothesis.
5. Devise a *minimal* experimental installation addressing the core problem —i.e. use a minimalist apparatus.
6. Define and perform carefully controlled experiments.
7. Evaluate hypothesis. Go to 4 if failure. If successful try to generalise the problem and go to 2 (with parsimony).

It is necessary to focus on the concrete theories that are behind the animats and have a way of *comparing and deciding about them*. This issue has been previously raised and stressed, without much success in the community, by animat researchers (Meyer & Guillot, 1991; Guillot & Meyer, 2001).

A Final Analysis

In a sense, present day animat construction is just a form of robotic art. Let's include another Wikipedia quotation about what art is:

> *"Art is the process or product of deliberately arranging elements in a way that appeals to the senses or emotions."*

Mesmerising people with animats is hence a form of art. Not science. From an external, objective point of view nobody can tell the difference between current animat research in cognitive science and the works shown at the Kinetica Art Fair [9] —an art fair devoted to kinetic, electronic and new media art.

In 1950 Turing said that there was: *"little point in trying to make a 'thinking machine' more human by dressing it up in such artificial flesh."*(Turing, 1950).

At the end of the day, looking at the scientific emptiness of this animat endeavour, we can only conclude that *animat (research) is a (research) medium without (research) message*.

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References

Cassimatis, N. L., Bello, P., & Langley, P. (2008). Ability, breadth, and parsimony in computational models of higher-order cognition. *Cognitive Science*, *32*, 1304-1322.

Courtney, P., Michel, O., Cangelosi, A., Tikhanoff, V., Metta, G., Natale, L., et al. (2009). Cognitive systems platforms using open source. In R. Madhavan, E. Tunstel, & E. Messina (Eds.), *Performance evaluation and benchmarking of intelligent systems* (pp. 139–168). Springer.

Dennett, D. (1978). Why not the whole iguana? *Behavioral and Brain Sciences*, *1*, 103-104.

Guillot, A., & Meyer, J.-A. (2001). The animat contribution to cognitive systems research. *Cognitive Systems Research*, *2*(2), 157 - 165.

Guillot, A., & Meyer, J.-A. (2008). *La bionique : Quand la science imite la nature*. Dunod.

Hull, C. L., Hovland, C. I., Ross, R. T., Hall, M., Perkins, D. T., & Fitch, F. B. (1940). *Mathematico deductive theory of rote learning: a study in scientific methodology*. New Haven: Yale University press.

Ishiguro, H. (2006). Android science: conscious and subconscious recognition. *Connection Science*, *18*(4), 319-332.

Kim, S., Spenko, M., Trujillo, S., Heyneman, B., Santos, D., Member, S., et al. (2008, February). Smooth vertical surface climbing with directional adhesion. *IEEE Transactions on Robotics and Automation*, *24*(1).

Lee, J., Fearing, R. S., & Komvopolous, K. (2008). Directional adhesion of gecko-inspired angled microfiber arrays. *Applied Physics Letters*, *93*(191910).

MacDorman, K. F. (2006). Introduction to the special issue on android science. *Connection Science*, *18*(4), 313-317.

Madhavan, R., Tunstel, E., & Messina, E. (Eds.). (2009). *Performance evaluation and benchmarking of intelligent systems*. Springer.

Metta, G., Sandini, G., & Vernon, D. (2010). *Robotcub final activity report* (Tech. Rep.). Project IST-004370 RobotCub.

Meyer, J. A., & Guillot, A. (1991). Simulation of adaptive behavior in animats: review and prospect. In J. A. Meyer & S. Wilson (Eds.), *From animals to animats. proceedings of the first international conference on simulation of adaptive behavior* (pp. 2–14). Cambridge, MA: The MIT Press.

Mori, M. (1970). The uncanny valley. *Energy*, *7*(4), 33–35.

Passino, K. M. (2004). *Biomimicry for optimization, control, and automation*. London: Springer-Verlag.

Sanz, R. (2003). Against biologism. contribution to the panel on intelligent control imitating biology: Promises, challenges and lessons. In *Ieee international conference on intelligent control.* Houston, USA: IEEE Press.

Sanz, R., Hernández, C., Gómez, J., Bermejo-Alonso, J., Rodríguez, M., Hernando, A., et al. (2009). Systems, models and self-awareness: Towards architectural models of consciousness. *International Journal Of Machine Consciousness*, *1*(2), 255-279.

Sharkey, N., & Sharkey, A. (2006). Artificial intelligence and natural magic. *Artif. Intell. Rev.*, *25*(1-2), 9–19.

Simon, H. A. (1996). *The sciences of the artificial*. Cambridge,USA: MIT Press.

Taubes, G. (2000, April 7). Biologists and engineers create a new generation of robots that imitate life. *Science Magazine*, 80-83.

Turing, A. (1950). Can a machine think? *Mind*, *59*.

Webb, B. (2007). Animals versus animats: or why not the real iguana? *Theoria et Historia Scientarum*, *9*(1).

Webb, B., & Consi, T. R. (Eds.). (2001). *Biorobotics. methods and applications*. Cambridge, MA, USA: The MIT Press.

Wilson, S. W. (1990). Perceptron redux: Emergence of structure. In S. Forrest (Ed.), *Emergent computation* (p. 249-256). Amsterdam: North Holland.

[9] http://www.kinetica-artfair.com/