The Digital Renaissance from Leonardo da Vinci to Alan Turing

O Renascimento Digital de Leonardo da Vinci a Alan Turing

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Abstract

The Italian Renaissance started a rebirth of culture and knowledge not experienced since Roman times. Leonardo da Vinci was arguably the leading polymath of the era. We are now in the throes of a Digital Renaissance, arguably started by Alan Turing in England. The information revolution that we are now experiencing is as disruptive as any change since the Renaissance. This paper draws some parallels between these two periods and speculates on the future of digital developments.

Keywords

Computational culture. Digital culture. Digital identity. Information revolution. Italian Renaissance.

Resumo

O Renascimento Italiano iniciou um reaparecimento de uma cultura e conhecimento não experimentados desde os tempos romanos. Leonardo da Vinci foi, sem dúvida, o principal polímamo da época. Agora estamos no auge de um Renascimento Digital, indiscutivelmente iniciado por Alan Turing, na Inglaterra. A revolução da informação que estamos experimentando agora é tão disruptiva quanto qualquer mudança desde o Renascimento. Este artigo traça alguns paralelos entre esses dois períodos e traz algumas especulações sobre o futuro do desenvolvimento digital.

Palavras-chave

Cultura computacional. Cultura digital. Identidade digital. Revolução da informação. Renascimento italiano.

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Introduction

Now in the third decade of the 21st century, we are witnessing the merger of two revolutions across digital time and space – that of Italian Renaissance of Leonardo da Vinci's (1452–1519)world with the digital information revolution of Alan Turing's (1912–1954) (COPELAND et al., 2017) world as we enter a new "Digital Renaissance" where digital and human states of being are morphing into a new postdigital era. As the Turing Test (TURING, 1950) predicted, human and artificial intelligence would work side by side to advance science, art and technology as it replaces old hierarchies of society with new ways of thinking, an outcome intrinsic to the global digital ecosystem of everyday life. Owing to this, for the first time, we all have access to Leonardo da Vinci's works on the web[3].

Where they reside and interact with the art world. New fields of research such as the digital humanities and digital art history have developed in response to the wealth of digitised and born-digital material on the Internet, ripe for discovery and new contemporary interpretations, as fresh perspectives on art and life flow from digital culture.

From the vantage point of digital life, we look back 500 years to the death of Leonardo da Vinci in 1519, and are now able to study the full range of his genius through a digital lens and experience his codices and art works enhanced by the emerging technologies of VR, AR, and MR. Juxtaposing this body of work with that of Alan Turing focusing on the Turing Digital Archive (TURING DIGITAL ARCHIVE s.d.) and publications online, brings into public view an exciting meeting of the minds between the great Italian Renaissance master (ZÖLLNER, 2003) and the father of computer science (BOWEN, 2016). Concentrating on their late period work, for da Vinci, 1512 to 1519, and for Turing 1948–1954, this paper illuminates their shared vision of art and science, and how they were driven by their fixation on the natural world and the complex processes that create life, real and artificial.

Turing's groundbreaking work during the last years of his life, documented in the Turing Digital Archive (TURING DIGITAL ARCHIVE, s.d.), concern his studies on artificial intelligence and machine thinking and learning (TURING, 1950), neural networks and finally, morphogenesis (TURING, 1951a) including cell structure, patterns in nature, flowers and seeds, areas of study that we see strongly represented in da Vinci's drawings, such as those depicting the human foetus in the womb, flowers, plants, patterns, and the human brain. Finding disciplinary coherence, their work encompasses the fields of mathematics, geometry, embryology and engineering, areas of study that both men sought to advance, and by so doing, have deepened our understanding and appreciation of human consciousness and identity. Given the magnitude and impact of their work, we are awed by da Vinci's scientific discoveries and the life he breathed into his beyond-human paintings, which is matched by the brilliance of Turing's discoveries around thinking machines, AI and machine learning – making artificial life seem all too real.

Through digital research online, we see new relationships and connections between da Vinci and Turing. Travelling on a digital platform from present to past and back again, we can immerse ourselves in their writings and thoughts as they interlink in ways that expose their similarities of vision, and values, gleaned from

3 See WikiArt (n.d.). Leonardo da Vinci. WikiArt Visual Art Encyclopedia.
URL: https://www.wikiart.org/en/leonardo-da-vinci

natural and computational worlds. As mathematicians, both observed nature in order to deepen their understanding of its processes, with an eye for patterns and a love of Euclidean geometry. While Turing broke secret codes, da Vinci wrote codes in secret texts and drawings, using real and symbolic imagery to open our eyes to the mysteries of the human mind and body. Working from new ideas of perspective in art and the science of painting that ushered in Renaissance ideology, Leonardo da Vinci uncovered the inner workings of human anatomy, detailing its machine-like qualities in his drawings while Turing engaged with the notion of intelligent machines noting that this, "would of course be met with great opposition, unless we have advanced greatly in religious toleration from the days of Galileo" (TURING, 1951b: 15), adding that "at some stage therefore we should have to expect the machines to take control" (TURING, 1951b: 16)

Thus, each moderated and influenced dominant religious beliefs of their time. Both were left-handed, so right-brain dominant associated with creativity (TIGAR, 2018) and both were intensely passionate about studying human states of being and thinking. Significantly, both men identified as gay, and for that personal expression of identity, faced persecution by state authorities. In this article, we explore the work of da Vinci and Turing using digital research methods on the web which drives new ways of thinking about how we think, which invites complexity, non-linear approaches and interdisciplinarity while revealing new contexts and connections. As we travel across the global digital ecosystem, we can see that da Vinci and Turing not only laid the foundations for the age of AI, and more than human art and life, but as well, they envisioned the Digital Renaissance we are experiencing today and into the future.

Digital da Vinci – The Codices and Artworks Breaking the Code – Human and Artificial Life

Leonardo da Vinci and Alan Turing were pioneers of code breaking, da Vinci for revealing the mechanisms and processes of the human body as seen especially in his drawings of the beginning of life of the foetus in the womb, to the architecture of the brain based on his first-hand observation dissecting the body at death, while Turing, through his studies in morphogenesis and phyllotaxis, explained the processes and patterns of cellular formation, patterns of growth in plants, and implying the neural networks of the brain through its electrical currents, expressed as ones and zeros of a digital computer.

Digital da Vinci enables a new era of discovery into his mind and work. In the words of Alice Roberts, science professor at the University of Birmingham, "Leonardo saw the body as a complex, beautiful machine." In her article for *The Guardian* newspaper, she writes:

> For me, Leonardo's notebooks represent a triumph and a tragedy. How wonderful that we can see the workings of this man's mind, 500 years on. But how tragic that his own generation did not benefit from his discoveries. His notebooks lay unpublished for centuries. A few pages were copied and published as etchings at the end of the 18th century but it took until 1916 for all of Leonardo's anatomical papers to be published. They remain, to a modern anatomist's eye, utterly extraordinary and breath-taking in their scope and accuracy. (ROBERTS, 2012)

The Human Machine – Body and Mind

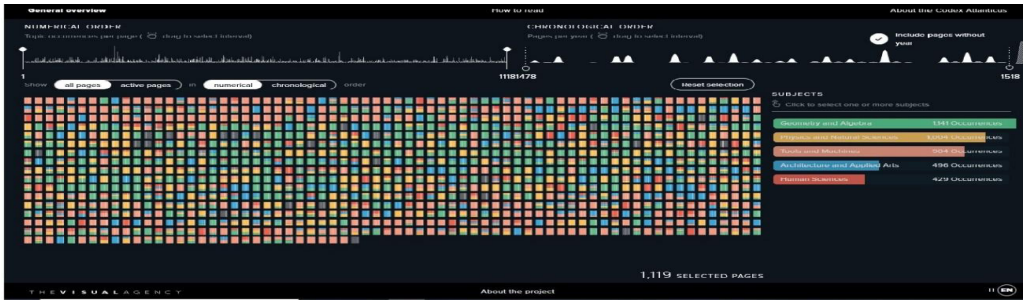
The neuroscientist Jonathan Pevsner, in evaluating da Vinci's work on the brain, writes that it represents, "an astonishingly sharp break from the field that had seen little if any progress in the previous 13 centuries. His work reflects the emergence of the modern scientific era and forms a key part of his integrative approach to art and science" (PEVSNER, 2019). The digitisation of da Vinci's notebooks has catapulted them into public consciousness, their digital images in lights on the Internet – we are amazed at their beauty and the breadth and depth of the innovation and discovery that they represent, having been virtually hidden for 500 years. Thus, with digitisation, we can read da Vinci's notebooks (MACCURDY, 1923) in the contemporary context shedding new light on his ways of thinking and expressing his artistic and scientific vision.

Made freely accessible for the first time, the notebooks are having significant impact on our understanding of his work, while with the Turing Digital Archive online (TURING DIGITAL ARCHIVE s.d.), we can go beyond his achievements and influence in computer science (BOWEN, 2019), AI and machine learning, to his studies in morphogenesis and embryology to arrive at his broad concepts of the processes of nature and the human brain. In light of Turing's work (COPELAND et al., 2017), we can look back to da Vinci and gain greater insight into the relevance of his work today and how both viewed the intrinsic beauty of nature and the human mind and body, from outside in and inside out, and the patterns and shapes of flowers and human form as they develop.

Visualising da Vinci: The Codex Atlanticus

The Biblioteca Ambrosiana in Milan, working with the design firm Visual Agency, have produced a highly effective interactive visualisation of the Codex Atlanticus (BONERA, s.d.) that allows users to search the 1,119 leaves of this 12-volume collection in new and innovative ways. This Codex constitutes the largest collection of da Vinci drawings and texts. Its brown leather cover adorned with gold lettering reads, "DISEGNI-DI-MACHINE-ET-DELLE-ALTRE-COSE-RACOLTI DA POMPEO LEO" (Pompeo Leoni, Italian sculptor and medallist, born 1533 in Milan, died 1608 in Madrid). This collaborative digital rendering of the Codex Atlanticus no doubt points to future developments in interactive visualisations of digital text and images for discovery. See Figure 1 below.

Figure 1. Codex Atlanticus – Screen shot of its interactive visualisation. Codex Arundel – MS 263, British Library, 2021.



Source:
http://www.codex-atlanticus.it/#/Overview

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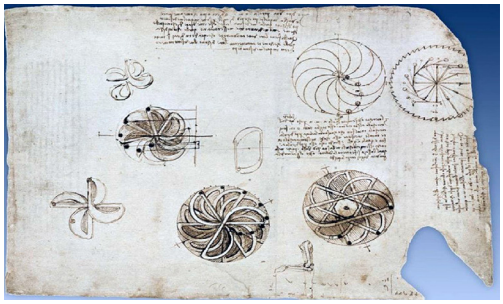
The Codex Arundel was owned by Thomas Howard (1585–1646), 2nd Earl of Arundel, 4th Earl of Surrey, and 1st Earl of Norfolk, art collector and politician, and then owned by Henry Howard (1628–1684), 6th Duke of Norfolk, who in 1667 presented the Codex Arundel to the Royal Society in London. In 1831, the British Museum purchased the Codex with 549 other Arundel manuscripts from the Royal Society. The Codex is currently housed in the British Library[4], where it has been fully digitised. After its long aristocratic past of minimal access, happily, it has been made available online for public view; its 283 folios (570 images) can be viewed by anyone on the British Library website, including magnification facilities

The Codex Leicester on Display in Florence

The Codex Leicester (https://mostre.museogalileo.it/codiceleicester/en/codex), privately owned by Bill Gates, was featured at the Uffizi Gallery in Florence for the exhibition *Water as Microscope of Nature*, which was on view from 30 October 2018 to 20 January 2019. Also in Florence, the Museo Galileo mounted two exhibitions on da Vinci – *Leonardo in Valdichiana: A Map of the Territory and the Science of Water*, August 2019, which ties to the Uffizi exhibition, and *Leonardo da Vinci and Perpetual Motion* from October 2019 to January 2020. (see Figure 2). The exhibition website uses 3D video animation to illustrate perpetual motion which da Vinci concluded was not possible in nature (VISIT UFFIZI 2019).

Figure 2. Leonardo da Vinci drawing from the Codex Atlanticus, f1062r, was on view at the 2019–20 Museo Galileo exhibition *Leonardo da Vinci and Perpetual Motion*



Source:
https://mostre.museogalileo.it/motoperpetuo/en/?_ga=2.205581971.1647228362.1573505300-1512439500.1573505300.

Also known as the "Hammer" codex from the name of the American millionaire who owned it before Bill Gates, the Codex Leicester was compiled between 1506 and 1513, during the period when Leonardo da Vinci was dividing his time between Florence and Milan, under the protection the French king, Louis XII. Unique to this Codex, it is almost entirely concerned with the study of water in the natural landscape, such as its shapes, movements and flow. The Codex was on exhibition in London at the British Library during summer 2019, which was the first time it was available for public view in the UK since Gates purchased it in 1994 (BROWN, 2019).

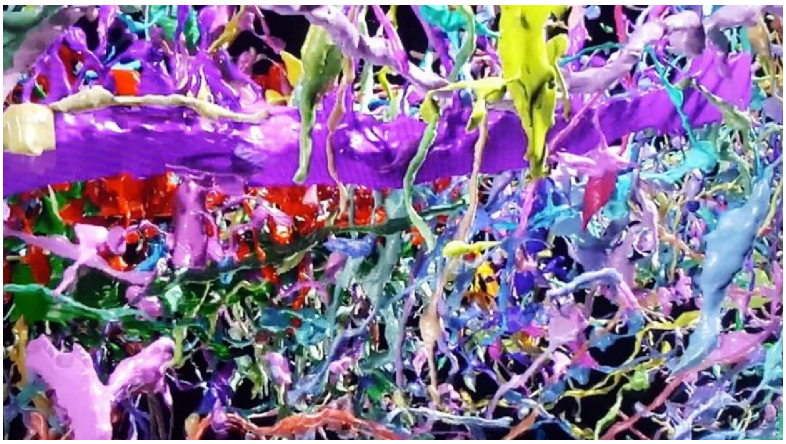
4 See http://www.bl.uk/manuscripts/Viewer.aspx?ref=arundel_ms_263_f001r

Museum Exhibitions: Florence, Paris and London

The global celebration of 500 years since the death of Leonardo da Vinci takes us back in time to the Italian Renaissance to mark the birth of humanism most vividly defined and visualised by da Vinci's work. His observations of the natural world and the human mind and body as seen in his notebooks and paintings, now inspire us to more closely observe what it means to be human in the age of AI and artificial life. Are we not surprised that we find answers and insights in his notebooks and more than real paintings?

In Florence, the Palazzo Strozzi featured a retrospective exhibition of 120 paintings, sculptures and drawings, including those of da Vinci and his teacher, Andrea del Verrocchio, and other pupils, that ran between 9 March – 14 July 2019. In September 2019, a curated version of the show was on view at The National Gallery of Art in Washington, D.C., and at the Denver Museum of Nature and Science, the exhibition Leonardo da Vinci: 500 Years of Genius, which displayed reproductions of Leonardo's inventions and a 360-degree replica of the Mona Lisa. The exhibition at the Louvre Museum in Paris, which houses nearly a third of Leonardo da Vinci's surviving artworks, including the Mona Lisa, was a retrospective of the artist's paintings that opened in October 2019. Vincent Delieuvin, a co-curator, notes that "We want to illustrate how he placed utmost importance on painting and how his investigation of the world, which he referred to as 'the science of painting,' was the instrument of his art, seeking nothing less than to bring life to his paintings" (WALSH, 2019) and why King Charles I of England's prize painting was da Vinci's St Jerome (HART, 2018). Although the Mona Lisa was not included in the exhibition, it was on display in the Louvre, and its appearance complimented by a VR show of the Mona Lisa, designed for the Louvre by Vive Arts, created an enormous sensation (MONA LISA, 2019) In London, the Barbican exhibition, AI: More than Human (GOOGLE, 2019), took visitors on a journey in time beginning with many of the iconic objects, images and leaders of AI development from the 1940s and 1950s to the present, especially Alan Turing. Figure 3a and 3b shows two works on view.

Figure 3a. "Unlocking the Brain – The human brain is an incredibly sophisticated machine that excels at a multitude of tasks. Scientists around the world are attempting to recreate its most complex processes to potentially improve AI. Surprisingly a crucial tool in pursuing this research has been AI itself." (Quoted from the exhibition label.) Photograph by T. Giannini.



Source: https://www.researchgate.net/figure/a-Unlocking-the-Brain-The-human-brain-is-an-incredibly--sophisticated-machine-that_fig3_340000301

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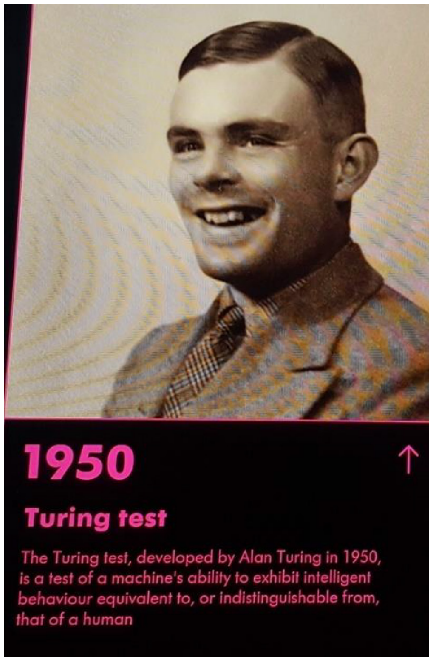
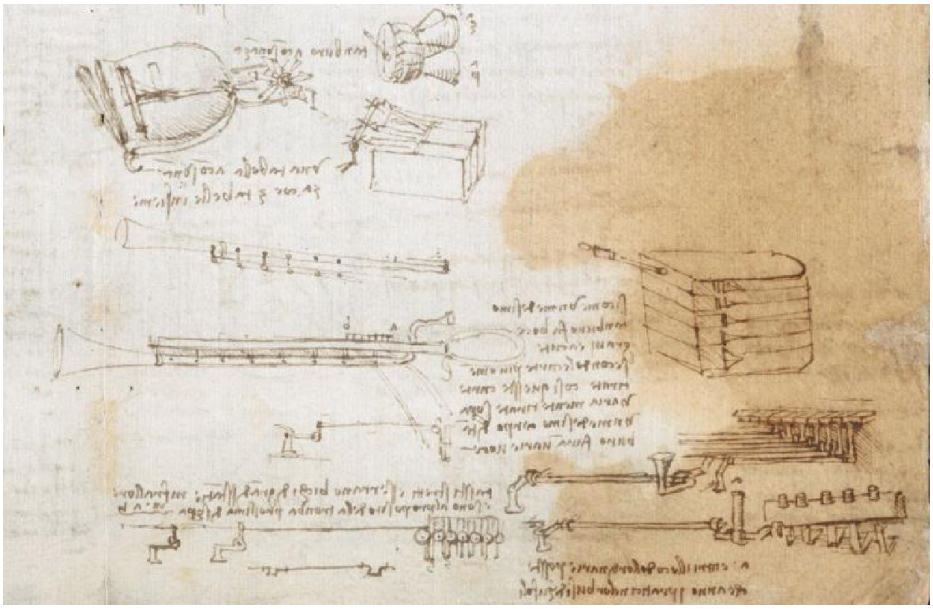
Figure 3b. Alan Turing photo with exhibition text. Photograph by T. Giannini.



Source: https://www.researchgate.net/figure/a-Unlocking-the-Brain-The-human-brain-is-an-incredibly--sophisticated-machine-that_fig3_340000301

Figure 4. Drawing by Leonardo da Vinci of various musical wind instruments. Arundel Codex, MS 263, 175r.



Source: British Library
http://www.bl.uk/manuscripts/FullDisplay.aspx?ref=Arundel_MS_263

Digital Humanism In Science And Art
Soundscapes of Da Vinci's World

As we visualise the sights and sounds of da Vinci's *environs,* we hear the music of Philippe Verdelot (c.1480s–1530s) (VERDELOT et al. 1973), the most prominent composer of his time, who spent his career in Italy working in Rome and Florence supported by the Medici family. He is recognised as the father of the madrigal, a musical form that inspired the great composers of his day and into the late Renaissance, including Monteverdi and Gesualdo. Da Vinci's affinity for music is seen in his inventions for key systems for wind instruments. The drawing in Figure 4 confirms Leonardo's interest in musical instruments and his advanced knowledge of key mechanisms. He compares the poet, painter and musician writing (MACCURDY, 1938):

> When the poet ceases to represent in words what exists in nature, he then ceases to be the equal of the painter … But if he returns to the representation of some definite thing he would become the equal of the painter if he could satisfy the eye with words as the painter does with brush and colour, [for with these he creates] a harmony to the eye, even as music does in an instant to the ear.

During first decade of the 16th century, the French composer Philippe Verdelot (see Figure 5) worked in Florence and Rome. He became known for the development of the Italian madrigal, as its leading composer. The Verdelot madrigal brings together voice and instruments set to the poetry of the likes of Petrarch evoking a visualisation of human expression, a soundscape of the da Vinci milieu. He collaborated with Niccolò Machiavelli (1469–1527) on his comedies. His compositions continued to be popular throughout the 16th century such as his madrigal, *Italia mia (*VERDELOT, 2006), set to the poetry of Petrarch that appeals for truth and peace.

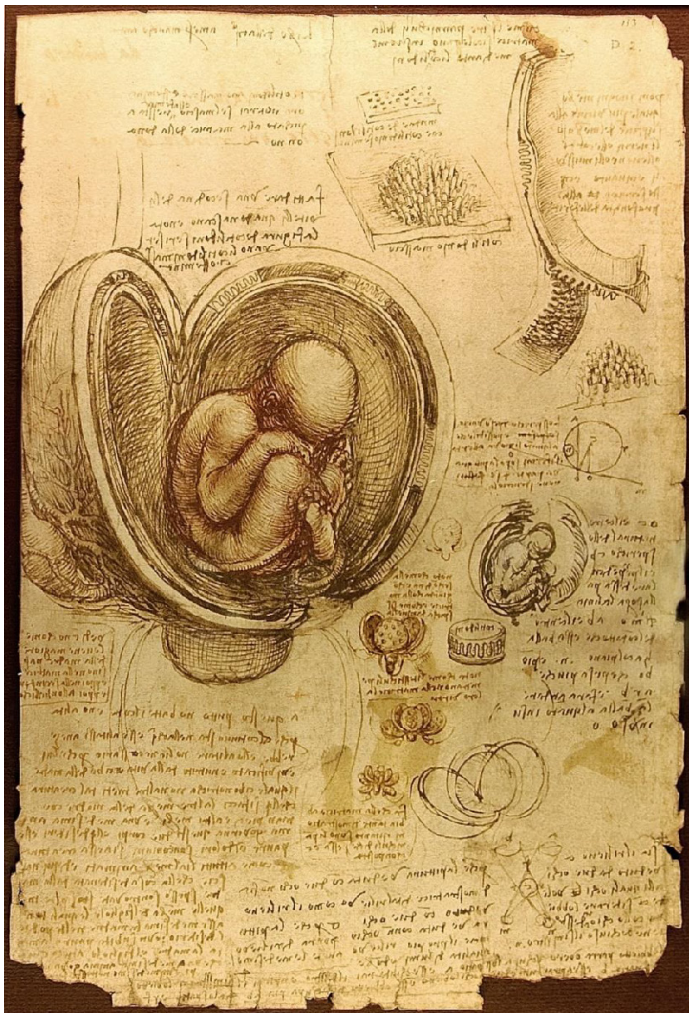
Figure 5. The Three Ages of Man (or Reading a Song), painting by Giorgione (c.1501). Left to right, Jacob Obrecht (composer), Sebastiano Luciano, and Philippe Verdelot. Galleria Palantina, Palazzo Pitti, Florence.

Source: Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Giorgione_-_Three_Ages_of_Man_-_Palazzo_Pitti.jpg).

Mother and Child – Body and Soul

The female body and soul dominated da Vinci's consciousness and seeing. His most favoured subject matter in terms of his paintings seems to be that of the mother and child, while among his drawings, the series on the foetus in the womb contained in the Windsor Notebook draws much public attention and was featured in the 2019 da Vinci exhibition at the Queen's Gallery, Buckingham Palace. Understanding their power to stir human emotion was vividly expressed by the Gallery's poetry competition to which visitors were invited to submit poems inspired by the drawings (ROYAL COLLECTION TRUST, 2019). According to Hilary Gilson of the Embryo Project at Arizona State University, Leonardo da Vinci's work in embryology was groundbreaking. He observed and diagrammed the previously undemonstrated position of the foetus in the womb with detailed accompanying annotations of his observations (GILSON, 2019).

Figure 6. Studies of Embryos by Leonardo da Vinci (pen over red chalk 1510–1513).



Source: Wikimedia Commons (http://commons.wikimedia.org/wiki/File:Da_Vinci_Studies_of_Embryos_Luc_Viatour.jpg)

Figure 6 is a drawing by Leonardo da Vinci from his series of drawing of the foetus in the womb, and his studies on embryology (Windsor Library Notebook) It is one of the two drawings on this subject displayed in the Queen's Gallery, Buckingham Palace for the exhibition Leonardo da Vinci: Anatomist, which served to inspire the Poetry Society in the UK to hold a poetry competition that was judged by Clive Wilmer, British poet and fellow at Cambridge University. He wrote (ROYAL COLLECTION TRUST, 2019): "Most of the poets were either appalled or fascinated by the creative mind the drawings suggest: the emotional detachment needed, the precision of hand and eye, the reverence for life."

Although the competition poems do suggest "emotional detachment", from the perspective of the human interaction between mother and child, they bring focus to their physical and emotional bonds and the process that transforms the foetus in the womb to mother and child, while the competition poems seem to interpret the subject matter as rendered by da Vinci from a more technical and clinical perspective. This inspired Giannini to write the following poem around the notion of a conversation and relationship between mother and child, a foetus in the process of becoming a child. Clearly, for da Vinci, the subject was one of intense study and reflection, and we see the mother and child pictured in 10 out of his c.14 known paintings (see Figure 6 for example), and in his series of drawing on the foetus and womb reminding us of his strong emotional ties to his own mother, while some historians speculate that da Vinci painted the Mona Lisa in her likeness. Turing also was close with his mother, Sara Turing (1881–1976). She took custody of his archives and wrote the biographical book, Alan M. Turing, originally published in 1959 and revised in 2012 for Alan Turing's centenary (TURING, 2012). The rich correspondence between them survives.

Figure 7. Virgin of the Rocks, Leonardo da Vinci, completed 1508, National Gallery, London.

Source: Wikimedia Commons.
https://commons.wikimedia.org/wiki/File:Leonardo_da_Vinci_-_Virgin_of_the_Rocks_(National_Gallery_London.png

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Decoding da Vinci

Mother and Child
(by Tula Giannini, 2019)

My child –
Cry not silently
I can't see your face
Can't embrace
Your head hangs down
Your face hidden between hands
No Instagram
My Mother –
Dreaming of you
I hear your silent voice
Hold me close
Lift me up
Let me breathe
Breathe in your smell
Hold me
close to your breast
Let me drink
your heavenly nectar of life
and think, of you

With the decoding of da Vinci's handwriting and the translation and digitisation of the texts incorporated into his drawings, we discover what his series of drawings on the foetus and womb meant to him. This digitally liberated text found on the Internet Archive is from Edward MacCurdy's translation of Leonardo da Vinci's notebooks (MACCURDY, 1923). It is astonishing to learn that he writes, "that it is the soul of the mother which first constructs within the womb the shape of the man, and in due time awakens the soul that is to be its inhabitant" (quoted from the text below), which he defines as a process of nature entrusted to the mother that gives birth to a human being with heart and soul:

> Although human subtlety makes a variety of inventions answering by different means to the same end, it will never devise an invention more beautiful, more simple, or more direct than does nature, because in her inventions nothing is lacking, and nothing is superfluous ; and she needs no countervailing weights when she creates limbs fitted for movement in the bodies of the animals, but puts within them the soul of the body which forms them, that is the soul of the mother which first constructs within the womb the shape of the man, and in due time awakens the soul that is to be its inhabitant. For this at first remained asleep, in the guardianship of the soul of the mother, who nourishes and gives it life through the umbilical vein, with all its spiritual members, and so it will continue for such time as the said umbilical cord is joined to the placenta– and the cotyledons [a lobule of mammalian placenta – also, an embryonic leaf in seed-bearing plants, one or more of which are the first leaves to appear from a germinating seed.] by which the child is attached to the mother. And this is the reason why any wish or intense desire fright experienced by the mother, or any other mental suffering, is felt more powerfully by the child than by the mother, for there are many cases in which the child loses its life from it. (MACCURDY, 1923)

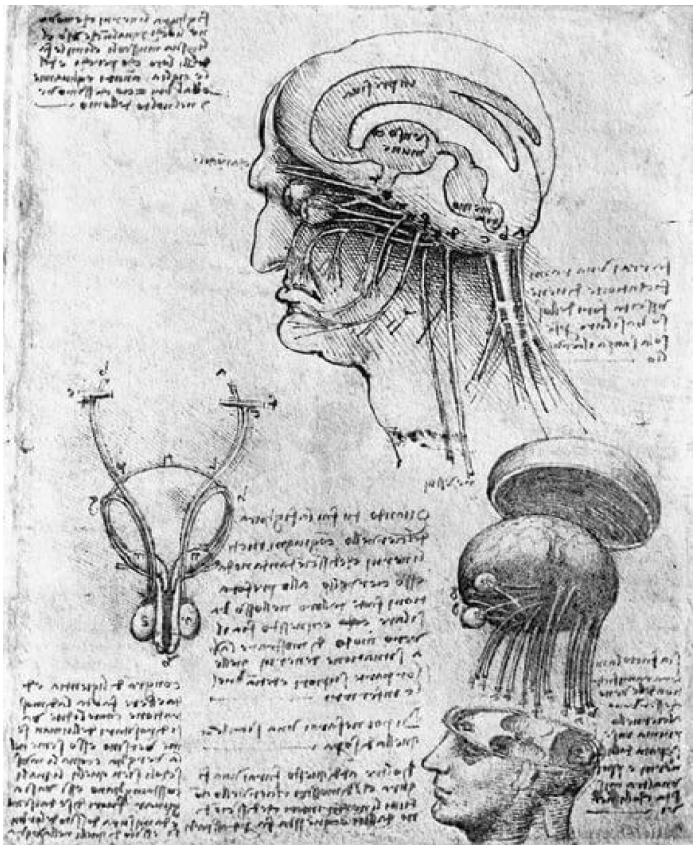
The Leonardo da Vinci notebook that belongs to the Queen's Library at Windsor Castle in the UK is composed of more than 600 sheets that were brought together in a leather binding by Pompeo Leoni (1533–1608), an Italian sculptor of the late Renaissance. The gilt letters on the cover read, Drawings by Leonardo da Vinci restored by Pompeo Leoni. Considered by many to be da Vinci's most awe-inspiring notebook and exceptional among the codices for its anatomical drawings of the foetus and womb as seen above, it is thought by Jonathan Jones, art critic for The Guardian newspaper, to be the most important of da Vinci's notebooks (JONES, 2006).

Neuroscience – The Human Brain and the Senses

Leonardo da Vinci wrote: "the common sense is the seat of the soul, and the memory is its monitor, and its faculty of receiving impressions serves as its standard of reference." (MACCURDY, 1923). He thought that information passed to and through the fluid-filled ventricles rather than brain matter (see Figure 8), writing (FESSI, 2019):

> The senses are moved by the objects; and these objects send their images to the five senses by which they are transferred to the imprensiva [da Vinci's term and concept], and from this to the senso commune. From thence, being judged, they are transmitted to memory, in which according to their power they are retained more or less distinctly.

Figure 8 - Drawing of the brain by Leonardo da Vinci in 1510, showing cerebral ventricles and cranial nerves.



Source: Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Leonardo_da_Vinci,_Manuskriptblatt_mit_anatomischen_Zeichnungen_und_Notizen.jpg

Turing, like da Vinci, studied the flow of information to and from the human brain by way of neural networks of interaction through the senses. Recent advances by the computer scientists receiving the 2018 A. M. Turing Award (ACM, 2018) focus on AI, machine learning, and the senses: seeing, hearing, reading, and speaking.

Seeing Nature – Inspriring Art And Science

Leonardo da Vinci felt that a painter could only achieve perfection and originality by taking nature as his standard. Thus, he links the study of nature and original work, and warns against imitating others' work, which led to the decline of art, a notion that rings true with contemporary art. To quote Leonardo da Vinci in translation:

> The painter will produce pictures of little merit if he takes the works of others as his standard; but if he will apply himself to learn from the objects of nature, he will produce good results. This we see was the case with the painters who came after the time of the Romans, for they continually imitated each other, and from age to age their art steadily declined.
> After these came Giotto the Florentine … turning straight from nature to his art … began to draw the figures of all the animals which were to be found in the country, in such a way that after much study he not only surpassed the masters of his own time but all those of many preceding centuries. After him art again declined… until such time as Tommaso the Florentine, nicknamed Masaccio, showed by the perfection of his work how those who took as their standard anything other than nature, the supreme guide of all the masters, were wearying themselves in vain. (MACCURDY, 1923)

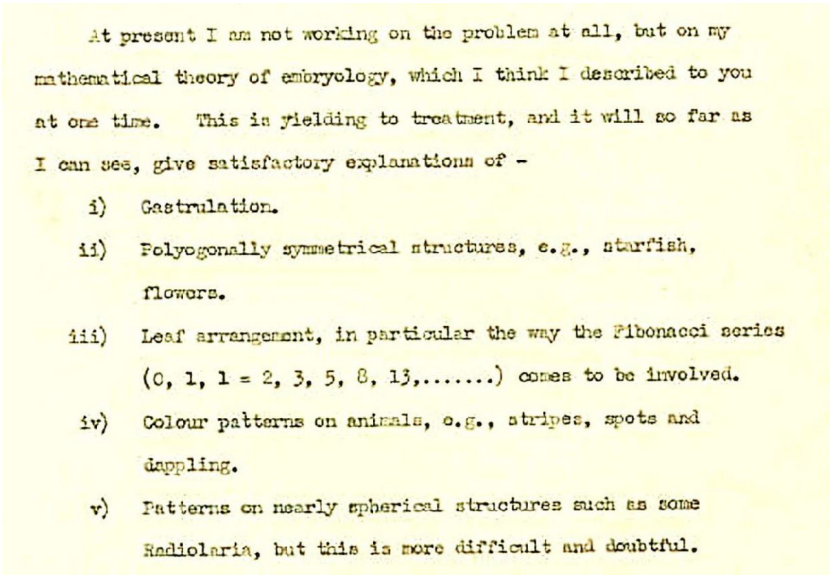
Turing and da Vinci – Kindred Spirits

The Turing Test, devised to compare human and machine intelligence deploying AI and machine learning, begs the question, can robots be "more than human" (GOOGLE, 2019). At the heart of artificial life (A-Life) is the process of simulating nature, what might be called "digital nature" as we see in the latest research on using mapping neural networks of the human brain using AI. The connections their work makes across art, nature, science and technology, is still groundbreaking in our 21st-century world. But perhaps it is with the ties between nature, math and computing, where human and artificial neural networks come together as one in ways that challenge the nature of being human, thinking and consciousness.

Turing's work on morphogenesis, considering the algorithms of nature that instruct the processes generating life itself, reflects his work with digital computers to simulate that process for which he developed AI and machine learning. Turing asks (TURING, s.d.): "How much information could be stored in the human brain in this way?" Here he is referring to the number of neurons. He writes: "The answer is simply MN binary digits, for there are MN paths each capable of two states," (where M is the number of outlets and N is the number of neurons) and goes on to say that, "the particular combinations which will be facilitated will not be fixed at birth but determined by training." Thus, he connects the embryology of plants and humans (see Figure 9), and the neural net-

works and processes of the human brain, which determine development based on binary digits that can be turned on and off. From the images in Figure 10, we see that both Turing and da Vinci studied flowers and their patterns to gain insight into the "mathematical theory of embryology", a phrase Turing uses in his typescript below.

Figure 9. Excerpt from letter dated 8 February 1951, Turing to Professor J. Z. Young on brain structure and the storage capacity from Turing's work, a mathematical theory of embryology. AMT/K/78: image 78a. (TURING, s.d.).



At present I am not working on the problem at all, but on my mathematical theory of embryology, which I think I described to you at one time. This is yielding to treatment, and it will so far as I can see, give satisfactory explanations of -

i) Gastrulation.

ii) Polygonally symmetrical structures, e.g., starfish, flowers.

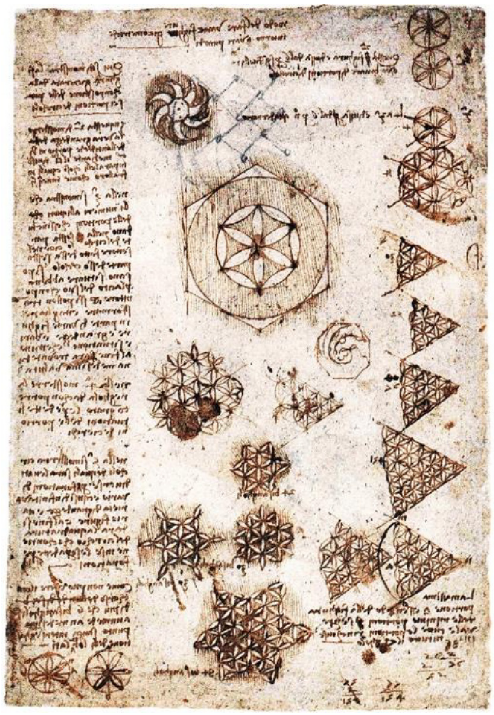
iii) Leaf arrangement, in particular the way the Fibonacci series (0, 1, 1 = 2, 3, 5, 8, 13,.....) comes to be involved.

iv) Colour patterns on animals, e.g., stripes, spots and dappling.

v) Patterns on nearly spherical structures such as some Radiolaria, but this is more difficult and doubtful.

Source: The Turing Digital Archive
http://www.turingarchive.org/viewer/?id=439&title=78a

Figure 10a. Leonardo da Vinci, Codex Atlanticus, folio 459r. This is one of da Vinci's drawings of geometrical structures related to the ornamental structure named today "flower of life".



Source: Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Leonardo_da_Vinci_%E2%80%93_Codex_Atlanticus_folio_459r.jpg

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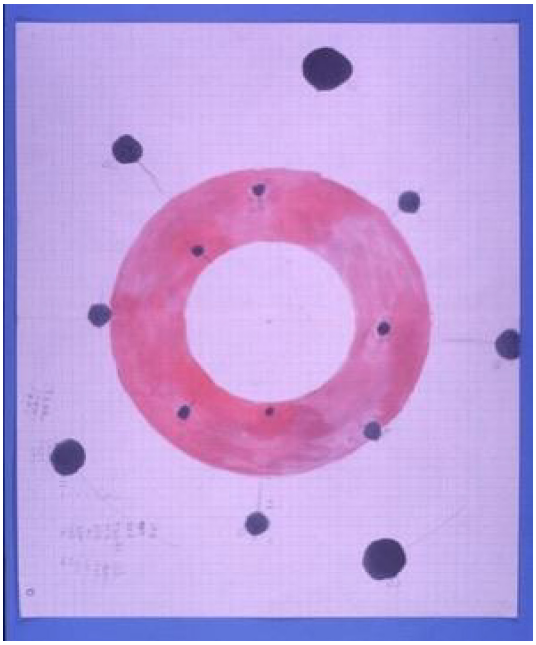
Figure 10b. Daisy ring diagram by Alan Turing. Coloured diagram in connection with work on morphogenesis. AMT/K/3 image 3. (TURING DIGITAL ARCHIVE, s.d.).



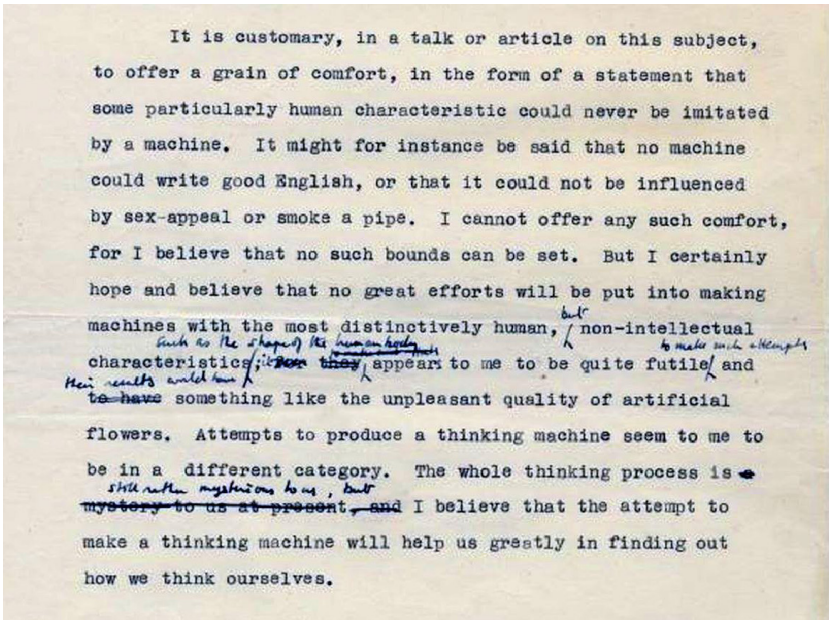
Source: The Turing Digital Archive

Can Computers Think? – by Alan Turing

The work of da Vinci and Turing reveals humanistic perspectives on art and human identity and has sparked revolutionary changes in the ways we see and express the underlying connections between nature, art, and science. Da Vinci's pioneering work was foundational to transitioning to the Enlightenment, while Turing's introduction of computer Science (TURING, 1936). AI, machine learning and thinking (TURING, 1950), sparked the digital revolution paving the way for the age of AI. Turing's reflections on the reach of AI and computing show that he did not impose any limitations.

Today, these connections between the physical and digital world are essentially AI and machine learning in a human context. As we see with the Turing Test, he never lost sight of the "thinking machine" in relationship to the human mind (ROBERTS, 2012). On May 15, 1951, Turing gave a talk for the BBC with the title, "Can Digital Computers Think?" (see Figure 11). Turing ends by saying (TURING, 1951, p.8): "The whole thinking process is still rather mysterious to us, but I believe that the attempt to make a thinking machine will help us greatly in finding how we think ourselves."

Figure 11. Typescript with annotations from the talk, "Can digital computers think?" by Alan Turing, broadcast on the BBC, 15 May 1951.



It is customary, in a talk or article on this subject, to offer a grain of comfort, in the form of a statement that some particularly human characteristic could never be imitated by a machine. It might for instance be said that no machine could write good English, or that it could not be influenced by sex-appeal or smoke a pipe. I cannot offer any such comfort, for I believe that no such bounds can be set. But I certainly hope and believe that no great efforts will be put into making machines with the most distinctively human, but non-intellectual characteristics, such as the shape of the human body, to make such attempts appear to me to be quite futile and their results would have to have something like the unpleasant quality of artificial flowers. Attempts to produce a thinking machine seem to me to be in a different category. The whole thinking process is still rather mysterious to us, but mystery to us at present, and I believe that the attempt to make a thinking machine will help us greatly in finding out how we think ourselves.

Figure Digital Archive
http://www.turingarchive.org/viewer/?id=459&title=8

Beyond Human

The human mind-body relationship generally is considered within an individual being, while understanding this relationship in the context of computational culture focuses on extending the power and capabilities of the human mind and body through embedded technology, neural networks, AI and machine learning and virtual experience, informed by an interdisciplinary framework that harnesses science, art and technology, directed by human creativity, imagination, and innovation. Having now reached new milestones in human-machine interaction set in our expanding digital universe, where computational culture proliferates effecting the integration of real and virtual worlds, we are increasingly challenged to reimagine our existence in an augmented reality state.

Both da Vinci and Turing were deeply immersed in developing tools and machines that could augment human capacity, and the extent to which they realized this dream seems quite astonishing – and more so now in the 21st century, where automation, human and artificial intelligence and machining learning are driving the rapid changes that we experience in our daily lives. This makes obsolete the old siloed infrastructure of the disciplines, education, and work, which are being replaced systematically by a new global computational ecosystem of enormous proportions spurred by global participation across networks and platforms while our interactions with the physical world are more and more mediated by computational systems. We see over the past few months of the COVID-19 lockdown that these trends are accelerating at unprecedented speed and "studies have shown that on average, it takes 66 days for new behaviours to become automatic (SOLIS, 2020).

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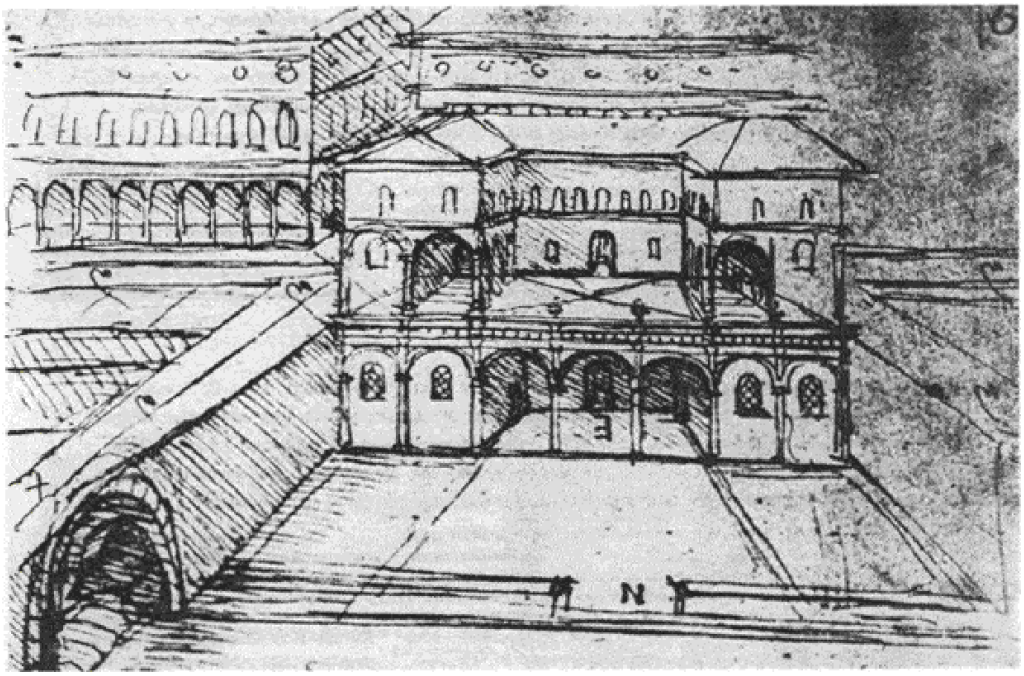
Figure 12. City concept design, drawing by Leonardo da Vinci, Paris made in response to the bubonic plague in Milan 1484 - 1485. Paris Codex b. Institut de France.



Source: Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Projekt_idealnego_miasta.gif

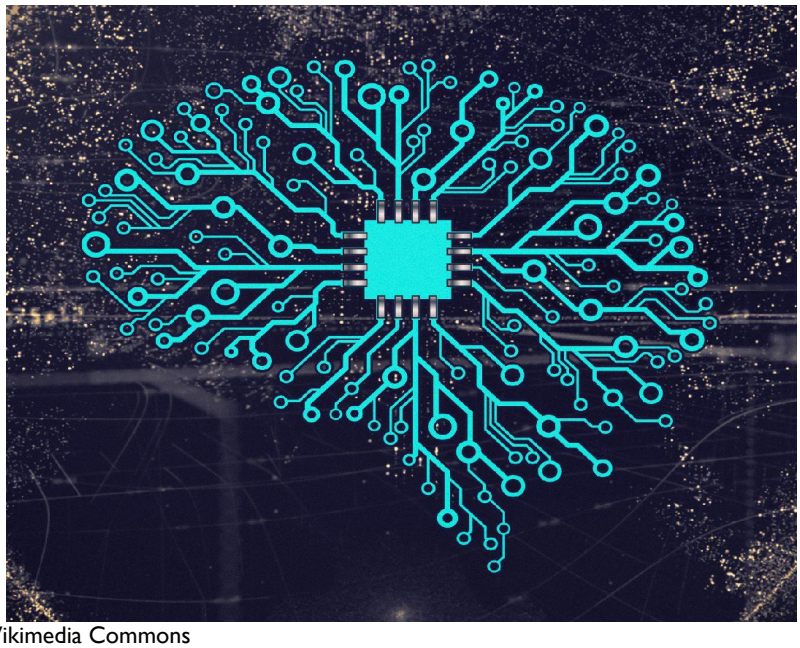
Just as Covid-19 has created an extreme challenge to our ways of living, so it was with da Vinci when he visited Milan at a time during which the Bubonic plague was raging in 1484–1485. Then a city of 150,000 people, history records that 50,000 Milanese residents died of the plague. Known as the Black Death, the plague killed some 50 million people when the world population was about 450 million. Based on his observations that Milan had remained a Medieval city, having narrow and crowded streets prone to breeding disease, motivated da Vinci to design a new city of the future featuring wide streets, canals, three level living space, transportation, and sanitation systems (LIDDELL, 2018).

Machine Inventions

From da Vinci's notebooks, in particular the Codex Atlanticus (see Figure 1), which contains 904 drawing on the subject of "machines and tools", the drawings of his inventions include automobiles, flying machines, planes, robots, and weapons of war, while from the Turing archives and papers, we see the mathematics and computations that underpin his life-changing inventions of computer science and artificial intelligence, that have led to augmenting human intelligence, senses and analytical powers, but at the same time compete with human ability.

Recently, the American inventor, Elon Musk in an article for *Dezeen* unveiled his updated *Neural Link* invention revealing a new simpler design "for an implant that aims to create brain-to-machine interfaces, alongside a large robot that inserts it." The idea is to "connect human brains with computer interfaces via artificial intelligence" (HITTI, 2020).

Figure 13. Artificial neural network with chip.



Source: Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Artificial_Neural_Network_with_Chip.jpg

Neural Link captures a new aesthetic sense of machine design and uses AI and neural networks that no doubt take inspiration from da Vinci and Turing, while pointing to new directions in human and artificial integration as we more fully enter the world of computational culture, merging real and artificial life (MCKIE, 2018).

Figure 14. Leonardo da Vinci, flying machine, metalpoint, pen and ink on paper, Institut de France, Paris, c.1487, Paris Codex b.

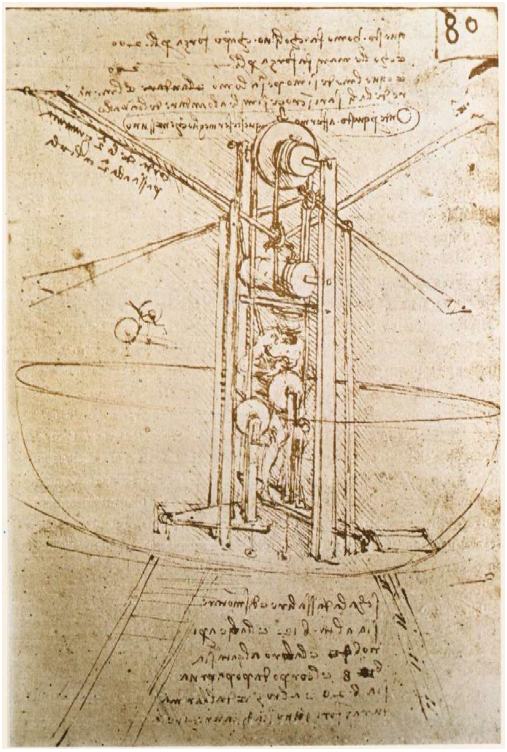


Figure Wikimedia Commons
https://commons.wikimedia.org/wiki/File:Leonardo_da_vinci,_Flying_machine.jpg

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Figure 15. A photograph of Turing's Bombe, and electro-mechanical machine on view at the Barbican Exhibition, London, AI More than Human, 16 July 2019. Photograph by T. Giannini.

A key aspect of the digital renaissance stems from changes we experience in our sense of time and space as we navigate present to past and into the future studying the 500 years of human thought and creativity since the death of da Vinci. Travelling via the computational landscape of the Internet and Web, we narrate history with new stories as we make new connections and comparisons of knowledge across centuries transmitted using digital media facilitated by the compressed nature of time and place in cyberspace – the past becomes our digital present acquiring an unexpected emotional power that fuels and sets into high gear a digital renaissance of diversity, equality and inclusion that is reshaping our world.

The Digital Mona Lisa

Through his paintings, Leonardo da Vinci goes beyond nature and ultimately changes the way we see ourselves as beyond human when our interaction with his paintings becomes intensely emotional, spiritual, and magical, as da Vinci melds reality, imagination and the science of painting. Creating a painting such as the *Mona Lisa*, considered by many to be the most valuable and loved painting in the world – yet simply the portrait of a woman – da Vinci goes beyond representation to a genre of augmented hyperreality.

The "digital" *Mona Lisa* stars in the database of her namesake, the Jocande database, which contains the digitized collections and documentation of the museums of France (http://www2.culture.gouv.fr/documentation/joconde/fr/pres.htm):

> The collective catalog of museum collections in France (Joconde database) is the result of a partnership between the museum service of France and the participating museums. Rich with nearly 600,000 records of objects of all kinds (archeology, fine arts, ethnology, history, sciences and techniques ...), this catalog is accessible to all. Themed tours, zooms and virtual exhibitions enhance this set.

Fig. 16. Mona Lisa by Leonardo da Vinci, Louvre Paris, oil on poplar panel, 1503-1505. Wikimedia Commons,

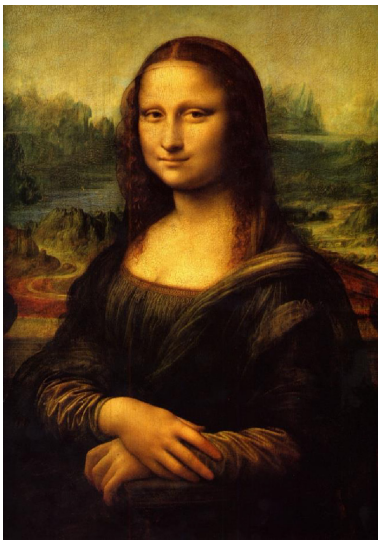

Figure Wikimedia Commons

Digital museum collections are serving growing numbers of the museum communities online and onsite from curators to visitors across a range of digital interaction, a subject which is taken up in-depth in the authors' book, Museums and Digital Culture (GIANNINI; BOWEN, 2019). With the advent of the coronavirus pandemic requiring museums temporarily to close their physical doors to the public, more than ever museums are searching for effective ways to create virtual surrogates of exhibitions and tours, and other museum activities. Yet viewing the digital Mona Lisa compared to being onsite at the Louvre, standing before her "real" presence, still leaves one longing for the awe-inspiring experience of being in the physical gallery viewing da Vinci's masterpiece, although both become integrated in the mind's eye.

As noted above, for the Leonardo da Vinci exhibition at the Louvre in 2019 celebrating 500 years since his death, the Louvre created the concurrent exhibition, Mona Lisa: Beyond the Glass, that marked the museum's first use of VR (virtual reality) – La Jaconde meets digital! Happily, the VR show drew enthusiastic audiences as they watched Lisa become animated. Produced by HTV Vive Arts, the Louvre used the same company that created the popular VR experience for the Tate Modern's 2018 Modigliani exhibition in London, where visitors wearing VR headsets felt they were being transported back to 1920, seated in the artist's Paris atelier at 8 Rue de la Grande-Chaumière (GIANNINI; BOWEN, 2019). With the current pandemic environment, use of VR and AR (augmented reality) has grown significantly as museums seek to imagine new digital ways to open up the museum experience to the public more broadly and these two examples of museum VR experiences make a convincing case

Conclusion

In many ways Leonardo da Vinci and Alan Turing define what we now see as our postdigital information-rich world – a world in which the material and virtual, physical and digital states of being are becoming integrated – part of a living ecosystem at once natural, artificial, real and simulated, that can be unders-

tood across neural and digital networks that are fuelling the Digital Renaissance. Because da Vinci's notebooks were not publicly accessible until the late 19th, early 20th century, and their digitisation and online publication is a relatively recent development (MACCURDY, 1923), they are encouraging new research and public engagement that enables researchers to gain a deeper understanding and appreciation of his work.

Similarly, Turing gained wide recognition during World War II for his work on codebreaking, which lead to his stunning breakthroughs in computer science in the 1950s, while at the same time, being a gay computer scientist, he suffered the consequences of the UK's anti-gay legislation which in many respects lead to his untimely death in 1954. With the availability of the Turing Digital Archive at King's College, Cambridge, researchers and the general public now have access to some 3,000 documents online (TURING DIGITAL ARCHIVE, s.d.). Reading these documents is like hearing the words of Turing and his circle, as we gain a fuller understanding of his of thinking and can see that he envisioned current developments in AI and machine learning and was able to intuit the future of the field which is sparking new conversations and questions that open our mind to the inherent relationships of science, art, technology and culture. In this context a new social and cultural order is emerging.

With the embrace of diversity and individual identity, the legacy of da Vinci and Turing moves front and centre in the fields of HCI, art, and technology, as it sets the stage for what can be achieved in the Digital Renaissance of the 21st century, a revolution that still has some way to go. Both da Vinci and Turing were intense observers of the natural world, inspiring them in Science (BOWEN, 2012) and art. These newly found relationships of postdigital thinking are integrating machine and human learning, so that increasingly, natural and artificial life inhabit

Acknowledgements

This paper has taken inspiration from a recent book (GIANNINI; BOWEN, 2019) and previous EVA London Conference on *Electronic Visualisation and the Arts* papers (2016; 2017; 2018; 2019) .The paper has an associated sister paper (GIANNINI; BOWEN, 2021) in the EVA London 2020 conference proceedings (WEINEL, J.,et al. Eds., 2010) [54]. Thank you especially to Vito Cappellini of EVA Florence for encouragement in writing a shorter initial conference version of this paper (GIANNINI; BOWEN; 2020). We dedicate this paper to all those involved with EVA Florence and EVA London in these difficult times. We also specifically dedicate this paper to Kim Veltman, friend of EVA, historian of art and science, and a scholar of Leonardo da Vinci (VELTMAN; KEELE, 1986), who sadly succumbed to COVID-19 on 1 April 2020. Jonathan Bowen is grateful to Museophile Limited for financial support.

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