CAN COMPUTERS THINK FOR THEMSELVES?

A STUDY ON TO WHAT EXTENT A COMPUTER IS CAPABLE OF ORIGINAL THOUGHT, THE IMPACTS THIS MAY HAVE ON THE FIELD OF MATHEMATICS, AND HOW OUR FUTURE ACCESS TO RESOURCES MAY CHANGE THIS OUTCOME

By Amy Barnhouse

THE BASIS OF THIS DISCUSSION

The debate surrounding the extent of a computer's abilities has been long-standing, with strong opinions from philosophers, engineers and mathematicians arguing for or against the development of human-level intelligence. The argument extends further than the mere possibility of this occurrence, towards the questioning of *if* it happens, whether it would be beneficial to humanity. The catalyst to rapid technological growth was Alan Turing, who in his 1950 paper suggested a machine could be made to think for itself.[1] Turing made responses to objections to his idea, many of which have since been seen as weak or invalid. However, Lady Lovelace's Objection is one that remains still significant today and relates to the question being asked in this essay, implying that a machine can "never do anything really new." Researchers have taken this challenge and worked in separate ways over the last few decades to prove or disprove this belief. One such method commonly used today is the implementation of neural networks, modelling an algorithm in an analogous way to the human brain. However, there have been doubts about neural networks, including concerns about the resources currently available and a quantum limit to computer power. This paper aims to come to a conclusion about a computer's ability to think, or at least guide the reader to a point of view founded upon reliable data.

THE PHILOSOPHER'S DEBATE

For the ability of Artificial Intelligence to be assessed, one must first question what exactly is being asked. When Alan Turing first posed the question "Can machines think?" ("Artificial Intelligence in Society | en | OECD") (Turing, 1950) he says that the terms 'machine' and 'think' should first be defined. For centuries, the true nature of the mind has been puzzled over by philosophers and scientists alike. Greek polymath Aristotle wrote in 350BCE [2] that intellectual activity is impossible without an image or form of memory, whilst Islamic philosopher Razi proposed in the 10th century that the brain is non-physical and immortal[3]. Numerous theories have come and gone over time, but one which stands out as most relevant to this case is the Classical Computational Theory of Mind (CCTM)[4].

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[1] Turing A. M. 1950, 'Computing Machinery and Intelligence'. *Mind Vol LIX Issue 236,* accessed 17th February 2022

[2] Aristotle 350 B.C.E., 'On Memory and Reminiscence'. *The Internet Classics Archive,* accessed 26th August 2021

[3] Ivry, A 'Arabic and Islamic Psychology and Philosophy of Mind'. *The Stanford Encyclopaedia of Philosophy,* accessed 26th August 2021

[4] Milkowski, M 'Computational Theory of Mind'. *Internet Encyclopaedia of Philosophy,* accessed 26th August 2021

CCTM suggests that the mind can be treated as a computational system[5] like a Turing machine (a hypothetical computer that performs calculations using an infinite tape and tape head that reads and writes to it[6]). With this approach, one may believe it to be more possible to replicate the human mind in a computer as their layouts are similar. This idea rose to popularity in the 1960s and 70s, after being suggested by McCulloch and Pitts in 1943, at a time when AI (Artificial Intelligence) advancement was rapidly progressing. During this 'Golden Age' (Woolridge, 2018), efforts were made to program computers that could communicate in natural conversation with humans. A significant breakthrough occurred in 1972 when Terry Winograd wrote SHRDLU, a robot that moved around objects in a virtual BLOCKS world. SHRDLU could fluently type in English and answer questions, but unfortunately, it could not understand the meaning behind its actions and such rich language processing was only possible in a microworld. Winograd's success could not be translated into reality.[7]

Disappointing results such as this one has been seen countless times throughout AI development, where promises have not come to fruition. Whether this is due to an overestimation of AI's ability,[8] or that the right approach has not yet been taken, is still to be determined.

In Alan Turing's 1950 paper 'Computing Machinery and Intelligence', the mathematician proposed an Imitation Game, now commonly called the Turing Test, to assess the ability of a computer to mimic a human. The game consists of three players: a human (player A), a machine (player B), and an interrogator who asks A and B questions. The interrogator's task is to figure out who is the machine and who is the human.[9] Turing hoped that by the year 2000 "an average interrogator will not have more than 70 percent chance of making the right identification after five minutes of questioning" due to large advancements in computational logic and engineering. However, there have been mixed opinions regarding the accuracy of the test and its suitability for testing AI. Researcher Robert French called the Imitation Game "virtually useless" for testing machine intelligence unless a computer has lived and "experienced the world" like a human has.[10] On the other hand, philosopher Hubert Dreyfus thought the test was "just what was needed"[11] , demonstrating the mixed views on Turing's assessment. Though suggestions have been made for better tests, it can clearly be seen how difficult it is to construct a suitable assessment for a machine to test its ability of being something which it is not. The richness of humanity, with its diverse ethnic cultures, has proven to be something difficult to artificially reproduce, since Turing's goal for 2000 has still not been met by 2022. Perhaps a universal model is too unrealistic since there is no 'universal human'.

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[5] Rescoria, M 2020 'The Computational Theory of Mind'. *The Stanford Encyclopaedia of Philosophy,* accessed 26th August 2021

[6] Moore K et al., 'Turing Machines'. *Brilliant.org,* accessed 28th August 2021

[7] Copeland, B J 2020, 'Artificial Intelligence'. *Encyclopaedia Brittanica,* accessed 28th August 2021

[8] Fjelland, R 2020 'Why artificial intelligence will not be realized'. *Humanit Soc Sci Commun,* accessed 28th August 2021

[9] Oppy, G et al. 2021, 'The Turing Test'. *Stanford Encyclopaedia of Philosophy,* accessed 21st February 2022

[10] French, R. M.1990 'Subcognition and the Limits of the Turing test'. *Mind Vol XCIX issue 393,* accessed 21st February 2022

[11] Dreyfus, H, 1992 'What Computers Still Can't Do' pg. 73. *MIT Press,* accessed 23rd February 2022

A strong philosophical argument against Turing's belief came from John Searle's analogy of the Chinese Room. For contextual purposes, a brief summary of the argument is as follows:

Picture a man inside a room. He is a native English speaker. The man is passed a sheet with Chinese words on it through a door. The man does not have any knowledge of the Chinese language. The man is then passed another sheet with Chinese words, along with a set of instructions written in English to follow. The man is shown how to write responses to the first sheet using the second sheet. The man passes his response back through the door.[12]

This story in essence describes the workings of a digital computer. The computer understands through the programs that it runs, allowing it to process requests from an input and produce an output. In this case, the man does not realise that the first sheet was asking him questions and the second sheet were model answers, but he was able to respond using the instructions made in his native language, English. Searle argues that there is no actual computer understanding even for complex operations like a translation.[13] Despite this convincing argument, there is reason to belief that models have changed since it was made in 1980, and with machine learning gaining traction computer scientists are leaving room in their programs for computers to learn and improve their decision making. Still, could these improvements in computer accuracy be because of better algorithms that merely give the illusion of intelligence?

METHODS OF MACHINE LEARNING

As briefly proposed, the overall aim of computer scientists who want thoughtful AI is to create Artificial General Intelligence (or AGI) and there have been several ways that this has been tried since Turing's claim that machines will be able to think consciously in the future. As previously mentioned, the Golden Age of AI in the 1960 and 70s caused great excitement amongst computer scientists, as great progress was made in communication between machines and humans. SHRDLU appeared to demonstrate an understanding of rich human dialogue, carrying out commands within BLOCKS World.[14] Similarly, the robot SHAKEY could understand its surroundings and move within a microworld, pushing objects as instructed by a remote computer.[15] Whilst the respective designers behind these systems, Terry Winograd and Bertram Raphael, made important contributions to computing through the breakthroughs in robotics and coding, both had to make considerable simplifications to the environments for the programs to run as well as they did. This realisation introduced the issue of 'computational complexity,' in which for certain problems a computer can quickly determine if it is solvable, but it takes substantial amounts of time to solve it.[16] These models could not be translated into the real world. With unsuccessful attempts in creating generalised AI without any experience in specific areas, it was clear something needed to change. Following the so-called 'AI Winter ', complex systems such as MYCIN (Shortliffe, 1975) were knowledge-based experts in niche areas such as blood diseases, being able to rival humans in their accuracy of diagnosis and treatment in quantitative and qualitative decisions. In the more recent past and now present, the preferred method of training AI is through the

[12] Searle, J. R. 1980 'Minds, brains and programs'. *Behavioural and Brain Sciences,* accessed 23rd February 2022

[13] Oppy, G, et al. 2021. See footnote no. 9

[14] Woolridge, M 2018 'Artificial Intelligence' pg. 16. *Ladybird books ltd.,* read 18th February 2022

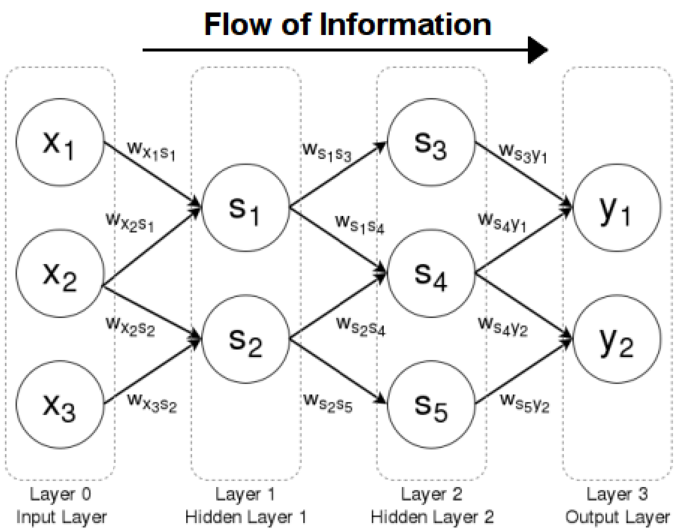
[15] Copeland, B. J. 2020. *See footnote no.7*

[16] Woolridge, M 2018, 'Artificial Intelligence' pg. 20. *Ladybird books ltd.,* accessed 18th February 2022

implementation of neural networks and deep learning, a method that has brought greater success in providing an answer to the question of AI's ability to generate thought. For example, DeepMind's Alpha Go beat the human Go champion in 2016 and IBM's Deep Blue beat the world chess champion Gary Kasparov in 1996.[17]

Artificial neural networks (ANNs) model the brain's neuron structure in the hope that intelligence in humans stems from this design, while also providing a greater understanding of the human body.[18] These models contain input and output nodes, with hidden layers in between to compute the data. The term 'deep learning' refers simply to neural networks which contain more hidden layers to improve AI reasoning. AI uses Bayesian reasoning to evaluate executed actions to choose a response which is best suited to the situation with reduced uncertainty.[19] A clear limitation to the neural net approach is the current lack of understanding of the human brain, meaning that a replica of human thought-processing is not possible. This could potentially invalidate arguments from the CCTM since the brain is more than a series of logic gates and algorithms.

There are numerous deep learning models being used in practice to train AI, each with varying levels of success. One such model is the feedforward neural network. This is a network containing multiple perceptrons, algorithms which produce a binary output by producing a straight line where either side of the line represents a class (e.g., 1 or 0).[20] As indicated by the name, information in a deep feedforward network only moves in one direction, through different hidden layers composed of many perceptrons. This is shown in the figure A below. The aim is to produce an output that equates to its actual value. Deep feedforward networks appear promising to help achieve general AI, since they perform well with large datasets.[21]



A) Feedforward neural networks, Brilliant.org

[17] Tegmark, M 2017, 'Life 3.0' pg. 51. *Penguin Books,* read 17th February 2022

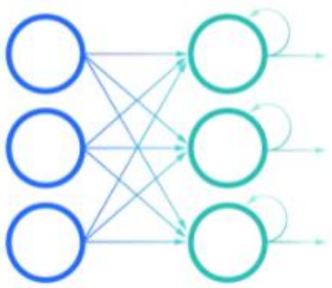
[18] Goodfellow, I et al 2016, 'Deep Learning' chapter 1. *MIT Press,* accessed 18th February 2022

[19] Korb, K. B. et al 2003, 'Bayesian Artificial intelligence', pg. 3. *CRC Press,* accessed 18th February 2022

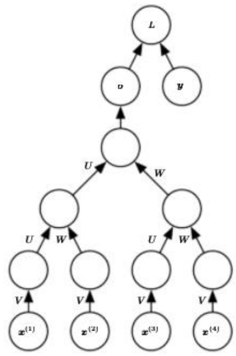
[20] Padmanabha, A et al., 'Perceptron'. *Brilliant.org,* accessed 19th February 2022

[21] Goodfellow, I et al. 2016, 'Deep Learning' chapter 6. *MIT Press,* accessed 19th February 2022

Feedforward neural networks were first developed in the 1950s, but since then improvements have been made to the model, such that in the 1980s a new method rose to popularity: recurrent neural networks (or RNNs). RNNs are similar in process to feedforward networks but allow for information to flow in more than one direction. This has been beneficial towards more accurate language processing since the algorithm is able to take information which has previously been given, or which will be given in the future, to form some context around the scenario and give a suitable response accordingly.[22] RNNs can interpret any data that comes in a sequence, such as speech, text, or translation. However, they do have an issue with retaining past information when computing long sequences, so altered models are required to reduce this. Recursive neural networks operate in a comparable way to RNNs, but have a tree structure, allowing for less dependency on previous operations.[23]



B) A recurrent neural network, IBM Cloud Education



C) A recursive neural network, Deep Learning Book

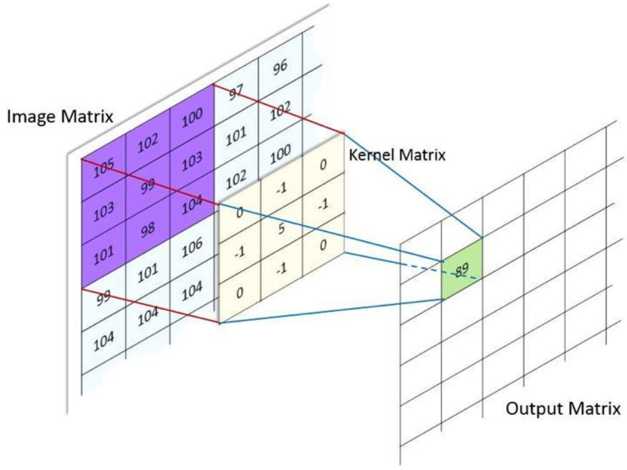
Convolutional neural networks (or CNNs) are another form of deep learning model, used when dealing with other data types which exist in a grid form. For example, images are made up of small square-shaped pixels that form a large grid. They are useful in supporting object recognition and classification software.[24] Therefore, CNNs could be used to help machines *understand* their surroundings to a similar level to humans, allowing them to think without added human support. The main elements of a CNN are the convolutional layers, the pooling layers, and the fully connected layer. In a convolutional layer, a matrix of a section of the image is taken (e.g., a 3x3 grid) and then combined with a kernel, a matrix used to sharpen the image, to produce a single value which takes the place in a new grid. See figure D below. This is repeated multiple times, each layer making the image quality more precise. Then the image is pooled, selecting the maximum value from smaller split-up groups. The final layer, the fully connected layer, produces a set of possible object identifications based on the output matrix produced.[25] CNNs are currently used in popular social media apps such as Snapchat to create facial and environmental filters. With further developments, these models have the potential to learn to recognise objects with more accuracy and use this to interact with the surroundings.

[22] 2020 'Recurrent Neural Networks'. *IBM Cloud Education,* accessed 20th February 2022

[23] Goodfellow, I et al. 2016 'Deep Learning' chapter 10. *MIT Press,* accessed 20th February 2022

[24] 2020 'Convolutional neural networks'. *IBM Cloud Education,* accessed 19th February 2022

[25] Hirschkind, N et al., 'Convolutional Neural Network'. *Brilliant.org,* accessed 19th February 2022



D) Convolutional neural network, Brilliant.org

Some of the most common and effective neural network models have been outlined above, with their most common applications described. As seen so far, computer systems are not advanced enough to make human decisions and perform human actions to a complete standard. Current research appears promising, but there are still factors yet to be considered.

THE PROBLEM CONCERNING TECHNOLOGICAL DECLINE

In 1965, Gordon Moore suggested that the number of transistor devices on integrated circuit chips doubled every two years and predicted that this would continue for years to come. In fact, up until a few years ago, this has held true,[26] a pattern becoming commonly known as Moore's Law. However, calculations by physicist James Powell in 2008 show a quantum limit to Moore's law as the year 2036. This estimate was made by computing the maximum computer power with electrons as the smallest elements on IC chips.[27]

A quite fascinating point in AI's evolution called the Singularity, or **S**, works upon the basis that the intelligence of AGI will rapidly increase to a point unfathomable to humans.[28] The stages of **S** are a result of the human development of AI and are shown as follows

1. *There will be AI (created by HI (Human Intelligence) and AI = HI)*
2. *There will be AI+ (created by AI)*
3. *If there is AI+, there will be AI++ (created by AI+)*

*Conclusion: There will be AI++ (AI++ = **S**)*[29]

where the progression of AI to AI+ to AI++ represents the increase of machine intelligence, initially equal to that of a human but growing to an incomprehensible super-intelligent being, being made possible if AI can produce a version of itself which is smarter than humans.

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[26] McCullough, I 2017 'Has Moore's Law Held Up Over the Last Five Years?'. *Forbes,* accessed 26th August 2021

[27] Powell, J. R. 2008 'The Quantum Limit to Moore's Law'. *Proceedings of the IEEE Vol 96 Issue 8,* accessed 20th February 2022

[28] Bringsjord, S and Govindarajulu, N 2020 'Artificial Intelligence'. *The Stanford Encyclopaedia of Philosophy,* accessed 31st December 2021

[29] Chalmers, D 2010 'The singularity: A philosophical analysis'. *Journal of Consciousness Studies 17,* accessed 31st December 2021

To achieve this, sufficient materials are needed, and new research suggests that more is required to replicate the human brain than just a neural network. The cemi-field theory of consciousness is the idea what when a neuron fires in the brain, some EM (electromagnetic) radiation is emitted, creating an electromagnetic field around the brain. These waves have been found to have the ability to encode information, suggesting that they could have a role in how humans think.[30] Current computer chips do not work well with EM radiation as it can disrupt the signal, so new computer design may be required, which communicates between the hardware and the EM field, to bring about AGI. In addition, if there is a physical limit to computer power, there is a possibility that engineers will not have the resources to build AI.

THE LONGEVITY OF THE HUMAN MATHEMATICIAN

The abilities of potential AGI have reached a vast range of outcomes, but one of the most significant is the question of whether the ‘created’ can replace its creator. More specifically, will the dawn of super-intelligence render mathematicians, the minds behind computer logic and algorithms, obsolete?

The renowned mathematician G. H. Hardy said in 1940 that “a gift for mathematics is one of the most specialised talents”[31], suggesting that to succeed at the subject to a high standard, an element of creativity is required as well as the skills of analysis and numerical accuracy. This creativity is needed for problem-solving and developing new theorems or methods, which needs a novel approach. Any so-called ‘deep' mathematics has some aspect of originality to have a substantial impact in the field.[32] In line with this view, computers will require an imagination to fill the role of a mathematician to a worthy standard.[33]

At the time of writing, machines have since been shown to effectively aid humans in producing art and presented other signs of artistic expression.[34] Original works of art have been produced by AI using large data sets containing thousands of pictures, from which the computer gains ’inspiration’ and develops new paintings through the detection of colour combinations and patterns commonly used. Computers are capable of this due to a Generative Adversarial Network (GAN), an algorithm developed by machine learning researcher Ian Goodfellow, which teaches AI to produce a new data set, which has equivalent properties to the training set inputted, but is entirely generated by the machine.[35] This method has been applied in other ways, such as in the composition of new music melodies which appeal to popular audiences. IBM’s Watson AI has analysed years of songs and text conversations to produce the Watson Beats original series of melodies.[36] On the other hand, this could be seen

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[30] McFadden, J 2021 ’Brain Wi-Fi’. *Aeon magazine,* accessed 14th July 2021

[31] Hardy, G.H. 1940 ’A Mathematician’s Apology’ p.70. *Cambridge University Press*, read 23rd December 2020

[32] Budd, C 2018 ’Will machine learning replace mathematicians?’. *Plus Maths Magazine,* accessed 15th February 2021

[33] du Sautoy, M 2019 ’The Creativity Code’ p.7. *Fourth Estate,* read 26th December 2021

[34] Marr, B 2020 ’Can Machines and Artificial Intelligence be Creative?’. *Forbes,* accessed 16th February 2021

[35] Goodfellow, I 2014 ’Generative Adversarial Nets’. *Advances in neural information processing systems,* accessed 26th December 2021

[36] Bixenspan, D 2016 ’The Next Trick for IBM’s Watson? Composing Music’. *Vice,* accessed 26th December 2021

as not an act of originality, but an observation of patterns in data which have been emulated through logic.

The reader should also be reminded of the alternative view on humanity's creativity, that we are not original ourselves[37], but repeat things already seen in a separate way. If this is true, then one may be led to believe that, with time and evolution, computers should eventually be capable of the same level of ingenuity as any other human, regardless of biology or physiology. However, there are milestones in our evolution such as the harnessing of electricity or development of aerospace engineering, feats which show such originality, that make it difficult for one to accept this argument as significantly valid or strong in comparison to the numerous ones already made.

With current technologies and materials to hand, computers have only gone as far as been aides to the work of mathematicians. In 1998, Thomas Hales and Sam Ferguson announced a proof of the Kepler Conjecture, which states that 'No packing of congruent balls in Euclidean three space has density greater than that of the face-centred cubic packing'.[38] This proof required a rigorous approach to ensure that no configuration existed which was more efficient for packing spheres, so Hales made use of computer programs to speed up the process, as predicted by Fejes Tóth in the 1950s.[39] The outcome was complex and tiresome to verify by mathematicians, but a revised proof was published in 2017 with a formalised description of both the computer calculations and text code accompanying it.[40] This could be seen as the beginning of AI's journey to becoming capable of defining and proving mathematical theorems, shown by its contribution to a proof of an unsolved statement made in 1611.[41] However, others saw it as a sign that computers are unsuited to take on the role of mathematician. Michael Harris of Columbia University said 'even if computers understand, they don't understand in a human way'[42], implying that though the ability of a machine should not be underestimated, there could never be a true communication between them and humans. A clearer example of this is evident in a proof for the Four Colour Theorem, which states that any map in a plane can be coloured using four colours such that no areas sharing a boundary have the same colour.[43] The proof put forward by Kenneth Appel and Wolfgang Haken in 1976 required a computer to check 1476 possibilities over 1,000 hours after the rest were proven algorithmically. For this reason, many mathematicians do not accept this proof

[37] Klingemann, M, quoted by Miller, A 2019 'Can machines be more creative than humans?'. *The Guardian,* accessed 16th February 2021

[38] Hales, T 1998 'A proof of the Kepler conjecture'. *Annals Of Mathematics 162,* accessed 29th December 2021

[39] Ornes, S 2020 'How Close Are Computers to Automating Mathematical Reasoning?'. *Quanta Magazine,* accessed 15th February 2021

[40] Hales, T et al 2017 'A FORMAL PROOF OF THE KEPLER CONJECTURE'. *Forum of Mathematics, Pi Vol. 5,* accessed 29th December 2021

[41] Weisstein, E 'Kepler Conjecture'. *MathWorld- A Wolfram Web Resource,* accessed 29th December 2021

[42] Harris, M quoted by Ornes S. *See footnote no. 18*

[43] Weisstein, E 'Four-Color Theorem'. *MathWorld-A Wolfram Web Resource, accessed 29th December 2021*

as valid, since some of the computer logic is not understandable to humans so cannot be proven entirely true.[44]

Despite thoughts that a lack of creativity prohibits computers from obtaining automating mathematical reasoning, some progress has been made in the cause. To speed up the validation of proofs for new potential theorems, computerized theorem provers have grown in popularity, favoured over the laborious task of humans reviewing them by hand.[45] These are either automated theorem provers (ATPs) or interactive theorem provers (ITPs), the latter presented in a more human-readable and assistant-like manner, whilst the former makes use of axioms and previous proofs to independently ratify.[46] As stated by Leibniz, "It is unworthy of excellent men to lose hours like slaves in the labour of calculation which could safely be relegated to anyone else if machines were used"[47], and these provers are helping to realise it. While some mathematicians reject the idea of not performing calculations with pen and paper, others see it as an opportunity to teach undergraduate students the correct way to write a proof through the analysis of computer outputs.[48] This results from theorem provers being designed to be more concise and clearer to other mathematicians.

Not only this, but Markus Rabe from Google research has also led a team on developing an ATP that produces and proves a theorem, using neural networks. Out of the conjectures produced by the model by itself, 12.7% of them were new and provable.[49] This finding suggests that through the combining of neural networks with current ATPs and ITPs, machines can generate innovative ideas when given enough examples to follow, or 'gain inspiration' from. While computers may not yet have the ability to take on the job of a mathematician, though at the current rate they will in decades to come, they can certainly be seen as a valuable tool.

AN ANALYSIS OF TURING'S PREDICTIONS

More than seventy years have passed since Alan Turing published 'Computing Machinery and Intelligence' in the philosophy journal MIND, yet the majority of what was said is still relevant to the field of computing. Turing inspired many things which have advanced current knowledge of AI further. At the end of the 1950 paper, he says:

"We may hope that machines will eventually compete with men in all purely intellectual fields. But which are the best ones to start with? Even this is a difficult decision. Many people think that a very abstract activity, like the playing of chess, would be best."[50]

Could this suggestion of building a chess-playing machine have motivated the making of IBM's Deep Blue computer which beat Garry Kasparov, the chess world champion at the

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[44] Xiang, L 2009 'A formal proof of the four-color theorem'. *ArXiv,* accessed 29th December 2021

[45] Ornes, S 2020. *See footnote no.18*

[46] Portoraro, F 2021 'Automated Reasoning'. *The Stanford Encyclopaedia of Philosophy,* accessed 30th December 2021

[47] Leibniz, G 1765 'New Essays on Human Understanding'. *Cambridge University Press,* read 30th December 2021

[48] Doré, M 2017 'ELFE-An interactive theorem prover for undergraduate students'. *Imperial College London undergraduate archive,* accessed 30th December 2021

[49] Rabe, M 2020 'Mathematical Reasoning via Self-supervised Skip-tree training'. *ArXiv,* accessed 30th December 2021

[50] Turing, A 1950 'Computing Machinery and Intelligence' *see footnote no. 1*

time, in 1997? Either way, the achievement led to others, including AlphaGo's victory over Go champion Lee Sedol. Despite seeming minute compared to the overall goal of producing AGI, AlphaGo made moves that shocked even the experienced opponent, choosing to go against common practice in its 37th move, only for that to be the reason for winning fifty moves later.[51] This demonstrated the incredible improvements being made to machine learning, since many consider Go to be a difficult game of immense strategy. It seems machines can rival the human mind in at least one field, but growth had been significantly lower than expected.

Lady Lovelace's Objection in Turing's 1950 paper makes the argument that a machine only does what it is asked, so there are no original ideas. This seems somewhat questionable when considering the way in which computers are trained today. With the popularity of RNNs running systems, it is supposed that what the machine is being asked in this case *is* to learn. Evidence described here and seen elsewhere has demonstrated that when given the option or incentive to do so, a computer will repeat a process until it improves on the subject, *learning* from its past errors. In some cases, such as the Go match between AlphaGo and Lee Sedol, the machine did take its designers by surprise. There are 10^{360} possible combinations, making it practically impossible to work through every possibility algorithmically. Through identifying patterns in the movements, AlphaGo made an unexpected move which ultimately led to its success.[52]

TO CONCLUDE THE DISCUSSION

This essay set out to investigate the true ability of a computer to *be* human. More specifically, the intent was to find out if a computer can be innovative, producing new ideas without human help. By not defining a timeline alongside my question, I have enabled the scope of the study to reach across past, present, and future advancements. It is clear from all the topics discussed that AI has improved immensely since its conception in 1950 by Alan Turing, but to which extent is more complex to define.

Has Turing's vision been brought to life? Can computers think for themselves? Well, not yet, but I believe it soon will be. In many of the areas discussed here, people who were at first hesitant are now hopeful, and those who have been working from the start have made noteworthy progress in bringing about AGI.

As said at the start, it is up to the reader to make their decision, but I believe human-level intelligence will impact our lives in the next 10 years.

[51] Tegmark, M 2017, 'Life 3.0' pg.88.'. *Penguin Books,* read 17th February 2022
[52] Koch, C 2016 'How the computer beat the Go master'. *Scientific American, accessed 23rd February 2022*