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Will recent advances in AI result in a paradigm shift in Astrobiology and SETI?

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Abstract

The steady advances in computer performance and in programming raise the concern that the ability of computers would overtake that of the human brain, an occurrence termed 'the Singularity'. While comparing the size of the human brain and the advance in computer capacity, the Singularity has been estimated to occur within a few decades although the capacity of *conventional* computers may reach its limits in the near future. However, in the last few years, there have been rapid advances in artificial intelligence. There are already programs that carry out pattern recognition and self-learning which, at least in limited fields such as chess and other games, are superior to the best human players. Furthermore, the quantum computing revolution, which is expected to vastly increase computer capacities, is already on our doorstep. It now seems inevitable that the Singularity will arrive within the foreseeable future. Biological life, on Earth and on extraterrestrial planets and their satellites, may continue as before, but humanity could be 'replaced' by computers. Older and more advanced intelligent life forms, possibly evolved elsewhere in the Universe, may have passed their Singularity a long time ago. Post Singularity life would probably be based not on biochemical reactions but on electronics. Their communication may use effects such as quantum entanglement and be undetectable to us. This may explain the Fermi paradox or at least the 'Big Silence' problem in SETI.

Introduction

Recent major breakthroughs in computing and artificial intelligence (AI) may change human existence on Earth and our thinking in astrobiology, especially in relation to the Search for Extraterrestrial Intelligence (SETI).

Estimates of the values of the terms in the well-known Drake formula, which puts together the chances for contact with intelligent life forms, have made great progress in the last decade. The Kepler mission provided estimates of the values of three factors in the equation, which until the Kepler mission were uncertain: the fraction of stars with planets, the average number of planets per star in the habitable zone and the fraction of Earth-size planets. These parameters, are now believed to be of order unity (e.g. Batalha *et al.*, 2013; Dressing and Charbonneau, 2015; Wandel, 2017).

Our main ignorance remains in the last three terms: (i) the chances for the evolution of biological life; (ii) the probability of intelligence and (iii) the lifespan of a technological communicating civilization. As may be inferred from the evolution of life on Earth, planets with primitive biological life may be quite abundant (Wandel, 2015; Gale and Wandel, 2017). However, if the last two terms were small, intelligent and communicating civilizations could be exceedingly rare (Wandel, 2017).

Complex life is a relatively recent development on Earth, where, for approximately 3.5 Gy (about a quarter of the lifetime of the Universe) only simple mono-cellular life appeared (Fig. 1). Life elsewhere may have evolved at a different rate. It is reasonable to assume that many instances of any intelligent life would be more advanced than humanity.

Science fiction is replete with humanoids, despite their short appearance on Earth. *Homo sapiens* has only been around for about 200 000 years, and advanced technology for only two centuries (Fig. 1). Science fiction authors have described advanced and even intelligent computers, nearly always stopping at the inability of computers to carry out advanced pattern recognition, the basis of intelligent thinking. For this, a huge computing ability is considered essential, as in the human brain.

Moore's law

In the last few decades many scientists, futurists and Science Fiction authors have proposed that in the near future computers would have the same calculating capacity as human brains, which have $\sim 10^{11}$ neurons, each connected to thousands of synapses. This proposition has

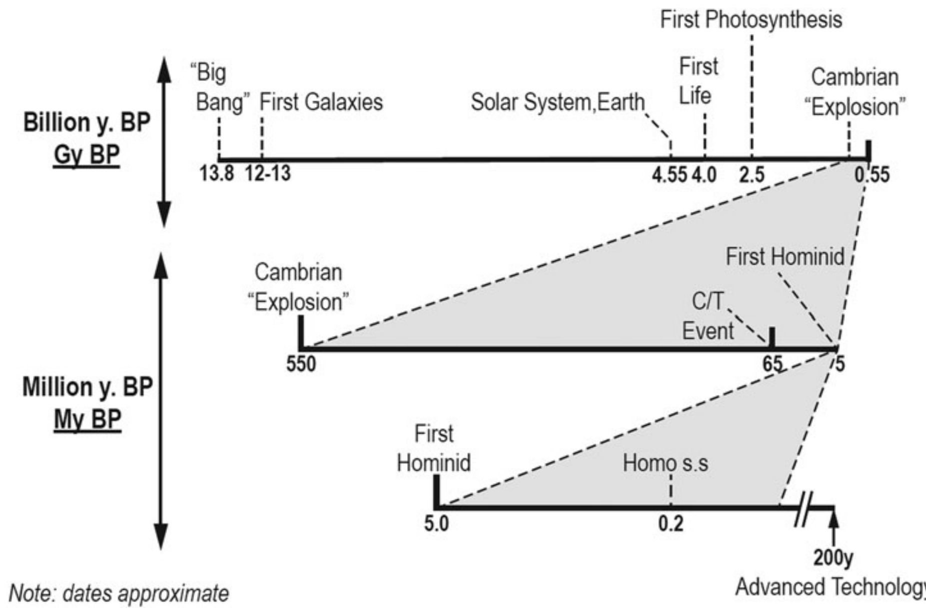

Fig. 1. Time line for the evolution of life on Earth. Data from Lyon *et al.* (2014) and elsewhere.

been based on projections of 'Moore's law' of the evolution of computers. This is an observation that the number of transistors in integrated circuits doubles about every 2 years (Moore, 1965). Remarkably, that prediction has held till today, 50 years later (Fig. 2). This advance has probably reached its almost inevitable limit, as a result of the nano-meter size of today's transistors and the impossibility of providing electrical insulation at this scale (Hennessey and Patterson, 2019). However, with the development of quantum computers, even this limit appears to be passable.

Vernor Vinge, a mathematician and science fiction author, introduced the term 'Singularity' to describe the convergence of the capacities of the human brain and computers (Vinge, 1993). This term was previously used in mathematics and natural sciences to describe a point where some quantity becomes infinite, or ill behaved. In the context of the advance of technology, the concept received support from eminent polymath John von Neumann, quoted as saying that 'the singularity will be reached when technological progress becomes incomprehensively rapid and complicated' (Shanahan, 2015). The 'Singularity' concept[1] and its possible consequences were popularized by the futurist author Ray Kurzweil in his book 'The Singularity is near' (Kurzweil, 2005). Extrapolating Moore's 'Law', he estimated that this event would occur in about 2050. Others have suggested that it may come even earlier if quantum computers are realized.[2]

Brains

Neurologists have long been pointed out the poor correlation between brain size and advanced thought. Some collated data on the relative sizes of different animal brains (here, the number of neurons) are shown in Table 1 (data collated from Herculano-Houzel, 2009 and elsewhere).

As apparent from the number of neurons (Table 1), brain size is not well correlated with intelligence. For example, humans have less than half the brain size of the not very intelligent elephants. Of particular significance is the very small brain capacity of insects; here e.g. bees. With just 1 million neurons, bees carry out: Flight; Navigation; Hunting and Gathering; Communication with other bees; Social organization; inheritable home Architecture; preparation of hive Emergency Procedures, etc. (for numerical ability in bees, see Howard *et al.*, 2018). Clearly, programming seems to be no less important than brain capacity.

Human brains have developed an extraordinary ability for pattern recognition, which has long been thought to be beyond the ability of computers.

Rapid advances in computers

Recently, computers have been catching up. In 1997, IBM's program Deep Blue beat reigning chess champion Gary Kasparov. However, it was mainly a victory for brute force and the use of a small number of preset strategies.[3] In 2016, the program AlphaGO, fortified with neural networks and learning modes, defeated Lee Sedol, the Go world champion.[4]

Recently, Google described 'Alpha Zero', a self-learning, pattern-recognizing, AI program (Silver *et al.*, 2018). Given just the basic rules of Chess, Shogi and Go, this program plays itself millions of times over, selecting and remembering the most favourable winning strategies. The program has beaten human masters in all three games, by using strategies *previously unknown to programmers*.

The Google program is predicted to be able to solve many hitherto almost intractable problems. For example, in Astronomy – searching data banks for enigmatic radio bursts, in Medicine – reviewing millions of combinations of illness-causing gene and intermediate interactions, as opposed to single-gene errors and in Meteorology – predicting weather patterns from huge data banks.

Brown and Sandholm (2019) have described an AI program, based on Neumann and Nash game theory, which challenges hitherto unbeatable multi-player poker games.

[1]https://en.wikipedia.org/wiki/Technological_singularity, retrieved 30.8.2019.
[2]https//singularityhub.com/2019/02/26/quantum-computing-now-and-in-the-not-too-distant-future, retrieved 31.8.2019.
[3]https//en.wikipedia.org/wiki/deep_blue_versus_gary_kasparov, retrieved 30.8.2019.
[4]https://en.wikipedia.org/wiki/AlphaGo_versus_Lee_Sedol, retrieved 30.8.2019.

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Fig. 2. Moore's law: the number of transistors per microprocessor versus time. Data taken from Rupp (2017). We have added the straight line, which shows exponential growth, doubling every 2 years.

Table 1. Some animal brain sizes

Number of neurons (in millions)	
Sperm whales	250 000
African elephants	207 000
Homo sapiens sapiens	86 000
Gorillas	33 400
Rattus rattus	103
Bees (Anthophila)	1

For many years, the concept of quantum-based computers has been predicted as a way forward, once the physical limits of transistors are reached. In theory, a quantum-based computer would be able to utilize an analogue characteristic of multiple positions between zero and one, a limitation of today's digital technology. Until recently, intrinsic difficulties caused by de-coherence, an instability due to the statistical nature of quantum phenomena, and the sensitivity of such computers to vibration, temperature fluctuations and external electromagnetic waves, have prevented practical realization. However, a combination of improved hardware and error reducing software has very recently promised to overcome these problems (Levine *et al.*, 2019; Niu *et al.*, 2019). It has been predicted that Quantum Supremacy, a term used to describe the point at which quantum computers will out-perform the largest digital computers, could be reached by the end of 2019 (Arute *et al.*, 2019).

These advances in computer capacity and AI suggest that the Singularity may indeed be imminent. It may not come in the very near future but it will arrive, eventually. When it does, *H. sapiens*, sapiens may move from the bio-chemical realm to the electronic, or to some hybrid combination, with hardly predictable implications for humans (Kurzweil, 2005).

While life appeared on Earth some 4 Gy ago, for 3.5 Gy only mono-cellular life existed. Complex life evolved only some 0.5 Gy ago, when a high oxygen atmosphere developed. *H. sapiens* sapiens appeared just 200 000 years ago, and advanced technology – only in the last two centuries (Fig. 1).

Consequences of the Singularity for astrobiology

The search for extraterrestrial biological life will probably continue along the present lines. Singularity only applies to advanced civilizations, and consequently to SETI. Since some putative extraterrestrial civilizations have probably had more time than us to evolve, they might have long passed their Singularity.

Once the Singularity is attained, optimal conditions for advanced, complex life may fundamentally change. We may find that the Universe is populated by autonomous, intelligent, space ships driven by quantum-computing devices. If future computers are anything like ours of today (of course they may be quite different), they may prefer dry, non-corrosive conditions, with low temperatures, which would provide a 'quiet' electronic environment and enable super-conductivity (Dougherty and Kimel, 2012). They would preferably operate not from the surface of 'habitable' planets but in space, perhaps parked in dynamically stable Lagrangian points. However, because of the huge interstellar distances, SETI would not be able to distinguish if broadcasts originated from a planet or rather from a Lagrangian point of the planet and its moon or sun.

If an alien civilization ever visited Earth long ago, it may have parked its beacons in one of the Earth-Moon or Sun-Earth Lagrangian points. An attempt to find such artefacts by photography was unsuccessful (Freitas and Valdes, 1980).

Furthermore, post-Singularity civilizations may not be communicating by radio waves but rather by quantum entanglement, which is only in its very first stages of development on Earth (Ursin *et al.*, 2007; Kumar *et al.*, 2019). This may provide yet another solution to the Fermi paradox, or at least to the Big Silence problem in SETI.

As for humanity's future, perhaps the superior brains of the new computers will solve Earth and humanities many problems. Science Fiction is replete with predictions, some reasonable, some disturbing, such as that mortality can be overcome by downloading the brain's contents to computers. In 2014, Stephen Hawkins stated in an interview[5] 'The development of full artificial intelligence could spell the end of the human race'. In other words, AI and the Singularity may be humanity's greatest and last advance.

References

Arute F, Arya K, Babbush R, Bacon D, Bardin JC, Barends R, Biswas R, Boixo S, Brandao FGSL, Buell DA, Burkett B, Chen Y, Chen Z, Chiaro B, Collins R, Courtney W, Dunsworth A, Farhi E, Foxen B, Fowler A, Gidney C, Giustina M, Graff R, Guerin K, Habegger S, Harrigan MP, Hartmann MJ, Ho A, Hoffmann M, Huang T,

[5]https://www.bbc.com/news/technology-30290540, retrieved 30.8.2019.

Humble TS, Isakov SV, Jeffrey E, Jiang Z, Kafri D, Kechedzhi K, Kelly J, Klimov PV, Knysh S, Korotkov A, Kostritsa F, Landhuis D, Lindmark M, Lucero E, Lyakh D, Mandrà S, McClean JR, McEwen M, Megrant A, Mi X, Michielsen K, Mohseni M, Mutus J, Naaman O, Neeley M, Neill C, Niu MY, Ostby E, Petukhov A, Platt JC, Quintana C, Rieffel EG, Roushan P, Rubin NC, Sank D, Satzinger KJ, Smelyanskiy V, Sung KJ, Trevithick MD, Vainsencher A, Villalonga B, White T, Yao ZJ, Yeh P, Zalcman A, Neven H and Martinis JM (2019) Quantum supremacy using a programmable superconducting processor. *Nature* **574**, 505–510.

Batalha NM, Rowe JF, Bryson ST, Barclay T, Burke CJ, Caldwell DA, Christiansen JL, Mullally F, Thompson SE, Brown TM, Dupree AK, Fabrycky DC, Ford EB, Fortney JJ, Gilliland RL, Isaacson H, Latham DW, Marcy GW, Quinn SN, Ragozzine D, Shporer A, Borucki WJ, Ciardi DR, Gautier TN, III, Haas MR, Jenkins JM, Koch DG, Lissauer JJ, Rapin W, Basri GS, Boss AP, Buchhave LA, Carter JA, Charbonneau D, Christensen-Dalsgaard J, Clarke BD, Cochran WD, Demory B-O, Desert J-M, Devore E, Doyle LR, Esquerdo GA, Everett M, Fressin F, Geary JC, Girouard FR, Gould A, Hall JR, Holman MJ, Howard AW, Howell SB, Ibrahim KA, Kinemuchi K, Kjeldsen H, Klaus TC, Li J, Lucas PW, Meibom S, Morris RL, Prša A, Quintana E, Sanderfer DT, Sasselov D, Seader SE, Smith JC, Steffen JH, Still M, Stumpe MC, Tarter JC, Tenenbaum P, Torres G, Twicken JD, Uddin K, Cleve JV, Walkowicz L and Welsh WF (2013) Planetary candidates observed by Kepler. III. Analysis of the first 16 months of data. *Astrophysical Journal Supplement* **204**, 24B, 24–45.

Brown N and Sandholm T (2019) Superhuman AI for multiplayer poker. *Science* **365**, 885–890. 10.1126/science.aay2400.

Dougherty R and Kimel JD (2012) *Superconductivity Revisited*. Boca Raton: CRC Press.

Dressing CD and Charbonneau D (2015) The occurrence of potentially habitable planets orbiting M dwarfs estimated from the full Kepler dataset and an empirical measurement of the detection sensitivity. *Astrophysical Journal* **807**, 45–67.

Freitas Jr RA, and Valdes F (1980) A search for natural or artificial objects located at the Earth-Moon libration points. *Icarus* **42**, 442–447.

Gale J and Wandel A (2017) The potential of planets orbiting red dwarf stars to support oxygenic photosynthesis and complex life. *International Journal of Astrobiology* **16**, 1–9.

Hennessey JL and Patterson DA (2019) A new golden age for computer architecture. *Communications of the ACM* **62**, 48–60.

Herculano-Houzel S (2009) The human brain in numbers: a linearly scaled-up primate brain. *Frontiers in Human Neuroscience* **3**, 1–11.

Howard SR, Avagues-Weber A, Garcia JE, Greentree AD and Dyer AG (2018) Numerical ordering of zero in honey bees. *Science* **360**, 1124–1126.

Kumar S, Lauk N and Christoph S (2019) Towards long-distance quantum networks with superconducting processors and optical links. *Quantum Science and Technology* **4**. doi: 10.1088/2058-9565/ab2c87.

Kurzweil R (2005) *The Singularity is Near: When Humans Transcend Biology*. U.S.A: Viking Press.

Levine Y, Sharir O, Cohen N and Shashua A (2019) Quantum entanglement in deep learning architecture. *Physical Review Letters* **122**. doi: 10.1103/PhysRevLett.122.065301.

Lyon TW, Reinhard CT and Planavsky NJ (2014) The rise of oxygen in Earth's early ocean and atmosphere. *Nature* **506**, 306–315.

Moore GE (1965) Cramming more components onto integrated circuits. *Electronics* **38**, 114–117.

Niu Y, Boixo S, Smelyanskiy VN and Neven H (2019) Universal quantum control through deep reinforcement learning. *npj Quantum Information* **5**, 33. htpps://doi.org/10.1038/s41534-019-0141-3.

Rupp K (2017) Our world in data. Available at https://ourworldindata.org/grapher/transistors-per-microprocessor?time=1971..2017.

Shanahan M (2015) *The Technological Singularity*. U.S.A.: MIT Press.

Silver D, Hubert T, Schrittwieser J, Antonoglou I, Lai M, Guez A, Lanctot M, Sifre L, Kumaran D, Graepel T, Lillicrap T, Simonyan K and Hassabis D (2018) A general reinforcement learning algorithm that masters chess, Shogi and Go, through self-play. *Science* **362**, 1140–1144.

Ursin R, Tiefenbacher F, Schmitt-Manderbach T, Weier H, Scheidl T, Lindenthal M, Blauensteiner B, Jennewein T, Perdigues J, Trojek P, Ömer B, Fürst M, Meyenburg M, Rarity J, Sodnik Z, Barbieri C, Weinfurter H and Zeilinger A (2007) Entanglement-based quantum communication over 144 km. *Nature Physics* **3**, 481–486.

Vinge V (1993) Technological Singularity. *Vision-21, NASA symposium*. Available at https//frc.ri.cmu.edu/~hpm/books98/com.chl/vinge.singularity.html.

Wandel A (2015) On the Abundance of extraterrestrial life after the Kepler mission. *International Journal of Astrobiology* **14**, 511–516.

Wandel A (2017) How far are extraterrestrial life and intelligence after Kepler? *Acta Astronautica* **137**, 498–503.