The early history & future implications of self-reproducing and evolving robots

Tim Taylor

Monash University, University of London & Independent Researcher

tim@tim-taylor.com @drtimt "Oh my goodness, shut me down! Machines making machines – how perverse!"

C-3PO, Star Wars: Episode II Attack of the Clones (2002)

"We realized that the true problem, the true difficulty, and where the greatest potential is — is building the machine that makes the machine"

Elon Musk, Tesla Annual Shareholder Meeting (2016)



If we had a machine that could build more copies of itself...

Then, for a fixed capital outlay (the cost of designing and building *one* machine), we could get exponentially increasing production and returns:

- Harvest for production of valuable materials or energy (at macro-, micro-, or nano-scales)
- Very desirable for mining off Earth (e.g. asteroids, moons) launch costs massively reduced
- In the far future, a means of allowing humankind to colonise other worlds

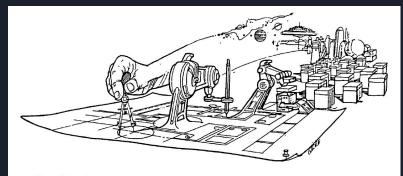


Figure 5.1. - Automated space exploration and industrialization using self-replicating systems.

Image from NASA report by Freitas & Gilbreath (1982)

Many risks!

- Causing an environmental disaster
- Mutating and evolving



The Theory of Self-Reproducing Automata

John von Neumann put the subject on a firm theoretical grounding in the late 1940s and early 1950s

Showed it was logically possible to build a machine that could build another copy of itself...

...or that could build something more complicated than itself



The (much) earlier history of the idea of self-reproducing machines

Four major steps in the development of the idea of self-reproducing machines

- The idea that animals can be understood as machines → so some machines can reproduce? Rene Descartes (1630s-1640s)
- 2. The idea that animals have evolved Charles Darwin (1859)
- 3. The idea that machines, like animals, could evolve Samuel Butler (1863)
- 4. Development of rigorous theory & practical implementations of self-reproducing machines John von Neumann (c. 1948), Nils Barricelli (1953), Lionel Penrose (1957)



Step 1: The idea of animals as machines

"Do you say that beasts are machines just as watches are? Put a male dog-machine and a female dog-machine side by side, and eventually a third little machine will be the result, whereas two watches will lie side by side all their lives without ever producing a third watch."

Bernard Le Bovier de Fontenelle, *Letter XI "to Monsieur C..."* (1683)





Step 1: The idea of animals as machines

"And so if this sentient and animated harpsichord was now endowed with the faculty of feeding and reproducing itself, it would live and, either on its own or with its female partner, give birth to little keyboards, living and resonating."

Denis Diderot, Conversation Between D'Alembert and Diderot (1769)





Step 1: The idea of animals as machines

"...[Imagine that the watch] possessed the unexpected property of producing, in the course of its movement, another watch like itself ... That it contained within it a mechanism, a system of parts, a mould for instance, or a complex adjustment of laths, files, and other tools, evidently and separately calculated for this purpose ... "

William Paley, Natural Theology (1802)

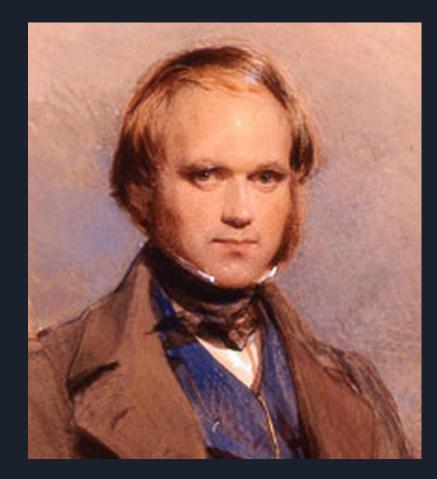




Step 2: The idea that animals evolve

The melting pot of London in the mid-1800s: Intellectual society was a rich web of social, professional and family connections

Darwin ~ Babbage ~ Lovelace ~ Byron ~ Shelley ~ Butler ~ Marshall ~ Paley ~



Step 3: The idea that machines can evolve

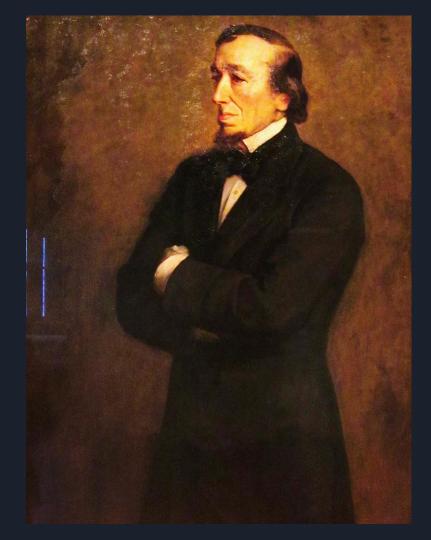




Step 3: The idea that machines can evolve

"And why should one say that the machine does not live? It breathes ... It moves ... And has it not a voice? ... And yet the mystery of mysteries is to view machines making machines; a spectacle that fills the mind with curious, and even awful, speculation."

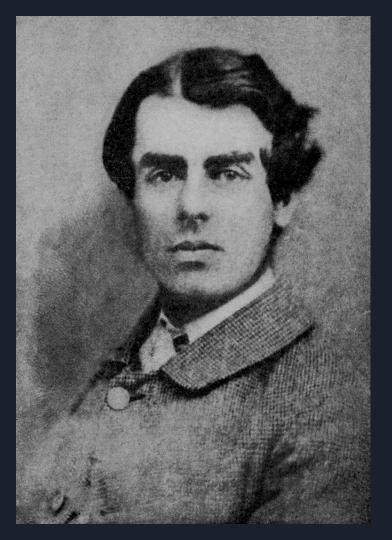
Benjamin Disraeli, Coningsby (1844)





Samuel Butler (1835-1902)

- Emigrated from England to New Zealand in 1859
- Read The Origin of Species shortly after arriving
- Inspired many of his works:
 - Darwin Among the Machines (1863)
 - Lucubratio Ebria (1865)
 - The Mechanical Creation (1865)
 - Erewhon (1872)



THE PRESS

" Nhi atto good can bosestam."

Vot. III .- No. 192

SATURDAX JUNE 13, 1863.

PUBLISHED DAILY-PARK 3D.

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Vol. III.-No. 192

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" Nihil utile quod non honestum."

PRESS

SATURDAY, JUNE 13, 1863.

PUBLISHED DAILY-PRICE 3D.

Correspondence.

DARWIN AMONG THE MACHINES. TO THE EDITOR OF THE PRESS. SIR,-There are few things of which the present generation is more justly proud than of the won-

derful improvements which are daily taking place in all sorts of mechanical appliances. And indeed it is matter for great congratulation on many grounds. It is unnecessary to mention these here, for they are sufficiently obvious; our present business lies with considerations which may somewhat tend to humble our pride, and to make us think seriously of the future prospects of the



Samuel Butler Darwin Among the Machines

- Machines are being endowed with increasingly sophisticated powers of self-regulation and self-acting
- Freed from constraints of feelings and emotions, machines will become "the acme of all that the best and wisest man can ever dare to aim at"
- Machines will still be reliant upon humans for feeding them, repairing them and producing their offspring. However ...

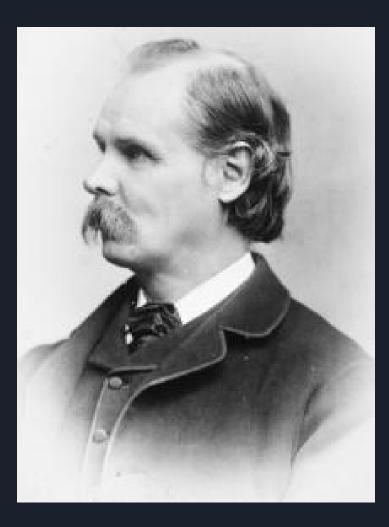
"it is true that machinery is even at this present time employed in begetting machinery, in becoming the parent of machines"

"the reproductive organs of the machines [might become] developed in a manner which we are hardly yet able to conceive"

Samuel Butler, Darwin Among the Machines (1863)

Alfred Marshall (1842-1924)

- Well known in his later career as one of the founding fathers of neoclassical economics
- In early career, presented a series of lectures at a philosophical discussion club at Cambridge University (~1867)
 - Exploring how far it was possible to account for human behaviour in purely physical terms
 - The third lecture was entitled "Ye Machine"
 - Discussed basic designs for a machine (a robot) that could learn from experience



Speculations in the early 1900s



Early American pulp science fiction (late 1920s onwards)

"I think ... that this is the end ... of man ... But not the end of evolution. The children of men still live - the machines will go on. Not of man's flesh, but of a better flesh, a flesh that knows no sickness, and no decay, a flesh that spends no thousands of years in advancing a step in its full evolution, but overnight leaps ahead to new heights."

John W. Campbell, The Last Evolution (1932)

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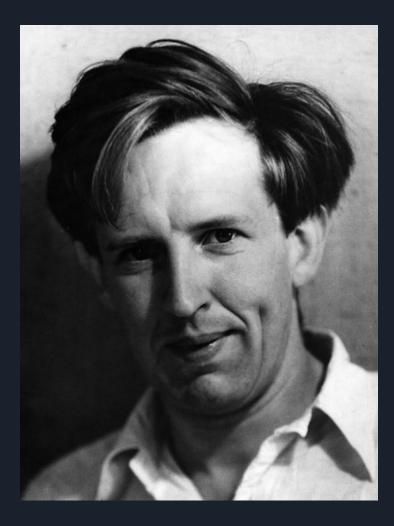
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te had enough in the first place-mastdeath-robots. But when they began to eators, it was time for the human race to

er made his way nervously up the ragged side of gun ready. He glanced around him, licking his dry an time to time he reached up a glowed hand and om his neck, pushing down his coat collar. poral Leone. "Want him? Or can I have him?" He ports brone. Want nits/ or can't rate nits/ re-ight so the Russian's features squarely filled the 1g across his hard, somber features. The Russian was close, moving rapidly, almost Wait." Leone tensed. "I don't think we're needed."

John Desmond Bernal (1901-1971)

- Well known in his later career for pioneering work in structural crystallography
- Also wrote many papers on science and society
- The first of these was "The World, the Flesh and the Devil" (1929)
 - Explored what we might predict about the future of humanity
 - Including space colonisation in "Bernal spheres"



The "Cambrian Explosion" of self-reproducing robots (1940s-1950s)



The Theory of Self-Reproducing Automata

John von Neumann put the subject on a firm theoretical grounding in the late 1940s and early 1950s

Showed it was logically possible to build a machine that could build another copy of itself...

...or that could build something more complicated than itself

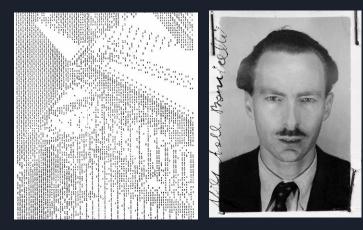




First implementations

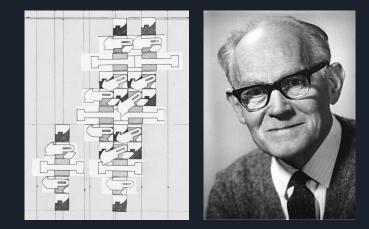
In software

Nils Aall Barricelli (1953) In von Neumann's group at IAS, Princeton



In hardware

Lionel Penrose (1957) At UCL, London



But these are "bottom-up", not "top-down", approaches!

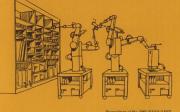


More recent work

NASA Study (1980)

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Advanced Automation for for Space Missions



ordings of the 1980 NASAASE Summer Study held at the University of Santa Claro Santa Claro, California June 23-August 29, 1980

NASA

Foresight guidelines (2000-)

FORESIGHT

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Foresight Guidelines

Foresight Guidelines for Responsible Nanotechnology Development

Neil Jacobstein

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Nanotechnology will alter our relationship with molecules and matter as profoundly as the computer changed our relationship with bits and information. Research on productive nanosystems will eventually develop programmable, molecular-scale systems that make other useful nanostructured materials and devices. These systems will enable a new manufacturing base that can produce both small and large objects precisely and inexpensively. The Foresight Guidelines are designed to address the potential positive and negative consequences of this new technology base in an open and scientifically accurate matter. The objective is to provide a basis for informed policy decisions by citizens and governments, and guidelines for the responsible development of productive nanotechnology by practitioners and industry.

The Guidelines are presented in the active format of self-assessment scorecords for nanotechnology practitioners, indicative organizations, and regulatory agencies. Indicative organizations for example can assess and score their own degree of compliance with the Guidelines, in much the same way they do with quality programs. This allows the dialog about nanotechnology safety to move from losse recommendations to self assessment of compliance with an operational set of nanotechnology development guidelines. Precise scoring is not necessary at this point, but the process of regular self assessment is critical. As the dialog progresses, more precise scoring guidelines are likely to worke.

And continuing work...

Affordable, Rapid Bootstrapping of the Space Industry and Solar System Civilization

Philip T. Metzger, Ph.D., A.M.ASCE¹; Anthony Muscatello, Ph.D.²; Bobert P. Mueller, A.M.ASCE³; and James Mantovani, Ph.D.⁴

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CE Database subject headings: Manufacturing; Robotics; Moon; Space colonies; Space exploration; Mining.

Author knywords: ISRU: Space manufacturing: Robolics: Space resources; Lunar industry: In situ resource utilization: Setting space; Space colosization; Space exploration; Space mining.

Introduction

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et al. 2010). The challenge is in finding a way to access those resources for the benefit of humanity. Until now this has not been economically feasible because of the

vasi distances and orbital energies separating the bodies in this solar system with the high expense of spaceflight. Of Neill (1989) estimated in the 1980s that an orbiting space colony could become economic

only if it had a human population of greater than 10,000 to perform

mantfacturing tasks. History has since proven that there was little

In injoints to instantiate the projects to manually one minimity. Once successfully bootstrapped, a robotic network can access, process, transport, and use the solar system's neurons for humankind's benefit. Appropriately designed robots will not have the problems involving the ward distances of the solar system final humans

18 / JOURNAL OF A EPOSPACE ENGINEERING © ASCE / JANUARY 2013

J. Acarsp. Eng. 2013;25(18:29)



What use is history?

- Intellectual context and assumptions
 - The idea of what an organism is
 - The idea of how reproduction works
- Approaches to self-reproduction
 - Top-down vs bottom-up
- Purpose and goals
 - Scientific
 - Commercial
 - Sociological

The future of self-reproducing technology

Questions / hopes / fears:

- Will it replace us and become the dominant intelligent species?
- Will it help us explore the universe?
- Will we co-evolve with it?
- Will it lead to the degeneracy of the human race?
- Will we forsake technology and return to a simpler way of life?

The barriers to creating such technology are (just) technical & economic, not theoretical:

- Potential financial returns mean we must assume it will become a reality
- Need to continue developing guidelines for safe design and deployment

Hardware version of the technological singularity:

• Timescales may be longer, but impact on humanity more profound?