# The early history and near future of artificial life

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# The near future: Artificial life on the web

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## WebAL Comes of Age: A Review of the First 21 Years of Artificial Life on the Web


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**Abstract** We present a survey of the first 21 years of web-based artificial life (WebAL) research and applications, broadly construed to include the many different ways in which artificial life and web technologies might intersect. Our survey covers the period from 1994—when the first WebAL work appeared—up to the present day, together with a brief discussion of relevant precursors. We examine recent projects, from 2010–2015, in greater detail in order to highlight the current state of the art. We follow the survey with a discussion of common themes and methodologies that can be observed in recent work and identify a number of likely directions for future work in this exciting area.

# The intertwined history of evolution and computers

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## Digital Genesis: Computers, Evolution and Artificial Life

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**Abstract**

The application of evolution in the digital realm, with the goal of creating artificial intelligence and artificial life, has a history as long as that of the digital computer itself. We illustrate the intertwined history of these ideas, starting with the early theoretical work of John von Neumann and the pioneering experimental work of Nils Aall Barricelli. We argue that evolutionary thinking and artificial life will continue to play an integral role in the future development of the digital world.

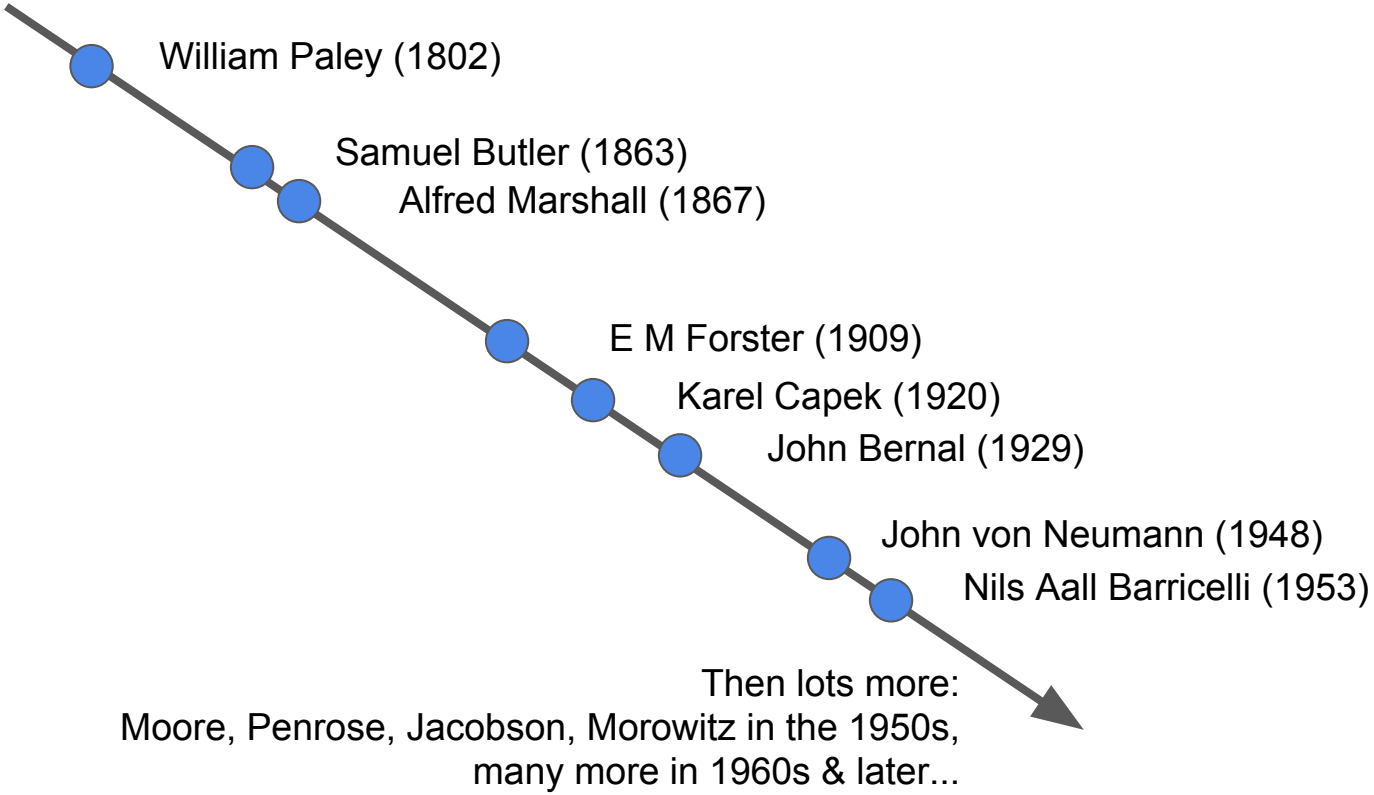
### Introduction

In *The Origin of Species*, Darwin introduced his theory of natural selection as an explanation of the complexity of the biological world (Darwin, 1859). Simply put, in a population where heritable variation exists in the characteristics of individual organisms, if one variety of a particular characteristic leads to enhanced reproductive success among those individuals that carry it, then, over time, that variant will become more common than others in the population.

The logic of Darwin's argument seems to apply to *any* system of entities which possesses the three such machines could therefore participate in a process of evolution. Looking for a suitable formalism that was both simple and enlightening, von Neumann developed a two-dimensional cellular automaton framework in which to demonstrate his ideas.[1] Although the design was not implemented on a computer before his death in 1957, von Neumann's work can be regarded as the first attempt to instantiate an evolutionary process in the context of a modern, digital computational framework.

At around the same time, Alan Turing also considered the application of evolution to computers. In his seminal paper *Computing Machinery and Intelligence* he described a method of machine learning involving mutations (random or otherwise) to a computer program and feedback from a human experimenter (Turing, 1950). Turing drew explicit parallels between his proposal and the process of biological evolution. Intriguingly, he began practical experiments with this approach, although these apparently met with little success and were not reported in detail: "I have done some experiments with one such child machine, and succeeded in teaching it a few things, but the teaching method was too unorthodox for the experiment to be

# Timeline of thought on self-reproducing machines



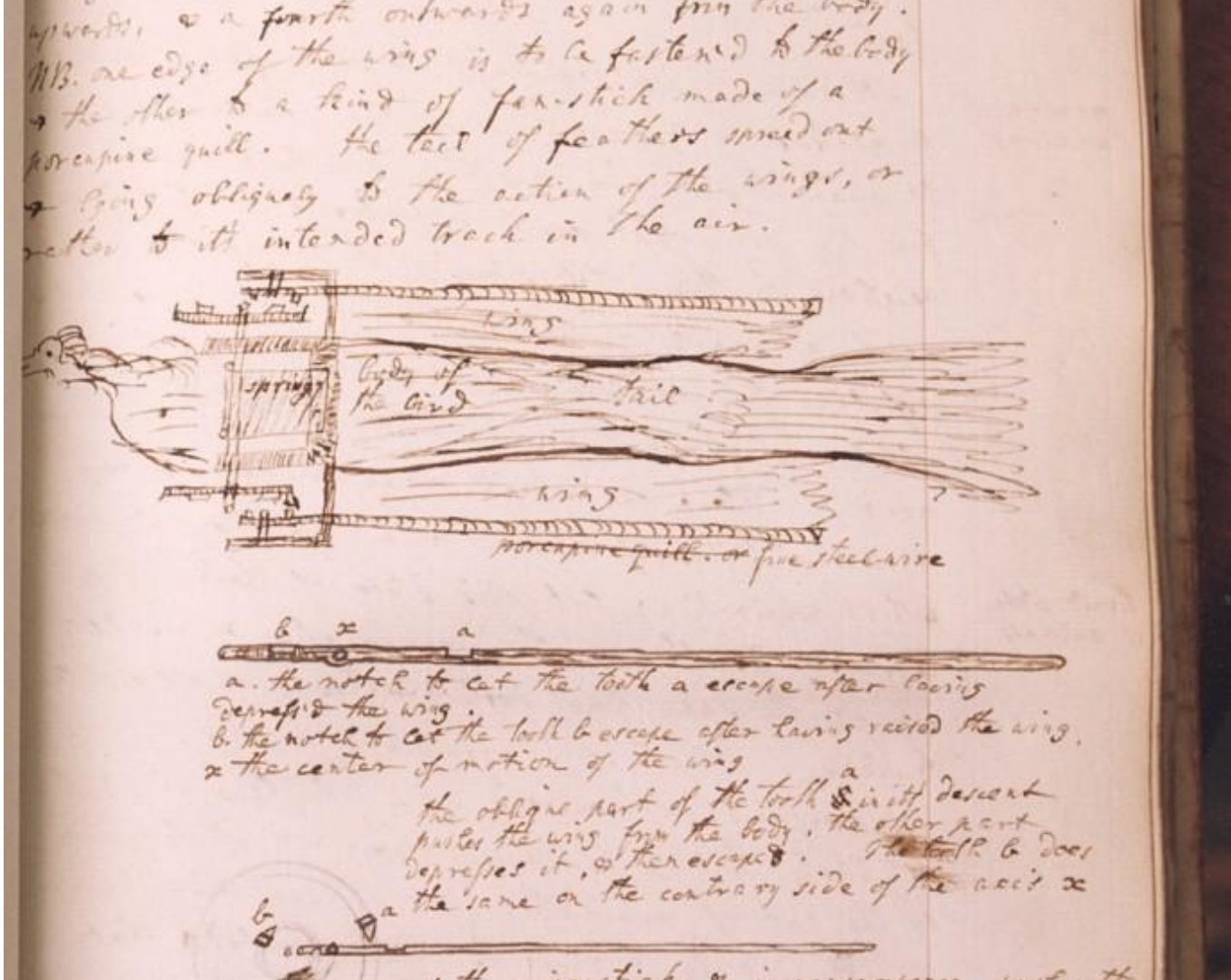
# Precursors

# Erasmus Darwin (1731-1802)

- A medical practitioner
- Explored early ideas on the theory of evolution in his book *Zoonomia: Or the Laws of Organic Life* (1794)
- Also a keen mechanical inventor
  - Carriage steering
  - Copying machines (The Bigrapher, 1777, The Polygrapher, 1778-9)
  - The artificial bird (1777)

## Erasmus Darwin's artificial bird

- Fully specifies the movement-cycle of the wings
- Power provided compressed air in a copper globe



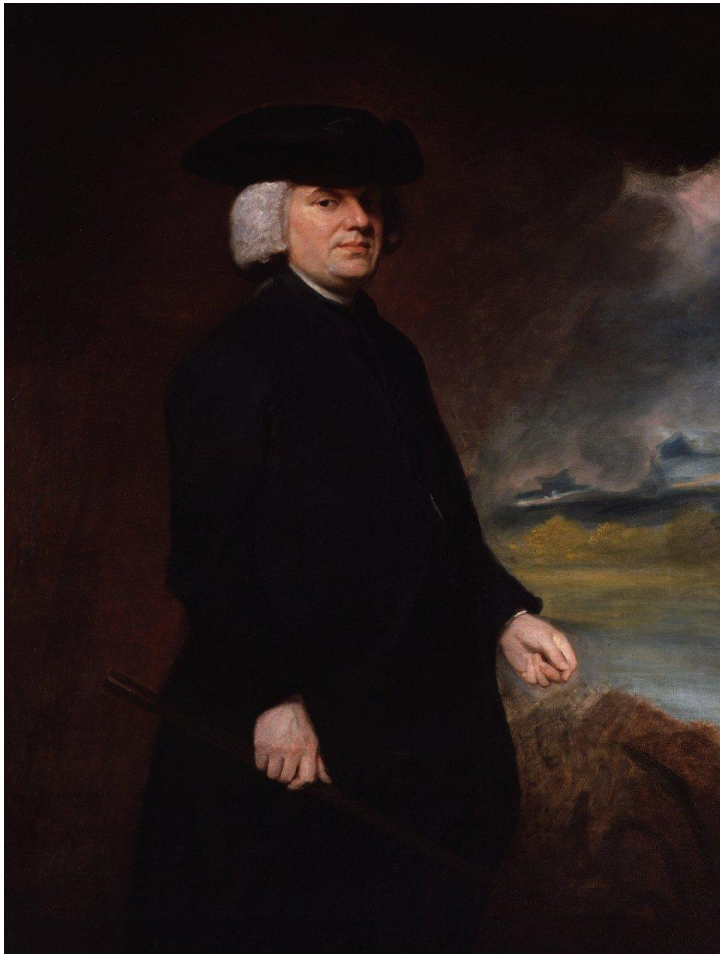
# Artificial bird reconstruction

On view at Erasmus Darwin's House in Litchfield, near Birmingham, England

http://www.erasmusdarwin.org/collections/

# William Paley (1743-1805)

- Paley's final book, published in 1802: *Natural Theology: or Evidences of the Existence and Attributes of the Deity, collected from the appearances of nature*
- Introduced the "watchmaker" analogy: explaining the existence of a stone vs a watch
- "There cannot be design without a designer"
- Even considered the case of a self-reproducing watch



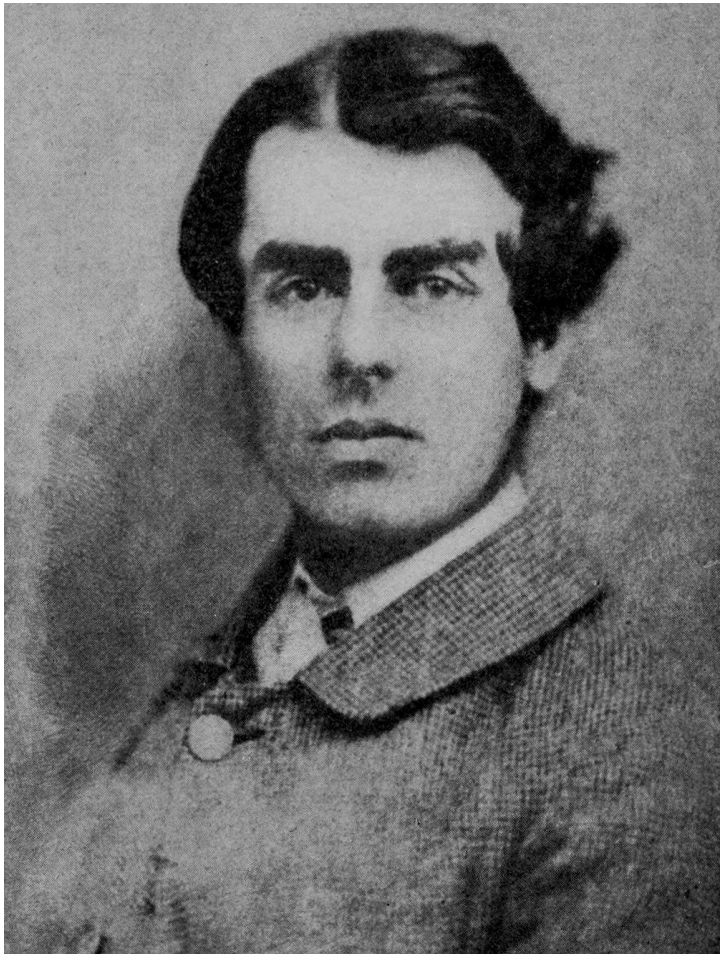
“If the difficulty [of a design requiring a designer] were diminished the further we went back [in the lineage of self-reproducing watches], by going back indefinitely we might exhaust it. And this is the only case to which this sort of reasoning applies”

William Paley, *Natural Theology* (1802)

# Machine evolution

# 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

"Nihil utile quod non honestum."

Vol. III.—No. 192 SATURDAY, JUNE 13, 1863. Published Daily—Price 3d.



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## 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 wonderful 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

“We may suppose the Machine to contain an indefinite number of wheels of various sizes, and in various positions . . . Now suppose that when any two wheels were together performing two partial revolutions, the Machine itself connects them by a light band, slightly fitting. Then, when one of them again revolved, the other would also revolve, unless there were a resisting or opposing force, in which case the band would slip. But every time the same double motion was repeated the band would be tightened.”

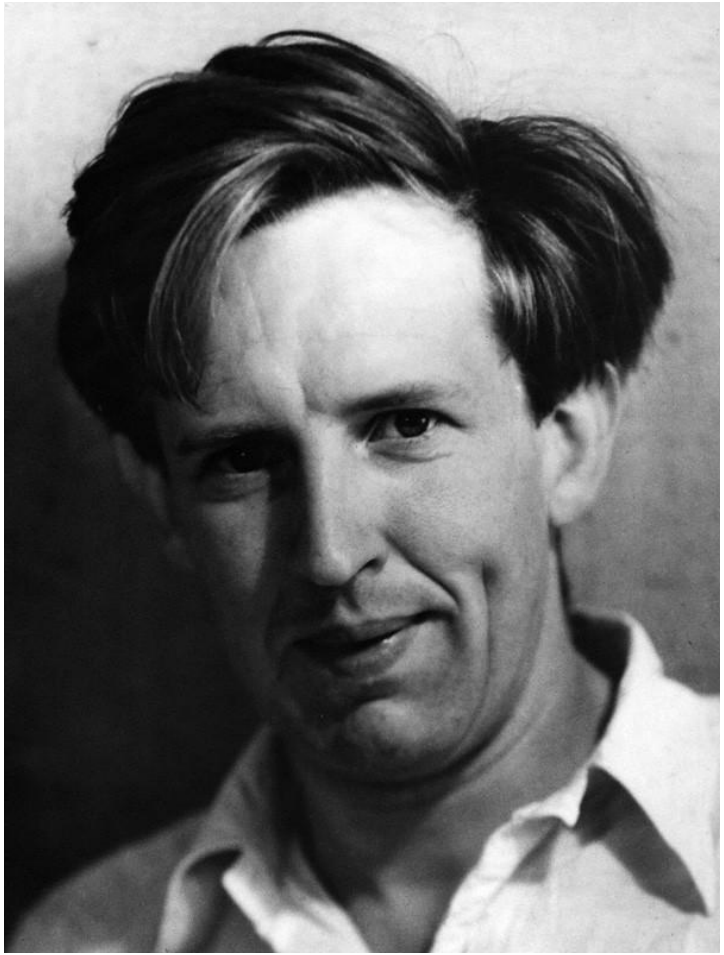
Alfred Marshall, *Ye Machine* (~1867)

“Nay, further, the Machine, like Paley’s watch, might make others like itself. We thus get hereditary and accumulated instinct. For these descendants, as they may be called, may vary slightly, owing to accidental circumstances, from the parent. Those which were most suited to the environment would supply themselves most easily with fuel, etc. and have the greatest chance of prolonged activity. The principle of natural selection, which indeed involves only purely mechanical agencies, would thus be in full operation.”

Alfred Marshall, *Ye Machine* (~1867)

# John 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"



“However, the essential positive activity of the globe or colony would be in the development, growth and reproduction of the globe. A globe which was merely a satisfactory way of continuing life indefinitely would barely be more than a reproduction of terrestrial conditions in a more restricted sphere.”

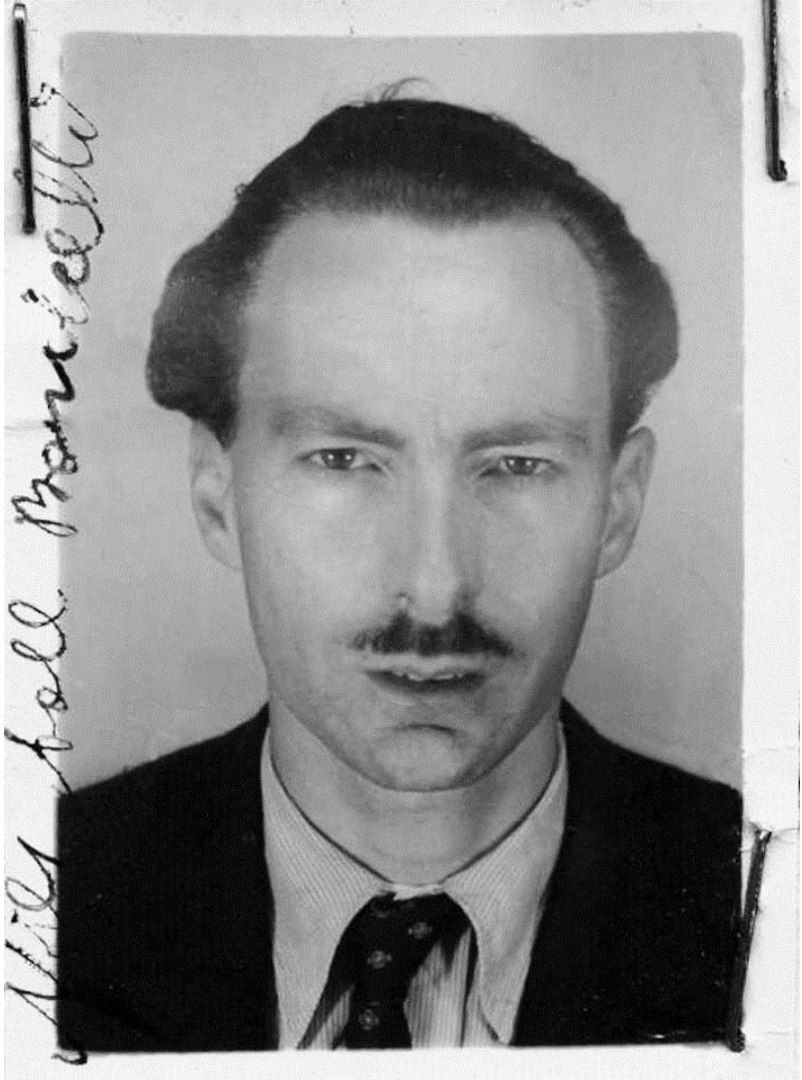
John Bernal, *The World, the Flesh and the Devil* (1929)

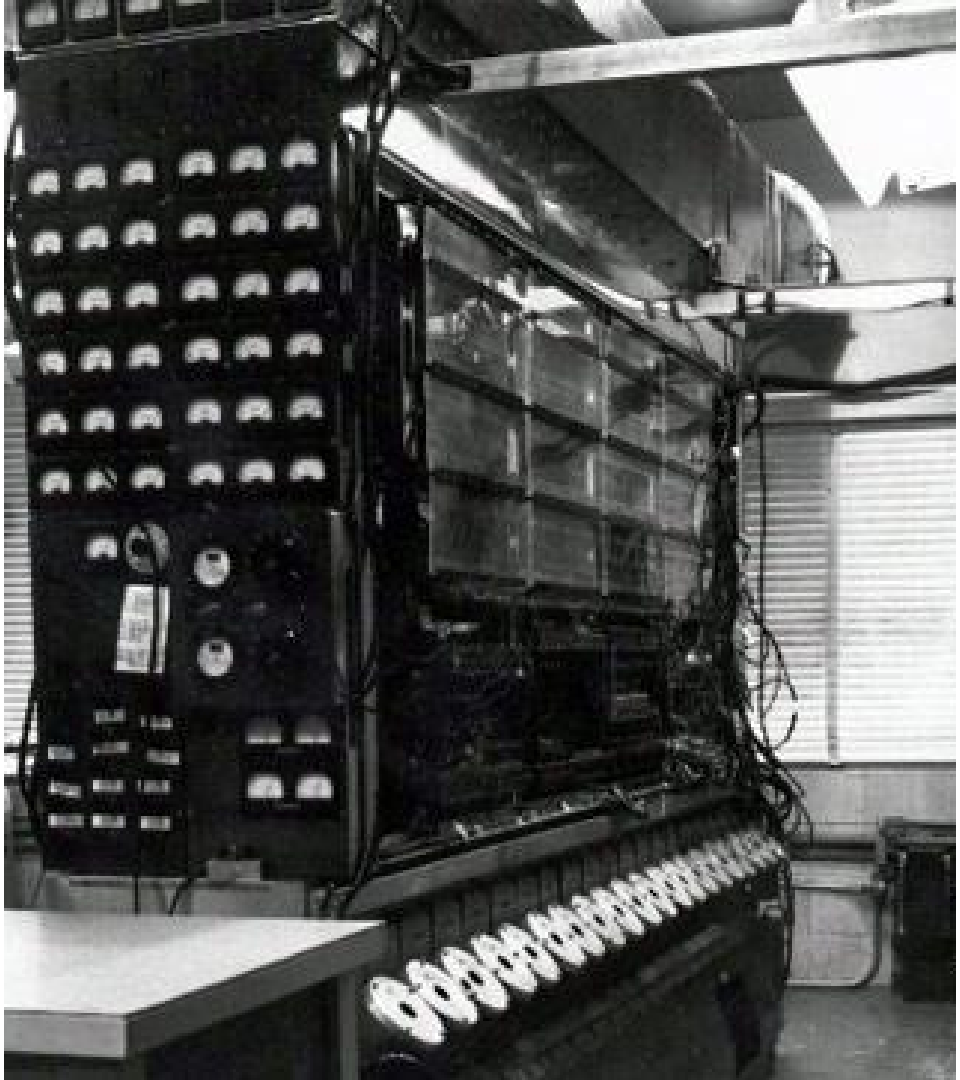
“As the globes multiplied they would undoubtedly develop very differently according to their construction and to the tendencies of their colonists, and at the same time they would compete increasingly both for the sunlight which kept them alive and for the asteroidal and meteoric matter which enabled them to grow. Sooner or later this pressure . . . would force some more adventurous colony to set out beyond the bounds of the solar system.”

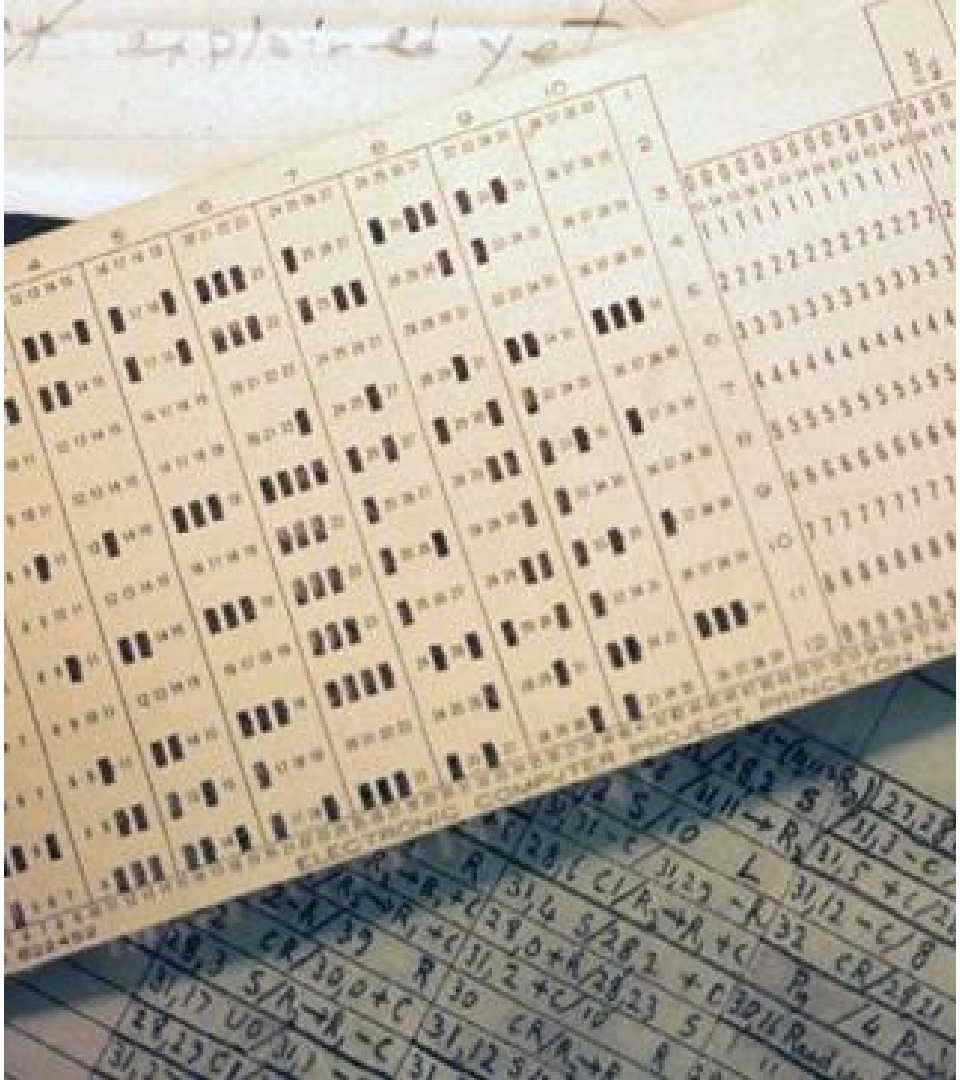
John Bernal, *The World, the Flesh and the Devil* (1929)

# Nils Aall Barricelli (1912-1993)

- Worked in John von Neumann's group at the Institute of Advanced Studies in Princeton on several occasions in the 1950s
- In 1953, performed the first computational experiments that we would now regard as Artificial Life
- Interested in unlimited (open-ended) evolution of digital organisms







# Attempt 1: Self-reproduction and mutation

“A process of adaptation to the environmental conditions, that is, a process of Darwinian evolution, will take place”

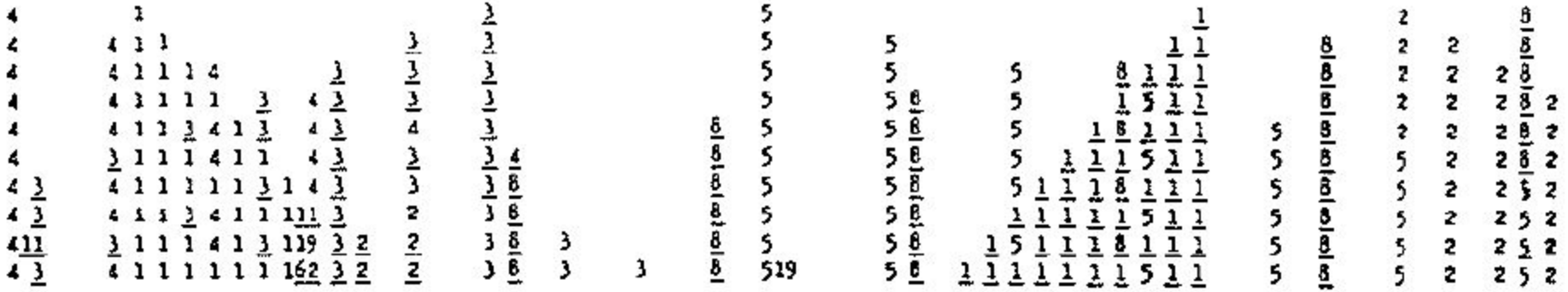


Fig. 1.-Selfreproducing numbers (see text). Adaptive selection but no extensive evolution phenomena are possible.

“[the model] clearly shows that something more is needed to understand the formation of organs and properties with a complexity comparable to those of living organisms. No matter how many mutations occur, the numbers ... will never become anything more complex than plain numbers”

Nils Barricelli (1962)

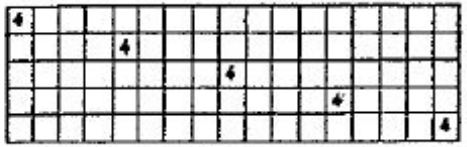


Fig. 2.

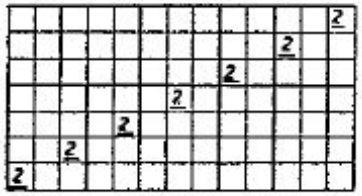


Fig. 3.

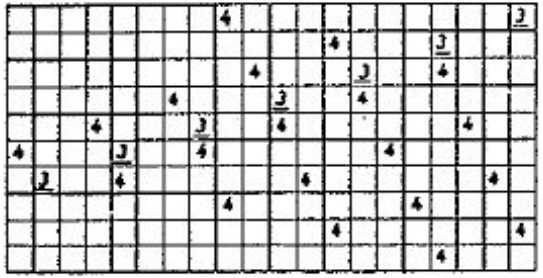


Fig. 4.

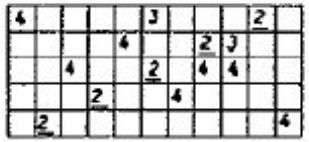


Fig. 5.

2,3,4,5. Reproduction rules requiring symbiosis (see

# Attempt 2: Reproduction requiring symbiosis

A number can only reproduce with the help of another number in the right position

# Symbioorganisms

Adding the new rule led to the emergence of relatively stable, mutually supporting groups of numbers

(Barricelli also found that using heterogeneous environments helped in maintaining interesting dynamics)

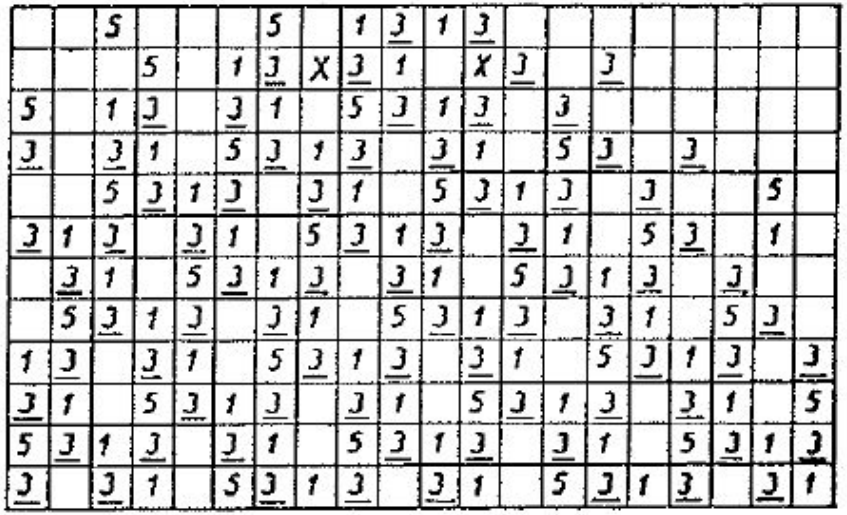


Fig. 6.

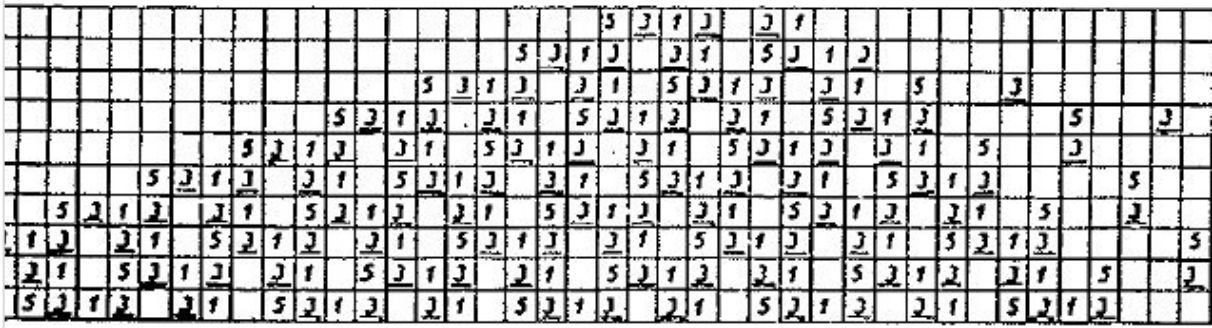
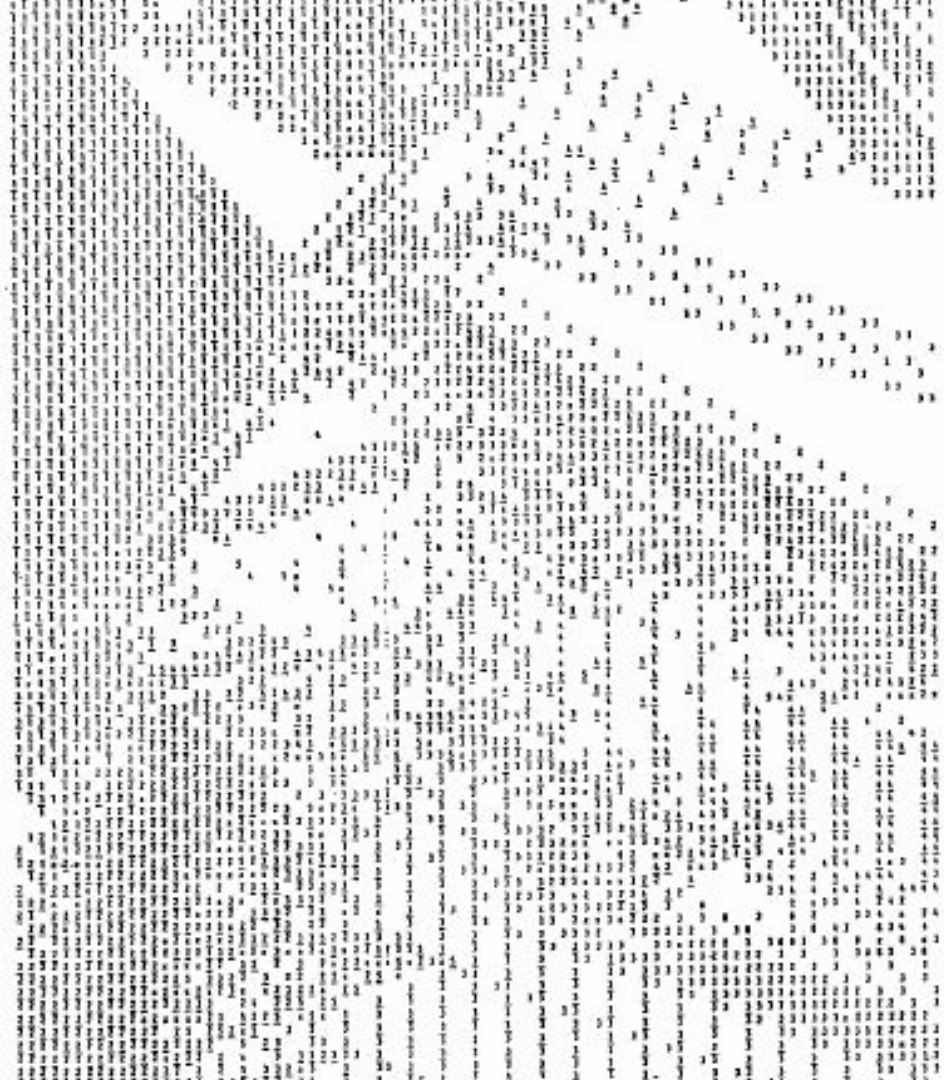


Fig. 7.

g. 6 and 7. Formation of a symbioorganism (6) and its reproduction characteristics (



# Further results

- Self-reproduction
- Crossing
- Great variability
- Heritable mutations
- Spontaneous formation
- Parasitism
- Repairing mechanisms
- Evolution
- Plus later work on evolving game playing strategies

# Back to well mapped territory

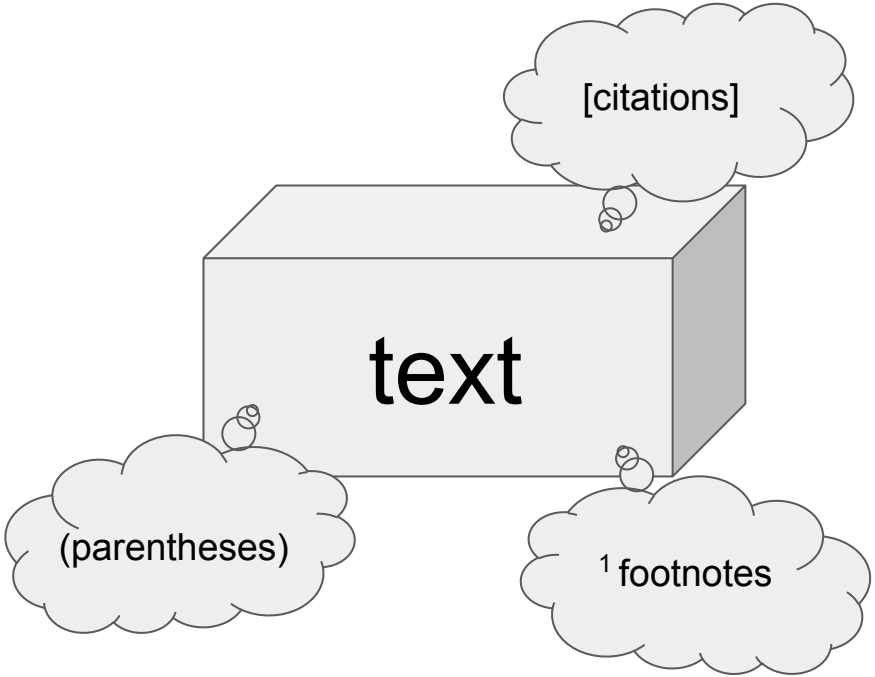
# More recent work

- John von Neumann’s seminal work on the logical design of self-reproducing and evolvable machine (from late 1940s)
- Plus other developments in the 1950s
  - Demonstrations of simple physical replicators (Penrose, Jacobson, Morowitz)
  - Proposal for artificial living plants (Moore)
  - Various studies in the cybernetics literature
  - Early work on evolutionary computing
- Then lots of well documented work from the 1960s to the present day
  - Cellular automata-based approaches
  - NASA study (1980)
  - Tierra and Avida
  - 3D printing
  - etc.

*an interlude:*

# the joy of discovery

# Connections

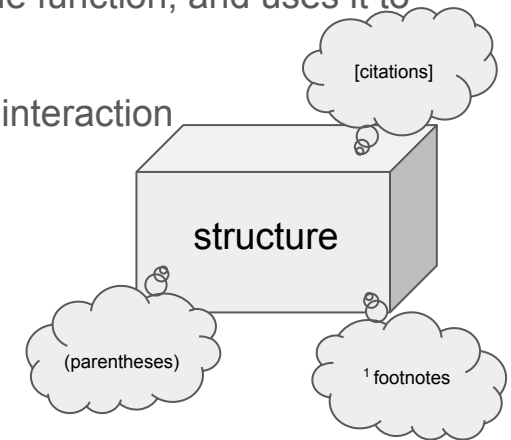



- Personal connections
  - Butler and Darwin
  - Marshall and Paley
  - Barricelli and (nearly) the current ALife community
- Connections of ideas
  - Each person reads a text with their own individual background and angle
  - What you get out of a text will therefore be different to what someone else might get from it
  - Each text has leads to related ideas (citations, footnotes and parenthetical remarks)
  - There’s always “a little bit extra”...

# Creativity

# Creativity in research and in evolution

- This “little bit extra” is an important input for creativity
  - Reading from a different perspective
  - Finding leads to other work
  - Forming new associations between different pieces of work (maybe from different fields)
- It’s also analogous to a form of creative evolution of biological structures
  - Physical structures have multiple properties in different modalities
  - Evolution often takes an existing organ/structure that performs one function, and uses it to perform a different function (exaptation)
  - This is one approach to the evolution of completely new forms of interaction with the world (new sensors and new effectors) - an aspect of open-ended evolution. For example:
    - Feathers: heat regulation → flight
    - Tetrapod limbs: locomotion in water → locomotion on land




*and finally, the future...*
WebAL
Artificial life on the web

# Prospects for web-based artificial life

- Agents that can evolve to use new information sources
  - e.g. by following links, using dictionary look-ups, semantic web info, searching for similar terms, etc
  - using web resources not just “as is”, but looking for the “little bit extra”
  - (Margaret Boden recently claimed this was a major stumbling block for AGI)
- Possibility of long running experiments (over many years), long-term learning and open-ended evolution

# Prospects for web-based artificial life

- Also other nice features of HTML5 APIs, providing standardised, native methods for doing things such as:
  - Client-side storage (Web storage)
  - Client-side processing (Web workers)
  - Communications (Web socket) - providing a geography of the web
- Leading to possibility of fully client-side ALife agents
  - Living on client machines
  - Roaming between clients
  - Require “energy” from user to awaken them (therefore must be doing something useful or interesting)
  - *Artificial life in the wild…*
  - *...or (another take on) Darwin among the Machines*

# References


Paper on early history of evolving machines:

Tim Taylor and Alan Dorin. "***The Birth of Self-Reproducing Robots: An early history of the idea of evolving machines***"
(in preparation)

Paper on artificial life and the web:

Tim Taylor, Joshua E. Auerbach, Josh Bongard, Jeff Clune, Simon Hickinbotham, Charles Ofria, Mizuki Oka, Sebastian Risi, Kenneth O. Stanley and Jason Yosinski. "***WebAL Comes of Age: A review of the first 21 years of Artificial Life on the Web***". Artificial Life vol 22(3) pp. 364-407 (2016)

Paper on open-ended evolution:

Tim Taylor, Mark Bedau, Alastair Channon, David Ackley, Wolfgang Banzhaf, Guillaume Beslon, Emily Dolson, Tom Froese, Simon Hickinbotham, Takashi Ikegami, Barry McMullin, Norman Packard, Steen Rasmussen, Nathaniel Virgo, Eran Agmon, Edward Clark, Simon McGregor, Charles Ofria, Glen Ropella, Lee Spector, Kenneth O. Stanley, Adam Stanton, Christopher Timperley, Anya Vostinar and Michael Wiser. "***Open-Ended Evolution: Perspectives from the OEE Workshop in York"***. Artificial Life vol 22(3) pp. 408-423 (2016)

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- William Paley
  - Portrait by by George Romney, obtained from http://www.npg.org.uk/collections/search/portraitLarge/mw04831/William-Paley [available under Academic Licence and Creative Commons Licence]
- Samuel Butler
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