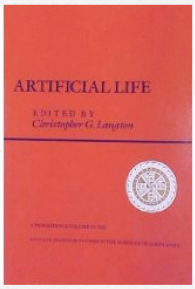
Artificial life, brains and complexity

Andrés Pérez-Uribe
HEIG-VD

Artificial Life...



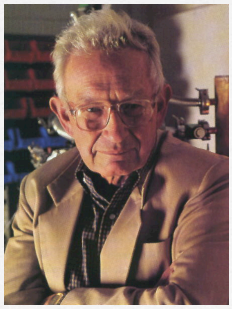
Santa Fe Institute

- Artificial Life I: conference organised by C. Langton at Los Alamos National Lab. (LANL) in 1987
- "Life as it is & life as it could be"
- SFI "think tank" started in may 1984 to study "complex adaptive systems"
- Nobel Prizes: P. Anderson et M. Gell-mann (physics), K. Arrow (economy).

The edge of reductionism

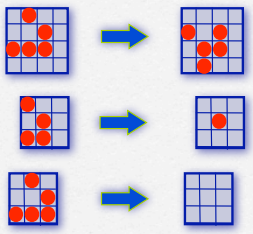
(Nature, 21 May 2009)

- "Research at the frontier between computer science and physics illustrates the shortcomings of the reductionist approach to science"
- "In his 1972 [Science] paper 'More is different', Philip Anderson claimed that multi-component physical systems can exhibit macroscopic behaviour that cannot be understood from the laws that govern their microscopic parts - a feature known as emergent or complex behviour"



Phil Anderson

Langton's cellular automata



Cellular automata example
(Game of life)

- 8 states
- 4 neighbors
- 219 transition rules

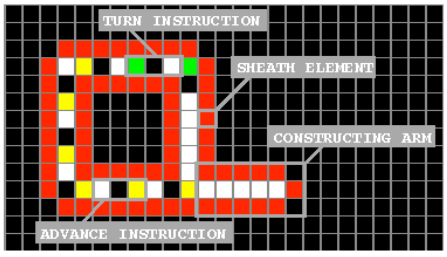


Figure 3-6: The initial configuration of Langton's Loop (iteration 0).

Langton, Physica 22D, 1986

Self-replication

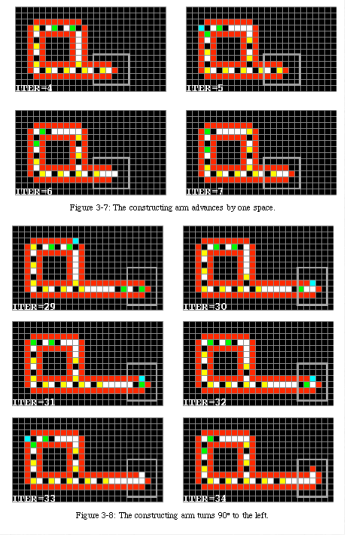


Figure 3-7: The constructing arm advances by one space.

Figure 3-8: The constructing arm turns 90° to the left.

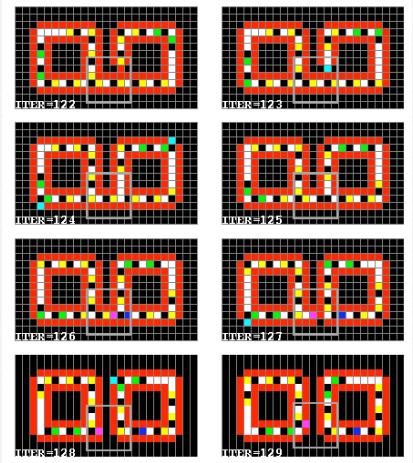


Figure 3-9: The copy is complete and the connection from parent to offspring is severed.

G. Tempesti, EPFL

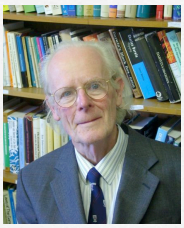
Artificial Life goals

C. Langton

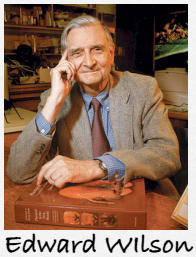
- "By synthesizing 'life-like' behaviors in the study of artificial life, we want to try to distinguish between the relevant and irrelevant details of life's biochemical implementation in order to uncover the 'molecular logic' of life."
- "The ultimate goal of the study of artificial life would be to create 'life' in some other medium, ideally a virtual medium where the essence of life has been abstracted from the details of its implementation in any particular hardware."

C. Langton, Physica 22D, 1986

Complexologists criticized

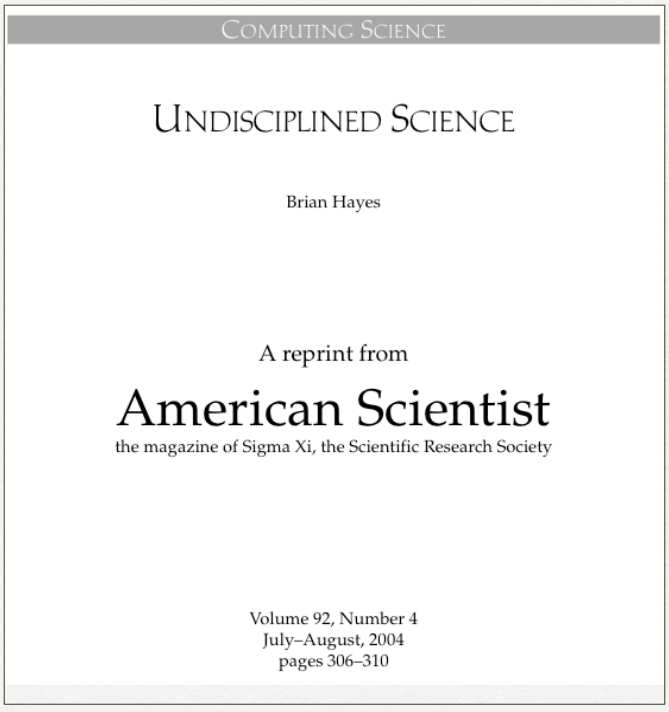


John Maynard Smith



Edward Wilson

- "Fact-free science", said John Maynard Smith, who pioneered the use of mathematics in biology
- " ", E.O. Wilson in Consilience
- "Complexity exists, in some murky sense, in the eye of the beholder", wrote John Horgan in Scientific American (1995)



COMPUTING SCIENCE

UNDISCIPLINED SCIENCE

Brian Hayes

A reprint from

American Scientist

the magazine of Sigma Xi, the Scientific Research Society

Volume 92, Number 4
July–August, 2004
pages 306–310

Scientific method[s]

Descartes

Bacon

(Nature Methods, Editorial of April 2009)

- "The rise of 'omics' methods and data-driven research presents new possibilities for discovery but also stimulates disagreement over how science should be conducted and even how it should be defined."
- "It is still unclear whether even this marriage of the two methods [hypothesis-driven and data-driven] will deliver a complete understanding of biology, but it arguably has a better chance than either method on its own."

How to use Alife models?

Stephen Jay Gould

"What if the [historical] tape were run again ?"
Stephen Jay Gould

The approach is to rerun the experiments under a wide range of conditions (parameters) in order to statistically analyze the obtained results.

Brains…

- the brain is considered the most complex "machine" ever…

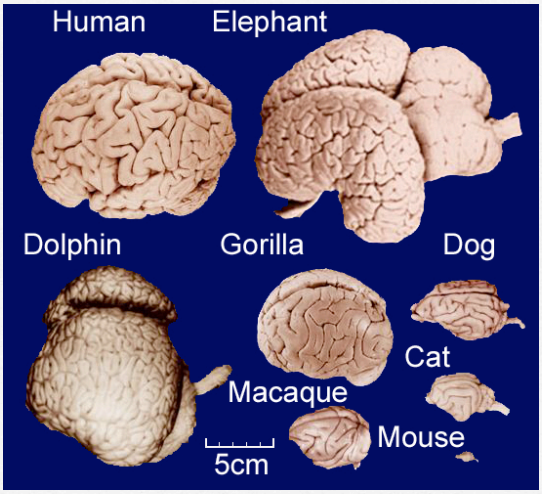
Steven Pinker

- Pinker was right in saying that "the 1990s were named the Decade of the Brain, but there will never be a Decade of the Pancreas"

Brains can be extremely complex

- Human brains
  - ~ 1350 grs
  - ~ 10^{11} neurons
  - ~ 10^{14} synapses
- There is some relationship between behavioral complexity and brain size, but humans do not have the largest brains
- A 6Kg elephant brain contains ~2-3 times more neurons!

Brain size for diverse species



Brain weight vs body weight

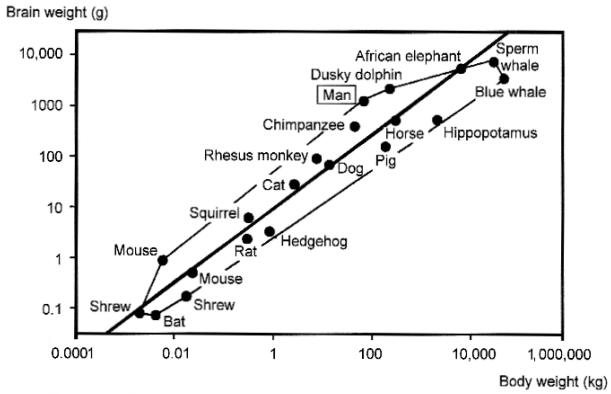


Figure 2.3. The relationship between brain size and body size in mammals. Data from 20 mammalian species (double-logarithmic graph). Modified from Nieuwenhuys, ten Donkelaar and Nicholson (1998)

Relative brain weight vs body weight

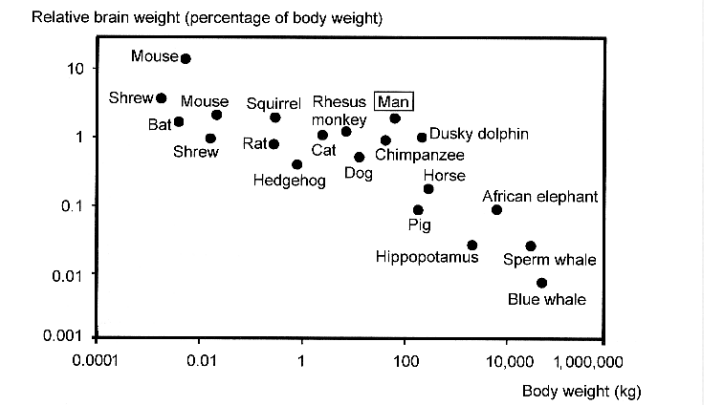
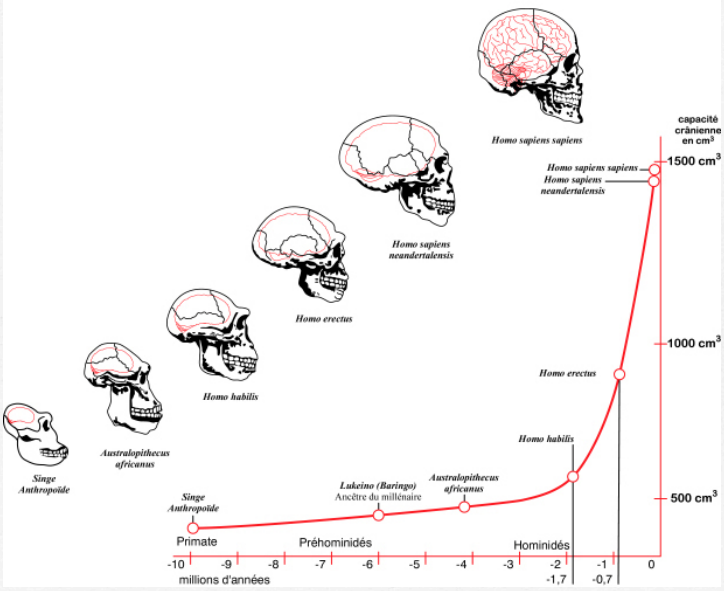
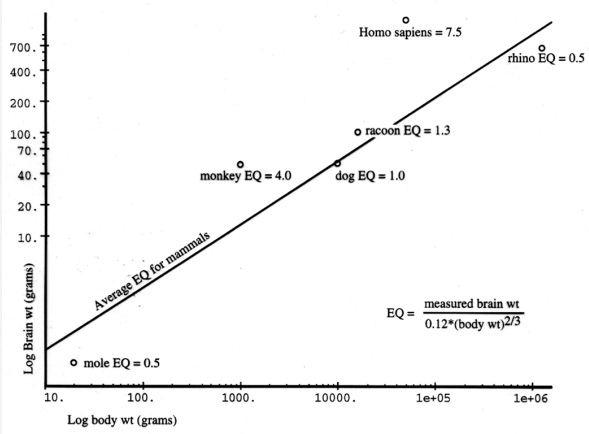


Figure 2.4. Brain weight as a percentage of body weight for the same 20 mammalian species as in Figure 2.3 (double-logarithmic graph). Modified from Nieuwenhuys, ten Donkelaar and Nicholson (1998)

Brain volume evolution



Encephalization quotient



- EQ = Actual brain mass/expected brain mass
- Em(brain) = 0.12 x body mass$^{2/3}$ (for mammals)

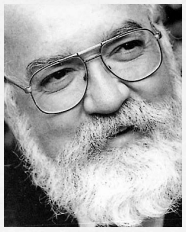
Brain complexity…

- Brain size in humans is not largest
  - Overall brain size: not largest
  - Relative (to body weight) brain size: not largest
  - ☑ Encephalization quotient is largest (and it is largely due to size of neocortex)

Behavioral complexity

What make us specifically human?

- culture, language, theory of mind, ...
- > 4th-order intensionality



Daniel Dennett

"I suspect [1] that you wonder [2] whether I realize [3] how hard it is for you to be sure that you understand [4] whether I mean [5] to be saying that you can recognize [6] that I can believe [7] you to want [8] me to explain that most of us can keep track of only about five or six orders of intensionality"

Daniel Dennett

What are big brains for ?

Theodosius Dobzhansky

- Nothing in biology makes sense except in the light of evolution

- Ecological explanations
- Social brain hypothesis
- Sexual selection hypothesis

Ecological explanations

- Among primates, relative brain size (corrected for body weight) is greater in species with larger home ranges and greater in species that are fruit-eating or omnivorous than in species that eat leaves
- Species that feed on fruit may face special problems in learning and memory because they depend on widely spaced food that is ephemeral in both space and time

Costs of large brains

- Energy consumption !!!!
- Higher birth mortality (infant + mother)

Social brain hypothesis

- "Primates live in relatively large groups where an individual's survival and reproductive success depends on its ability to manipulate others within a complex web of kinship and dominance relations"

Robin Dunbar

- "The social function of the intellect", by primatologist Nicolas Humphreys (1976)
- "Machiavellian intelligence", a book by Byrne and Whiten (1988)
- "The social brain hypothesis", by Robin Dunbar (1998)

Social brain hypothesis (2)

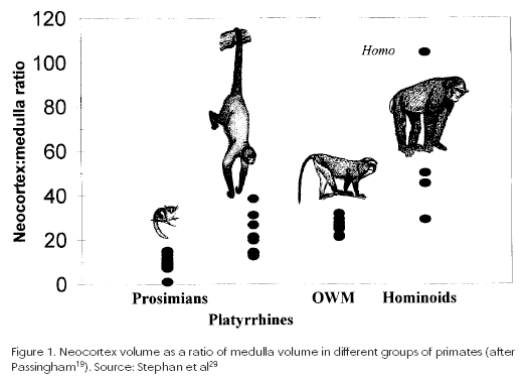
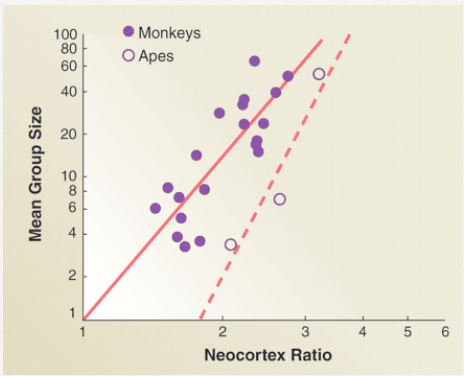


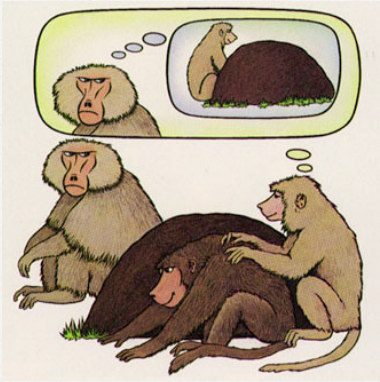
Figure 1. Neocortex volume as a ratio of medulla volume in different groups of primates (after Passingham[19]). Source: Stephan et al[29]



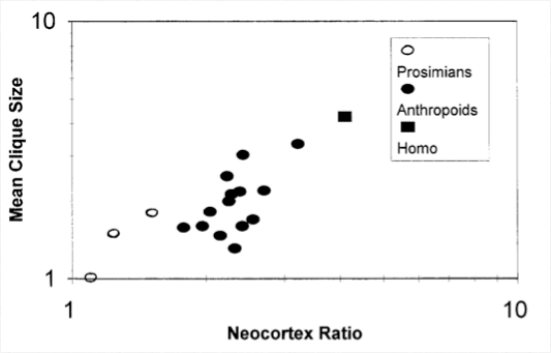
Increasing social complexity could have resulted in increased intelligence

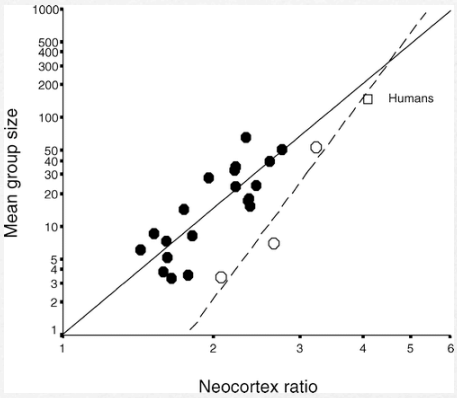
Social brain hypothesis (3)

- Primate's large brains reflect the computational demands of their complex social systems (e.g., tactical deception, coalition-formation, "mind-reading", "theory of mind")



Social brain hypothesis (4)

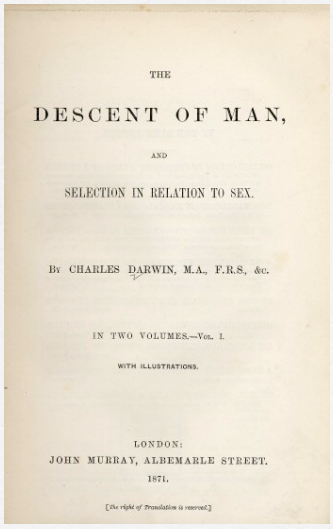




*Grooming clique size = alliance size

~150 : Dunbar's number, a theoretical cognitive limit to the number of people with whom one can maintain stable social relationships

Sexual selection



THE

DESCENT OF MAN,

AND

SELECTION IN RELATION TO SEX.

By CHARLES DARWIN, M.A., F.R.S., &c.

IN TWO VOLUMES.—Vol. I.

WITH ILLUSTRATIONS.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1871.

[The right of Translation is reserved.]

Darwin, 1871

- Natural selection: competition for survival
- Sexual selection: competition for reproduction
- "Many traits in many species have evolved through sexual selection specifically to function as 'fitness indicators' that reveal good genes and good health." G. Miller
- "Good genes" & "good taste" theories

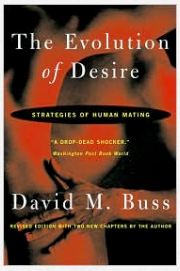
Sexual selection hypothesis

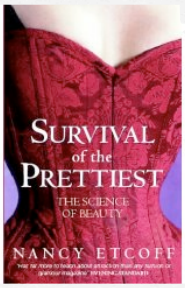
Geoffrey Miller

- "Our minds evolved not just as survival machines, but as courtship machines"
- "The human mind's most impressive abilities are like the peacock's tail: they are courtship tools, evolved to attract and entertain sexual partners. By shifting our attention from a survival-centered view of evolution to a courtship-centered view, we can understand more of the richness of human art, morality, language, and creativity"

"The mating mind" (2001)

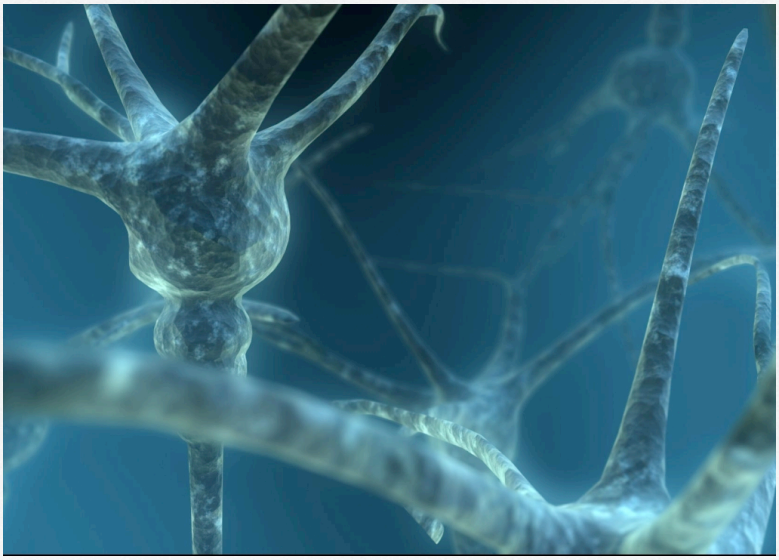
Sexual selection hypothesis (2)





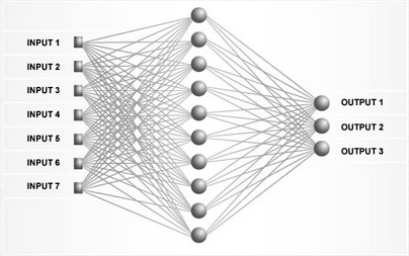
- Researchers such as David Buss have gathered impressive evidence that we have evolved sexual preferences that favor pretty faces, fertile bodies, and high social status.
- But evolutionary psychology in general still views sexual preferences more often as outcomes of evolution than as causes of evolution.

Alife & brain complexity

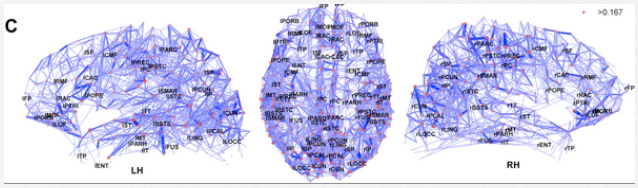


Artificial brain models

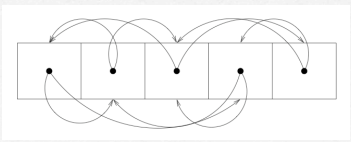
- Artificial neural networks



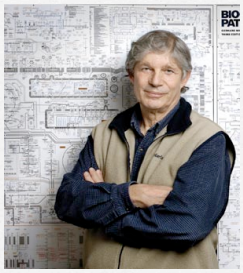
- Complex network models



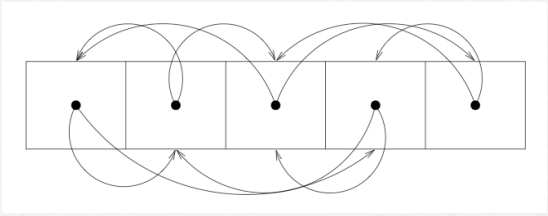
- N-k models



Kaufmann's N-K models



Stuart Kaufmann

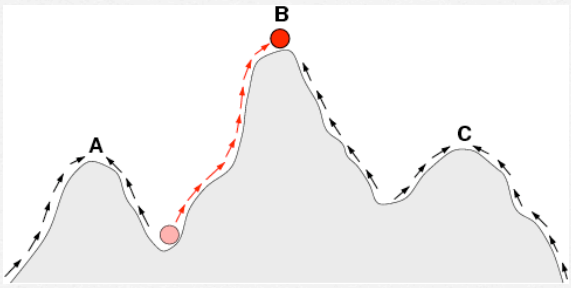


N=5, K=2

- N stands for the number of elements in a system (e.g., genes)
- K stands for the number of interdependencies between components (e.g. epistasis) with range: $0 \leq K \leq N-1$

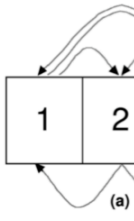
Fitness landscapes and adaptive walks

- A "fitness function" is a scalar, real valued function which assigns a "fitness" value to each possible individual (Wright, 1932)



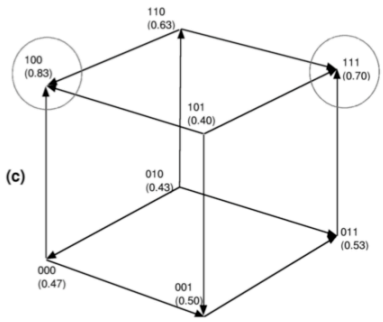
A population's adaptive evolution is illustrated by a point performing a walk towards a landscape's peak (a local maximum)

N-K fitness landscapes



(b)

c_1 c_2 c_3	f_1	f_2	f_3	$\sum_{i=1}^{N} f_i / N$
0 0 0	0.6	0.3	0.5	0.47
0 0 1	0.1	0.5	0.9	0.50
0 1 0	0.4	0.8	0.1	0.43
0 1 1	0.3	0.5	0.8	0.53
1 0 0	0.9	0.9	0.7	0.83
1 0 1	0.7	0.2	0.3	0.40
1 1 0	0.6	0.7	0.6	0.63
1 1 1	0.7	0.9	0.5	0.70

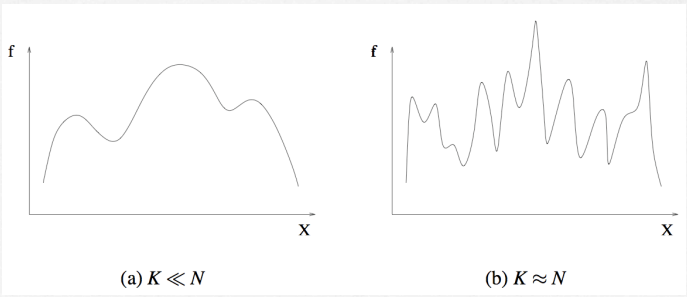


- Component's context: it is defined by randomly choosing k other components
- Component's contribution: it is defined by a random value between 0 and 1.0
- The overall system's value is the mean of the contribution of its components

Patricio Lerena, PhD thesis, University of Fribourg, 2003

N-K landscape "ruggedness"

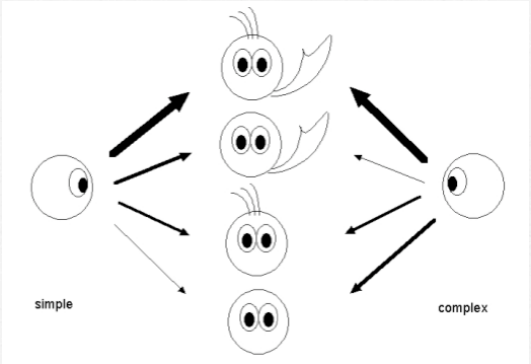
- Increasing K rapidly increases the number of local maxima and decreases the correlation among neighbors
- The fitness of local optima tends towards the mean for increasing K and N (complexity catastrophe), but the global optimum increases
- The mean adaptive walk length (towards a local maximum) decreases



(a) $K \ll N$ (b) $K \approx N$

Lerena's model of "good taste" mate choice

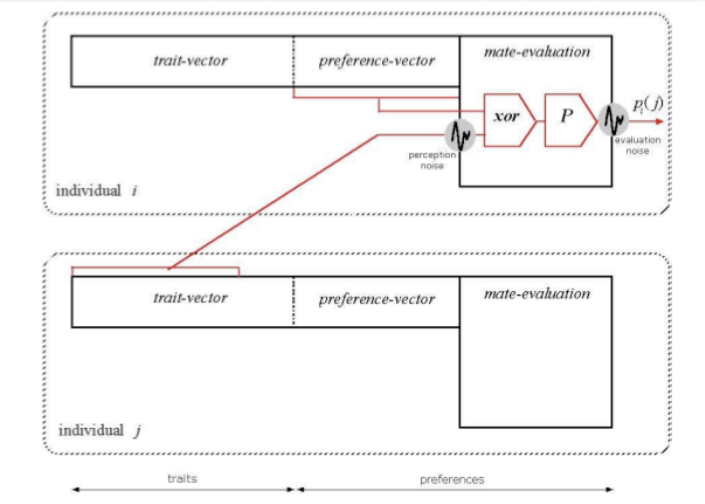
Patricio Lerena, freelance researcher

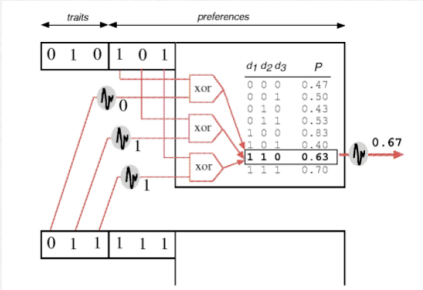


Simple vs complex mating preferences: the complexity level refers to the degree of interaction in the evaluation of traits

Patricio Lerena, PhD thesis, University of Fribourg, 2003

Lerena's model of mate choice





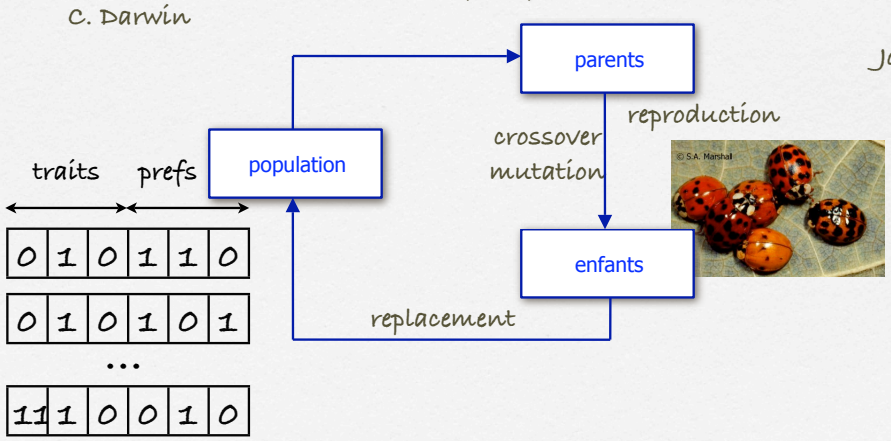
Mate evaluation

Artificial evolution

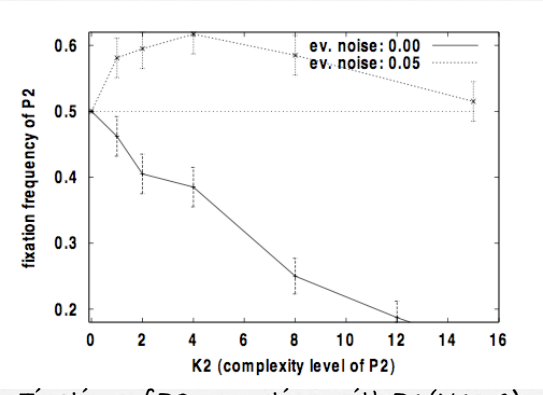
C. Darwin

artificial selection
"survival of the fittest"

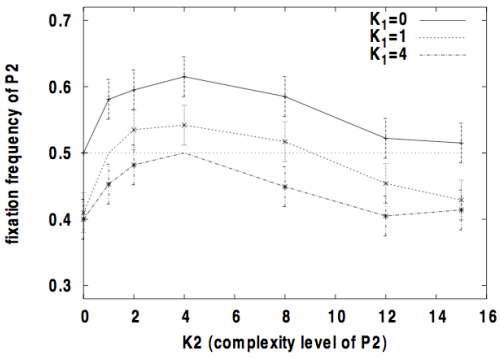
John Holland



Lerena's experiments



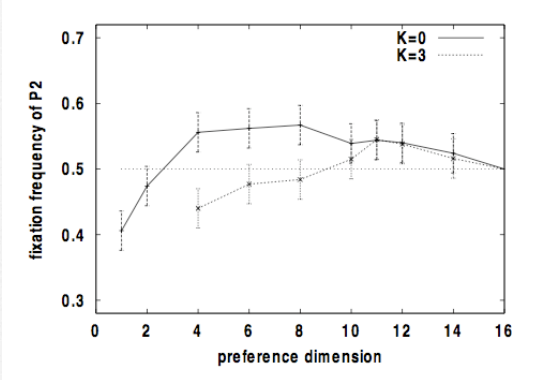
Fixation of P2 competing with P1 (K1=0)
N = 16



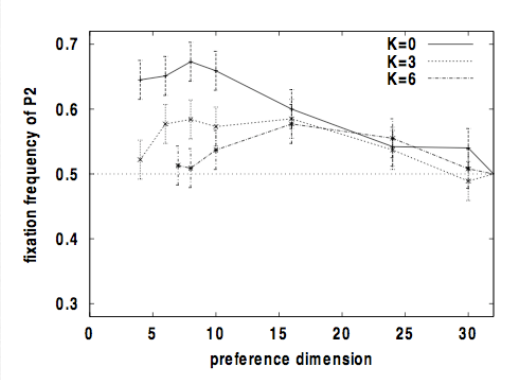
Fixation of P2 competing with P1,
N=16, evaluation noise = 0.05

When evaluation noise is present, moderate evaluation complexity should be favored

Lerena's experiments (2)



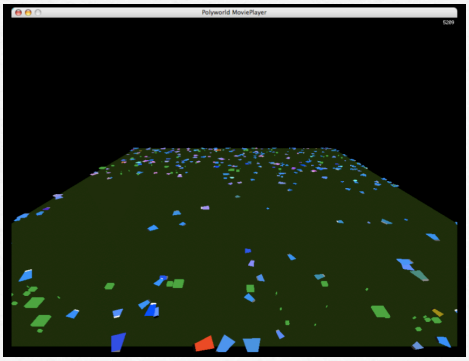
Fixation of P2 competing with P1 (N1=16),
evaluation noise = 0.05



Fixation of P2 competing with P1 (N1=32),
evaluation noise = 0.05

When evaluation noise is present, preferences should tend to inspect a moderate number of traits

Polyworld - evolving neural complexity
(Larry Yaeger & Olaf Sporns)

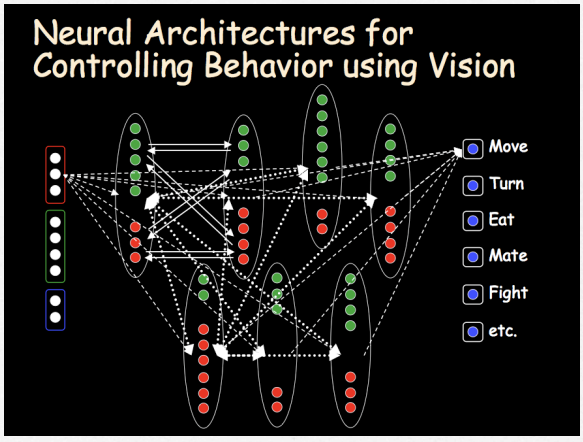


Polyworld

L. Yaeger

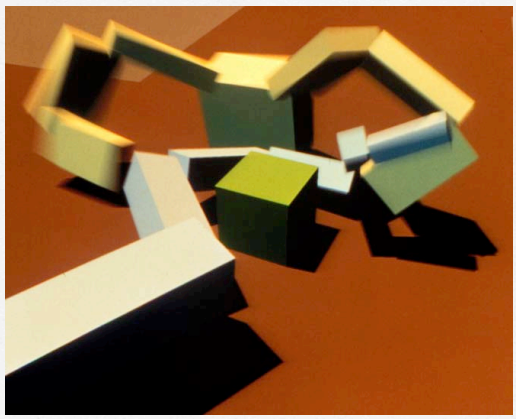
- Yaeger was Apple distinguished scientist and conceived the Newton's "Print Recognizer"
- Yaeger et al.'s last paper on Alife XI (2008)
- Yaeger's paper on Alife III (1994)
- They seek an "ecological explanation"

Polyworld neural network evolution



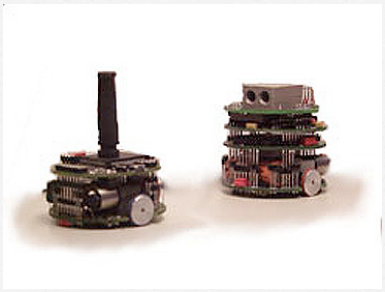
Emergent behaviors: foraging, grazing, swarming

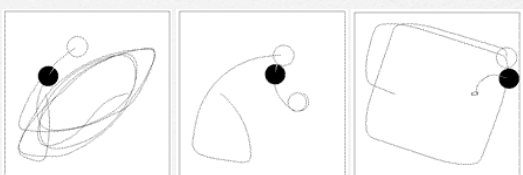
Creatures



Karl Sims (Alife IV, 1994)

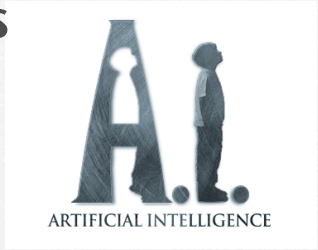
Embodied experiments of neural network evolution





Prey-predator (Floreano & Nolfi 98)

Concluding remarks



- Alife models of Machiavellian intelligence and sexual selection brain evolution shall be explored in order to support (or not) these hypotheses
- Embodied models shall lead us to more complex behaviors
- AI should pay more attention to the social complexity of our society if we want to have one day robots among us, and behaving as they do in the movies