How Concepts of Evolution Fertilized Complex Systems Theory?

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“Darwin was a Newtonian without his knowing”

(Otto Rössler)

“Modern thought is most dependent on the influence of Charles Darwin”

(Ernst Mayr)
1. How Darwin fertilized theories about the emergence of physical, biological and social complexity?

2. How do we see now the hypothesis which states that the evolution is irreversible?

3. Is natural selection, i.e. a spontaneous mechanism sufficient to develop moral rules of cooperation from the interaction of self-interested people?

4. Can we establish "artificial life" and "artificial societies" by evolutionary computational models?

5. Conclusions
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

- Darwin founded a new branch of life science: evolutionary biology:
  - non-constancy of species
  - branching (instead of linear) evolution
  - gradualism
  - mechanism: natural selection. Causal (without 'final cause') and not teleological description
  - natural selection is neither purely deterministic nor purely random
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Newtonian Clockwork Universe

Mechanical clock and feedback control: the “verge-and-foliot” escapement

The measurement of time is reduced to define a unit, and a counter to count the impacts (“ticks and tocks”). While mechanics is generally considered as a discipline dealing with smooth, continuous motions, the clock itself is a mixture of continuous and discrete devices.
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Newtonian Clockwork Universe

- Mechanical clock: measures the continuous irreversible passing time, it is based on periodic motion and on control processes.

- Nicole d’Oresme) (1323–1382): the Universe as a big mechanical clock created and set by God.

- Clockwork analogy was used by Descartes to describe the human body (excluding mental activity).

- Darwinian evolution theory sees natural selection as a The Blind Watchmaker. Dawkins: the watchmaker analogy is ”as mistaken as it is elegant”.

How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Evolution of Physical, Biological and Social Complexity
Boltzmann, Darwin, Marx and the intellectual modernism
László Ropolyi (1982)

Boltzmann: derived a relationship between entropy, i.e. a macroscopic quantity, and the micro states of matter by defining a quantity (expressed with microscopic characteristics) which had a never-decreasing property in time

Randomness and irreversibility
Debates on the he recurrence paradox (Nietzsche-Boltzmann-Poincare-Zermelo): statistical character of second law of thermodynamics
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Evolution of Physical, Biological and Social Complexity

**Statistical assumptions**: such concepts as “probability” and “randomness” became legitimate notions of modern science.

Connection between:
microscopic, discrete, stochastic and macroscopic, continuous, deterministic models
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Evolution of Physical, Biological and Social Complexity

Boltzmann had a tremendous admiration for Darwin and he wished to extend Darwinism from biological to cultural evolution. In fact he considered biological and cultural evolution as one and the same things. ... In short, cultural evolution was a physical process taking place in the brain. Boltzmann included ethics in the ideas which developed in this fashion ... (S.R. de Groot)

**Statistical assumptions** behind evolutionary changes: large number of small variations

Debates on the statistical assumptions:

Gradual evolution $\leftrightarrow$ Gaussian distribution.

Punctuated equilibrium $\leftrightarrow$ extreme value statistics
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Evolution of Physical, Biological and Social Complexity

Malthus: The disputed bridge between biology and political economy (between Darwin and Marx) (population thinking)

Marxian political economics:
+ mechanisms: struggle among classes
+ theory: how economic systems change over time
+ not too different in its intention what is now ”evolutionary economics”

Self-regulated market vs. central planning: Is the debate over??
Alan Greenspan in 2008 October admitted that he had put too much faith in the self-regulating power of free markets
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Evolution of Physical, Biological and Social Complexity

Self-regulation, Mechanism and Organisms: Back to Cybernetics
Warren McCulloch and Norbert Wiener: logics, neuroscience, human knowledge feedback mechanisms in biological, technological and social systems, by the aid of concepts like circular causality and self-regulation,
How Darwin fertilized theories about the emergence of physical, biological and social complexity?

The Evolution of Physical, Biological and Social Complexity

Robert Rosen (1934-1998). EVOLUTION of LIFE is NOT the CONSTRUCTION of a MACHINE. Organisms: not only make and reproduce themselves, but are also able to repair themselves. Cells as self-referential systems. Systems biology (often without knowing it) rediscovers Rosen’s concept.
How do we see now the hypothesis which states that the evolution is irreversible?

Dollo’s law in retrospective

- Evolution is irreversible: Louis Dollo (1857–1931), a paleontologist
- Dollo’s law: observational statement
- New morphological structures established by complex adaptive steps don’t resemble an ancestral condition.
- It is not an absolute rule, and reversal of isolated characters (such as size) was not excluded.
- Structures or functions discarded during the course of evolution do not reappear in a given line of organisms. If a species becomes extinct, it has disappeared for ever.
- Recent debates about a set of findings, which state the reversal of certain morphological characters
How do we see now the the hypothesis which states that the evolution is irreversible?

Dollo’s law in retrospective


1. An a priori assumption that a whole organism never reverts completely to a prior phylogenetic stage.

2. A testable hypothesis that a complex part of an ancestor never reappears in exactly the same form in a descendant.

3. Certain evolutionary trends are necessarily unidirectional. This interpretation can be attached only to a very few of Dollo’s statements. If this thought was in Dollo’s mind at all, it played an extremely minor role in his thought on irreversibility
How do we see now the hypothesis which states that the evolution is irreversible?

Dollo’s law in retrospective: Re-evolution?

- While probably very few (if any) evolutionary biologists would suggest that long-term evolution would be reversible at all levels of biological hierarchical organization, since a series of steps back would be highly improbable, the reversibility of evolution for particular phenotypes is a controversial issue.

- Reverse evolution (or re-evolution): the reacquisition of the same character states, including fitness, as those of ancestor populations by derived populations.

- There are a few examples when re-evolution was accomplished under laboratory conditions, and there are few instances where reverse evolution has been observed in nature.

- Loss and recovery of wings in stick insects
How do we see now the hypothesis which states that the evolution is irreversible?

Dollo’s law in retrospective (Günther Wagner)

1. the whole (evolutionary) trajectory cannot be reversed

2. the exactly same genotype cannot be re-evolved

3. assuming the existence of different developmental pathways, in a weak sense the process is re-evolutionary, if an ancestral state is attained by any mechanism
How do we see now the hypothesis which states that the evolution is irreversible?

Is something never-decreasing during evolution? Fisher’s fundamental theorem (modern terminology):

"The rate of increase in the mean fitness of any organism at any time ascribable to natural selection acting through changes in gene frequencies is exactly equal to its genetic variance in fitness at that time”.

- $x_i$: the gene frequency of the allele $i$
- $\sum_i x_i = 1$, $f_i$: individual fitness,
- $\Phi := \sum_i x_i f_i$: mean fitness

variance of $\Phi$:

$$\text{var}(\Phi) = x_i (f_i - \Phi)^2 \quad (1)$$

variance measures the “spread” of the individual values. The smaller the variance the more closer are the individual values to each other.
How do we see now the hypothesis which states that the evolution is irreversible?

Is something never-decreasing during evolution?
Fisher’s fundamental theorem

“...It will be noticed that the fundamental theorem proved above bears some remarkable resemblances to the second law of thermodynamics... Both are statistical laws; each requires the constant increase of a measurable quantity...”

Difficulties about the interpretation

Since variance is a never-decreasing quantity, any non-zero variance implies the increase of the average fitness. Fisher knew that his theorem was not about the total change in mean fitness, but rather the change in mean fitness due to natural selection operating in a constant environment. The correct interpretation of Fisher’s theorem was given by George Price (1922-1975), and led to the formation of evolutionary game theory. From ecological perspective Fisher’s theorem remained fundamental.
How do we see now the hypothesis which states that the evolution is irreversible?

Adaptive Landscape

Sewell Wright: The average fitness values are plotted against the allele frequencies, and evolutionary gene frequency changes imply the increase of the average fitness of a population, i.e the system climbs on the hill towards the top during evolution.

Fitness of different combinations of genes as a hilly landscape, in which the valleys represent less-fit combinations of genes and the peaks represent the fitter one.
Is natural selection sufficient to develop moral rules of cooperation from the interaction of self-interested people?

Evolutionary Dynamics - Evolutionary Game Theory

Kin selection was suggested by William D. Hamilton (1936-2000) by using genetic arguments.

Hamilton’s rule says that:

\[ r > C/B. \]  

Here, C is the fitness cost to the altruist and B is the fitness benefit to the individual helped, and \( r \) is a measure of genetic relatedness.
Is natural selection sufficient to develop moral rules of cooperation from the interaction of self-interested people?

Direct reciprocity

mutual reciprocity; in the animal world between different species. An animal helps another and expects help back in the future ("iterative game").

Direct reciprocity can lead to evolution of cooperation if the probability $w$ of the encounter between the same individuals should be larger than the cost-benefit ratio of the altruistic act:

$$w > C/B.$$
Is natural selection sufficient to develop moral rules of cooperation from the interaction of self-interested people?

**Indirect reciprocity**

+ a mechanism for the case even if recipients have no chance to return the help to their helper
+ helping improves reputation, which in turn makes one more likely to be helped
+ modeled as an asymmetric interaction between two randomly chosen players
+ the interaction is asymmetric, since one of them is the “donor”, who can decide whether or not cooperate, and the other is a passive recipient
+ the result of the decision is not localized. It is observed by a subset of the population, who might propagate the information
+ the decision to cooperate might increase one’s reputation

A cooperative donor would like to cooperate with a player, who is most likely a cooperator, and would not cooperate with a defector.

The probability, \( q \), of knowing someone’s reputation should be larger than the cost-benefit ratio of the altruistic act:

\[
q > \frac{C}{B}. \tag{4}
\]
Is natural selection sufficient to develop moral rules of cooperation from the interaction of self-interested people?

Network reciprocity

Well-mixed population pure natural selection would favor to defectors, interaction in real populations can better characterized by spatial structures or social networks, where the probability matrix of the binary interaction between individuals has some structure.

Effect of the network structure on evolutionary dynamics: for many network structures (including small-world and scale-free networks) a simple rule describe the condition of favoring cooperativity. The cost-benefit ratio should exceed the average number of neighbors, $k$:

$$B/C > k.$$ (5)
Is natural selection sufficient to develop moral rules of cooperation from the interaction of self-interested people?

**Group selection**

- \( n \) the maximum group size, and by \( m \) the number of groups
- A population is subdivided into groups
- Cooperators help others in their own group, defectors do not help
- Individuals reproduce proportional to their payoff: offspring are added to the same group
- If a group reaches a certain size, it can split into two
- Another group becomes extinct in order to constrain the total population size
- Only individuals reproduce, but selection emerges on two levels

Under certain conditions, group selection supports evolution of cooperation if

\[
B/C > 1 + (n/m)
\]  

(6)
Is natural selection sufficient to develop moral rules of cooperation from the interaction of self-interested people?

Constructive evolution?

Evolutionary game theory suggests that selection and mutation, the fundamental principles of evolution can be supplemented with possible mechanisms for the evolution of cooperation. In each mechanism the benefit-to-cost ratio of the altruistic act should exceed some critical value. The appropriate ratio between competition and cooperation may be the driving force of constructive evolution.
Can we establish "artificial life" and "artificial societies" by evolutionary computational models?

Digital evolution Hommage a Michael Conrad

Michael Conrad (1941-2000) was a pioneer of simulating evolution around 1970 studied a model of the evolution of an artificial open-ended ecosystem. Individuals with given genotypes were defined, and these genotypes were interpreted as instructions, leading to phenotypes. The organisms competed in a simple one-dimensional world for the possession of resources which they use for self-repair and reproduction. Interactions between organisms for providing co-evolutionary selection pressure for increased complexity has been emphasized. Twenty years later his evolutionary computer simulations became more realistic.
Can we establish "artificial life" and "artificial societies" by evolutionary computational models?

Digital evolution Tierra
Thomas Ray

- an abstract, not too biologically detailed model

- programs are able to mutate, replicate and recombine (also called crossover).

- evolution is embedded in a computer, and programs evolved by the rules of evolution

- artificial evolution has two goals
  - first, to help in understanding real biological evolution
  - second, to provide evolutionary computational algorithms to solve hard optimization problem.
Can we establish "artificial life" and "artificial societies" by evolutionary computational models?

Digital evolution Tierra
Motivations

- Life on Earth is a single example of evolution (sample size of one)

- it is possible (to create and observe a new and independent instance of evolution,

- it is possible broaden our perspective of evolution by increasing the sample size (to more than one)

- is possible to observe the properties of evolution in a (silicon-based) digital medium. According to this approach, real carbon-based biology is not the essence of an artificial evolutionary systems.

Digital evolution is not constrained by the laws of our physics. Cyberspace is nothing to do with our 3D Euclidean space. The laws of conventional physics and chemistry of our organic medium is replaced by the rules of the program languages and operating systems used in the digital medium.
Can we establish "artificial life" and "artificial societies" by evolutionary computational models?

Digital evolution Avida
Charels Ofra and Richard Lenski (now at Michigan State Univ.)

extension of Tierra at least in two respects;

- each program is stored in a different part of the memory
- the speed of the program running may be different for the individual programs,

“digital organisms in Avida evolve to survive in a complex computational environment and will adapt to perform entirely new traits in ways never expected by the researchers, some of which seem highly creative.'
Can we establish "artificial life" and "artificial societies" by evolutionary computational models?

Digital evolution

“... Of course, digital organisms differ from organic life in their genetic constitution, metabolic activities and physical environments. However, digital organisms undergo the same processes of reproduction, mutation, inheritance and competition that allow evolution and adaptation by natural selection in organic forms.”

- Genetic algorithms
- Genetic programming
- Artificial societies

Generative (constructive) modeling
Yes