Short Course in Biosemiotics

2. Evolution of Natural Agents: Preservation, Development, and Emergence of Functional Information

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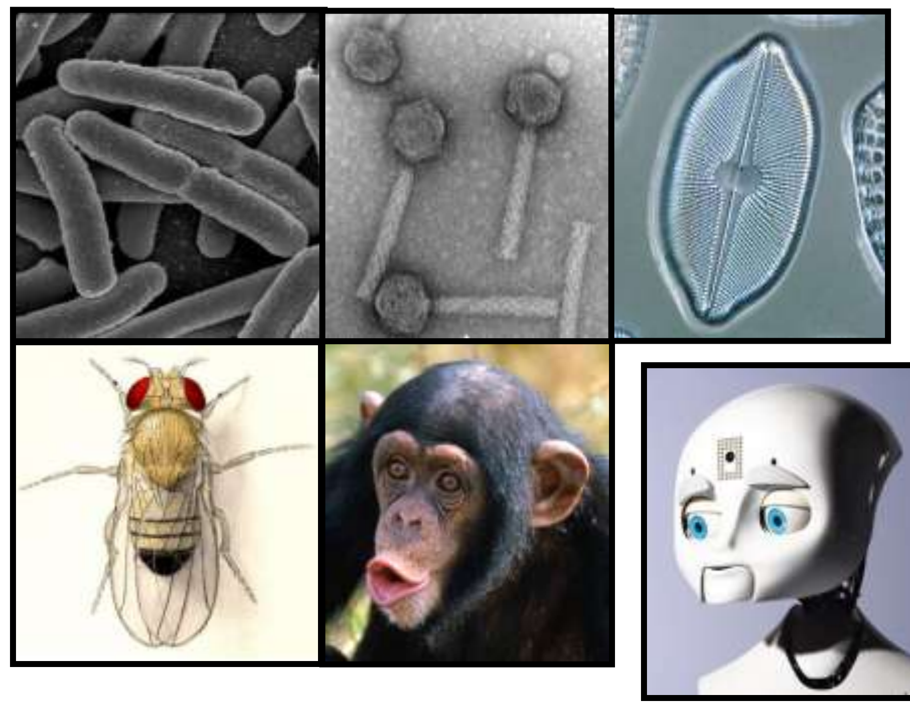


The “modern synthesis” is incomplete and often misleading

Myths of the “modern synthesis”:

1. Organisms are <u>copied passively</u>
2. “Natural selection” is a <u>passive sieve</u> (Nature is a “blind watchmaker”)
3. Heritable variations are <u>random</u> and not controlled by organisms
4. Heritable variations are <u>small</u>
5. <u>Fitness can be predicted</u> for any genotype
6. <u>Competition</u> is the major driving force in evolution

Topics ignored by the “modern synthesis”:

1. Macroevolution and increase in complexity
2. Directionality of evolution
3. Adaptability
4. Role of embryonic development in evolution
5. Molecular mechanisms (e.g., epigenetics, compensatory ptheways)
6. Horizontal transfer of genes
7. Baldwin’s effect
8. Evolution of artifacts

Can biosemiotics help to update the theory of evolution?

Living organisms are "natural agents"

Functional information = a set of signs that encode and control actions of agents

Function = a reproducible* sequence of actions that is beneficial at some level of the hierarchy of agents

Evolution of agents = **evolution of functional information**

* To be reproducible, functions have to be encoded by functional information

Agents are not digital

Agent = functional information + interpretation module

A new agent should be supplied with:
(a) copy of functional information
(b) minimal interpretation module (including tools and resources).

The interpretation module is encoded by functional information. But to use this information, the agent needs a physically existing interpretation module.

Thus, functional information and interpretation module are <u>equally important</u> and non-separable.

Agents are active players in evolution

1. Selection is done by agents (not by “Mother Nature”). Organisms select their actions based on functional information.

2. “Struggle for existence” is a better term than “natural selection” because it captures the activity of organisms and their goal-directed behavior

3. Organisms/agents are active in performing their functions, including self-reproduction (i.e., there is no “passive copying”)

4. Agents follow the program (i.e., functional information) but they also manipulate their programs at a larger time scale or switch from one program to another

Two meanings of signs in biosemiotic interpretation of evolution

Meaning #1 = meaning assigned by a scientist who studies living organisms

Meaning #2 = internal meaning within the living agents

Meaning #1 = Meaning #2 ?

Does the cell associate a triplet of nucleotides with aminoacid?
Does the cell "compose its genes"?

Populations ("swarm agents") can manipulate genes at the nucleotide level via mutations in individual organisms and genetic selection.

Three components of the evolution of functional information

1. Preservation of functional information

Preservation of functions does not generate novelty (globally), but without preservation evolution would not be possible

2. Development of functional information

Improvement and modification of already existing functions via random or targeted search within constraints of the internal logic of agent behavior and development

3. Emergence of new functions

Emergence is a fast qualitative change of functions that is based on a new interpretation of already existing signs

1. Preservation of functional information

Evolution requires preservation of functions in agents

The only way to preserve functions is to encode it in functional information and preserve it within individual life of agents (memory) as well as in the sequence of generations (heredity)

Memory and heredity are examples of self-communication

Other kinds of communication in agents:

Horizontal communication

Examples: horizontal gene transfer, communication between humans

Reprogramming of other agents

Examples: programming of subagents (e.g., ribosomes, computer)
Parasites reprogram their hosts (viruses, insect parasites).
Prey reprogram predators via mimicry
Reprogramming in the human society: media, propaganda

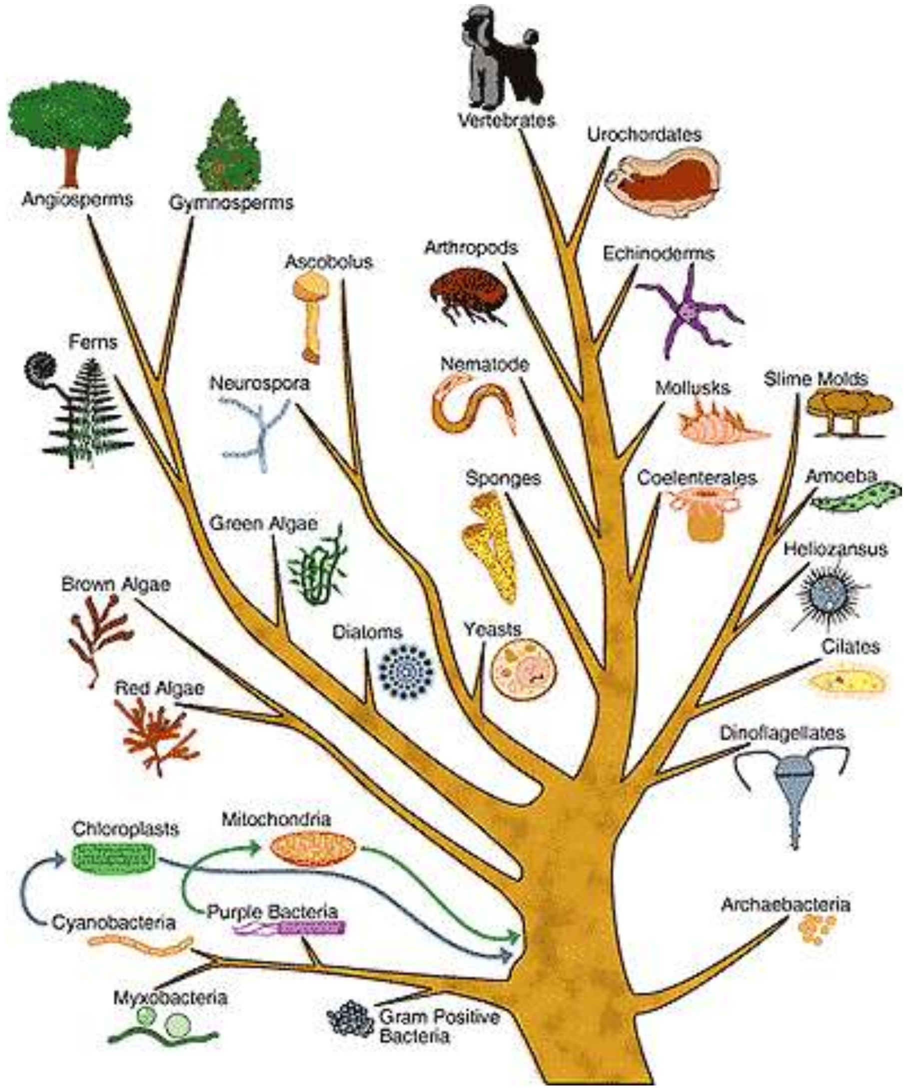
Individuation of communication systems

Organism – individual memory

Family/colony – inter-family signs

Species – genetic communication of genome variants

Phylogenetic lineage – genetic communications of high-level variations



Genetic code versus "Da Vinci Code"

Marcello Barbieri: Code is a correspondence between signs and "meanings" (e.g., DNA triplets and aminoacids). Decoding is based on a rule (i.e., it is algorithmic, mechanical)

Dan Brown: Code is a hint for those who are eligible to know. Decoding requires active search, learning, and luck. A sign may have many meanings

In case #1, the interpreting system (cell) already "knows" the rule of the code, and in case #2, the interpreting system does not know the rule of the code

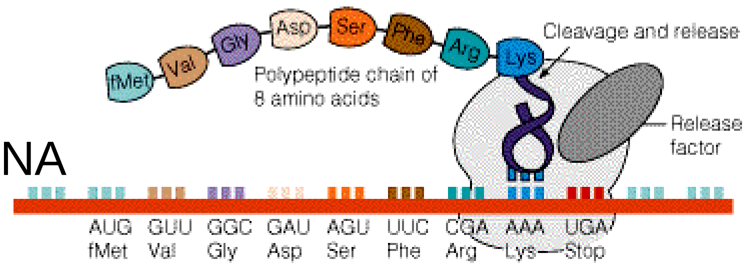
Organism: a Turing Machine or Dr. Robert Langdon?

Coding: simple and complex

1. Some decoding methods are automatic and similar to the Turing machine

Protein synthesis

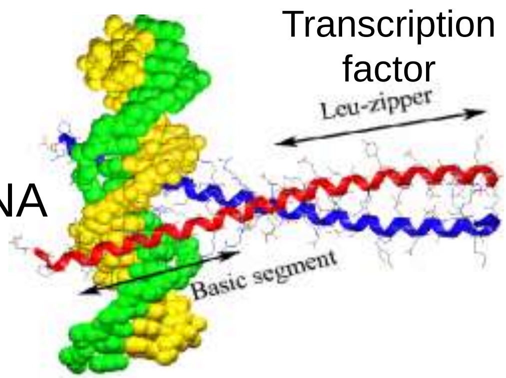
mRNA

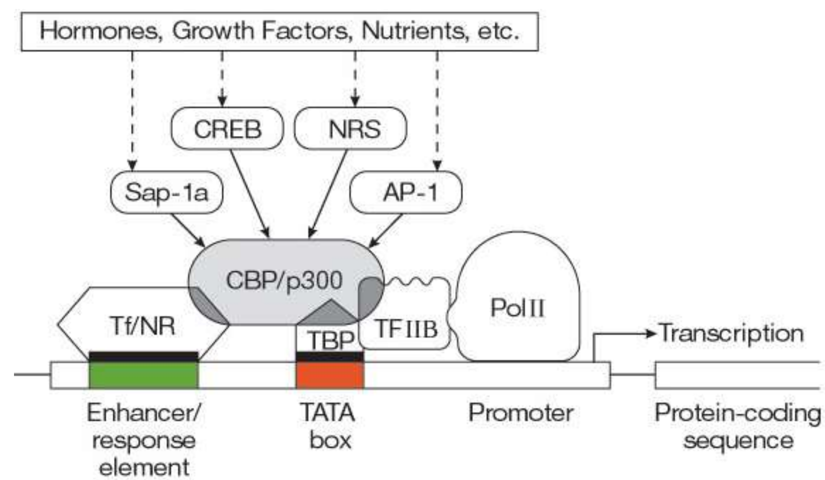


Regulation of transcription

Transcription factor

DNA

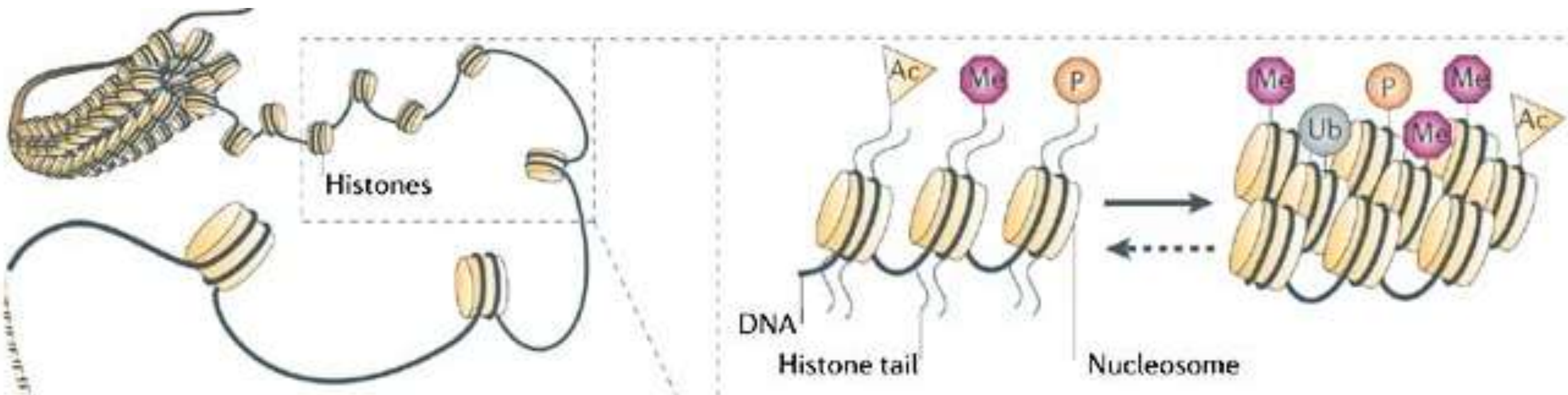




Coding: simple and complex

2. However, organisms do not have a finite and universal algorithm for interpreting the genome. Cells “learn” how to interpret the genome during development.

Chromatin structure marks the genome as we highlight the text



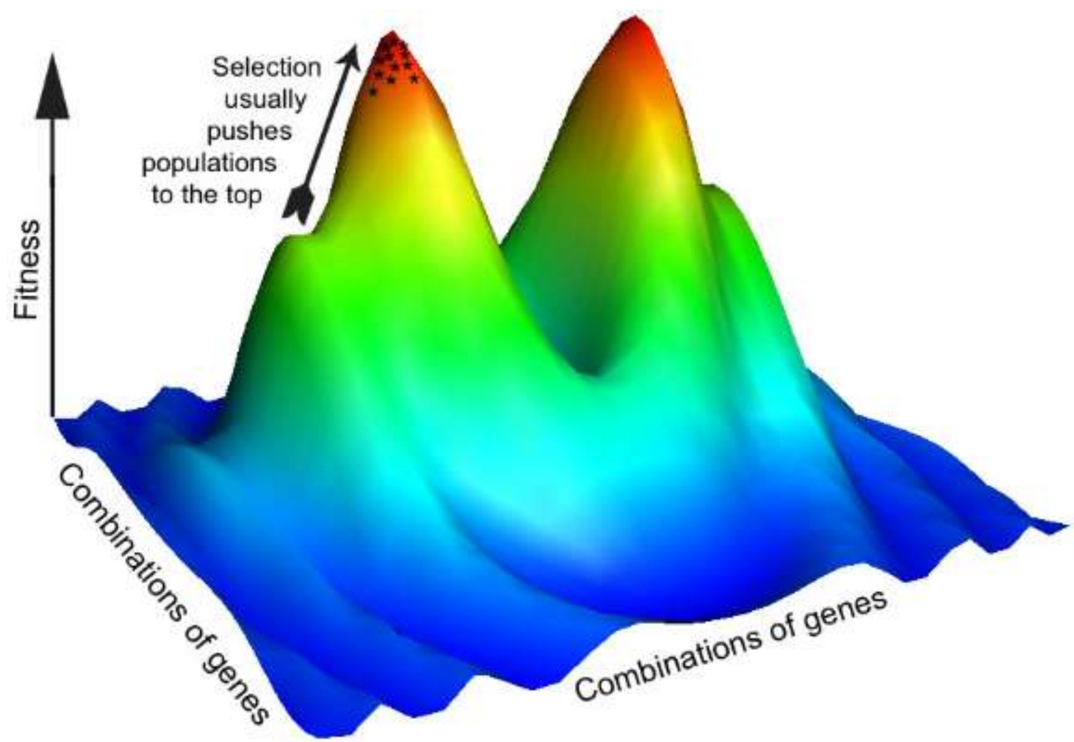
Cells and organisms make errors in the interpretation of the genome
Errors are later corrected and/or compensated

2. Development of functional information

By “development” I mean **predictable changes:**
(1) Optimization of functions
(2) Changes directed by the internal logic and directed variation

Darwinism is focused on the short-term optimization and ignores the directionality of evolution

Model of optimization via “natural selection”



The model works for a small number of genes and their variants and for short time intervals (in microevolution)

In general, the fitness landscape is not fixed

Theories that attempted to explain the directedness of evolution

1. Vitalism, Lamarckism (Hans Driesch)
2. Orthogenesis, Nomogenesis (Theodor Eimer, Lev Berg)
3. Theory of morphological field (Alexander Gurvich)
4. Self-organization versus selection (Stuart Kauffman)

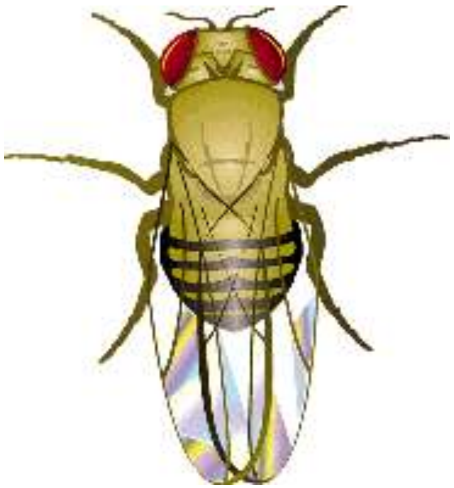
There are constraints for optimization, which may leave very limited freedom in certain dimensions

Directedness of variation may be stronger than selection pressure

With the increase of the level of organization, the role of selection decreases due to elaborate compensation mechanisms

Logic of embryo development

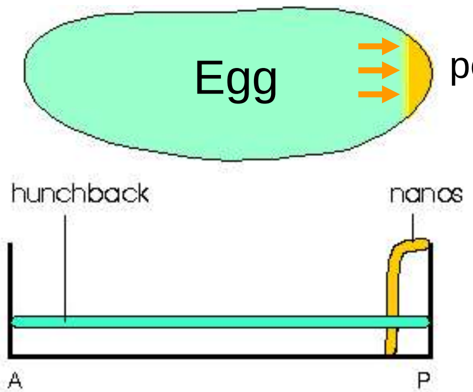
Genome encodes the mechanism of embryo development by a set of logical switches



Drosophila
fly

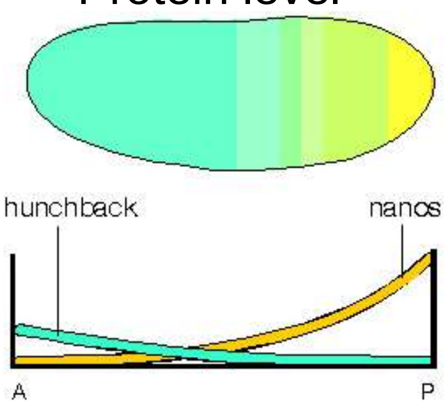
Messenger RNA

anterior



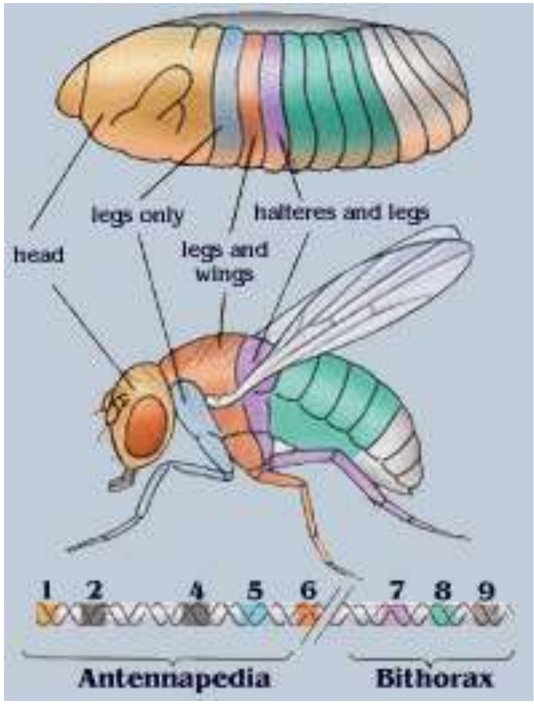
posterior

Protein level



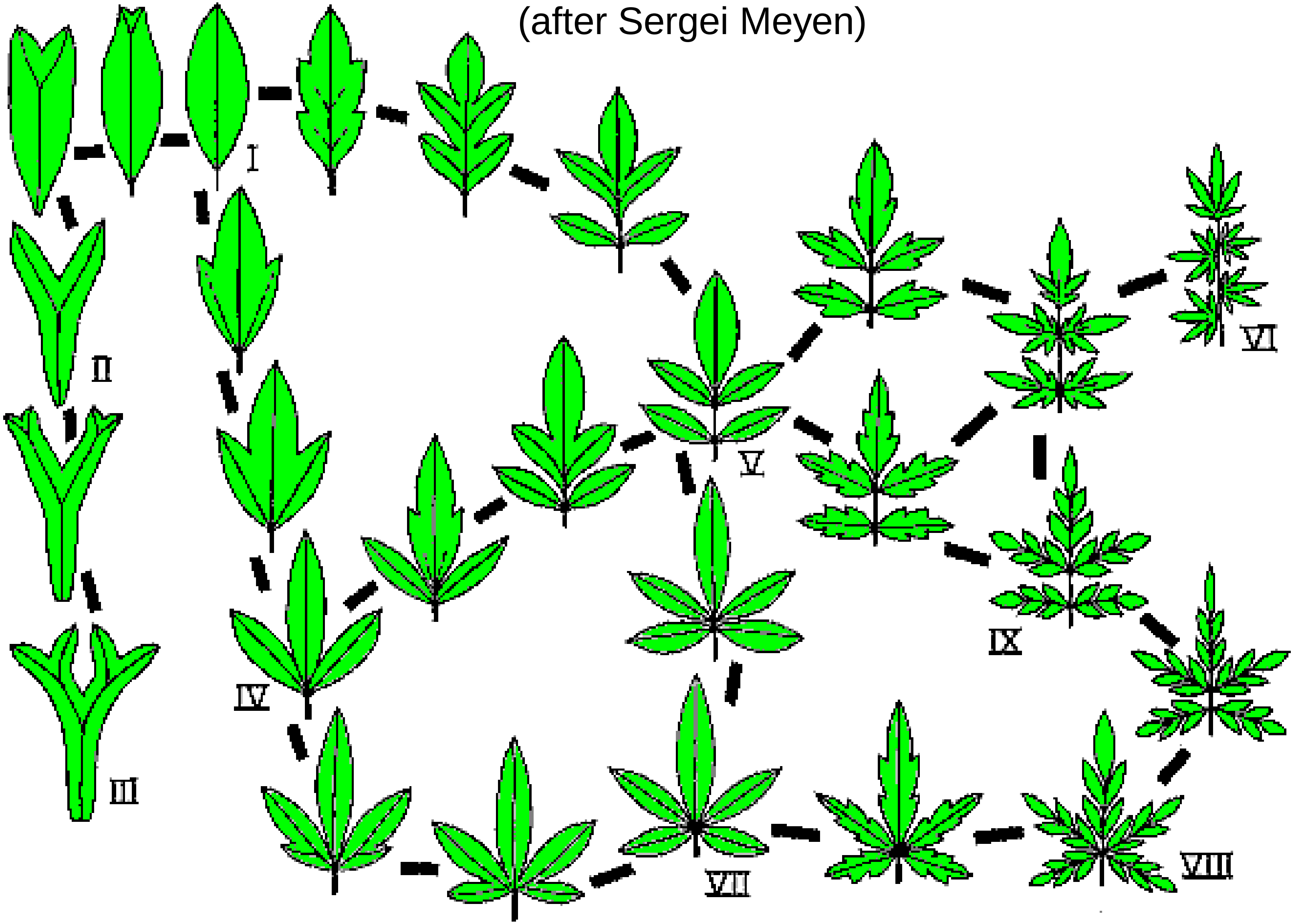
Nanos blocks translation of hunchback

Expression of homeobox genes



Logic of leaf evolution

(after Sergei Meyen)



Meyen, S.V. (1987). Fundamentals of palaeobotany. London, Chapman and Hall

Where the logic comes from?

Logic is not a product of “natural selection” because it is highly stable within each lineage due to conserved developmental programs

Vitalism, Objective idealism: logic is embedded in nature (Plato’s ideas)

Kauffman: logic comes from self-organization in nature (a free gift)

Biosemiotics: logic (adaptability) is a product of **macro-selection**

Logic is a tool for efficient derivation of useful novelties

Example: A is useful + B is useful => A+B is likely to be useful

Macro-selection:
Lineages with better logic (adaptability) will produce more species and occupy more niches, thus they contribute more to the future lineages

Self-organization is not a “free gift” but a tool picked by lineages via long-term evolution and macro-selection

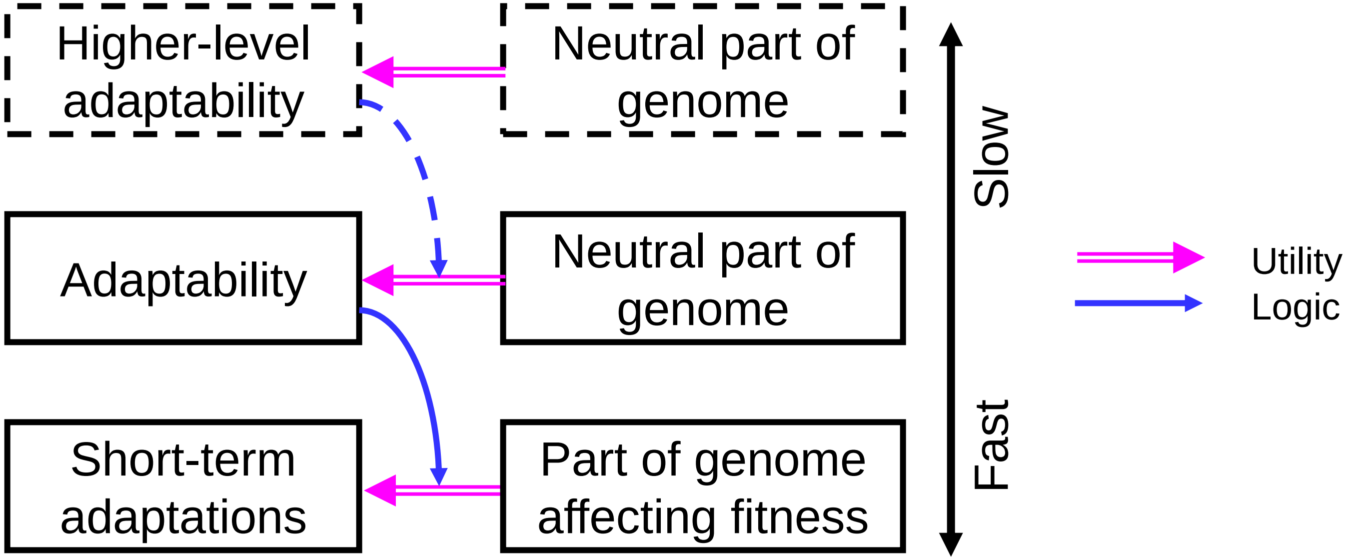
Philosophical implications

What is the balance between utility and logic in evolution?

Pragmatism and Darwinism are focused on utility
Vitalism, nomogenesis are focused on logic

Utility and logic are both important and independent factors in the short-term evolution

However, **the utility of logic is tested in macro-evolution**



Sharov, A.A. 2009. Role of Utility and Inference in the Evolution of Functional Information. Biosemiotics, **2**: 101–115. http://home.comcast.net/~sharov/pdf/functional_information.pdf

3. Emergence of new functions

- Emergence is a rapid development of new functions based on **re-interpretation of functional information**
- Emergence is **unpredictable** but some organisms have a higher capacity to capture novel functions (adaptability)

Mechanisms that facilitate emergence:

(a) Reshuffling of genes or gene fragments
(b) Dense functional networks
(c) Encapsulation of functions
(d) Reprogramming of other agents
(e) Baldwin's effect (feedback from behavior to evolution)

Encapsulation and Reprogramming

Encapsulation of developmental programs

<u>Example 1:</u> Reptiles initially used feathers for sexual display and parachuting. But the same program was applied to make feathers on wings

<u>Example 2:</u> The vertebral column and skull are generated from different cell types (paraxial mesoderm and neural crest). However, the bone is made using the same program.

Already existing signs are used to manipulate other agents

<u>Example 1:</u> cAMP is a signal of starvation within a cell. But in slime molds, cAMP is secreted and used to orchestrate the formation of a fruiting body

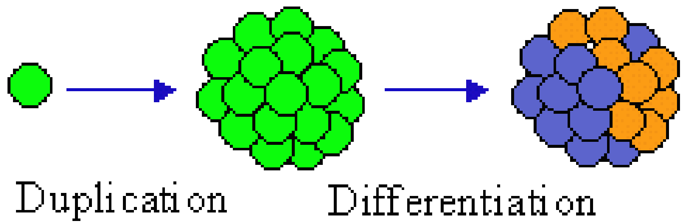
<u>Example 2:</u> Insect parasites utilize hormones to manipulate the development of their host

<u>Example 3:</u> Colony formation; symbiogenesis

Emergence of new hierarchical levels

Valentin Turchin

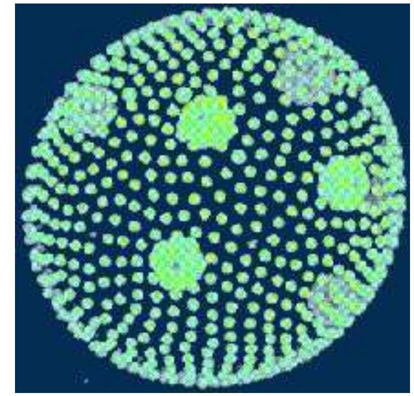
Theory of metasystem transition

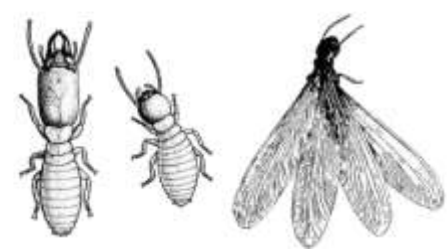


Organism and its sub-agents participate in different communication systems

1. Genetic inheritance
2. Intra-cellular communication
3. Inter-cellular signals
4. Hormonal communication
5. Neural signaling and memory
6. Social communication

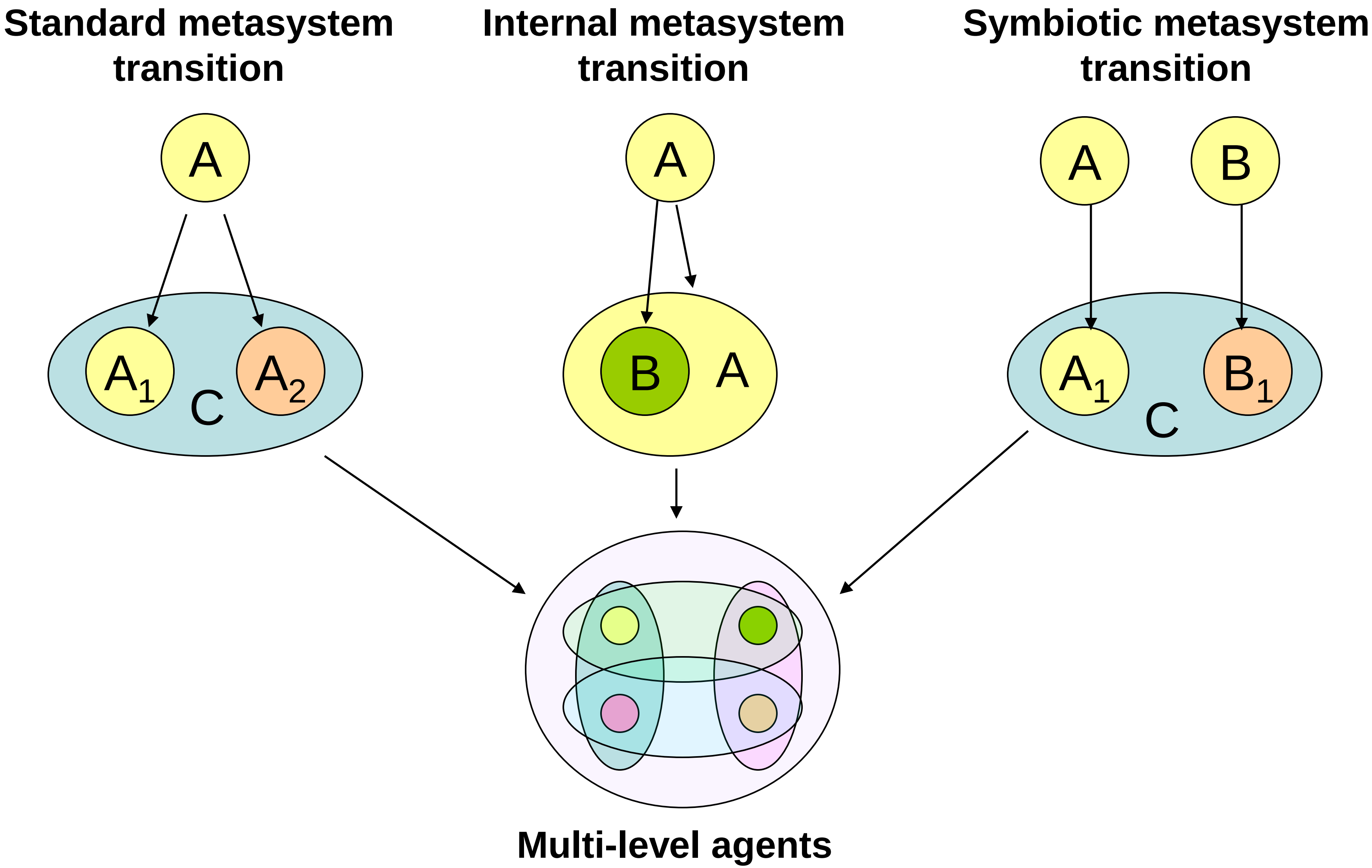
Examples





Turchin, V. F. 1977. The phenomenon of science. New York: Columbia University Press
http://pespmc1.vub.ac.be/PoS/TurPOS-prev.pdf

Types of metasystem transitions



Baldwin's effect

Feedback from behavior to evolution can facilitate re-interpretation of existing functional information

James Mark Baldwin

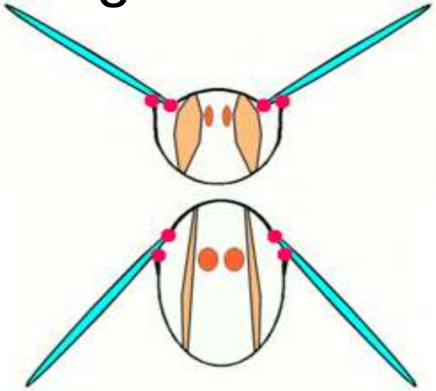
Animals may find new applications for their existing organs (new functions)

The change of behavior reshapes the fitness landscape

As a result, organs will start evolving in a new direction - towards optimization of the new function

High rates of evolution in mammals and birds is possibly related to the Baldwin's effect

Example: emergence of insect flight



Evolution of functional complexity

In 2006, I proposed that functional complexity of living organisms should increase exponentially and thus can be used as a clock for life origin and evolution

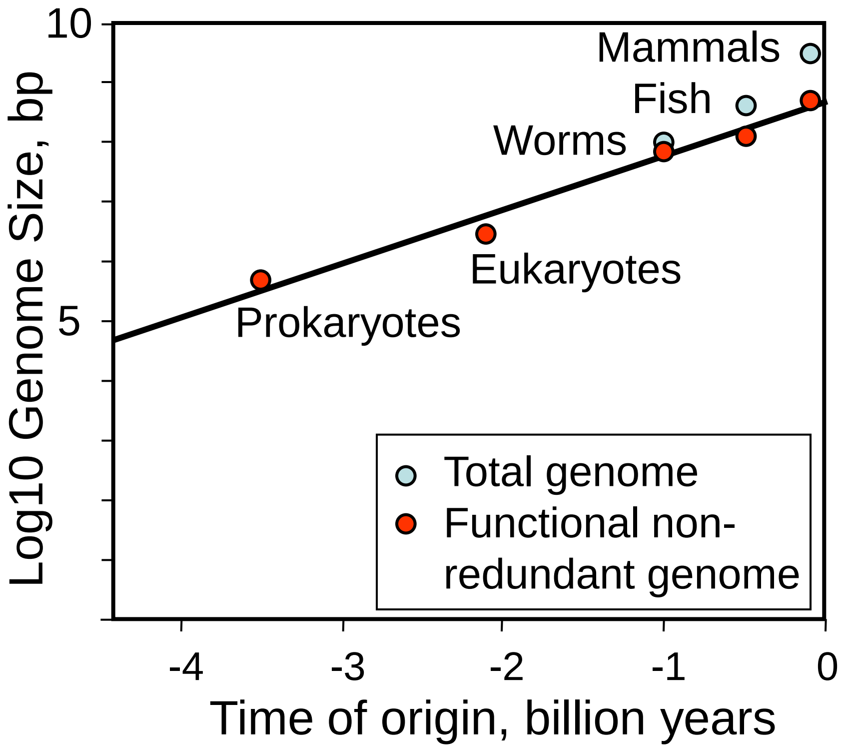
Functional complexity	=	**Amount of functional information accumulated in evolution**	~	**Length of functional and non-redundant fraction of the genome**

Mechanisms of positive feedback:

1. Gene cooperation (hypercycle effect)
2. New genes originate as copies of existing genes (branching effect)
3. Existing functional complexity creates new functional niches for novel genes (niche effect)

Sharov AA. 2006. Genome increase as a clock for the origin and evolution of life. Biol Direct. 2006 Jun 12;1:17. http://home.comcast.net/~sharov/pdf/GenomeIncrease.pdf

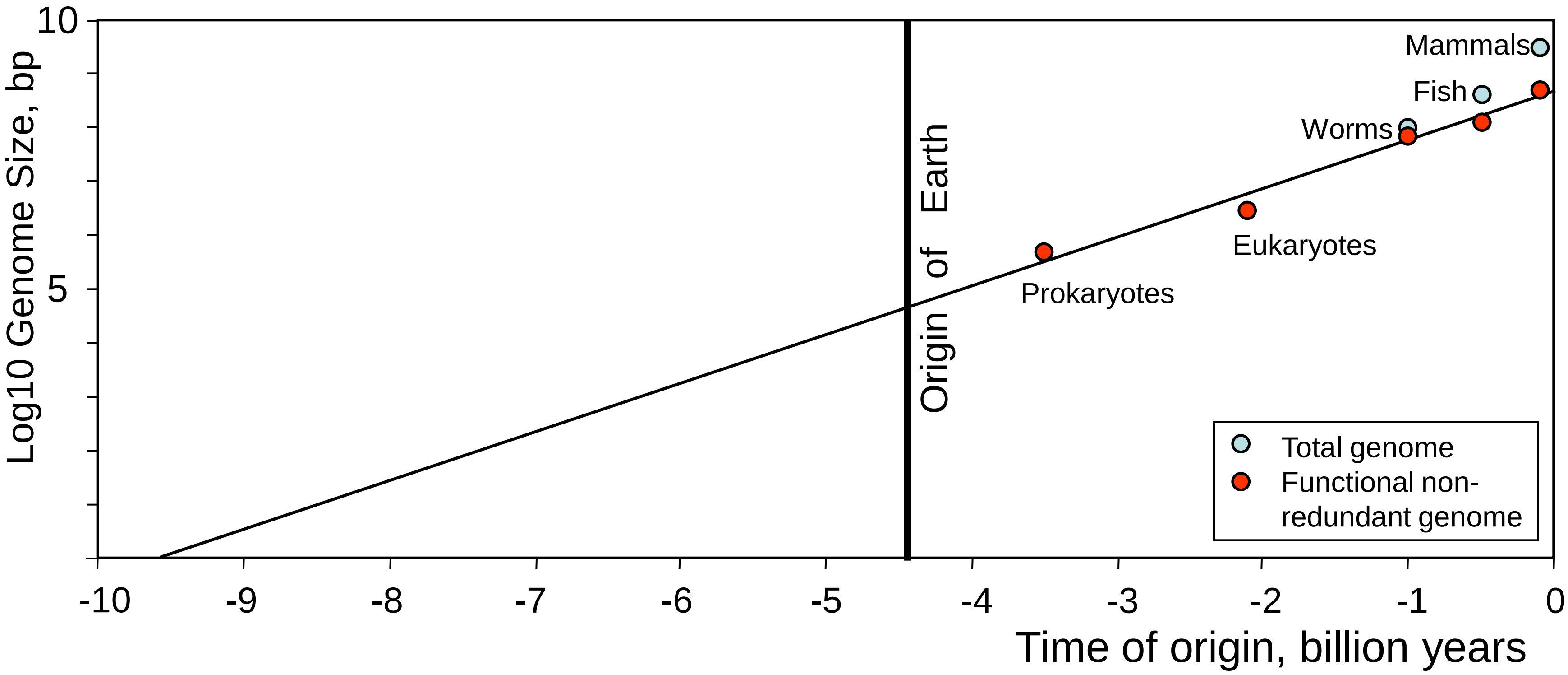
Genome complexity increased exponentially in biological evolution



Principle of gradualism:

Functional complexity of produced agents cannot be much higher than the functional complexity of parental agents

Genome complexity increased exponentially in biological evolution



Hypotheses:

Life originated long before the origin of Earth, hence we have to assume that Earth was contaminated with bacterial spores (panspermia)

Possibility of Panspermia

Zagorski: sterilizing effect of radiation makes the interstellar transfer of bacterial spores impossible.

However, survival of a few spores is sufficient to transfer life. This possibility cannot be rejected based on the mortality rates of spores.

Earth could have been contaminated with spores originated from the parental stellar system and retained in rogue planets. This makes the travel shorter.

Clostridium bacteria seem to be closest to the “founder” of life on Earth (have spores, survive deep underground, autotrophic)

For details see:

Wallis, M.K., Wickramasinghe, N.C. 2004. Interstellar transfer of planetary microbiota. Mon. Not. R. Astron. Soc., 348: 52-61.

Conclusions

1. To overcome the crisis in evolutionary theory biologists need to consider the semiotic nature of biological evolution
2. Organisms are agents who select their actions. In particular, survival and reproduction are not passive (i.e., “struggle for existence” is a better metaphor than “natural selection”)
3. Communication processes support life functions at various levels of organization: in organisms, organs, tissues, cells, and even molecules. Thus, biological evolution is the evolution of communication systems
4. Evolution of functional information has three main components: preservation, development, and emergence
5. Utility and logic are both important and inependent factors in the short-term evolution, However, the utility of logic is tested in macro-evolution
6. New functions emerge via re-interpretation of functional information
7. Re-interpretation can be facilitated by behavioral change (Baldwin) or cooperation (metasystem transition)
8. Dynamics of functional complexity suggests extraterrestrial origin of life