Increasing Information and Self-Organized Complexity: Some Examples

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Punchline

1) There are many kinds of information.
2) Natural processes can **create** vast amounts of some kinds of information.
3) Natural processes can **convert** some kinds of information into other types.
4) We can understand, and at least partially model, where the information comes from each step of the way from particles-at-the-Big-Bang to ecosystems-of-complex-organisms.

Outline: Many types of information

Information required to specify…

1) Rules and initial conditions

2a) Combinatoric possibilities

2b) Paths through "combinatoric space"

3) Contingent history of system

4) Full description of environment

5) Full description of interesting object (e.g. self-replicator) within an environment

6a) Description of "interesting features" of environment for the self-replicator

6b) Full "genome" of a self-replicator

7) Interdependent complexity of a portion of a genome required to perform a selected function

Combinatoric possibilities

- Small number of basic pieces can combine in a vast number of ways.
  - Information required to specify the **rules and initial conditions** is small, but information required to specify **combinatoric possibilities** is huge.

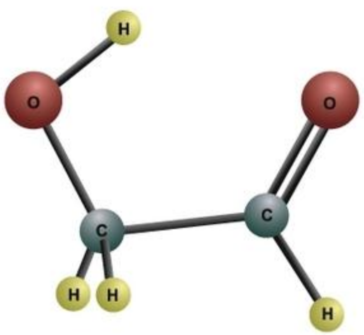
Example:

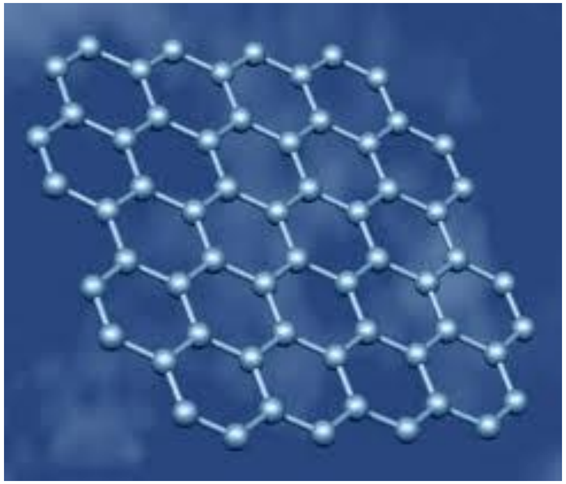
- 64 squares on a chess board, 32 chess pieces (12 types of pieces)
- Can be arranged $\frac{(64!)(32^2)}{(8!)(2^7)}$ ≈ 10^{85} ways.

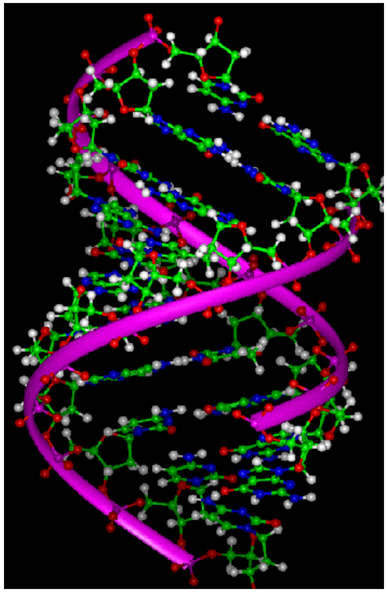
Combinatoric possibilities

Example:

- 3 particles (electron, up and down quarks)
- Can be arranged into ~100 different atoms
- … can be combined into billions of different molecules, each with unique properties
- … can be combined into mind-bogglingly many different substances, objects, living cells…







Combinatoric possibilities

Example:

- 4 nucleobases: ACTG
- Can be arranged into 4^N different DNA strands of length N.

Paths through combinatoric space

"Laws" (both deterministic and probabilistic) specify **allowed "moves" from one location in combinatoric space to another** and the probabilities of each move happening. This can create a **vast web of possible pathways** which takes astronomical information to completely describe.

Examples

- From standard starting chess position: ~10^{120} different possible games.
- Starting from a vat of chemicals and energy inputs: reaction pathways produce N=??? new molecules.
- Point mutations, transpositions, duplications, deletions, and other mutations connect genomes to other genomes with various probabilities.

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Contingent History of System

- Each time a “contingent event” happens – selecting one path in combinatoric space rather than another – the **contingent history information increases**.

- Each contingent event converts some of the **“potential information”** of combinatoric space pathways **into “real information”** which describes actual games, actual objects, actual environments, actual computer programs, or actual genomes.

Contingent History of System

Examples:

- Many computers running many chess games; the information required to record all the actual games can vastly exceed the information required initially to program the computers.

- Starting from a clonal population of bacteria, microevolution increases genetic diversity of population, requiring more information to describe.

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From simple to highly varied environments

Starting **from a simple, uniform environment** requiring little information to describe, contingent historical events can **produce a highly varied environment** requiring lots of information to describe.

Example:

“Screen saver” computer model of atoms and molecules

```
1     45              376            2          25        7
         1       2            34       6        6          1
                 4           2  5      2        5          3
 2      37                   1  6              5                  64
                  6           87          3
     3           2                    2                  71
```

From simple to highly varied environments

Example:

From shortly after the Big Bang

- a fairly uniform environment of particles and photons

to the universe about 4.6 billions years ago:

- All atoms in the periodic table, stars, galaxies, black holes, nebulea, gas giant planets, asteroids, and even planets with dry land and oceans and atmospheres and a collection of small organic molecules – a highly varied environment requiring vast amounts of information to describe all of the different parts.

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Self-assembly of complex objects

Once the environment is highly varied, even if the objects within it are still fairly simple, deterministic and probabilistic laws can also bring about the **self-assembly of new, more complex objects with novel properties** within the environment.

Examples

- Particles → atoms → molecules
- “Screen saver” computer model of a self-assembling **stable, rotating clock molecule**

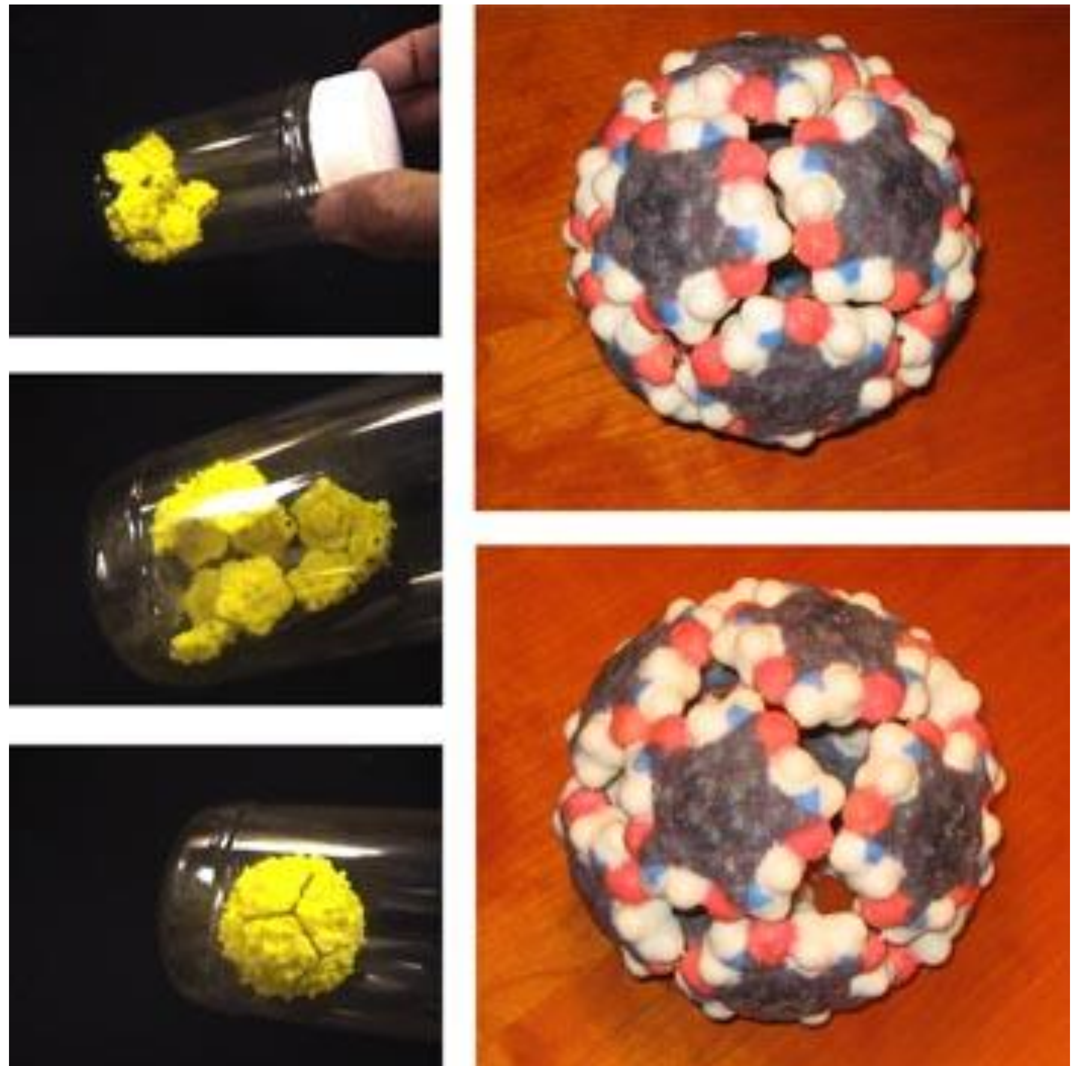
```
1     45               376           2          25        7
        1       2            34       6        6          1
                4           2  5      2        5          3
2      37                   1  6              5                 64
                 6           87          3
    3           2                   2                 71
```

Self-assembly of complex objects

Examples

- Man-made model of self-assembly of a virus

mgl.scripps.edu/projects/tangible_ models/movies (A.J.Olson)



Self-assembly of self-replicator?

The really big question:

Once the environment is highly varied, even if the objects within it are still fairly simple, deterministic and probabilistic laws can also bring about the **self-assembly of a self-replicator?**

Example: Computer model of evolution of autocatalytic sets of chemicals:

"A model for the emergence of cooperation, interdependence, and structure in evolving networks" Sanjay Jain and Sandeep Krishna, *Proceedings of the National Academy of Sciences* **98**(2), 543-547 (2001).

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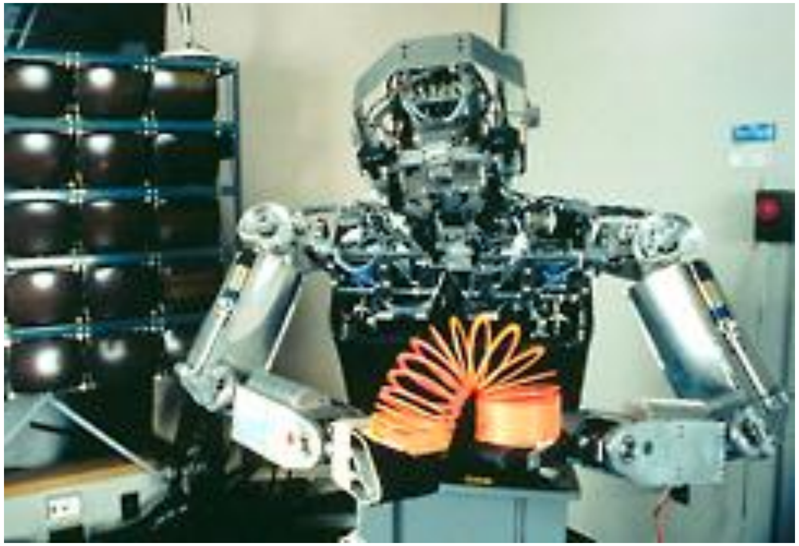
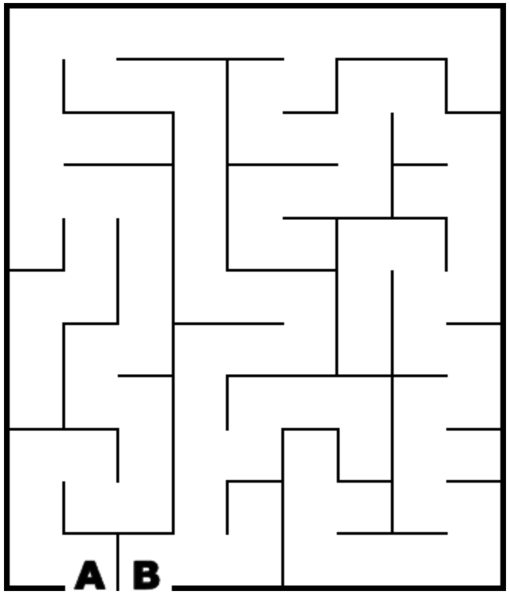
Information transfer from environment

Feedback loops between varied environment and an object such as a self-replicator, utilizing variation and selection, can greatly increase the information content of the object.

Examples

- Neural networks that learn
- Maze-navigating programs using genetic algorithms
- Living organisms evolving/adapting to a new environment





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Evolving interlocking complexity

- Variation produces novel combinations, some of which are adaptive (positively selected).
- Alternatively, changing environments create new functions and new selection pressures for existing (previously non-selected) combinations.

Examples

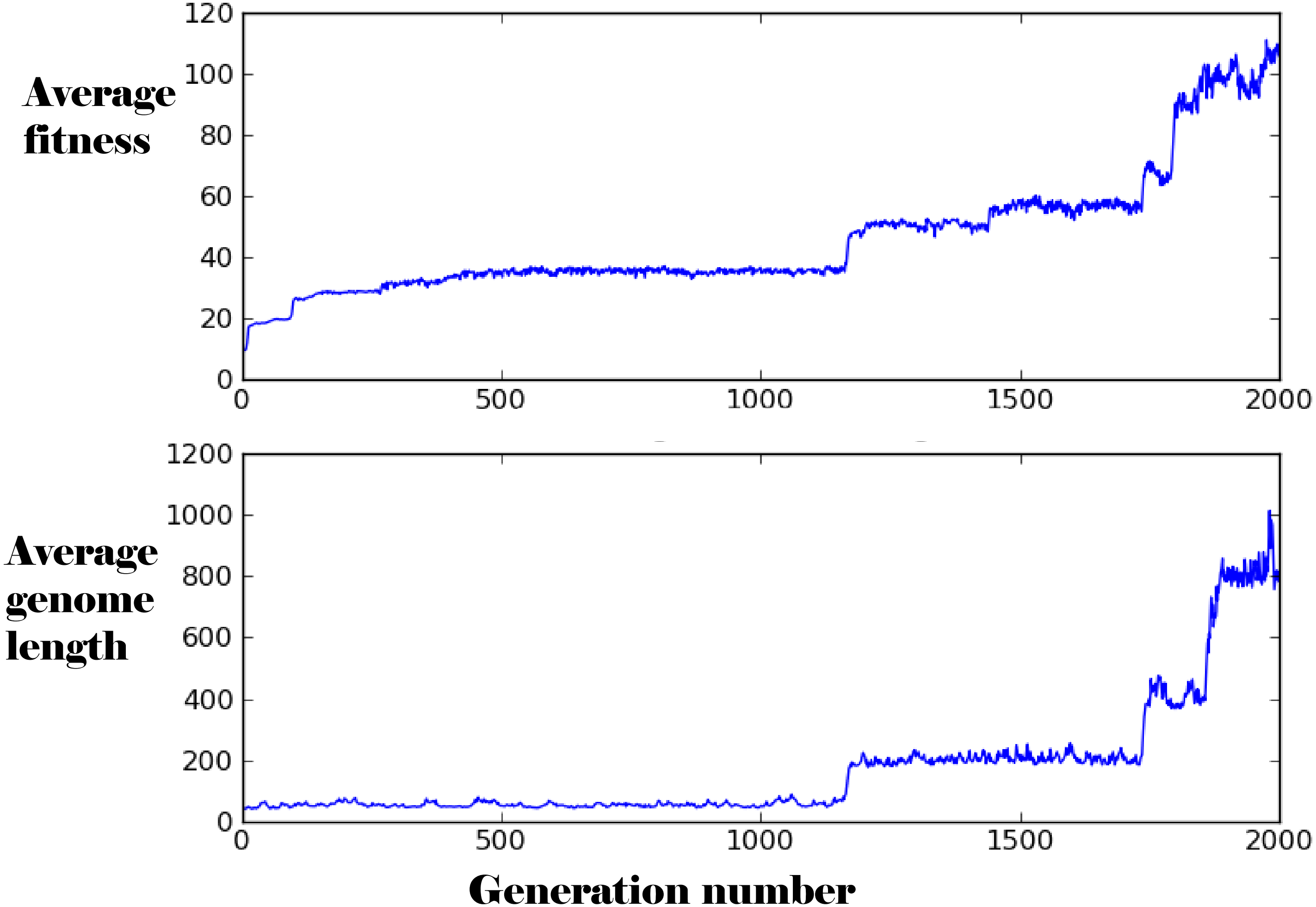
- Adaptive radiation in a new environment
- Mammalian middle ear
- Heterogeneous ion channels
- Pykaryotes

Pykaryote: digital organism

- It gather chemicals from the environment.
- It has a genome which is strings of codons.
- It makes proteins from strings of gathered chemicals.
- Proteins sometimes combine into complexes.
  - Most proteins and complexes are non-functional, but a few are functional.
- After a certain number of genome reading steps, its fitness is calculated based on amounts of chemicals it gathered.
- Its fitness determines its reproductive probability.
- Various types of mutations happen during reproduction.

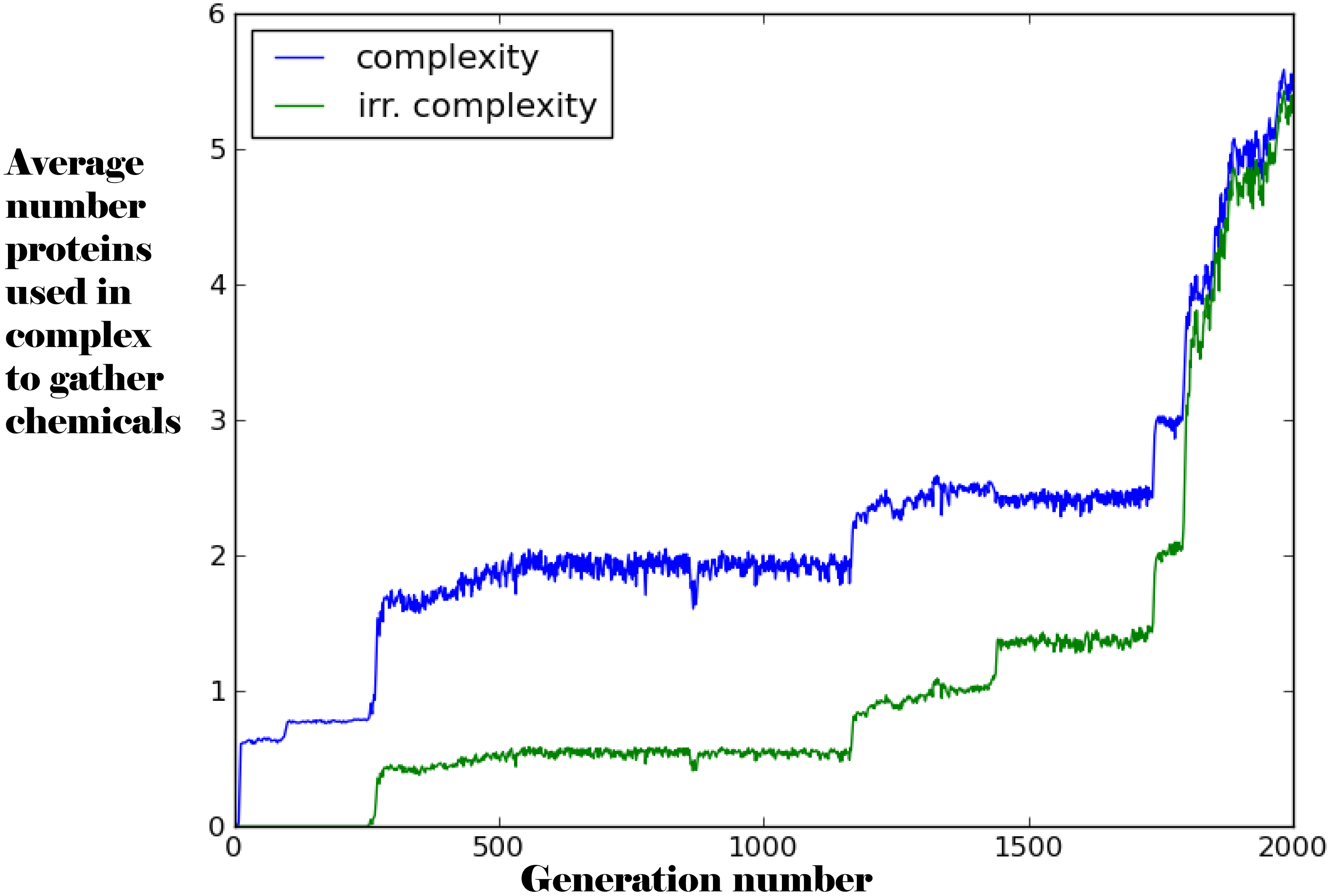
Pykaryotes

Average fitness and genome length increase with generation number.



Pykaryotes

Complexity and irreducible complexity evolve.



Probablity vs. Information arguments

Arguments against abiogenesis and evolution of interlocking complexity

are sometimes framed in terms of **probability**,

and are sometimes framed in terms of **information.**

Probablity vs. Information arguments

Information and Chess (standard starting position)

- "Rules and initial conditions information" is small.
- "Combinatoric information" is vast (${10}^{120}$ games).
- "Contingent history information" can become vast by running lots of chess-playing programs.

Probability and Chess (standard starting position)

- A tiny fraction of positions are impossible.
  - E.g. white king on e3 surrounded by black pawns, back king on h1
- A tiny fraction of positions are very probable.
- Most positions are very improbable.
- A tiny fraction are very improbable and "very interesting."
  - E.g. white rook on e3 surrounded by black pawns, kings on h1, a1

Probability-based arguments against abiogenesis and evolution of complexity

(Arguments that, starting from the initial conditions on the early earth, abiogenesis and the evolution of certain kinds of complexity are **impossible** or **very improbable**.)

I could imagine such arguments being convincing if future scientific experiments turn out in certain ways.

(Although for now I suspect that future scientific will support abiogenesis and evolution of complexity as being probable.)

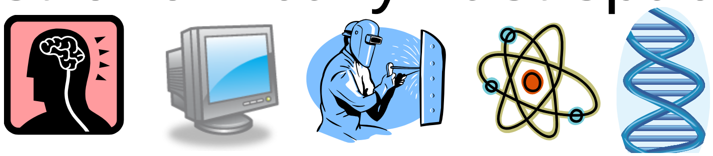
Information-based arguments against abiogenesis and evolution of complexity

No.

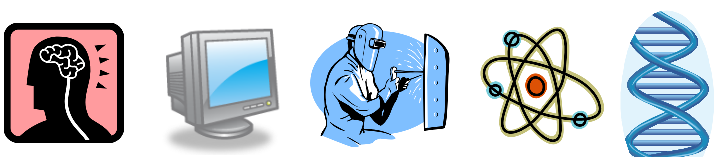
Because:

1) There are many kinds of information.
2) Natural processes can create vast amounts of some kinds of information.
3) Natural processes can convert some kinds of information into other types.
4) We can understand and at least partially model where the information comes from, each step of the way from particles to ecosystems.

Creating and transforming information

1 & 2) A **small set of simple objects** plus a few rules for how they interact can create, by simple **combinatorics**, create an astronomically vast space of possibilities and pathways. 

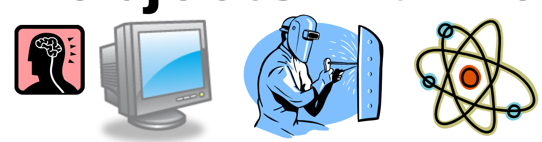
3) When real systems navigate those combinatoric pathways via rules which are partly deterministic and partly probabilistic, each contingent event generates new **contingent history** information.



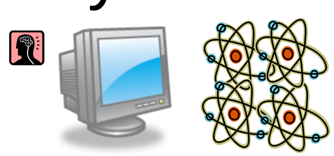
Creating and transforming information

4) Starting **from a simple, uniform environment** requiring little information to describe, natural processes can **produce a highly varied environment** requiring lots of information to describe.

5a) Self-assembly of complex objects with novel properties.

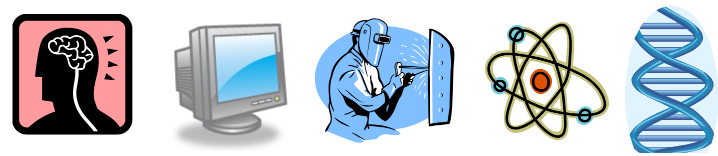


5b) Self-assembly of auto-catalytic cycles and **self-replicators**



Creating and transforming information

6) Feedback loops between highly varied environment and an object such as a self-replicator, utilizing variation and selection, can greatly increase the information content of the object.



7) In self-replicators, new combinations with novel properties, or new selection pressures on existing combinations, can lead to **evolution of interlocking complexity** and greater information required to specify functional subunits.

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