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A Simple Foothold For Evolution

The Origin Of Life: A Network Oriented View

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Introduction and Motivation

Origin of Life theories are in two main categories: 'template replication first' and 'metabolism first'.

A network oriented view is presented: Properties of metabolic networks played a key role in the origin of the first evolving systems.

A mechanism for memory in chemical networks is illustrated. The simplicity of 'network memory', especially in comparison with template mechanisms, suggests its plausibility as a prebiotic phenomenon and as a fruitful area for Origin of Life research.

Conceptual Background

- The metabolism first theories of Aleksandr Oparin, Stuart Kauffman and Freeman Dyson
- The Lipid World theory of Doron Lancet's group
- Günter Wächtershäuser's chemo-autotrophic theory
- Graham Cairns-Smith's clay crystal theory

Network Memory

Networks Store Information Too

Evolution is a process of trial and error. For it to gain a foothold, successful trials must be inherited ('remembered' and passed on).

Inheritance based on templates (eg RNA) is problematic for the Origin of Life. The highly evolved enzymes required would not have been available. This is the well known 'chicken and egg' problem.

The view presented here is that early organisms contained chemical networks that were capable of carrying information about successful variations and transmitting it to offspring.

An intuitive argument for this view is that there are many examples in which networks are known to carry information. The most striking is the brain.

Static And Dynamic Chemical Networks

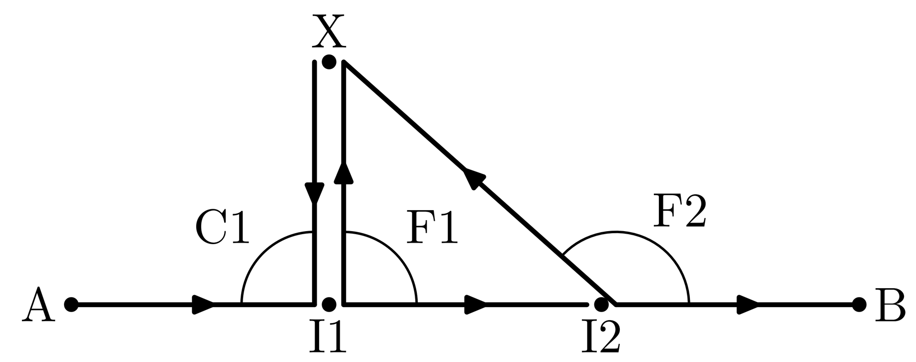
Chemical networks are of two kinds:

- **Static Network:** Defined by the molecular species that are possible, the interactions between them that are possible, and the rate constants. The static network is determined for all time by the laws of physics. Since there is no limit to the number of possible species and interactions, the static network is effectively infinite
- **Dynamic Network:** A set of actual molecules, the actual interactions taking place, and the rates of these interactions. It is useful to think of a dynamic chemical network as one of the possible configurations that can exist on the static chemical network

A 'Toy Model' Chemical Network Memory Unit

The figure shows a simple (static) network for an artificial chemistry consisting of three elementary reactions C1, F1 and F2.

$A + X \rightarrow I1$ (C1)
$I1 \rightarrow I2 + X$ (F1)
$I2 \rightarrow B + X$ (F2)



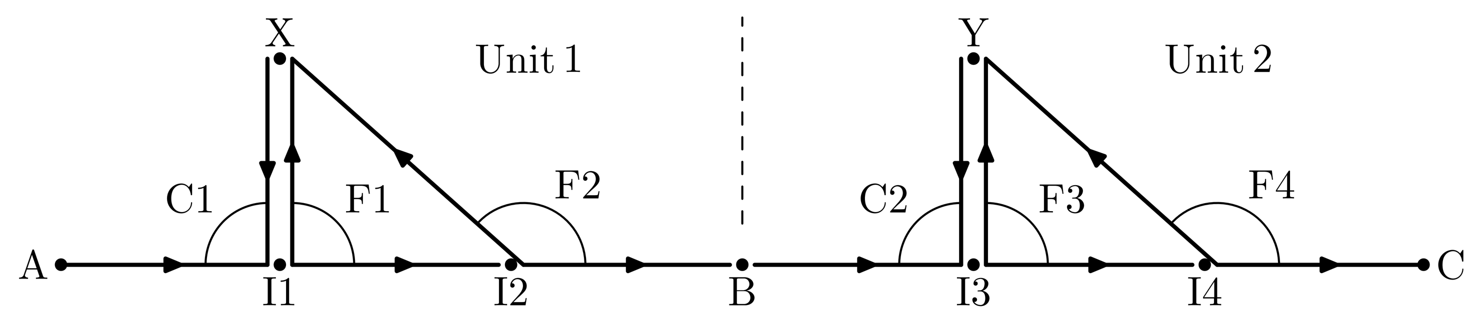
Setup and Behaviour:

- A is abundant 'food'; no other molecules are present initially
- If a single molecule of X is introduced:
  - A molecule of I1 is constructed (reaction C1)
  - This subsequently splits (reaction F1) to release an X molecule and an I2 molecule
  - The I2 molecule then splits (reaction F2) to release another X molecule plus a B molecule
- Overall, for each A molecule consumed, one X molecule becomes available in addition to the B molecule. As a result, the supply of X is maintained (even if there is some 'leakage').

Observations:

- The dynamic network has two states, one in which only A molecules are present and no reactions occur, and another in which the reactions proceed and a supply of X is maintained
- The introduction of a single molecule of X is 'remembered' because it triggers a switch to a new persistent state
- The network is a two-state memory unit with a capacity of 1 bit

The Dynamic Network Explores The Static Network



This figure shows a static network in which two memory units are connected in series. As above, only A is available as 'food'.

Observations:

- There are three possible persistent states:
  - Neither unit is active (only A is present)
  - Unit 1 only is active
  - Both units are active
- The dynamic network 'explores' the static network. A perturbation (such as the addition of a single X or Y molecule) causes new parts of the network to become accessible

Individuality, Splitting, Stability, and Information Transfer

Metabolism first theories usually assume that:

- Early organisms had a level of individuality (eg by being enclosed within a lipid membrane or by being bonded to a surface)
- They could divide and produce offspring

The toy model shows that the stability of a dynamic network is not dependent on the concentrations of the molecular species remaining within narrow bounds.

Even if there is 'leakage', the network will remain active as long as a single molecule of X is present. Dynamic chemical networks are stable because they are attractors.

Provided the molecular composition of each offspring is roughly similar to that of the parent, new sub-networks discovered by the parent will be retained by the offspring. *This is how inherited information can be transferred from parent to offspring without accurate replication.*

Conclusions and Open Questions

Conclusions

- Chemical networks adopt dynamic configurations that are inherently stable
- A new configuration arising from a perturbation can be 'remembered' and passed on to offspring, forming the basis of an inheritance mechanism in early organisms
- The simplicity of this mechanism enables evolution to begin without having to overcome the 'chicken and egg' and error catastrophe problems that apply for template based origins

Open Questions

Open questions regarding the role of such mechanisms in the Origin of Life include:

- How many attractors existed in prebiotic chemical networks?
- Is network evolution 'limited'?
- Does network evolution require large molecules?
- How frequent are transitions between attractors in a chemical network?
- What causes them?
- What mechanisms could support individuality and splitting in non template replicating organisms ?
- How could the transition to template replicators be made? Genetic Takeover?