From Prescriptive Programming of Solid-state Devices to Orchestrated Self-organisation of Informed Matter

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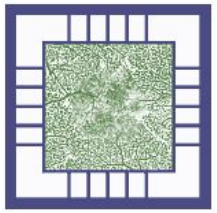
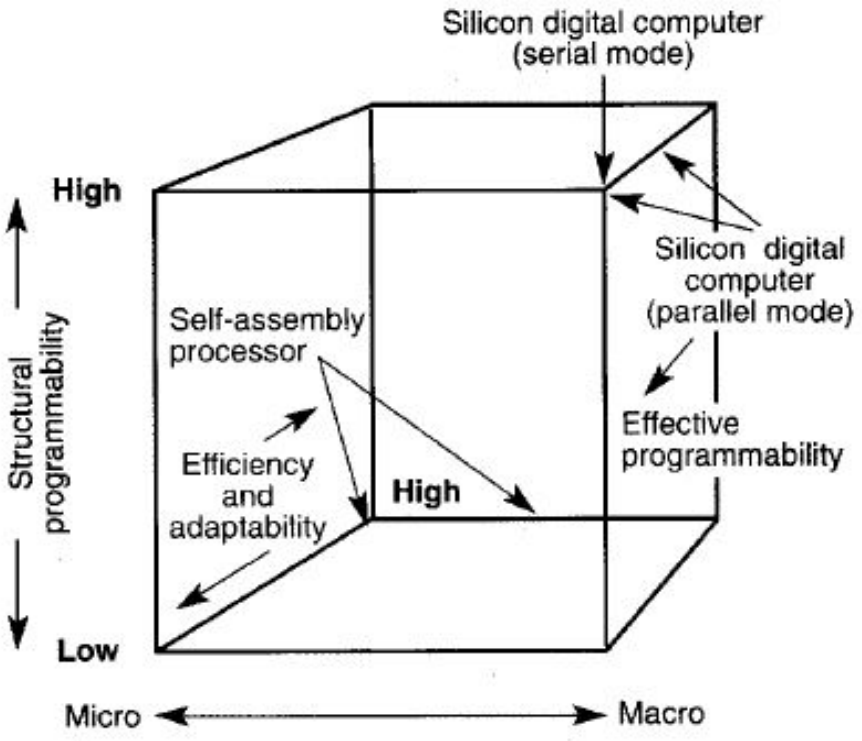


BIO@ECS

Conrad's Tradeoff Principle:

- Programmability and Adaptability are incompatible



M. Conrad, 1985, 1992

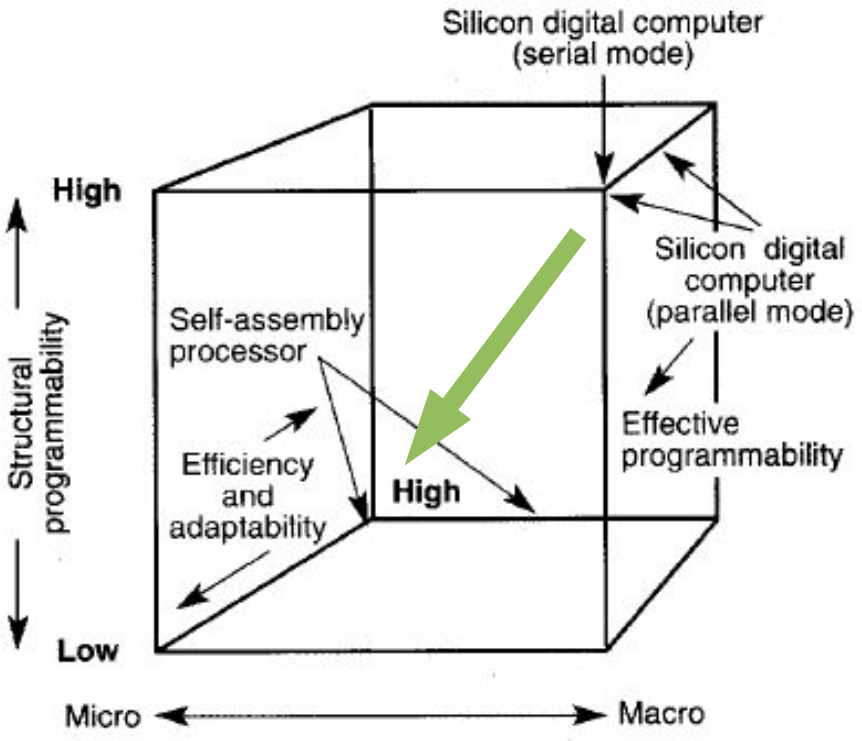
- The price for combining both is inefficiency

-> Brains are slow in simulating Turing Machines

-> Turing Machines are slow in simulating Evolution

Conrad's Tradeoff Principle:

- Programmability and Adaptability are incompatible



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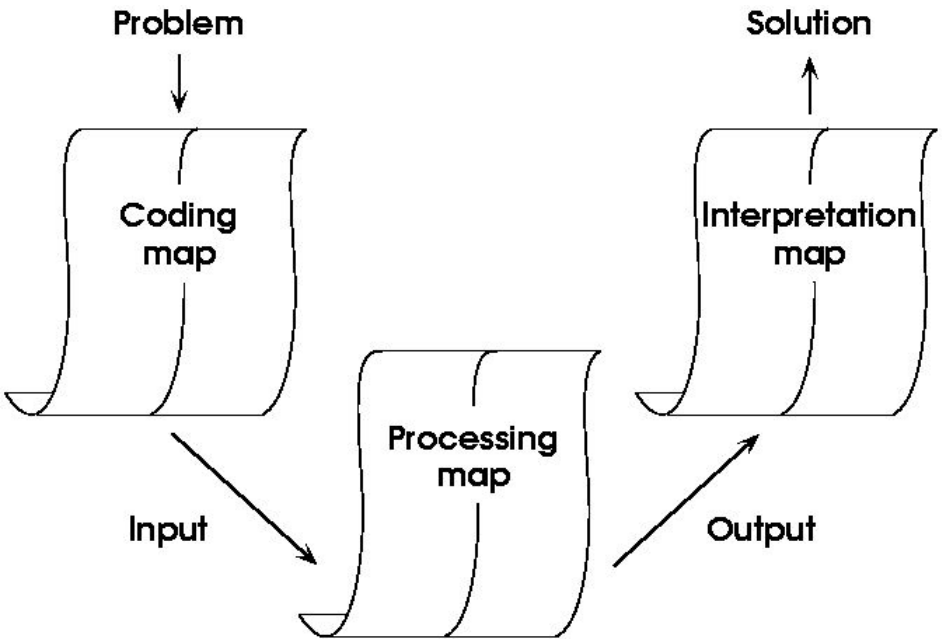
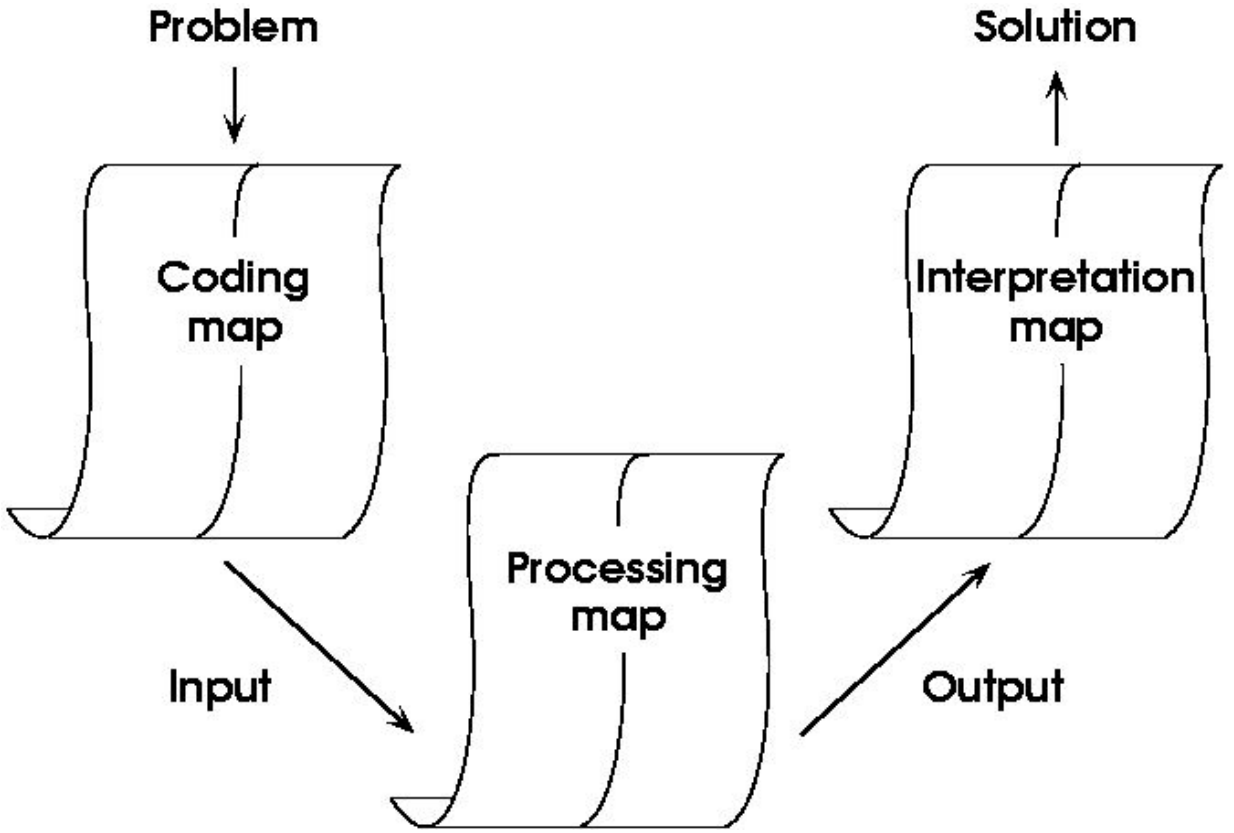
Computers

A computer is a system that starts from a state which encodes a problem specification and changes, following the laws of nature, interpretable as a solution to the problem.



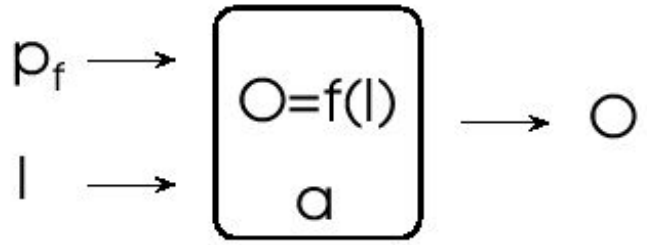
Programming

Programming requires to communicate the processing map to the computing system.

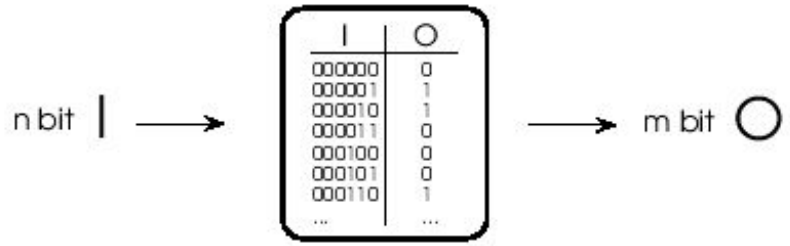


- Prescriptive Program
- Training Program

Where are we now?



Program p_f specifies the mapping $f(\cdot)$ of input I to output O wit respect to the given architecture a.



The number of maps for that map n bit input patterns into m bit output patterns is:

$$(2^m)^{2^n} = 2^{(m2^n)}$$

Selecting an arbitrary map from this set requires a specification of length:

$$\log_2 \left[2^{(m2^n)} \right] = m2^n \tag{1}$$

Consider, for example, a 100×100 bit input image that is to be classified whether it does or does not contain a certain feature (= 1 bit output). Specifying the processing map for this problem may require 2^{10000} bits, i.e. 10^{20} GB!

Where are we now?

$$\mathcal{K}(f) \leq \mathcal{K}(a) + \mathcal{K}(p_f) \qquad (2)$$

Every realizable information processing machine can only implement a small subset of the possible input-output transforms and is therefore a special purpose device.

"It is not at all certain that in this domain a real object might not constitute the simplest description of itself, that is, any attempt to describe it by the usual literary or formal-logical method may lead to something less manageable and more involved."

John von Neumann (with respect to the visual cortex), 1948

...we can implement the highly compressible I-O maps.

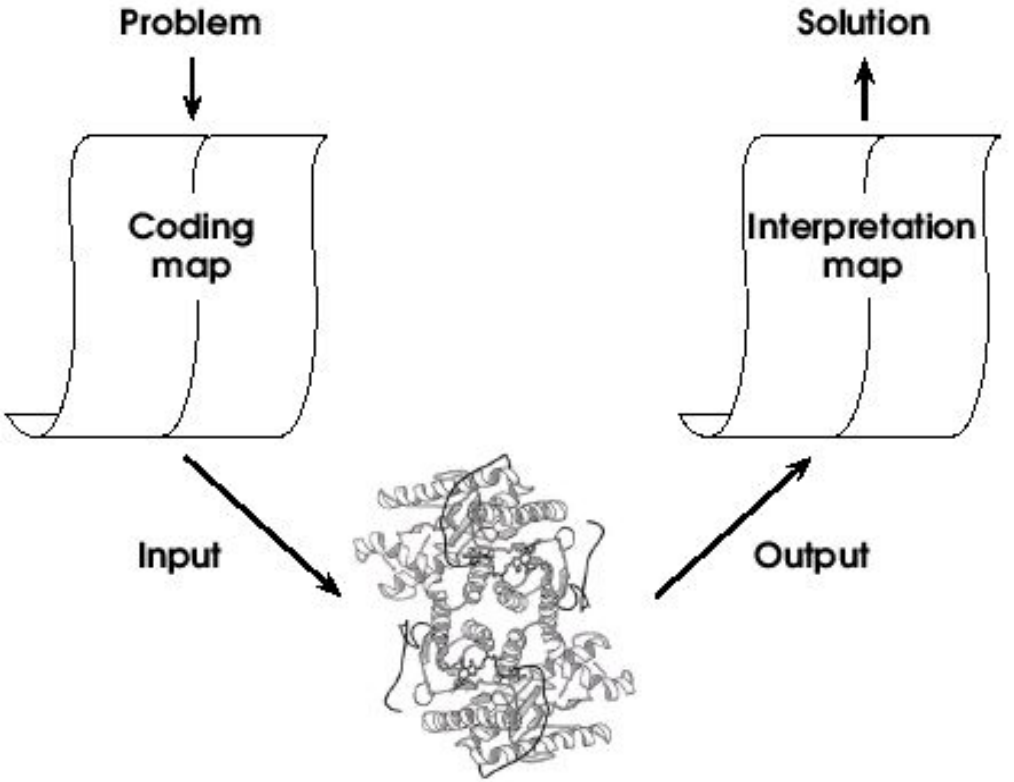
Broadening the material basis

About 18 million organic compounds are known today-, a neglible number if compared to the space of possible organic molecules, estimated to 10^{63} substances.

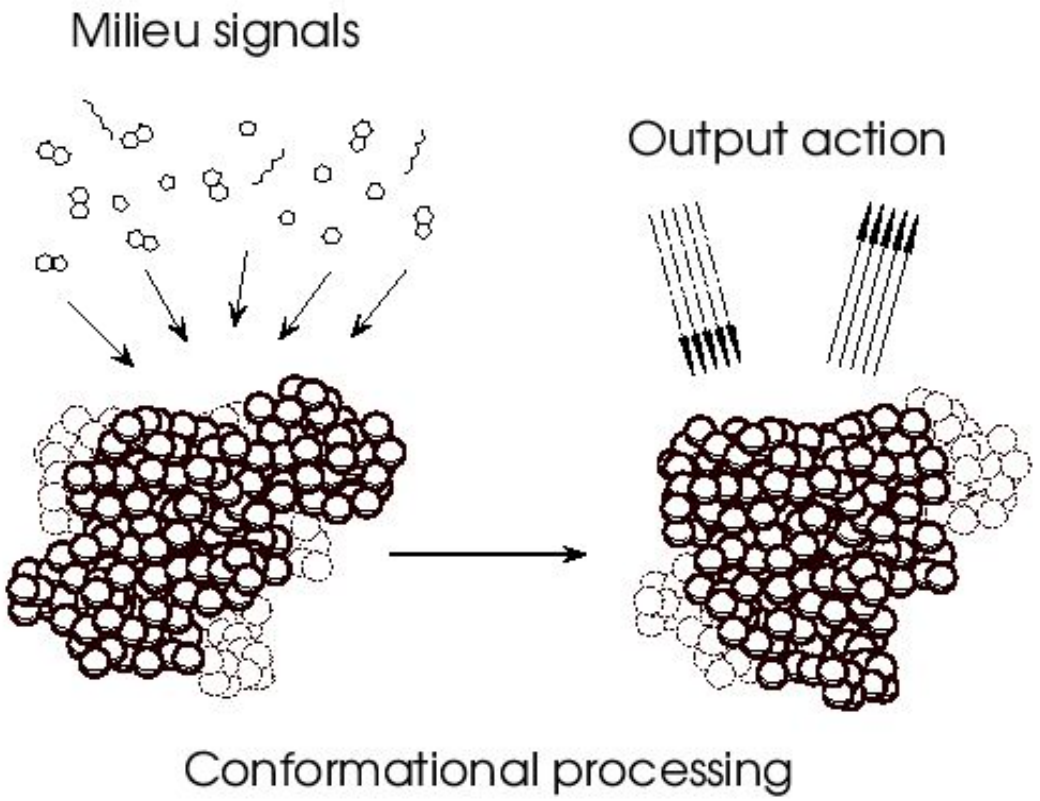
In the near future we will see materials with unprecedented characteristics arriving at an increasing rate.
But there is nothing to indicate that we are on a path to harnessing these materials in an effective way for increased computational power.

Conformation-based Computing

The conformational dynamics of proteins is a computational resource.

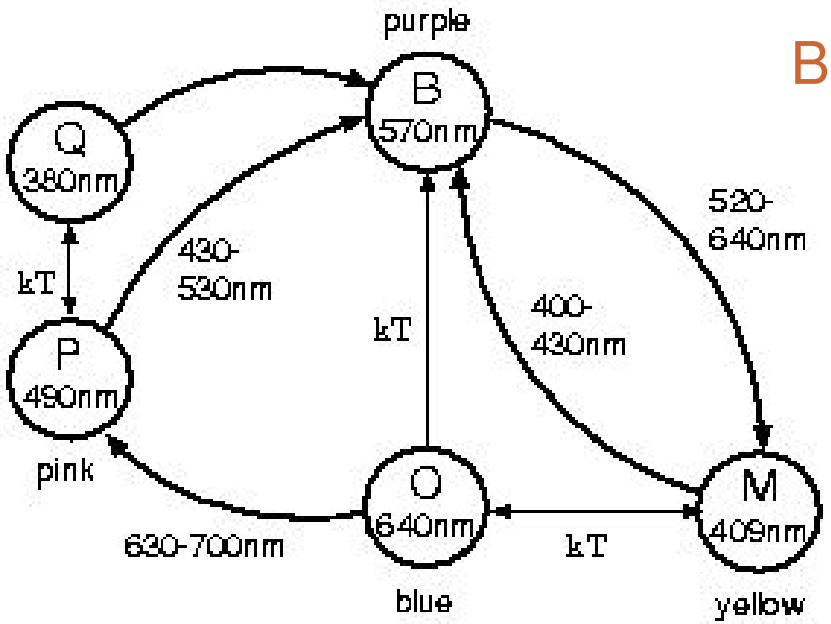


Conformation-based Computing

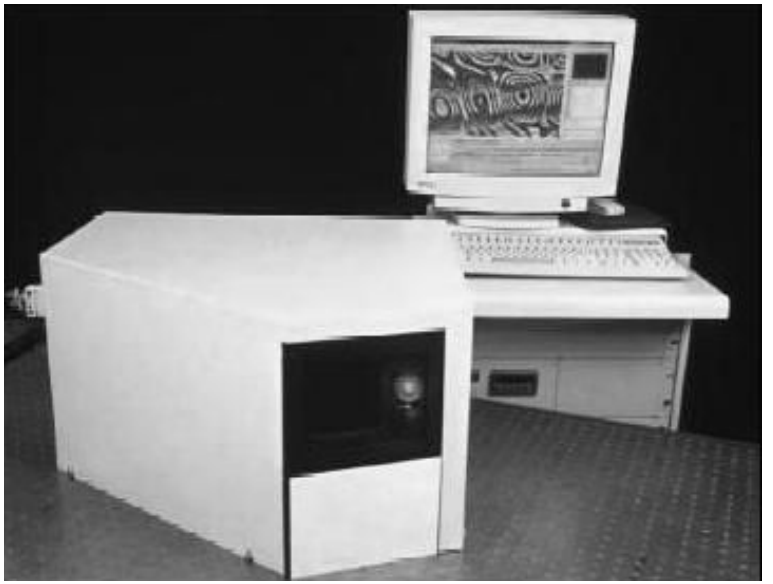


The protein can be regarded as an immense processing network of nuclei and electrons that fuses input signals through its nonlinear conformational dynamics.

Conformation-based Computing

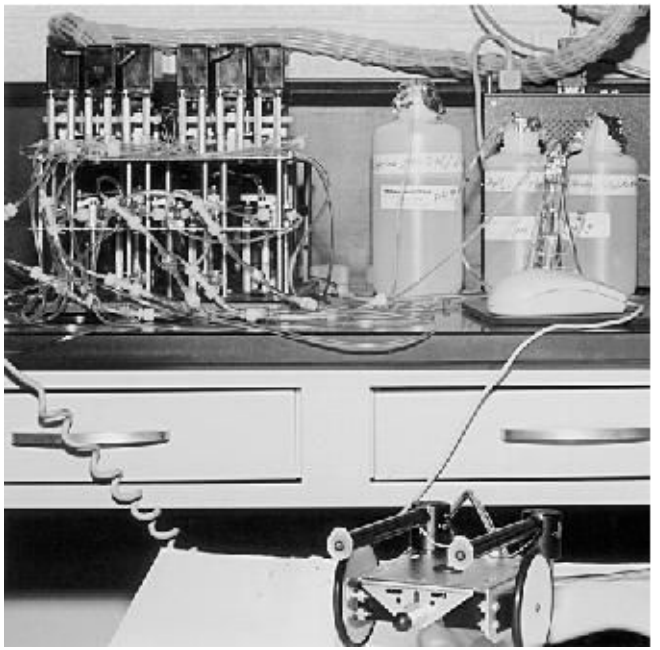


BR

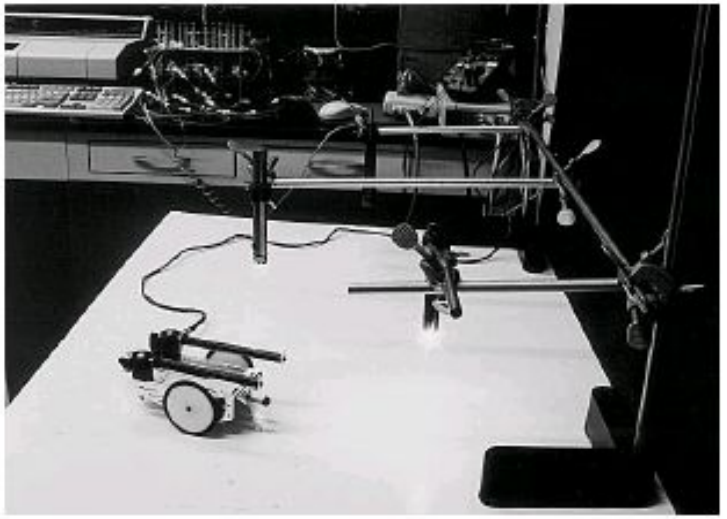


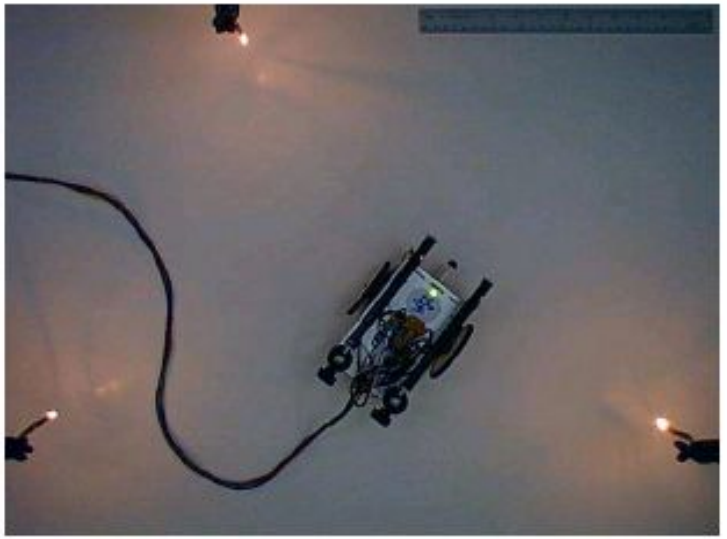
N. Hampp, 2000

MDH

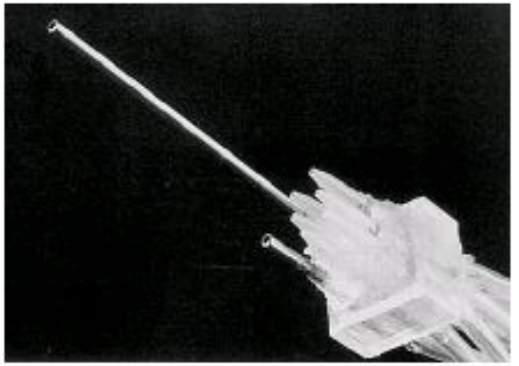


Conformation-based Computing



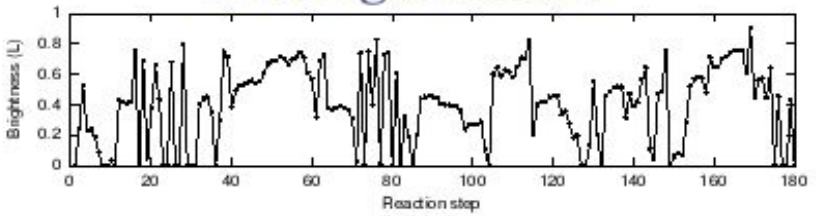


- **Braitenberg Vehicle (minimalistic design: two light sensors, two actuators)**
- **Light intenisity is encoded as $MgCl_2$ concentration ('second messenger')**
- **Control imitates bacteriochemotaxis**

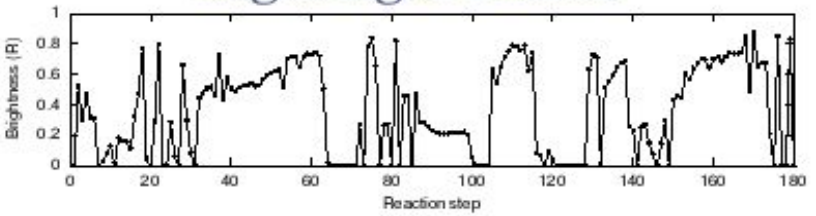


Conformation-based Computing

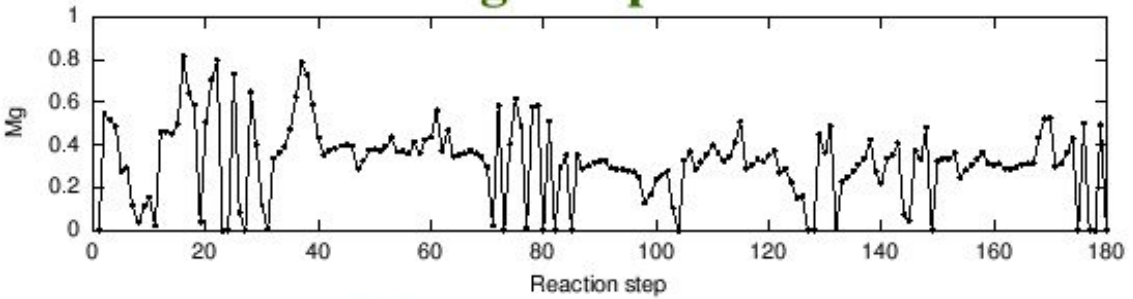
Left light sensor



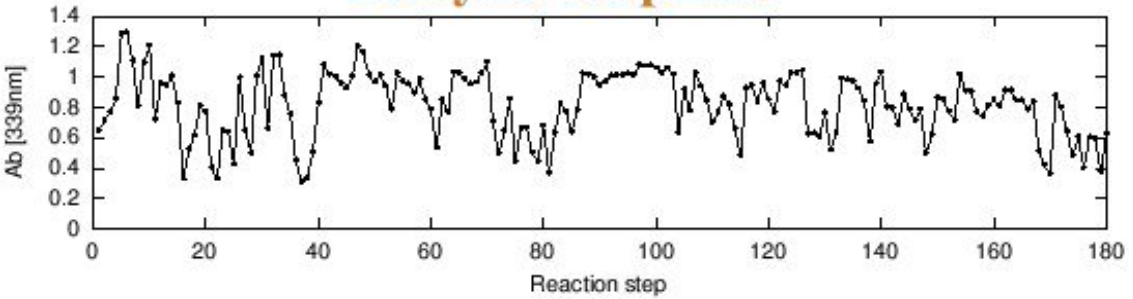
Right light sensor



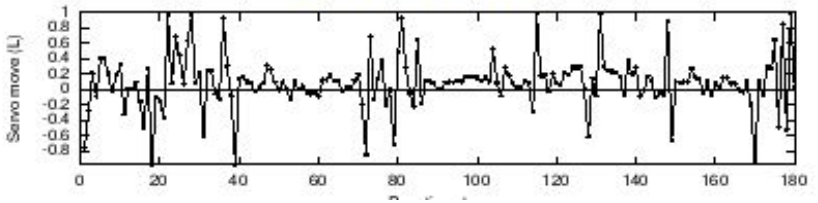
Mg^{2+} input



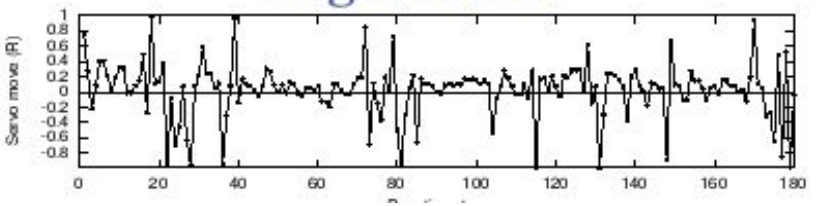
Enzyme response



Left servo



Right servo



The challenge:

Implement desired functionality on substrates that cannot be controlled prescriptively.

- Evolutionary Methods?
- Learning?
- Selection?
- Management?

The future...

Select desirable components.

High failure rates are acceptable, if density of components is very large. (Memory, polymer chips).

Coerce materials to implement formal systems? (Efficiency?)

Can we do better?

Course of computation driven by physics and not prescribed...

Informed Matter

J.-M. Lehn, 2004

Embedding of information into physical properties of molecules.

Can we “program” systems that need detailed physical simulation even for approximate predictions about the consequences of “instructions”?