Computation with Dynamics and Attractors

GC7 : Journeys in Non-Classical Computation

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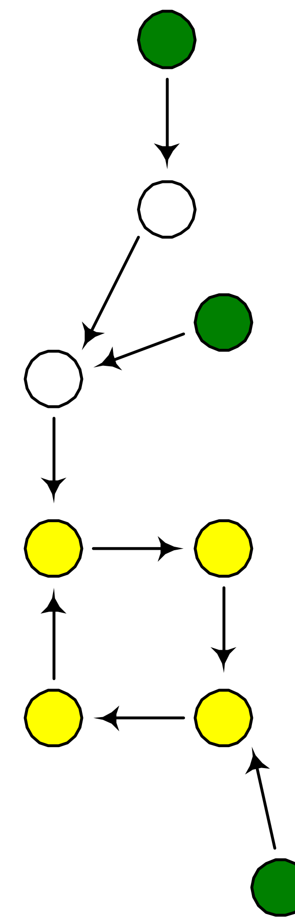
phase space and attractors



- discrete trajectories in discrete ***state space***
  - the states placed to make the structure explicit
  - attractors are cycles in state space, after any transients have died away
- dynamical systems moving in space
  - discrete state space $\rightarrow$ continuous ***phase space***
    - one dimension for each parameter needed to specify the state
  - system trajectory is movement through this space
    - eg, system of N particles as a point moving in a $3N$-dimensional positional space, or in a $6N$-dimensional "position+momentum" space
    - eg, pendulum in a 2D "displacement+velocity" space

random Boolean networks

- Stuart Kauffman
  - RBN as a *very* simplified model of *gene regulatory networks*
- network of N binary valued nodes
  - each node take binary inputs from K randomly chosen nodes
  - inputs combined by a random Boolean function
- effect of K on :
  - *cycle length*, number of *attractors*
  - *stability*
    - does it return to same attractor after a small transient perturbation
  - *reachability*
    - how many other attractors reachable after a single small permanent perturbation

dynamic patterns in the brain

- spatio-temporal patterns
  - one attractor while idle
  - move into another when "thinking"

> ***"the strange attractor characteristic of the attention state was replaced by a new, much more ordered attractor related to the recognition process"***
>
> --[Solé & Goodwin, 2000]

- attractor structure of the brain enables cognition
  - similar applications for general computation
  - set up a computational system (evolve, grow, learn) with the appropriate attractors

computational trajectories and attractors

- for fully dynamic computation with no halting, the computation emerges as (an observed projection of) the trajectory
  - dynamic associative memories, neural networks, artificial cognitive processes, …
  - robotics controllers, …
- the trajectory is governed by the structure of the underlying phase space and its attractors
  - whether discrete or continuous
- particularly important if the phase space itself is dynamic
  - parameters changing due to the environment, etc

open, far-from-equilibrium systems

- open – constant addition of new resources
  - energy, matter, information flowing into and out of the system
    - new sand added to the pile (Per Bak 1987)
- **far-from-equilibrium** systems
  - not in a steady state, but at the computational "edge of chaos"
    - avalanches "on all scales"
- tend to form stable structures, *patterns*, that persist
  - *stable*, but not *static*
    - can change readily in response to stimuli, are "*poised*"
  - these patterns are ***emergent properties***
    - levels of emergence -> hierarchical structures, in space and time
- impossibility of pre-defining the phase space

the proposed journey

- **to develop a new computational paradigm expressed in dynamical terms of attractors and trajectories**
  - can a computation be expressed as a trajectory amongst various attractors, each changing as the result of some parameter / input?
    - does the state transition analogy hold?
  - can a computation be expressed as movement between the unstable periodic orbits of a strange attractor?
    - how are these orbits selected?
  - how can we reason about "emergent" phase spaces?
    - where the phase space changes as the computation progresses
  - what kinds of algorithms are most suited to this paradigm?
  - what are the programming primitives and higher level languages?