How Minds Work

Neurobiological Non-linear Complex Systems

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Systems

- Undefined term
- Examples: solar system, automobile, weather system, desktop computer, nervous system, chair
- Systems often composed of parts or subsystems
- Subsystems generate the behavior of the system

Dynamical System

- X a set, called the *state space*
- Each point $x \in X$ is a *state* of the system
- A state is a snapshot of the system's condition at some point in time
- T:X—>X the system's *global dynamics*
- T(x) is the next state following x

Itinerary

x_0 the state at time 0

$T(x_0) = x_1$ state at time 1

$T(x_1) = x_2$ state at time 2

…

$T(x_n) = x_{n+1}$

The sequence

$x_{0,}\ x_{1,}\ x_{2,} \ldots x_n \ldots$

Is called an itinerary

Dynamical systems theory studies the long range behavior of itineraries

Does it

- Stabilize (fixed point)?
- Endlessly repeat (periodic)?
- Go wild (chaotic)?

One Dimensional Example

- X the set of digits {0,1,2,3,4,5,6,7,8,9}
- Itinerary an infinite decimal between 0 and 1
- .1212121212… an itinerary with $x_0 = 1$, $x_1 = 2$, $x_2 = 1$, etc.

Example Itineraries

- .3333333… stabilizes (converges to a fixed point 3)
- .98765432111111… stabilizes after a transient
- .123412341234… oscillates with period 4
- .654321212121… oscillates after a transient

Chaotic Itinerary

- .41421256... ($\sqrt{2}$ - 1) chaotic itinerary
- Deterministic (in this case algorithmic)
- Inherently unpredictable
- Sensitive dependence on initial conditions

Long-term Behavior of Itineraries

- An itinerary can
  - Converge to a fixed point (stabilize)
  - Be periodic (oscillate)
  - Be chaotic (unpredictable)
- Attractors – itineraries of states close to them converge to them
- Basin of attraction – set of initial states whose itineraries converge to an attractor

One-dimensional dynamical system

State space

X = real numbers & ∞

Global Dynamics

$T(x) = x^2$

Itineraries

0,0,0,0,… fixed point

1,1,1,1,… fixed point

2,4,8,16, … converges to ∞

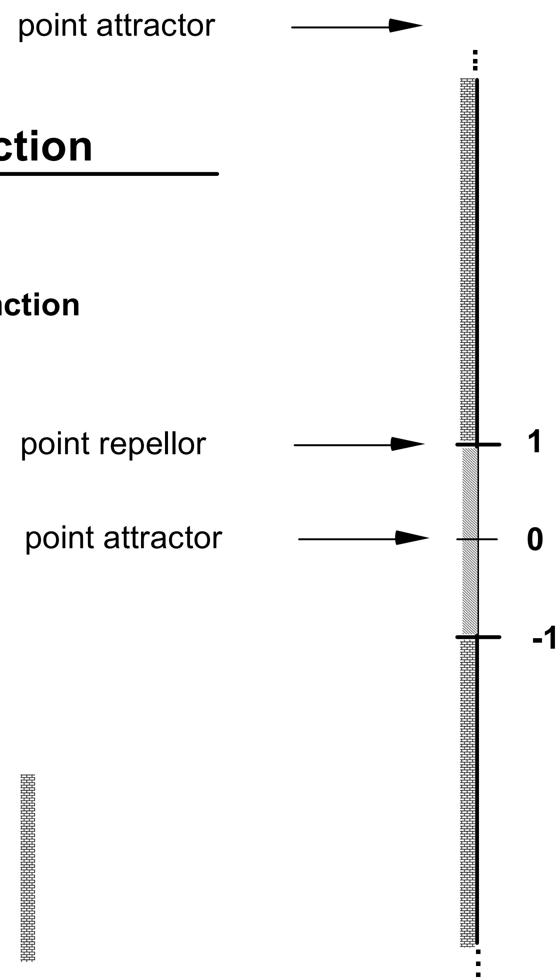
.5, .25,.125 … converges to 0

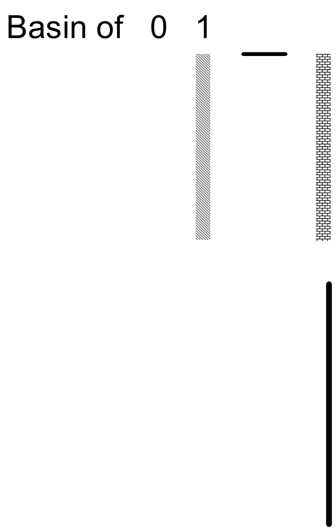
-2,4,8,16, … converges to ∞

Basins of attraction

X = reals plus

T = squaring function

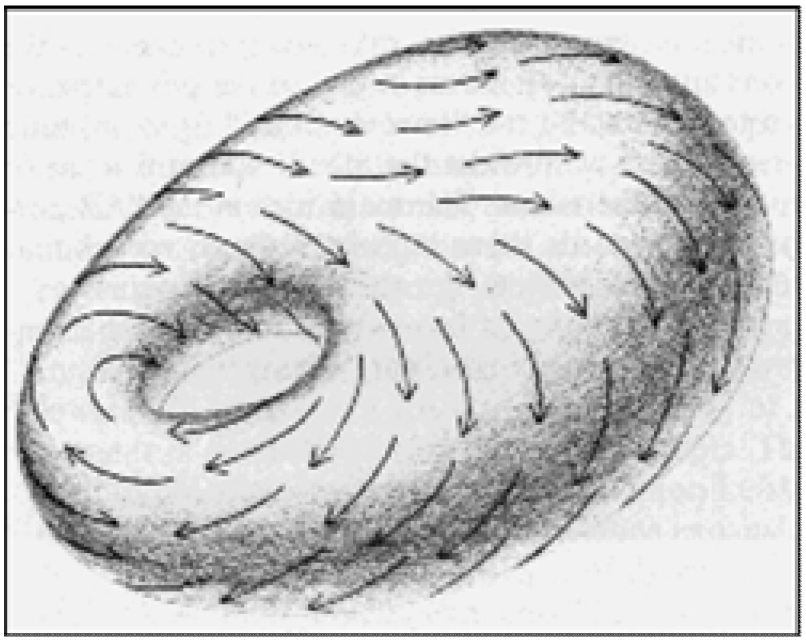




Continuous vs Discrete

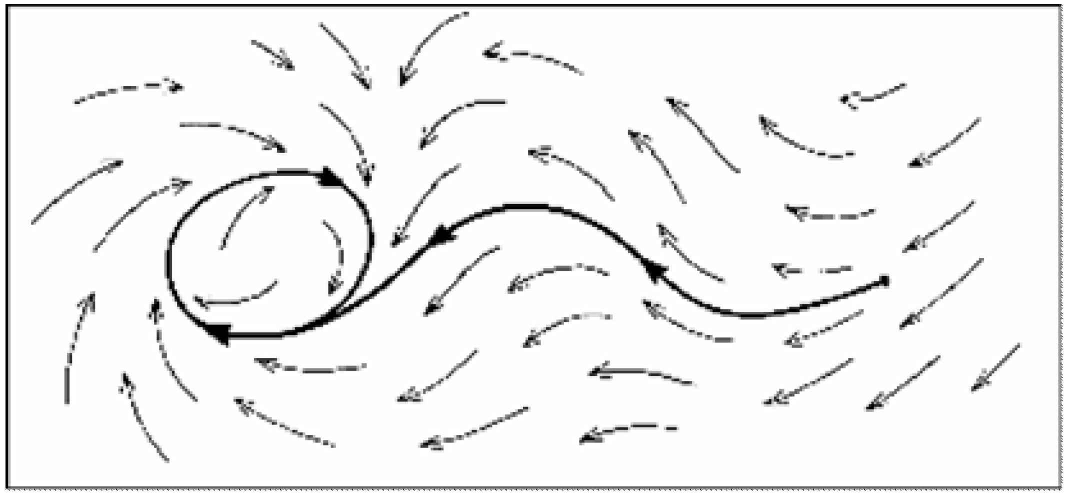
- Discrete dynamical system, discrete time steps, $x(t + 1) = T(x(t))$
- Continuous dynamical system, continuous time, update continuously via solutions to differential equations
- Either can be approximated by the other

Vector Field



- Vector field – vector at each state specifies the global dynamics
- Vector gives direction and velocity of the instantaneous movement of that state
- Trajectory instead of itinerary

Limit Cycle

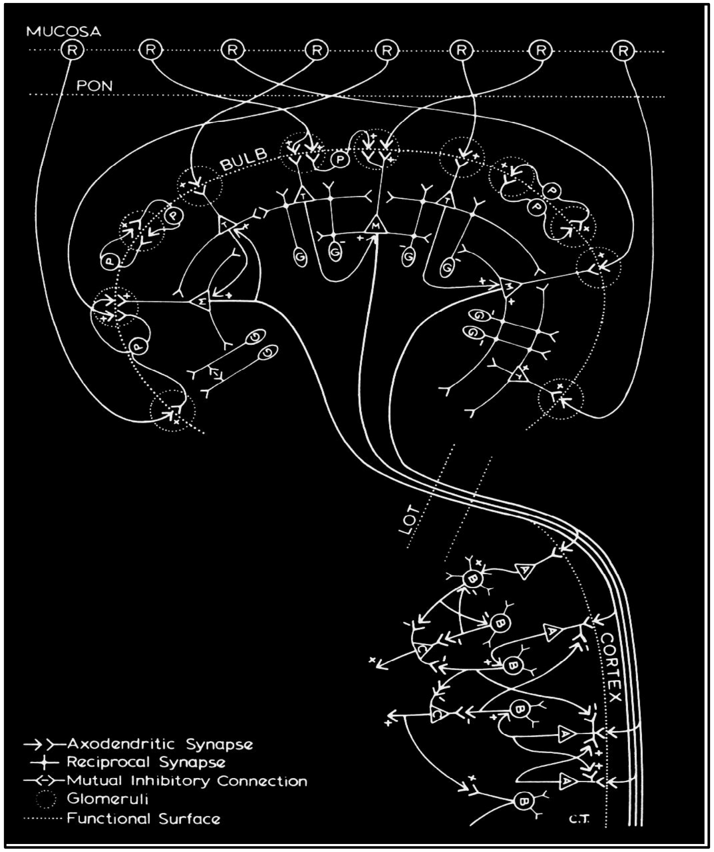


- Limit cycle attractor denoted by heavy line
- Trajectory of any state ends up on the limit cycle, or approaching it arbitrarily closely
- Basin of attraction the whole space
- Continuous version of a periodic attractor

Olfactory Perception

- Particular to a certain sensory modality, for example, olfaction
- Distinguish between the smell of a carrot and the smell of a fox
- Of critical importance to a rabbit
- How is it done?

Anatomy of olfaction



Receptors

Bulb

Cortex

Limbic & motor systems

Olfactory Receptors

- Receptors are chemoreceptor neurons, each with a docking place for a molecule of complementary shape
- Born with receptors keyed to many differently shaped molecules
- Receptor cells sensitive to a particular odorant are clustered non-uniformly
- Receptors occupy a two dimensional array
- Odor specific data is in spatial and temporal patterns of activity in this array

Olfaction in Action

- A sniff sucks in molecules of smoke, which dock at some of the receptors
- Changes activity on the receptor array
- Signal passed to olfactory bulb
- New pattern recognized as smoke
- Smoke signal passes to olfactory cortex
- Become alarmed and signals
  to the motor cortex "get me out of here"

Recognition Problems

- Smoke composed of many types of molecules
- Different fires produce different smoke stimulating very different receptors
- Pattern of receptors stimulated depends on the air currents and the geometry of nostrils
- Particular pattern stimulated might occur only once in the lifetime of the individual
- Each resulting pattern must be recognized as smoke—how?

The HOW of Recognition

- Meaning comes from pattern of activity over entire olfactory bulb
- Every bulb neuron participates in every olfactory discrimination
- Same odorant produces distinct patterns
- Intention required for pattern to form
- All patterns change with new learning

Dynamics of Recognition

- Exhalation – olfactory bulb stabilized in its chaotic attractor
- Inhalation – input from the receptor sheet destabilizes the olfactory bulb
- If smell is known, the trajectory falls into a limit cycle basin of attraction
- The odorant is recognized

Readings

- Freeman, W. J. 1999. *How Brains Make Up Their Minds*. London: Weidenfeld & Nicolson General.
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