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
- $T:X \rightarrow X$ 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 $x_0, x_1, x_2, ... x_n, ...$
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
• \( .1212121212 \ldots \) an itinerary with \( x_0 = 1, x_1 = 2, x_2 = 1 \), etc.
Example Itineraries

• .3333333… stabilizes (converges to a fixed point 3)
• .987654321111111… stabilizes after a transient
• .123412341234… oscillates with period 4
• .65432121212121… oscillates after a transient
Chaotic Itinerary

- \(0.41421256... (\sqrt{2} - 1)\) 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
$X = \text{real numbers} \& \infty$

Global Dynamics
$T(x) = x^2$

Itineraries
$0,0,0,0,\ldots$ fixed point
$1,1,1,1,\ldots$ fixed point
$2,4,8,16,\ldots$ converges to $\infty$
$.5, .25, .125 \ldots$ converges to 0
$-2,4,8,16,\ldots$ converges to $\infty$
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Basins of attraction

$X = \text{reals plus}$

$T = \text{squaring function}$

point attractor

point repellor

point attractor

Basin of 0 1
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
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


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