# Explanations in Neuroscience 2 Explaining Without Mechanisms?

## Deductive Nomological Explanations Again

- Based in part on examples from physics, proponents of the D-N model viewed laws as the critical feature of an explanation
  - From Galileo's law of free fall, explain why an object fell 64 feet in 2 second

    $d = 1/2\ a\ t^2$

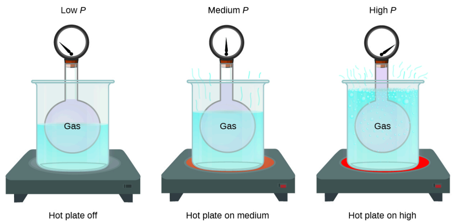
    $t = 2$

    $\underline{a = 32}$

    $\therefore\ d = 64$
  - $d = 1/2\ a\ t^2$ is a law that explains why the object falls the distance it does
- The function of laws in D-N explanations can be generalized to equations that describe a domain of phenomena

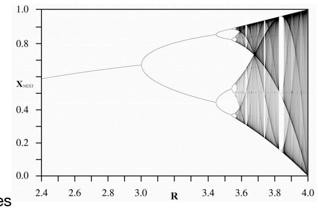
## Laws and Dynamics

- Some laws/equations characterize simple and easily intelligible relations between variables
  - In a gas, temperature = volume x pressure



# Some Equations Generate Surprising Behavior

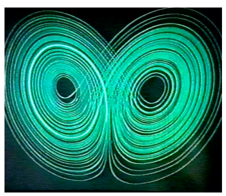
- Some laws are deceptive: $x_{t+1}=Ax_t(1-x_t)$
  - for values of A less than 3, successive iterations will ultimate approach a constant value
  - A little above A=3.4, the system will stabilize to an oscillation between two values
  - Around A=3.5, it stabilizes in an oscillation between 4 values
  - In some intervals, the system will never stabilizes but become chaotic




## Complex Behavior from Simple Equations

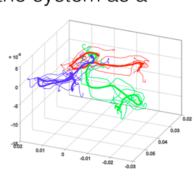
- Some systems, even relatively simple ones, exhibit very complex trajectories through state space

$$\frac{dx}{dt} = \sigma(y - x),$$
$$\frac{dy}{dt} = x(\rho - z) - y,$$
$$\frac{dz}{dt} = xy - \beta z.$$



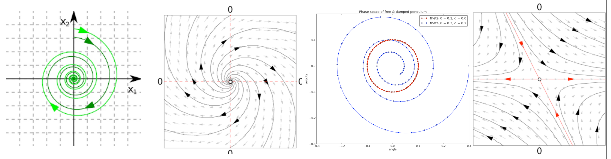
# Dynamical Explanation

- A set of differential equations specifies how variables characterized in the equations will change over time
- One can use such a set of equations to model a system
  - And represent the behavior of the system as a trajectory through a state space which has a dimension for every variable
  - Time appears not as a variable but as a succession of points



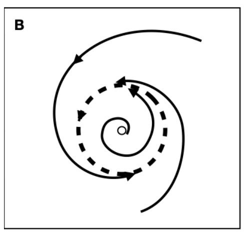
# Attractors

- Many dynamical systems exhibit an attractor structure
  - Starting the system from different values of variables one can trace the resulting trajectories
    - Sometimes all will converge (point attractor)
    - Other times they will diverge (point repeller)
    - Sometimes they will converge to a circle (cyclic attractor)
    - There may be multiple basins of attraction separated by a separatrix



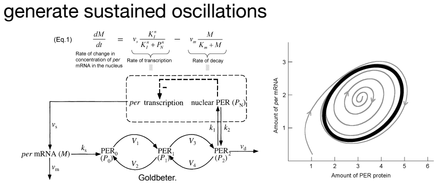
# Circadian Rhythms and Cyclic Attractors

- Hypothesis: rhythm results from a protein inhibiting the transcription of its own gene
  - As more of the protein is synthesized, the more the transcription is inhibited until it stops
  - As the protein degrades, transcription resumes, letting transcription begin again



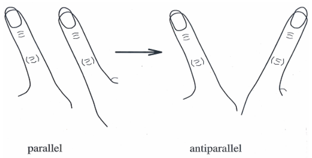

# Recomposing Using Computational Models

- Should one trust one's intuitions?
  - Will a feedback mechanism generate sustained oscillations?
- Goldbeter (1995) created a computational model that showed that with biological plausible parameters, it could generate sustained oscillations



# Explaining in Terms of Attractors without Mechanisms

- Bilateral animals move their limbs in coordinated ways, but speeding up can alter the relation (e.g., from walking to running)
- A simple illustration due to Scott Kelso and described by Chemero
  - Move your index fingers in parallel
  - Start slowly and gradually speed up
  - At some point you will no longer be able to maintain the parallel movement and will lapse into antiparallel movement




# Clicker Question

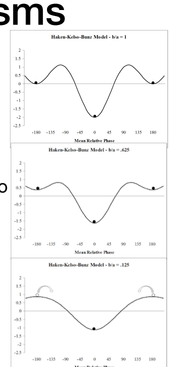
What, according to Chemero, explains why parallel coordination cannot be sustained at higher frequencies?

A. The behavior of the central pattern generator in the brain
B. The fact that an attractor disappeared at higher frequencies
C. The person's failure to try hard enough to maintain parallel coordination
D. None of the above



# Dynamical Explanations without Mechanisms

- What explains the change?
  - The phase between two limbs is described by the Haken-Kelso-Bunz equation
    - $V(\phi) = -a \cos\phi - b \cos 2\phi$,
  - where V is change in relative phase, $\phi$ represents the relative phase and the ratio of the parameters b/a is inversely related to the rate
    - When b/a = a, there are two relatively deep attractors but
    - As b/a declines, a point is reached at which there is only one attractor

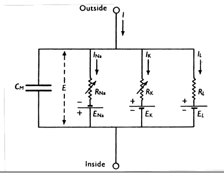


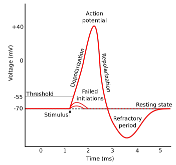
# Does an Equation Explain?

- Recall the Hodgkin-Huxley equation describing the action potential

$$I = C_m \frac{\mathrm{d}V_m}{\mathrm{d}t} + \bar{g}_{\mathrm{K}} n^4 (V_m - V_K) + \bar{g}_{\mathrm{Na}} m^3 h (V_m - V_{Na}) + \bar{g}_l (V_m - V_l),$$

- The equation provides a good description of how voltage changes over time
  - From it you can derive the graph of the action potential




# Does an Equation Explain?

- The Hodgkin-Huxley equation describes the action potential
  - But does it explain it?
- Craver: No. The equation represents curve fitting (by Huxley's own account
  - what do *n*, *m,* and *h* represent?
  - Why are they raised to particular powers?
    - Only once these were connected to ion channels and gates on them was the action potential explained

$$I = C_m \frac{\mathrm{d}V_m}{\mathrm{d}t} + \bar{g}_{\mathrm{K}} n^4 (V_m - V_K) + \bar{g}_{\mathrm{Na}} m^3 h (V_m - V_{Na}) + \bar{g}_l (V_m - V_l),$$

- Levy: Yes. What Hodgkin and Huxley did was identify how the different currents together generated the action potential
  - The channels and gates belong to a yet lower level

# Is A Mechanism Required for Explanation?

- Craver and Levy agree that a equation can serve to explain
  - But only if its terms correspond to components of a mechanism
    - They disagree about which components actually do this work in the case of the Hodgkin-Huxley equation
- Chemero disagrees
  - Citing the Haken-Kelso-Bunz equation suffices
    - From it we can show when one attractor disappears and the corresponding form of coordination is no longer possible

# Discussion Question

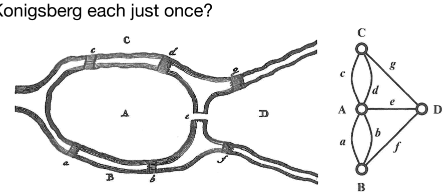
Does a dynamical equation that describes a phenomenon sufficiently accurately to predict it under varying conditions suffice to explain that phenomenon?

A. Yes. With the equation one understands why the phenomenon occurs as it does.
B. Yes, if the equation reveals complexity in the phenomenon itself that accounts for features of the phenomenon.
C. Yes, if the terms of the equation can be related to the components of the mechanism that generates the phenomenon.
D. No. The equation just describes the phenomenon. It doesn't explain it.



# Network Explanations

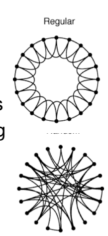
- In the 17th century Leonard Euler posed a problem:
  - Could one find a route to cross all seven bridges of Konigsberg each just once?




- Challenge: prove that it is not possible
  - For each node other than the first and last, there must be an even number of bridges. Why?

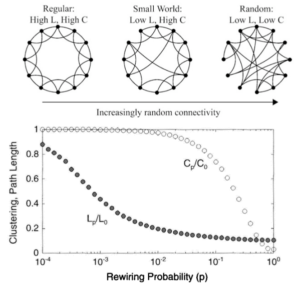
# Understanding Massive Mechanisms

- Strategy: Appeal to properties of particular kinds of network to explain features of systems that instantiate them
- Most work in graph theory in the 20th century focused on regular lattices and random networks
  - Regular lattices exhibit high clustering but long characteristic path length
- The main alternative that was considered was random networks
  - Random networks exhibit short characteristic path length, but low clustering



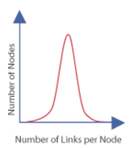
# Small-World Networks

- Watts and Strogatz (1998) showed that in between lattices and random networks lie networks with both short characteristic path length and high clustering
  - These are referred to as *small worlds*
- They argued that small worlds were efficient for information processing
  - Allows for group of nodes to specialize while still being connected to the whole



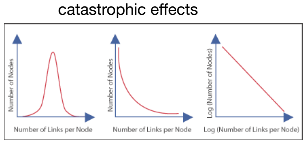

# Node Degree

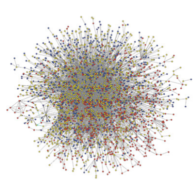
- The number of connections from a node is known as its degree
- Most 20th century graph theory analyses assumed that node degree is distributed normally—i.e., Gaussian




# Small Worlds with Scale Free Distribution

- Barabási discovered that in many real world networks the distribution exhibits a power law relation—most nodes have few connections but a few nodes have many connections
  - They referred to these as *scale-free networks*
- Most nodes have few connections
  - Can be eliminated with minimal effect
- A few nodes have many connections
  - Eliminating them can have catastrophic effects



*Caenorhabditis elegans* interactome map by Marc Vidal

# Discussion Question

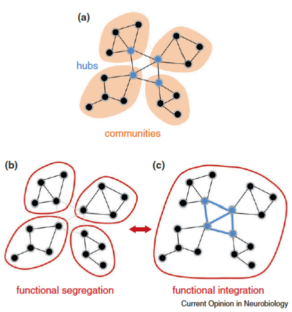
Both LAX and Carlsbad airports are shut down for one week. Why will shutting LAX affect airplane travel elsewhere in the world, but not Carlsbad?

A. LA is a bigger city than Carlsbad
B. LAX has more runways that Carlsbad
C. The number of airports to which you can fly from LAX is greater than that for Carlsbad
D. People are more likely to transfer between planes at LAX than at Carlsbad



# Interconnected Communities of Specialists

- Hubs
  - Nodes with an unusually large number of connections
    - within a local cluster (community)
    - with nodes in other clusters (communities)
- Hubs can create a network of specialists that still communicate




Sporns, 2013

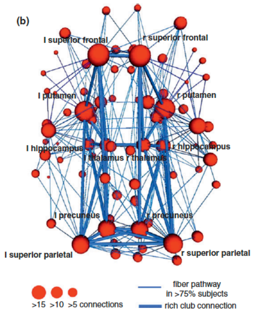
# Applying the Network Approach to the Brain

- Define networks in terms of brain structure
  - Clustering neurons that are interconnected by axons and dendrites
- Define networks in terms of brain activity
  - Clustering neurons whose activity is correlated

- In these networks identify hubs and communities

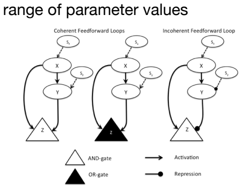
# Rich Club

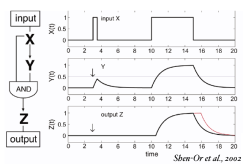
- Set of highly interconnected hubs that serve to integrate multiple specialized communities
  - Long distance connections between local clusters
  - Many of the shortest pathways between brain regions pass through hub units
- Damage to these areas can radically disrupt cognitive capacities
  - whereas others have relatively minor effects
- Complication: communities and patterns of connectivity may well be dynamic—changing as activity occurs within the nervous system




# Network Analysis at Small Scale: Motifs

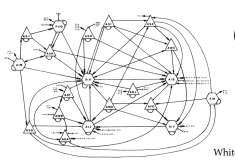
- In the late 1990s Alon and his collaborators began identifying motifs (sub-graphs consisting of two, three, or four nodes) in gene and protein regulatory networks in bacteria and yeast that appear far more frequently than expected by chance
- Using either Boolean or differential equation analysis, Alon and other researchers have identified how these will behave under a specified range of parameter values



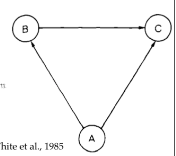




# A Motif in the *C. Elegans* Nervous System

- White et al. (1985) reconstructed the connectivity in the worm *C. Elegans* from electron micrographs, identifying 279 neurons linked by 6,393 chemical synapses, 890 electrical junctions, and 1,410 neuromuscular junctions
- White et al. commented on the prevalence of "triangular sub-circuits," which they suggest "is probably a consequence of the highly locally connected nature of the nervous system"



White et al., 1985



# Discussion Question

How do dynamical explanations and network explanations relate to mechanistic explanations

A. They are competitors. May the best account win
B. Both dynamical and network analyses provide ways to understand the organization of mechanisms
C. Dyanamical and network analyses are useful supplements to mechanistic accounts
D. Other