Complex Adaptive Systems

- Systems composed of many interacting parts that evolve and adapt over time. Organized behavior emerges from the simultaneous interactions of parts without any global plan.
- Course Philosophy
  - Unification of sciences
    - counter to trend of specialization
    - Deep analogies
    - Interdisciplinary
  - Mechanism-based explanations
    - Descriptive versus process models
  - Hands-on laboratories and concrete examples

Properties of Complex Adaptive Systems

- Many interacting parts
- Emergent phenomena
- Adaptation
- Specialization & modularity
- Dynamic change
- Competition and cooperation
- Decentralization
- Non-linearities

Many interacting parts

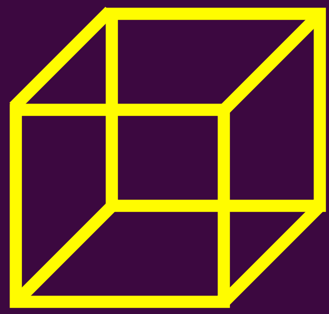
- Businesses made of people, colonies made of ants, , brains made of neurons, etc.
- Systems more than collections because of interactions
- Size matters
  - A critical number of amoeba needed to create clusters in slime molds
- Massive parallelism
  - Often, all agents do same, simple thing
  - Complexity comes from interactions

Emergent behavior

- Definitions of Emergence
  - Whole is more than sum of parts (spokes make wheels)
  - Could not have predicted behavior from lower levels
  - Higher-level descriptions
    - Special laws apply (Fodor on money)
    - High-level phenomena are not built in explicitly
      - predator-prey cycles
      - path finder
- Bridges between high and low levels of description
  - Not reductionism because high level is taken seriously
  - But, is higher-level description necessary?
    - functionalism, biological convergences, Dennett's "stances"
  - Finding bridges is a typically underdeveloped skill
  - Chaos Game

Adaptation

- Improved performance over time
- Three time courses of adaptation
  - Within a single event presented to an organism
    - Perception of an organized form
    - Adaptation of parts to each other
    - Adaptation of parts to external world
  - Within the lifetime of an organism
    - Learning
  - Across lifetimes
    - Evolution
- Interactions between levels of adaptation
  - Baldwin effect: Within-lifetime adaptation can facilitate evolutionary adaptation
  - Waddington's canalization: behaviors that are originally learned become genetically stipulated
  - Nowlan & Hinton: Learning facilitates evolution
  - Learning "greases pathway" for perception of an object



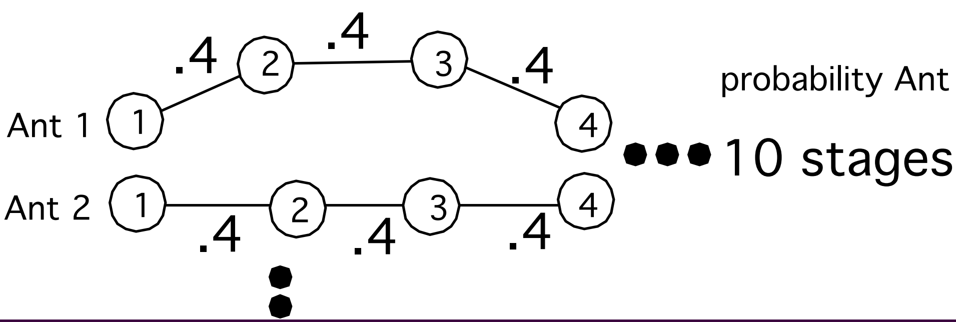
Specialization and Modularity

- Originally homogenous agents become differentiated as a result of interactions with each other
- Shift from renaissance thinkers to specialized scientists
  - Increased dependency of parts
  - The more dependencies between parts, the more organism-like is the whole
- Self-organization - systems become more structured than they were originally
- Advantages of modularity
  - Speed
  - efficiency
  - benefit of information encapsulation: module does not need to know about what is going on in the rest of the system
  - Modules in semantic processing, perception, action errors, neurological deficits
- Modules can be learned rather than innate
  - Jeff Elman, Robert Jacobs, David Rumelhart, etc.
  - Competitive learning
- E. O. Wilson on the benefits of specialization in ants

Specialization and Cooperation

10 stages, 20 ants, Probability of an ants completing a stage = 0.4

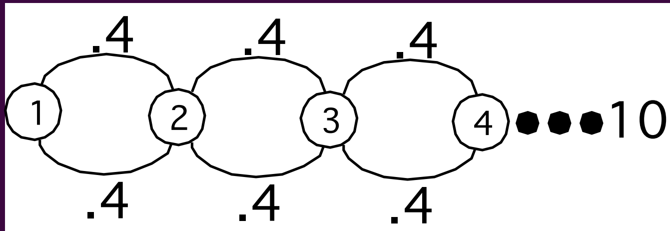
Jack-of-all-trades



probability Ant 1 finishes = $.4^{10}$ = .0001

probability of at least one completed task = 1- probability of no completions = $1-(1-.0001)^{20} = .002$

Specialization



probability one stage is completed by at least one of two ants = 1 - probability of no completions of a stage = $1 - (.6^2) = .64$

probability of at least one completed task = $.64^{10} = .012$

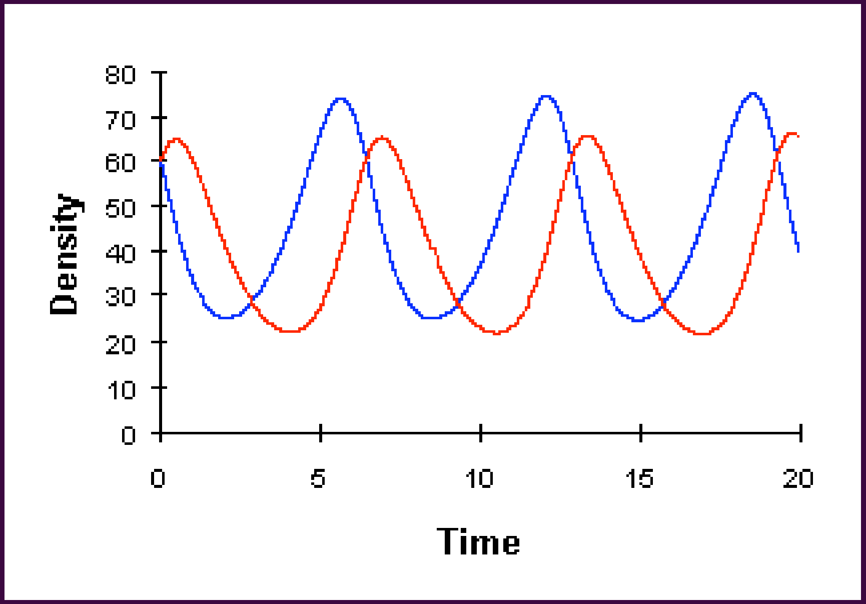
Moral: By specializing, probability of completing task is 6 times greater.

Dynamic Change

- Determination of trajectories rather than fixed points
- Complex systems often times never “settle down”

Competition and Cooperation

- Simple interactions: facilitation and antagonism
- Excitation and inhibition in neurons
- Diffusion and reaction
  - B-Z oscillating chemical reactions
  - Predator-prey dynamics
  - Movements and counter-movements
- Positive and negative feedback cycles



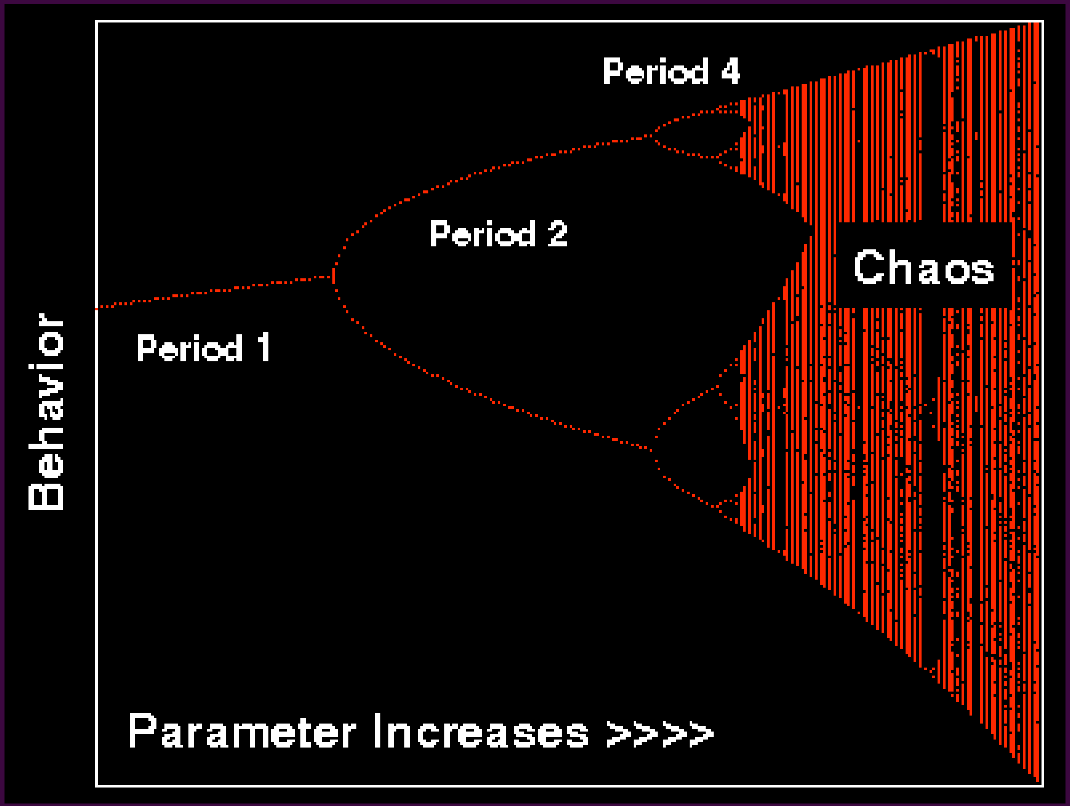
Decentralization

- Self-organization without leaders
  - Queen ants and head birds in a flock are not “in charge”
  - Alternatives to centralized mind-sets (Resnick, 1994)
  - Alternatives to the “Cartesian I”
- Peer-to-peer computing grids
- The World-wide-web
- Viral marketing
- Advantages of decentralization
  - Adaptability
  - System can be “smarter” than smartest agent
- Grass-roots movements

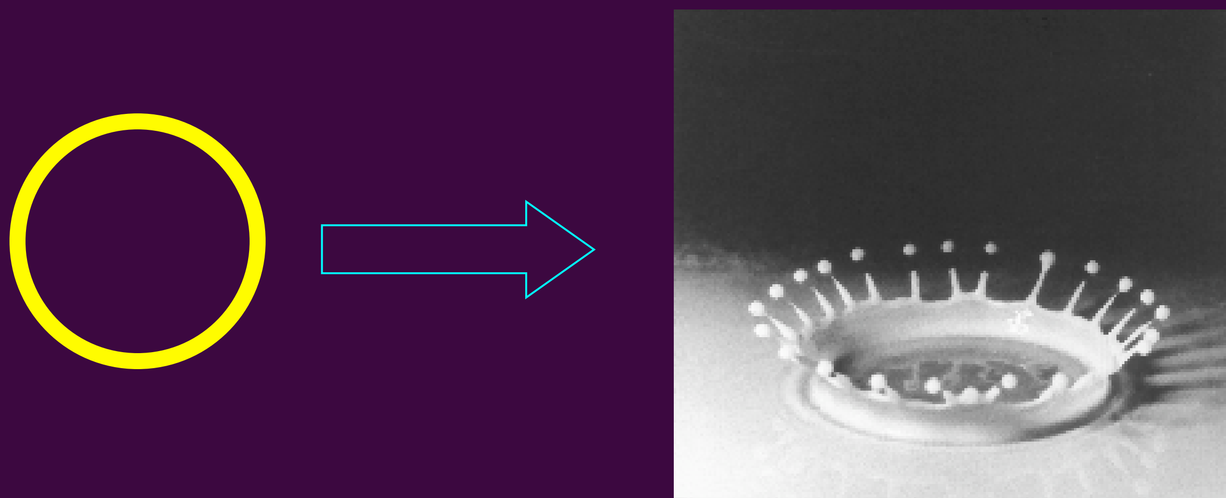
Nonlinearities

- Output is not proportional to input
  - Can’t predict how system will work by understanding parts separately, and combining them additively
- The tipping point (Gladwell)
  - Cascades of consequences from small events
  - Hushpuppies and a couple of East Village kids
    - 1994: 30,000 sold
    - 1995: 430,000
    - 1996: 2,000,000
- Phase transitions: ice to water to steam
- Bifurcation point: **Qualitative change in an attractor's structure as a control parameter is smoothly varied**
- **Symmetry breaking: Systems that start out (nearly) symmetric develop qualitatively large asymmetries**
  - Milk drops
  - Development of a fetus from blastula to embryo

Bifurcations in the logistic function for population change

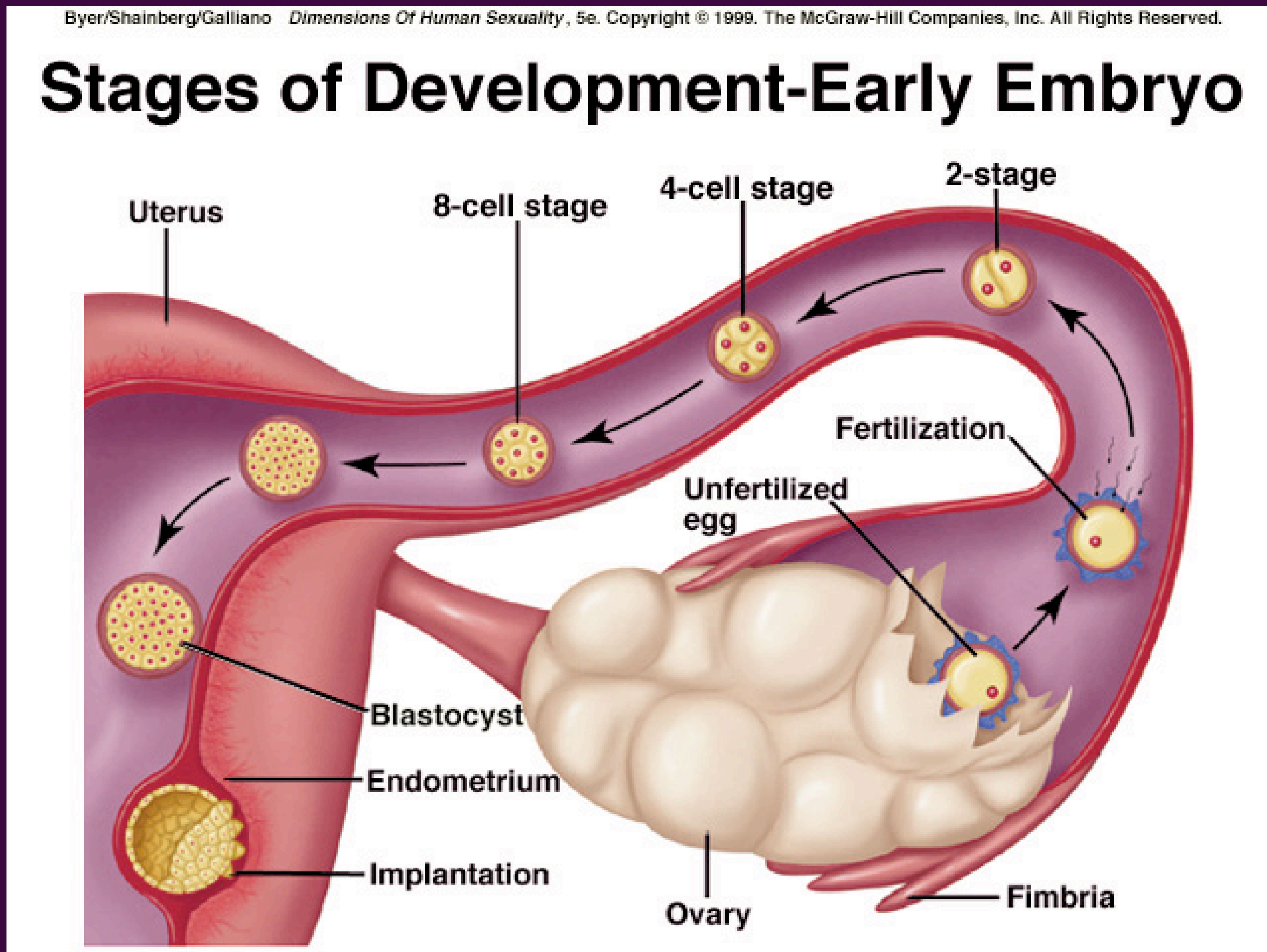


Symmetry Breaking in a droplet of milk



$O(2)$ symmetry -> D_{24}

Symmetry breaking in a fetal development



Model aesthetics

- High-level phenomenon is explained, not assumed
  - Mechanism-oriented accounts
- <u>Simplest</u> system that produces phenomena is preferred
- Complex adaptive system models as caricatures
  - Want explanations, not clones
  - concentrate on essence of a system
- Do parameters of variation correspond to existing natural systems?
  - Can most naturally occurring systems be modeled with parametric variations?
  - Do most parametric variations result in patterns that are found in nature?
    - Constraint is good
    - Want a system that could not have predicted anything

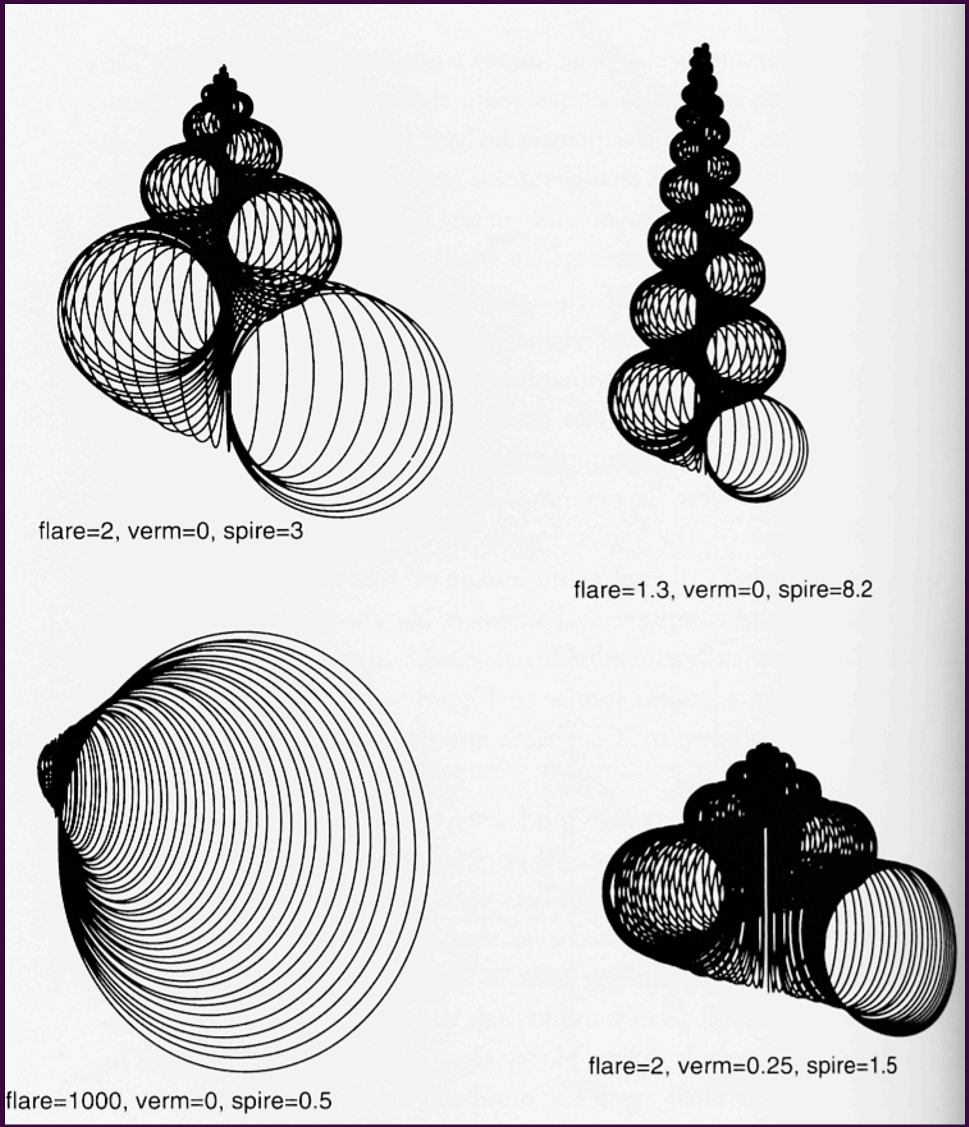
Raup’s Shell Generator

- Shells grow as tubes

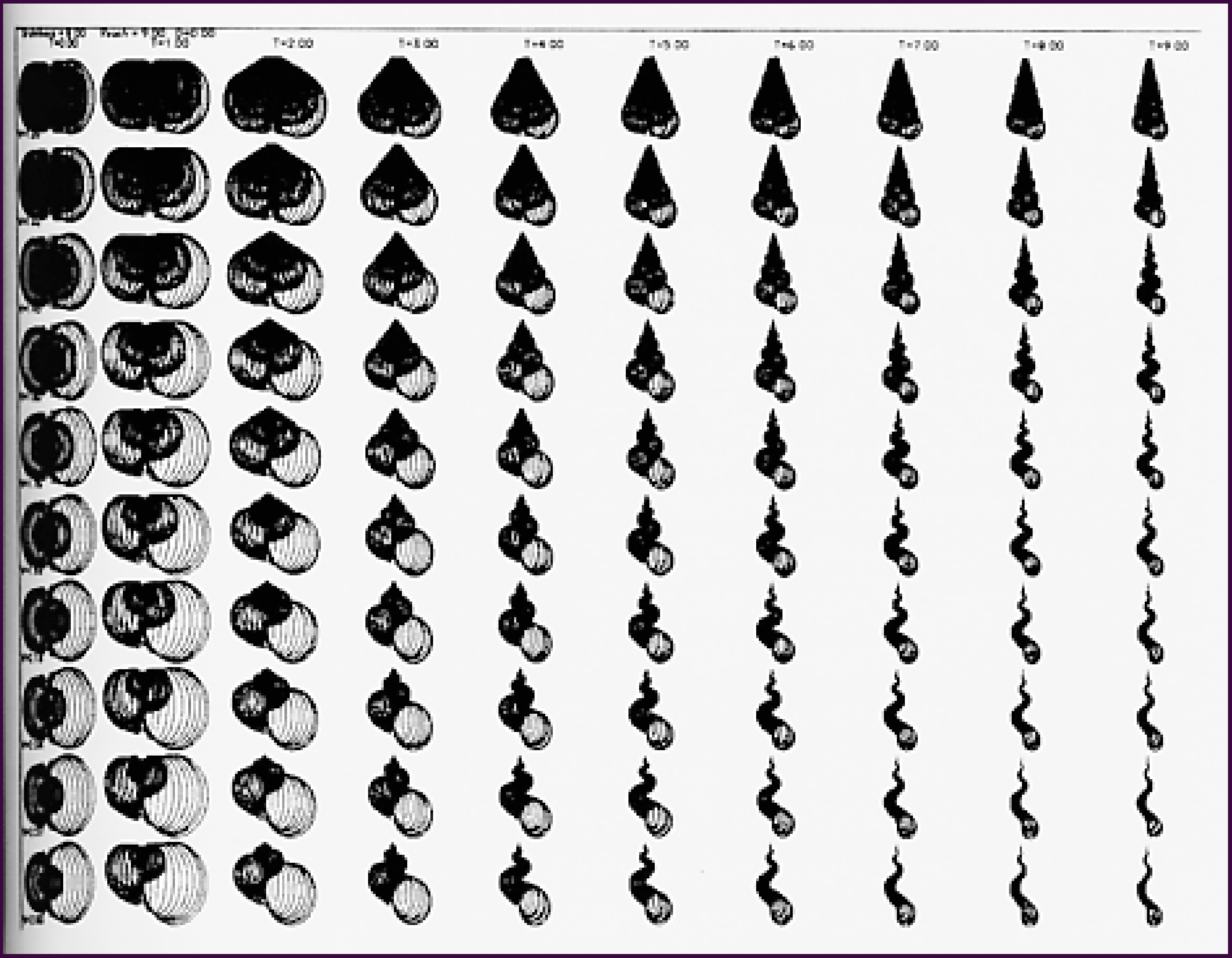
  Capture variations in shells with as few parameters as possible (explaining patterns that occur, and only those patterns)

- Flare: expansion rate of spiral
  - 2 = for every turn, spiral opens out to twice its previous size (spiral, not tube)
- Verm: How much tube fills area of spiral
  - .7 = distance from center of spiral to the inner margin of tube is 70% of the distance from center to outer margin.
- Spire: rate at which tube creeps up 3-D cone
  - 0 = all windings are in one plane
- Raup's Cube
  - Can explain many types of shells that are found
  - Cube is larger than set of existing shells, but this will always be the case.

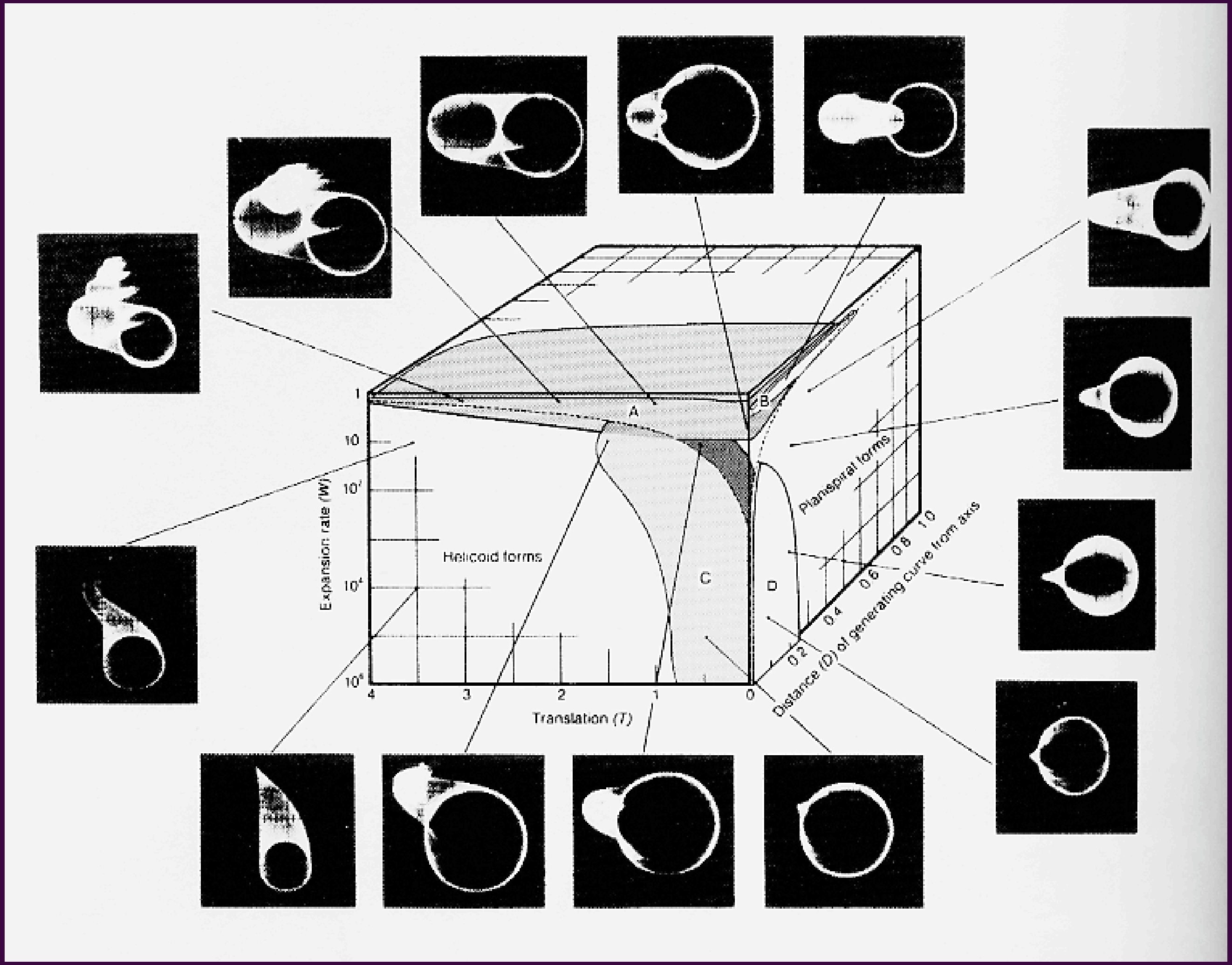
Raup's Shell Generator



Raup’s Shell Generator

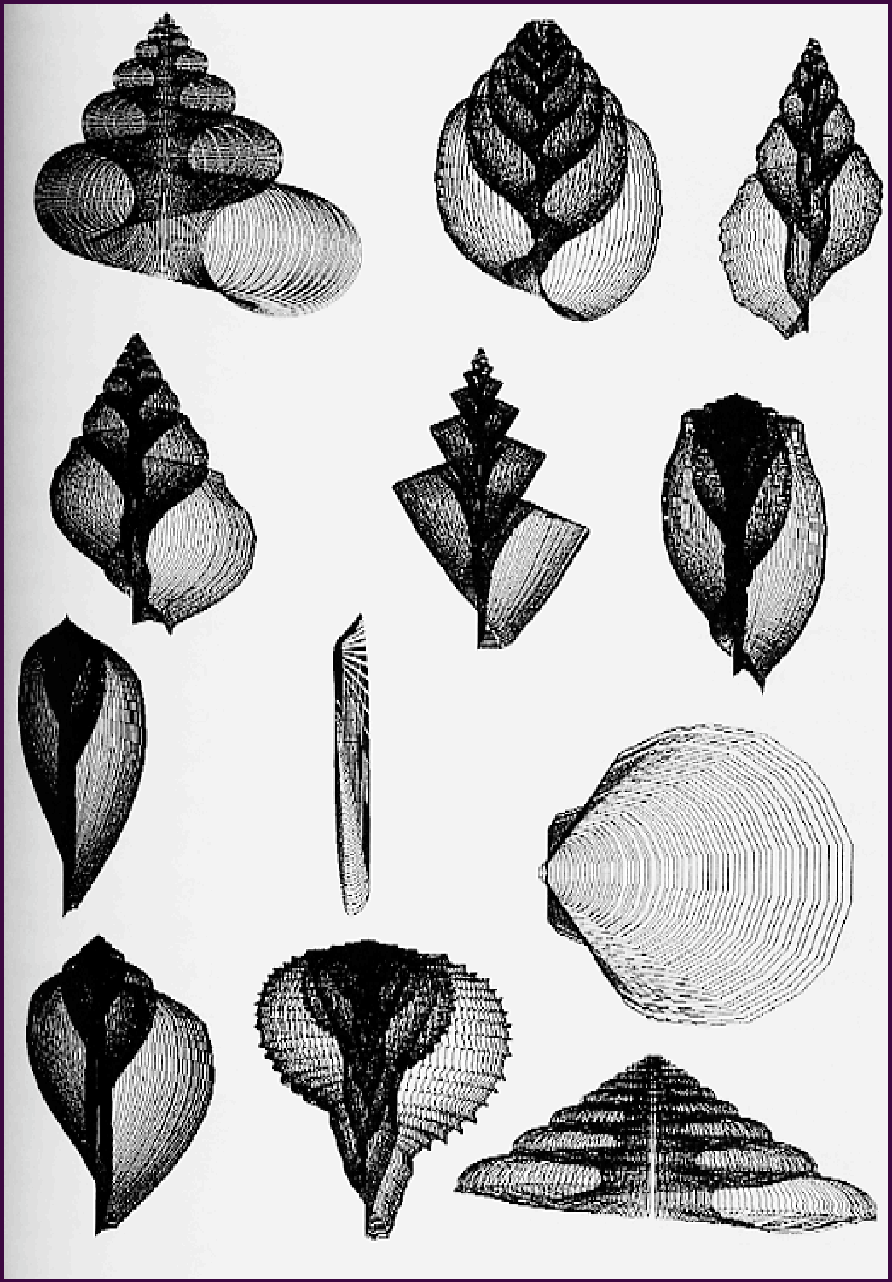


Raup's Cube

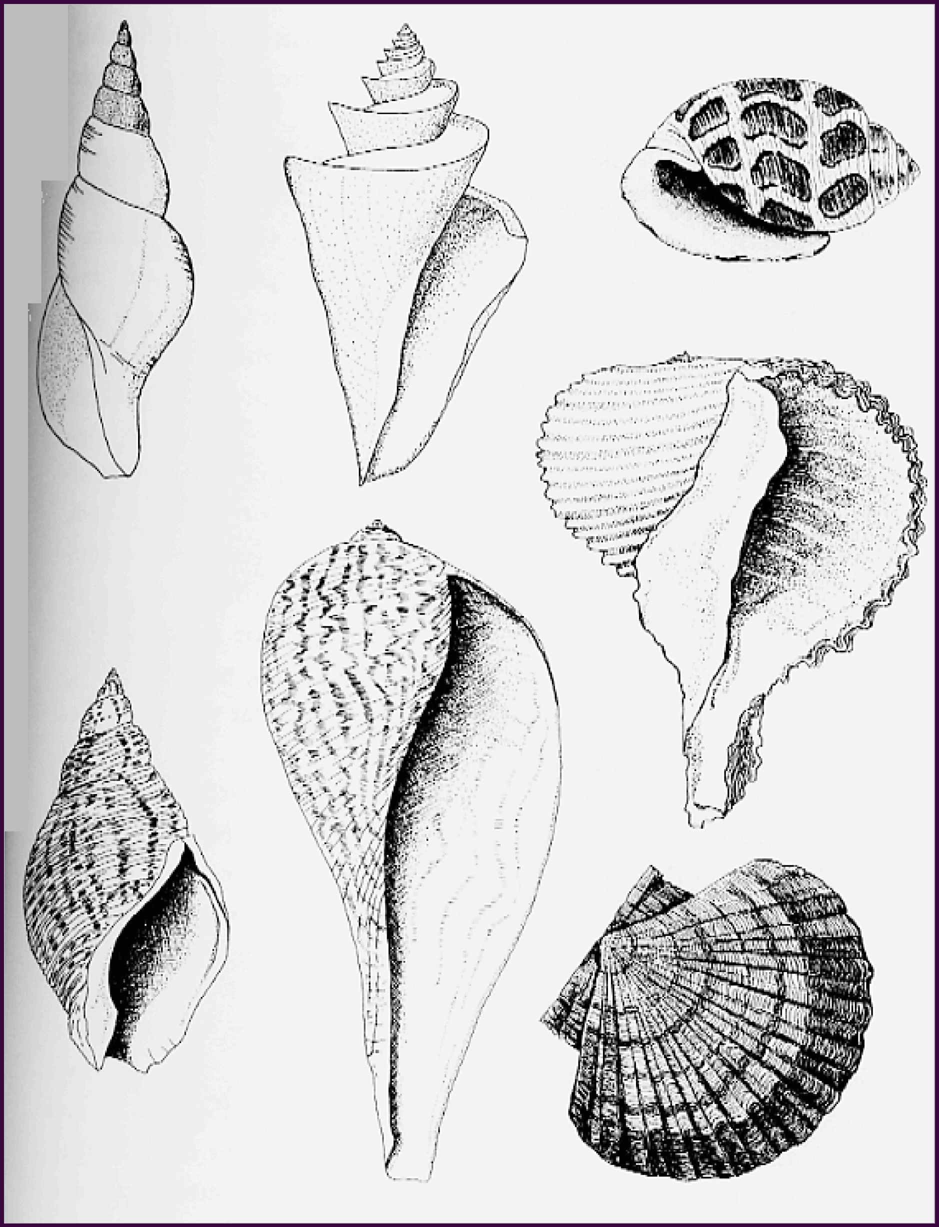


A
B
C
D
Helicoid forms
Planispiral forms
Expansion rate (W)
Translation (T)
Distance (D) of generating curve from axis

Dawkin’s Blind Snailmaker



Dawkin's Blind Snailmaker



D'arcy Thompson's constrained transformations

- Explain regularities in animal and plant forms by constrained transformations
- Transformations explained by growth processes
- Four standard transformations
  - Stretch the dimensions
  - Taper
  - Shear
  - Radial coordinates from a fixed focus

D’arcy Thompson’s constrained transformations

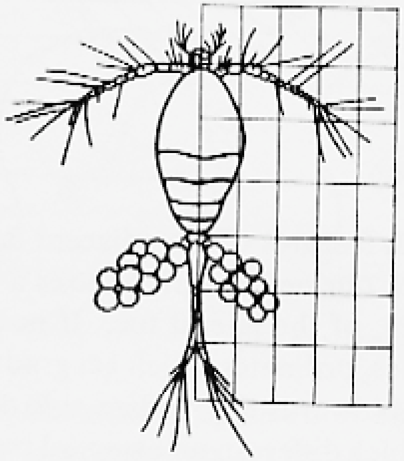


Fig. 140. *Oithona nana.*

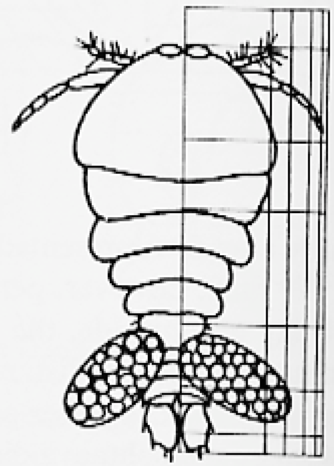


Fig. 141. *Sapphirina.*

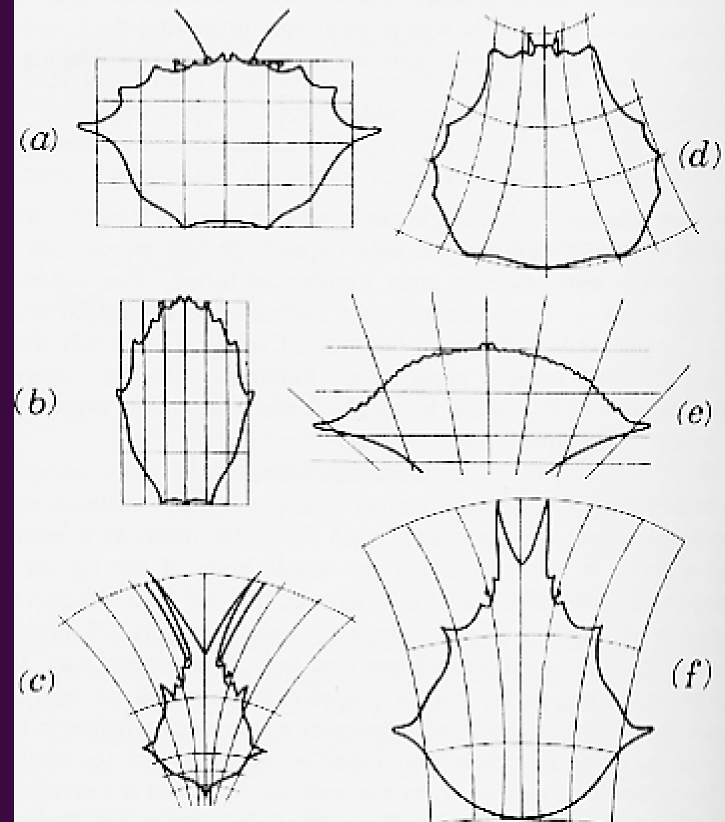


Fig. 142. Carapaces of various crabs. (a) *Geryon*; (b) *Corystes*; (c) *Scyramathia*; (d) *Paralomis*; (e) *Lupa*; (f) *Chorinus*.

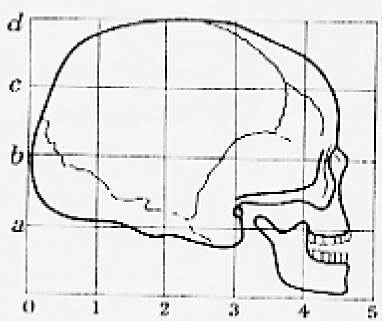


Fig. 177. Human skull.

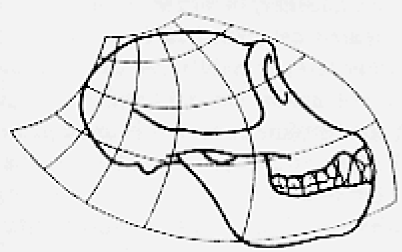


Fig. 179. Skull of chimpanzee.

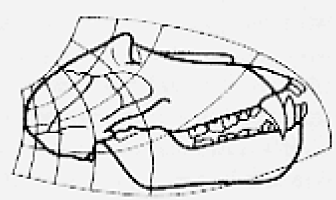


Fig. 180. Skull of baboon.