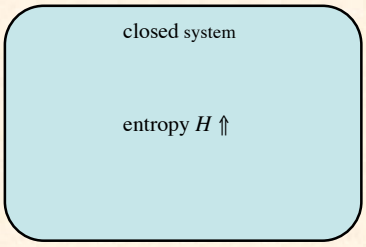
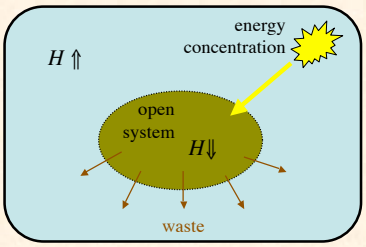
V. Evolutionary Programming

A. Thermodynamics & Evolution

The Second Law of Thermodynamics



The Second Law and Open Systems



Nonequilibrium Thermodynamics

- Classical thermodynamics limited to systems in equilibrium
- Extended by thermodynamics of *transport processes*
  - i.e. accounting for entropy changes when matter/energy transported into or out of an *open system*
- Flow of matter/energy can maintain a *dissipative system* far from equilibrium for long periods
- Hence, *nonequilibrium thermodynamics*

An Energy Flow Can Create Structure

(photo from Camazine & al. *Self-Org. Bio. Sys.*)

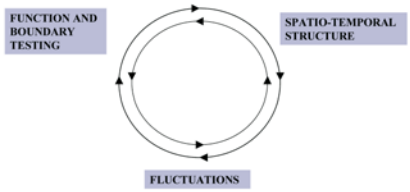
Bénard Convection Cells

(photo from Camazine & al. *Self-Org. Bio. Sys.*)

Persistent Nonequilibrium Systems

- *If* flow creates system so structured to maintain flow
- *then* positive feedback causes nonequilibrium system to persist indefinitely
  - but not forever (2nd law)
- Systems we tend to see are those most successful at maintaining nonequil. state
- Applies to species as well as organisms

Order Through Fluctuations



- Fluctuations (esp. when system forced out of ordinary operating range) test boundaries & nonlinear effects
- May lead to stabilization of new structures

fig. < Hart & Gregor, *Inf. Sys. Found.*

Stratified Stability: Higher Levels of Organization

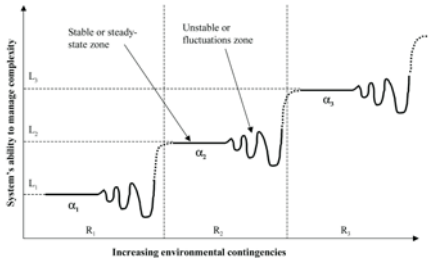


fig. < Hart & Gregor, *Inf. Sys. Found.*

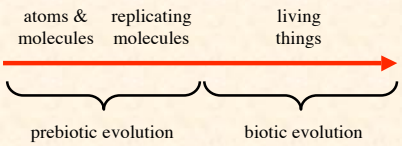
"Order for Free"

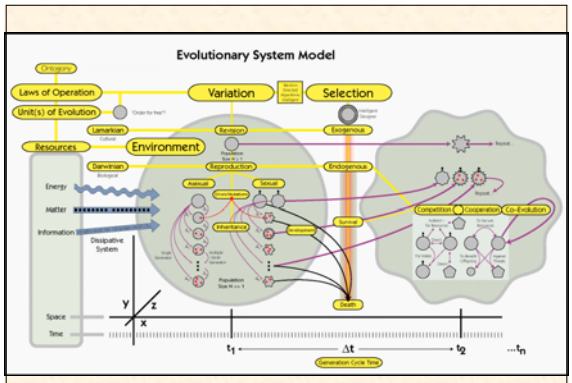
- Relatively simple sets of rules or equations can generate rich structures & behaviors
- Small changes can lead to qualitatively different structures & behaviors
- A diverse resource for selection
- A basis for later fine tuning (microevolution)
- See Kaufmann (*At Home in the Universe*, etc.) and Wolfram (*A New Kind of Science*)

Evolution in Broad Sense

- Evolution in the broadest terms:
  - blind variation
  - selective retention
- Has been applied to nonbiological evolution
  - evolutionary epistemology
  - creativity
  - memes

Evolution

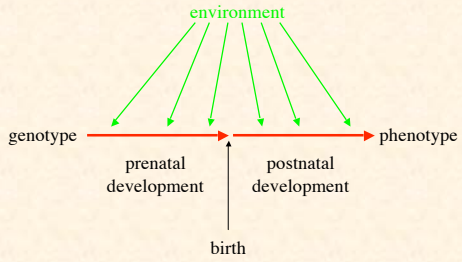




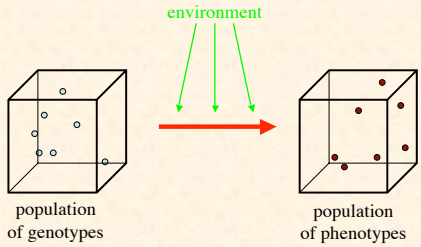
Genotype vs. Phenotype

- Genotype = the genetic makeup of an individual organism
- Phenotype = the observed characteristic of the organism
- Through interaction with environment, a genotype is *expressed* in a phenotype

Ontogeny



Genotype Space vs. Phenotype Space



Selection

- Selection operates on the phenotype, not the genotype
- Selection of genotypes is indirect

"Central Dogma" of Genetics

- "The transfer of information from nucleic acid to nucleic acid, or from nucleic acid to protein may be possible, but transfer from protein to protein, or from protein to nucleic acid is impossible."
  – Francis Crick
- A hypothesis (not a dogma)
- "New" Lamarckism: "jumping genes" and reverse transcription

Essentialism vs. "Population Thinking"

- Essentialism: each species has a fixed, ideal "type"
  - actual individuals are imperfect expressions of this ideal
  - species have sharp boundaries
  - the type is real, variation is illusory
- Population thinking: a species is a reproductive population
  - only individual organisms exist
  - species have blurred boundaries
  - species are time-varying averages
  - variation is real, the type is an abstraction

Fitness

- 1st approximation: the relative ability of an individual organism to optimize the energy flow to maintain its nonequilibrium state long enough to reproduce (survival fitness)
- 2nd approximation: reproductive fitness = the relative efficiency at producing viable offspring
  - of oneself (exclusive fitness)
  - of oneself or close relatives (inclusive fitness)

"Selfish Gene"

- An organism is a gene's way of making more copies of itself
- A gene (or collection of genes) will tend to persist in a population if they tend to produce physical characteristics & behavior that are relatively successful at producing more copies of itself
- Nevertheless, it is physical organisms (phenotypes) that confront the environment

Complicating Factors

- Individual genes influence multiple characteristics & behaviors
- Genes are not independent
- "Fitness" is in the context of a (possibly changing) environment including:
  - conspecifics
  - coevolving predators and prey
- Conclusion: beware of oversimplifications
  - keep entire process in mind

Can Learning Guide Evolution?

- "Baldwin Effect":
  - proposed independently in 1890s by Baldwin, Poulton, C. Lloyd Morgan
  - spread of genetic predispositions to acquire certain knowledge/skills
- Gene-culture coevolution
- Special case of *niche construction*: organisms shape the environments in which they evolve
- Also involves *extragenetic inheritance*
- Indirect causal paths from individual adaptation to genome

Example Effects of Single Genes

Butterfly Eyespots

- Major changes within 6 generations
- May lead to patterns not seen in previous generations

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Two Populations of *Astyanax mexicanus*

- Two populations of one species
- Regulation of one gene (controlling head development)
  - eyes, smaller jaws, fewer teeth
  - blind, larger jaws, more teeth

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Human Fear Response

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Single Gene Affecting Human Fear Response

- Two alleles for gene:
  - short allele ⇒ greater anxiety response to angry or frightened faces
  - long allele ⇒ lesser response
- Gene encodes transporter protein, which carries serotonin back into neuron after release
- Short allele produces 1/2 amount of protein
- Accumulating serotonin affects neighboring cells

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Human vs. Rat Cortex

- Human cortex relatively larger
- Also more structured

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Experiment

- Problem: How do organs know when to stop growing?
- Genetically engineer rats to express a mutant form of protein (β-catenin)
- More resistant to breakdown, ∴ accumulates
- Spurs neural precursor cells to proliferate

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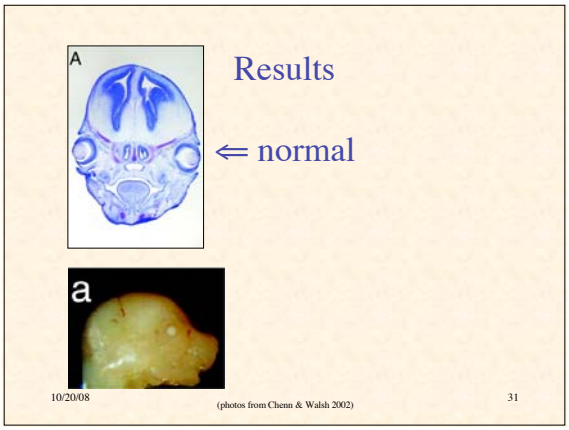
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Results
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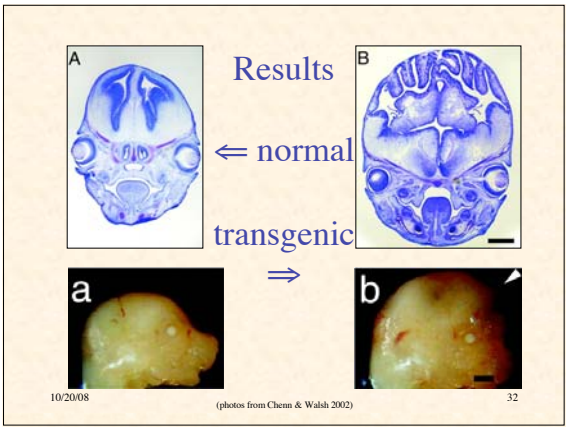
A
Results
B
⇐ normal
transgenic
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