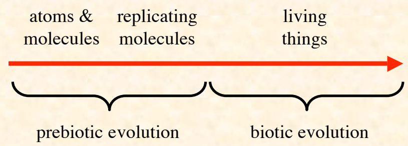
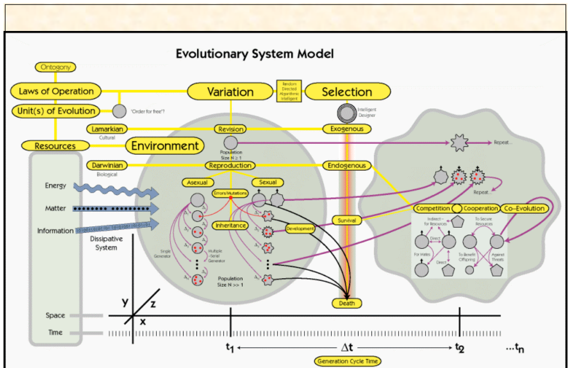
# Lecture 24



# Evolution






(from NECSI)

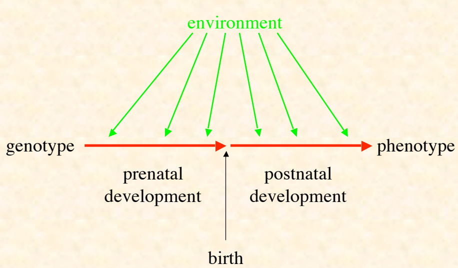


# Genotype vs. Phenotype

- 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

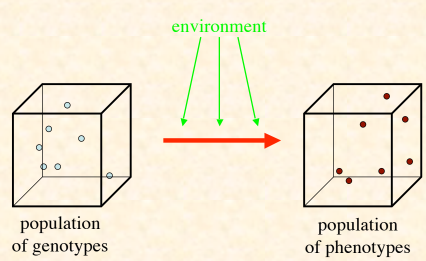


# Ontogeny






# 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

11/15/07 13

## Example Effects of Single Genes

11/15/07 14

## Butterfly Eyespots

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

11/15/07 (photos from *Science* 1 Nov 2002) 15

## 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

11/15/07 (photos from *Science* 1 Nov 2002) 16

## Human Fear Response

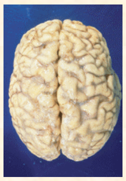
11/15/07 (photos from *Science* 19 July 2002) 17

## 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

11/15/07 18

## Human vs. Rat Cortex




- Human cortex relatively larger
- Also more structured

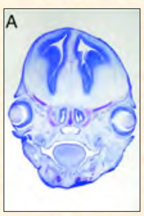
11/15/07 19

## 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

11/15/07 20

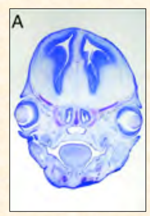
## Results




⇐ normal

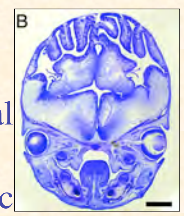

11/15/07 (photos from Chenn & Walsh 2002) 21

## Results

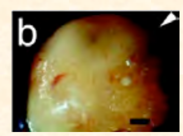



⇐ normal

transgenic ⇒








11/15/07 (photos from Chenn & Walsh 2002) 22

## Genetic Algorithms

- Developed by John Holland in ‘60s
- Did not become popular until late ‘80s
- A simplified model of genetics and evolution by natural selection
- Most widely applied to optimization problems (maximize “fitness”)

11/15/07 23

## Assumptions

- Existence of fitness function to quantify merit of potential solutions
  - this “fitness” is what the GA will maximize
- A mapping from bit-strings to potential solutions
  - best if each possible string generates a legal potential solution
  - choice of mapping is important
  - can use strings over other finite alphabets

11/15/07 24

## Outline of Simplified GA

1. Random initial population $P(0)$
2. Repeat for $t = 0, \ldots, t_{max}$ or until converges:
   a) create empty population $P(t + 1)$
   b) repeat until $P(t + 1)$ is full:
      1) select two individuals from $P(t)$ based on fitness
      2) optionally mate & replace with offspring
      3) optionally mutate offspring
      4) add two individuals to $P(t + 1)$



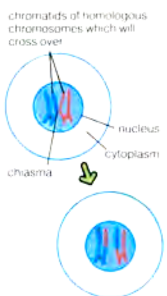
## Fitness-Biased Selection

- Want the more "fit" to be more likely to reproduce
  - always selecting the best ⇒ premature convergence
  - probabilistic selection ⇒ better exploration
- Roulette-wheel selection: probability ∝ relative fitness:

$$\Pr\{i \text{ mates}\} = \frac{f_i}{\sum_{j=1}^{n} f_j}$$



## Crossover: Biological Inspiration

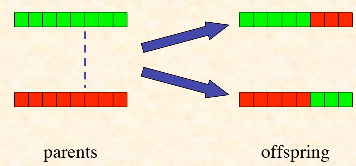



- Occurs during meiosis, when haploid gametes are formed
- Randomly mixes genes from two parents
- Creates genetic variation in gametes

(fig. from *B&N Thes. Biol.*)

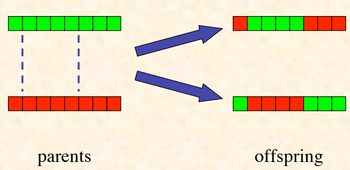


## GAs: One-point Crossover



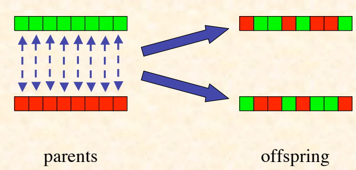



## GAs: Two-point Crossover



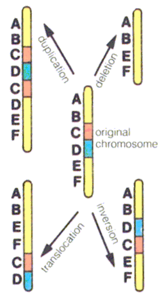



## GAs: *N*-point Crossover



## Mutation: Biological Inspiration

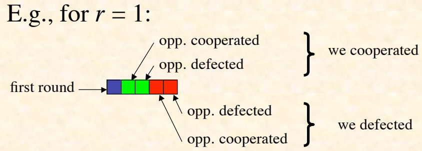
- Chromosome mutation ⇒
- Gene mutation: alteration of the DNA in a gene
  - inspiration for mutation in GAs
- In typical GA each bit has a low probability of changing
- Some GAs models rearrange bits




11/15/07 (fig. from *B&N Thes. Biol.*) 31

## Example: GA for IPD

- Genetic strings encode strategy
  - for first round
  - based on self's & opponent's action on $r$ previous rounds
  - hence $2^{2r} + 1$ bits
- E.g., for $r = 1$:




11/15/07 32

## Typical Result

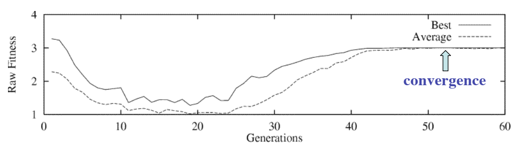



**Figure 20.4** Average and best raw fitness scores for the IPD-playing GA

11/15/07 33

## Demonstration of GA

11/15/07 34

## The Red Queen Hypothesis

"Now, *here*, you see, it takes all the running *you* can do, to keep in the same place."
— *Through the Looking-Glass and What Alice Found There*

- *Observation*: a species probability of extinction is independent of time it has existed
- *Hypothesis*: species continually adapt to each other
- Extinction occurs with insufficient variability for further adaptation

11/15/07 35

## Reading

- Read Flake, ch. 17, "Competition & Cooperation"

11/15/07 36