It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us.

Charles Darwin

Natural Selection

"Nothing in Biology makes sense, except in the light of evolution." T. Dobzhansky

Charles Darwin, 1859, The Origin of Species

- 3 key ingredients for adaptation by natural selection
  - Exponential growth of populations
  - Struggle for existence: Limited Capacity for any population
  - Variable, heritable survival and reproduction

Natural Selection

- The unity of life: all species have descended from other species
- Builds on Malthus, *An Essay on the Principle of Population,* 1798
- Domestic breeding shows hereditary modification is possible

- Fitness is a characteristic of individuals
- Natural Selection operates on populations
- Fitness is defined only for a particular environment
  - Environments always change
  - Species form the selective environments of other species

- Is ‘survival of the fittest’ a circular statement?
- Is natural selection an optimization process?

Natural Selection

- Natural selection
  - is often slow, but arms races result in complex, wonderful, bizarre (and stupid) things
  - can lead to cooperation
  - (largely) based on the fitness of reproductive individuals
- Natural selection is not
  - learned behavior passed on
  - group selection (Dawkins: selection acts on genes & on individuals, not groups)
  - Exceptions?
- There's a lot we don't know about evolution
  - The role of symbiosis & cooperation
  - The 'right' definition of species

Evolution in action

<u>At the start</u>

- Men are fish
  - Red clothing → fast
  - No red clothes→ slow
- Women are sharks

- If a slow fish is tapped by an adjacent shark, fish dies if it flips heads once. Dead fish becomes a shark.
- If a fast fish is tapped by an adjacent shark, fish dies if it flips heads twice in a row. Dead fish becomes a shark.
- Sharks stay alive as long as they are next to a fish, otherwise they die. Dead shark becomes a fast fish.

Evolution in action: Start again

At the start

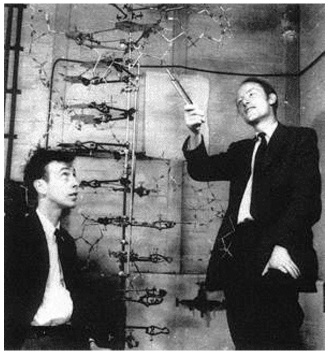
- Men are fish
  - Red clothing → fast
  - No red clothes→ slow
- Women are sharks

- If a slow fish is tapped by an adjacent shark, fish dies if it flips heads once. Dead fish becomes a shark.
- If a fast fish is tapped by an adjacent shark, fish dies if it flips heads twice in a row. Dead fish becomes a shark.
- Sharks stay alive as long as they are next to a fish, otherwise they die. Dead shark becomes a fast fish.
- Mutant shark eats fast & slow fish, but can't see green
  - If not wearing green, any fish next to a mutant shark gets eaten 100% of the time, and replaced by a new mutant shark.

Darwin did not have a mechanism for heritable, variable fitness

- Genes: strings of DNA that get transcribed to RNA, translated to proteins and expressed as phenotype

Genetics



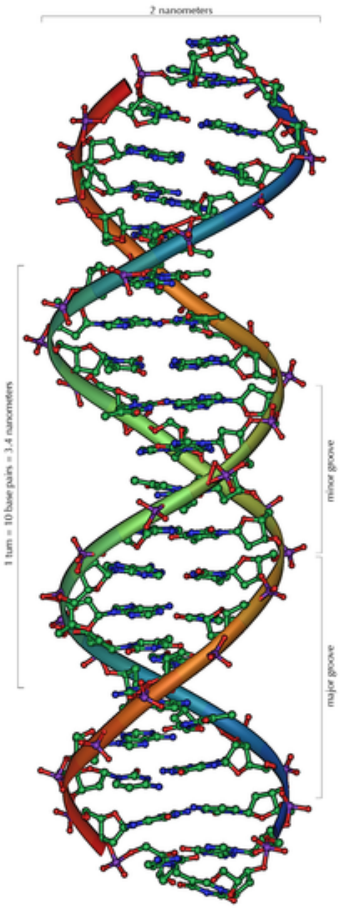
- Mendel: showed that genes exist by breeding pea plants genes exist as recessives and dominants, one copy from each parent
  - Given dominant AA mom and recessive aa dad,

    offspring are all Aa, and look like mom
  - Variation comes from combining genes from mom (BBCCddZz) and dad (bbccDdZZ)
  - Overly simplified. Still didn't know what a gene was.

- In 1953 Watson & Crick & Rosalind Franklin discover the molecular structure of DNA

DNA

- The molecule that carries heritable information
- Every cell in your body has ~30,000 bp of DNA that is transcribed into RNA and translated into proteins
  - Proteins do all the work: Make your eyes blue, your hair curly, your muscles strong, your heart pump
- DNA is arranged into genes on chromosomes
  - Humans have 23 chromosomes, 2 copies each (46)
  - Fits by supercoiling: 2-3m DNA / cell, your DNA goes to moon and back 70 times!



A-T
C-G

What mechanisms allow for heritable, variable fitness?

Heritable

Genes: encoded in DNA, transcribed to RNA, translated to proteins whose expression determines fitness

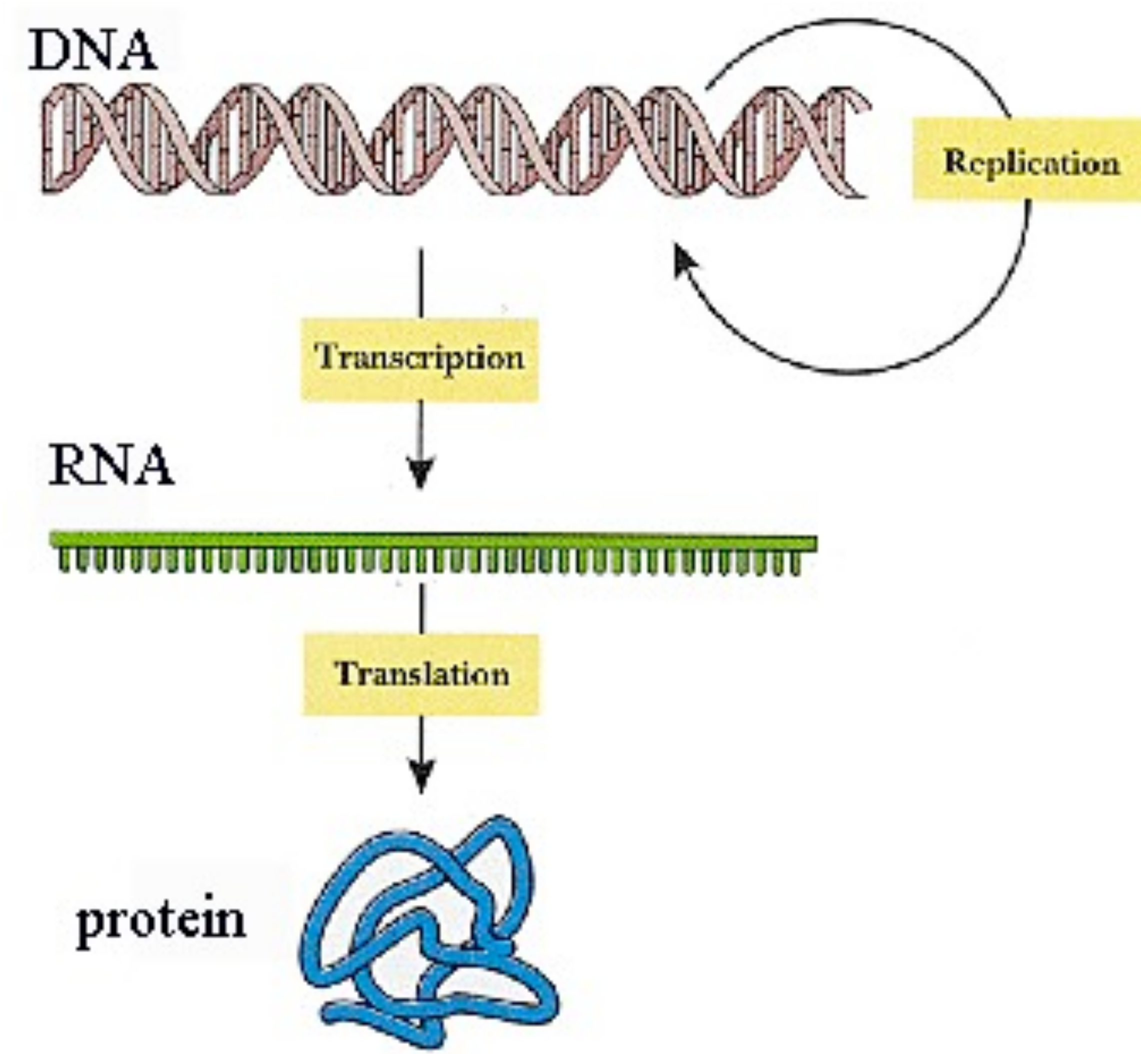
Variable

Mutations--copies are not perfect

Sex—genes are combined from 2 parents

Crossing over—allows for many different possible combinations

The Central Dogma



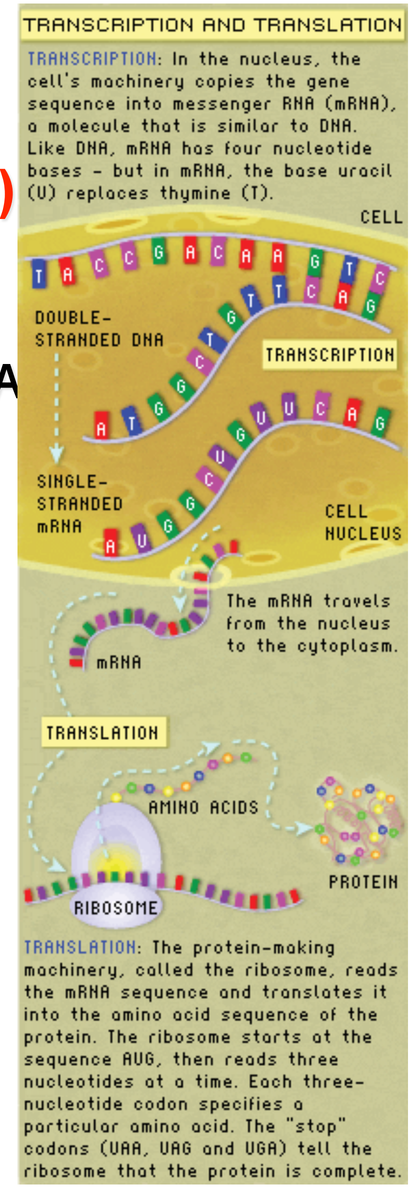
The Central Dogma

DNA (info storage)→RNA (info transfer) →protein (work)

- Segment of DNA is unwound
- An mRNA strand is transcribed from the template strand of DNA
- mRNA → travels out of nucleus (degrades quickly)
- RNA travels to ribosomes in cytoplasm, where it is translated

Why go through all this trouble?

The nature of biological information, the possibilities for variation, and the process of selection depend on these mechanisms

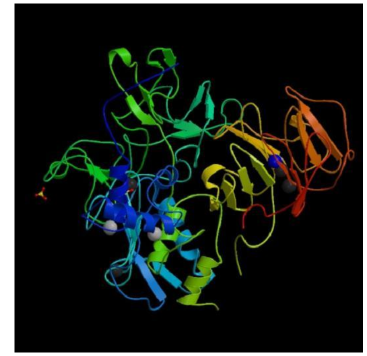


RNA codon TRANSLATION table
4 bases, 3 per codon = 4^3 codons = 64 codons
20 amino acids (redundancy is possible)

This table shows the 64 codons and the amino acid each codon codes for.
The direction is 5' to 3'.

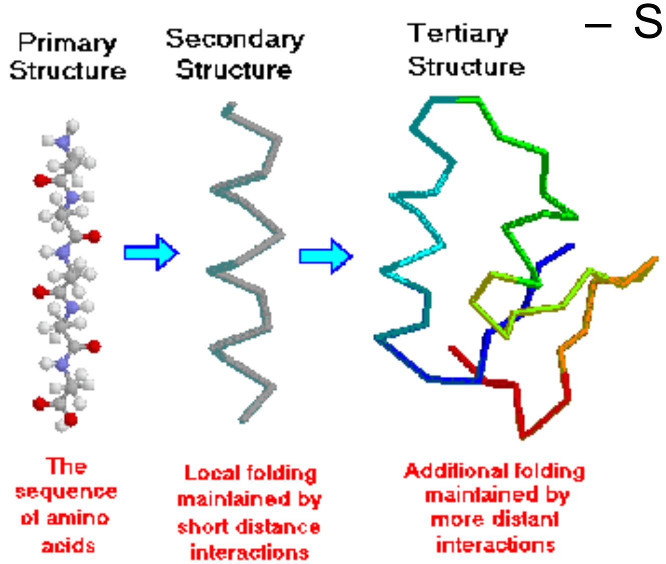
Ala/A	GCU, GCC, GCA, GCG	**Leu/L**	UUA, UUG, CUU, CUC, CUA, CUG
Arg/R	CGU, CGC, CGA, CGG, AGA, AGG	**Lys/K**	AAA, AAG
Asn/N	AAU, AAC	**Met/M**	AUG
Asp/D	GAU, GAC	**Phe/F**	UUU, UUC
Cys/C	UGU, UGC	**Pro/P**	CCU, CCC, CCA, CCG
Gln/Q	CAA, CAG	**Ser/S**	UCU, UCC, UCA, UCG, AGU, AGC
Glu/E	GAA, GAG	**Thr/T**	ACU, ACC, ACA, ACG
Gly/G	GGU, GGC, GGA, GGG	**Trp/W**	UGG
His/H	CAU, CAC	**Tyr/Y**	UAU, UAC
Ile/I	AUU, AUC, AUA	**Val/V**	GUU, GUC, GUA, GUG
START	AUG	**STOP**	UAG, UGA, UAA

Proteins



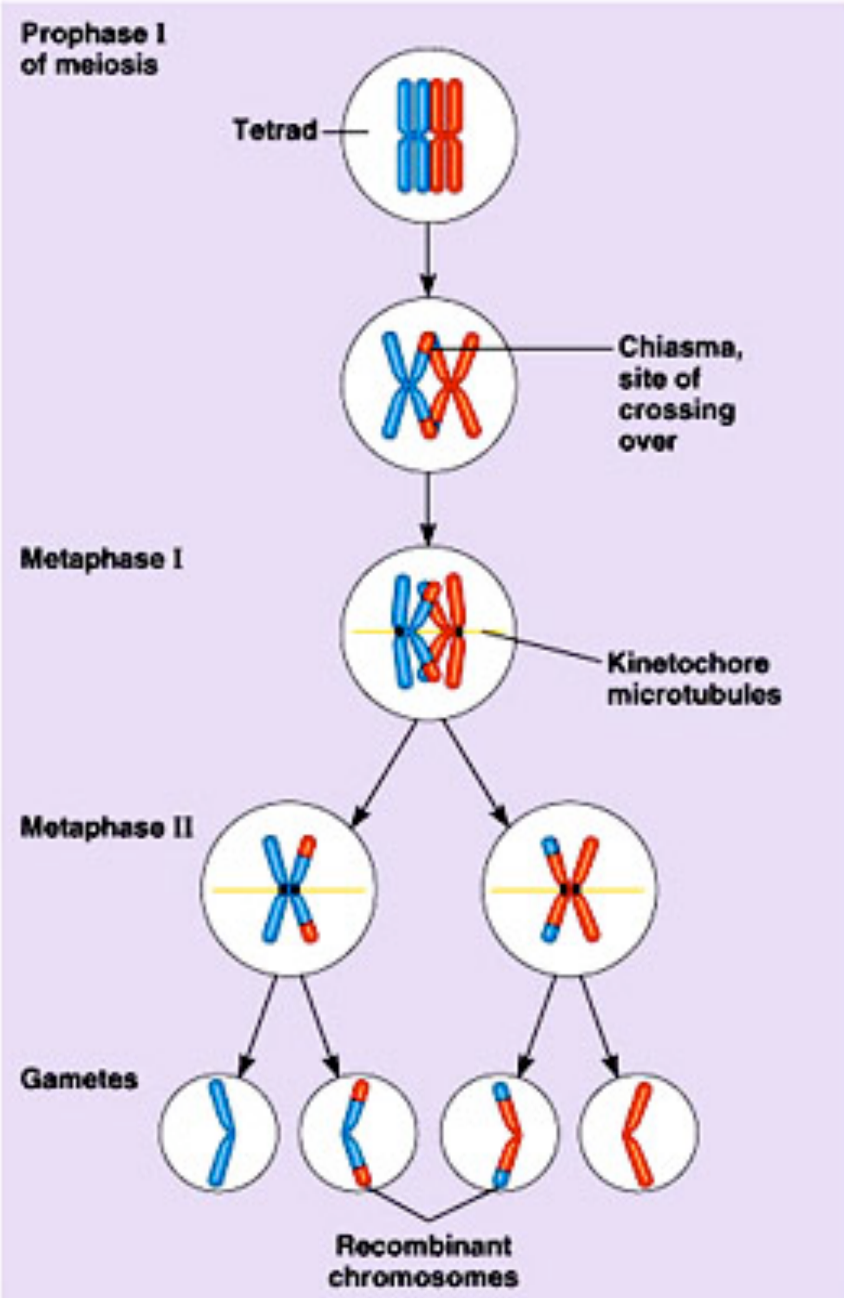
Proteins are strings of amino acids

- Primary, secondary and tertiary structure
- Proteins do all the work but
- 99% of human DNA is not translated into protein
    - Why carry around all that ‘junk’?
        - Some is not expressed in some cells or conditions
        - Some is evolution’s play ground
        - Some regulates other genes



Variation in DNA

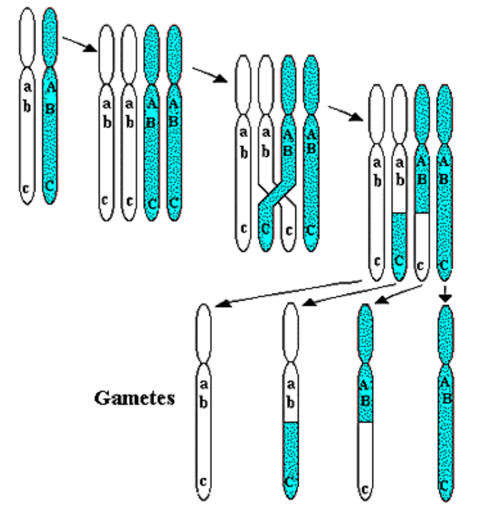
- How can the genetic content of a strand of DNA change?
  - Mutagens – many types of direct mutations – UV, particle radiation, oxygen radicals, other chemicals
  - Sex (Mendelian genetics)
  - Chromosomal crossing over
  - Gene exchange via gene transfer in bacteria
  - Viral DNA insertion and exchange (viruses do not have cellular machinery to reproduce their genomes, so use ours – mistakes happen)
  - Many ways we don’t understand



Sex & Crossing Over

- Each diploid human cell has 2 copies of each (of 23) chromosome
- Sex cells (sperm & eggs) are haploid with 1 copy of each chromosome.
- Crossing over shuffles genes shuffled from both parents onto 1 chromosome
- Your children can have grandma's near-sightedness and grandpop's left-handedness

Crossing over
(Important in Genetic Algorithms)



Crossing-over and recombination during meiosis

Mom: AAA_CAT_CCG_GTA…
tall, blue eyes, left-handed, no toe hair

Dad: AAG_CCT_TCC_GGA…
short, brown eyes, Right-handed, hairy toes

Baby -----> AAACATTCCGGA

tall, brown eyes, right handed, hairy toes

Summary: Genetics & Natural Selection

3 key ingredients for adaptation by natural selection

- Exponential growth of populations
- Struggle for existence: Limited Capacity for any population
- Variable, heritable survival and reproduction

Genetics: A discrete 4 letter alphabet (AGCT)

packaged into genes

Transcribed into RNA

3 letter codons are translated into amino acids which form proteins

Variation and Heredity

Letters can change: mutations, insertions, deletions

Chromosomes crossover to create sperm & eggs

Sperm and eggs combine to make new offspring