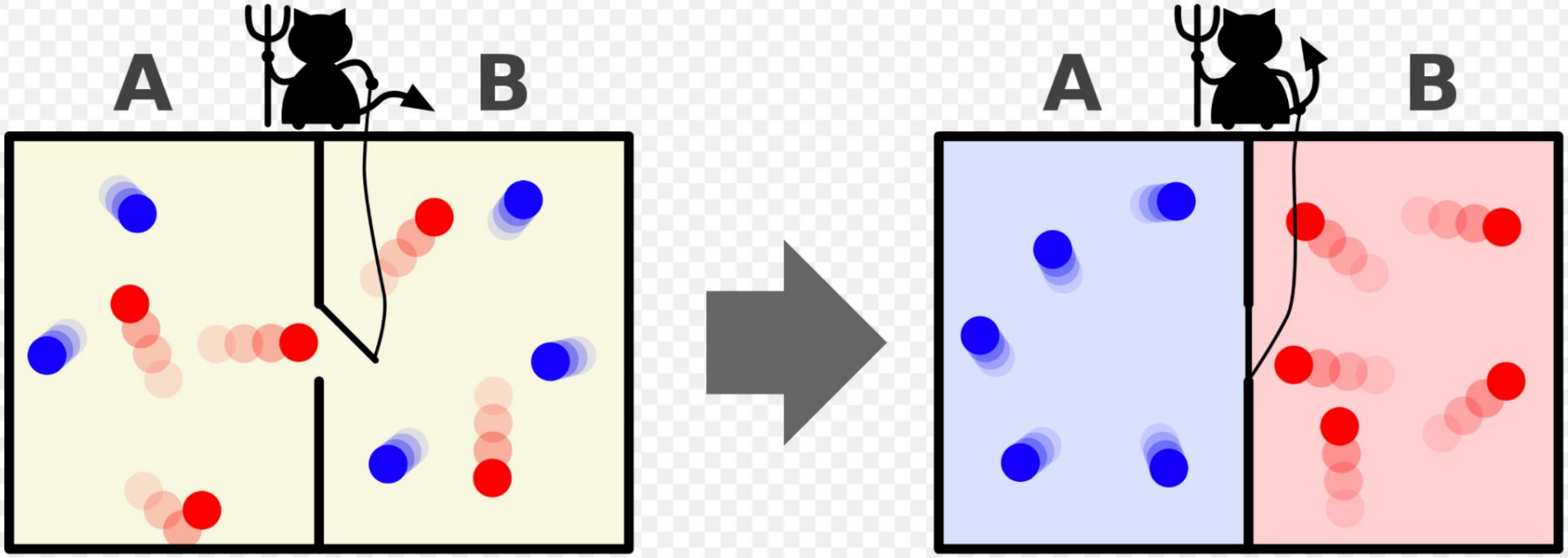
For next class

- Review videos & assignments
- CARC and SIMCoV tutorials
- See me after class if you registered after the first day of class to set up carc acct

Last class…

- Mitchell Ch 1: Complex Adaptive Systems
- Mitchell Ch 2: Logistic Map
  - Flake Chapter 10
- Mitchell Ch 3: Information Theory
- Mitchell Ch 4: Computation and self reference

Maxwell's Demon



Speedy Intro to CAS Part 2

Mitchell chapters 5 - 9

- **Evolution**
- **Genetics**
- Definitions of Complexity
- Self replication
- **Genetic Algorithms**

Things you should know

- What is the best idea anyone has ever had (according to Mitchell, according to Daniel Dennet?)
  - It was also an idea "in the air"
- What is the Central Dogma. What are Transcription, Translation?
- What is a neutral mutation (think about the mapping of codons to amino acids)?
.

Define and give an example of:
- Phenotypic plasticity
- Developmental bias
- Niche construction
- Inclusive inheritance (non-genetic inheritance)

- Define fractal dimension

- What is a "Frozen accident" (according to Gell-Mann)
- What is punctuated equilibrium?
- Bonus question. Fill in the blank:

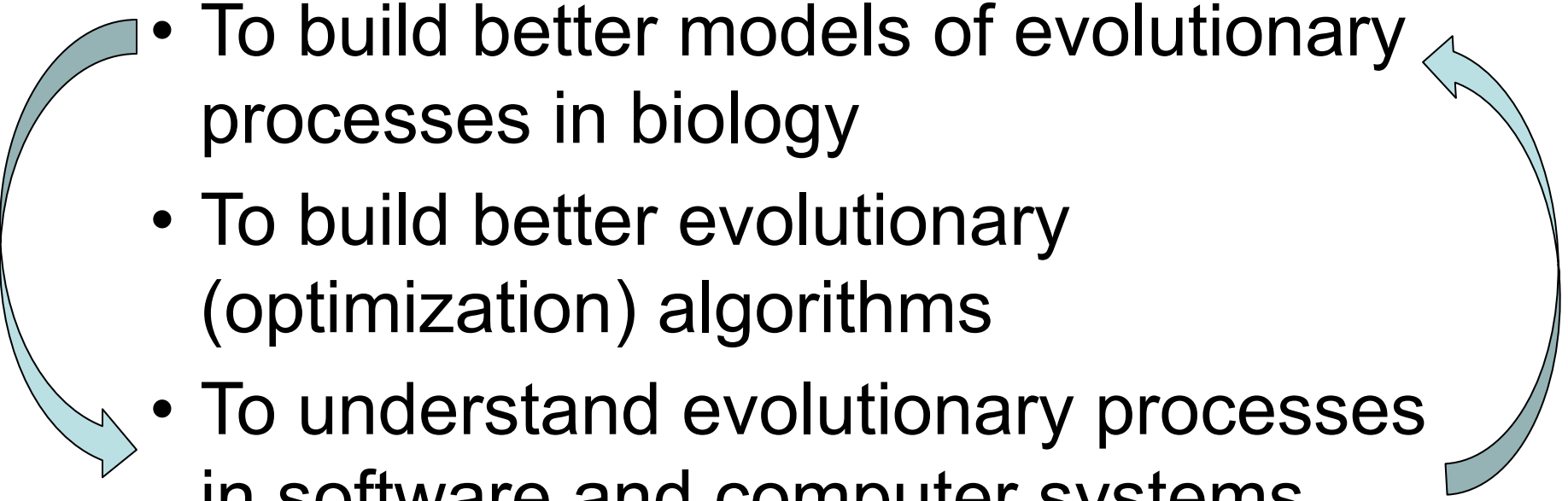
A scientist would rather use someone else's _____ than another scientist's nomenclature.

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

Why should computer scientists understand evolution?

- To build better models of evolutionary processes in biology
- To build better evolutionary (optimization) algorithms
- To understand evolutionary processes in software and computer systems



Natural Selection

"Nothing in Biology makes sense" T. Dobzhansky

Natural Selection

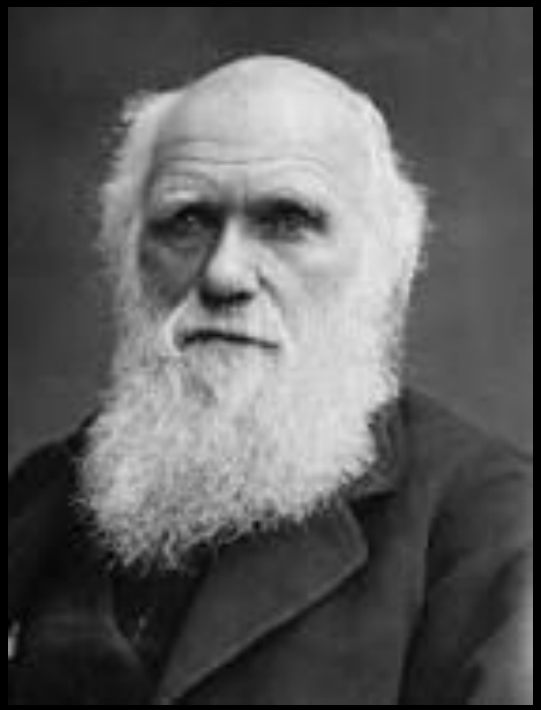
"Nothing in Biology makes sense, except in the light of evolution." T. Dobzhansky

Charles Darwin, 1859, The Origin of Species

3 key ingredients for evolution by natural selection

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

Evolution by Natural Selection

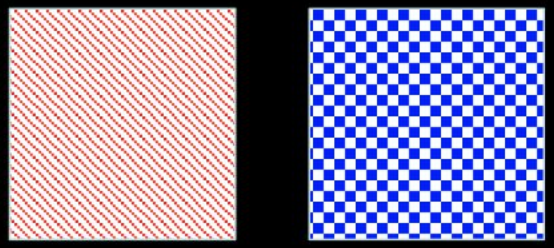


Variation

Inheritance

Selection

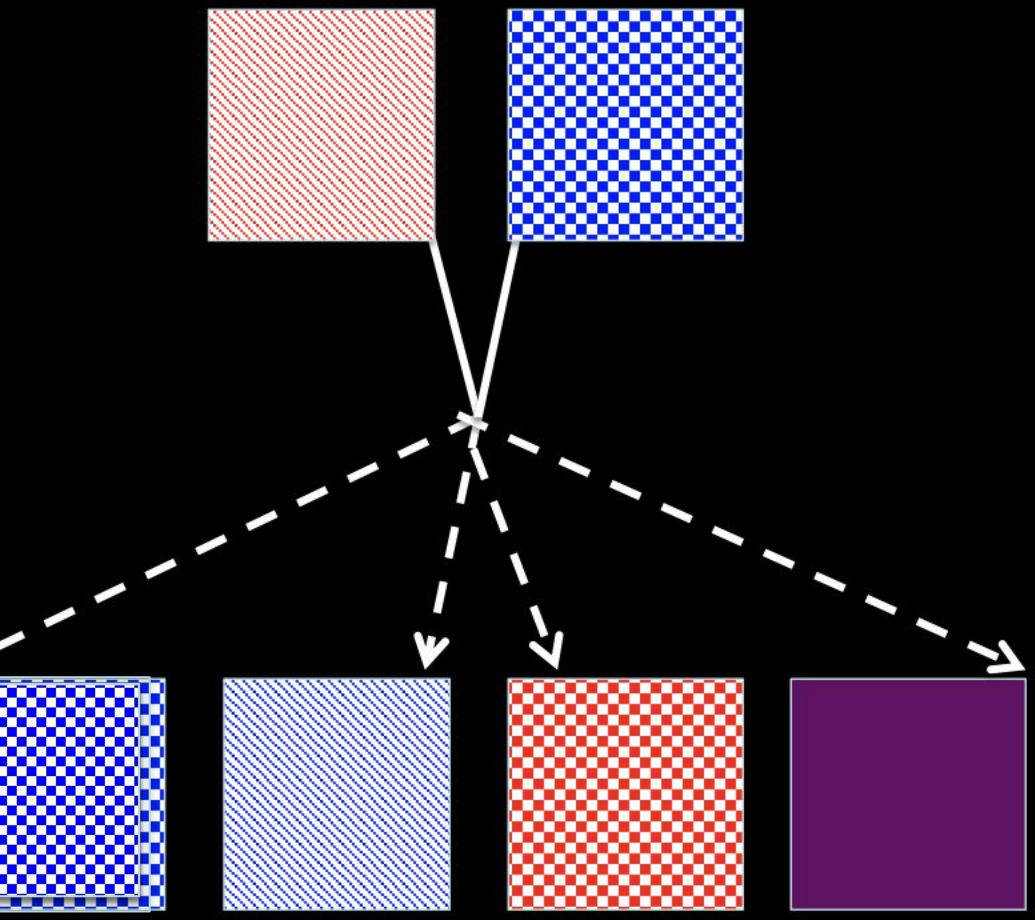
Evolution by Natural Selection



Variation

Diversity

Evolution by Natural Selection



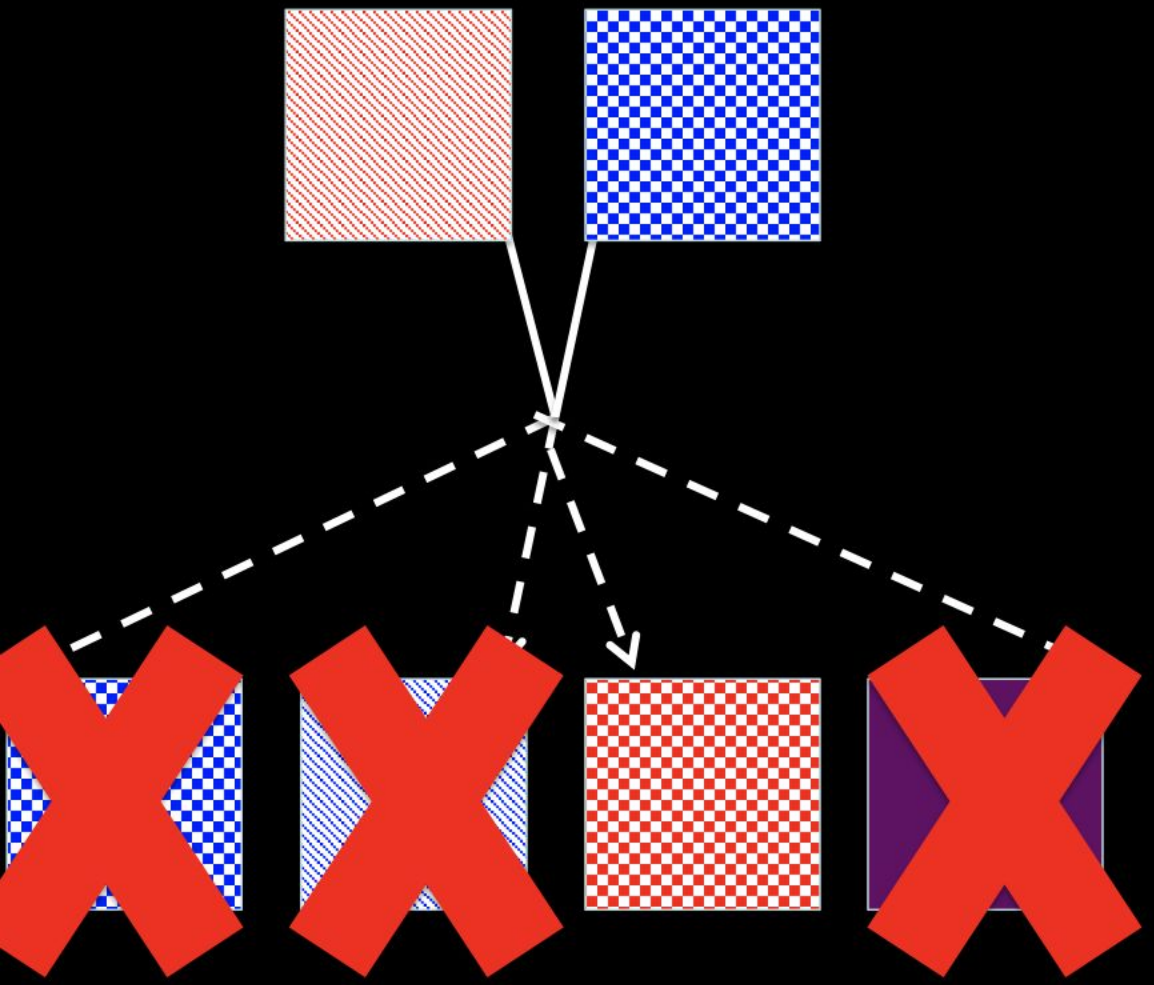
Variation

Diversity

Inheritance

Mutation &
Recombination

Evolution by Natural Selection



Variation

Diversity

Inheritance

Mutation &
Recombination

Selection

Environment

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

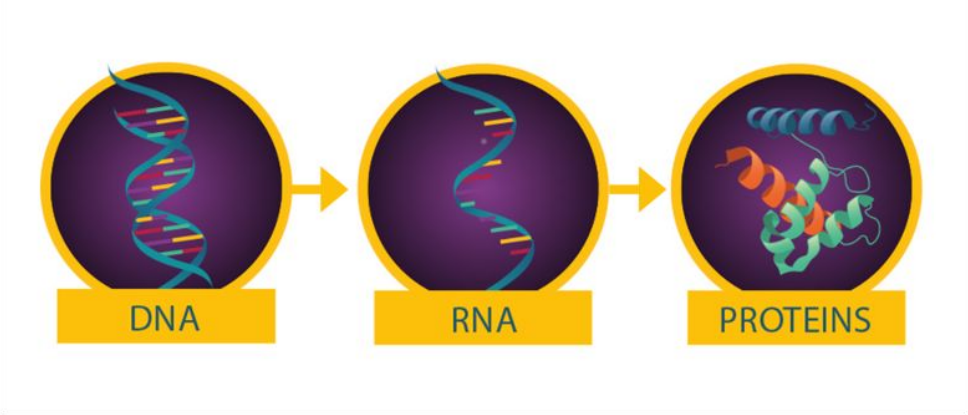
- Natural selection
  - is often slow, but arms races result in complex, wonderful, bizarre (and stupid) things
  - can lead to cooperation
  - (largely) based on the fitness of reproductive individuals
- Natural selection is not
  - learned behavior passed on *
  - group selection *
    - (Dawkins: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

* Except when it is

The Central Dogma

Darwin did not have a mechanism for heritable, variable fitness

The Central Dogma says Genes are strings of DNA that get transcribed to RNA, translated to proteins, and expressed as phenotype



What do we know about dogmas?

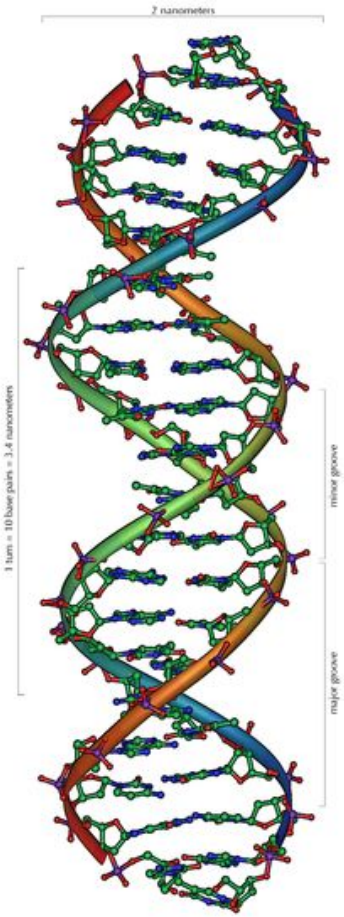
Toward Genetics

- 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.
- The Modern Synthesis unified Darwin & Mendel in mathematical population genetics (Wright, Haldane & Fisher)
- 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 base pairs 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. All of your DNA together would stretch 67 billion miles.

https://publications.nigms.nih.gov/insidelifescience/genetics-numbers.html



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 phenotype & fitness

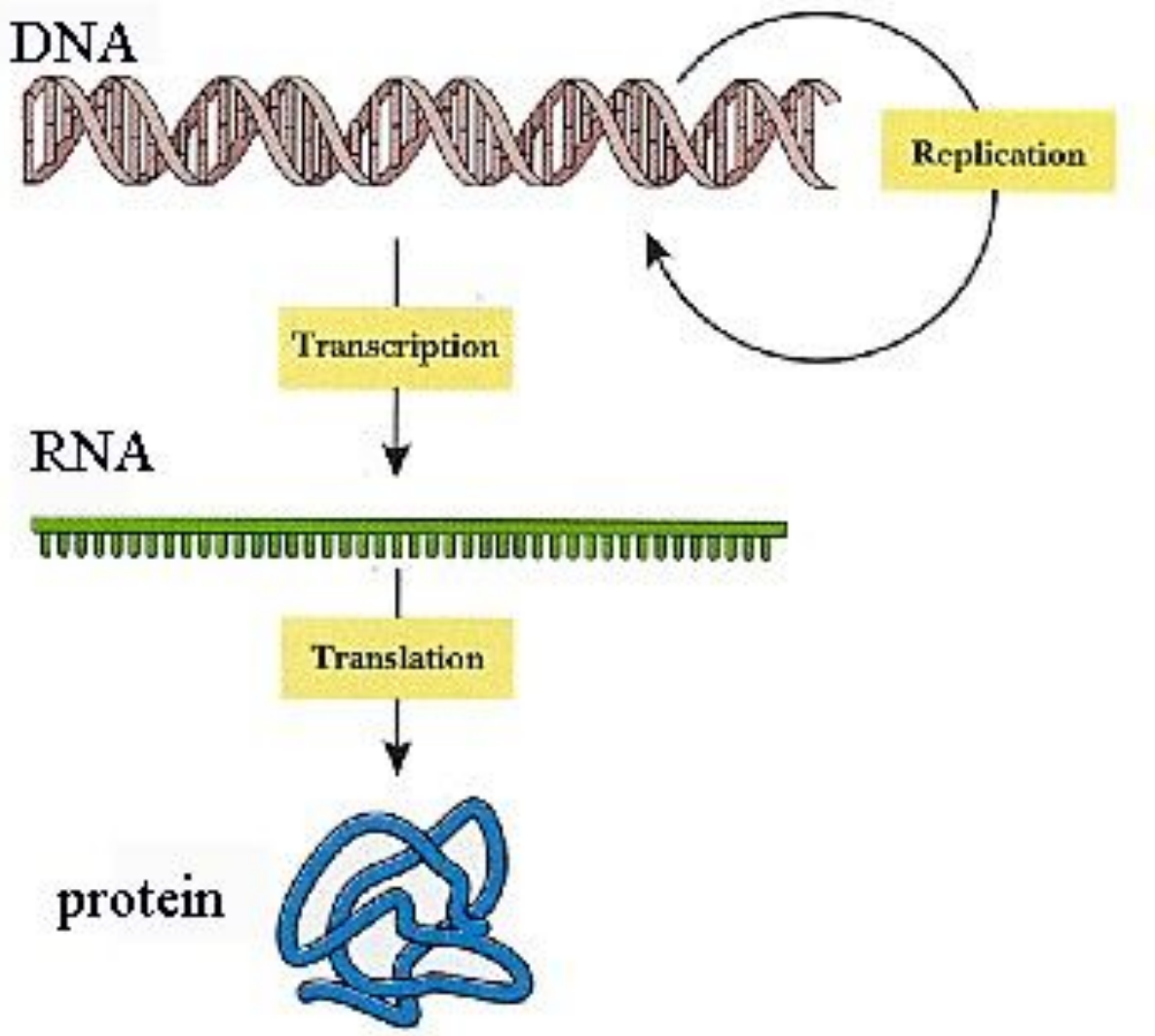
Variable

Mutations--copies are not perfect

Sex—genes are combined from 2 parents

Crossing over—allows for many different possible combinations

The Central Dogma



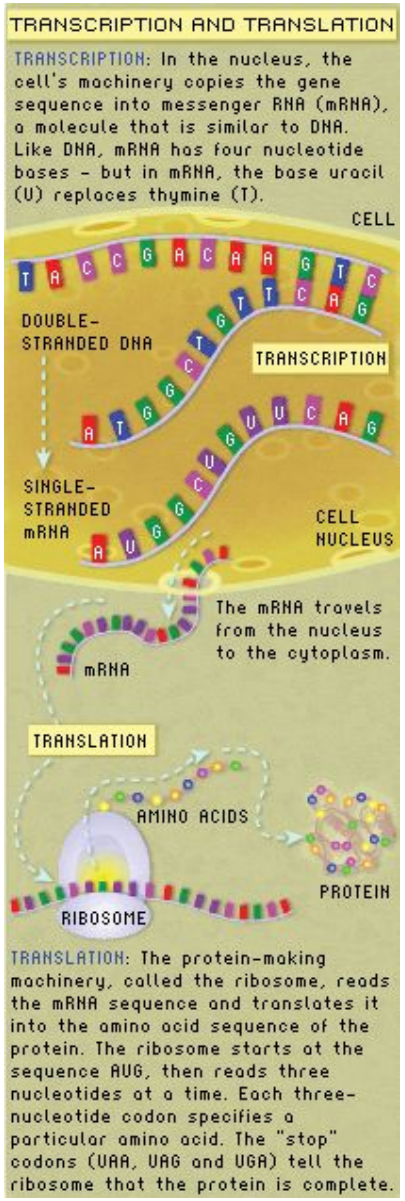
The Central Dogma

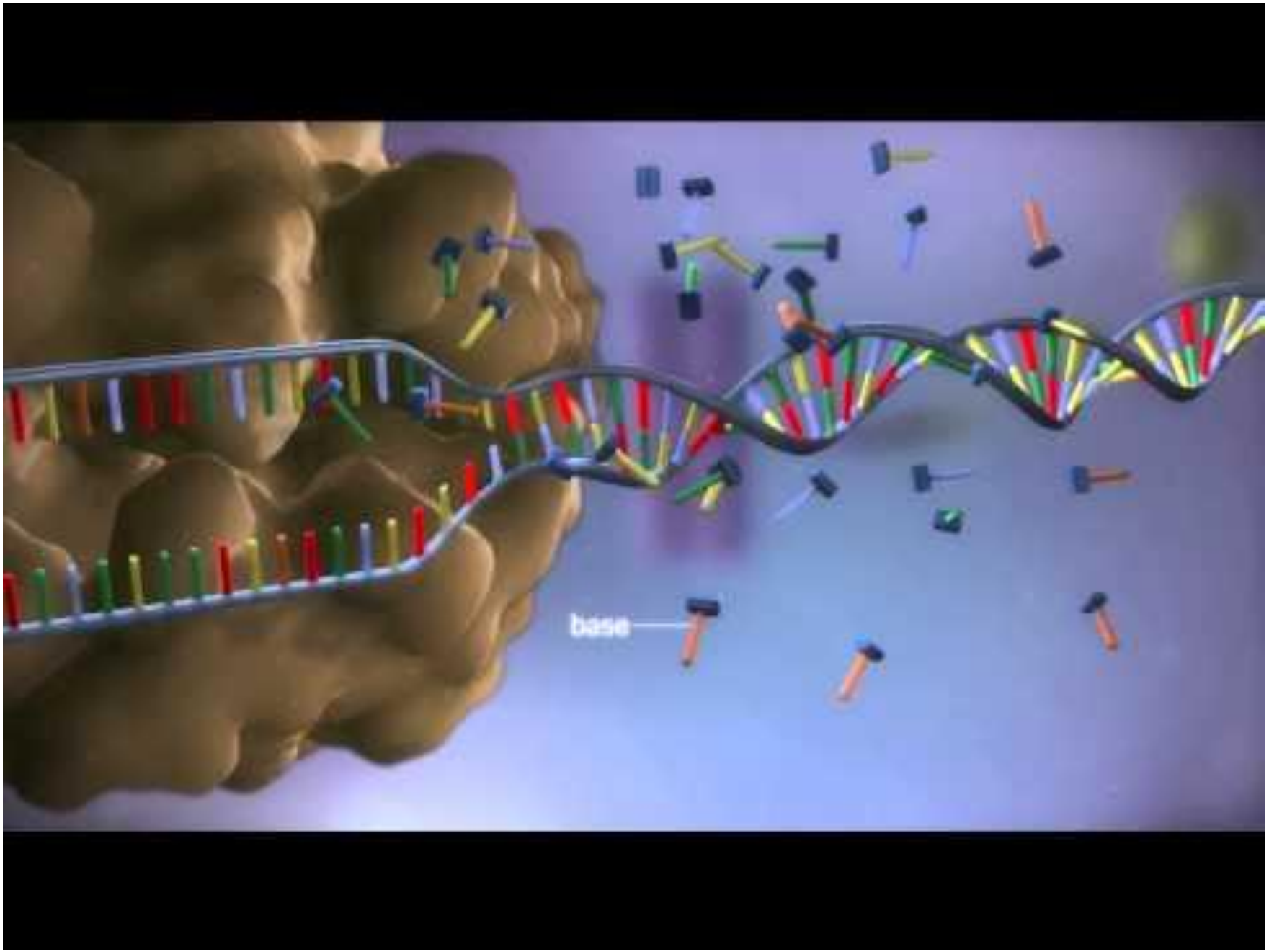
DNA (info storage) RNA (info transfer) protein (work)

- 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



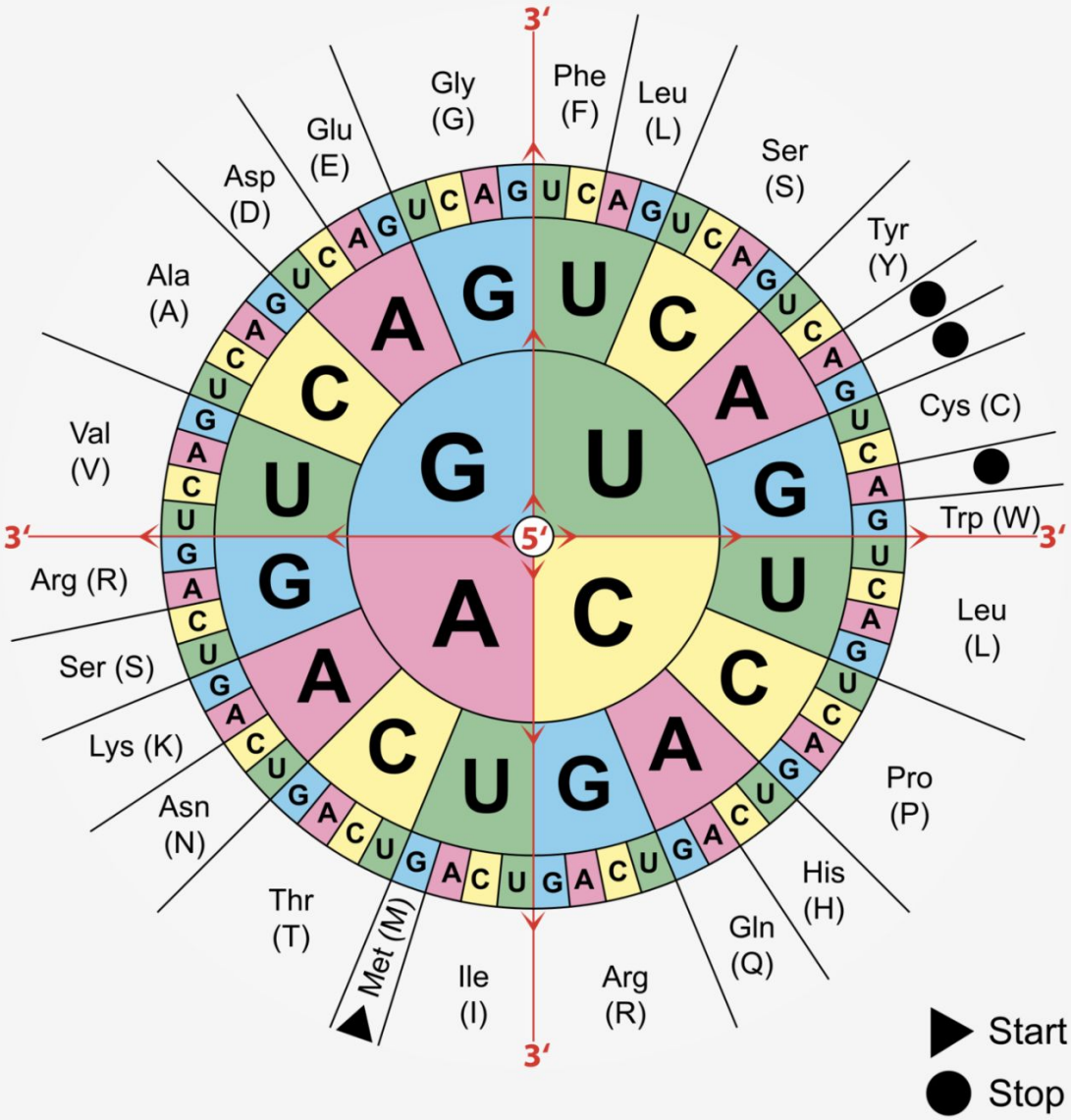

base

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

Table shows the 20 amino acids and how they are encoded in the 64 possible codons.

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

Adenine
Cytosine
Guanine
Thymine
(Uracil)



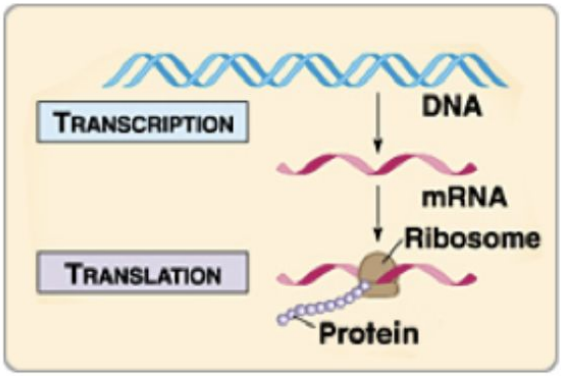


Table 1 - uploaded by Victor M Hernandez-Escalante
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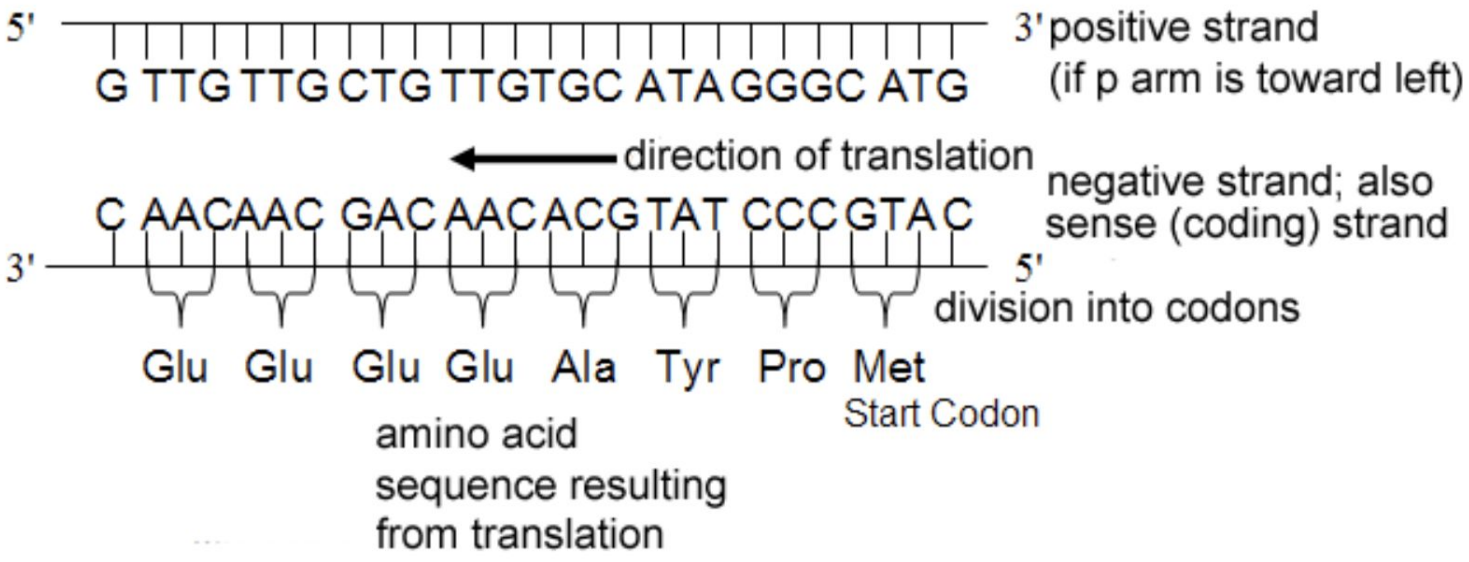
A	Alanine	M	Methionine
C	Cisteine	N	Asparagine
D	Aspartic Acid	P	Proline
E	Glutamic Acid	Q	Glutamine
F	Phenylalanine	R	Arginine
G	Glycine	S	Serine
H	Histidine	T	Threonine
I	Isoleucine	V	Valine
K	Lysine	W	Tryptophan
L	Leucine	Y	Tyrosine

Data from International Union of Pure and Applied Chemistry and International Union of Biochemistry.[70]

http://thebiologyprimer.com/chapter-transcription-translation

A-T
C-G

- 4 nucleotide bases in DNA
  - Adenine, Cytosine, Guanine, Thymine (Uracil in RNA)



Discuss: DNA transcription and translation, like a turing machine or not?

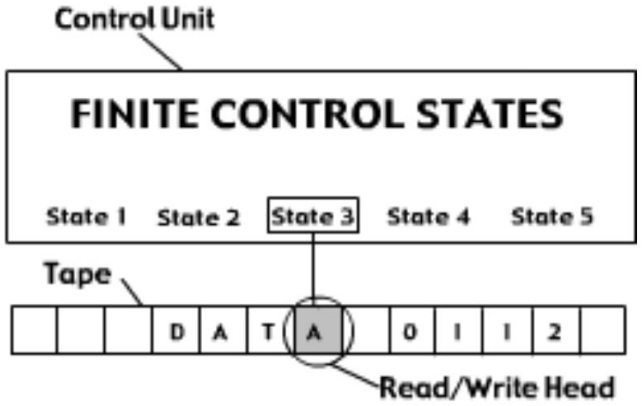
Turing Machines

Formal definition

Hopcroft and Ullman (1979, p. 148) formally define a (one-tape) Turing machine as a 7-tuple $M = \langle Q, \Gamma, b, \Sigma, \delta, q_0, F \rangle$ where

- Q is a finite set of *states*
- Γ is a finite set of the *tape alphabet/symbols*
- $b \in \Gamma$ is the *blank symbol* (the only symbol allowed to occur on the tape infinitely often at any step during the computation)
- $\Sigma \subseteq \Gamma \setminus \{b\}$ is the set of *input symbols*
- $\delta : Q \times \Gamma \to Q \times \Gamma \times \{L, R\}$ is a partial function called the *transition function*, where L is left shift, R is right shift. (A relatively uncommon variant allows "no shift", say N, as a third element of the latter set.)
- $q_0 \in Q$ is the *initial state*
- $F \subseteq Q$ is the set of *final* or *accepting states*.

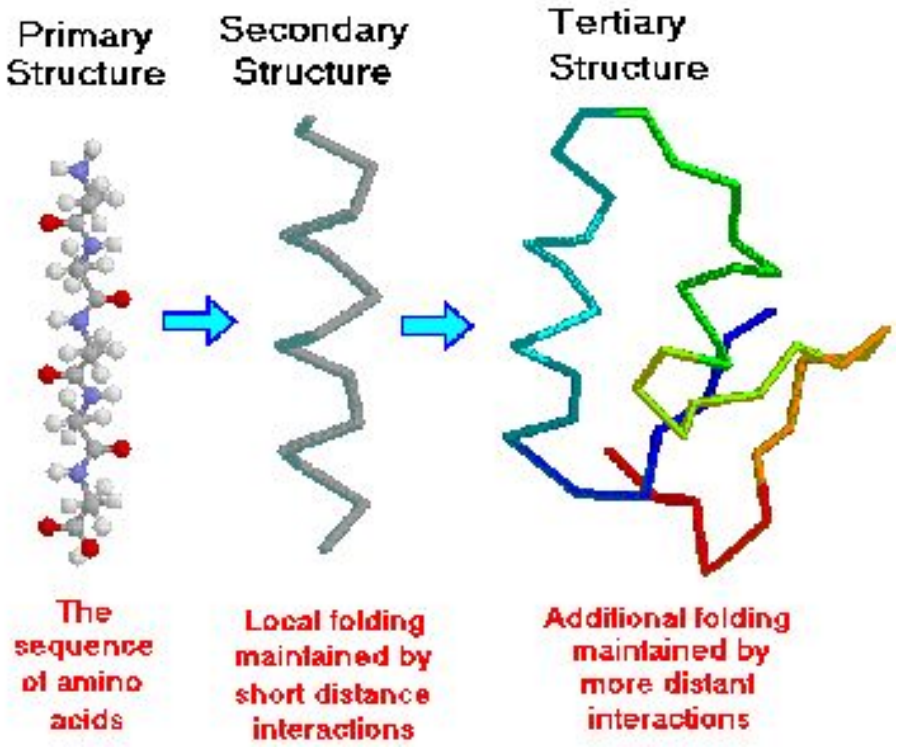
1. a tape
2. A head that can r/w & move l/r
3. Instruction table
4. State register

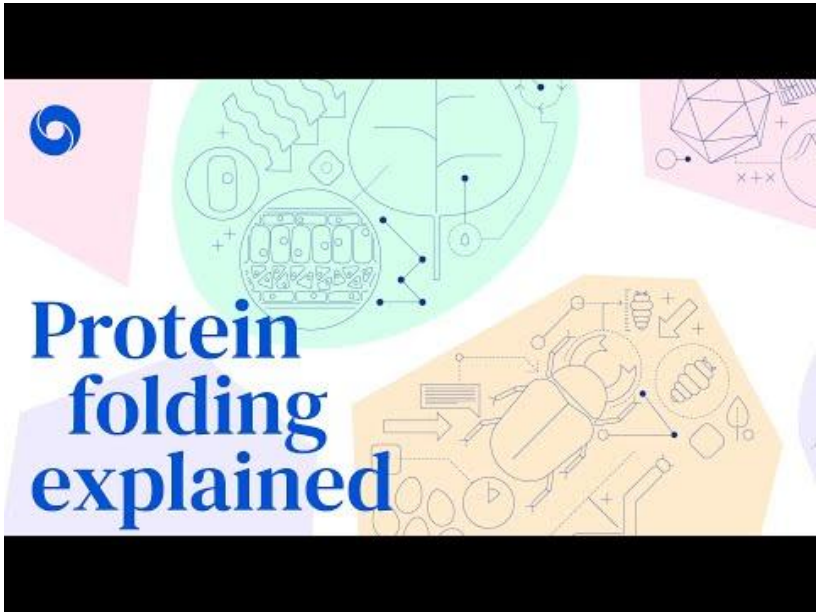


Tape is infinite, all else is finite and discrete

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 playground
    - Some regulates other genes



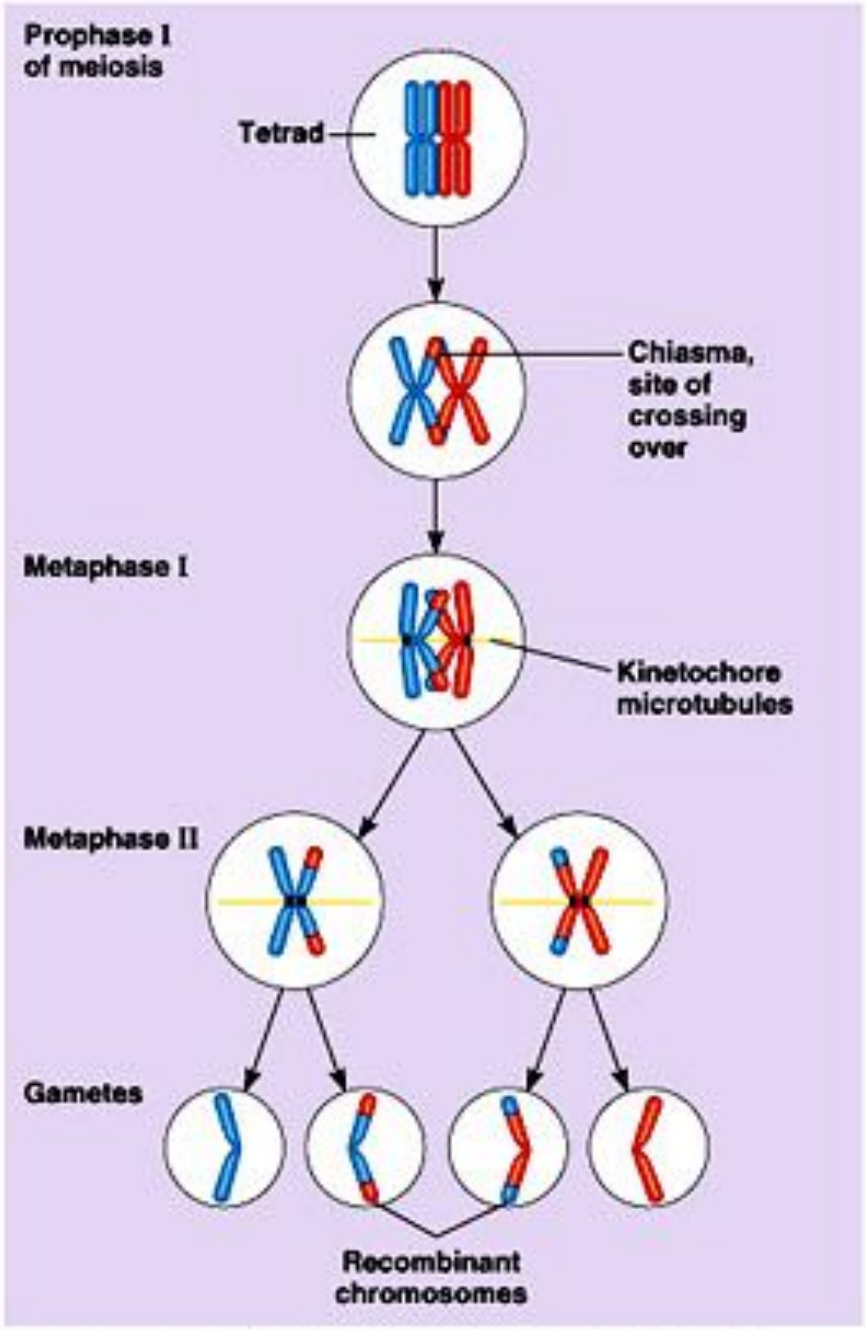


Variation in DNA

- 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

In summary:

- **Mutation**
- **Crossing Over**
- **Insertions/repetitions**
- **Deletions**



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Sex & Crossing Over

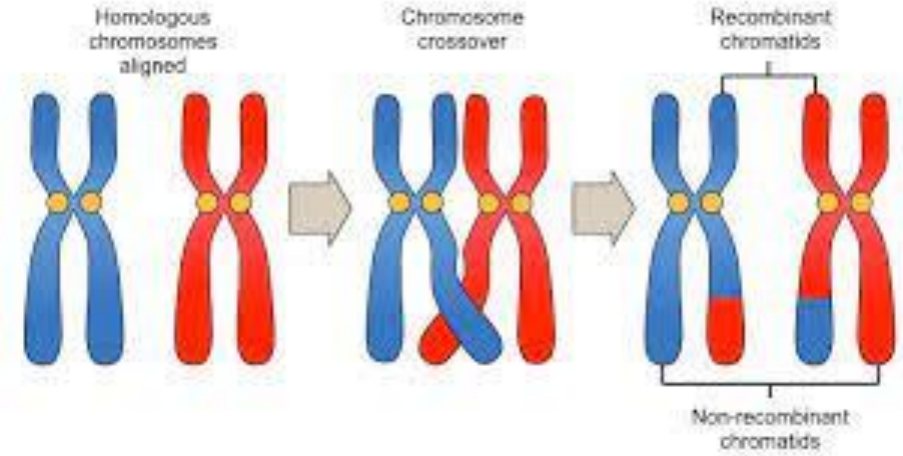
- Each diploid human cell has 2 copies of each (of 23) chromosome
- Sex cells (sperm & eggs) are haploid with 1 copy of each chromosome.
- Crossing over shuffles genes shuffled from both parents onto 1 chromosome
- Your children can have grandma's near-sightedness and grandpop's left-handedness

Crossing over
(Important in Genetic Algorithms)

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 -----> AAACCTTCCGGA
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

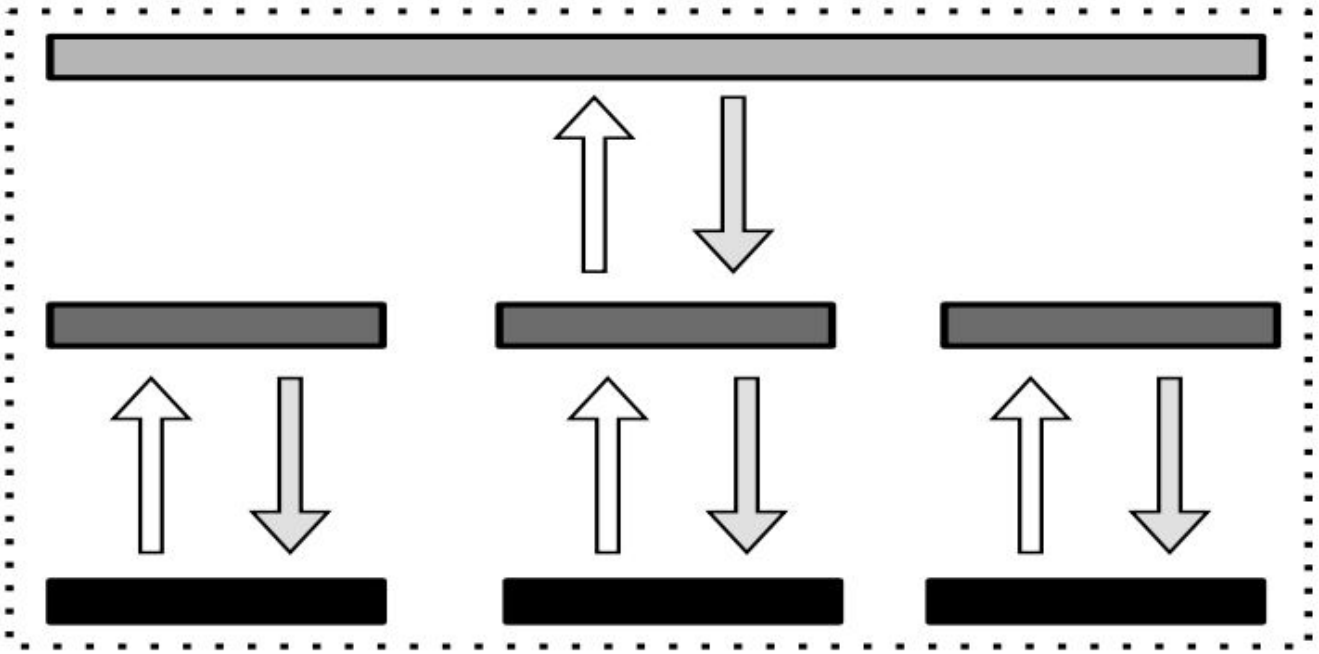
Variation and Heredity

Letters can change: mutations, insertions, deletions

Chromosomes crossover to create sperm & eggs

Sperm and eggs combine to make new offspring

Are Evolutionary Processes Top Down or Bottom Up?



1. Replicating molecules → Populations of molecules in compartments
2. Independent replicators → chromosomes
3. RNA → DNA and proteins
4. Prokaryotes → Eukaryotes
5. Asexual clones → Sexual reproduction
6. Single cells → Multicellular organisms
7. Solitary individuals → Colonies with non-reproductive castes
8. Primate societies → Human societies (language)