How Life Works

TO HELP US UNDERSTAND *EVOLUTION*, WE NEED TO DISCUSS *LIFE* --- WHAT IT IS AND HOW IT WORKS

A bolete in the wild

https://www.merton.ox.ac.uk/course/biology/all-things-fungal-summer-kew

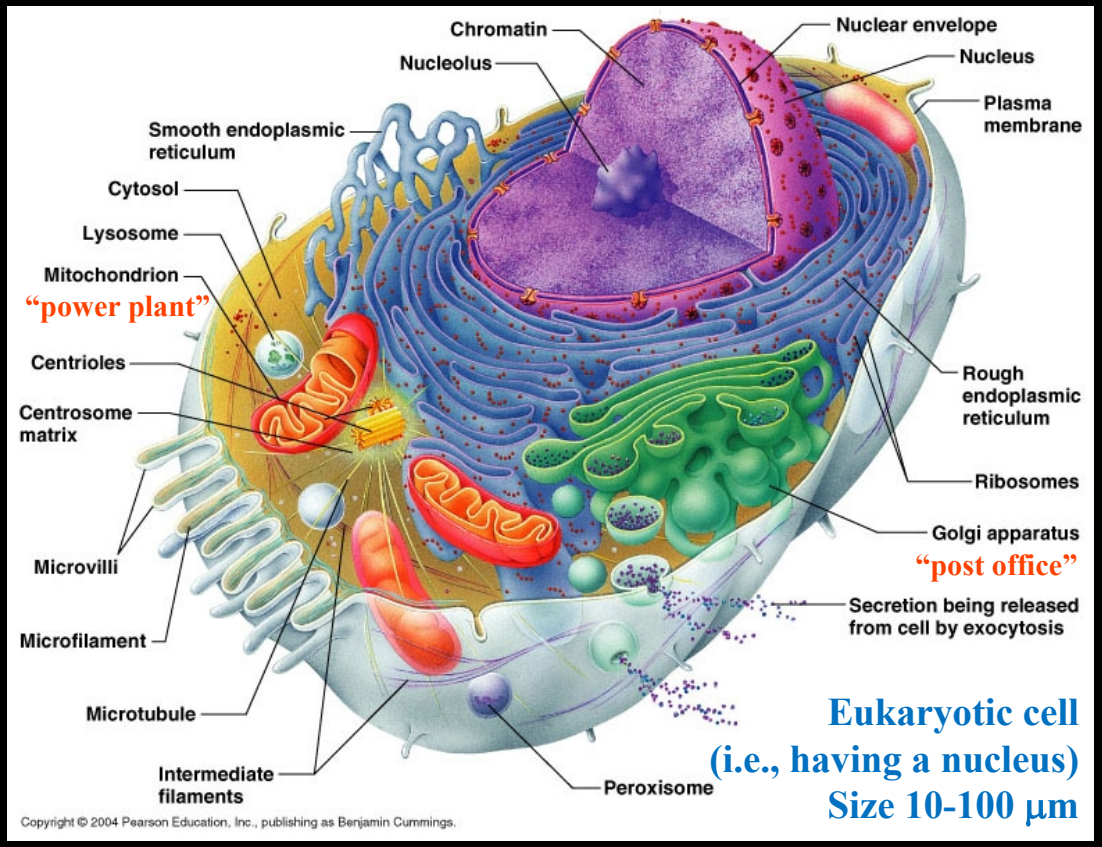
Life and evolution in Hindu thought

- *Samkhya* school is one of six orthodox philosophical traditions in Hinduism (in addition to four heterodox traditions)
  - Dualist: regards the universe as consisting of two realities, purusha (consciousness) and prakṛti (matter)
  - Theory of three gunas (qualities, innate tendencies)
    - *sattva*: goodness, compassion, illumination, positivity
    - *rajas*: activity, chaos, passion, impulsivity
    - *tamas*: darkness, ignorance, destruction, lethargy, negativity
  - Evolution:
    - disequilibrium of gunas triggers an evolution leading to manifestation of the world from unmanifested prakṛti
    - Intellect → ego-sense →5 sense organs, 5 organs of action →5 senses →5 elements (space, earth, air, fire, water)
    - Purpose of evolution: enjoyment and liberation of purusha

Kapila, founder of Samkhya school
6th-7th century BCE

https://en.wikipedia.org/wiki/Samkhya

WHAT IS LIFE?



This is a cell.

All living organisms are made up of cells

- Cell is basic structural and functional unit of all known organisms

A cell can do several things (at least):

- *Metabolism*
- *Genetics*
- *Reproduction*

WHAT IS LIFE?

- *Metabolism*
  - *A highly integrated network of chemical reactions, by which cells
    - extract energy from their environment
    - synthesize the building blocks of their macromolecules
- *Genetics*
  - Storage, transmission, and expression of information for regulating processes of life
- *Reproduction with variation*
  - offspring aren't identical to parent
  - permits evolution

**Biochemistry*, Lubert Stryer, W.H. Freeman and Co. (San Francisco) 1975.

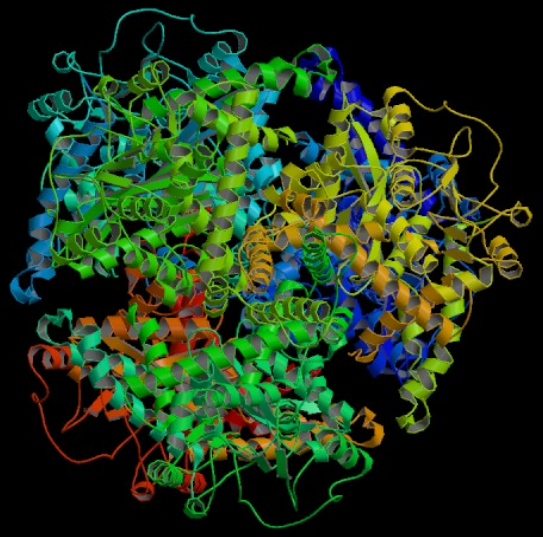
proteins

EVERY CELL DEPENDS ON *PROTEINS*

Proteins:

- large molecules made of building blocks called *amino acids*, arranged in a linear chain
  - Chain of amino acids folds up into a unique shape
- essential parts of all living organisms*
- participate in every process within cells
- *Enzymes* are a type of protein facilitating biochemical reactions
  - vital to metabolism
- In some cases have structural or mechanical functions
  - e.g. proteins in the *cytoskeleton*
    - system of scaffolding that maintains cell shape
- are also important in
  - cell signaling
  - cell adhesion
  - cell cycle
  - immune responses

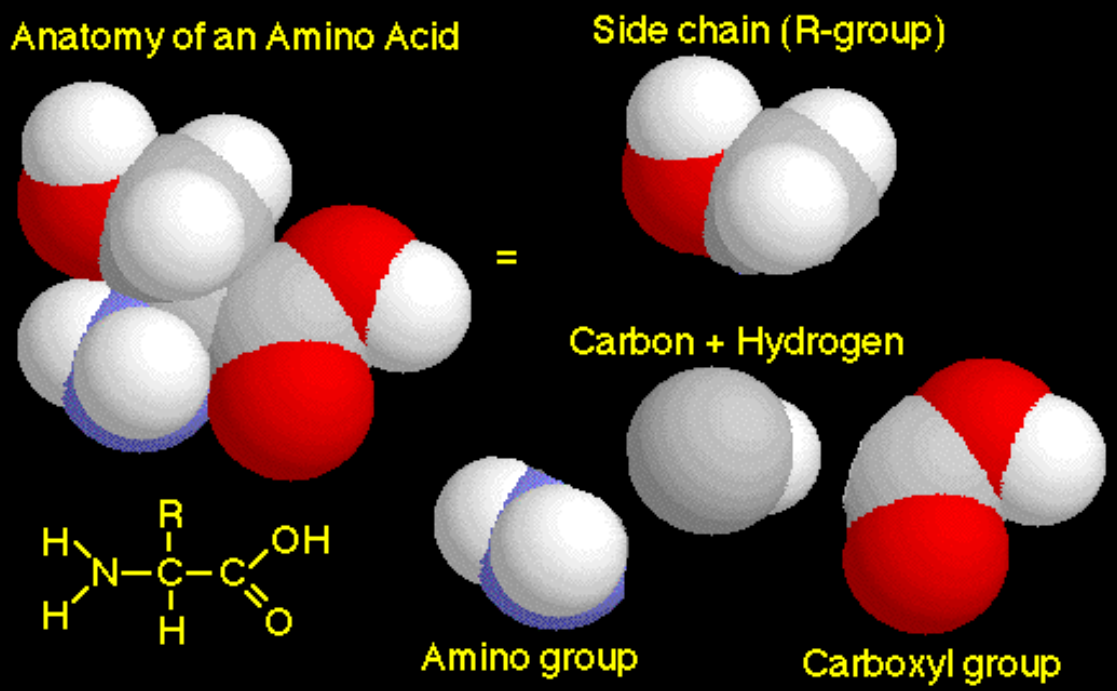
a-ketoglutarate dehydrogenase



*http://en.wikipedia.org/wiki/Protein

AMINO ACIDS ARE THE BUILDING BLOCKS OF ALL PROTEINS

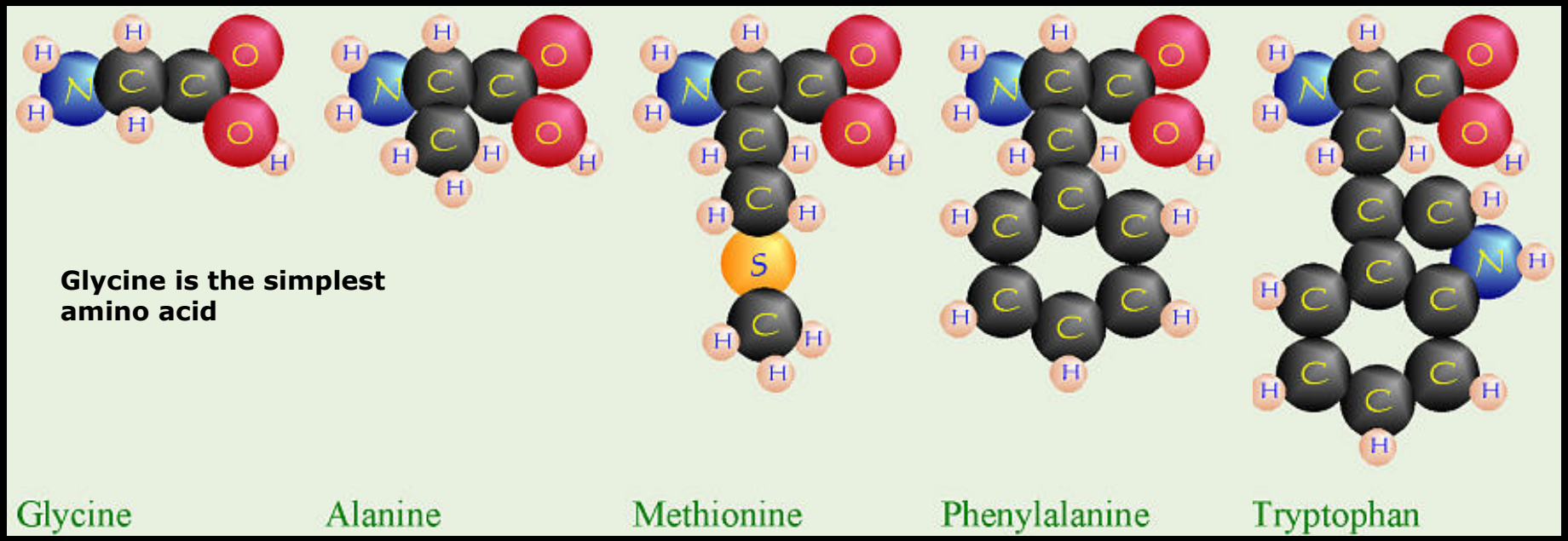
- All amino acids have:
  - amino group (NH_2)
  - carboxyl group (COOH)
  - carbon + hydrogen (CH)
  - *residue*



http://www.sp.uconn.edu/~terry/images/mols/aastructure.gif

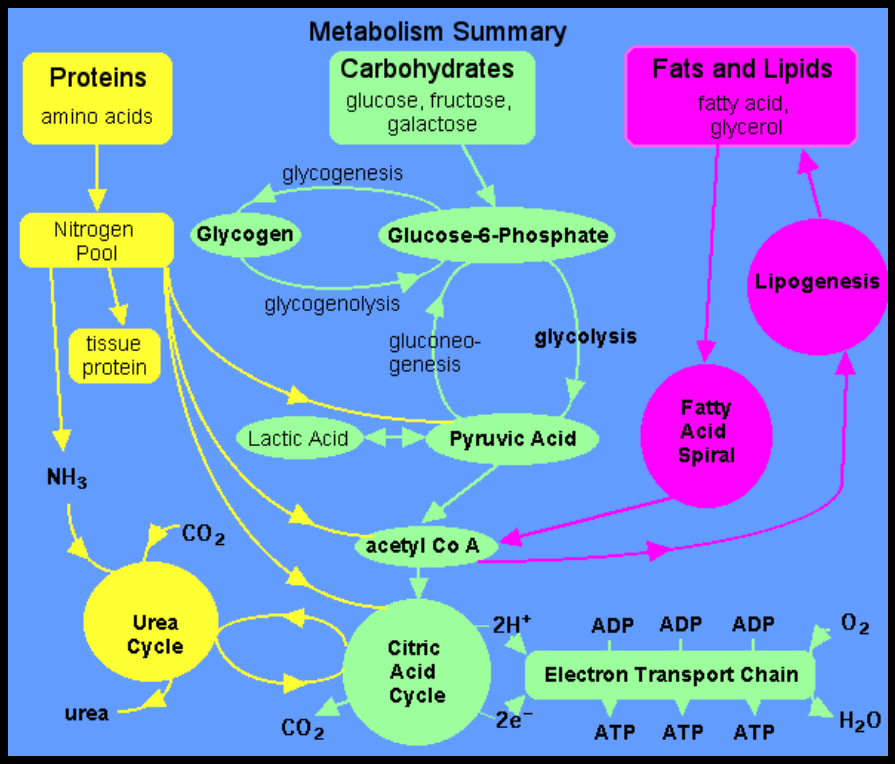
LIFE'S PROTEINS ARE BUILT FROM TWENTY KINDS OF AMINO ACID

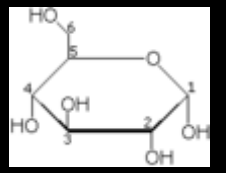
- A few examples:



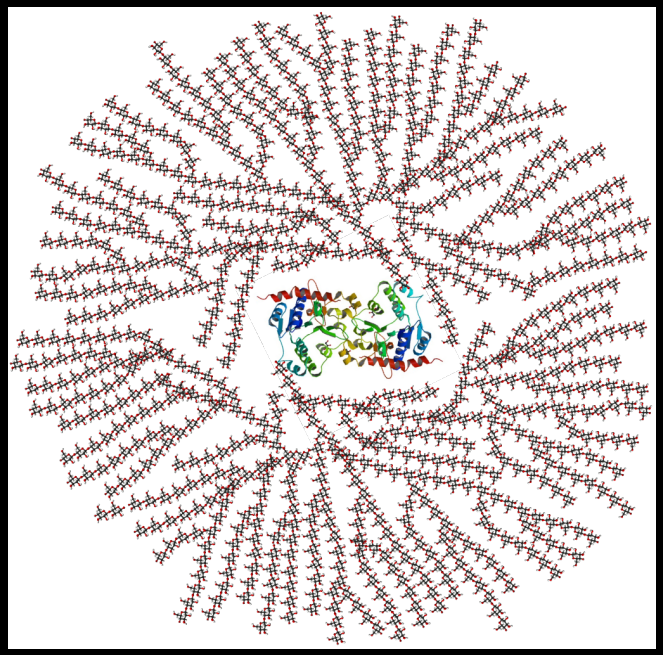
Metabolism:

a highly integrated network of chemical reactions to extract and store energy, and construct large molecules





glucose

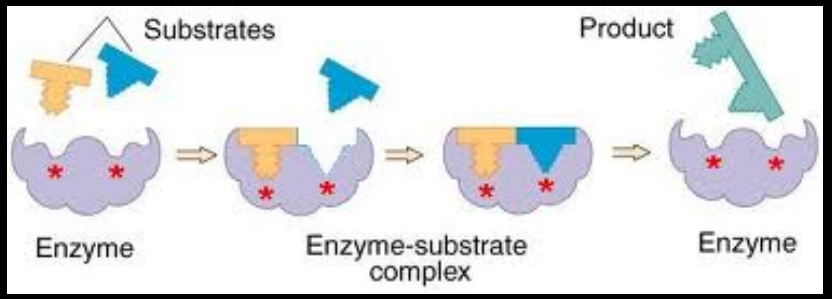


Glycogen granule may contain 30,000 glucose units

Really good web sites!
http://www.elmhurst.edu/~chm/vchembook/601glycolysissum.html
http://www.johnkyrk.com/CellIndex.html

METABOLISM REQUIRES *CATALYSTS*

- Living cell is site of *tremendous biochemical activity*
  - All the activities we call "life" are processes of *chemical and physical change going on continually* in living organisms
    - build-up of new tissue
    - replacement of old tissue
    - conversion of food to energy
    - disposal of waste materials
    - reproduction



- But there is an *apparent paradox*:
  - Most of these biochemical reactions do not take place spontaneously
  - Biochemical reactions require "catalysis"
  - Catalysis: the acceleration of a chemical reaction by some substance which itself undergoes no permanent chemical change
  - Catalysts of biochemical reactions are called "enzymes"

http://www.worthington-biochem.com/introBiochem/lifeProcesses.html

METABOLISM REQUIRES CATALYSTS CALLED *ENZYMES*

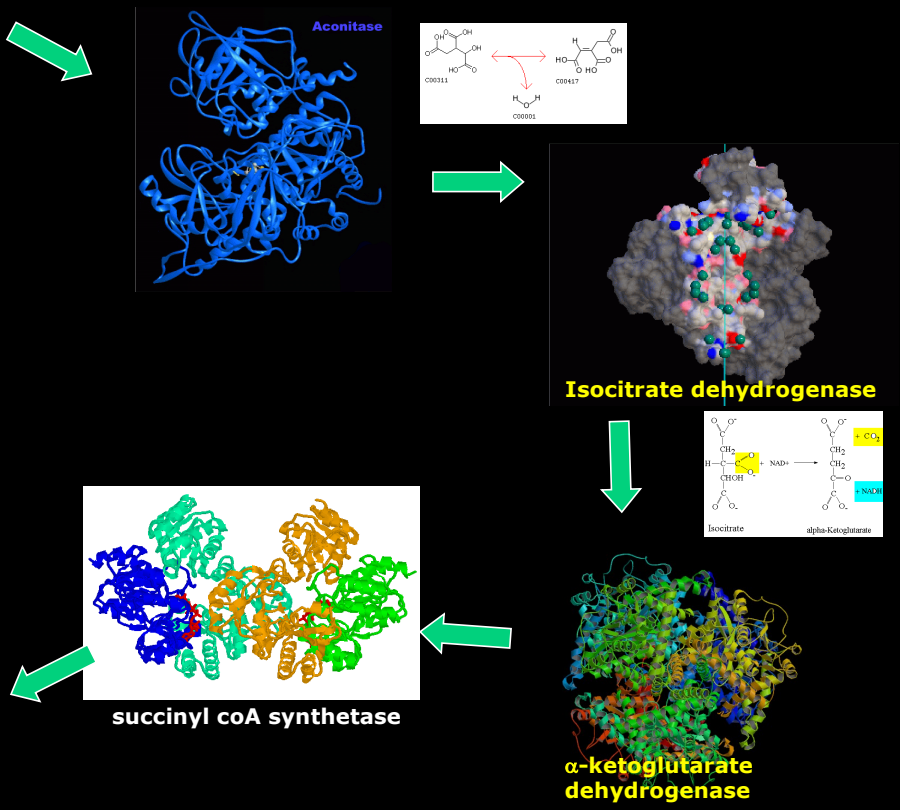
- Enzymes are proteins
- Enzymes bring about almost all of the chemical reactions in living organisms
- Without enzymes, reactions are way too slow for life!

http://www.worthington-biochem.com/introBiochem/lifeProcesses.html
http://160.114.99.91/astrojan/protein/pictures/aldreduc.gif
http://160.114.99.91/astrojan/protein/pictures/aldolase.jpg

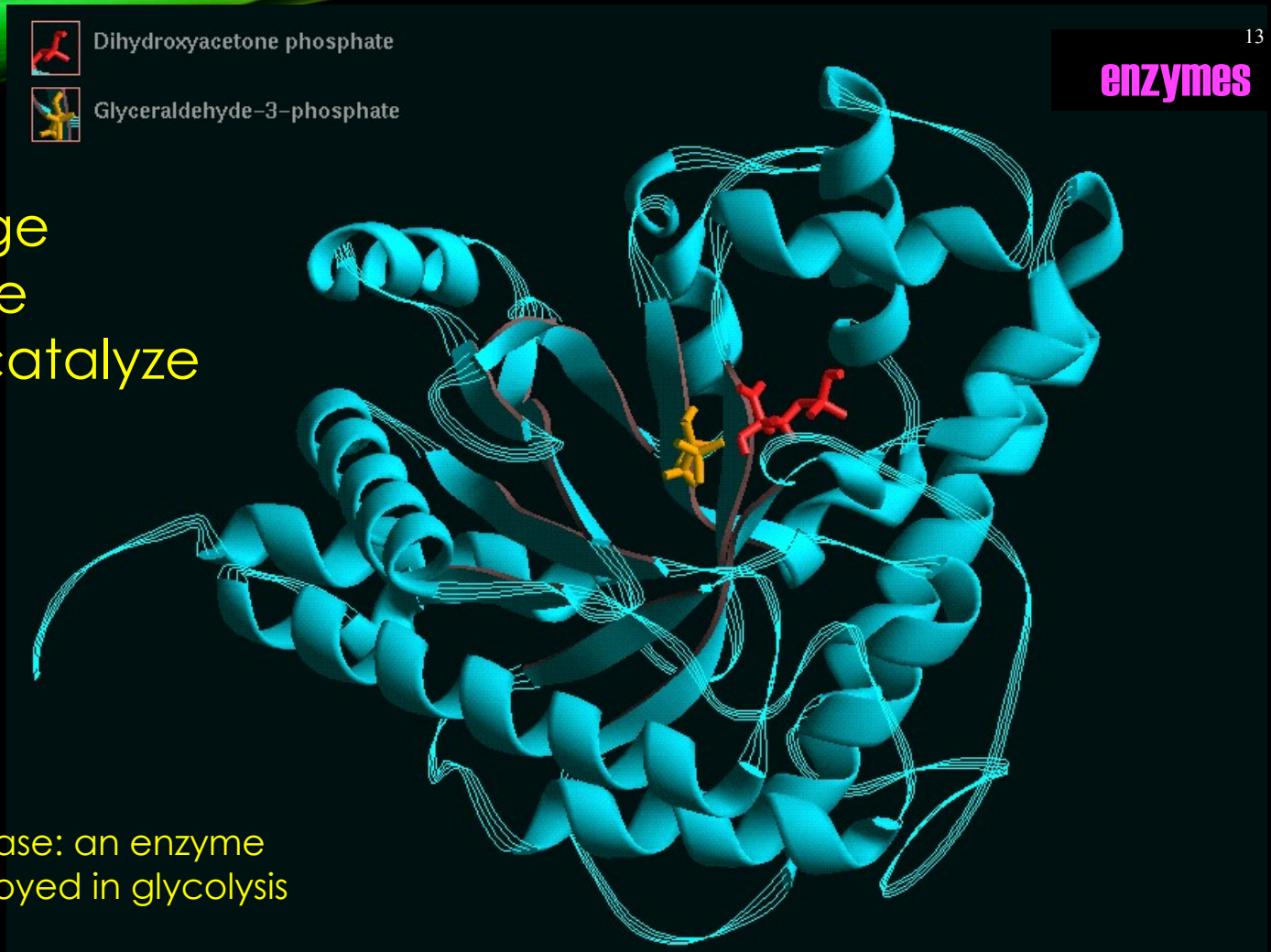
ENZYMES ARE LIKE MACHINES WITHIN THE CELL

enzymes

- Enzymes
  - ➢increase speed of chemical reaction without undergoing any permanent chemical change
  - ➢speed up reactions by factor of 10^6 to 10^7
  - ➢are neither used up nor produced in the reaction



Enzymes are large compared to the reactants they catalyze

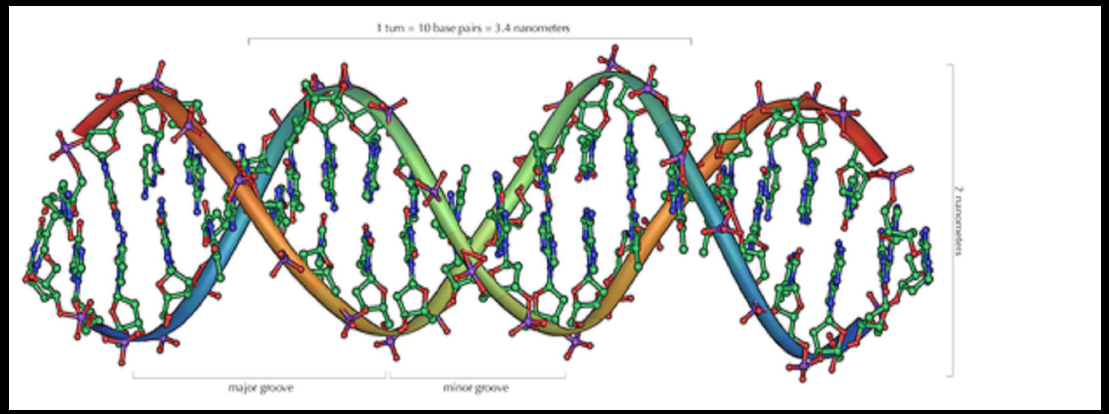


Aldolase: an enzyme employed in glycolysis

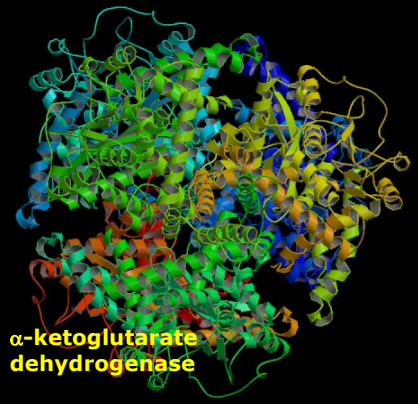
http://160.114.99.91/astrojan/protein/pictures/aldolase.jpg

Where do enzymes come from?

- Organisms create proteins using information encoded in the genetic molecule DNA (deoxyribonucleic acid)

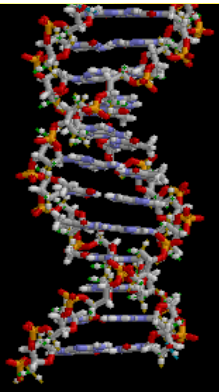


The general structure of a section of DNA



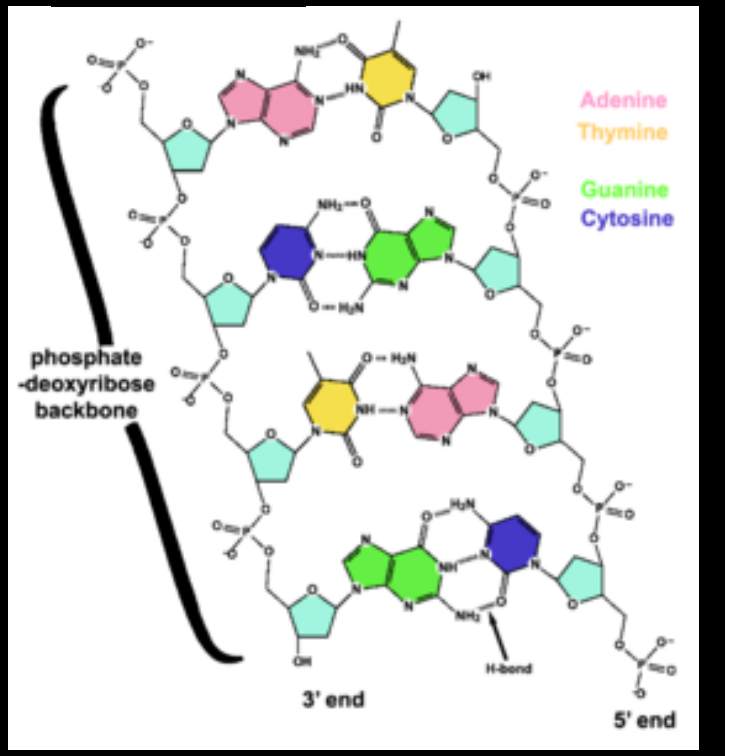
http://en.wikipedia.org/wiki/DNA

How DNA records information:



- DNA molecule is shaped like a twisted ladder
- Information is represented in the "rungs" of the ladder
- The twisted "uprights" or "backbone" of the ladder only provide structural support
- The rungs are made of only four chemicals, called "bases": adenine, thymine, guanine, cytosine
- *It is the sequence of these chemicals that encodes genetic information*
- Genetic code is like a language written with only four letters: A, T, G, and C

In the rungs, adenine always occurs with thymine, and guanine always occurs with cytosine



http://en.wikipedia.org/wiki/DNA

The genetic code uses triplets of bases to represent the twenty amino acids used to build proteins

- Genetic code consists of three-letter 'words' called *codons* formed from a sequence of three nucleotides (e.g. ACT, CAG, TTT).
- When making proteins, DNA molecule is split apart and one side of the "ladder" is read and copied to a strand of "messenger RNA" (mRNA)

Note: thymine is always replaced by uracil (U) in RNA when making proteins

Gly = glycine, Ala = alanine, etc.

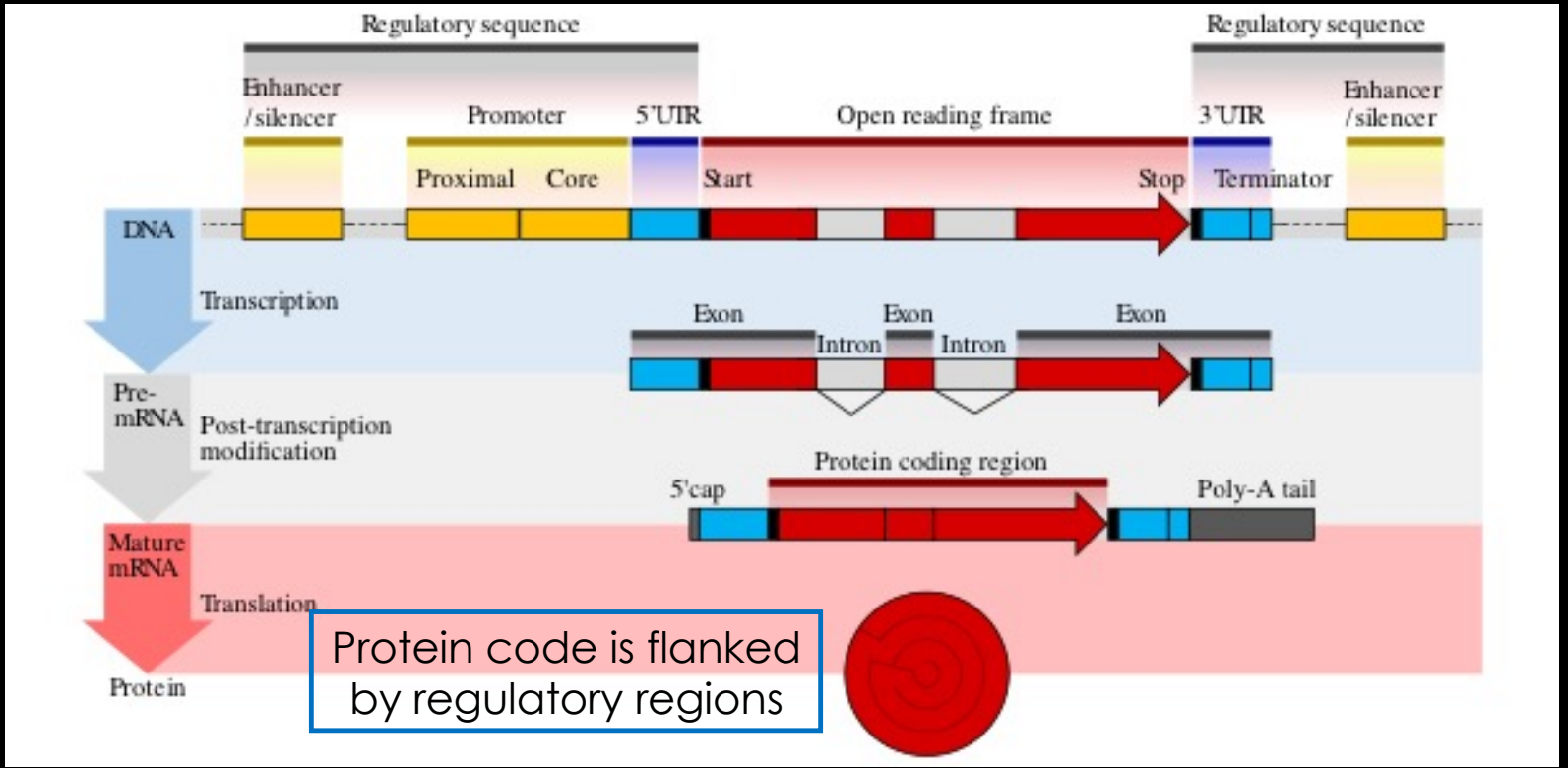
First letter	Second letter: U	Second letter: C	Second letter: A	Second letter: G	Third letter
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

WHAT A GENE LOOKS LIKE

Gene
-- sequence of DNA which contains the code for a molecule (e.g., a protein) that has a function

Regulatory sequence
-- sections of DNA that control gene expression

-- used by cells to increase or decrease the production of specific gene products (protein or RNA)



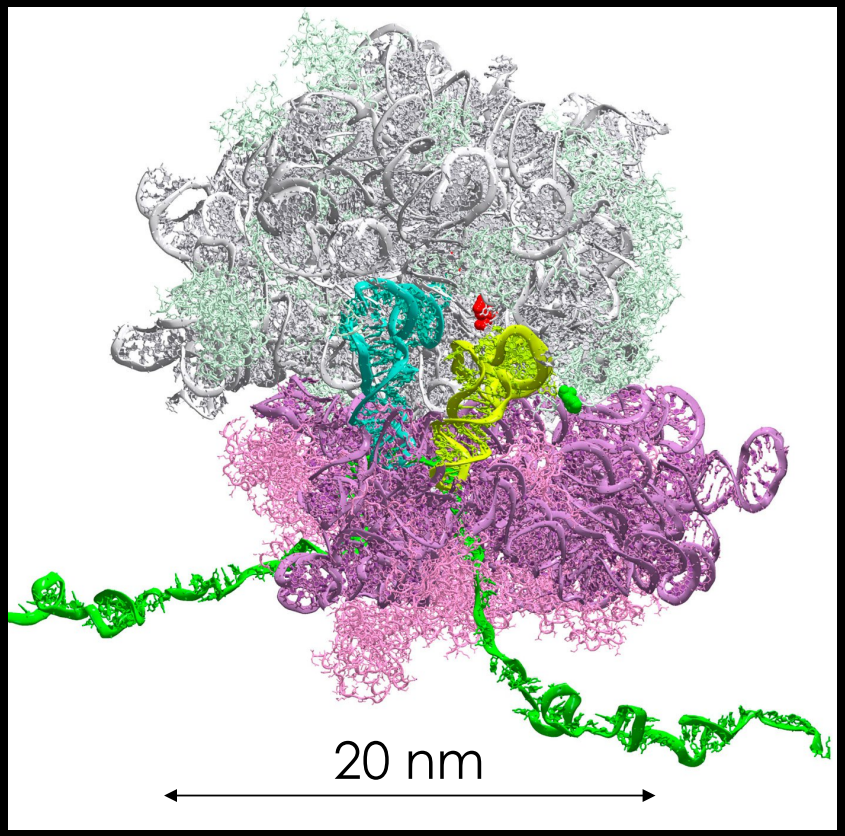
https://upload.wikimedia.org/wikipedia/commons/5/54/Gene_structure_eukaryote_2_annotated.svg

AN *ALLELE* IS A VARIANT FORM OF A GENE

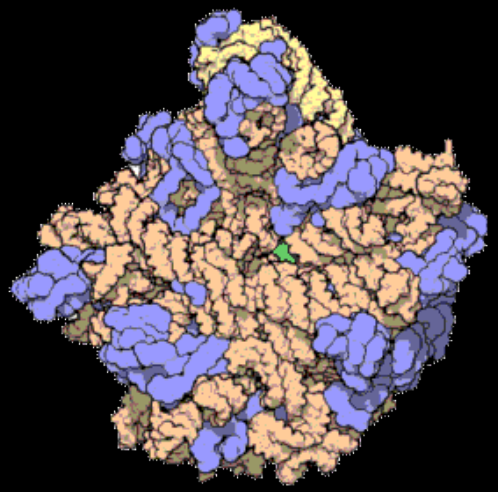
- Three alleles for blood type: I^A, I^B, and i
  - You get one allele from each parent, so you could have: I^AI^A, I^Ai, I^BI^B, I^Bi, I^AI^B, or ii

- Hair color and skin color are governed by several sets of genes

PROTEINS ARE MADE BY MACHINES CALLED RIBOSOMES

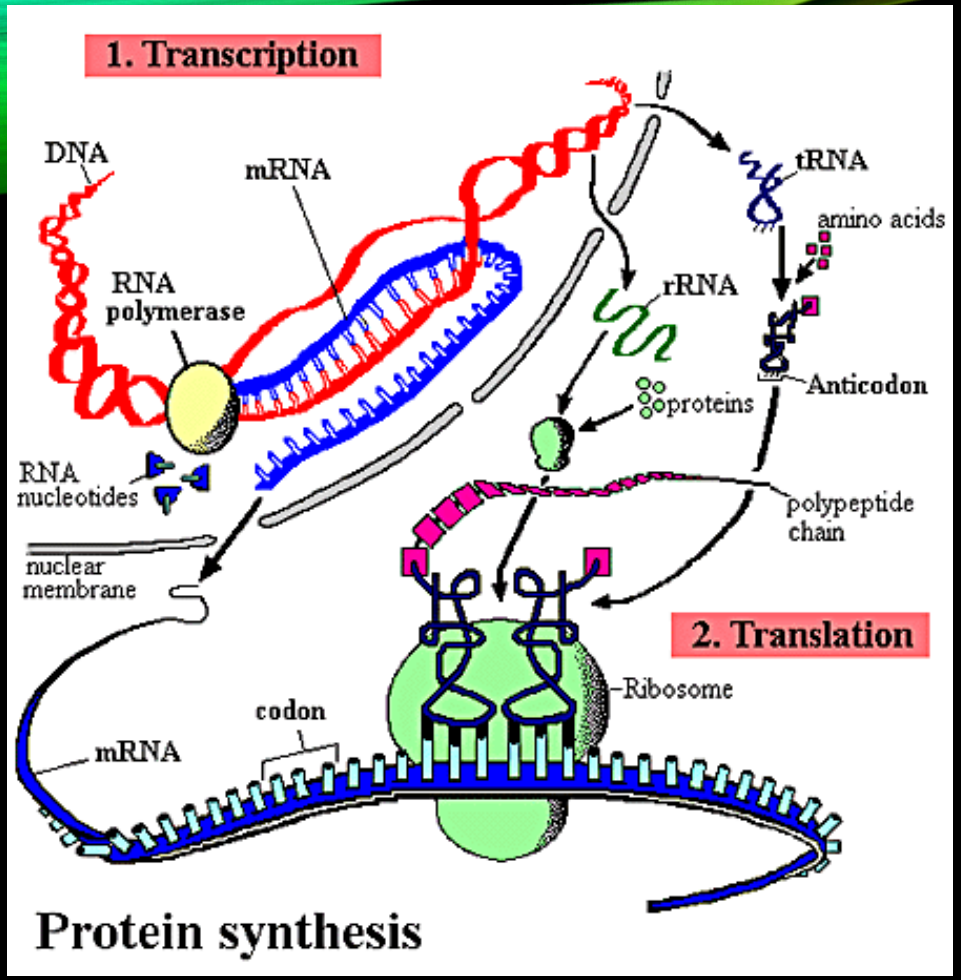


https://i1.wp.com/researchfeatures.com/wp-content/uploads/2017/08/sanbonmatsu4.jpg?fit=1400%2C1388&ssl=1



50S subunit from *Haloarcula marismortui*.
Blue – proteins
Orange, yellow – RNA chains

- A ribosome is composed of several RNA molecules and about 80 proteins
- There may be as many as 10 million ribosomes in a single mammalian cell



http://www.accessexcellence.org/RC/VL/GG/protein_synthesis.html

http://www.answers.com/topic/rna-polymerase

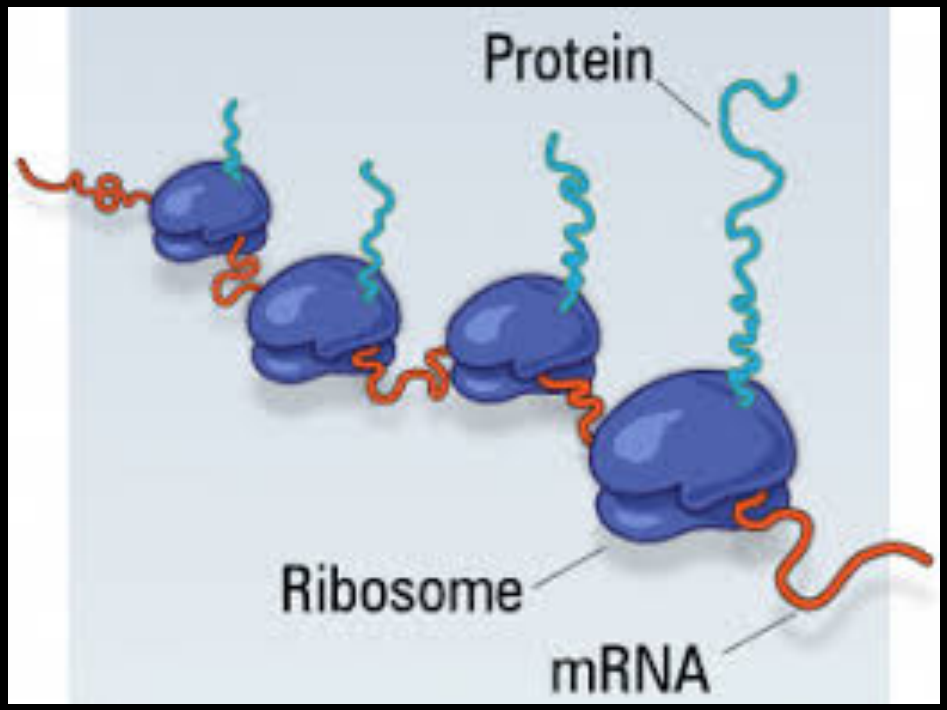
How proteins are made:

Protein synthesis works like this:

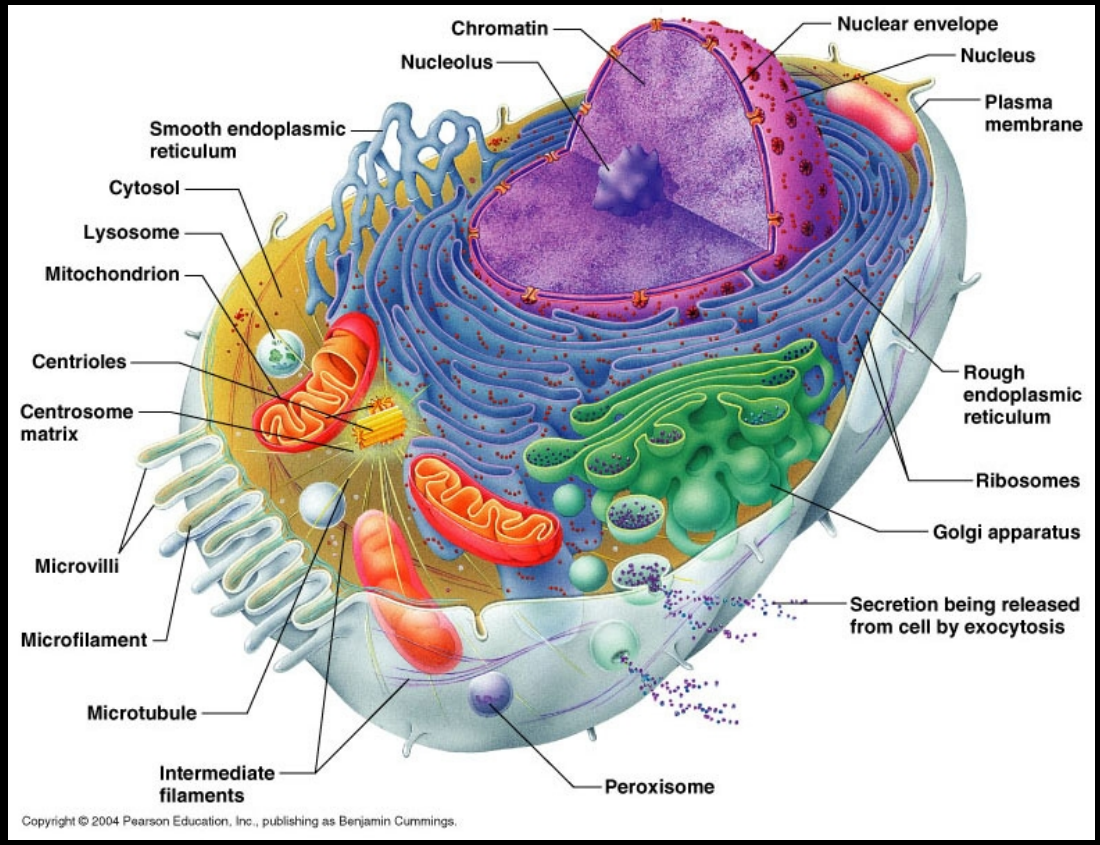
- DNA molecule is "unzipped" and its information is copied to a transfer molecule called "messenger RNA" or mRNA
- mRNA goes to ribosome, which reads the coded information
- Other molecules ("transfer RNA" or tRNA) bring amino acids to the ribosome
- Ribosome selects those amino acids specified by the mRNA and connects them to each other to make a protein

animation: http://www.johnkyrk.com/DNAtranslation.html

SEVERAL RIBOSOMES MAY WORK SIMULTANEOUSLY ON A SINGLE STRAND OF MESSENGER RNA



A SINGLE ONE OF YOUR CELLS MAY CONTAIN THOUSANDS OF RIBOSOMES



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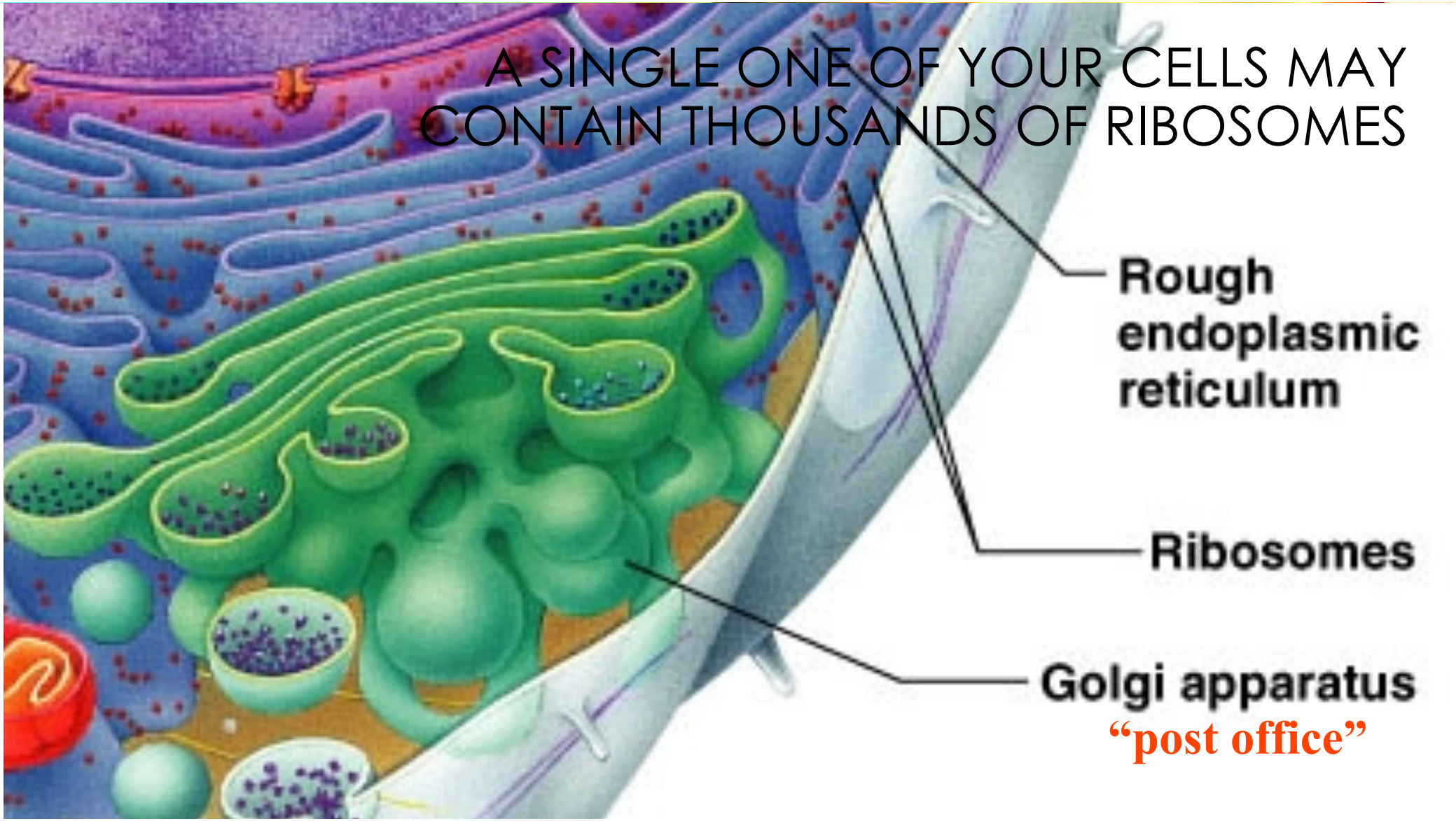
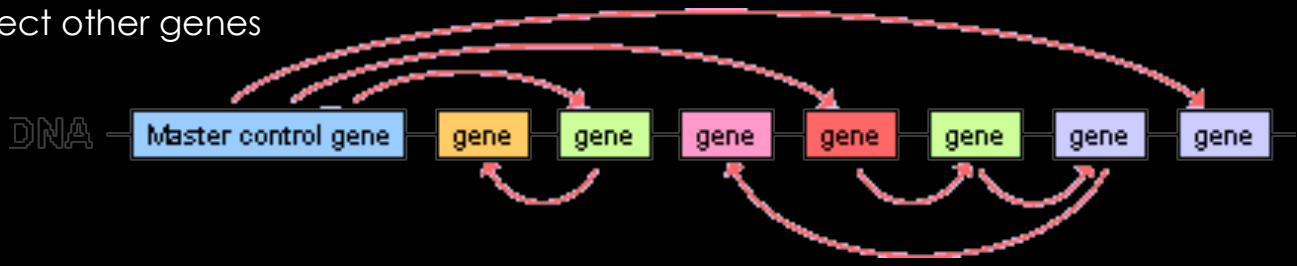


CERTAIN GENES CONTROL WHERE AND WHEN OTHER GENES ARE EXPRESSED

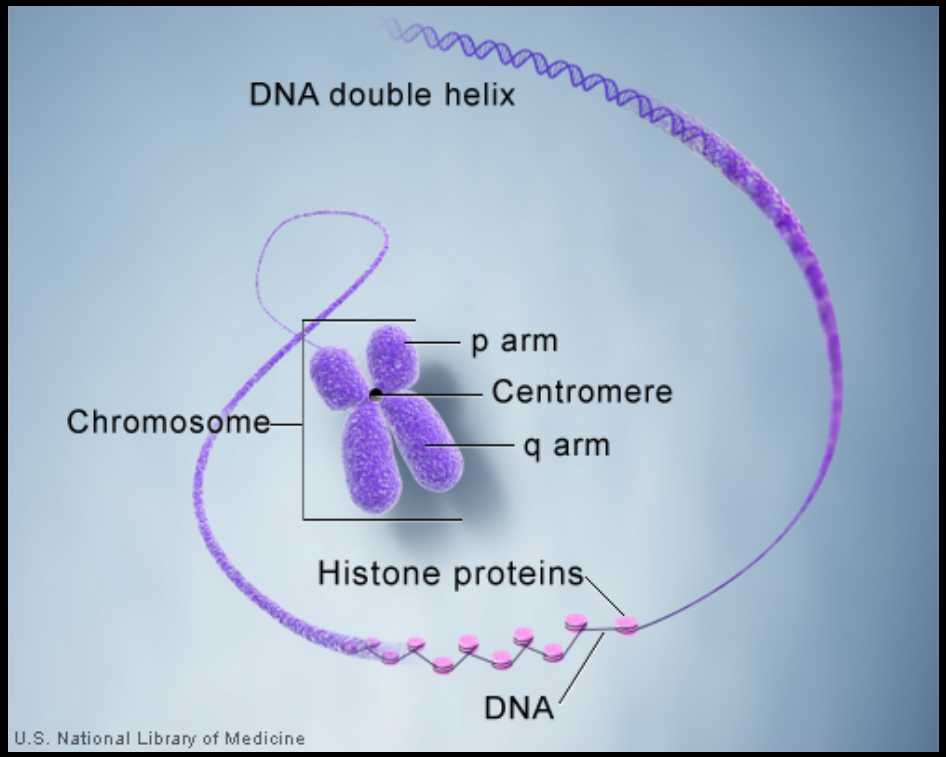
- Not all genes code for "building material" proteins
- Regulatory genes control when and where other genes get turned on
  - For example -- telling cells of fruit fly when and where to start building wings
- Regulatory genes can start "chain reaction" of effects
  - Turn on and off other genes
    - Whose products affect other genes
      - Whose products affect other genes
        - Etc.



Small changes in powerful regulatory genes could represent a major source of evolutionary change ("evo-devo")

https://evolution.berkeley.edu/evolibrary/article/0_0_0/evodevo_05

DNA IS PACKAGED INTO *CHROMOSOMES* IN THE CELL NUCLEUS



Chromosomes are thread-like structures in cell nucleus

Each chromosome is made up of DNA tightly coiled many times around proteins called *histones* that support its structure

Humans have 46 chromosomes in nucleus of (almost) every cell

-- 23 from mother
-- 23 from father

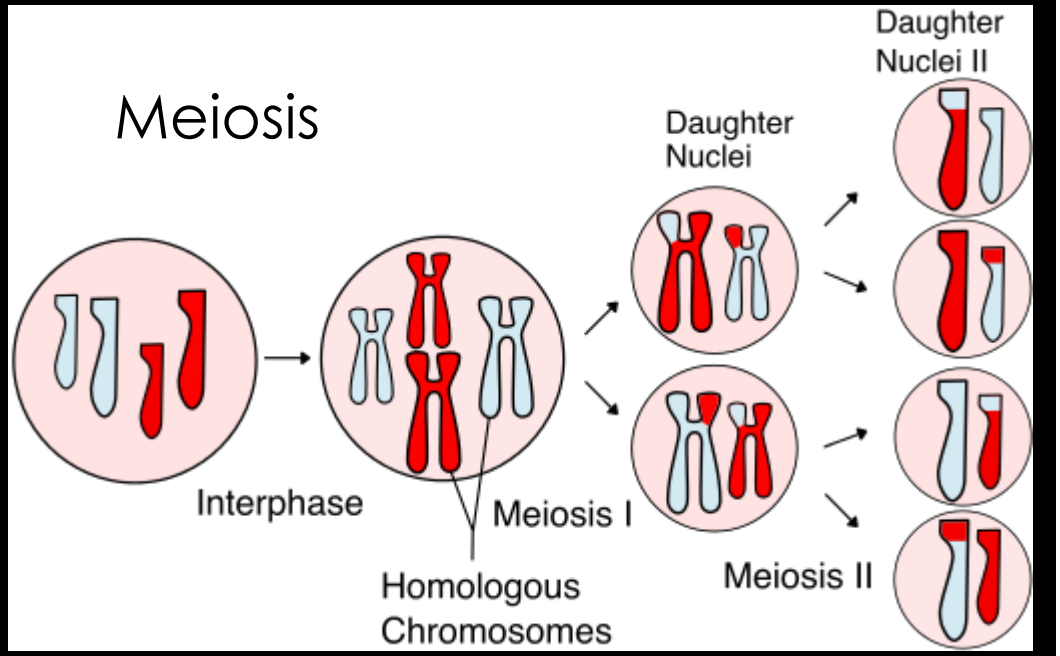
https://ghr.nlm.nih.gov/primer/basics/chromosome

REPRODUCTION

- Two kinds of cell reproduction (in mammals)

1. Cells can divide to form new identical cells (mitosis)
   - makes copy of all of its *chromosomes*
   - sends an identical copy to the two new cells
   - Muscle, skin, bone, tissue, …
     - ❑ Have two sets of 23 chromosomes
       - ➢ One set from mother, one set from father

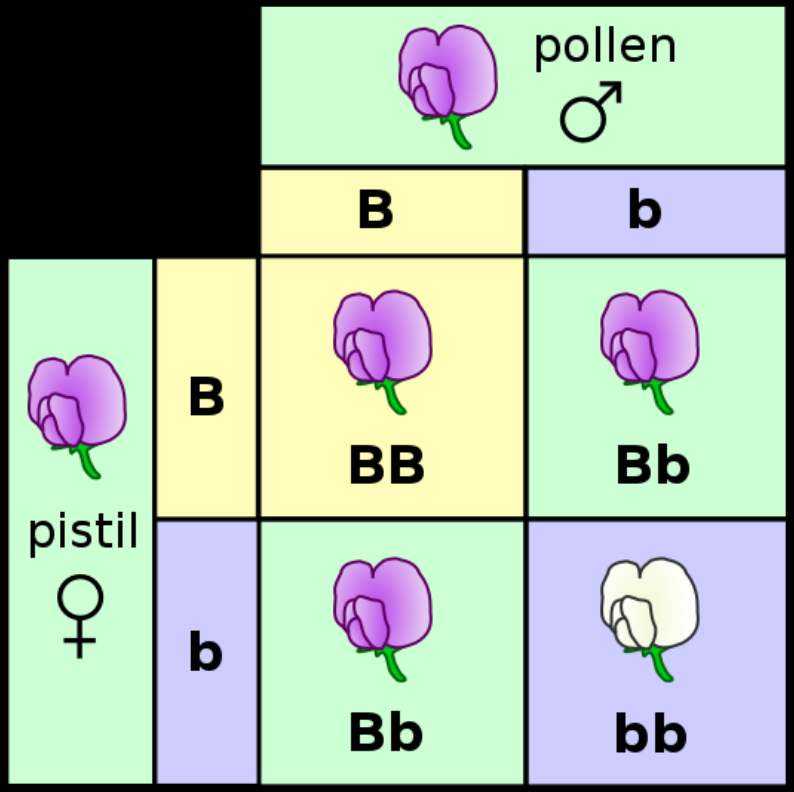
2. Cells can divide to form new non-identical cells with different DNA (meiosis)
   - Sperm, egg
     - ❑ Have only one set of 23 chromosomes
       - ➢ Some DNA from mother, some from father, in different combinations

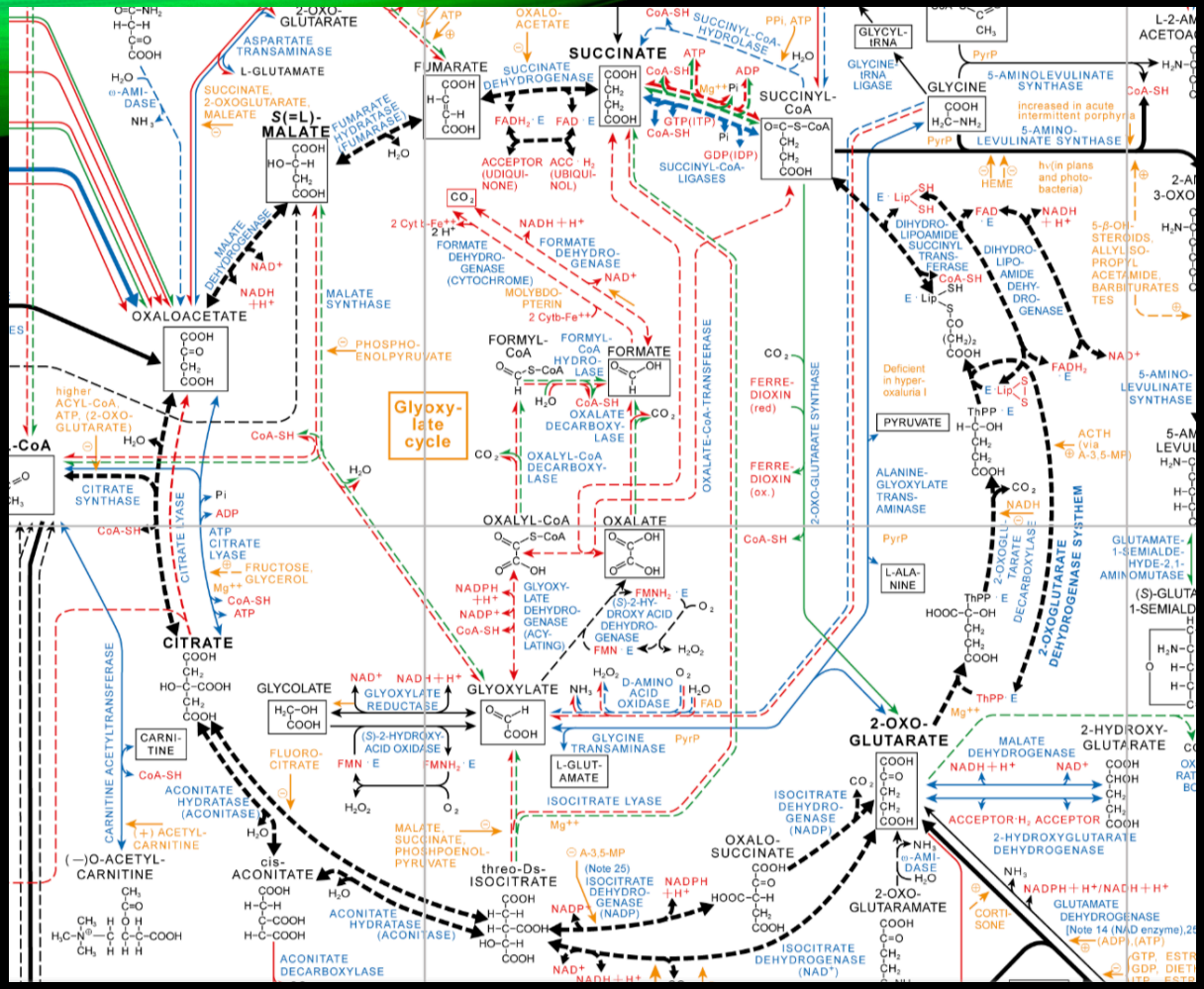


https://en.wikipedia.org/wiki/Meiosis#/media/File:Meiosis_Overview_new.svg

DEFINITIONS: PHENOTYPE AND GENOTYPE

- *Genotype*
  - What genes you have
  - What your genes look like
  - How your genes are regulated
- *Phenotype*
  - Your observable traits
  - What you look like



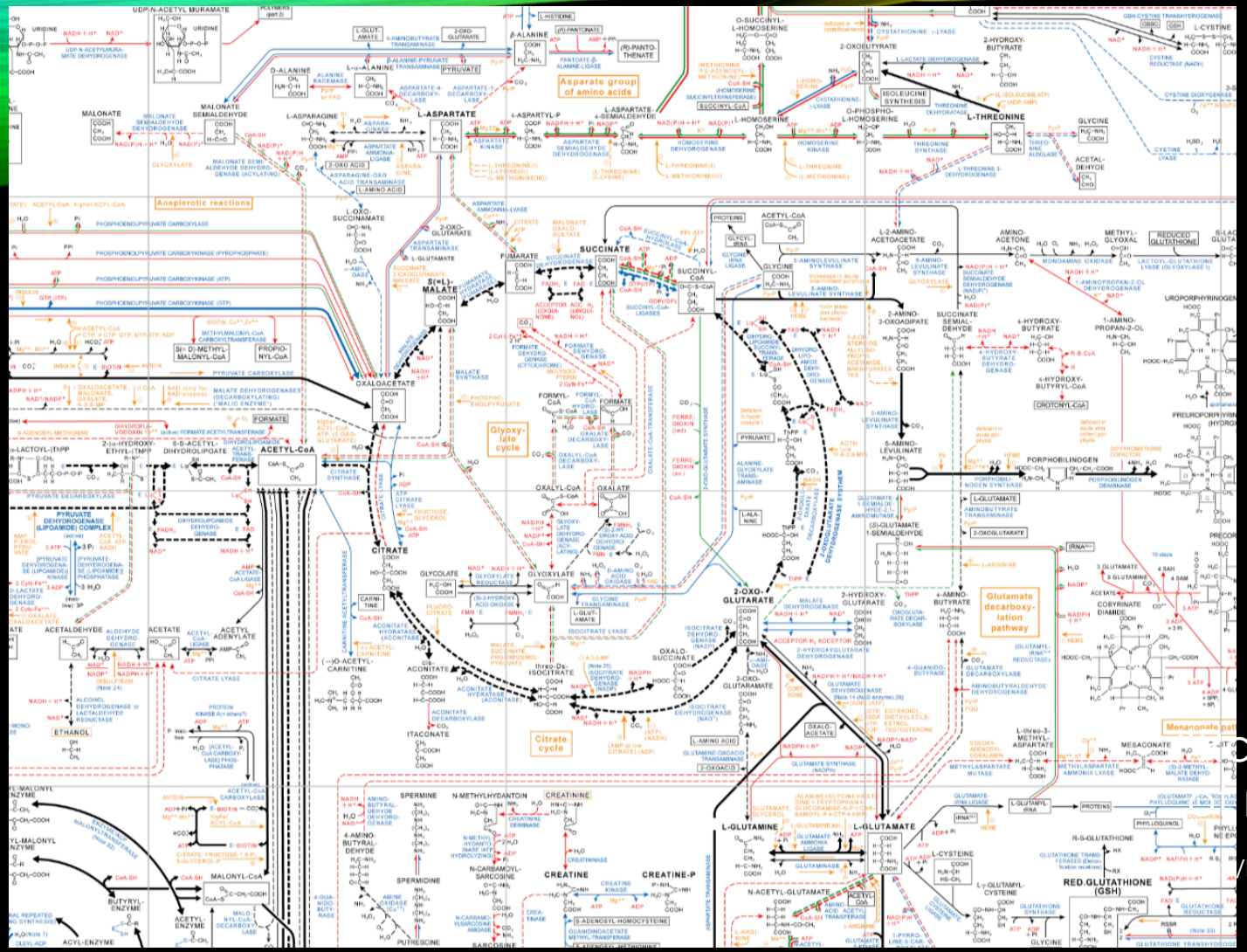


Life involves networks of networks of networks

…

"Roche chart" of metabolic pathways

http://biochemical-pathways.com/#/map/1



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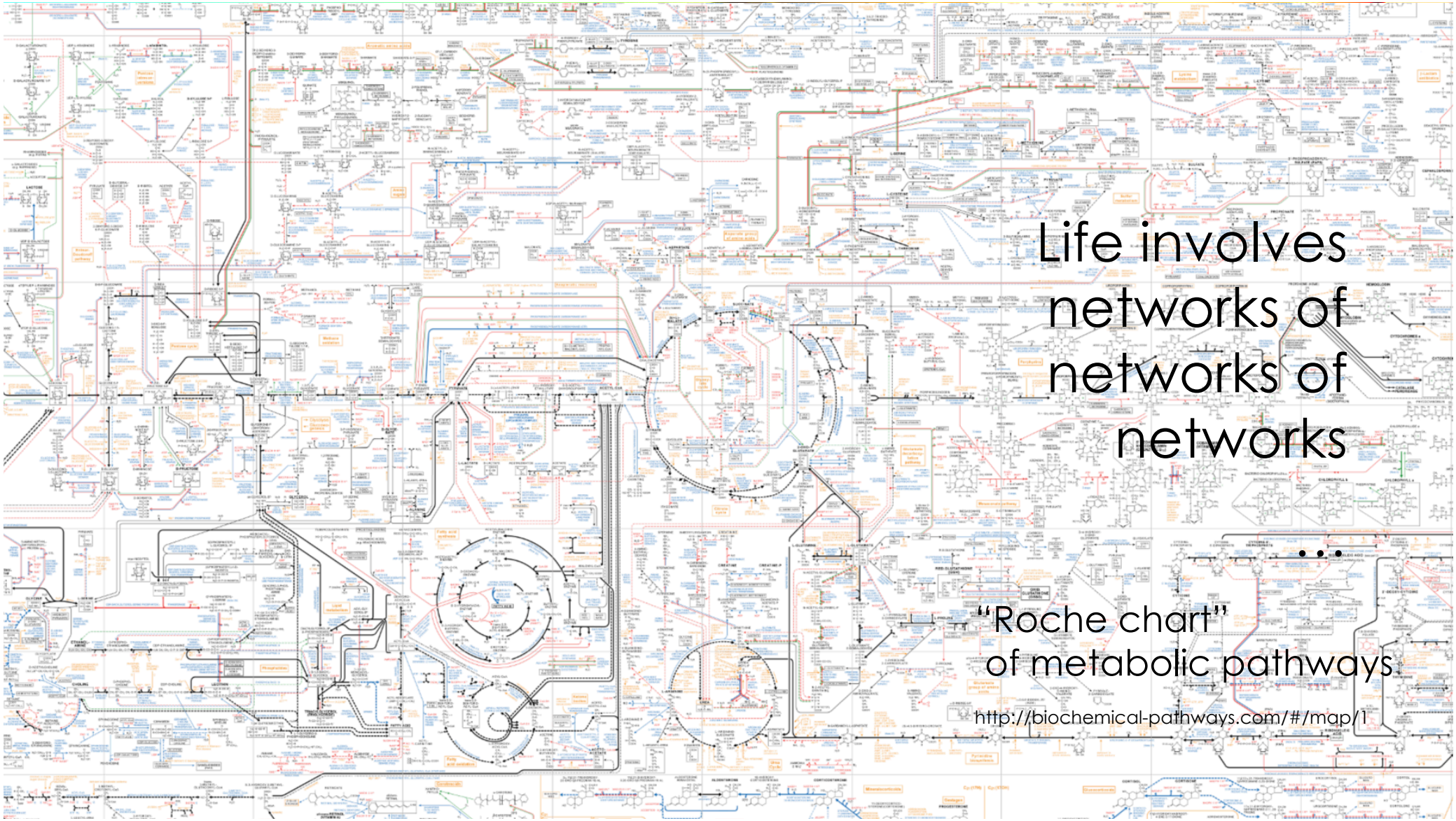
Life involves
networks of
networks of
networks
…
"Roche chart"
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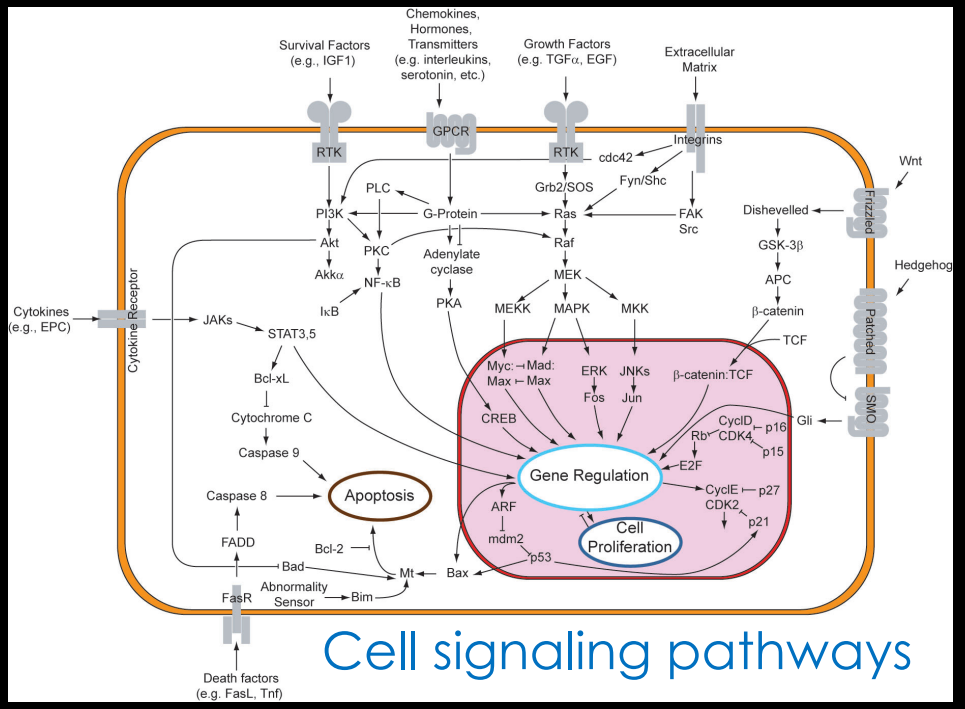
BIOLOGICAL NETWORKS INTERACT WITH EACH OTHER

- Protein–protein interaction networks
- Gene regulatory networks
  - DNA–protein interaction networks
- Gene co-expression networks
  - transcript–transcript association networks
- Metabolic networks
- Signaling networks
- Neuronal networks
- Networks beyond the individual organism
  - Food webs
  - Between-species interactions
  - Within-species interactions



Systems biology is the study of networks and their interactions, using computing and bioinformatics

https://en.wikipedia.org/wiki/Biological_network

THAT'S LIFE!

THAT'S (A SMALL FRACTION OF) LIFE!

- Life has
  - Cells
  - Metabolism
  - Genetics
  - Reproduction
  - Networks
  - ….

According to Genesis, life was here, very near the beginning

"And God said, Let the earth bring forth grass, the herb yielding seed, and the fruit tree yielding fruit after his kind … And the earth brought forth grass, and herb yielding seed after his kind … And God said, Let the waters bring forth abundantly the moving creature that hath life, and fowl that may fly above the earth… And God created great whales, and every living creature that moveth, which the waters brought forth abundantly…" (Gen 1:11-12, 20-21 KJV)

There are two ways we can say that Earth responded to God's command:

-- Biogenesis: production of living from nonliving material

-- Evolution: changes in biological forms across generations

QUESTIONS FOR DISCUSSION

Definition:

ribosome -- the protein-making machine in cells

Questions:

- Can we say that a ribosome has a *function*?
- Can we say that a ribosome has a *purpose*?
- What is the difference between those two statements?