Origin of Life

OoL

THE QUESTION:

How do you go from

Early Earth Conditions ⇒ "Simple" Bacterial Life

by purely natural mechanisms?

Main Scenarios:

RNA World	RNA did it
Protein first	Proteins did it
Catalytic rocks	Minerals did it
"Self-Organizing Criticality"	Anything can do it.

Outline

1. Early Earth
   - what was there to work with?
2. Life as we know it today
   - where do we have to go?

} background material

3. Origin of "biogenic" material
   - where did the "building blocks" come from?
4. Origin of life scenarios
   - how did it all happen?

} OoL active research areas

Before we even start: there are no complete, satisfactory OoL scenarios, by anybodies definition

We'll see why.

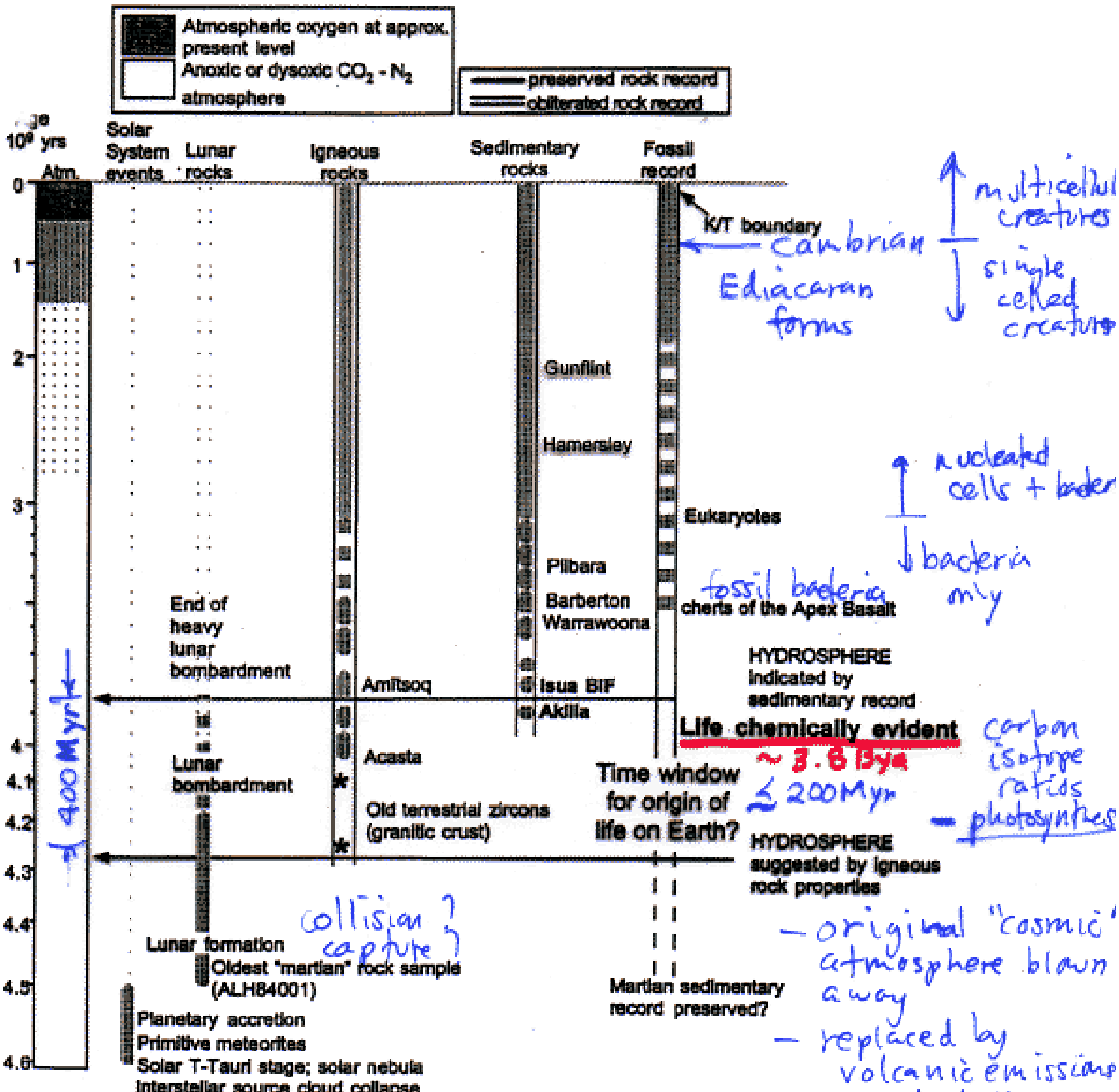


Figure 1 Time scale for events with relevance to the origin and early evolution of life.

cometary material
organic stuff, including aa's at ppm level

O_2 ?

CO_2, N_2, H_2O } inert
(H_2S, CO, CH_4, H_2) } react
few ppm — 100 ppm

Earth during OoL

- Liquid water present { crust has cooled }
- Weak sun (~ 30% less intense than today)
- heavy bombardment — comets, meteors, etc.
- lots of geological activity
  - earthquakes
  - volcanism
- Atmosphere:

  mainly N_2, CO_2, H_2O — inert

  also, maybe CO, CH_4, O_2, H_2S — reactive

  probably no NH_3, H_2 — very reactive (except locally).

  ← too light to be retained by earth's gravity
- ~ Neutral chemistry (neither oxidizing nor reducing)

- crust chemical composition similar to now except less oxidized

  Fe, Si, , H$_2$O, carbonates, etc.
  CO_3^{2-} + M

- weather violent ?

- T of seas, atmosphere ?

- High UV flux ?
  - ozone layer?

Local Enviroments of Interest

– Geysers, hotsprings

high temperatures
high T gradients
high concentrations of stuff
sources of reactive species
H_2S, CO, NH_3?
CH_4? H_2?
~~[illegible]~~ – ARCHAEA

– Undersea vents, cracks.

all the same reasons PLUS

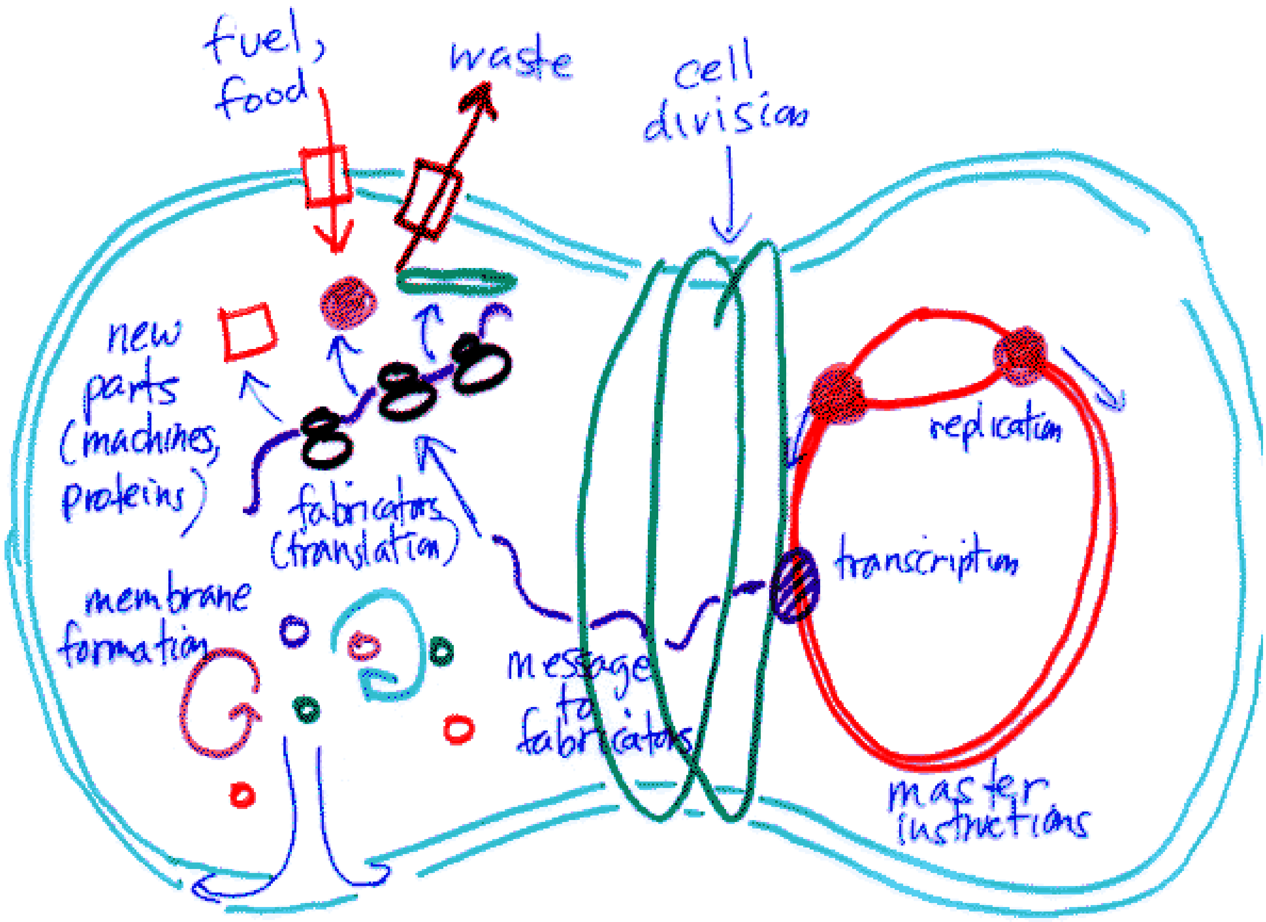
- some protection from impacts
- even higher T's, T gradients
- archa-ea, extremophiles
  - halophiles
  - acidophiles
  - thermophiles
- flow, concentration, strong mineral interactions in cracks, restricted enviromments

- Shorelines, ponds, lakes
  - evaporation as a means of concentrating rare chemical species (aa's, sugars, phosphates, etc).

- atmospheric aerosols
  - water droplets as substitutes for cells & cell membranes
  - access to volatiles in atmosphere

Life as We Know it Today

Minimal Cell



+ many auxilliary functions (topoisomerases, histones, tRNA's, tRNA synthases, etc)

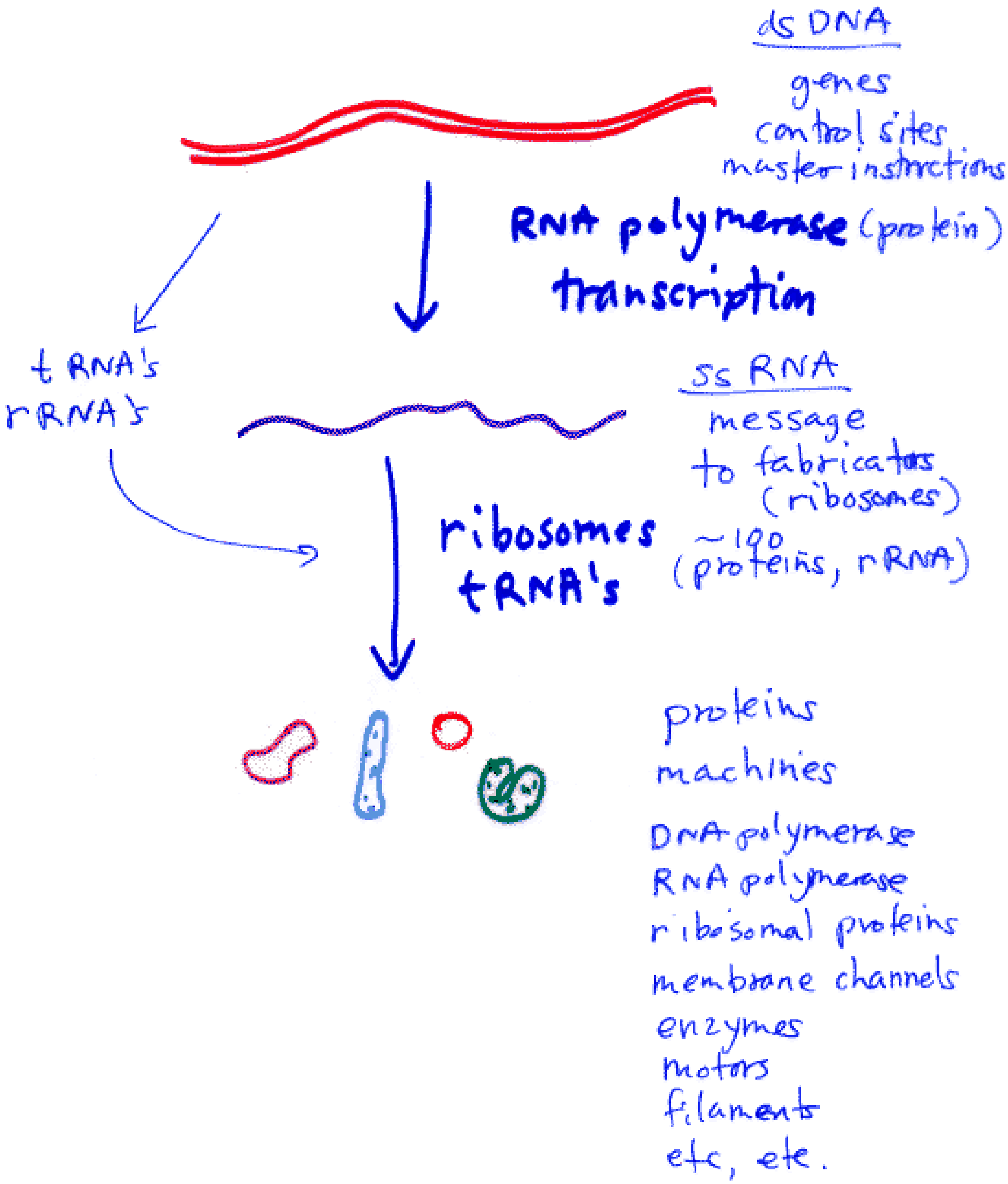
+ coordination and control of all these functions

~ VERY complicated ~

Complexity of Living Things

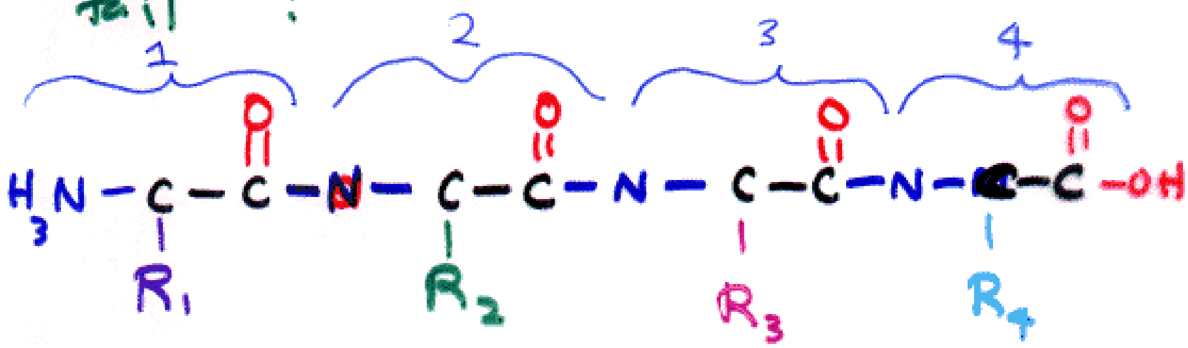
organism	genes	"complexity" (~genes²)
vertebrate animal	~50,000	10^9
S. cerevisiae yeast simple eukaryote	~6,000	10^7
E. coli complex prokaryote	~4,000	10^7
simple prokaryote	~1,000	10^6
mycoplasma M. genitalium	500	10^5
hypothetical simplest cell	~200	10^4

Genetic Apparatus



Proteins

Amino acids are hooked "head to tail":



Sequence

... – Gly – Ala – Leu – Lys – Trp – Ala – ...

This sequence of aa's is controlled by the DNA.

protein

... Gly Ala Leu Lys Trp Ala ...

... GGG GCU CUA AAA UGG GCG ...

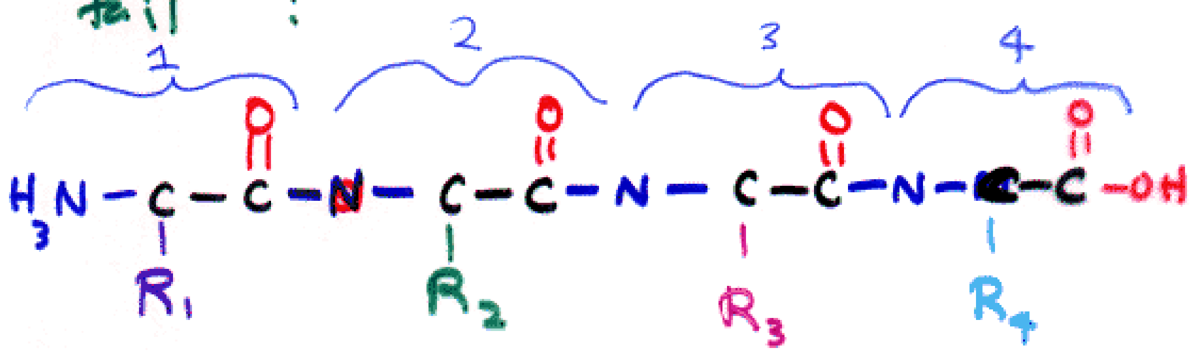
mRNA

... CCC CGA GAT TTT ACC CGC ...

DNA

Proteins

Amino acids are hooked "head to tail":



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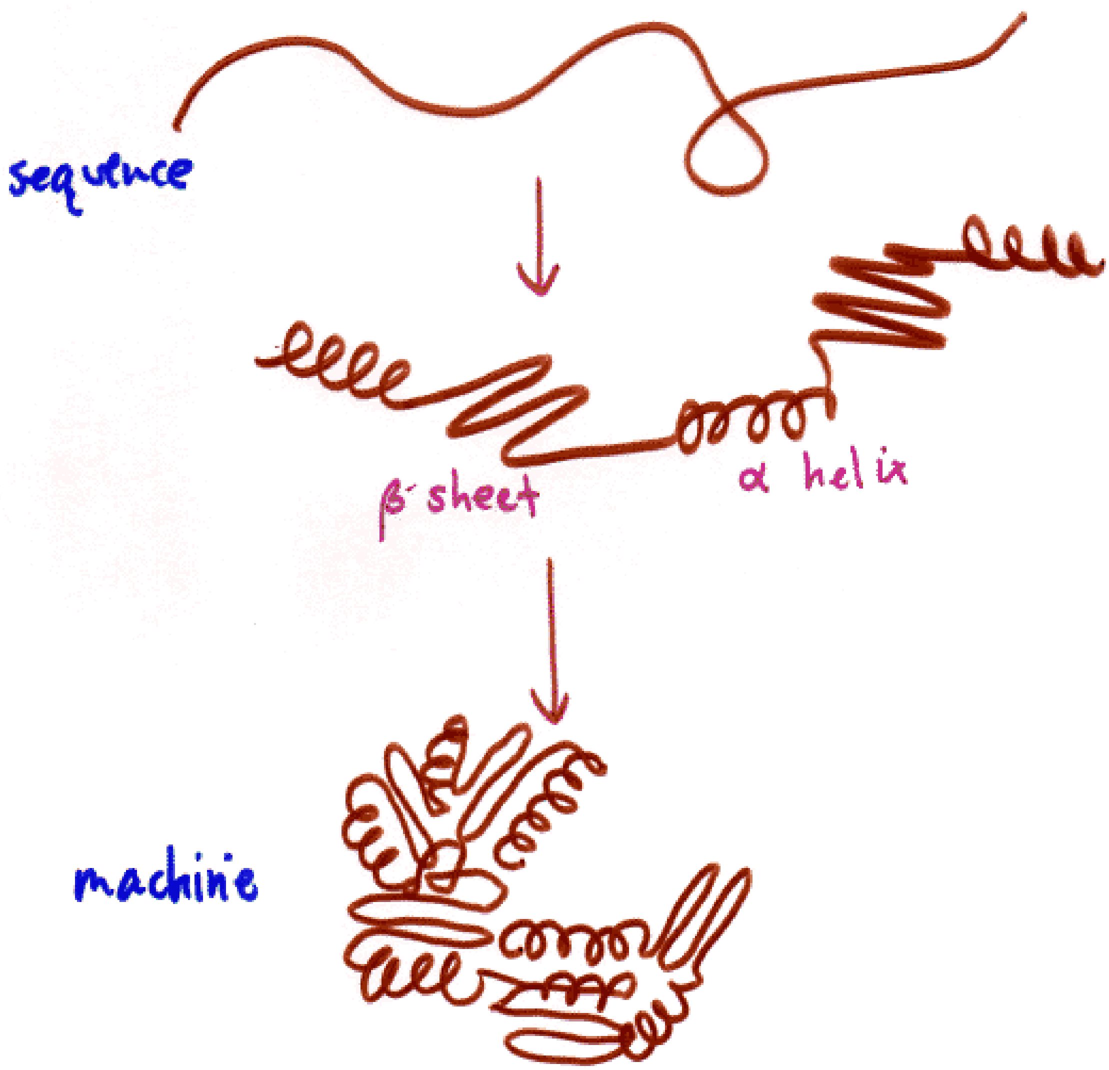
DNA

Proteins

The sequence of amino acids FOLDS up into a 3D "machine".



Protein Machine Examples

DNA polymerase

RNA polymerase

$F_1 F_0$ ATP synthase

Kinesin

Bacterial flagellar motor

Ribosome

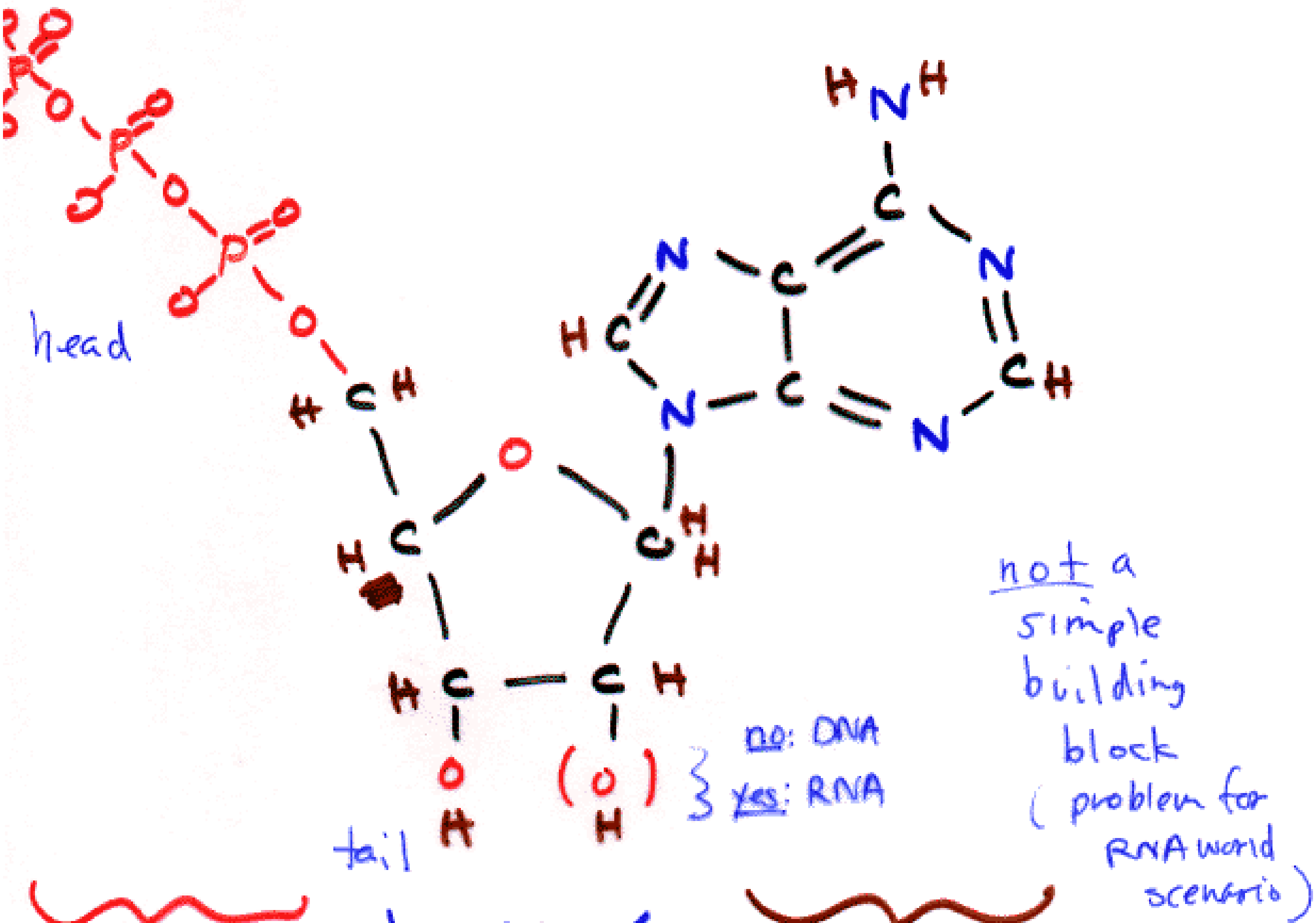
Proteasome

Topoisomerase

GroES-GroEL

Nucleic Acids

... are chains of nucleotides



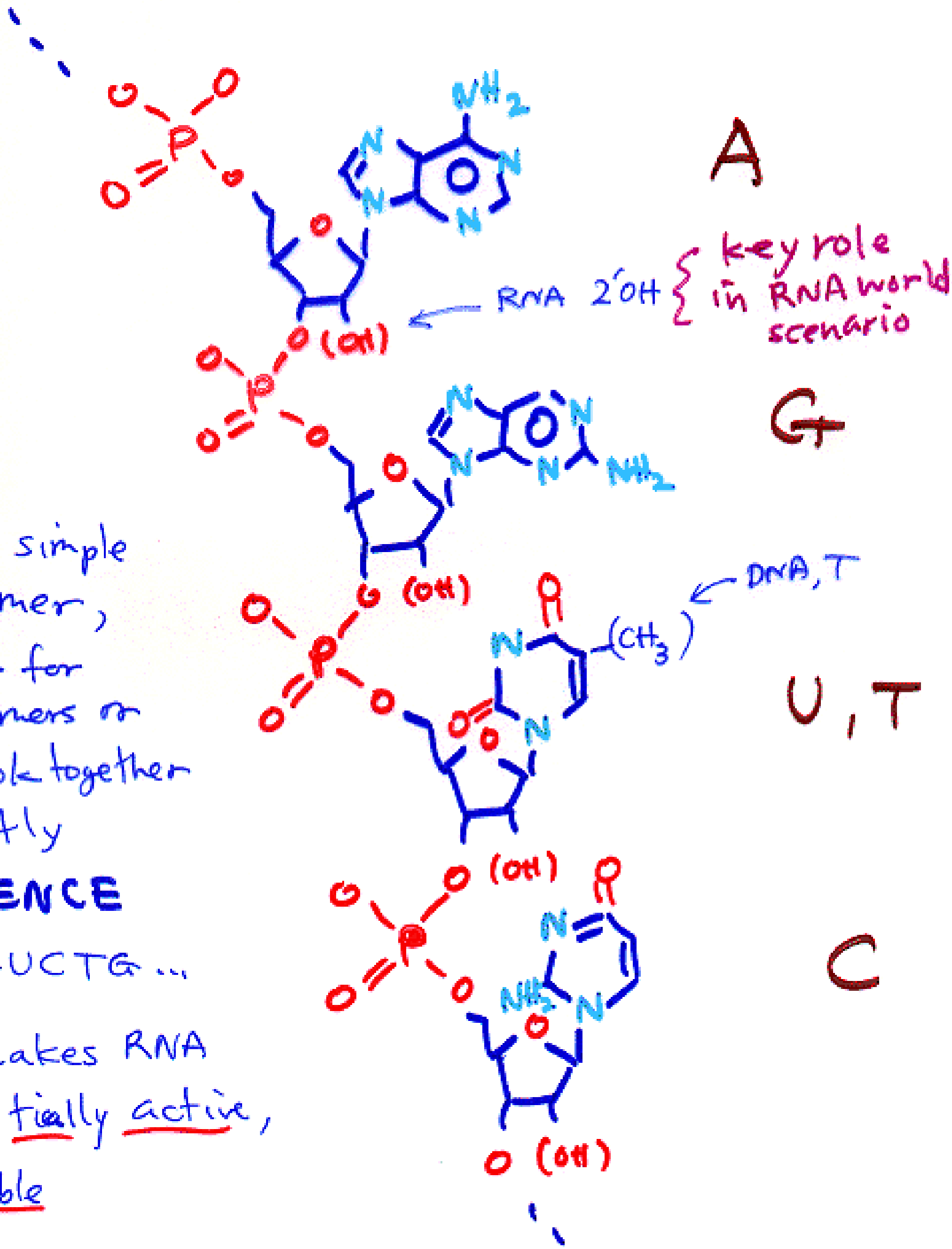
tri-phosphate

sugar (ribose, deoxyribose)

base (A, adenine) 4 bases
G, guanine
C, cytosine
T, thymine DNA
U, uracil RNA

Nucleic Acids

are formed from nucleotides hooked head to tail



- Not a simple polymer, either for monomers or to hook together correctly
- **SEQUENCE**

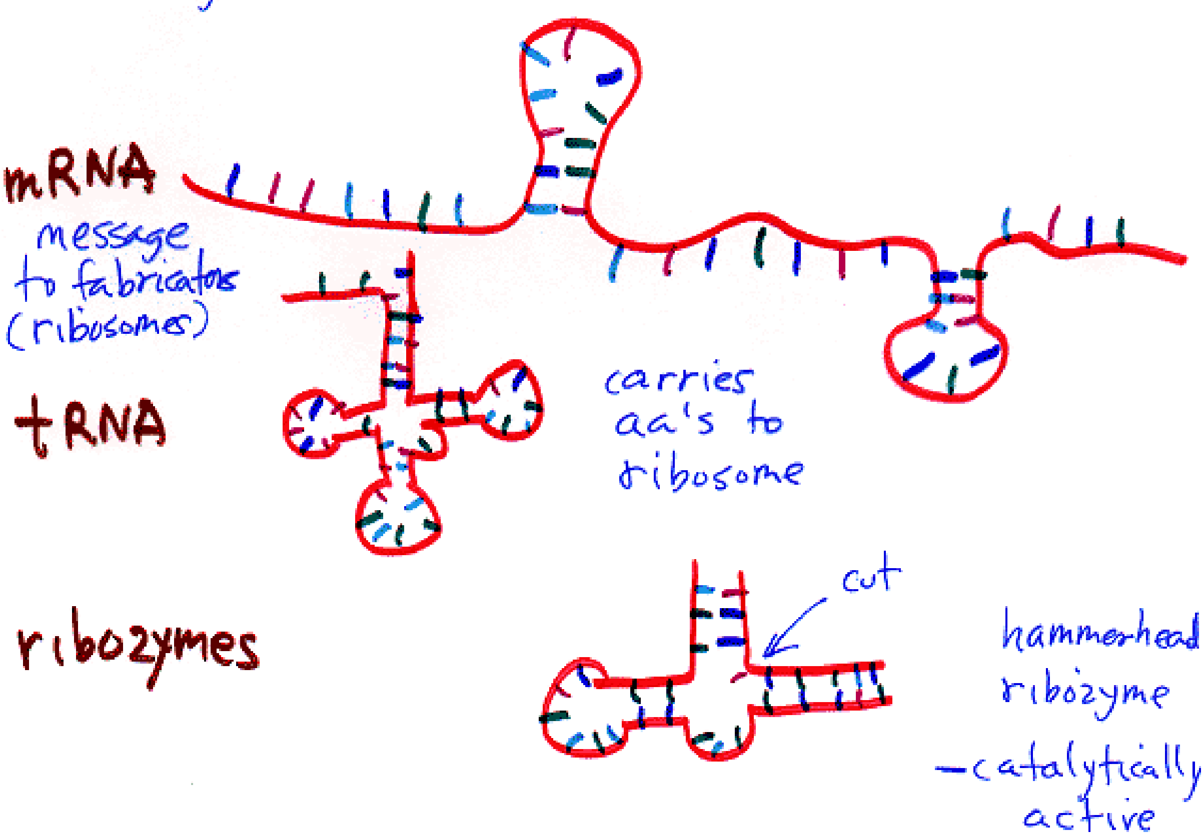
  ...AACGUCTG...
- 2'OH makes RNA catalytically active, unstable

DNA

Always double-stranded (protects genetic information)

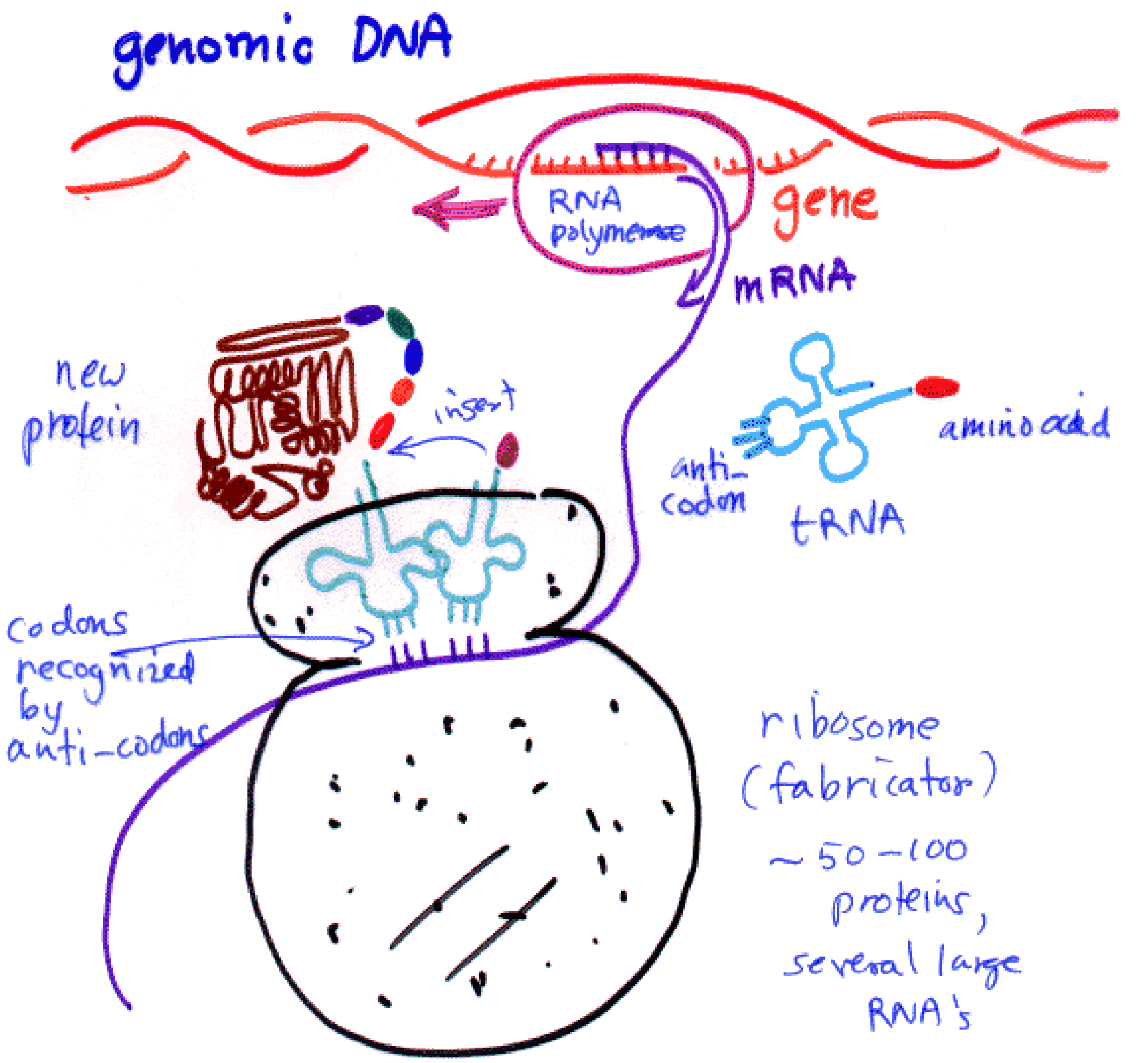
RNA

Usually single-stranded, folded up



How does DNA code for Protein Machines?

Translation: <u>very</u> complicated
~100 genes/proteins involved



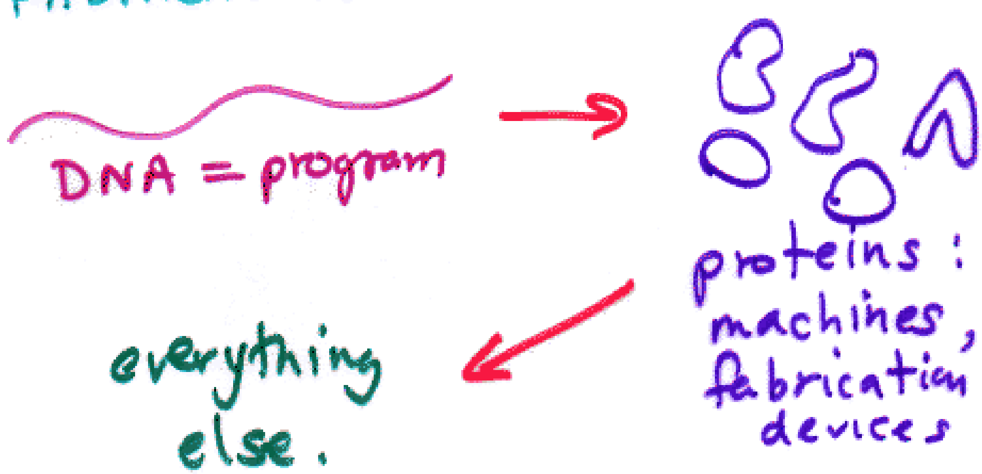
CONCLUSIONS

- Present-day living systems are **enormously** complex
  - even the minimal cell is WAY beyond chance.
- Is all this complexity NECESSARY?
  - The assumptions behind OoL is that it is NOT
  - The goal of OoL is to find a plausible natural scenario to get to this complexity by means of some simpler, intermediate "life" forms.

BVT

whether necessary or not, there is GOOD reason for all of it:

The DNA → RNA → protein system can be considered to be a PROGRAMMABLE UNIVERSAL FABRICATOR



1. There is no obvious limit to the size of the DNA genome, hence no limit to the complexity of the "program".

2. There is a "1-1" relationship between proteins and DNA sequences. ANY DNA sequence is possible, so ANY protein can be made.

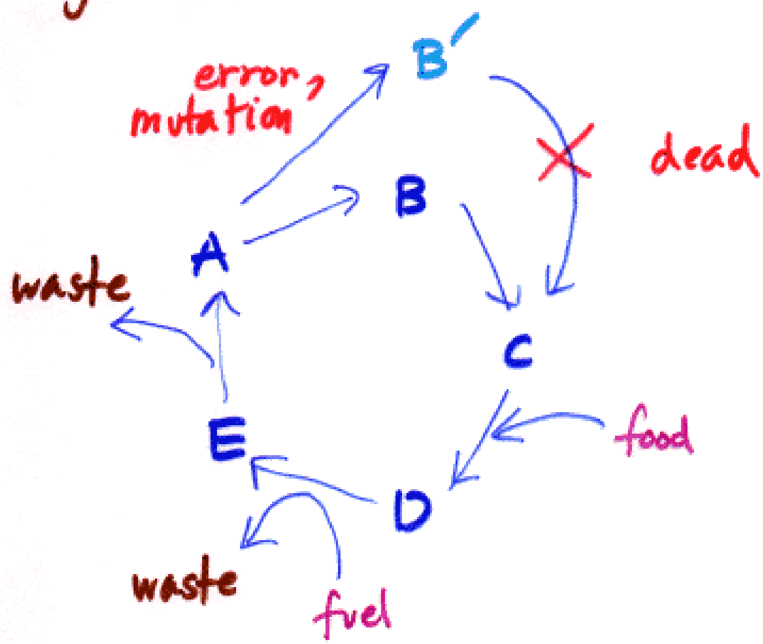
3. Once you have a "core" replicating system, you can add on extras without upsetting the core.

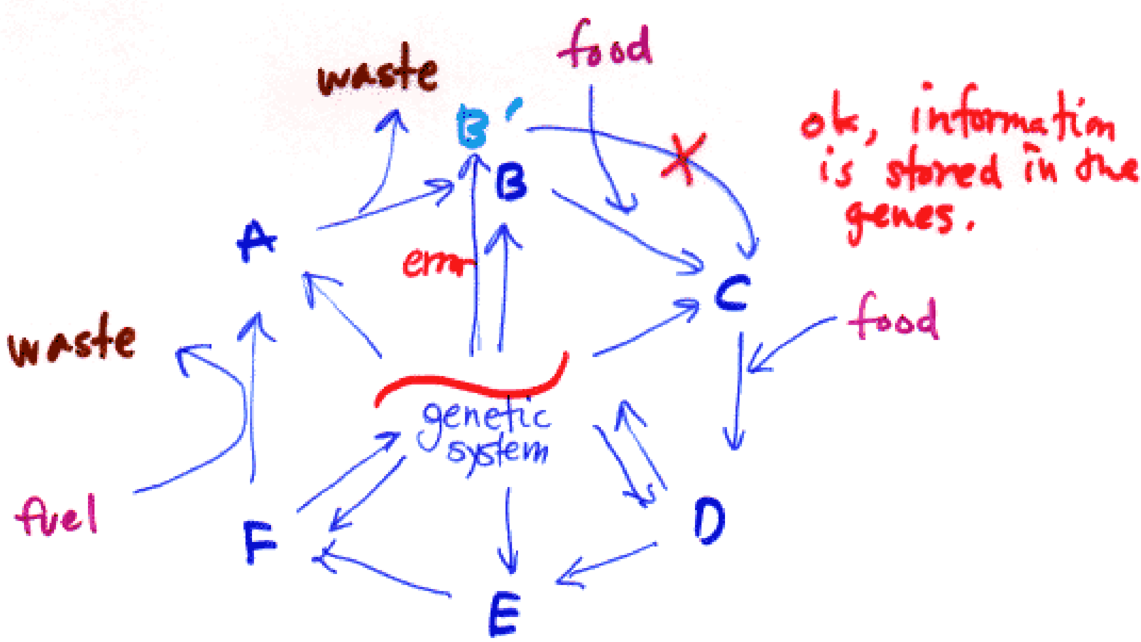
4. Generally, a change in the program is still a good program. (still makes a protein machine)

—system is very robust

COMPARISON

no genetic system





5. The molecules are well suited to their roles

- DNA is stable chemically
  resistant to damage
  contains TWO copies of info.
  (can be repaired)
  can be copied by templating
  has no sequence preferences
  can be opened to retrieve info, closed to store info.

- RNA can contain all the genetic info of DNA, but is unstable chemically
  - can be regulated by chewing it up
  - allows ~~messages~~ temporary messages to be sent between DNA and ribosome.

- protein is not very well suited to storing/transmitting information, but is very versatile catalytically, structurally
  - much better than RNA (which is much better than DNA) AS a MACHINE.

- The core systems of all living things are EXTREMELY well "designed".

  It's not by "chance" that these particular molecules are used, or that this particular kind of system is at the core of living things