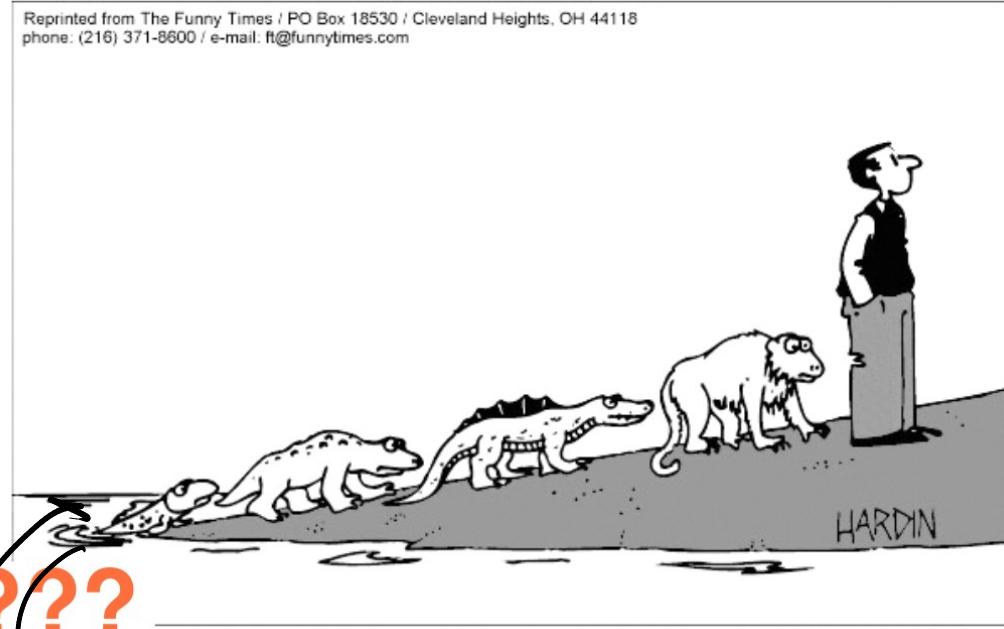


# How did we get here?

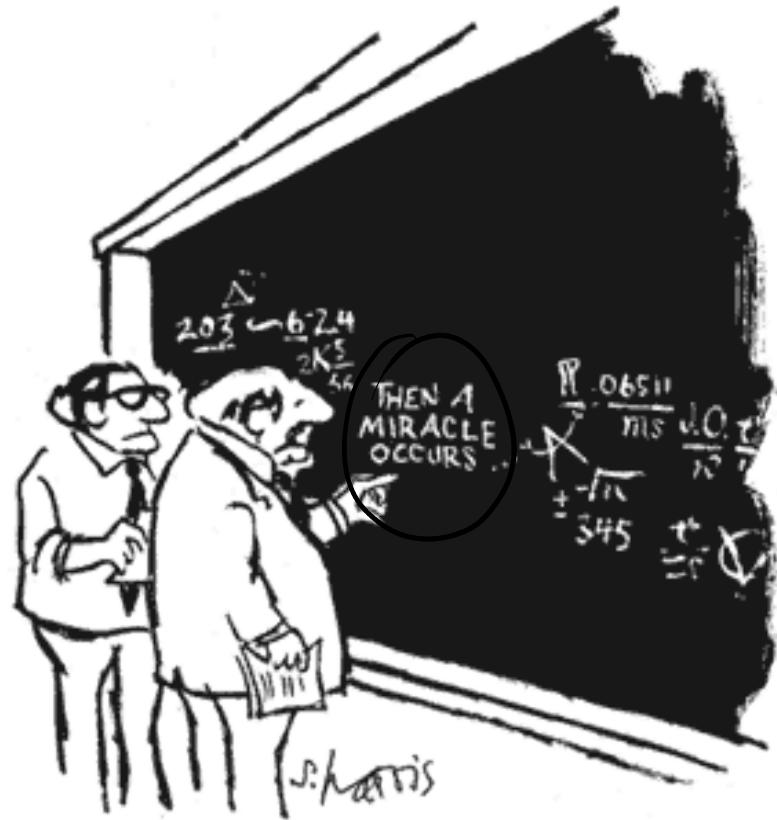
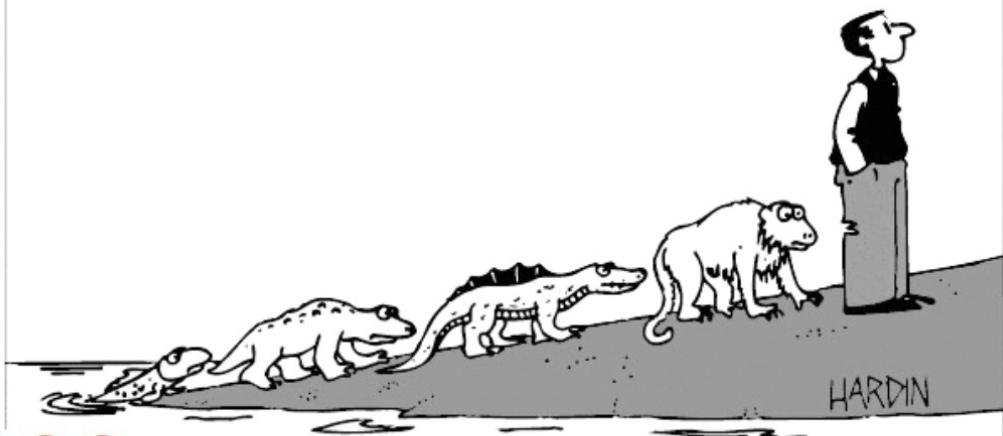
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phone: (216) 371-8600 / e-mail: ft@funnytimes.com



# Evolution and the Origins of Life

## How did we get here?

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"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

## A: Fundamentals of Life

- Definition of Life
  - Logic of Molecular Biology
  - History of Biology
  - Becoming alive
  - Soup of Life
  - Selection: before and in life
  - Three faces of Entropy
  - Death and equilibrium
  - Missing non-equilibrium
  - Structure of Origin of Life
  - Modes of non-equilibrium
  - Examples of evolution
- 

## B: Physics for Chemistry

- Polymerization
  - Theory of polymerization
  - P. by fast cooling
  - P. by stacking with 3'-5'-Ph.
  - Activation groups
  - P. on clay
  - P. by thermophoresis
  - Phase transitions with DNA
  - Sedimentation of DNA
  - Drying and its problems
  - Elegance of air interface

## Replication

- Templated polymerization
- Ligation
- Strand separation problem
- PCR in convection
- Ribo-PCR in convection

## C: Evolution Machines

- Replication with accumulation
  - Case of Ribo-PCR
  - Spiegelman problem
  - Case of trapped PCR
  - Trapped PCR with flow
  - Feeding problem
  - Replication with heated tRNA
  - Replication in driven Fog

## Rebustness of evolution

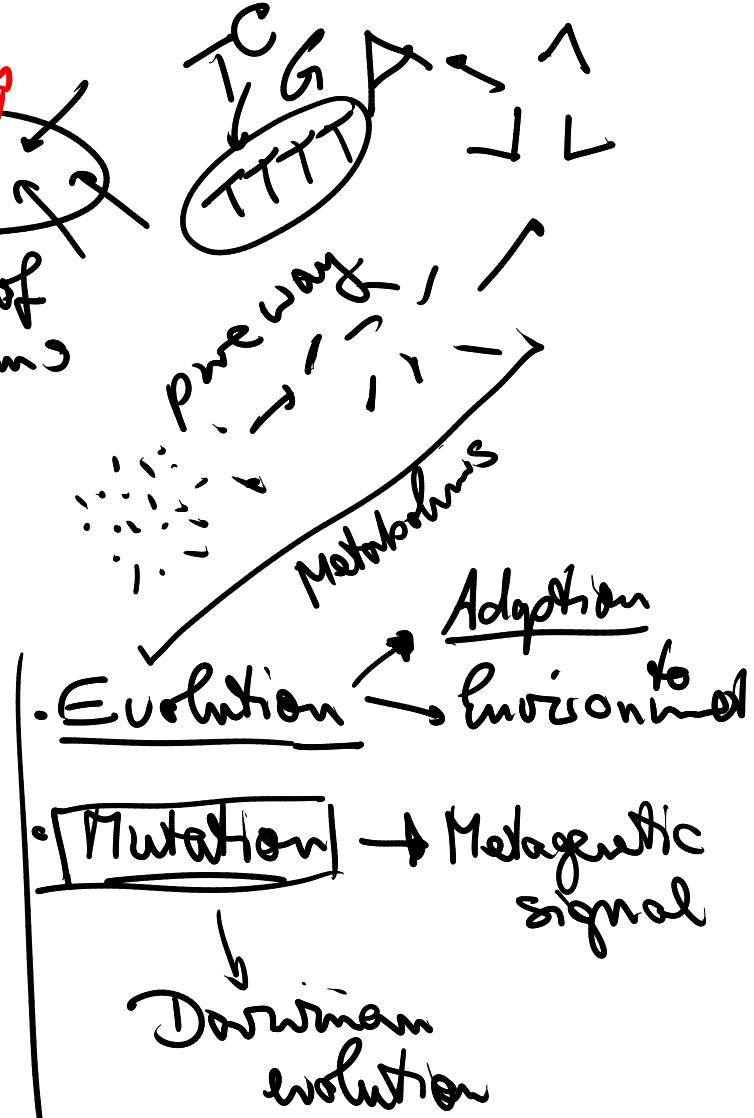
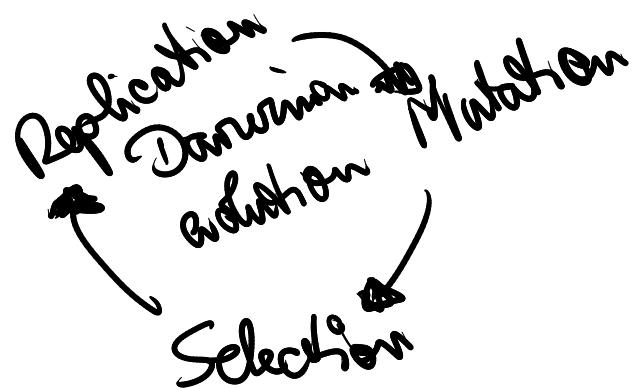
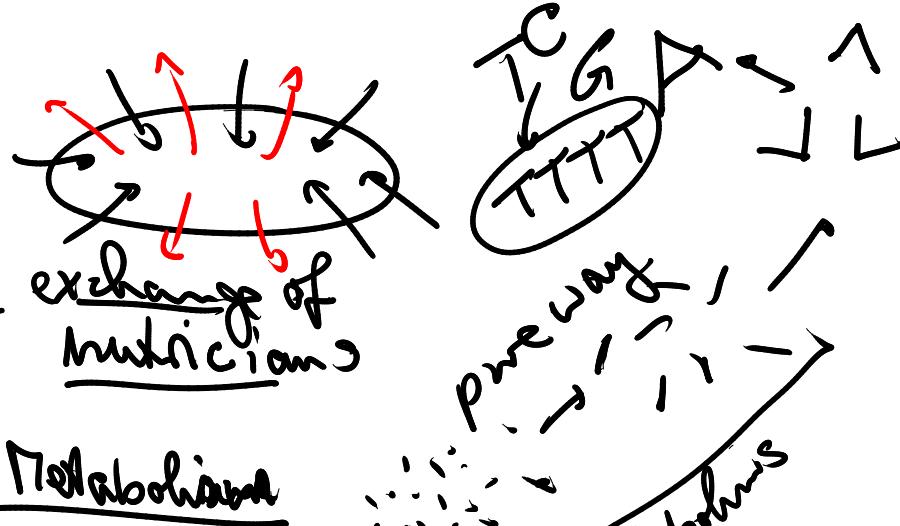
- Error threshold
- Instability of four bases
- Hypercycles with ligation
- Spont. Symmetry breaking
- Spont. sequence selection
- Cooperation within cells

## A: Fundamentals of Life

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- Examples of evolution

# What is life?

- Can replicate
- Contains, exclude from environment.
- "Stoffwechsel"



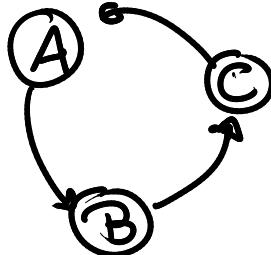
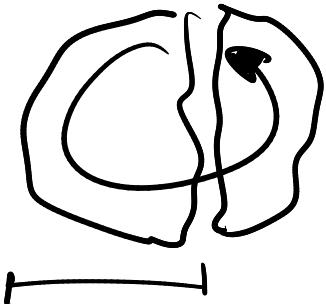
What is life?

Why Darwinian Evolution?

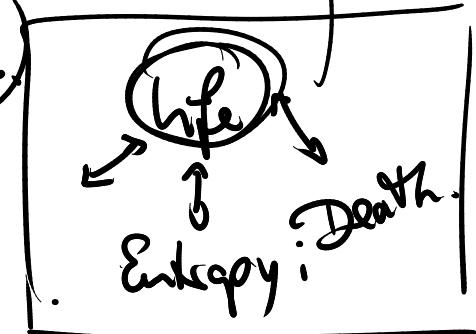
- Other Worlds?
- "pre" replicating System?

• Intrinsic

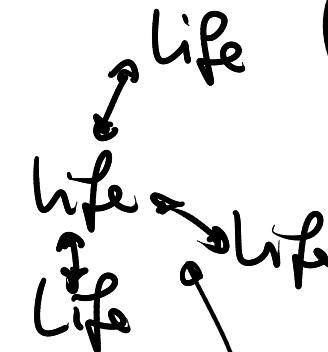
• Not self-sustained?



D.E.



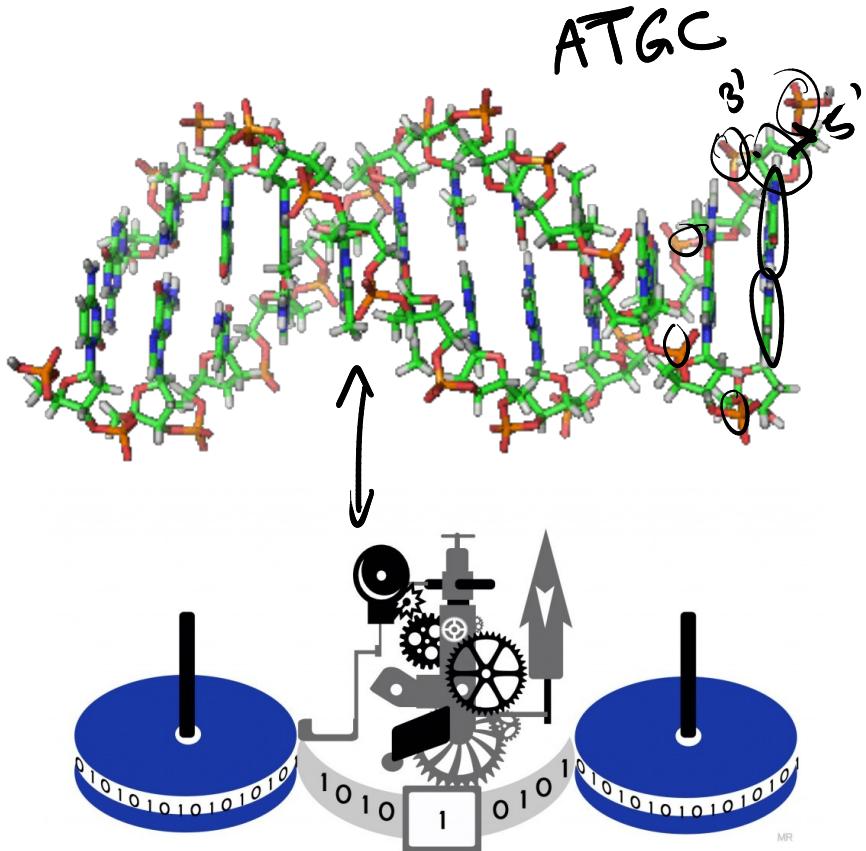
D.E.



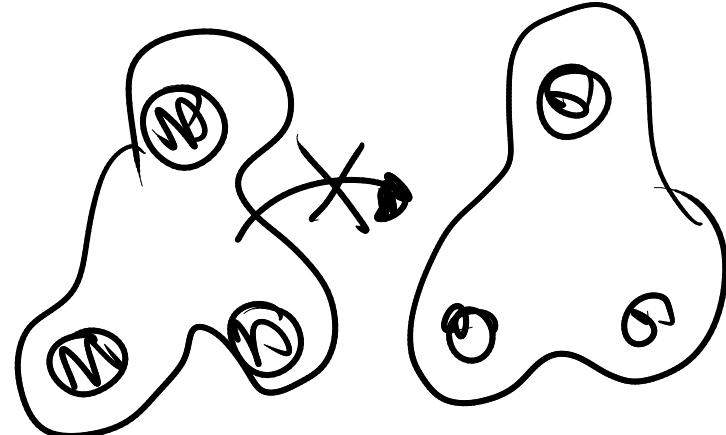
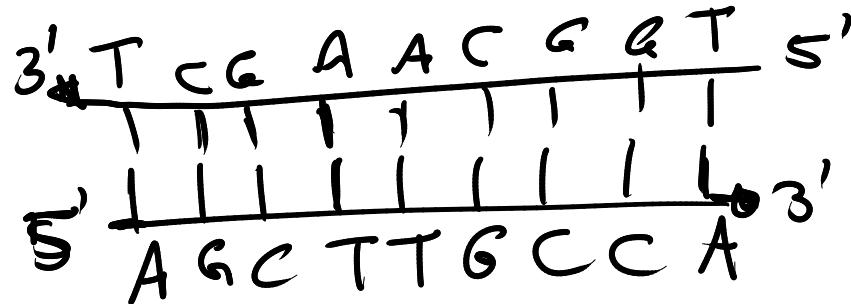
Physics;

Nasa working definition of Life:  
A self-sustained chemical system  
capable of undergoing Darwinian Evolution  
over increasing entropy

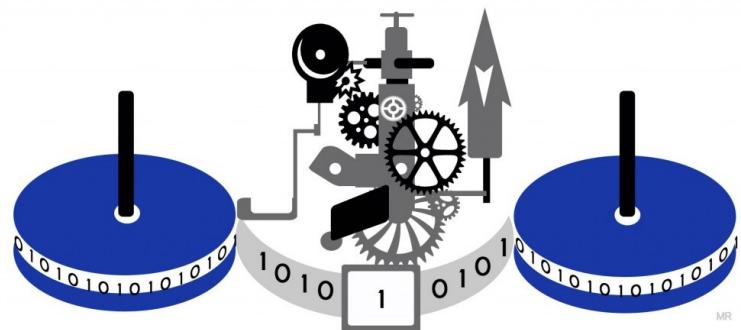
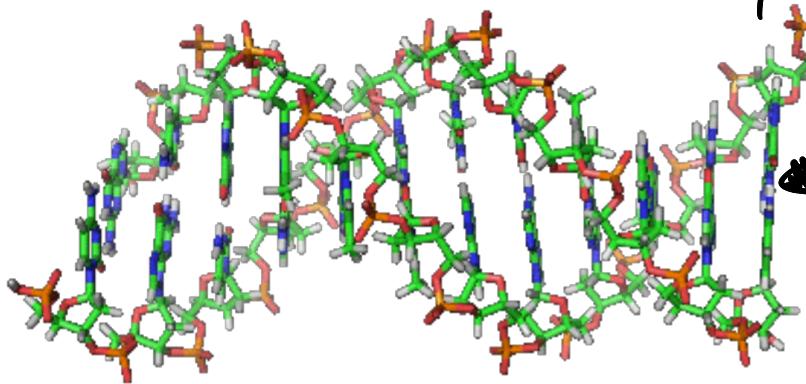
# Logic of Molecular Biology



Storage of information very similar  
to Turing machine => Computer

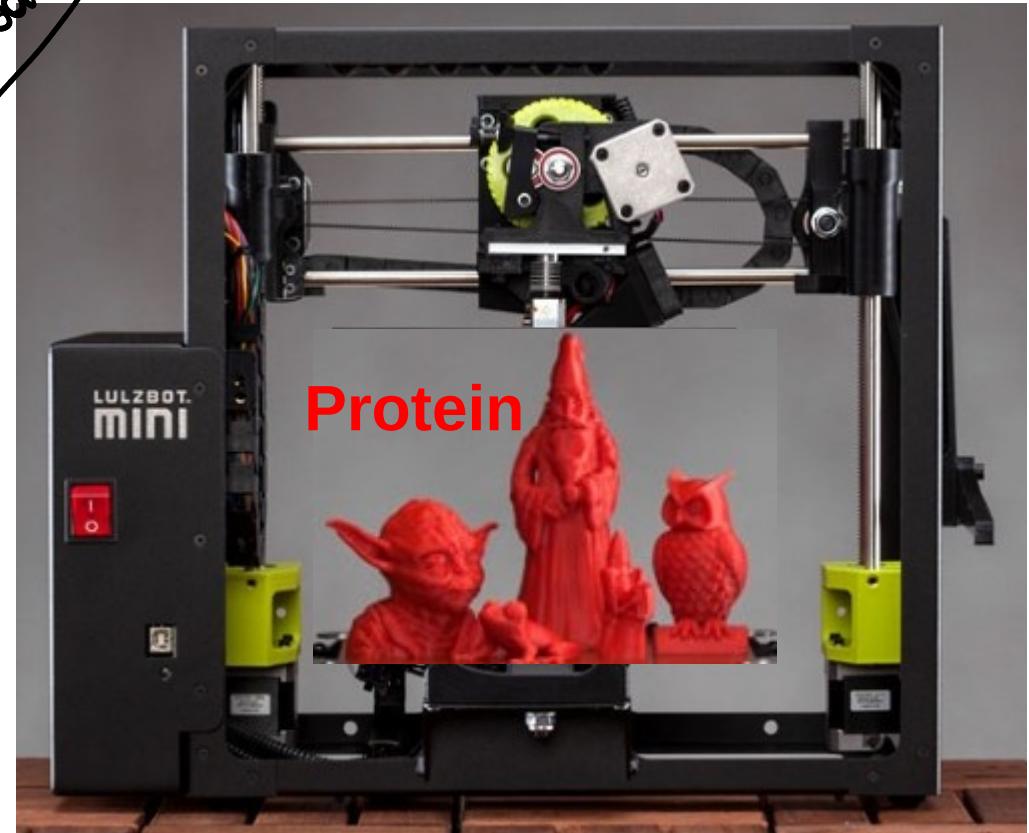


# Logic of Molecular Biology

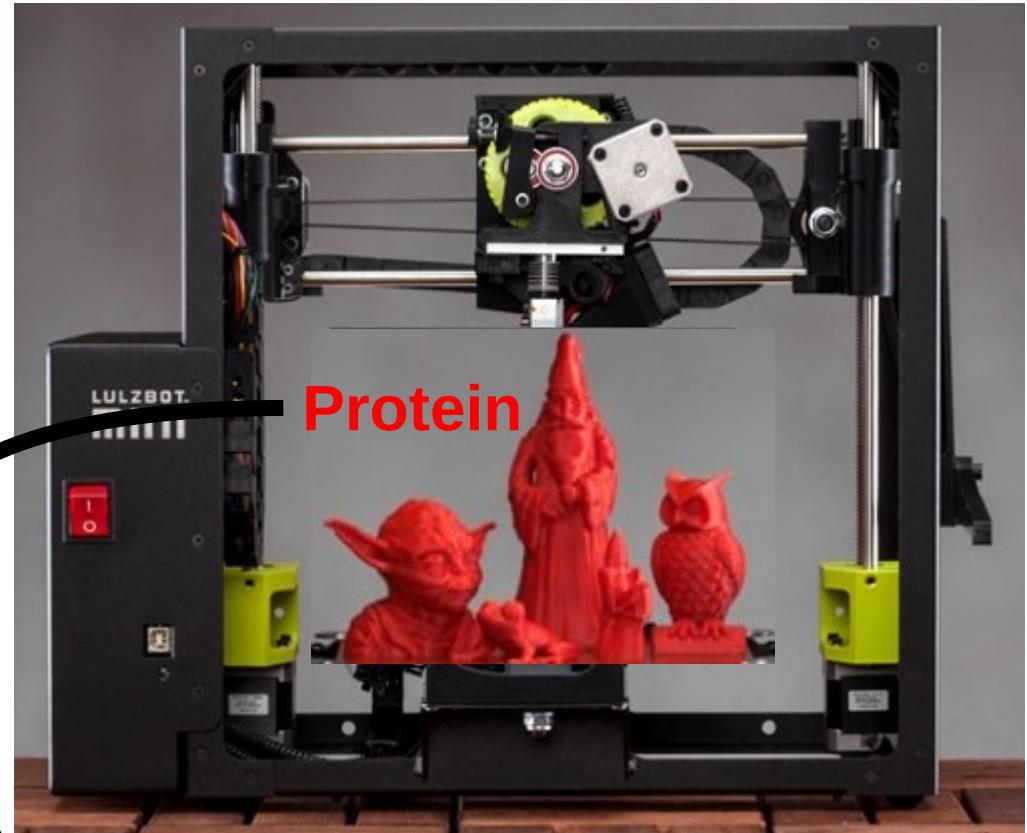


Storage of information very similar  
to Turing machine => Computer

Proteins  
Decimation



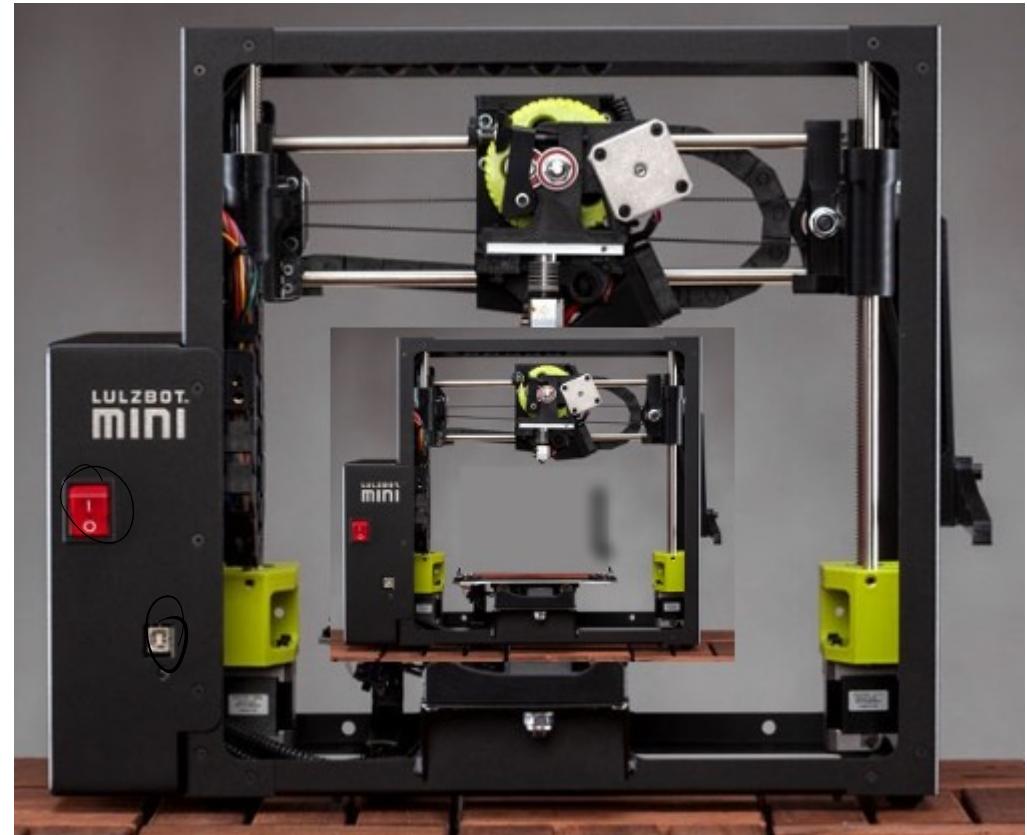
# Logic of Molecular Biology



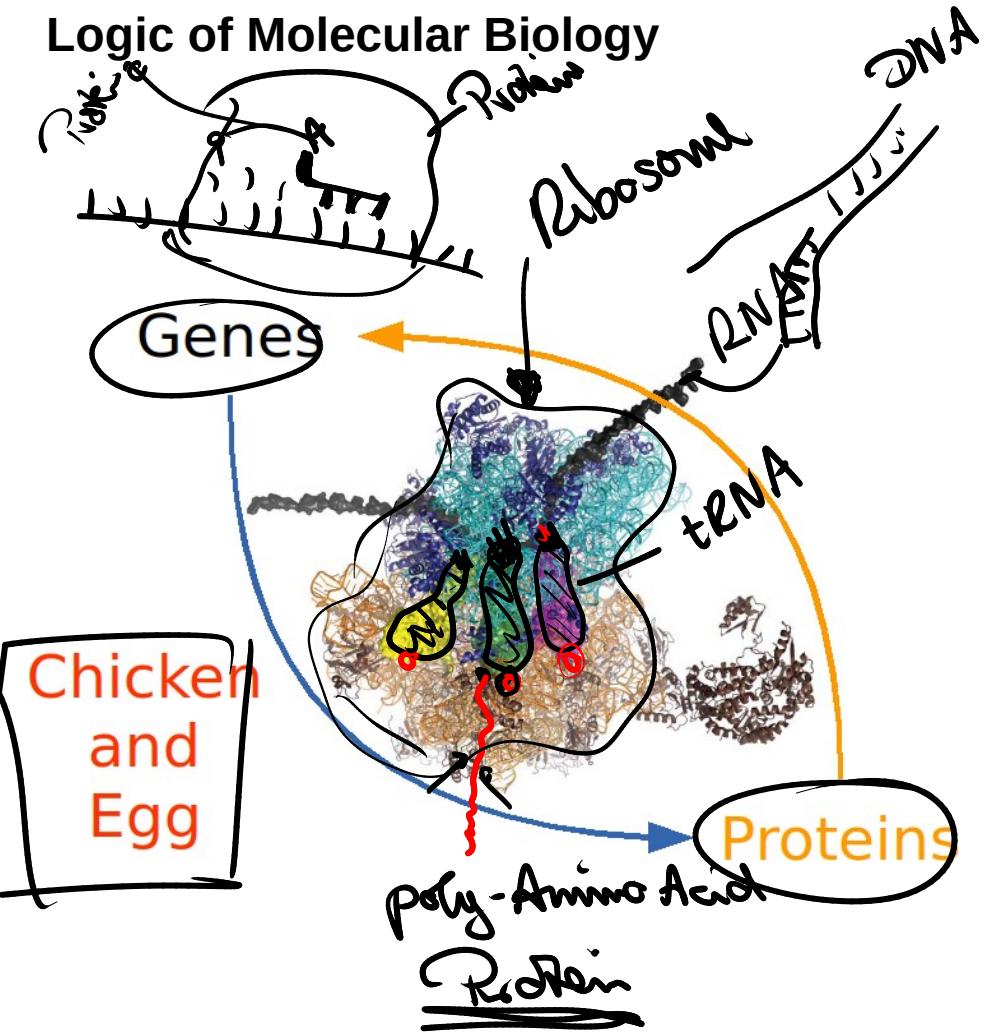
DNA+RNA

Protein

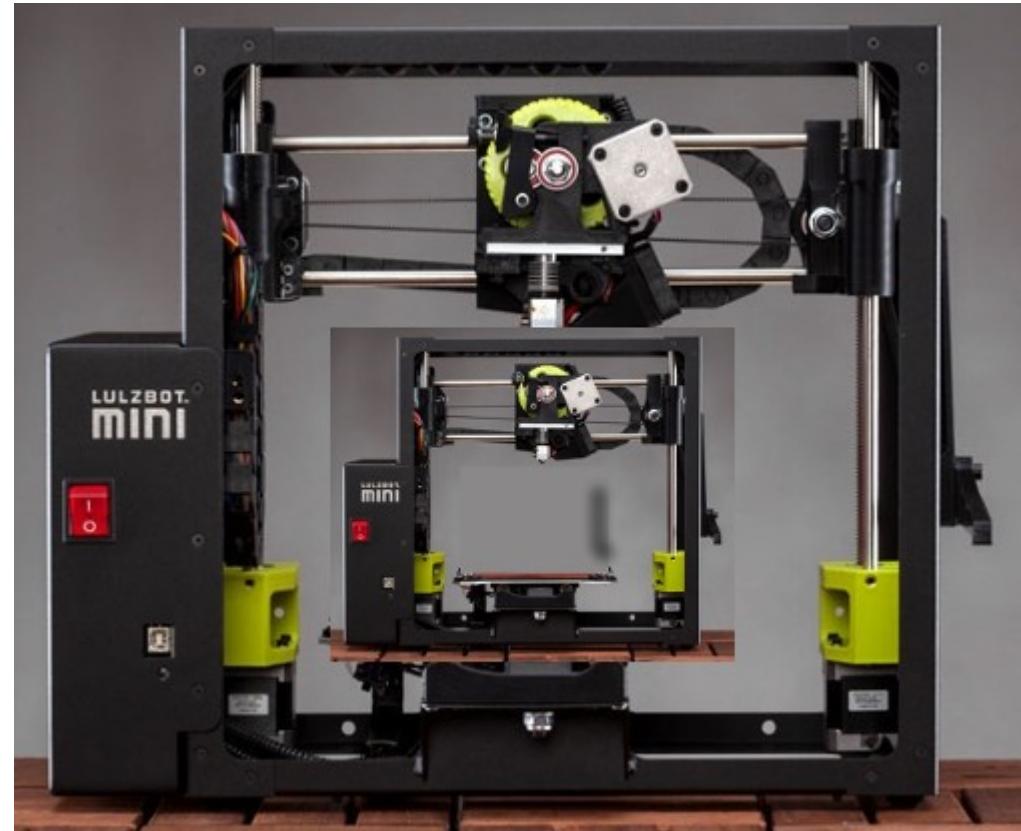
# How to make a machine that makes itself?



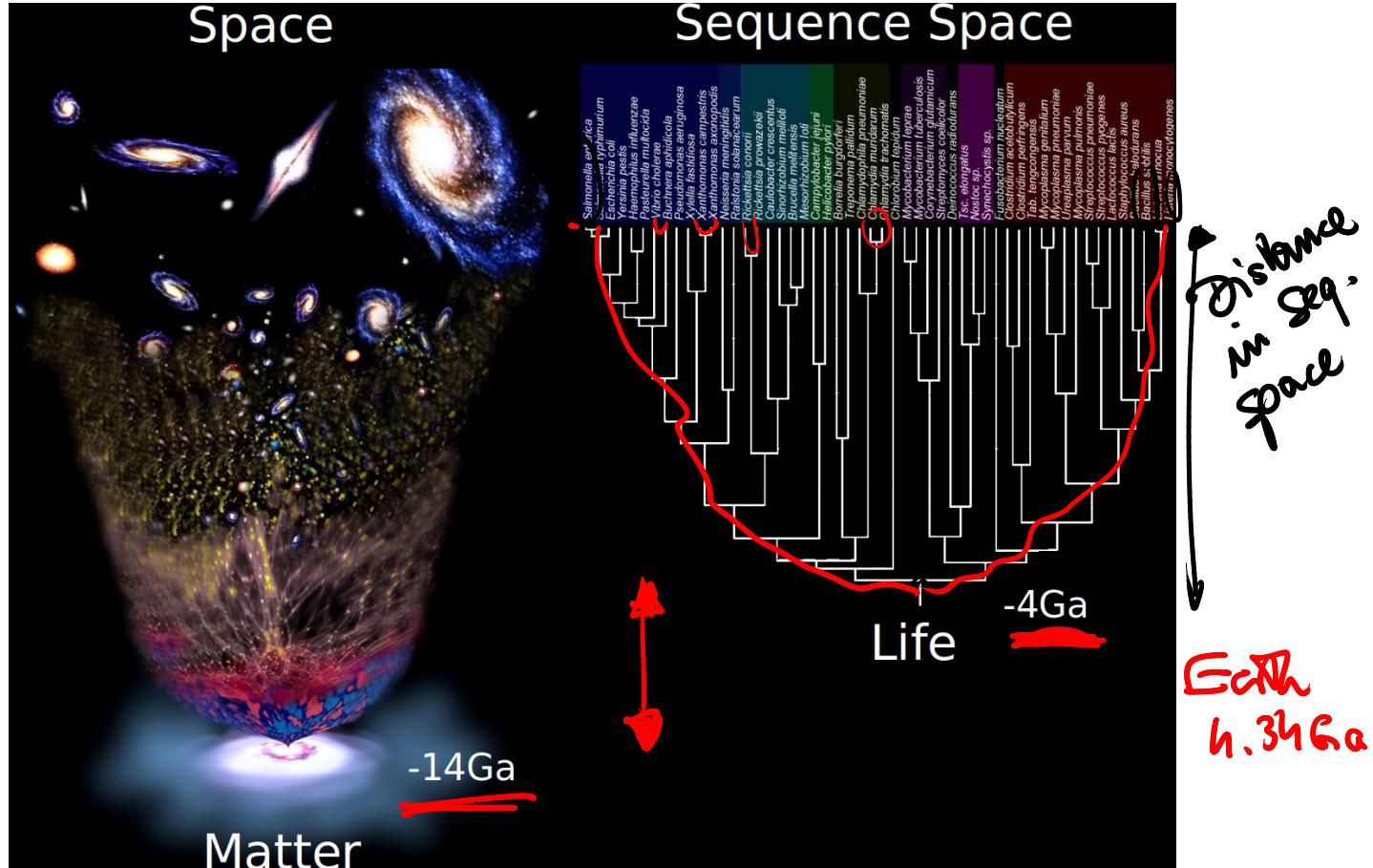
## Logic of Molecular Biology



## How to make a machine that makes itself?

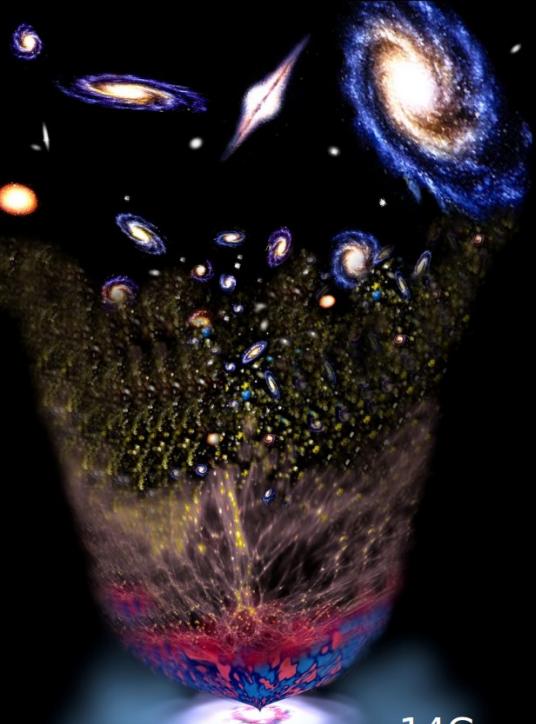


# History of Biology



# History of Biology

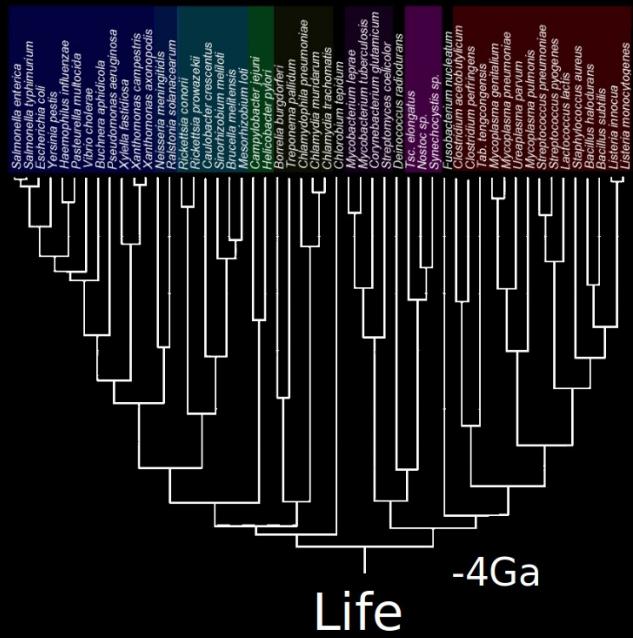
Space



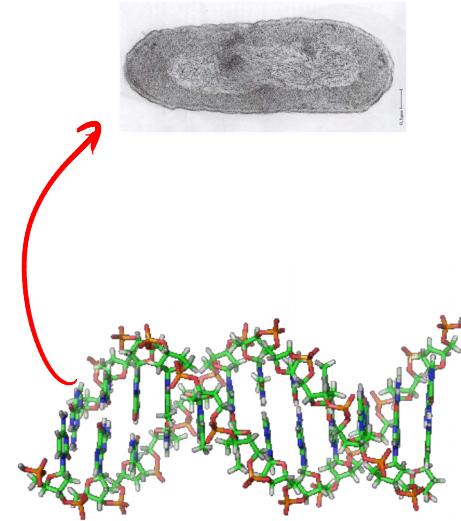
Matter

-14Ga

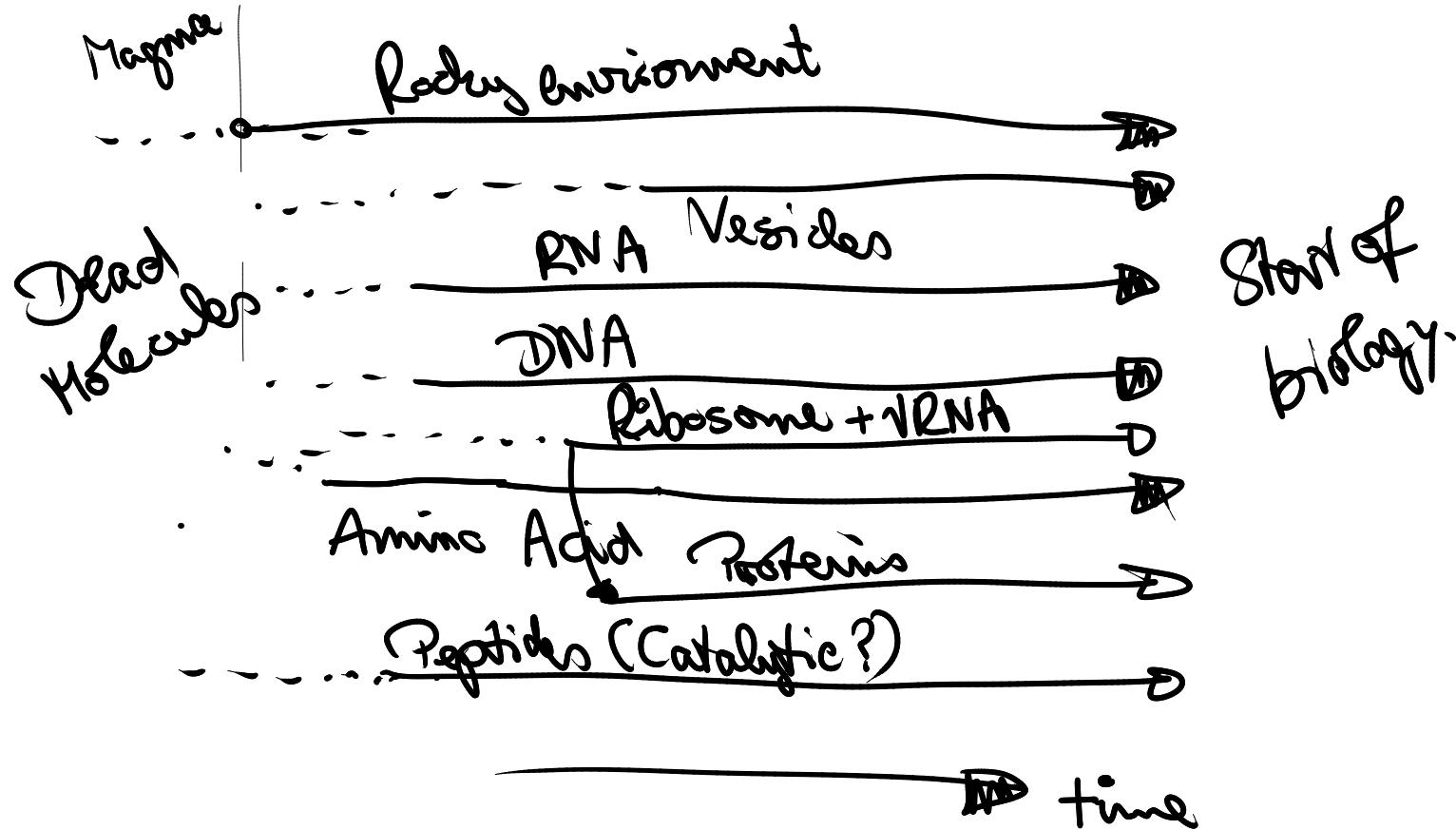
Sequence Space



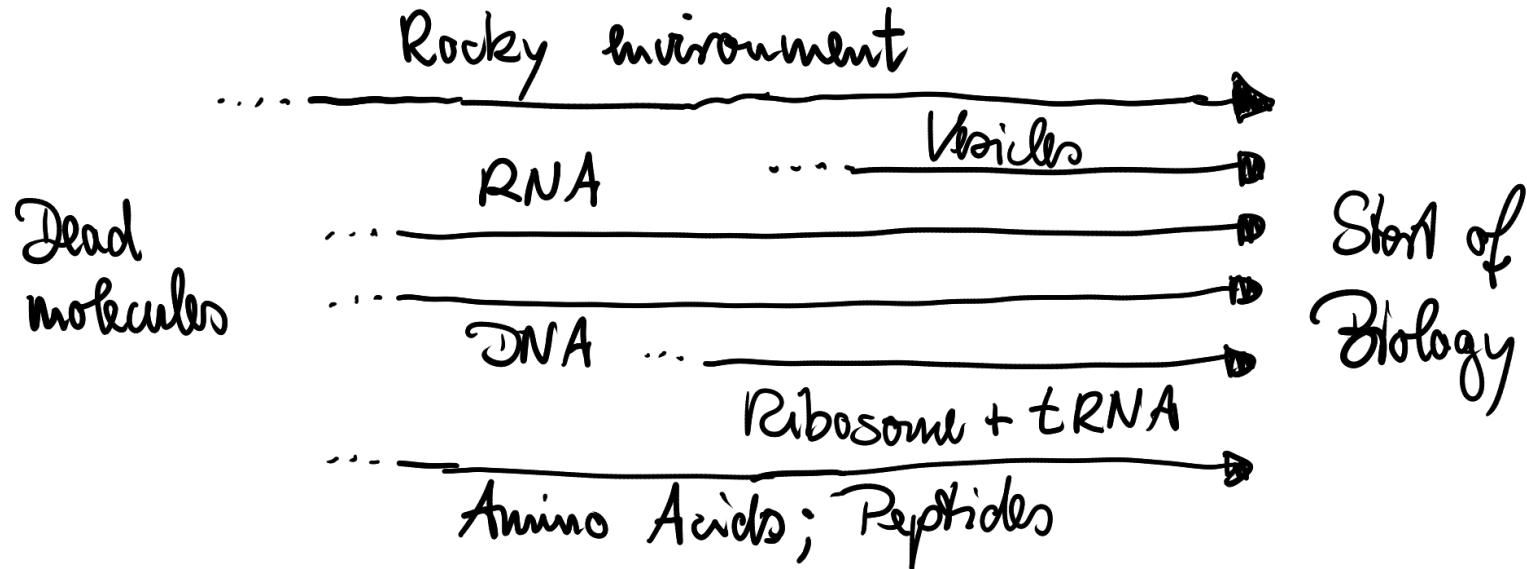
Life



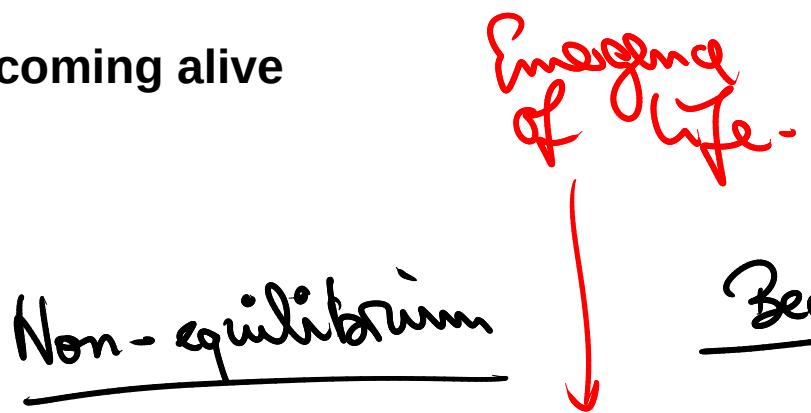
# History of Biology



# History of Biology



## Becoming alive



Non-equilibrium  
Molecular Steady state

Chemistry

Physics

Pre-life metabolism

Early Earth

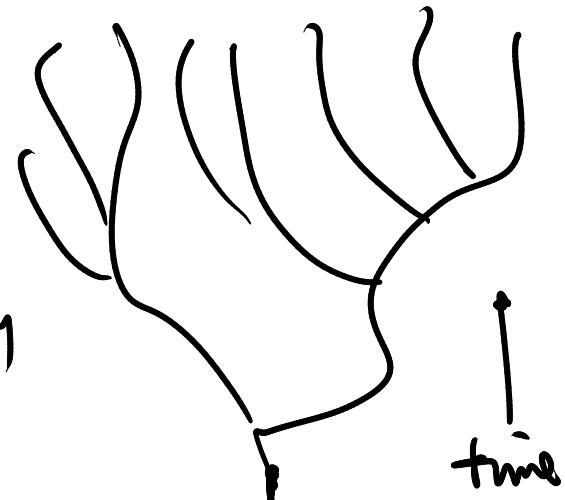
- Long time
- Concentrate Molecules
- Energy rich

## Becoming alive



- Memory of information without length limit for open ended D.E.

## Remaining alive.



Evolution of function

## Becoming alive

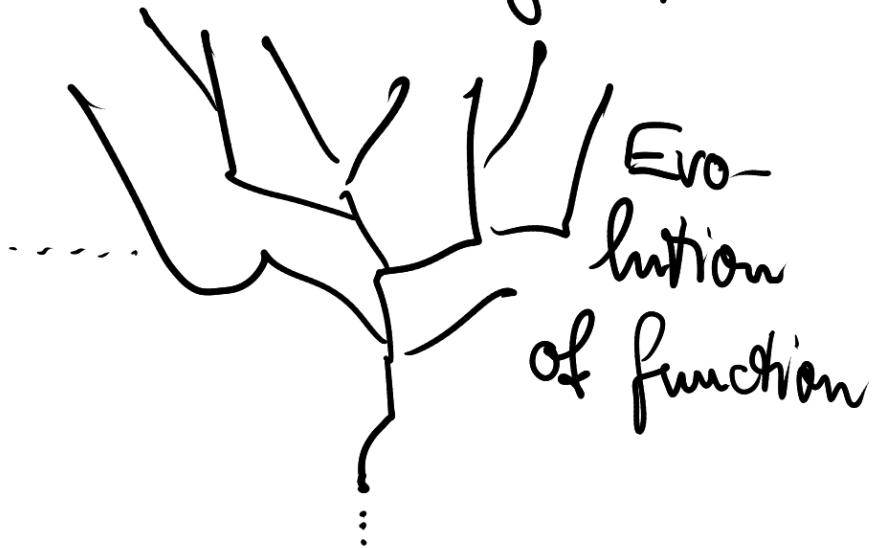
Non-equilibrium



Becoming alive

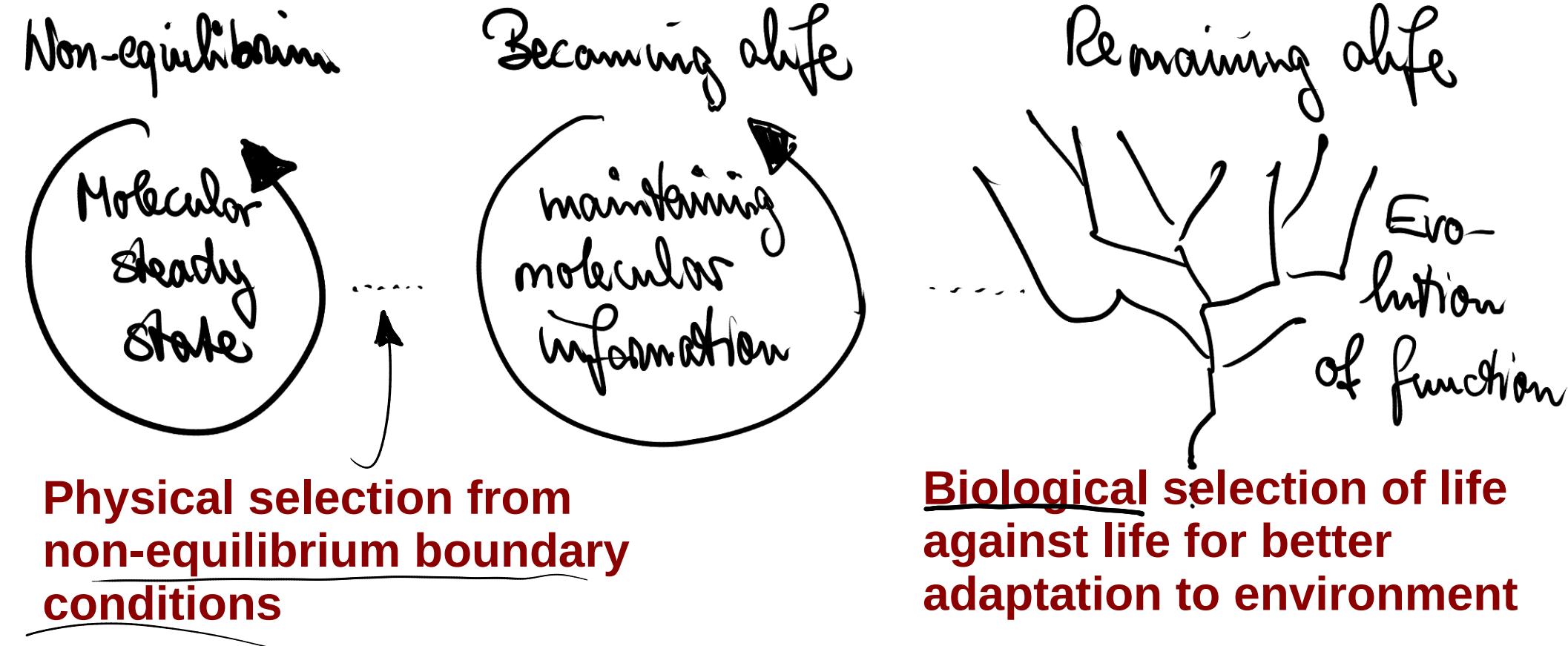


Remaining alive

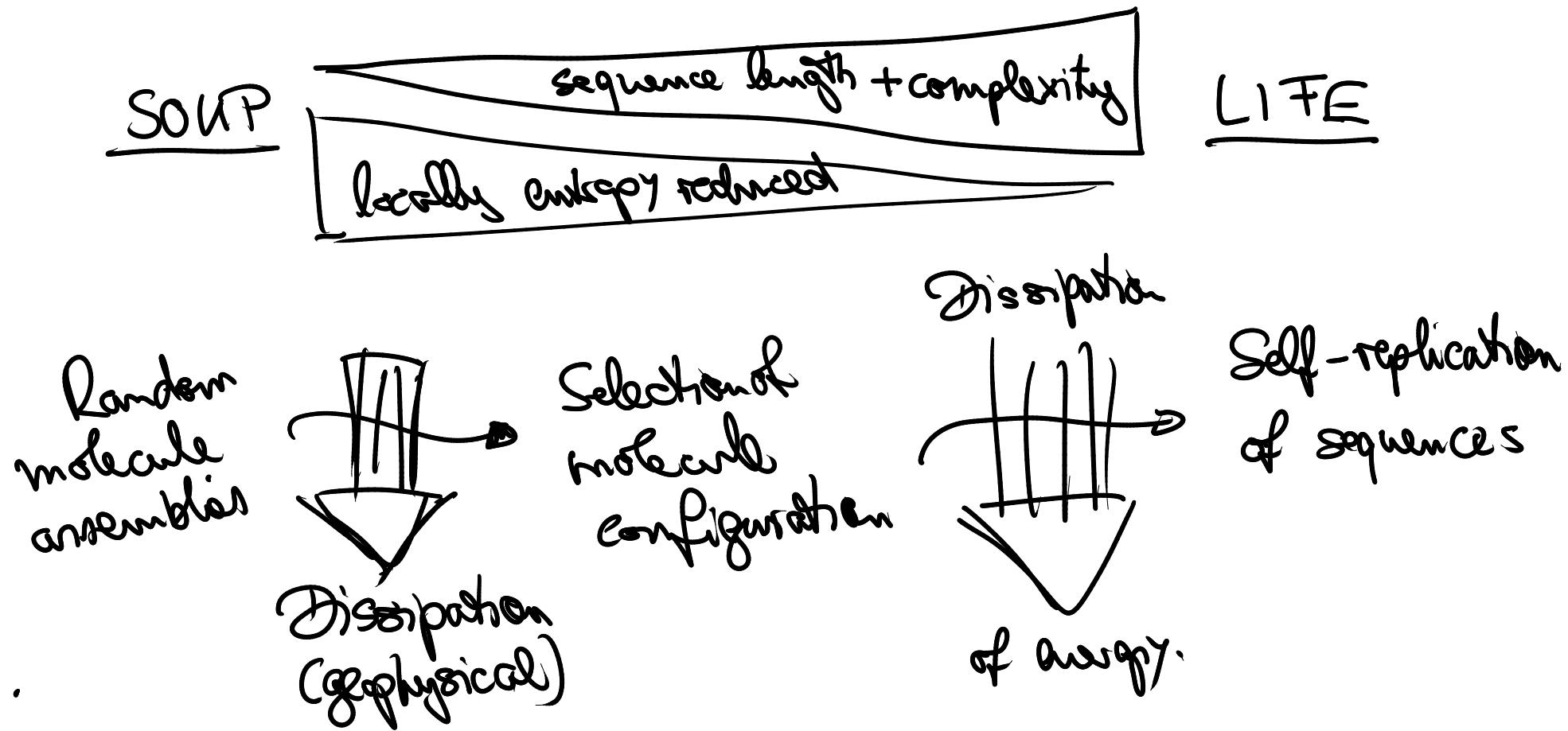


Evo-  
lution  
of function

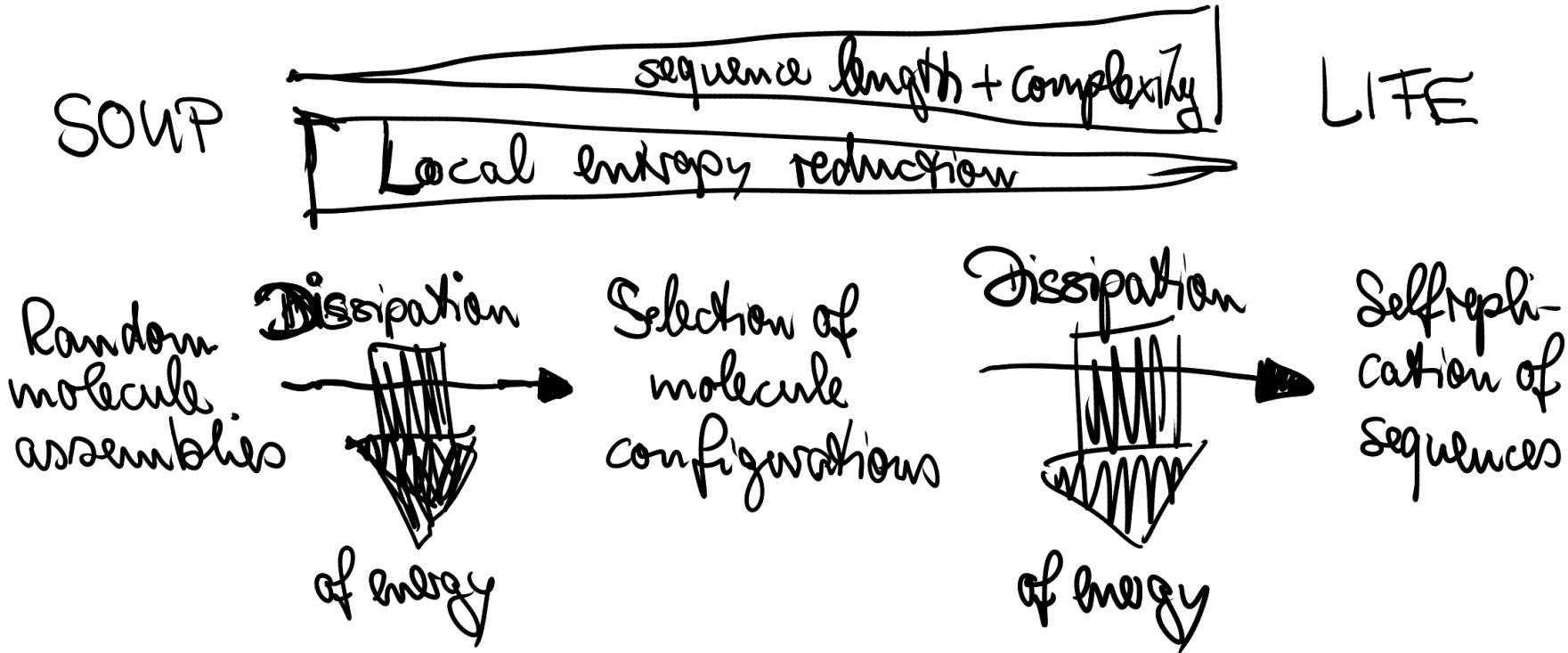
## Selection before and within life



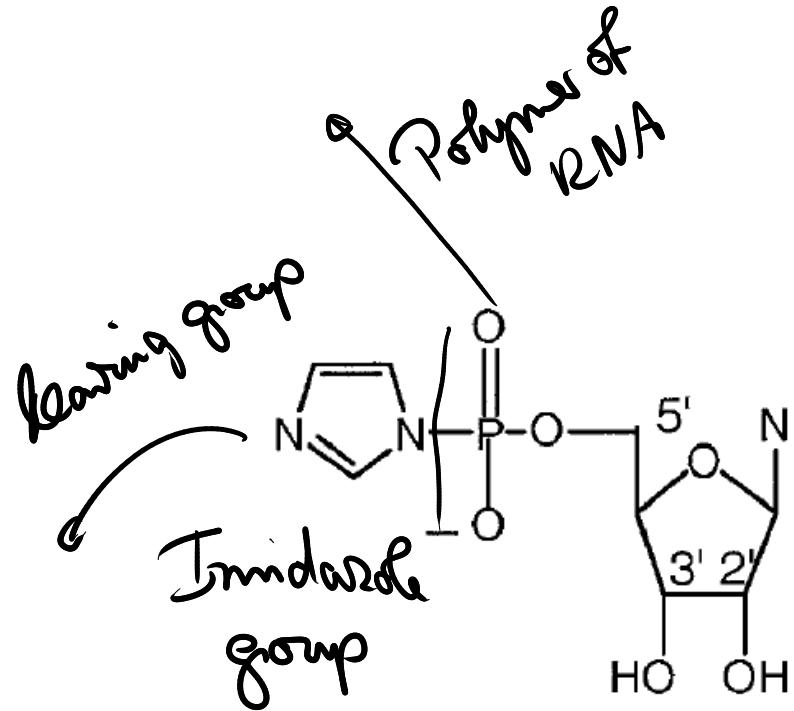
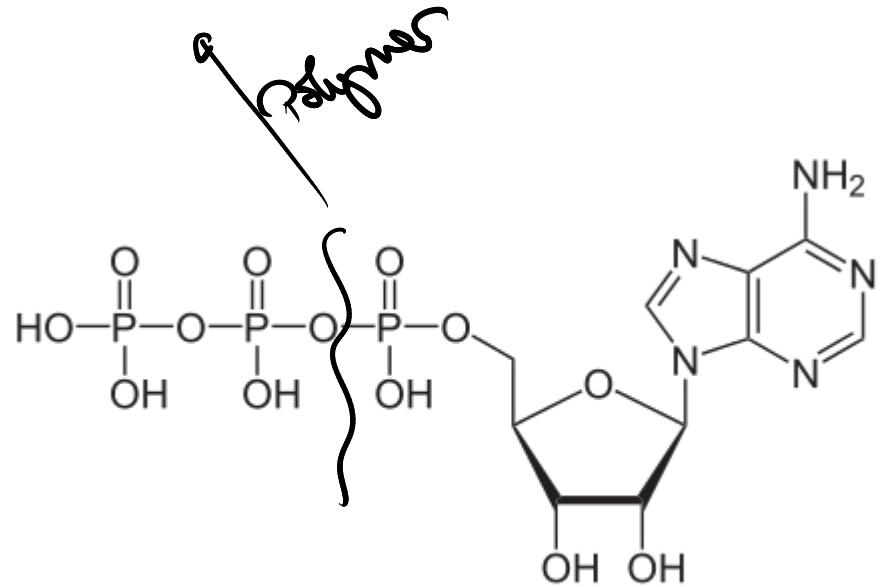
# Soup of life



# Soup of life

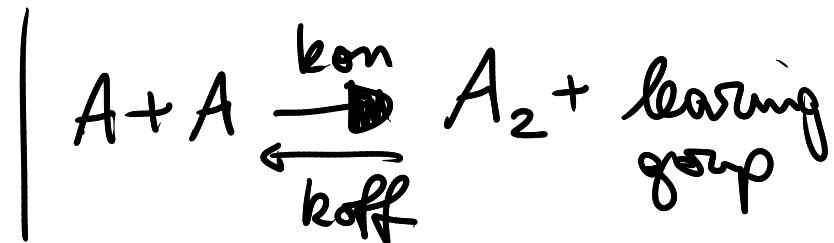


## Three faces of entropy



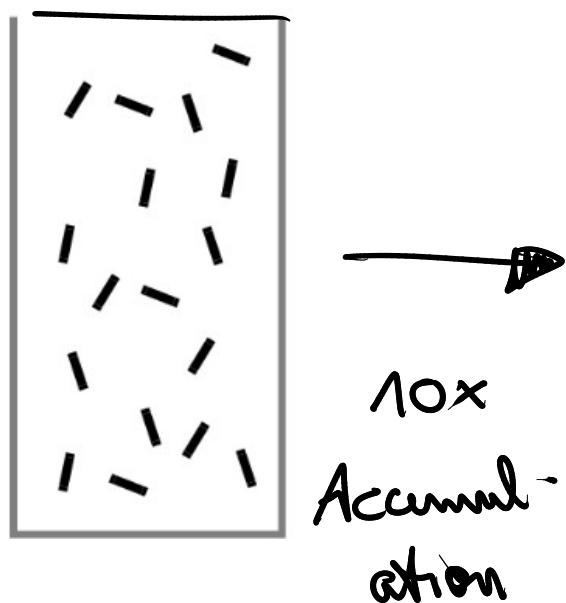
$$\frac{d}{dt} A_2 = +k_{on} \cdot A^2 - k_{off} \cdot A_2$$

$\frac{1}{MM \cdot s}$



Molecular Entropy: ATP vs AMP, activation, nucleophiles, leaving group

## Three faces of entropy

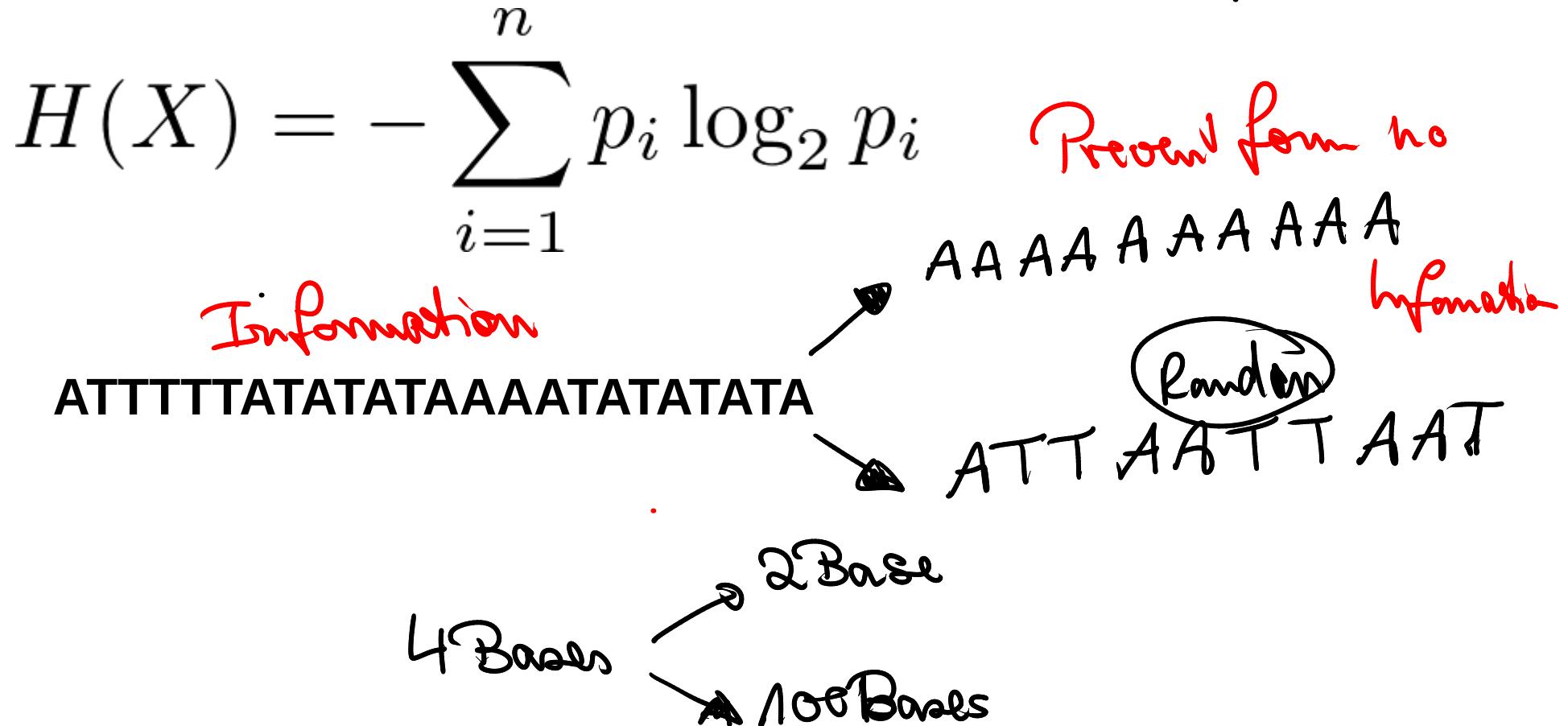


$$P_{\text{Acc.}} = \left( \frac{1}{10} \right)^{10} = 10^{-10} \dots$$

How to get to  
1mM concentration  
on early Earth.

Localization Entropy: chances to find molecules, probability of reaction, leaving group

## Three faces of entropy

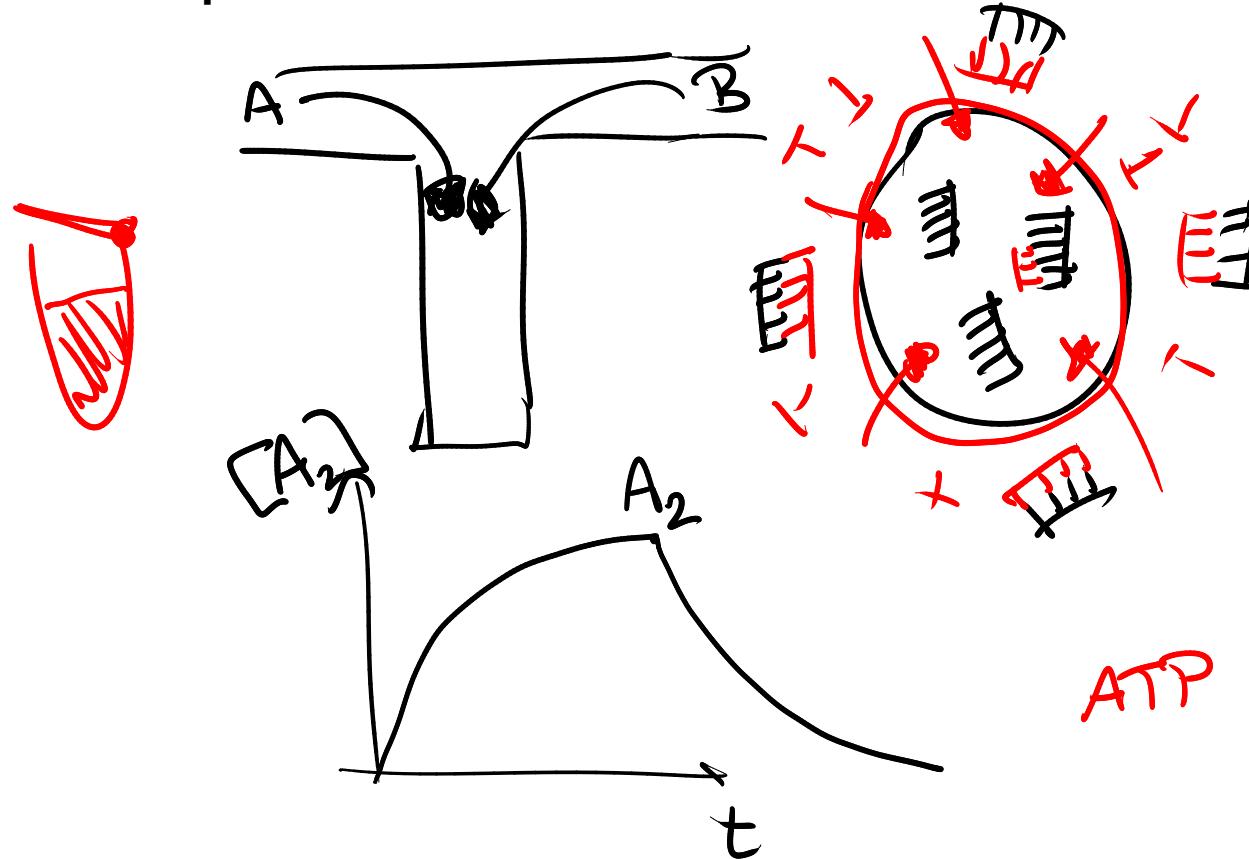


Sequence Entropy: information stored in DNA or RNA to be replicated

## Death of equilibrium

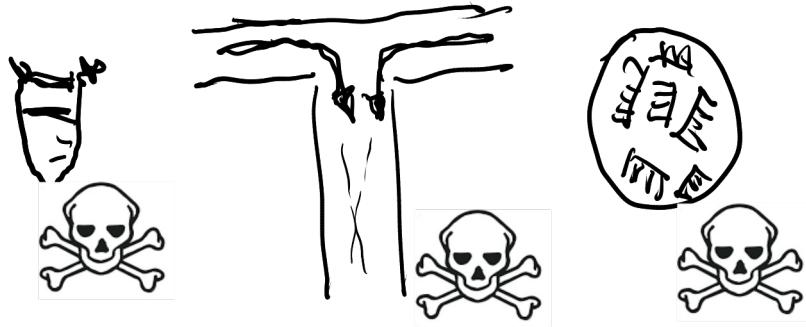


## Death of equilibrium

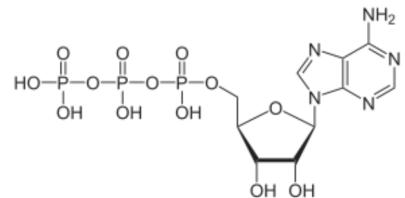


## Death of equilibrium

Equilibria are dead



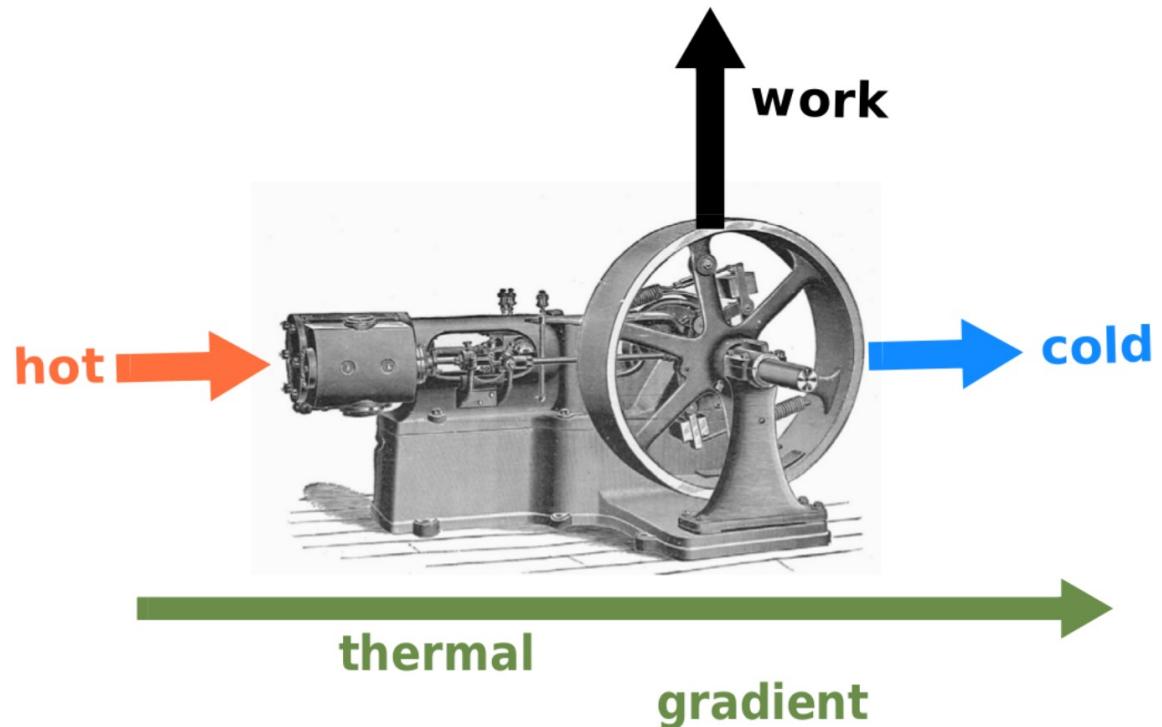
Assumed nonequilibrium



## Modes of non-equilibrium

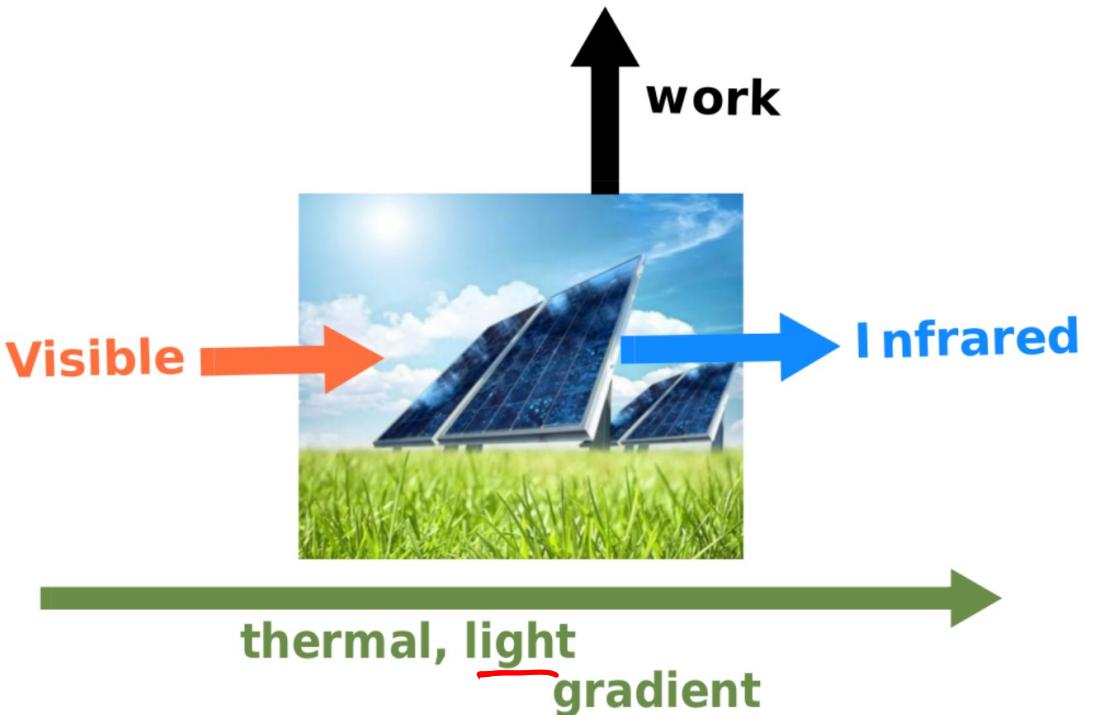
## Modes of non-equilibrium

Far from Equilibrium



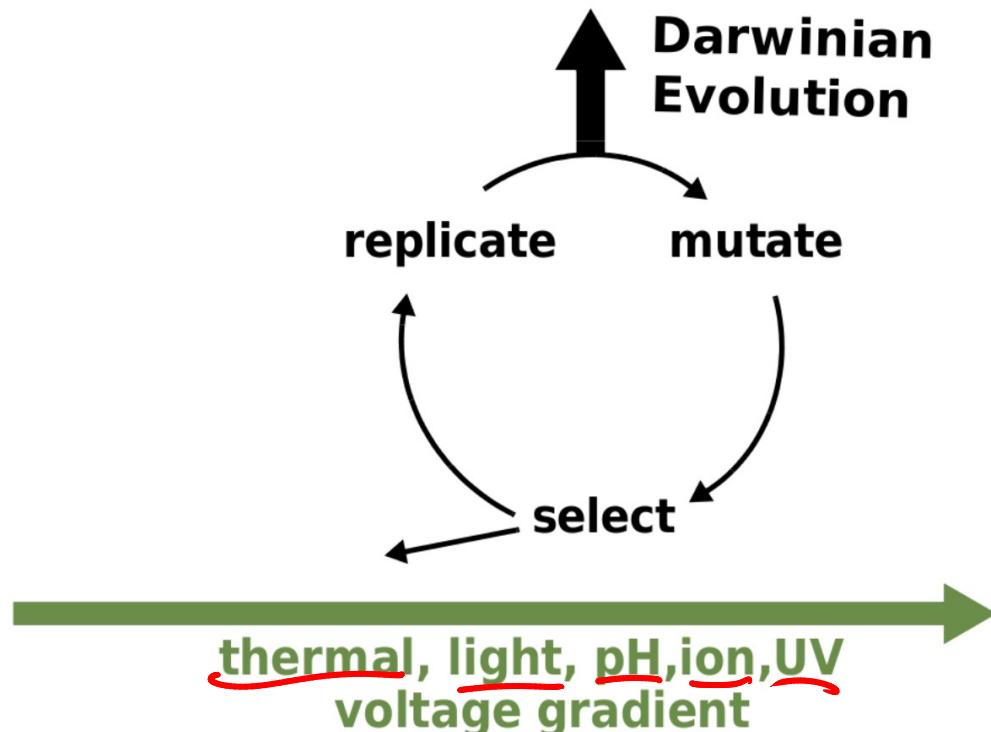
## Modes of non-equilibrium

Far from Equilibrium

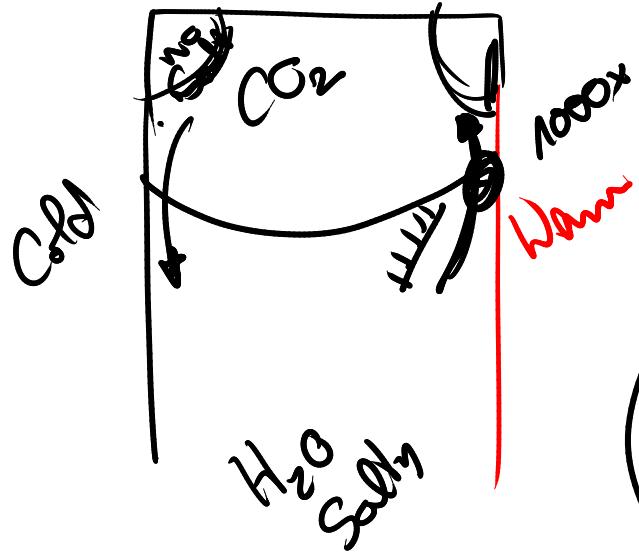


## Modes of non-equilibrium

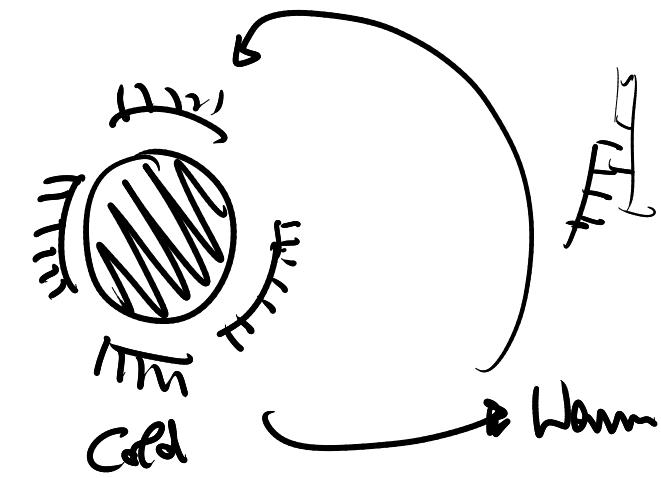
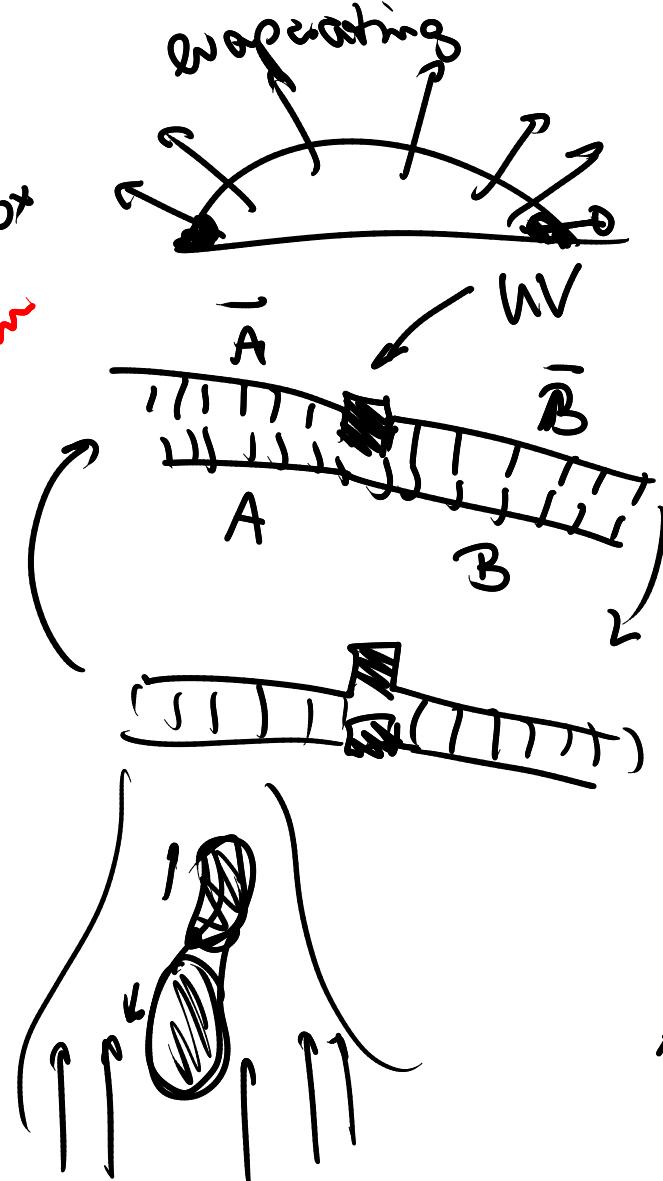
Far from Equilibrium



## Modes of non-equilibrium



*Phase separation*



$$\dot{m} = k_{\text{on}} \cdot c \cdot \frac{1}{4^{12}}$$

~~$\dot{m} = k_{\text{on}} \cdot c \cdot \frac{1}{4^c}$~~

$$\dot{m} = k_{\text{on}} \cdot c \cdot \frac{1}{4^c}$$

## Modes of non-equilibrium

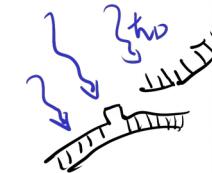
# Modes of non-equilibrium

Non-equilibrium physics  
for the emergence of life

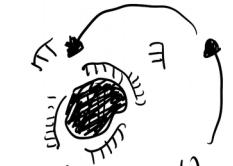
?



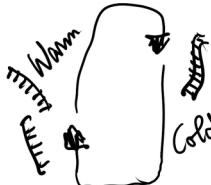
Accumulation by evaporation



Sequence selection  
and diversification  
with UV



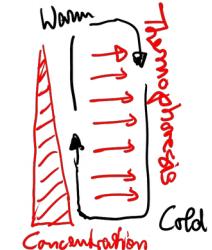
Selective adsorption  
and desorption



Laminar convection



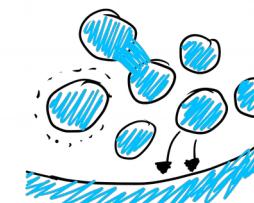
Cyclic changes in  
Temperature, Salt, pH



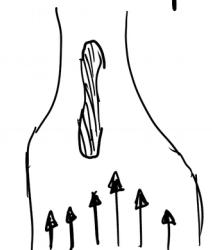
Thermophoretic  
molecule traps



Selection and  
catalysis by  
phase transitions



Fusion and Condensa-  
tion of droplets driven  
by Surface tension



Separation of  
molecule assem-  
blies by shear flow

# Structure of Origin of Life

Nucleotides (possibly stored) <sup>Taq. P.</sup>

Polymerase

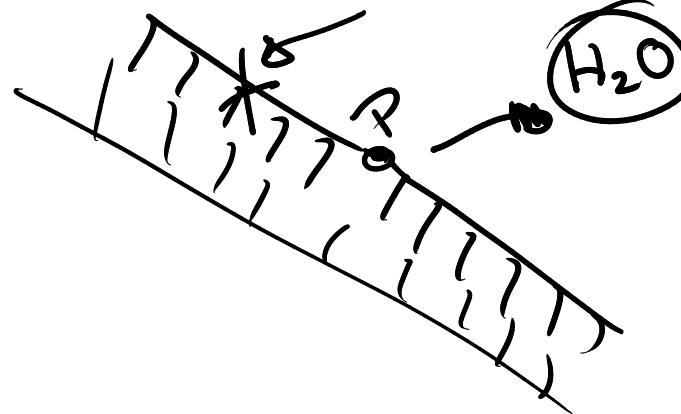
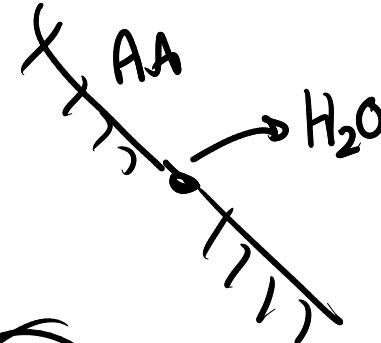
Chemical conditions:

- Polymerization

- Ligation

- Activation

- Nucleotides



Physical non-equilibrium:

- Strand separation

- Maintaining accumulation

- Feeding and

- Waste removal

Some upcoming molecular machines

# Structure of Origin of Life

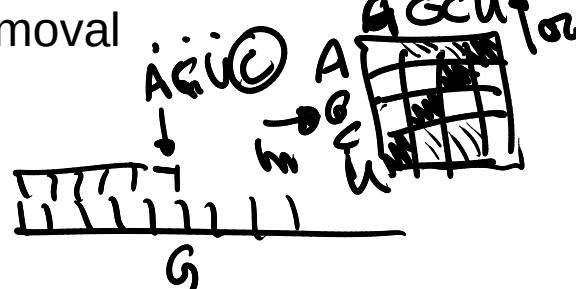
Nucleotides (possibly stored)

Chemical conditions:

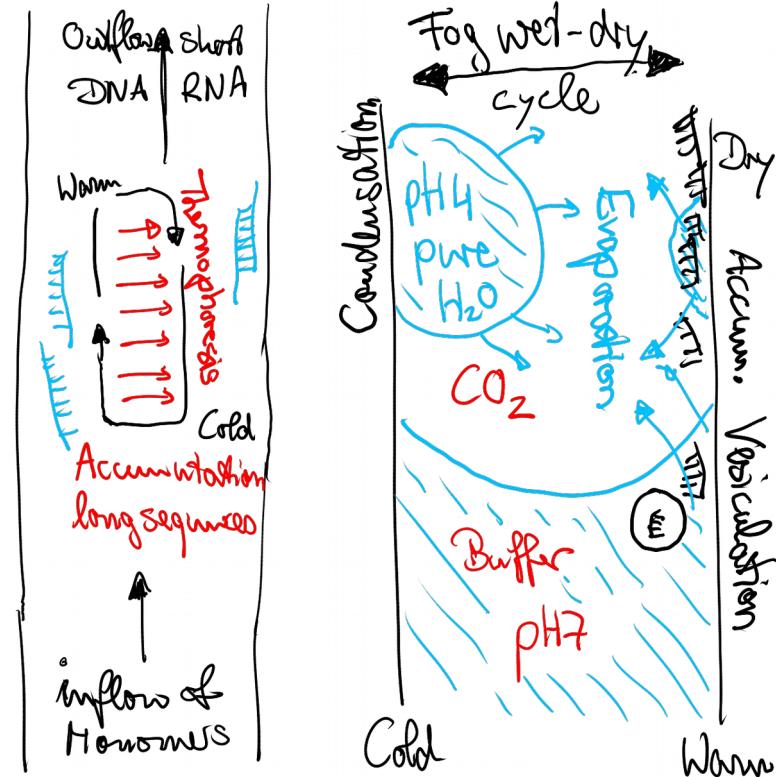
- Polymerization
- Ligation
- Activation

Physical non-equilibrium:

- Strand separation
- Maintaining accumulation
- Feeding and Waste removal



Chemical nonequilibrium in physical nonequilibrium



Some upcoming molecular machines