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1. The Emergence of Life

2. Entropy of an Organism and Natural Selection

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PART 1

Emergence of Life

• E.Smith and H.J.Morowitz: Energy flow and the organisation of life
• E.Smith: Thermodynamics of natural selection I
• E.Schrödinger: What is life? Mind and Matter
The Biosphere
The Biosphere

• Self organized system:
  – State with less entropy is statistically favored and remains under perturbation
  ➔ Implies that:
    - Life rejects entropy

➔ Possible Definition:
  - Life is everything which is not in thermodynamic equilibrium with its environment
Probability distributions for the emergence of the biosphere
Inevitable Life?

Life => Free Energy!

Free Energy => Life?
Inevitable Life?

- Source of Free energy on earth:
  1. Light
     - Energy can scatter into space
  2. Fission
     - High activity in earth core
     - A high amount of ionized matter is produced = reductive potential
     - Reductive potential is kept on earth and can not be equilibrated
Inevitable Life?

- A process reducing the reductive potential is kept working.
- Processes creating channels with higher order for higher efficiency are favored
- Life is such a process
Inevitable Life?

- Hints for the theory:
  - Split biosphere into autotrophical ecosystems
  - Universal core of 500 small organic molecules [hypothesized to be the beginning of life]
  - Reductive chemo-autotrophs formed the first living system
Inevitable Life?

Bettelheim 6/e
Fig 26.8
Inevitable Life?

• Entropy paradox:
  – Equilibrium entropy higher for a non-living system
  – „Living Earth“ is a driven system
  – Life-channel: higher order parameter => phase transition
    → Biosphere can be considered as an alloy of biotic and abiotic part, were the abiotic part serves as transport phenomenon
Inevitable Life?

- Link between Darwin and Thermodynamics:
  - Cell physiology with a statistical path of least resistance is considered to be the fittest
Summary Part 1

- **Definitions of life:**
  - Life is a transport phenomenon
    - Inevitable?
  - Life rejects entropy
    - Biosphere is a self-organized system
PART 2
Entropy approach to natural selection

• H.J. Morowitz: Some order-disorder considerations in living systems
• E. Smith: Thermodynamics of natural selection I
Entropy of a cell

- \( N = \# \text{ structural states} \)
- Living cell corresponds to \( L \) of \( N \) possible states
- Probability for Life: \( p = \frac{L}{N} \)
- \( L << N \rightarrow p \approx \frac{1}{N} \)
Entropy of a cell

- Definitions for Entropy:

\[ \Delta S = k \log L - k \log N \]

\[ I = \log_2 N - \log_2 L \]

- With: \( L << N \)

- Therefore: \( I = \log_2 N \)
Entropy of a cell

Experimental Data:

- Some cells withstand 95% drying

- Some cells withstand cooling down to 1.3K

→ no information, that is required to be alive, in water or motion of molecules
Entropy of a cell

- \( N_A = \# \text{ Atoms} \)

- \( n_i : \text{atoms of ith type:} \)

\[
N_A = \sum n_i
\]

- \( N_1 \text{ possibilities to put } N_A \text{ Atoms in } N_A \text{ boxes:} \)

\[
N_1 = \frac{N_A}{\prod n_i!}
\]
Entropy of a cell

- # bonding states = B
  - \( B_i \) ways for an atom to distribute its bonds:
    \[
    B < \prod_i B_i^{n_i}
    \]

- Total Entropy:
  \[
  I = \log N < \log N_1 + \log B
  \]
  \[
  \text{Stirling} \quad \approx N_A \log N_A - \sum n_i \log n_i + \sum n_i \log B_i
  \]

- Assuming 6 Nearest Neighbors:
  - \( B_O = 21 \quad B_H = 6 \quad B_C = 120 \ldots \)

- \( I_{B.\text{Coli}} = 1.2 \times 10^{10} \text{ Bits} \)
Entropy of a cell

• Experiment:
  – Idea: Grow bacteria in water and measure temperature increase:
    \[ \Delta Q = T \Delta S = -T k_B I \log 2 \]

• Result:
  – \( I_{\text{exp}} = 4 \times 10^{10} \) Bits

• Possible Reasons:
  – Real growth process is not reversible
  – Maintenance reduces entropy as well
Entropy in Natural Selection
Increase of Entropy: $\Delta S_1$
→ Decrease of Entropy : -ΔS_2

Natural Selection requires Energy as ΔS_2 > ΔS_1
Summary Part 2

• Entropy of an organism scales with # Atoms
• Entropy gives us various lower bounds for biological processes
PART 3
Growth and Aging

E. Smith: Thermodynamics of natural selection I
Aims of Part 3:

• Deduce links between energy balance, entropy and error correction
Summary

• Definitions of life:
  Life is a transport phenomenon
    → Inevitable ?
  Life rejects entropy
    → Biosphere is a self-organized system

• Entropy of an organism depends mainly on the # atoms.

• Entropy gives lower bounds for energy required for natural selection and growth

• The lifetime is bounded by error appearance and correction
References

• E. Smith: Thermodynamics of natural selection I: Journal of Theoretical Biology
• E. Smith and H. J. Morowitz: Energy flow and the organisation of life: Complexity
• H. J. Morowitz: Some order-disorder considerations in living systems: Bulletin of Mathematical Biophysics
• E. Schrödinger: What is life? Mind and Matter