

Physics and Information: Structures, Symbols, and Self-Organisation



Rainer Feistel

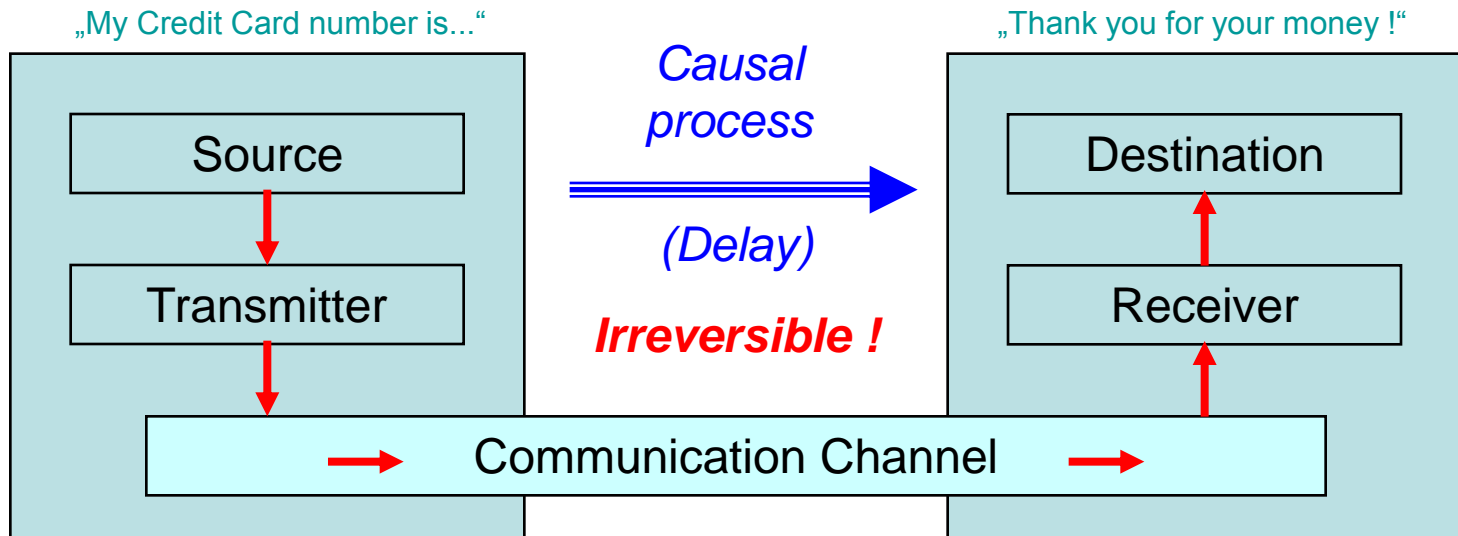
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Shannon's Concept

Information theory **founded in 1948** by Claude E. Shannon:
"A **Mathematical** Theory of Communication",
Bell System Technical Journal, 27 (1948) 379-423, 623-656

Information Transfer by Signals




What are the Physical Processes, Laws, Conditions or Limitations?

(Still subject to research)

Communication Channel

- Stores information **temporarily** from transmission till reception by means of a physical structure
- **Spatial** communication distance is physically only little relevant:
There exists always a reference frame in which both happen at the same place
- **Temporal** communication distance is physically very relevant:
Reception is always after transmission in ANY reference frame (causality)
- Physical structures (= storage media) have only **finite life times**

| | |
|-----------|---------------------------------|
| Examples: | Books about 1000 years |
| | Sound waves about 1 second |
| | RAM capacitor matrix about 1 ns |

 Physics of Information is Closely Related to Entropy & Dissipation

Storage Media = Physical Structures

Many alternative patterns must persist over the required life time
under the same boundary conditions

A) Equilibrium (e.g. crystal):

1 Macro-state = W Micro-states (molecular structures)

B) Macro-states near the equilibrium (e.g. CD, print):

Sluggish frozen-in structures

„Critical“ states

C) Macro-states far from equilibrium (e.g. computer, brain):

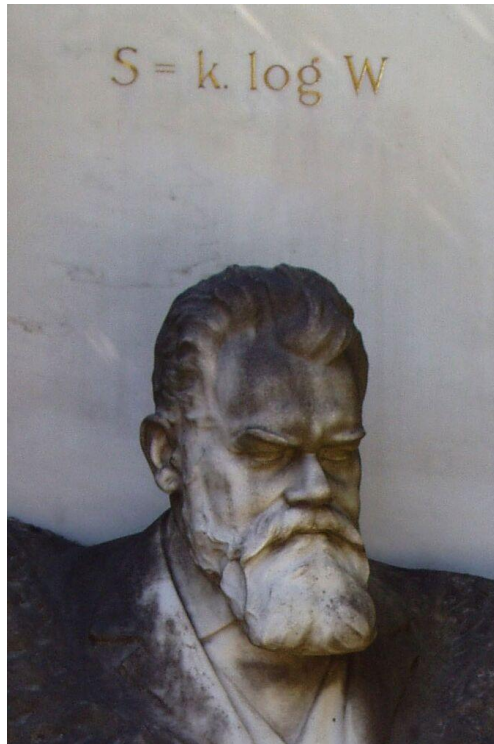
Dissipative Structures

Critical States

Multi-stability

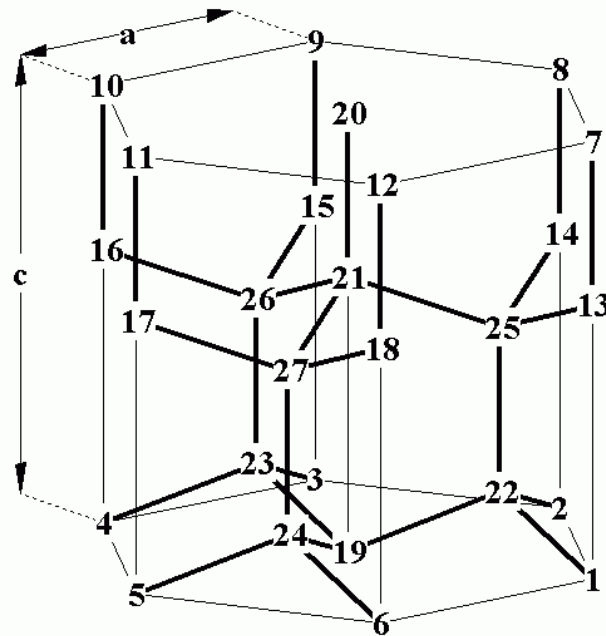
Equilibrium Micro-states

(must persist over the required life time)



Wiener Zentralfriedhof

Hexagonal ice Ih



Degenerate
Ground State

Residual Entropy
(Linus Pauling 1935)

$$S_0 = k \ln W = 189 \frac{\text{J}}{\text{kgK}} \cdot m$$

$$W = 2^{\text{bits}} \Rightarrow \frac{\text{bits}}{m} = 2 \times 10^{25} \frac{\text{bit}}{\text{kg}} \approx 2 \frac{\text{Terabyte}}{\text{Nanogram}}$$

Equilibrium Micro-states

Residual Entropy

- Cannot be measured thermodynamically
- Is NOT equivalent to heat, $dQ = dS/T$
- Is a macroscopic state quantity, not an exchange quantity
- Is related to heat, as relativistic rest mass is related to energy
- Requires Statistical Mechanics, i.e. particles, ensembles...
- **Is the closest link between physics and information**
- Was discovered long before information theory

Macro-states Near the Equilibrium

(must persist over the required life time)

Baltic Sea – layered sediments



This century

LIA

Recent 500 years



Littorina Sea
8000 years

Ancylus Lake
9500 years

Yoldia Sea
10 300 years

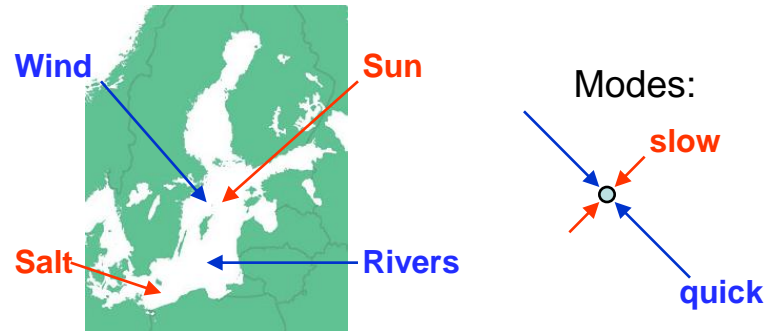
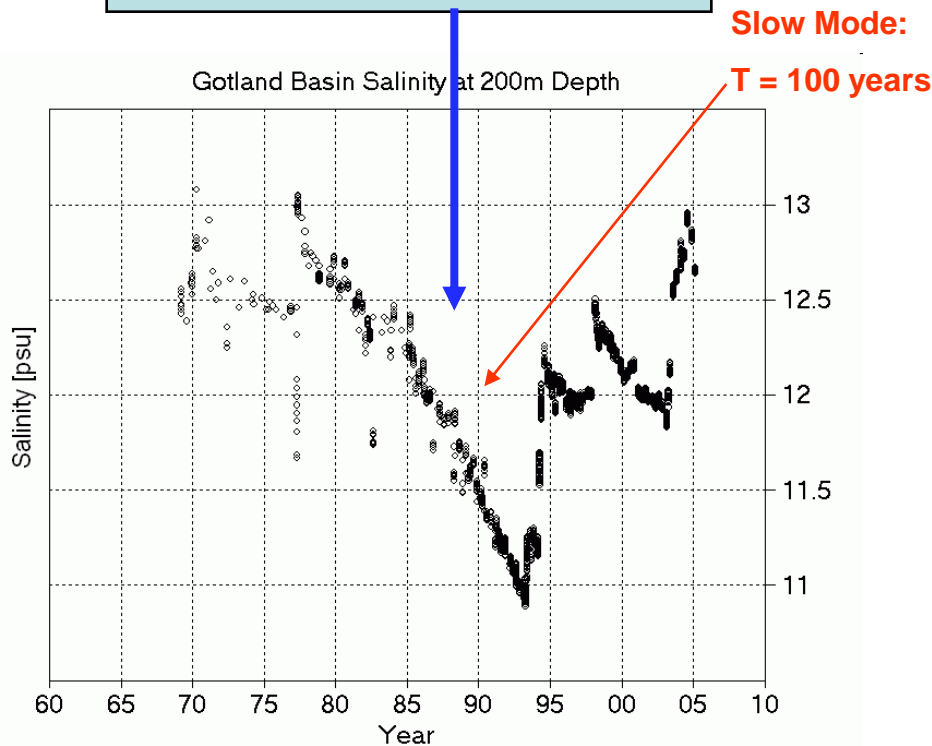
Baltic Ice Lake
14 000 years

Traces of the particular physical history

Macro-states Near the Equilibrium

(must persist over the required life time)

Decay toward equilibrium



Critical „Neutral“ Stability:

Decay Time \gg Observation Period

1. Vertical Exchange: $T = 100$ years
2. Surface Water Residence: $T = 30$ years
3. Deep Water Residence: $T = 20$ years

Entropy production =
Destruction of information

\Rightarrow **Fluctuations Persist for Decades**

\Rightarrow **Information on Climate is „encoded“**

Macro-states Near the Equilibrium

(must persist over the required life time)

Text printed on paper (1982):



Physical pattern: **Traces of the general cultural history**



Phoenician
pictography:
Aleph = Ox



Phoenician phonetic
language:
Aleph = Ox



Roman
Capitalis:
Alpha



Reality / Picture



Symbolic
Picture



Symbol



**Evolution of
Symbolic
Languages**

Information Stored in Physical Structures



Native, bound, analog

- Meaning is inherent to the carrier
- Cannot be copied loss-free
- Does slowly degrade
- „Encoded“ by natural laws
- Different structure = other meaning
- Obeys physical laws

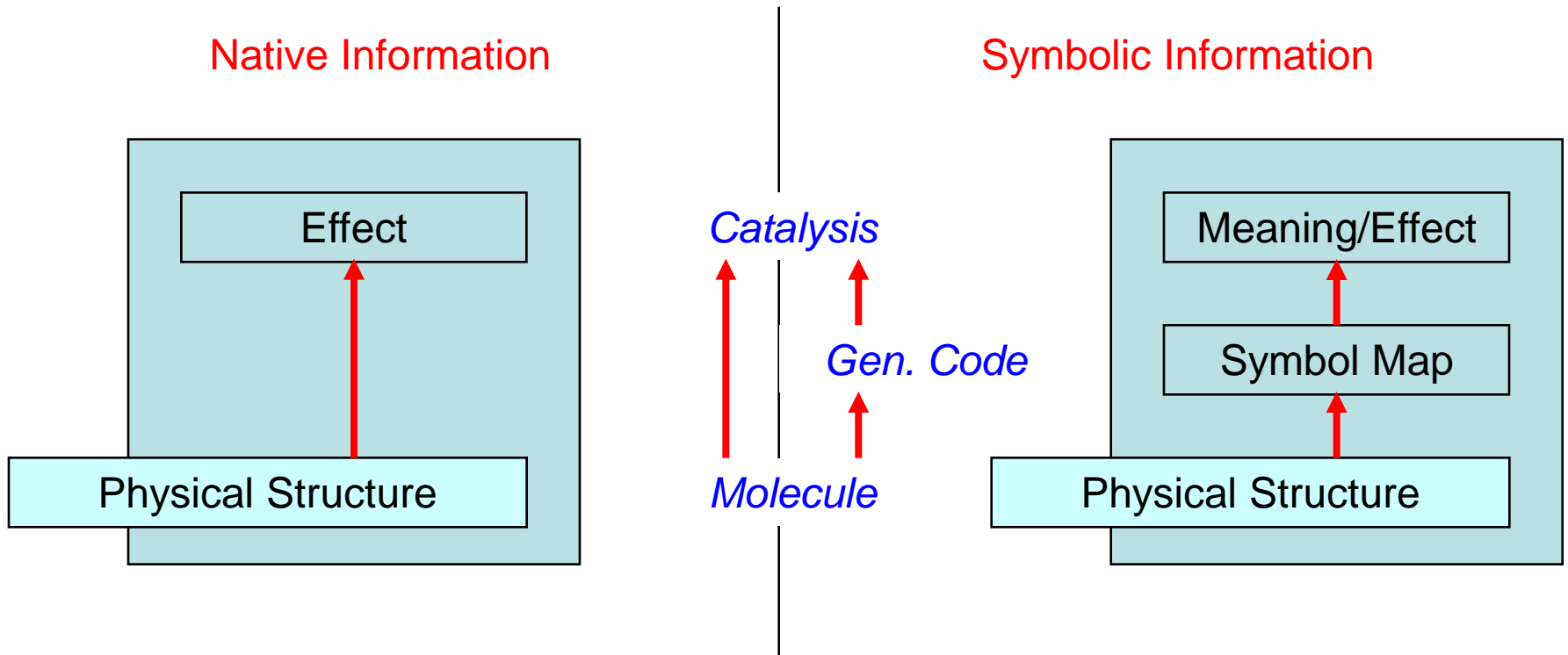
Physik der Selbstorganisation und Evolution

Von Werner Ebeling und Rainer Feistel

Symbolic, free, digital

- Meaning is independent of the carrier
- Can be copied loss-free
- Does not degrade („quanta“)
- Encoded by „conjugate“ „ciphers“
- Possesses a new symmetry:
„Code invariance“
- Obeys „higher“, „emergent“ laws

Emergence of Symbolic Information



Kinetic Phase Transition II Kind

Symmetry Change:

Appearance of a Neutral Mode, „Code“

Ritualisation: Emergence of Symbolic Information

Sir Julian Huxley, 1914:

I mean the gradual **change of a useful action into a symbol** and then into a ritual; or in other words, the change by which the same act which first subserved a definite purpose directly comes later to subserve it only indirectly (symbolically) and then not at all.

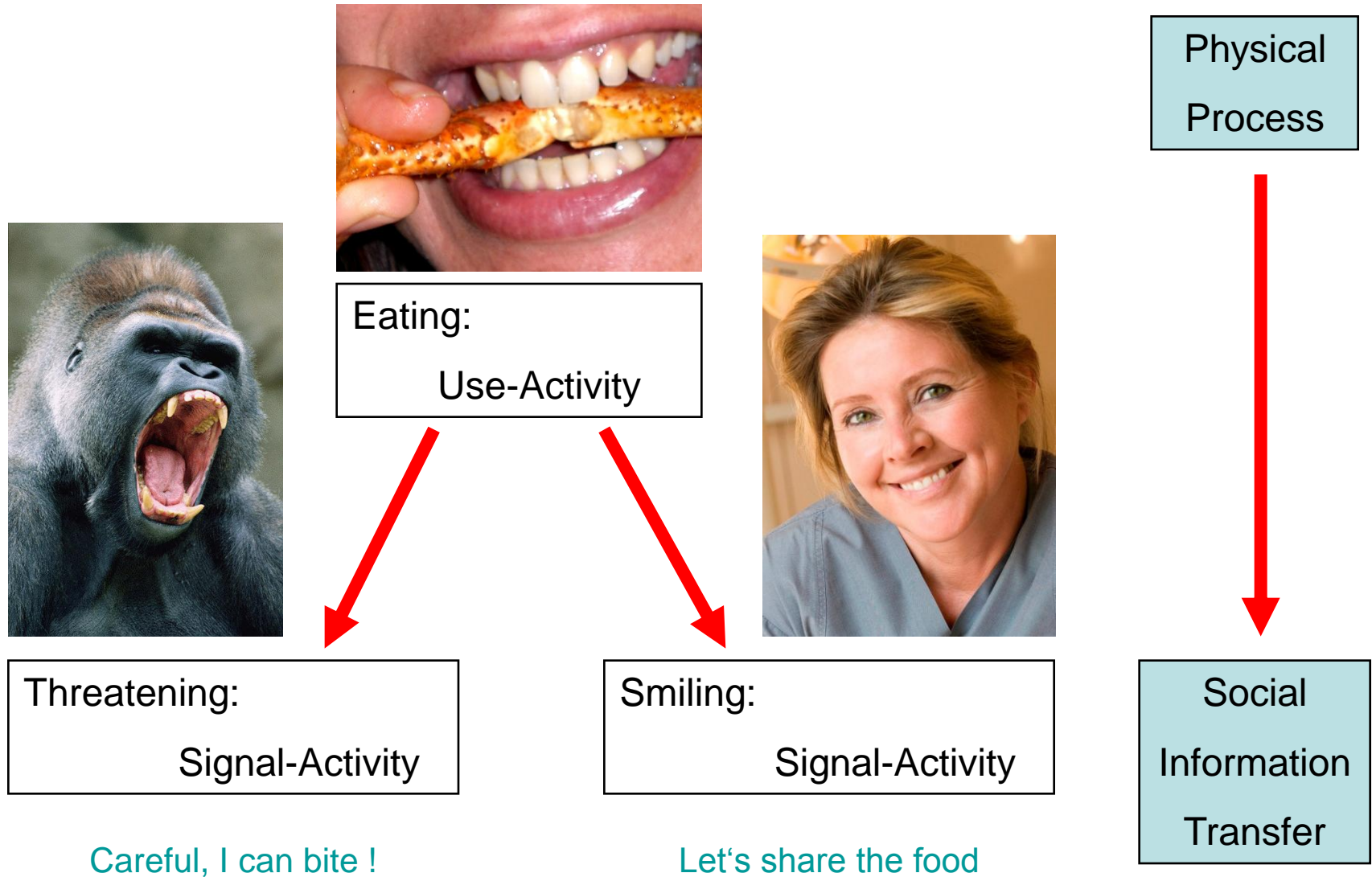
Konrad Lorenz, 1963:

... die anderen objektiven und subjektiven Zwecken dienende **Handlungskette** **wird** zum Selbstzweck, sowie sie **zum autonomen Ritual** geworden ist.

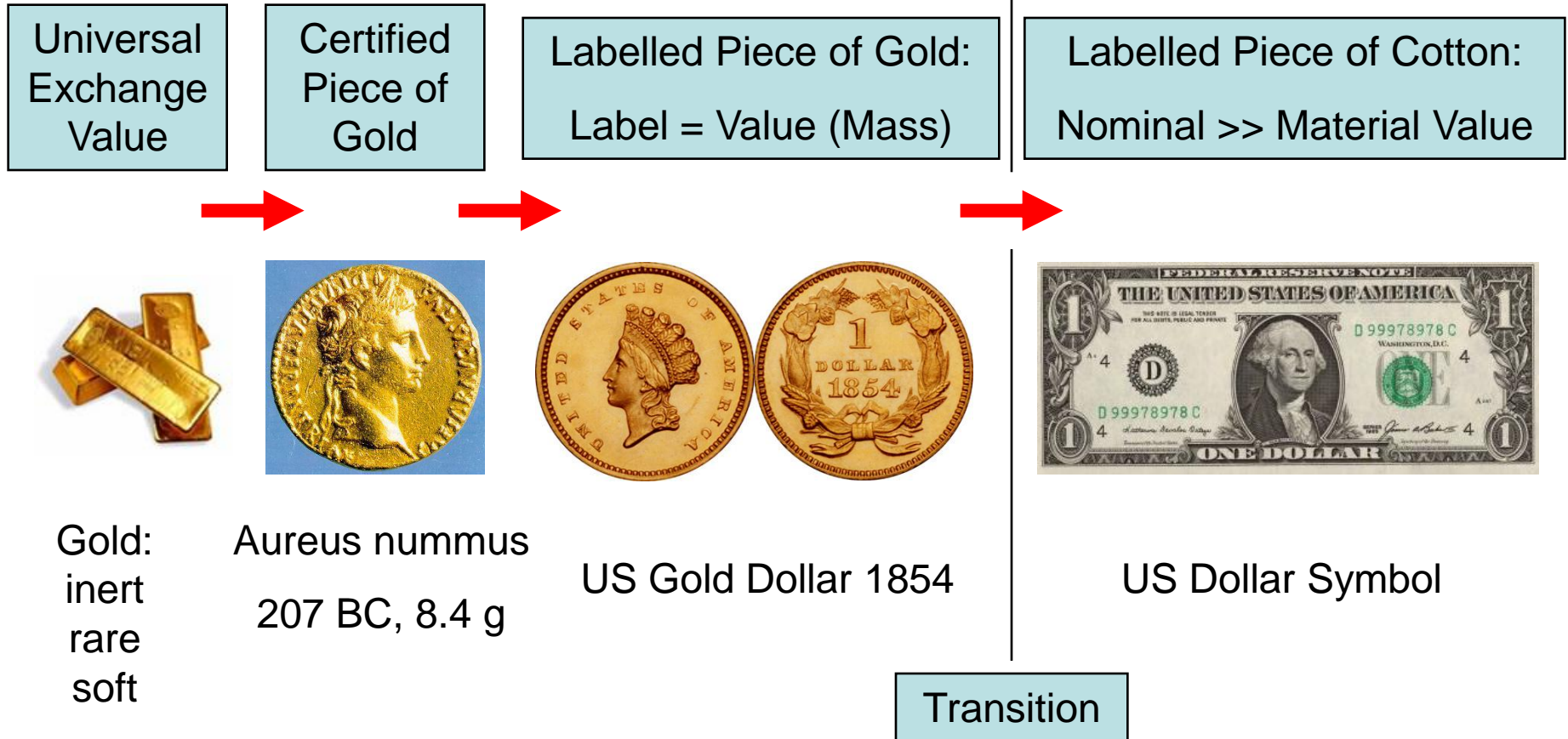
Günter Tembrock, 1976:

Stammesgeschichtlich leiten sich Signalsysteme von Gebrauchssystemen ab. Die Ethologie bezeichnet mit Huxley die **Entstehung von Signalhandlungen als Ritualisation**.

Ritualisation Example: Showing Teeth



Ritualisation Example: Society / Economy



It costs about four cents to produce a one-dollar bill -- a pittance, compared to the greenback's influence on the world's economy.

Physical Properties of Symbolic Information:

- Loss / Weakness of physical restoring forces
(Neutral or critical mode)
- New symmetry: Coding invariance
- Surge of fluctuations at the transition point
- Dualism of digital symbol and its analog carrier structure
- Historicity of the emergent structures
- Symbol structures keep information about their own evolution history

Analogy to Kinetic Phase Transition of II. Kind

Ritualisation: Historicity

Symbol structure is always an analog information carrier:

Traces of its evolution history in native form



Joachimsthaler
Guldengroschen,
coined in Sankt
Joachimsthal
(Bohemia) 1520



Thaler
Brunsvices et
Luneburg, 1799

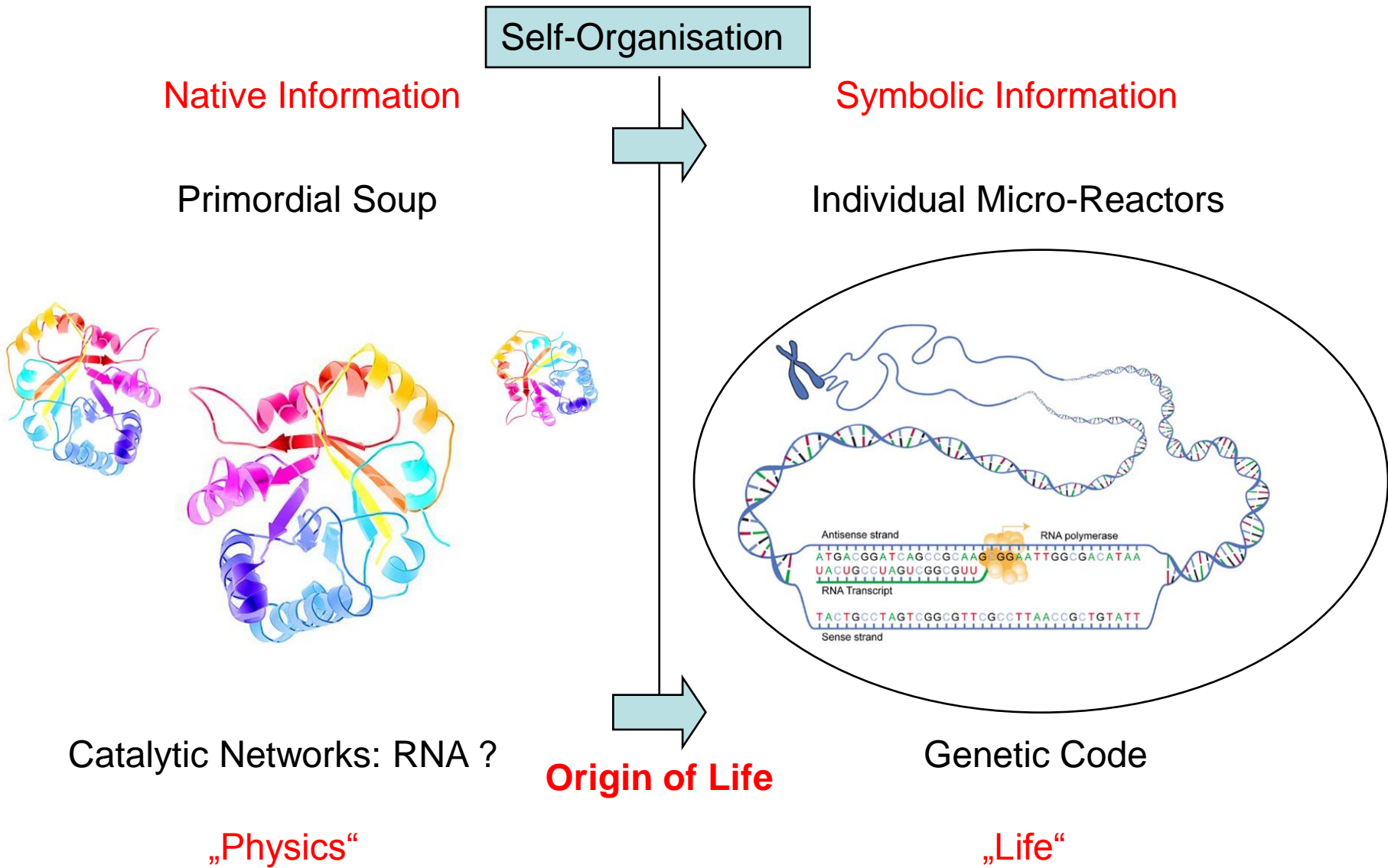


„Dollar“

„Aleph“

Arbitrary Dye Pattern
Sluggish Dissipation
Currency Changeover
Inflation etc

Very First Emergence of Symbolic Information



Macro-states far from Equilibrium: Life

Standard Codon Table

2. Base

| | | 2. Base | | | | | | |
|---|-----|---------------|-----|-----------|-----|---------------|-----|------------|
| | | U | C | A | G | | | |
| U | UUU | Phenylalanine | UCU | Serine | UAU | Tyrosine | UGU | Cysteine |
| | UUC | Phenylalanine | UCC | Serine | UAC | Tyrosine | UGC | Cysteine |
| | UUA | Leucine | UCA | Serine | UAA | Stop | UGA | Stop |
| | UUG | Leucine | UCG | Serine | UAG | Stop | UGG | Tryptophan |
| C | CUU | Leucine | CCU | Proline | CAU | Histidine | CGU | Arginine |
| | CUC | Leucine | CCC | Proline | CAC | Histidine | CGC | Arginine |
| | CUA | Leucine | CCA | Proline | CAA | Glutamine | CGA | Arginine |
| | CUG | Leucine | CCG | Proline | CAG | Glutamine | CGG | Arginine |
| A | AUU | Isoleucine | ACU | Threonine | AAU | Asparagine | AGU | Serine |
| | AUC | Isoleucine | ACC | Threonine | AAC | Asparagine | AGC | Serine |
| | AUA | Isoleucine | ACA | Threonine | AAA | Lysine | AGA | Arginine |
| | AUG | Methionine | ACG | Threonine | AAG | Lysine | AGG | Arginine |
| G | GUU | Valine | GCU | Alanine | GAU | Asparagic ac. | GGU | Glycine |
| | GUC | Valine | GCC | Alanine | GAC | Asparagic ac. | GGC | Glycine |
| | GUA | Valine | GCA | Alanine | GAA | Glutamic ac. | GGA | Glycine |
| | GUG | Valine | GCG | Alanine | GAG | Glutamic ac. | GGG | Glycine |

1. Base

Symbol

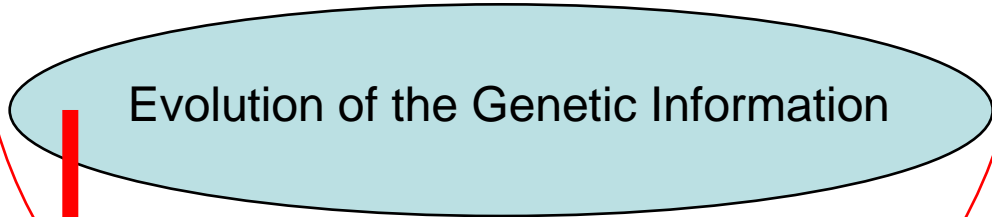
Code map

Meaning

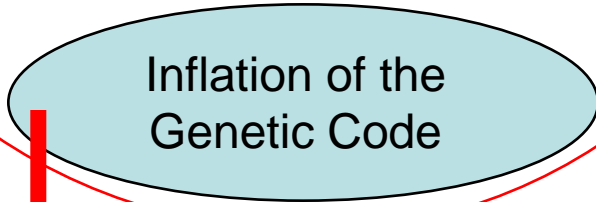
Genetic Code:

Traces of the chemical history during Ritualisation

Biological Models



Sequence Analysis



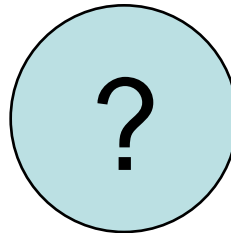
Emergent Laws

Fluctuation Phase

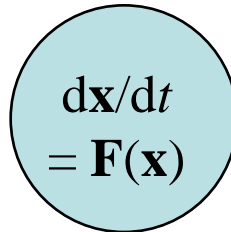
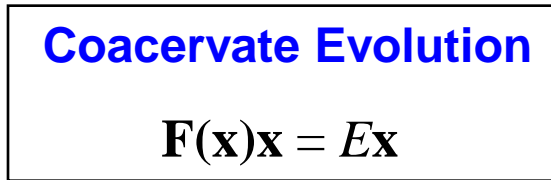
„Bio Big Bang“

Ritualisation Transition

Historicity

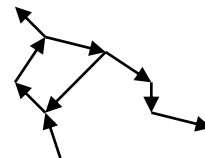
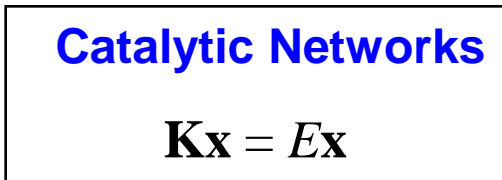


v. Neumann 1966,
Eigen & Winkler 1978,
Ebeling & Feistel 1982



Ratner & Shamin 1980, White 1980,
Feistel et al. 1980, Redko 1986

Physical Models



Perron 1907, Frobenius 1912,
Harary et al. 1965, Eigen 1971,
Eigen & Schuster 1977,
Ebeling & Feistel 1977

How Could the „Molecular Automaton“ Look Like ?

Physical Model with **Minimum Complexity**: John v. Neumann?

| Shannon machine | Physical system | v. Neumann automaton | Molecular automaton |
|------------------------|--------------------------|------------------------------------|----------------------------|
| Carrier (storage) | “Critical” microstate | Linear storing chain L | Polynucleotide matrix |
| Receiver (reader) | Microstate amplifier | Constructing automaton A | Translation enzyme |
| Sender (writer) | Microstate preparator | Copying automaton B | Replication enzyme |
| Instance (exemplar) | Spatial compartment | Controlling automaton C | Splitting during growth |

(adapted from V.G. Redko, 1990)

Symbols: Some Theses

1. Symbols are physical structures with non-physical properties, subject to „higher“ laws in their processing context

2. Symbols are critical physical structures possessing coding symmetry

3. Symbols have a purpose and exist only in the realm of life

4. There is no life known without symbolic information

5. The origin of life was the very first Ritualisation transition

6. Ritualisation is the Self-Organisation process of symbolic information