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

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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

„My Credit Card number is...“

Causal process

(Delay)

Irreversible!

„Thank you for your money!“

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

*(Still subject to research)*
Communication Channel

- Stores information \textit{temporarily} from transmission till reception by means of a physical structure.

- \textbf{Spatial} communication distance is physically only little relevant:
  There exists always a reference frame in which both happen at the same place.

- \textbf{Temporal} communication distance is physically very relevant:
  Reception is always after transmission in ANY reference frame (causality).

- Physical structures (= storage media) have only \textit{finite life times}.

\begin{tabular}{|c|c|}
\hline
Examples: & Books about 1000 years \\
& Sound waves about 1 second \\
& RAM capacitor matrix about 1 ns \\
\hline
\end{tabular}

\textit{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)

Hexagonal ice Ih

Degenerate Ground State

Residual Entropy
(Linus Pauling 1935)

\[ S_0 = k \ln W = 189 \frac{J}{kgK} \cdot m \]

Wiener Zentralfriedhof

\[ W = 2^{\text{bits}} \]

\[ \frac{\text{bits}}{m} = 2 \times 10^{25} \frac{\text{bit}}{\text{kg}} \approx 2 \frac{\text{Terabyte}}{\text{Nanogram}} \]
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

Littorina Sea
8000 years

Ancylus Lake
9500 years

Yoldia Sea
10 300 years

Baltic Ice Lake
14 000 years

Recent 500 years

Traces of the particular physical history
Macro-states Near the Equilibrium

(must persist over the required life time)

Decay toward equilibrium

Gotland Basin Salinity at 200m Depth

Slow Mode: $T = 100$ years

Wind

Sun

Salt

Rivers

Critical „Neutral“ Stability:

Decay Time $>>$ 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

=> Fluctuations Persist for Decades

=> Information on Climate is „encoded“
Macro-states Near the Equilibrium
(must persist over the required life time)

Text printed on paper (1982):

Physik der Selbstorganisation
und Evolution
Von Werner Ebeling und Rainer Feistel

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

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

Native Information

Physical Structure

Effect

Symbolic Information

Physical Structure

Meaning/Effect

Symbol Map

Gen. Code

Catalysis

Molecule

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

Eating: Use-Activity

Threatening: Signal-Activity

Careful, I can bite!

Smiling: Signal-Activity

Let’s share the food

Physical Process

Social Information Transfer

401. Heraeus-Seminar, Physikzentrum Bad Honnef, 21-23 January 2008
Ritualisation Example: Society / Economy

Universal Exchange Value

Certified Piece of Gold

Labelled Piece of Gold: Label = Value (Mass)

Labelled Piece of Cotton: Nominal >> Material Value

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

Gold: inert rare soft

Aureus nummus 207 BC, 8.4 g

US Gold Dollar 1854

Transition

US Dollar Symbol
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
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”**

  - Arbitrary Dye Pattern
  - Sluggish Dissipation
  - Currency Changeover
  - Inflation etc

- **“Aleph”**
Very First Emergence of Symbolic Information

Native Information
Primordial Soup
Catalytic Networks: RNA ?

Self-Organisation

Symbolic Information
Individual Micro-Reactors
Genetic Code

“Physics“

Origin of Life

„Life“
Macro-states far from Equilibrium: Life

Genetic Code:
Traces of the chemical history during Ritualisation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
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<tbody>
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Standard Codon Table

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Ritualisation Transition

"Bio Big Bang"

Molecular Automaton

Coacervate Evolution

Catalytic Networks

Historicity

Evolution of the Genetic Information

Inflation of the Genetic Code

Emergent Laws

Physical Models

Sequence Analysis

Biological Models

\[ F(x)x = Ex \]

\[ \frac{dx}{dt} = F(x) \]

\[ Kx = Ex \]

v. Neumann 1966,
Eigen & Winkler 1978,
Eigen & Schuster 1977,
Ebeling & Feistel 1977

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

Perron 1907, Frobenius 1912,
Harary et al. 1965, Eigen 1971,
Ebeling & Feistel 1977
### How Could the „Molecular Automaton“ Look Like?

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