Neocybernetics
A New Kind of Natural Philosophy

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- Chairman of the Finnish Artificial Intelligence Society (FAIS) 1999 – 2001
- Some 150 scientific publications
- Professor at HUT Control Engineering since Nov. 1, 2001
- Research topic

Complex Systems

Beginning: ”Ancient Greeks ...”

”You cannot step in the same river twice”

”Everything changes, everything remains the same”

Heraclitus

”Wisdom is knowing how all things are steered by all things”

Panta Rhei!

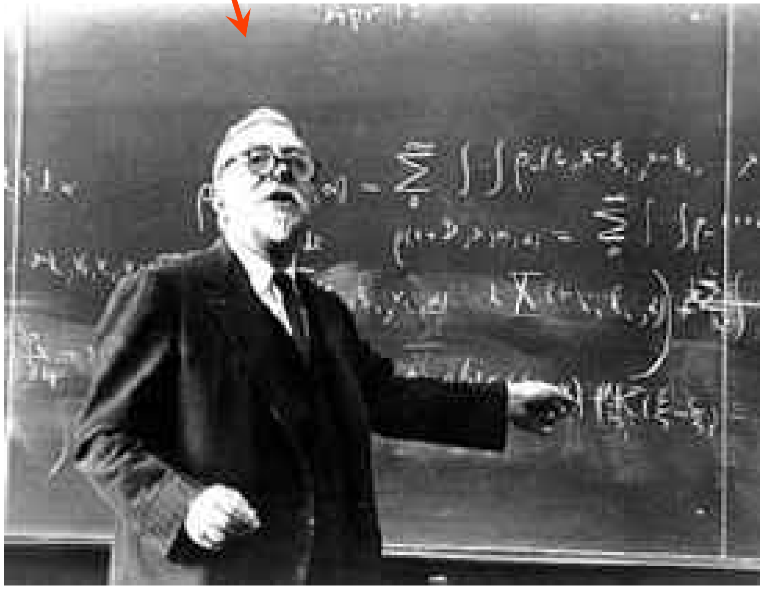
Everything is based on tensions – and the *hidden tensions* are the *most relevant*

- The deepest intuitions concerning complex systems date back to Heraclitus:
  - *Everything changes, everything remains the same*: Cells are replaced in an organ, staff changes in a company – still the function remains
  - *Everything is based on hidden tensions*: Species compete in ecology, companies in economy – resulting in balance and diversity
  - *Everything is steered by all other things*: There is no centralized control in economy, or in the body – but the interactions result in *self-regulation* and *self-organization*
- Today's approaches cannot answer (or even formulate) these observations
- Path to understanding goes through wondering: What is the nature of the "stable attractors" characterizing complex systems?

After Heraclitus, philosophy went astray – Plato: "*Change* is just illusion, *ideas* remain permanent"

Cybernetics

- Norbert Wiener (1948): *”**Cybernetics**, or Control and Communication in the Animal and the Machine”*
- Cybernetics: a special approach to study complex systems
- Cybernetics = the study of *systems* and *control* in an *abstracted sense*



Gregory Bateson (1966):

”I think that cybernetics is the biggest bite out of the fruit of the Tree of Knowledge that mankind has taken in the last 2000 years. But most such bites out of the apple have proven to be rather indigestible – *usually for cybernetic reasons*.”

- Long history of false interpretations
- Western hubris: Cybernetics was among the first modern ”isms” back in 1950’s – 1960’s
  - ”Panacea for all problems”
- Eastern hubris: Cybernetics was (another!) ”scientific” motivation for communism back in 1960’s – 1970’s
  - ”How to steer the society in an optimal way”

- Perhaps cybernetics is now free of false connotations?
- An excellent framework for combining control theory and information and communication theory with application domains (biology, ecology, economy, ...)

The field of traditional, centralized control theory has by now been exploited and exhausted – it is time to get *distributed*

- Modern connotations: *Cyberspaces* and *Cyborgs ...*

  ”Cybernetic Organism”, combining biological and non-biological organs

- Cybernetics becoming a hot topic again?

Many academic papers may sound like gibberish, but this one really is

BY JUSTIN POPE
ASSOCIATED PRESS

BOSTON — Three MIT graduate students set out to show what kind of gobbledygook can pass muster at an academic conference these days, writing a computer program that generates fake, nonsensical papers. And sure enough, a Florida conference took the bait.

The program works like the old "Mad Libs" books, generating sentences taken from real papers but leaving many words blank. It fills the blanks with random academic buzzwords.

The program, developed by students Jeremy Stribling, Max Krohn and Dan Aguayo, generated a paper with the dumbfounding title: "Rooter: A Methodology for the Typical Unification of Access Points and Redundancy." Its introduction begins: "Many scholars would agree that, had it not been for active networks, the simulation of Lamport clocks might never have occurred."

The program works like the old "Mad Libs" books, generating sentences taken from real papers but leaving many words blank. It fills the blanks with random academic buzzwords. And it adds meaningless charts and graphs.

Earlier this month, the students received word that the Ninth World Multi-Conference on Systemics, Cybernetics and Informatics, scheduled to take place in July in Orlando, Fla., had accepted the four-page "Rooter" paper. A second bogus submission — "The Influence of Probabilistic Methodologies on Networking" — was rejected.

The offer accepting a paper and inviting the students to present it in person in Orlando was rescinded after word of the hoax got out, and the students were refunded the $390 fee to attend the conference and have the paper published in its proceedings.

But they still hope to go, using the more than $2,000 raised in contributions to their prank, much of it from admirers who tested the program on the students' Web site.

"We wanted to go down there and give a randomly generated talk," Stribling said.

E-mails to a conference address and to organizer Nagib Callaos were not immediately returned Wednesday, and there was no answer at the Orlando telephone number listed under Callaos' name.

Stribling doubts the paper fooled anyone who actually read it, which keeps the hoax a notch below a famous 1996 prank in which physicist Alan Sokal persuaded a Duke University journal called Social Text to publish a bogus article titled "Transgressing the Boundaries: Towards a Transformative Hermeneutics of Quantum Gravity."

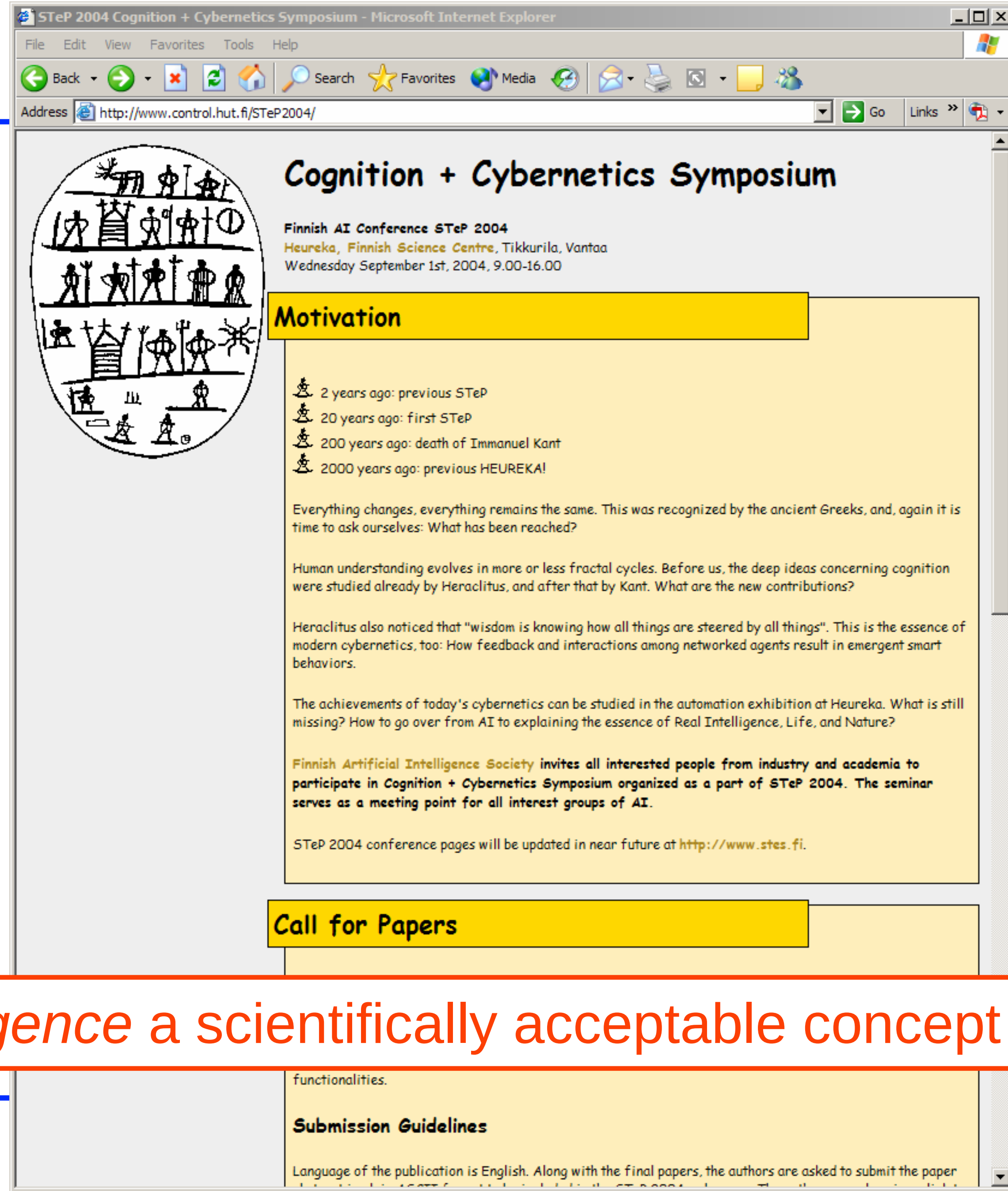
But in addition to mocking academic jargon, the prank sheds light on what Stribling sees as a problem: conferences with low standards that pander to academics looking to pad their resumés, but which harm the reputations of more reputable gatherings.

"We certainly exposed this conference as being willing to publish any paper regardless of whether it's been peer-reviewed, which is kind of a dangerous precedent to set," he said. "It's kind of dangerous to be able to pass anything off as scientifically valid."

STeP 2004

- Introduction of ”Neocybernetics”
- A coherent framework for cybernetic studies
- Engineering-like: Start from basics

- *Putting pieces back together*



Mission: Make *emergence* a scientifically acceptable concept

Neocybernetic starting points – summary

- The details are abstracted away, holistic view from the above is applied
- There exist local actions only, there are no structures of centralized control
- It is assumed that the underlying interactions and feedbacks are consistent, maintaining the system integrity
- This means that one can assume *stationarity* and *dynamic balance* in the system in varying environmental conditions
- An additional assumption: Linearity is pursued as long as it is reasonable

Sounds simple – are there any new intuitions available?

Course on ”Elementary Cybernetics”

1. Introduction
2. About complexity
3. Basic concepts needed
4. Neocybernetic basic models
5. Analogues in populations
6. Technical applications
7. Extension to networks
8. ”Emergent models”
9. Role of information
10. Evolutionary systems
11. Relation to practices
12. Cognitive systems
13. Sparse coding
14. Computationalism
15. Philosophical consequences

Mastering ”Simple complex systems”

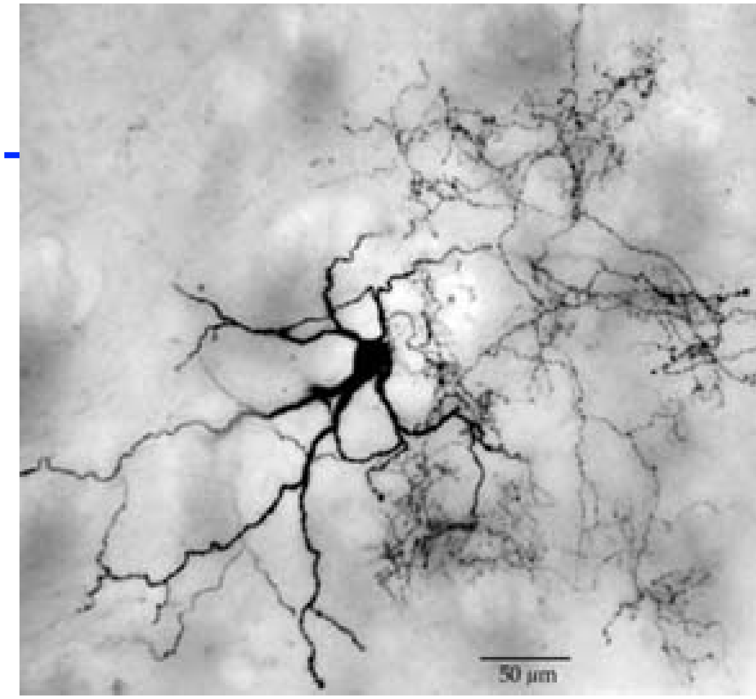
Challenge: ”Complex complex systems”

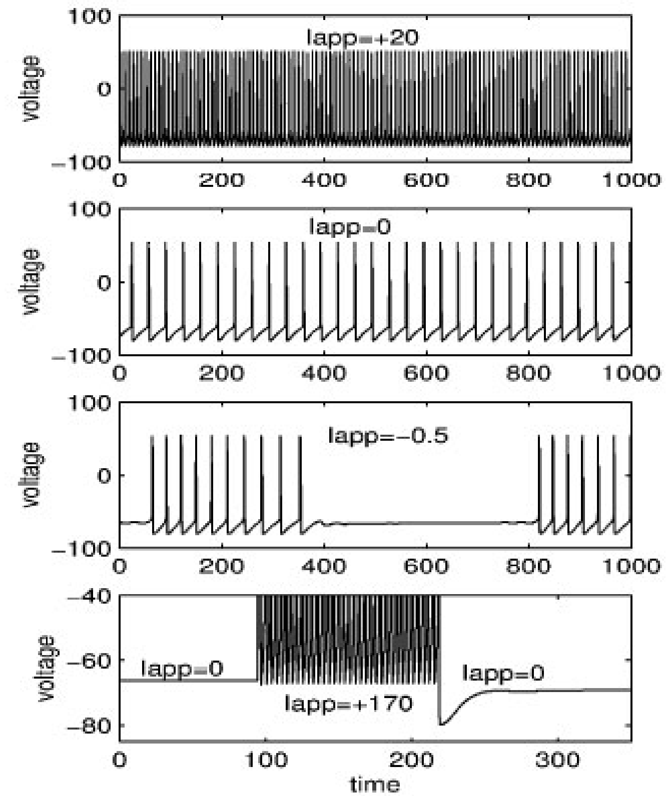
http://www.control.hut.fi/courses/AS-74.192

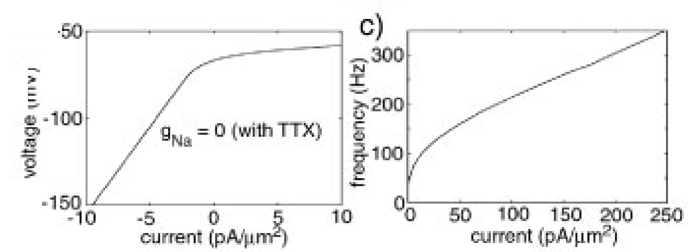
Towards neocybernetic ”basic models”

- Starting point when modeling real complex systems:
  - Observation: *Bottom-up* approaches (studying the mechanisms alone) is futile
  - Another observation: *Top-down* approaches alone are similarly hopeless – there is no *grounding*
- Mission: Both views have to be combined
  - One needs *vision from top*
  - One needs *substance from bottom*
- Try to apply the ideas to a prototypical example: Modeling of *neural networks* – the best understood of complex systems
- Remember that combining the two views is a big challenge: *Computationalism* (numeric) and *traditional AI* (symbolic) seem to be incompatible; low-level functions and high-level (emergent) functionalities are very different

Modeling a neuron







- Neural (chemical) signals are pulse coded, asynchronous, ... extremely complicated
- Simplification: Only the relevant information is represented – the *activation levels*

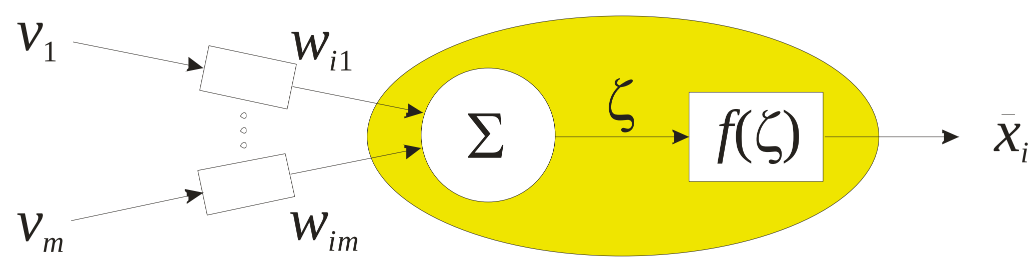
Abstraction level #1

- Triggering of neuronal pulses is *stochastic*
- Assume that in stationary environmental conditions the average number of pulses in some time interval remains constant
- Only study statistical phenomena: Abstract the time axis away, only model *average activity* (first-order cumulant)
- *Perceptron*: Linear summation of input signals v_j + activation function:

$$\bar{x}_i = f\left(W_i^T v\right)$$

and linear version

$$\bar{x}_i = W_i^T v = \sum_{j=1}^{m} w_{ij}^T v_j$$



- The emergence idea is exploited here – deterministic activity variables are employed to describe behaviors
- How to exploit the ”first-level” neuron abstraction, how to reach the *neuron grid* level of abstraction?
- Neural networks research studies this – opposite ends:

1. Feedforward perceptron networks
    - Non-intuitive: Black-box model, unanalyzable
    - Mathematically strong: Smooth functions can be approximated to arbitrary accuracy
2. Kohonen’s self-organizing maps (SOM)
    - Intuitive: Easily interpretable by humans (visual pattern recognition capability exploited)
    - ”Non-mathematical”: A mapping from m dimensional real-valued vectors to n integers

Now, trust ”deep structures” more than surface patterns!

- Today, artificial neural networks are mainly seen as computational tools only
- To capture the functional essence of neuronal systems, one has to elaborate on the domain area more extensively
- The Hebbian learning rule (by physician Donald O. Hebb) also dates back to mid-1900's:

  ”If the neuron activity correlates with the input signal, the corresponding synaptic weight increases”

- Are there some *goals* for neurons included here? Is there something teleological taking place?
- Bold assumptions make it possible to reach powerful models

Traditional Hebbian learning

- Assume: Perceptron activity $\bar{x}_i$ is a *linear* function of the input signal v_j, where the vector w_{ij} contains the synaptic weight:

$$\bar{x}_{ij} = w_{ij} v_j \qquad \text{with} \qquad \bar{x}_i = \sum_{j=1}^{m} \bar{x}_{ij}$$

- Hebbian law applied in adaptation: Correlation between input and neuronal activity expressed as $\bar{x}_i v_j$, so that

$$\frac{dw_{ij}}{dt} = \gamma \cdot \bar{x}_i v_j = \gamma \cdot w_{ij} v_j^2$$

assuming here, for simplicity, that $m = 1$.

- This learning law is unstable – the synaptic weight grows infinitely, and so does $\bar{x}_i$!

Enhancements

- Stabilization by the *Oja's rule* (by Erkki Oja):

$$\frac{dw_{ij}}{dt} = \gamma \cdot w_{ij} v_j^2 - \gamma \cdot w_{ij} \overline{x}_i^{\,2}$$

- Motivation: Keeps the weight vector bounded ($|W_i| = 1$), and average signal size $\mathrm{E}\{|\overline{x}_i|\} = 1$
- Extracts the *first principal component* of the data
- Extension: Generalized Hebbian Algorithm (GHA): Structural tailoring makes it possible to deflate pc's one at a time
- However, the new formula is nonlinear: Analysis of neuron grids containing such elements is difficult, and extending them is equally difficult – What to do instead?

Layer $\eta + 1$: Synapses

- Remember the neocybernetic starting points: The guidelines were *balance* and *linearity*
- Note: Nonlinearity was not included in the original Hebbian law – it was only introduced for pragmatic reasons

Are there other ways to reach stability – in linear terms?

- Yes – one can apply *negative feedback*:

$$\frac{dw_{ij}}{dt} = \gamma_i \cdot \bar{x}_i v_j - \tfrac{1}{\tau_i} w_{ij}$$ or in matrix form $$\frac{dW}{dt} = \gamma \cdot \bar{x} v^T - \tau^{-1} W$$

The steady-state is

$$\bar{W} = \gamma\tau \cdot \mathrm{E}\left\{\bar{x} v^T\right\} = \Gamma \cdot \mathrm{E}\left\{\bar{x} v^T\right\}$$

Synaptic weights can be coded in a correlation matrix

Layer $\eta + 2$: Neuron grids

- Just the same principles can be applied when studying the neuron grid level – *balance* and *linearity*
- Define

$$\bar{W} = \left(A \mid B \right) \quad \text{and} \quad v = \begin{pmatrix} -x \\ \hline u \end{pmatrix}$$

so that $A = \Gamma \cdot \mathrm{E}\left\{ \overline{x x^T} \right\}$ and $B = \Gamma \cdot \mathrm{E}\left\{ \bar{x} u^T \right\}$

- To implement negative feedback, one needs to apply the *anti-Hebbian* action between otherwise Hebbian neurons:

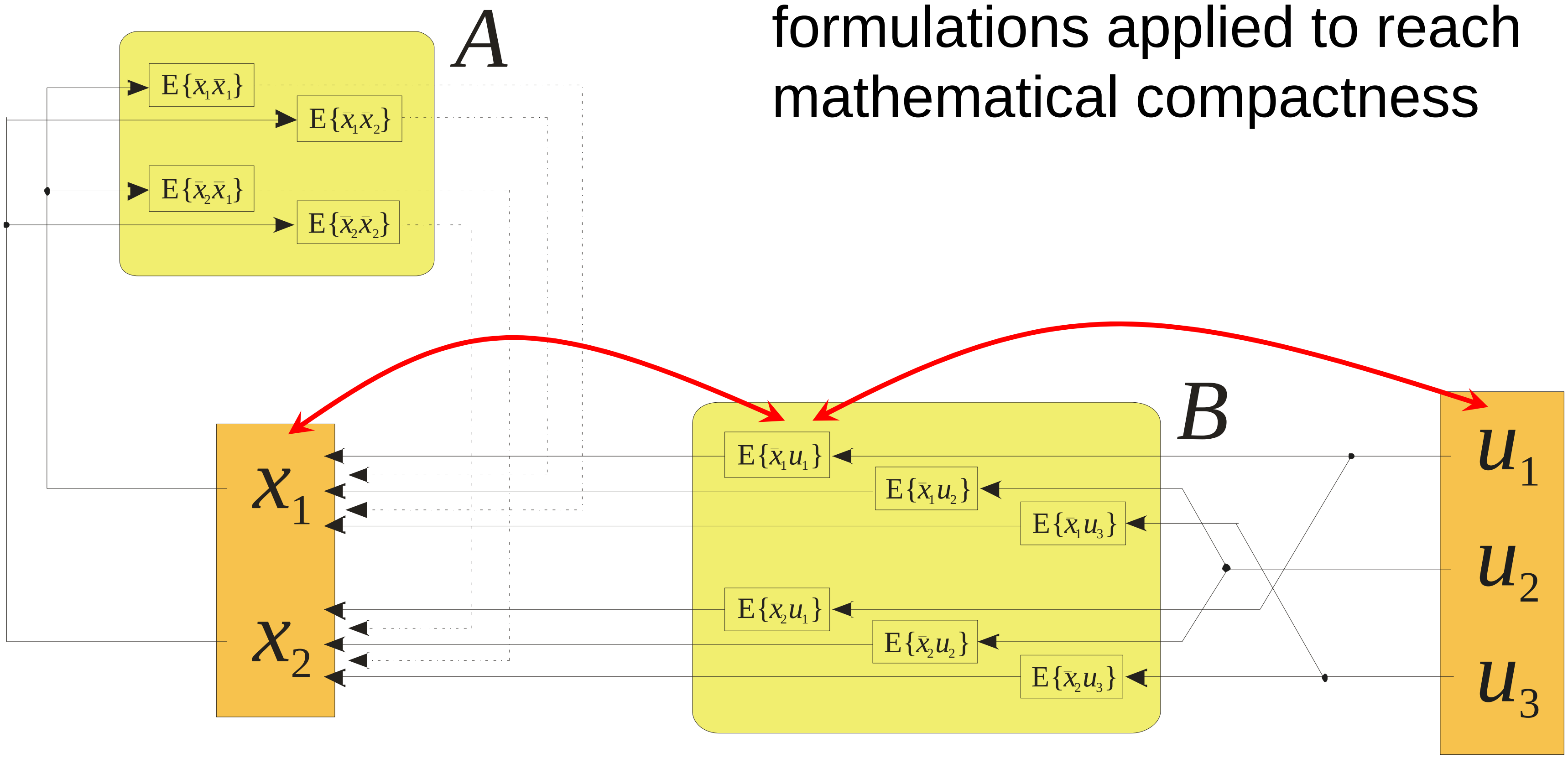
$$\frac{dx}{dt} = -Ax + Bu$$

Model is stable! Eigenvalues of A always real and non-negative

so that the steady state becomes

$$\bar{x} = A^{-1} B\, u = \mathrm{E}\left\{ \overline{x x^T} \right\}^{-1} \mathrm{E}\left\{ \bar{x} u^T \right\} u = \phi^T u$$

- Completely *local* operation, even though centralized matrix formulations applied to reach mathematical compactness



Towards abstraction level #2

- Cybernetic model = statistical model of balances $\bar{x}(u)$
- Assume dynamics of u is essentially slower than that of x and study the covariance properties:

$$\mathrm{E}\left\{\bar{x}\bar{x}^T\right\} = \mathrm{E}\left\{\bar{x}\bar{x}^T\right\}^{-1} \mathrm{E}\left\{\bar{x}u^T\right\} \mathrm{E}\left\{uu^T\right\} \mathrm{E}\left\{\bar{x}u^T\right\}^T \mathrm{E}\left\{\bar{x}\bar{x}^T\right\}^{-1}$$

or

$$\mathrm{E}\left\{\bar{x}\bar{x}^T\right\}^3 = \mathrm{E}\left\{\bar{x}u^T\right\} \mathrm{E}\left\{uu^T\right\} \mathrm{E}\left\{\bar{x}u^T\right\}^T$$

or

$$\left(\phi^T \mathrm{E}\left\{uu^T\right\} \phi\right)^3 = \phi^T \mathrm{E}\left\{uu^T\right\}^3 \phi \qquad\qquad n < m$$

- Balance on the statistical level = *second-order balance*

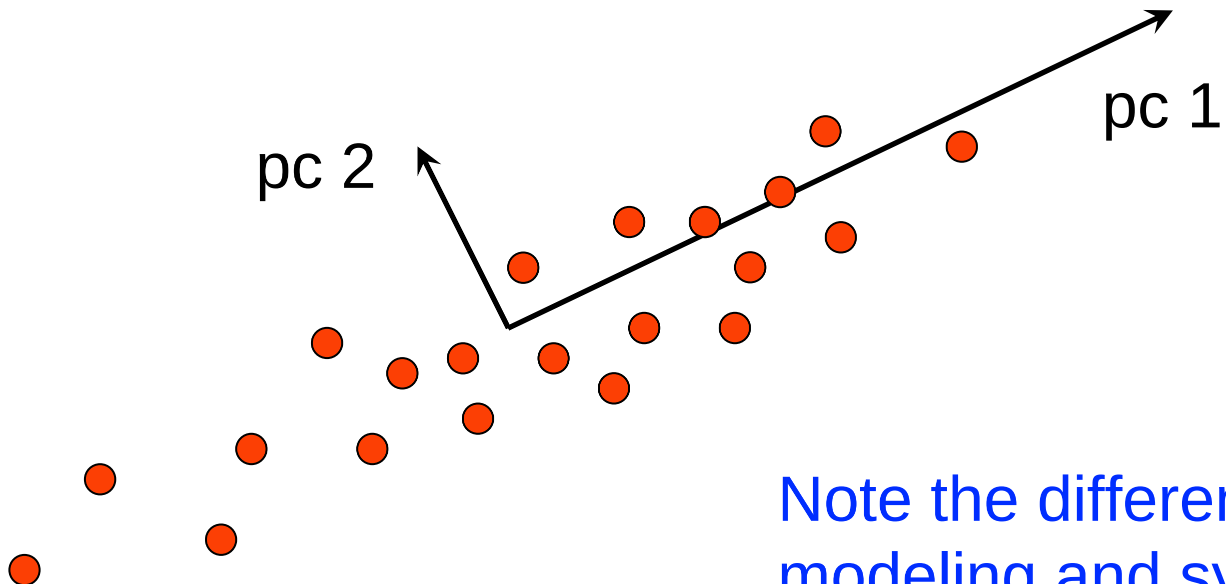
Principal subspace analysis

- Any subset of input data principal components can be selected for ϕ
- The subspace spanned by the n most significant principal components gives a stable solution
- Conclusion:

  Competitive learning (combined Hebbian and anti-Hebbian learning) without any structural constraints results in self-regulation (balance) and self-organization (in terms of principal subspace).

Principal components

- Principal Component Analysis = Data is projected onto the most significant eigenvectors of the data covariance matrix
- This projection captures maximum of the variation in data



Note the difference between data modeling and system modeling!

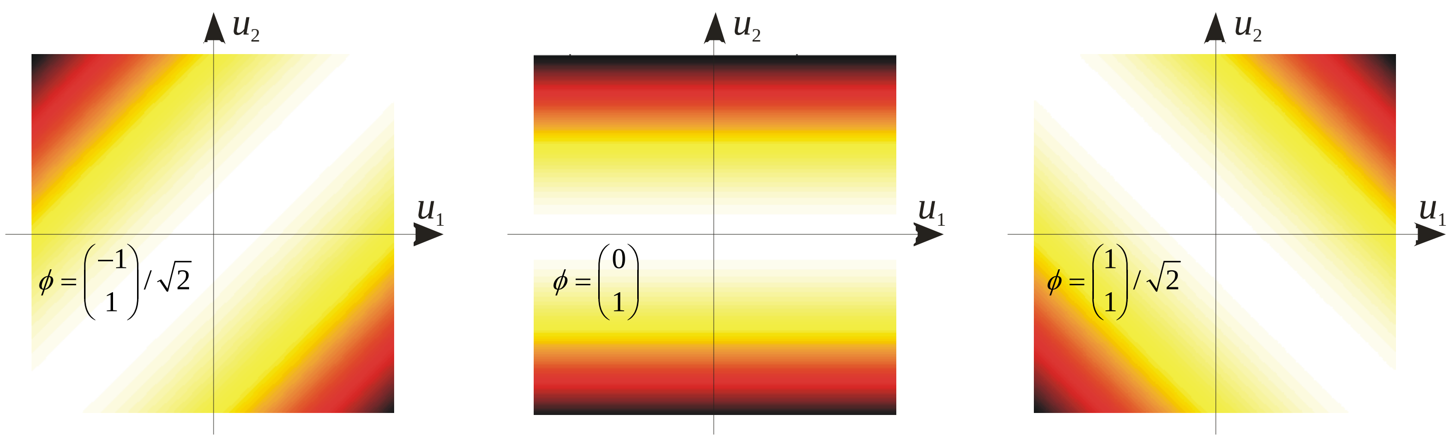
Emergent patterns

- The *process* (convergence of x) can be substituted with the *final pattern*: Details are lost, but the essence remains (?)
- The pattern is characterized in terms of a *cost criterion*

$$J(x,u) = \frac{1}{2} x^T \mathrm{E}\left\{ \overline{x x^T} \right\} x - x^T \mathrm{E}\left\{ \overline{x} u^T \right\} u$$

Process itself = Gradient descent minimization for the criterion!

- Models of local minima ($m = 2$, $n = 1$):



Pattern matching

- One can also formulate the cost criterion as

$$J(x,u) = \frac{1}{2}(u - \phi x)^T \mathrm{E}\left\{uu^T\right\}(u - \phi x)$$

- This means that the neuron grid carries out *pattern matching* of input data
- Note that the traditional maximum (log)likelihood criterion for Gaussian data would be

$$J(x,u) = \frac{1}{2}(u - \phi x)^T \mathrm{E}\left\{uu^T\right\}^{-1}(u - \phi x)$$

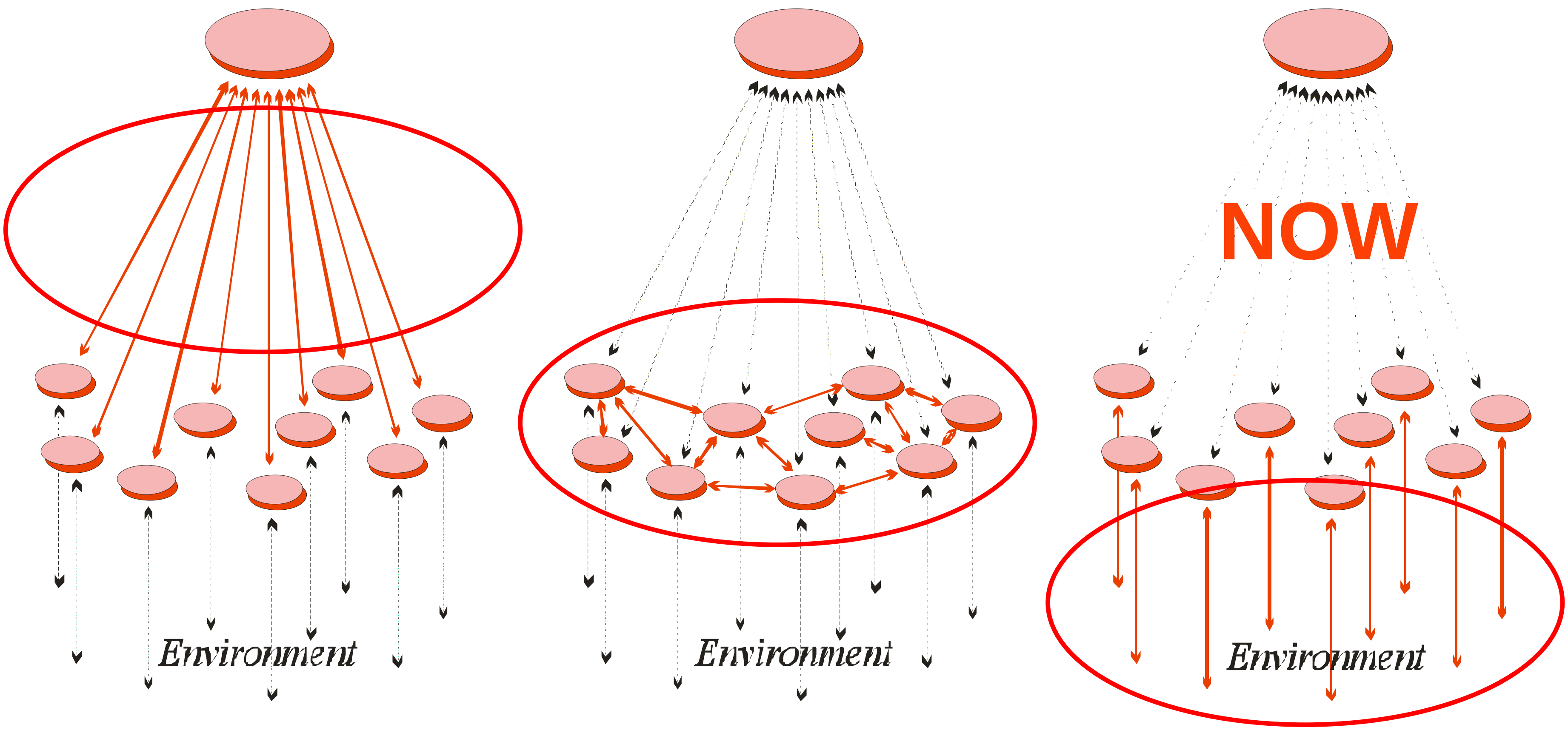
- **Now:** More emphasis on main directions; no invertibility problems!

Mathematics vs. reality

1. Correlations vs. covariances
   - The matrices being studied are *correlation matrices* rather than *covariance matrices* (as is normally the case in PCA)
   - This means that now data u is not assumed to be zero-mean, there is no need for preprocessing; in practice, the variables are always non-negative
   - From physical point of view, this is beneficial: Note that the actual signal carriers (chemical concentrations / pulse frequencies) cannot be negative

2. Principal subspace vs. principal components
   - When applying the linear structure, the actual principal components are not distinguished, only the subspace spanned by them
   - This means that the variables can again all be non-negative, so that the signals x again are physically plausible
   - There are other benefits, too: The assumption of local linearity is better justified

- Control neither *centralized* nor *distributed* (traditional sense)



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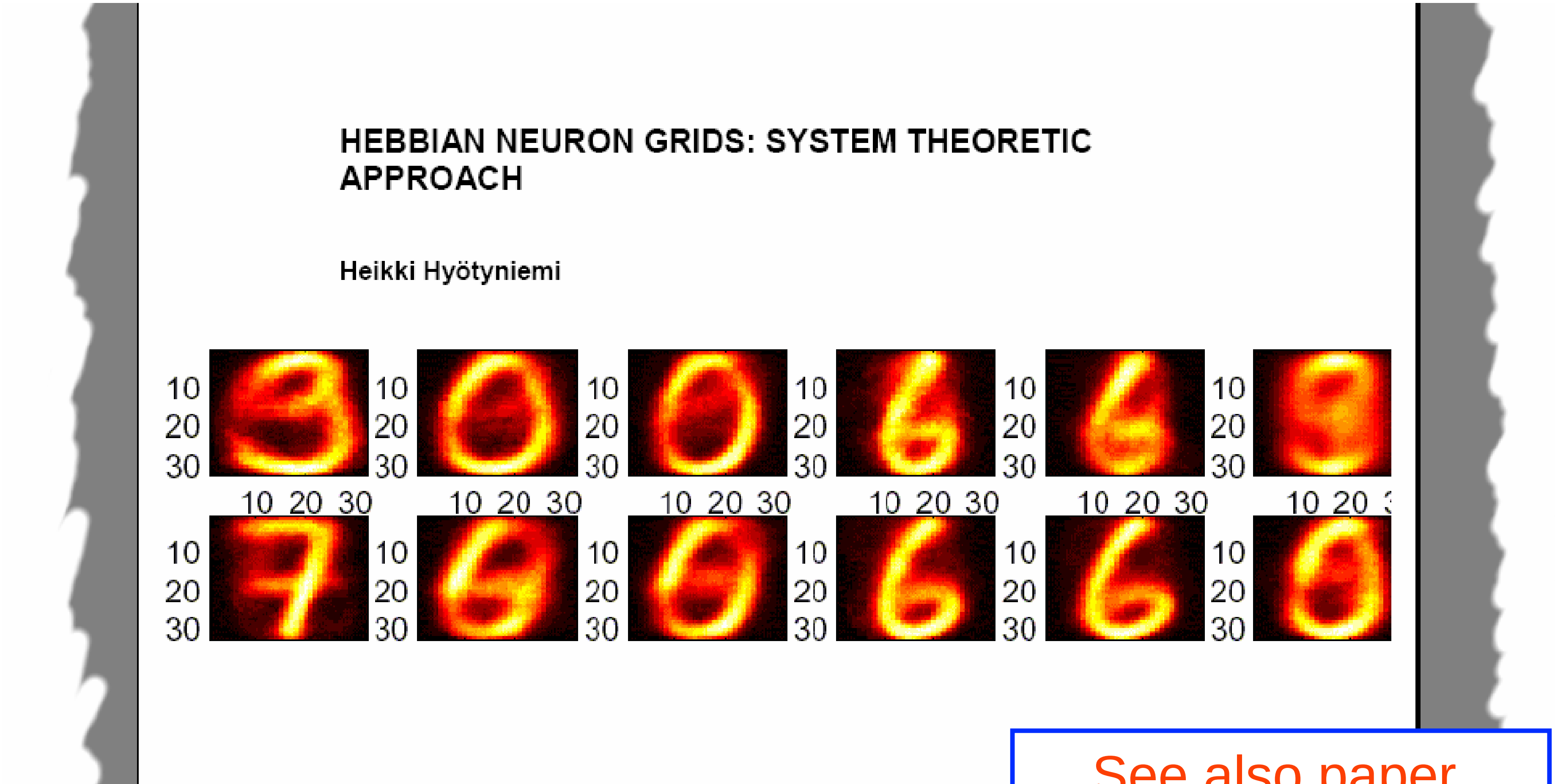
- Mathematical derivations carried out in an explicit way



HEBBIAN NEURON GRIDS: SYSTEM THEORETIC APPROACH

Heikki Hyötyniemi

See also paper
"`step1.pdf`"!

Summary: Neocybernetic models

- **First-order cybernetic system**: For any stable A, assume that there holds

$$\frac{dx}{dt} = -Ax + Bu \qquad \text{with} \qquad \bar{x} = A^{-1}B\,u = \phi^T u$$

- **Second-order cybernetic system**: Additionally, assume that the matrices are

$$A = \Gamma \cdot \mathrm{E}\left\{\overline{xx}^T\right\} \qquad \text{and} \qquad B = \Gamma \cdot \mathrm{E}\left\{\bar{x}u^T\right\}$$

- **Higher-order (optimized) cybernetic system**: Additionally, asume that

$$\Gamma = \mathrm{Var}\left\{\overline{xx}^T\right\}^{-1} \qquad \text{or} \qquad \Gamma = \mathrm{E}\left\{\overline{xx}^T\right\}^{-1}$$

Newton algorithm: Second-order convergence

Extensions to other domains?

The symbols can also be interpreted in different ways:

- x vector represents *population sizes* (or *activities*)
- u vector of available *resources*
- A, B matrices contain *interaction factors*, and
- Γ matrix can contain differing adaptation rates.

Questions that arise:

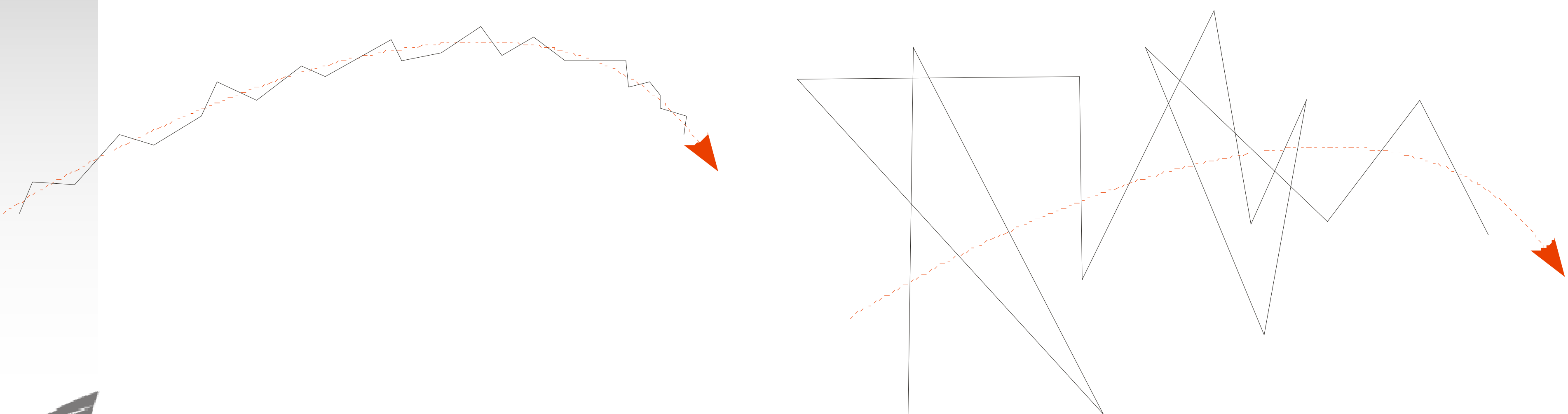
- Is this more than renaming?
- Are there really analogues between systems?
- *Is there universality among complex systems?*

Counterarguments

- Criticism #1: The dynamic underlying processes are undeniably different in different systems (and nonlinear).
  - Answer: Only the final (emergent) state is now studied, not the route there; what remains in the dynamic equilibrium is the tensions – and, if the system dynamics are *smooth*, these dynamics can be locally linearized.
- Criticism #2: There are too many degrees of freedom; all interactions among agents cannot be captured.
  - Answer: In balance, the number of variables is less, and only the activity levels are being represented; what is more, the interactions need not be modeled, only the *deprivation* (no ”negotiations”, etc., take place)
- Criticism #3: There are always many ways to self-organize; why should systems follow the same adaptation principles.
  - Answer: Following the neocybernetic model, there is evolutionary advantage; *optimality* in terms of resource usage is reached (as long as quadratic loss criteria are employed).

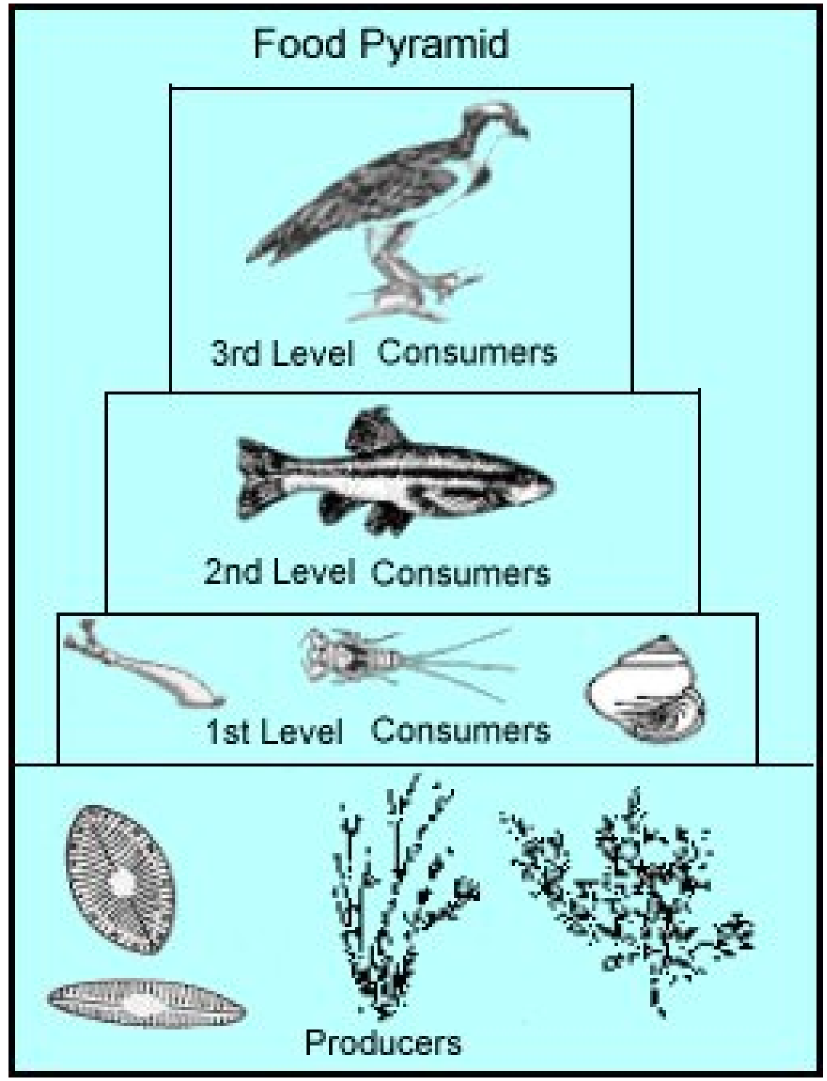
Species with optimal strategies outperforms others, resulting in more biomass + more probable survival

- In different environments, the adaptation processes can be very different, and there may not exist generic models
- However, the states where the processes finally end in are (more or less) unique and generally characterizable



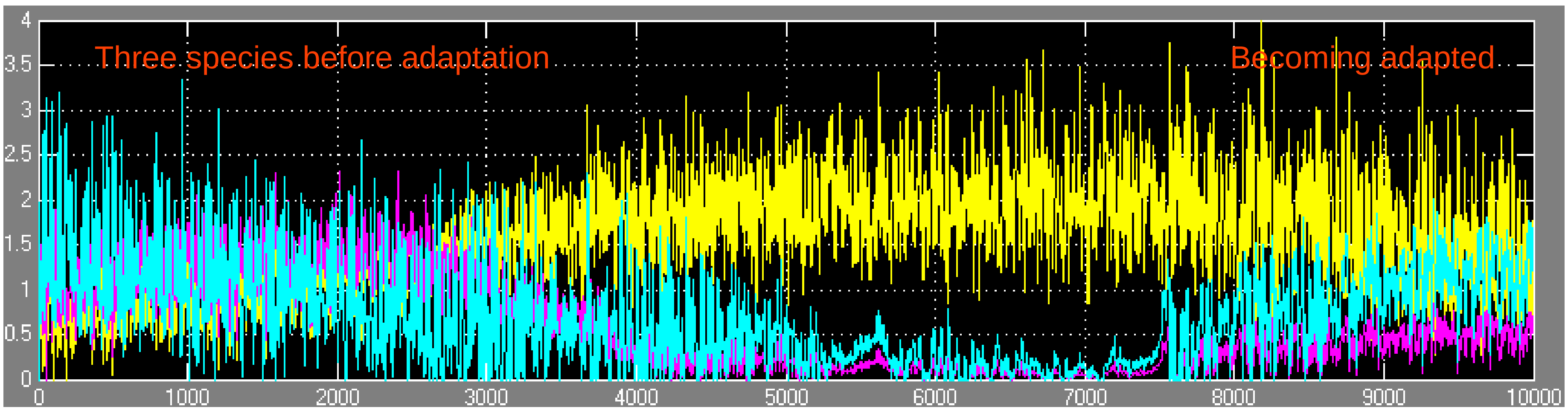
Example #1: Ecological system

- Actors: Individual animals
- Variables x_i: Population sizes in species i (actually, *biomasses*)
- Input u: Available food (or other environmental conditions)
- Model ϕ_i: *Forage profile* for i, revealing the range of prey (or other environmental demands)
- Learning of the system based on Darwinian evolution (and also on faster accomodation processes)



Input variables on the lowest level (very local): Temperatures, nutrients, diseases, rainfall, …

- Traditional ecological models only model a single species or interactions between two species (Lotka-Volterra, etc.)
- Models for complete ecologies need careful tuning; evolutionary strategies are typically unstable (extinctions)
- Applying the neocybernetic model, simulations remain stable even though the dynamics looks ”naturally chaotic”



Example #2: Economical system

- The above discussions on ecology can somewhat directly be applied to *market economy*:
  - Companies stand for populations
  - Individual humans are only ”signal carriers” (cf. ants in an ant colony)
  - Variables x_i are company turnovers
  - Input u_j is the available *money* in the market in product group j
  - Company profile ϕ_i contains the production profile
  - Strategies dictate the company-wise (or less wise!) adaptation styles, as being manifested in economic decisions involving recruitment policy, investments, etc.
  - Adaptation in a company is very nonlinear and non-continuous – however, if the company is to survive in the competition, the stochastic processes have to be more or less consistent in the long run, resulting in the same balance
  - However, market can be actively changed; and what are the final roles of different companies in the market is dependent of the individual strategies
  - Within a company there exist many interleaved subsystems ...

Some intuitions offered by the model

- Robustness.
  - In nature, no catastrophic effects typically take place; even key species are substituted if they become extinct (after a somewhat turbulent period)
  - Now, this can also be explained in terms of the principal subspace: If the profiles are almost orthogonal (PCA-like), disturbances do not cumulate
  - Also because of the principal subspace, sensitivity towards random variations are suppressed
- Biodiversity.
  - In nature, there are many competing species, none of them becoming extinct; modeling this phenomenon seems to be extremely difficult
  - Now, this results from the principal subspace nature of the model: As long as there are various degrees of freedom in input, there are different populations
  - Within populations, this also explains why there exists variation within populations as the lesser principal components also exist ...

The roles of the species cannot be predicted, only "subspace" that is spanned by all of them together

There are no unidirectional effects!

- Study how one individual (index i) affects its environment
- It prevents other ones from reaching their natural activity; this depressing effect can be modeled as

$$\frac{d\nu_i}{dt} = -A\nu_i + \begin{pmatrix} 0 & \cdots & 0 & 1 & 0 & \cdots & 0 \end{pmatrix}^T$$

Only element i is non-zero

- When all individuals are taken into account:

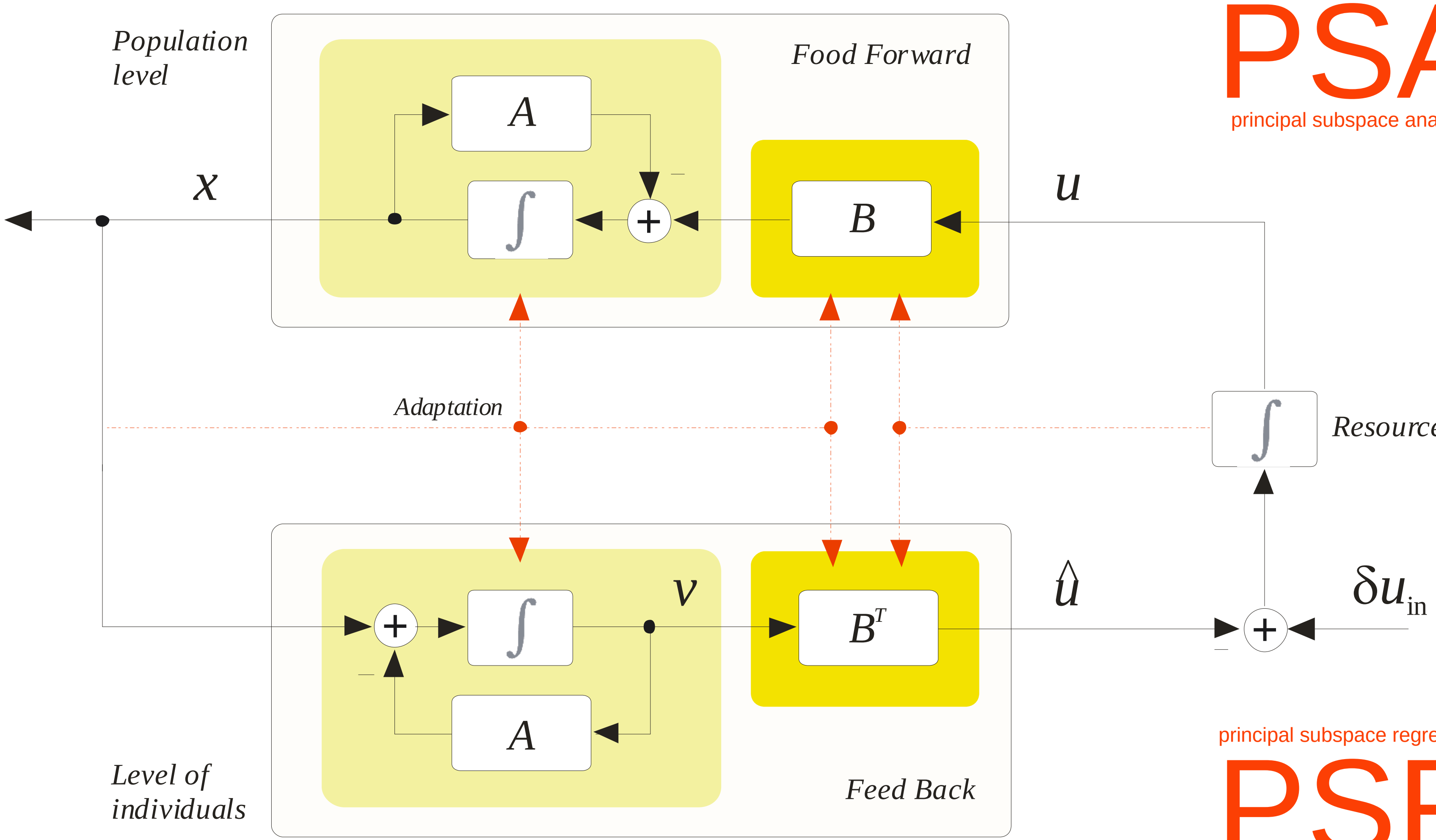
$$\frac{dv}{dt} = \sum_i x_i \frac{d\nu_i}{dt} = -Av + x$$

- Final effect on the environment

$$\Delta u = -B^T \bar{v} = -B^T A^{-1} \bar{x}$$

Harshest competition **within** the species!

Heraclitus: ”The way up and the way down ...”!



PSA
principal subspace analysis

principal subspace regression
PSR

Model based control

- Model.
  - It turns out that the neocybernetic strategy constructs the best possible (in the quadratic sense) description of the environment; the *latent variables* are

$$\bar{x} = \mathrm{E}\left\{\bar{x}\bar{x}^T\right\}^{-1} \mathrm{E}\left\{\bar{x}u^T\right\} u$$

A cybernetic system constructs a "mirror image" of its environment!

- Estimate.
  - It turns out that the neocybernetic strategy constructs the best possible (in the quadratic sense) estimate of the environment state; regression estimate is

$$\hat{u} = \mathrm{E}\left\{\bar{x}u^T\right\}^T \mathrm{E}\left\{\bar{x}\bar{x}^T\right\}^{-1} \bar{x}$$

- Control.
  - It turns out that the neocybernetic strategy integrates modeling and estimation *to maximally eliminate variation in the environment*.

- These results are related to age-old cybernetic intuitions:
- Ross Ashby (1952) – Law of Requisite Variety:

  ”The amount of appropriate selection that can be performed is limited by the amount of information available”, or

  ”For appropriate regulation the variety in the regulator must be equal to or greater than the variety in the system”
- Stronger version – Law of Regulatory Models:

  ”Regulator must not only have adequate amounts of variety available, but also be or have a homomorphic representation of that system” (see also Wonham: Model *inverse* needed)
- Less concrete – on the other hand more general ... *see later*

Also ...

- Starting point: Local level feedback controls – final result: Global level feedback control
- Model based control = The best control there is, now going towards balance along the (filtered) gradient direction
- Variation is suppressed by the control system
- In another perspective, variation is the ”nourishment” for higher-level systems

- Traditional matter/energy –oriented views: In *dissipative systems* constant flows of energy are essential
- Neocybernetic information –oriented view: In *control systems* constant flows are *trivial*

- The dualism between information vs. matter/energy (traditionally mind vs. matter) deserves to be studied closer
- The age-old dilemma of dualism is solved in a peculiar way in a cybernetic system: ”Marriage of information and matter”
- Extraction of information from a real-life system necessitates exploitation of matter/energy

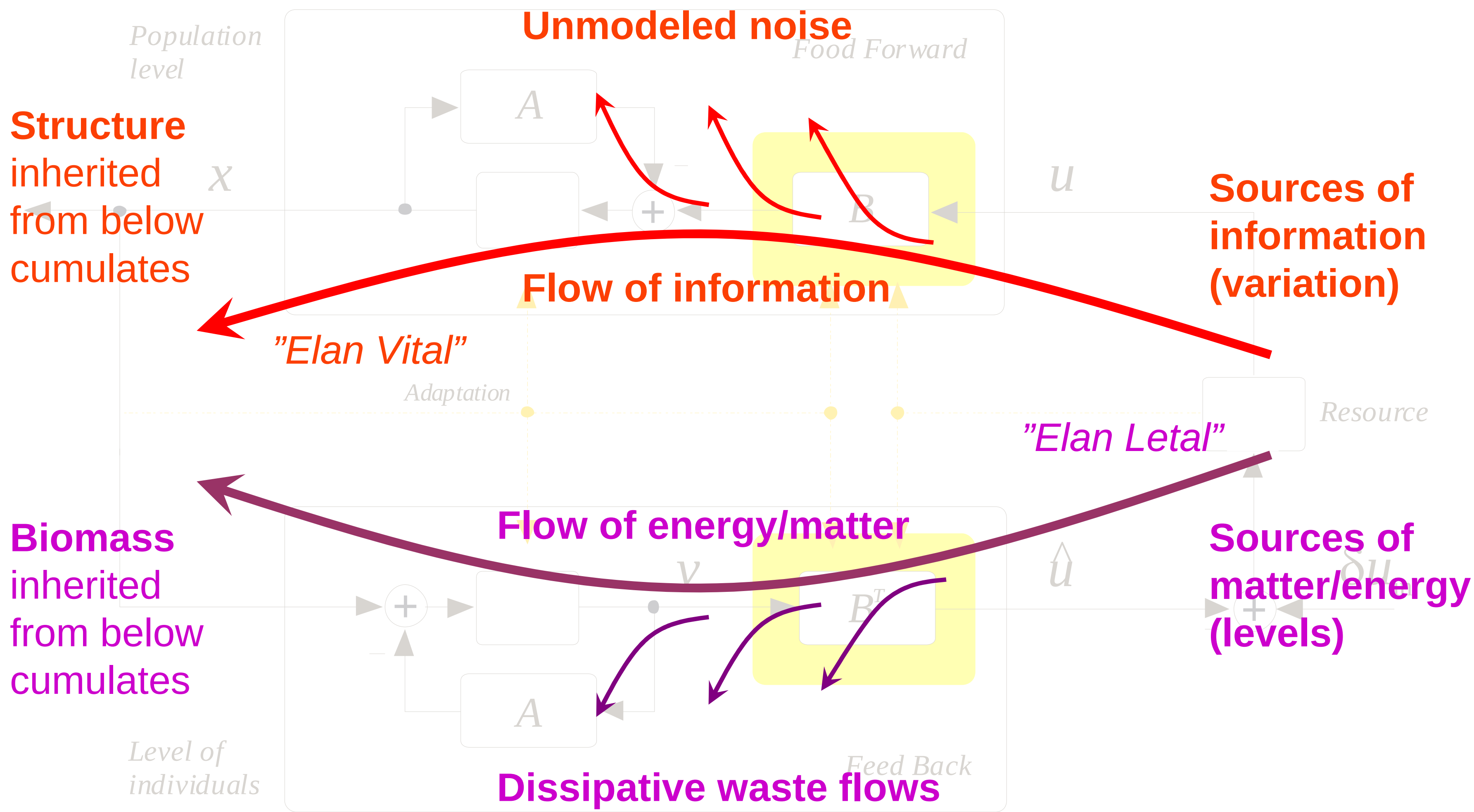
  Upstream: Construction of a model = information flow

  Downstream: Construction of feedback = matter/energy flow

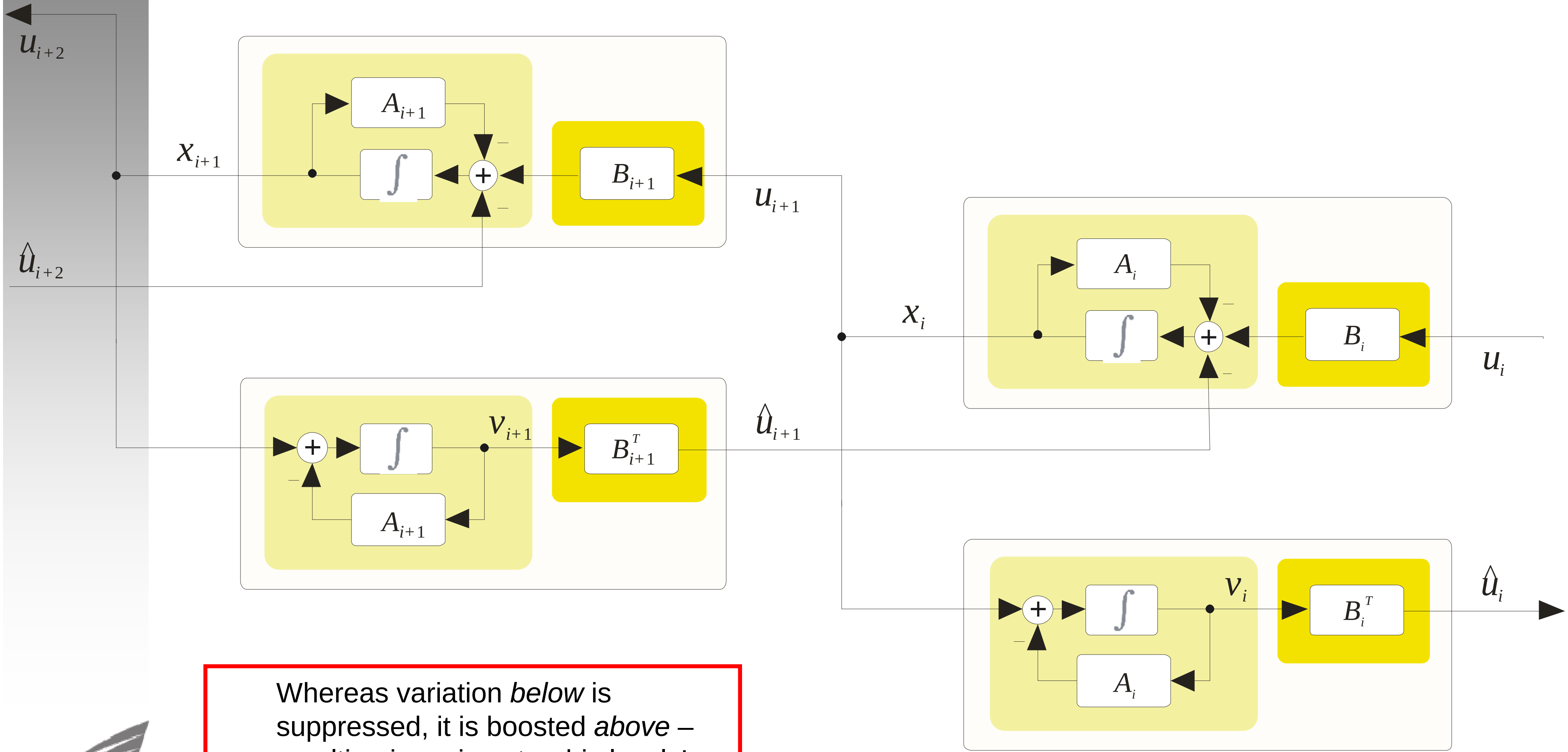
- Full closed loop control system is constituted only if both mechanisms are present

Note: The feedback loop is virtual, physically it does not need to be implemented by the agents

Abstract flows in a cybernetic system



Connection of trophic layers



Whereas variation *below* is suppressed, it is boosted *above* – resulting in various trophic levels!

"Generalized diffusion"

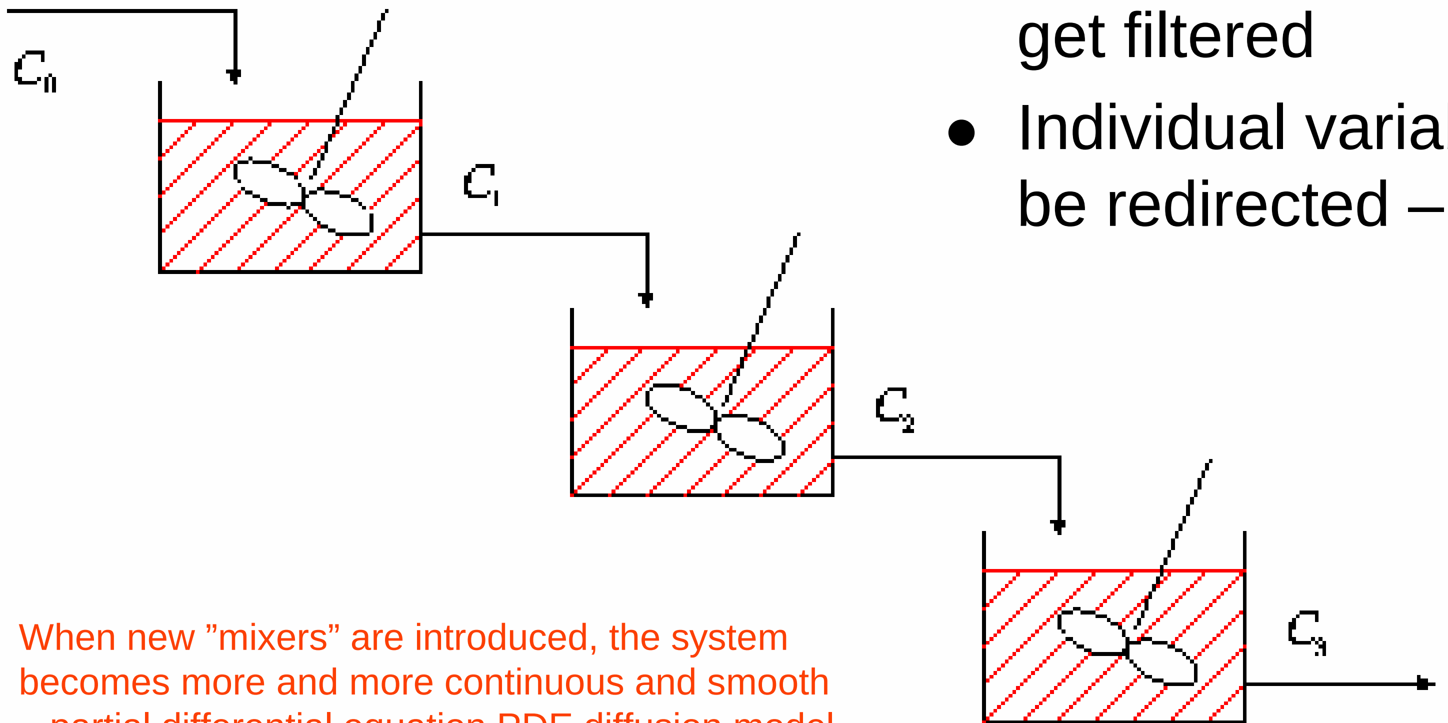
- Looking at the overall closed-loop controller structure, the internal system details can be abstracted away

$$\frac{du}{dt} = -\phi\phi^T u + \delta u$$

- The "most relevant" data directions tend towards balance, the rest (null space) following uncontrolled Brownian motion
- There is a "structured leakage in the resource reservoirs"; this can also be characterized as "directed diffusion"
- The same feedback structure emerges in different scales
  - Note: The starting point that was assumed when the original cybernetic model was derived for Hebbian/anti-Hebbian neurons (balancing negative feedback in the synapses) is a trivial (scalar) case of this diffusion phenomenon

Feedback model with A: Lumped parameter approximation of a parabolic PDE system!

- Potential flows from trophic layer (”ideal mixer”) to another (note that the flows are not scalar variables but vectors)



- Changes in resources get filtered
- Individual variables can be redirected – network

When new ”mixers” are introduced, the system becomes more and more continuous and smooth – partial differential equation PDE diffusion model

Systems of humans

- Study a project (or an ”intelligent organization”):
  - There are humans with varying properties
  - Tasks and workloads are organized according to individual abilities, becoming more streamlined along with learning of humans
  - Intuition: Different kinds of people are needed; no line production style optimization is ”robust” – a team contains organizers, ”mood makers”, etc.

There is a *niche* for one ”clown” in the classroom

”Humble agents”

- What are the actors in a cybernetic system like?
  - How does an agent know what to do to implement global behaviors?
    - It simply tries to *survive*: It uses resources, competing with others, taking what it can get, otherwise giving up, in a locally reasonable way
    - If others do the same, the atoms of global behaviors exist there (why should they do that – because there is the evolutionary advantage)
  - This inevitably results in ”nobody being satisfied”
    - Compare to Arthur Schopenhauer / Adam Smith / Eastern wisdom
  - Human systems can be more cultivated
    - To depart from anarchy, *categorical imperatives*, and *moral* is needed
    - More efficient modern imperatives offered by money, fashions, etc.
    - Motivation can also be supplied by feedback, feeling of ”success”
    - Human is an agent for constructing ”allocybernetic” systems: The ”engineering imperative” is *citius – altius – fortius*, being driven by curiosity and greediness

”Because it is there!”

- The agents in a cybernetic system can be *more* or *less* intelligent – obeying different levels of morals:

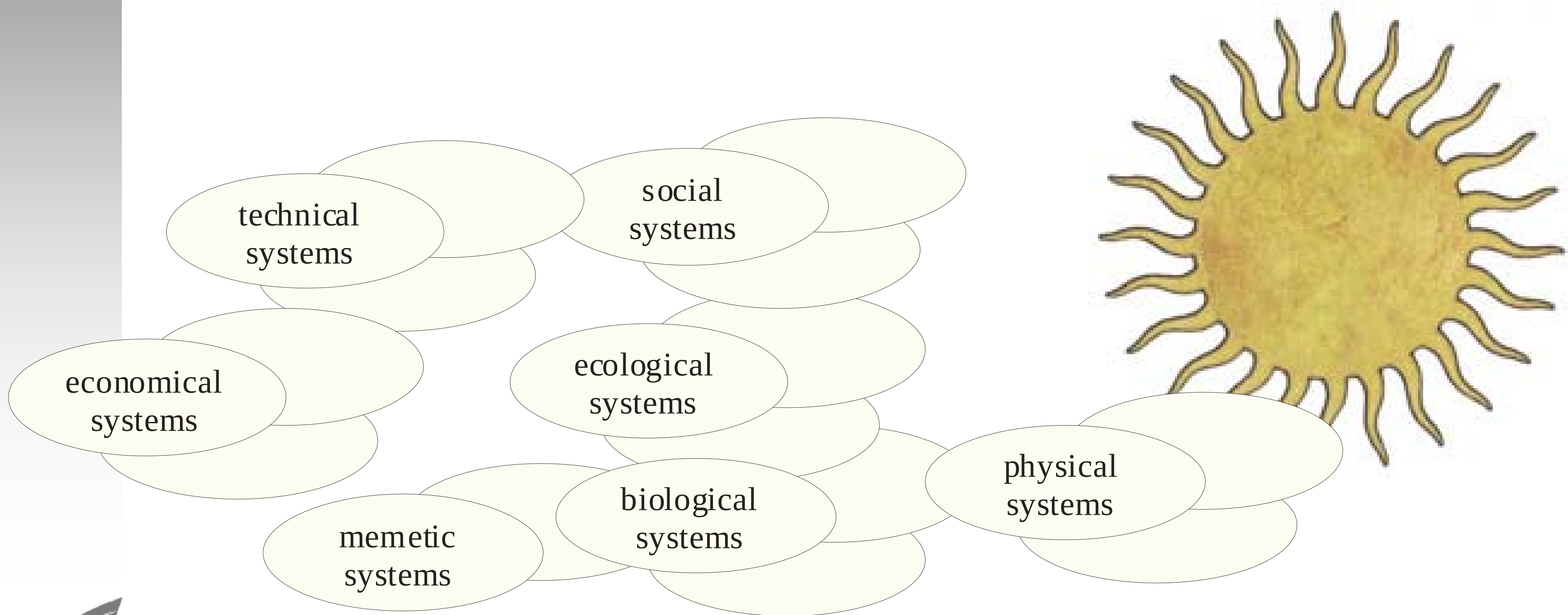
- No intelligence whatsoever: Maximum resource pursuit
  - Feedback from the environment, crude survival of the fittest
- *Some* level of intelligence: Additionally, avoid competition
  - Feedback implemented already in the survival strategy
- Local intelligence: Balance among a network of neighbors
  - Try to directly implement local equilibria
- Global intelligence: Directly optimize among agents
  - Design a system implementing global equilibrium

- *Latter strategies not studied here*

More intelligent strategies
have evolutionary advantage

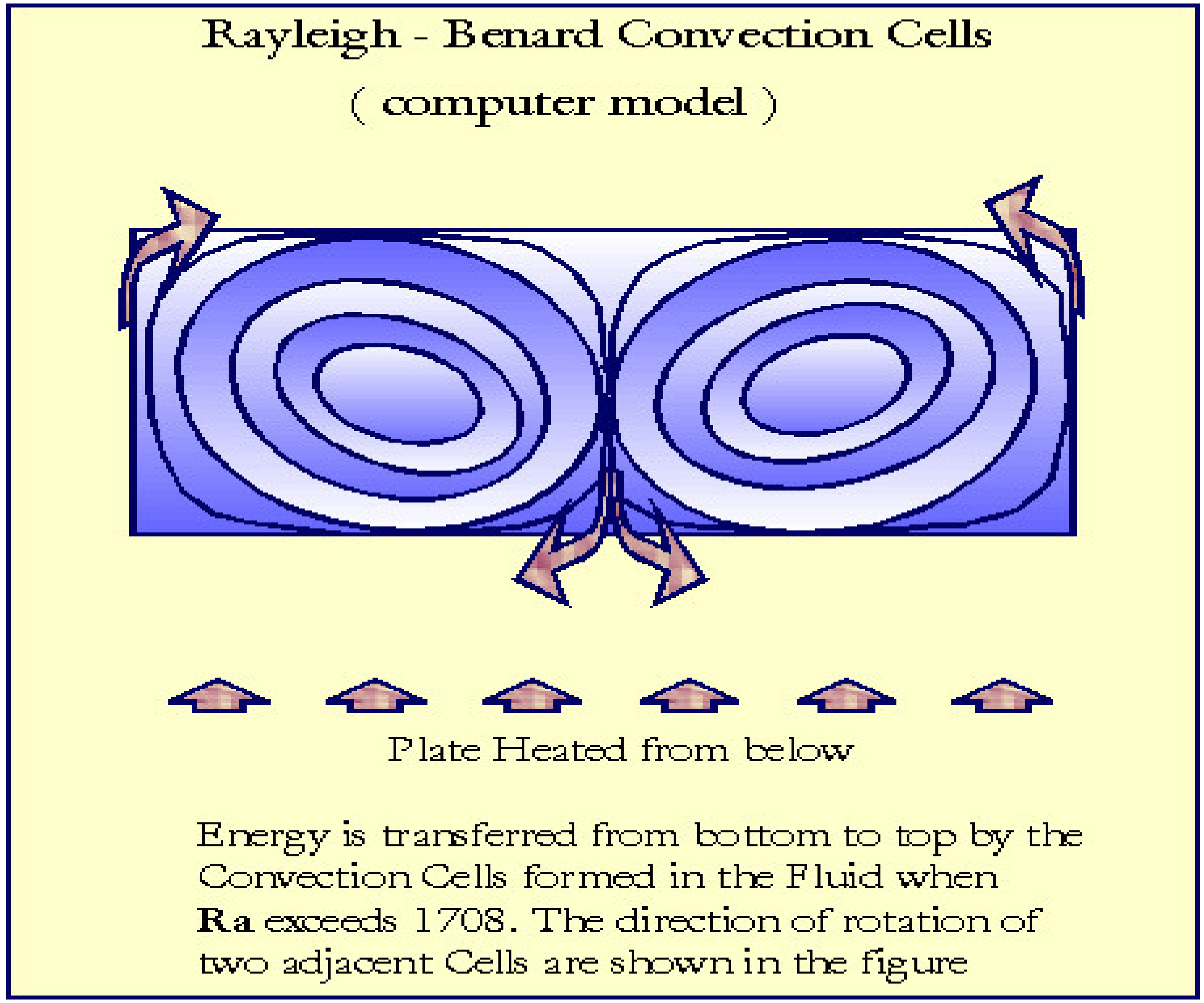
Overall view

- The question is not where the diversity comes from, but why there is *something* instead of *nothing*!



Bénard process

- Example of ”physical level” cybernetics and self-organization
- Convection patterns emerge when the plate below is heated above threshold value
- Also other such climatological processes
- *Chaotic patterns*



Also planetary motion, etc., is *noncybernetic*

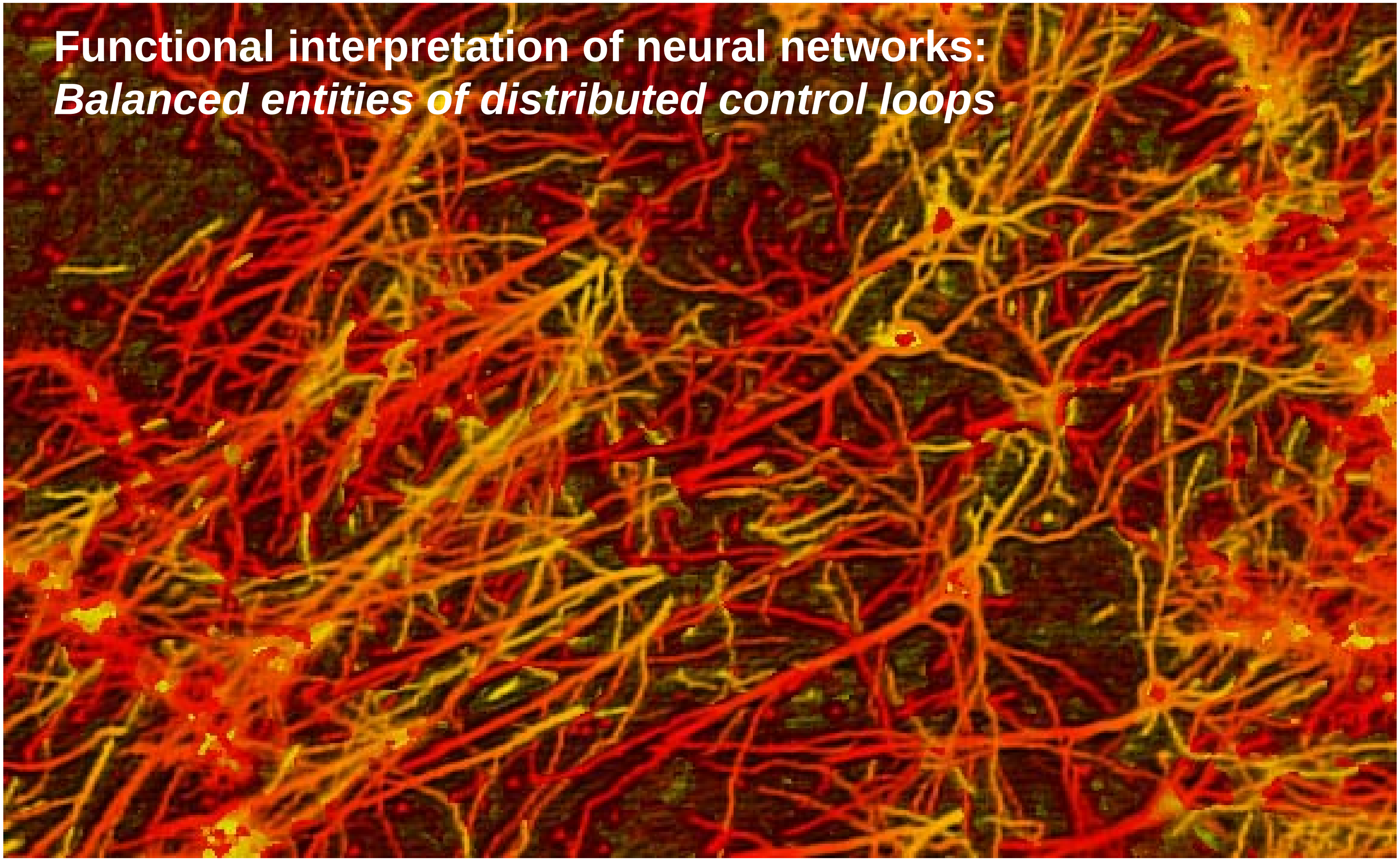
- There exist a plenty of application domains (skipped here)
  - Social systems, scientific systems, cellular systems, evolutionary systems, ...
- There exist a plenty of technical applications (skipped here)
  - Distributed sensor networks, different kinds of networks, ...

- In what follows, only one special case is studied closer:

Cognitive systems

- What happens when a cybernetic system of neurons is seen ”from above”?

Functional interpretation of neural networks:
Balanced entities of distributed control loops



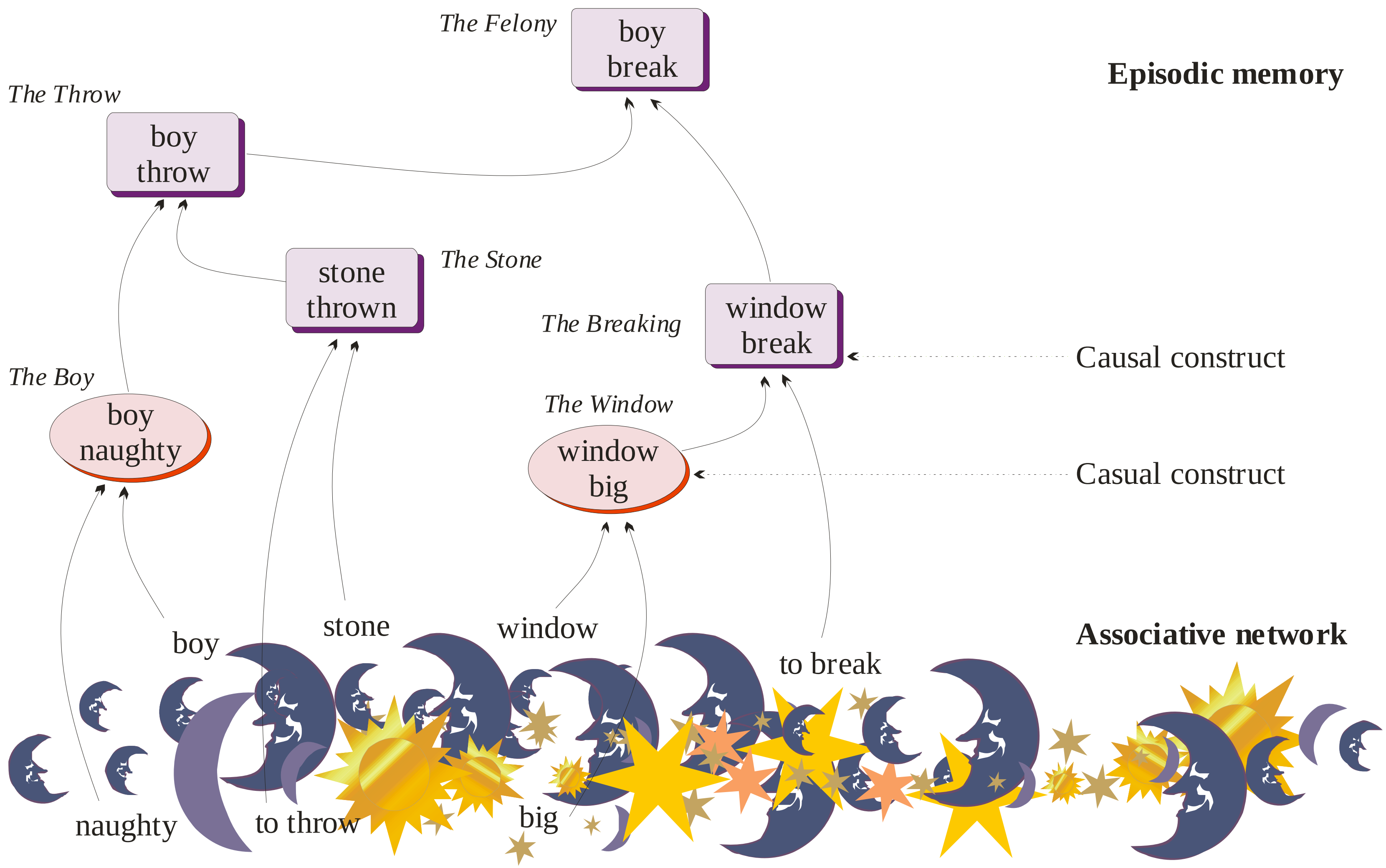
Bottom-up view

- Assumption: Cognition is based on identical neurons, neurons follow Hebbian/anti-Hebbian principles

  What kind of structures are possible in such a system?

- Neurons are the *atoms of association* – localized centers of correlation
- The pool of neurons compete for activation
- No additional functionalities are needed: The neuron grid suffices to implement non-trivial cognitive functionalities assuming it has high enough dimension and there is enough iteration is provided – without ”operating system”
- ... But how can a *story*, for example, be stored?

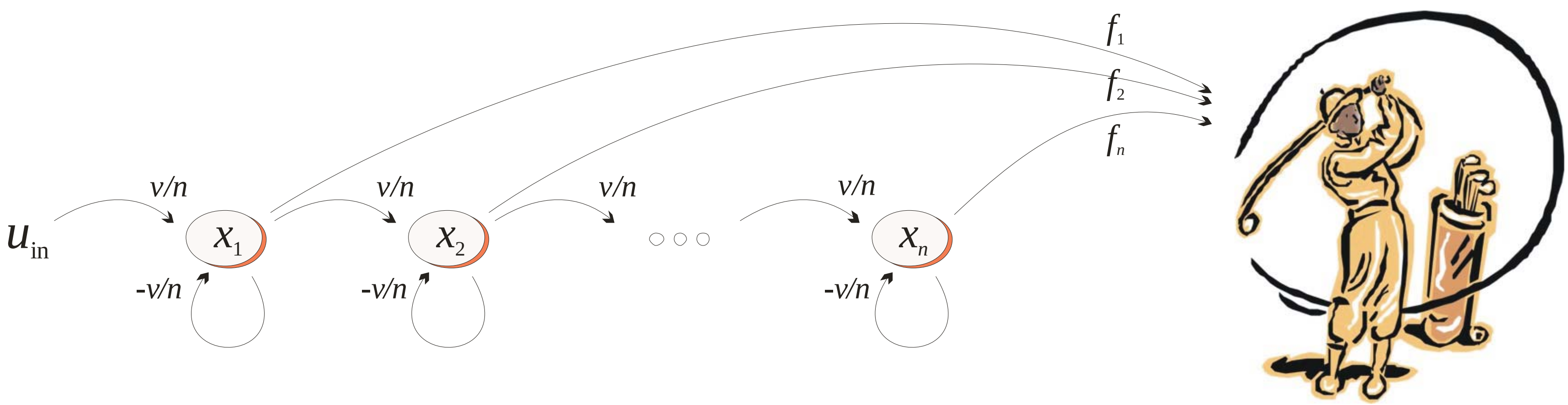
Flow of thought with a network of neurons



A neuron (set of neurons) connects the simultaneously active signal sources

”Deep structures”

- Linguistic representations can be implemented as linked sequences of neurons
- The same seems to apply to all declarative knowledge representations (”feedforward reasoning”)
- Also motoric activation trajectories can be implemented applying the same neuron structure:



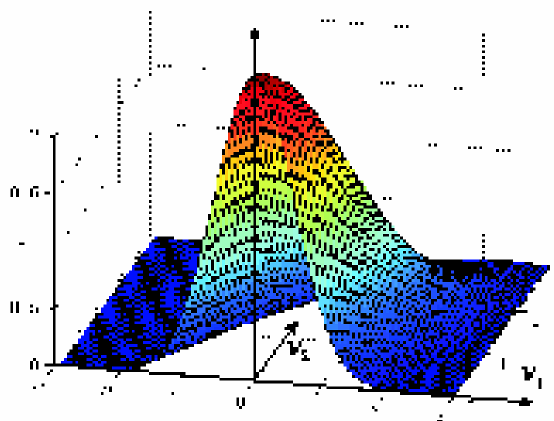
Just yet another model ... what's special?

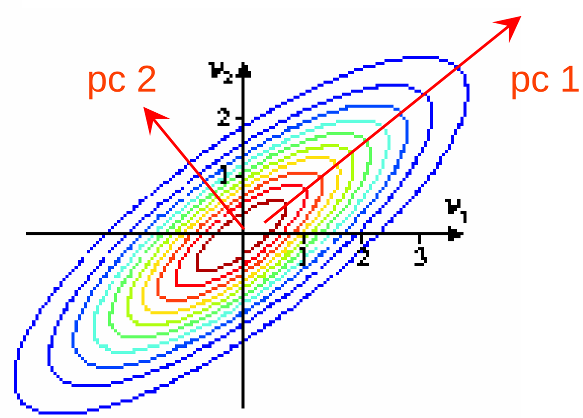
- Novice information processing is declaretive, whereas expert information processing is associative
- The key dilemma in cognitive science are those of *shift from novice to expert* and *automatisation*: *Now one can study it*
- When the neurons start adapting according to the Hebbian/anti-Hebbian laws, such a shift can be explained:
  - If some neurons are often activated at the same time, connections are constructed between them
  - Later, the sequential chain of neurons becomes a parallel group of simultaneously active neurons, competing for the same input resources
  - Finally, when the connections are complete, the neuron is ”swallowed” in the *associative medium* of pre-existing (conscious or subsymbolic) concepts – being available for ”next-level” associations

”Associative medium”?

- What do the above conceptual structures tell about the structures in the (hypothetical) observation data?
- So, assume the mental machinery is cybernetic:
  - The neocybernetic model structure is based on principal components
  - This structure is *forced onto the observation data* (see later)
- So, assume the data can be characterized by the pc’s:
  - Principal components can be interpreted in terms of *Gaussian distributions* (this is one choice)

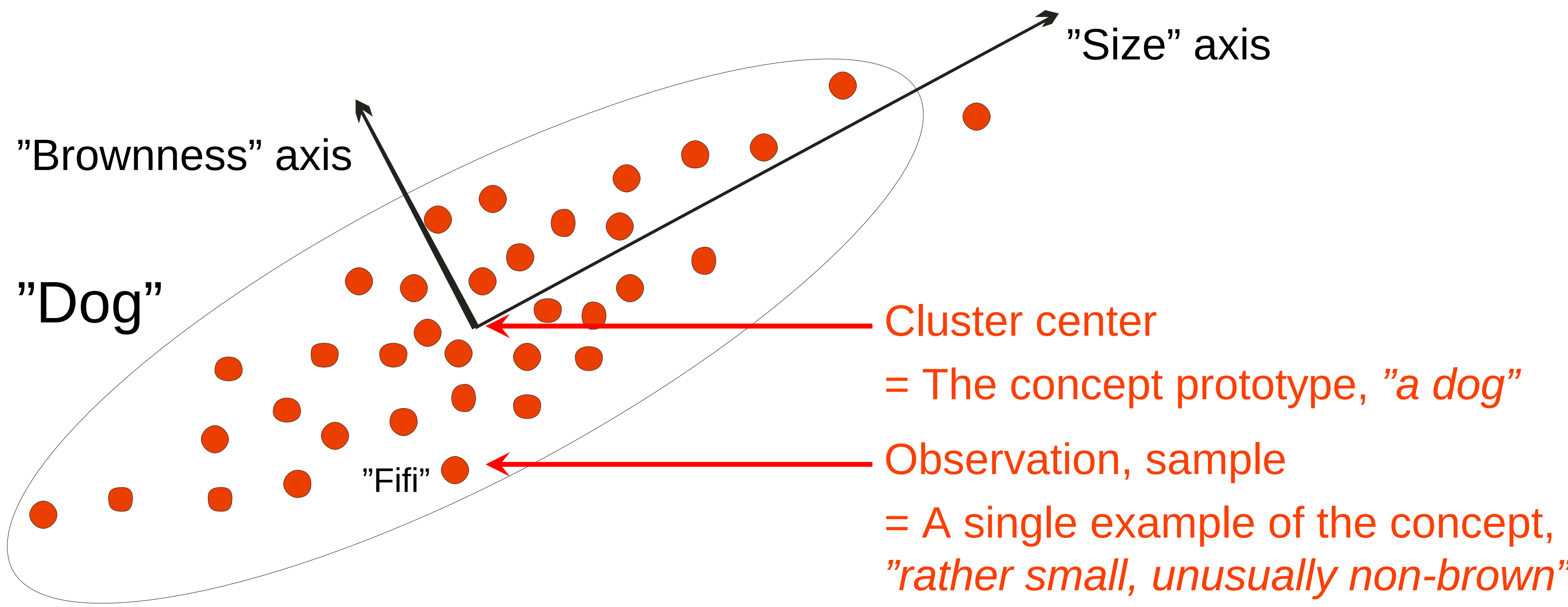
Declarative structures seen as ”virtual data”





”Numeric chunks”

- Data clusters, relevant conglomerates of observations: *Category centers, patterns, “concepts”*
- Degrees of freedom in data, fine tuning within the cluster: *Features, nuances, “attributes”*



- In the neocybernetic spirit, concepts are statistical constructs abstracted over individual observations
- Bias in data, or average vector = category prototype (”center of mass”)
- Typical examples are located near this center in data space
- The features determine the ”orientation” and extent of the cluster, most significant components revealing the directions of most variation
- Remember that the data dimension is assumed to be huge:
  - An observation data sample can simultaneously belong to various clusters
  - Seen from another perspective, an attribute can be interpreted as the category, and vice versa (appropriate interpretation depends on mutual ”activities”) ...

Connections

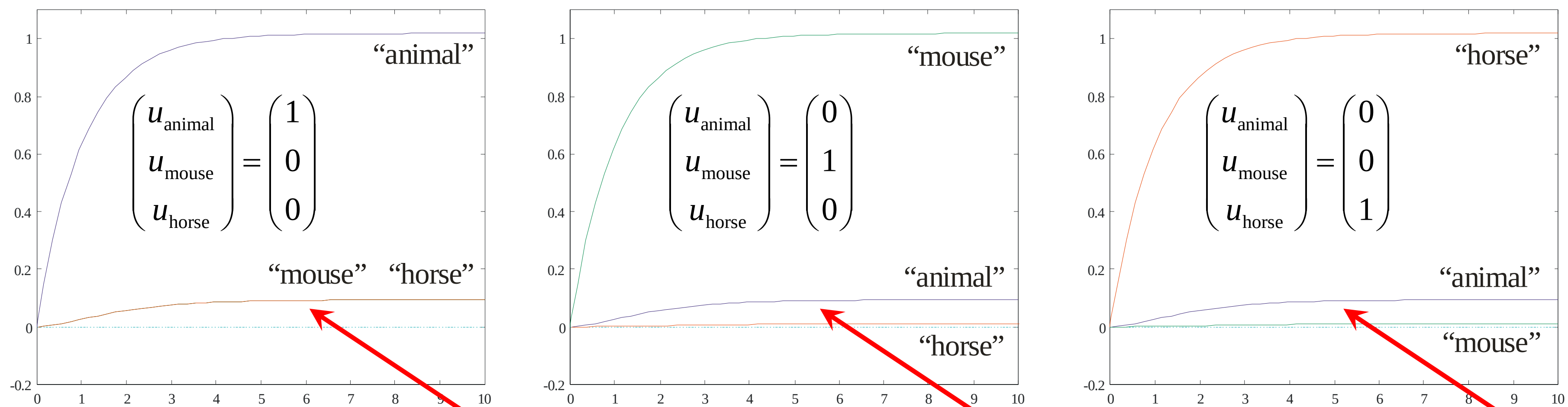
- The neocybernetic data structures can also be interpreted in the framework of *theory of mind*:
- Matrix A can be seen implementing ”hermeneutic balance”, an infinite recursion, where concepts determine each other. In a numeric environment such recursion is meaningful
- Matrix B can be seen implementing ”formalized ostension”, determining the connection from concepts to observable quantities in real world, giving the *grounding* to concepts
- If variables x_i and x_j are active at the same, elements a_{ij} and a_{ji} increase by equal amount – so that matrix A is symmetric
- *What are the consequences*?

Associations based on correlations

- Fully adapted system matrix is symmetric – this means that

$$\frac{d}{dt}\begin{pmatrix} x_{\text{animal}} \\ x_{\text{mouse}} \\ x_{\text{horse}} \end{pmatrix} = -\begin{pmatrix} 1 & -\frac{1}{10} & -\frac{1}{10} \\ -\frac{1}{10} & 1 & 0 \\ -\frac{1}{10} & 0 & 1 \end{pmatrix}\begin{pmatrix} x_{\text{animal}} \\ x_{\text{mouse}} \\ x_{\text{horse}} \end{pmatrix} + \begin{pmatrix} u_{\text{animal}} \\ u_{\text{mouse}} \\ u_{\text{horse}} \end{pmatrix}$$

Internal "perception" External evidence/observation



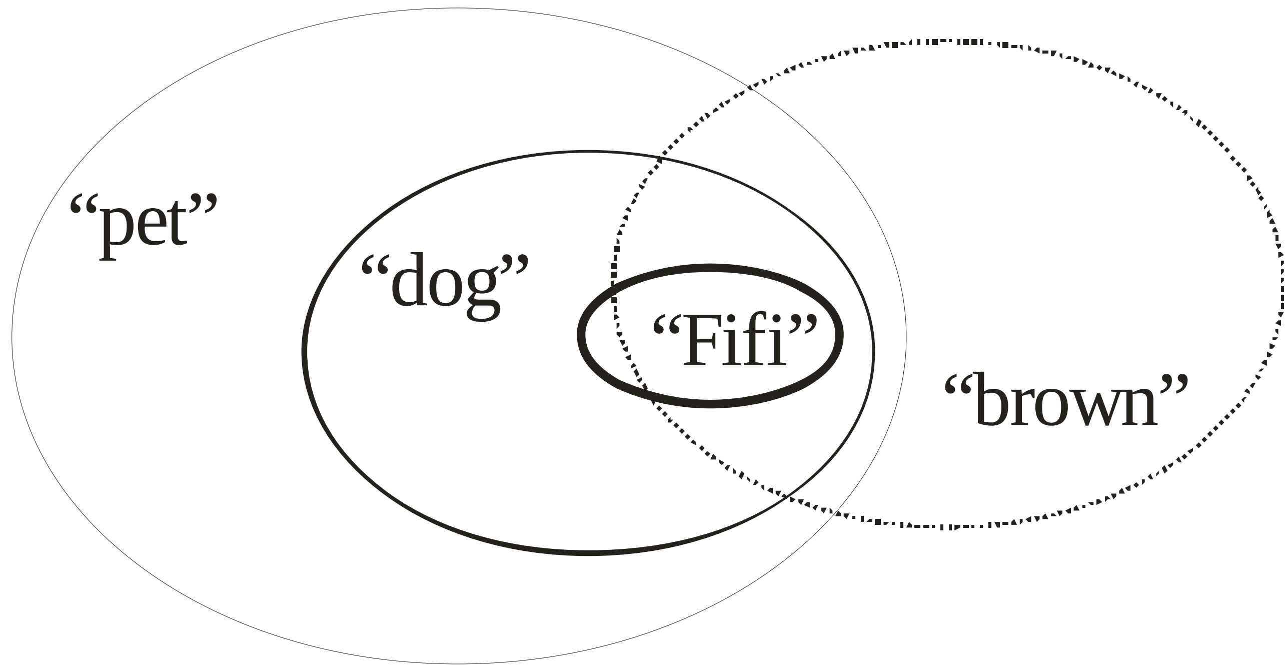
"Associations"

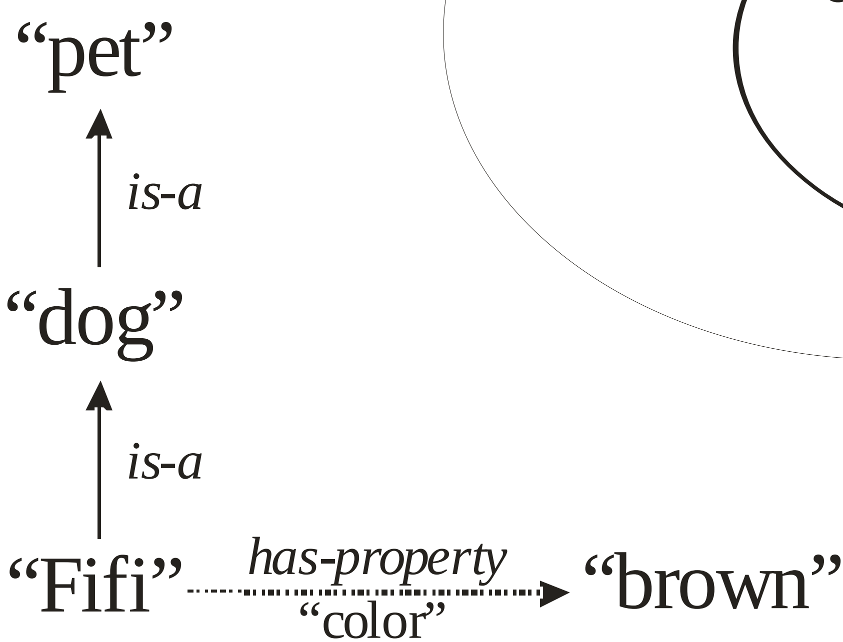
- The behavior of an associative network structure can be characterized in different conceptual frameworks:

- Fuzzy subsets: The internal classes are defined contextually. What is more, there is no strict distinction between super- or subclasses: Subclasses also partly determine superclasses
- As compared to object-oriented modeling, it needs to be noted that there is no distinction between ”classes” or ”objects”, or even ”methods” (or ”properties”)
- Semantic net: Similarly, the relationships between concepts and their properties can be described using a network formulation (see next page)

"Fifi is a brownish pet dog"

- "Fifi" has "dog" properties and others, too





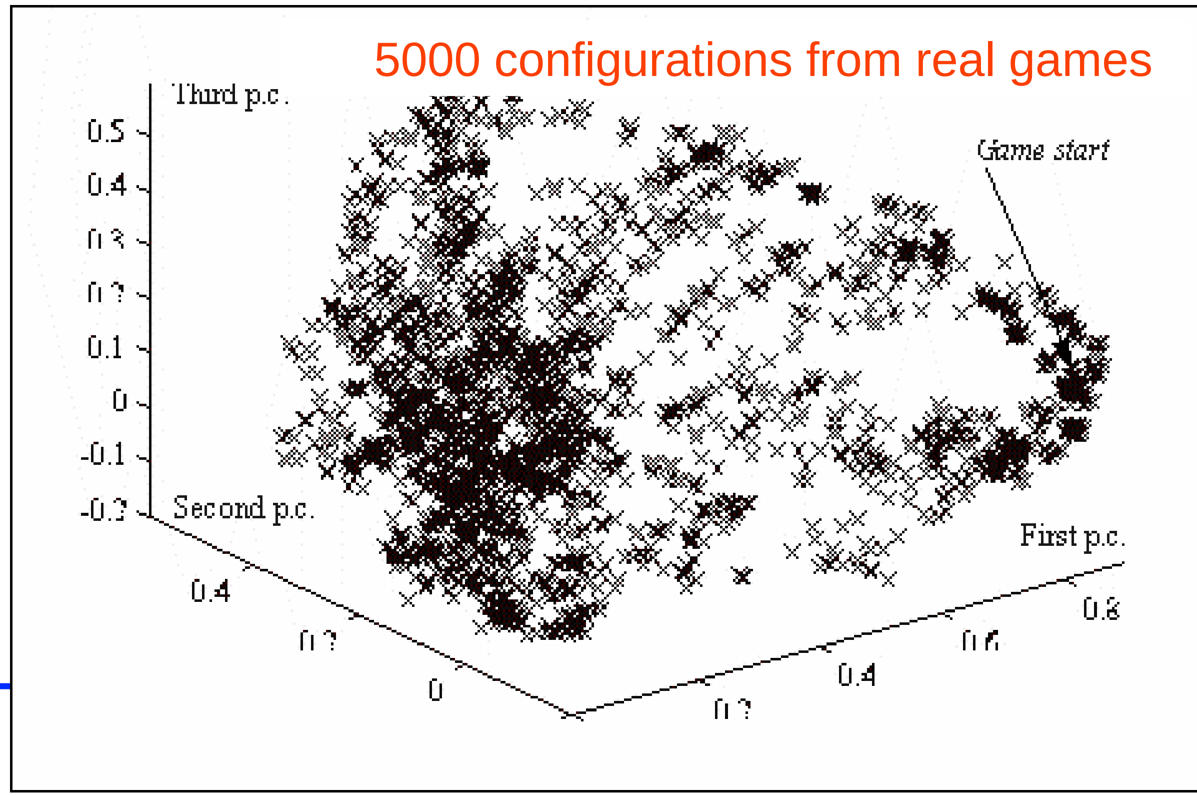
- "Fifi" partly *defines* what is a "dog" and how "brown" looks!

Grounding of concepts
is based on examples

Example: Modeling of a *chess board*

- Configurations are presented as real-valued vectors:
  - One segment for each location on the board (64)
  - One entry in each segment for each of the piece alternatives (12)
- Altogether 768 dimensional data space
- Visualization:

  No structures can be seen if projections are carried out in an incorrect way (mathematical, not physical)

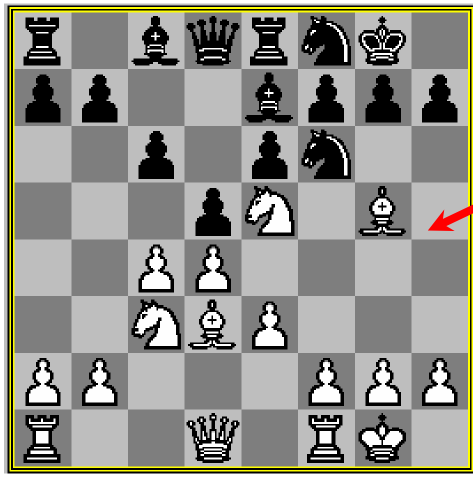


Chunks in chess

- For example, a *castling pattern* is a familiar chunk: Parts of the board are coded as one
- Traditionally, a chunk stands for a symbolic construct – there are problems if the patterns do not exactly match
- It has been assumed that some 50000 chunks are needed to appropriately reconstruct the board

- Now chunks, being numeric correlation entities, are additive
- Typical cluster centers now: *Openings* (”Spanish”, ”Nimzo-Indian”, ...), extending over the whole board
- Degrees of freedom around centers: Extra/missing pieces
- Only 100 chunks extracted applying GGHA (see later) ...

Reconstruction of the view

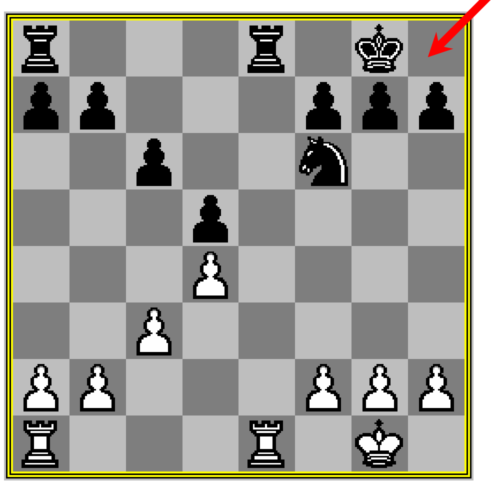


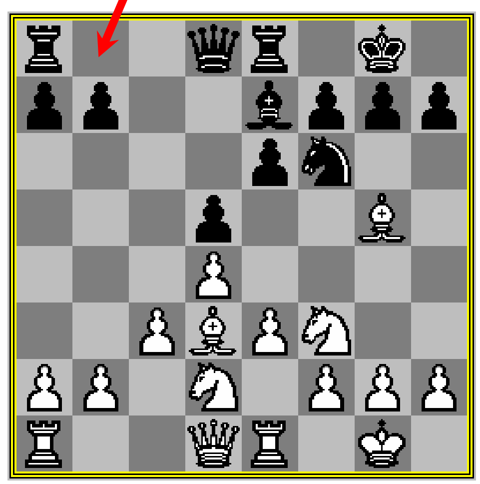
Original (observed) pattern

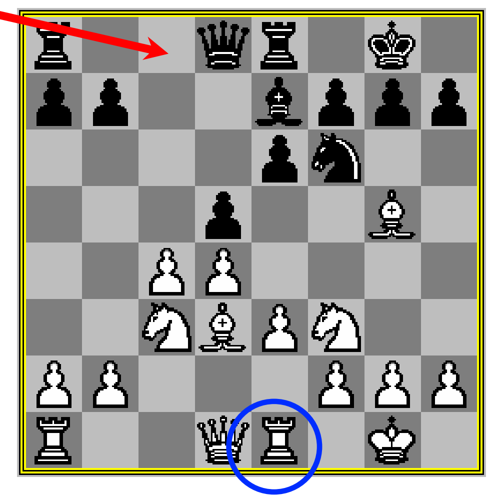
Reconstruction 1: One chunk

Reconstruction 2: Three chunks

Reconstruction 3: Five chunks

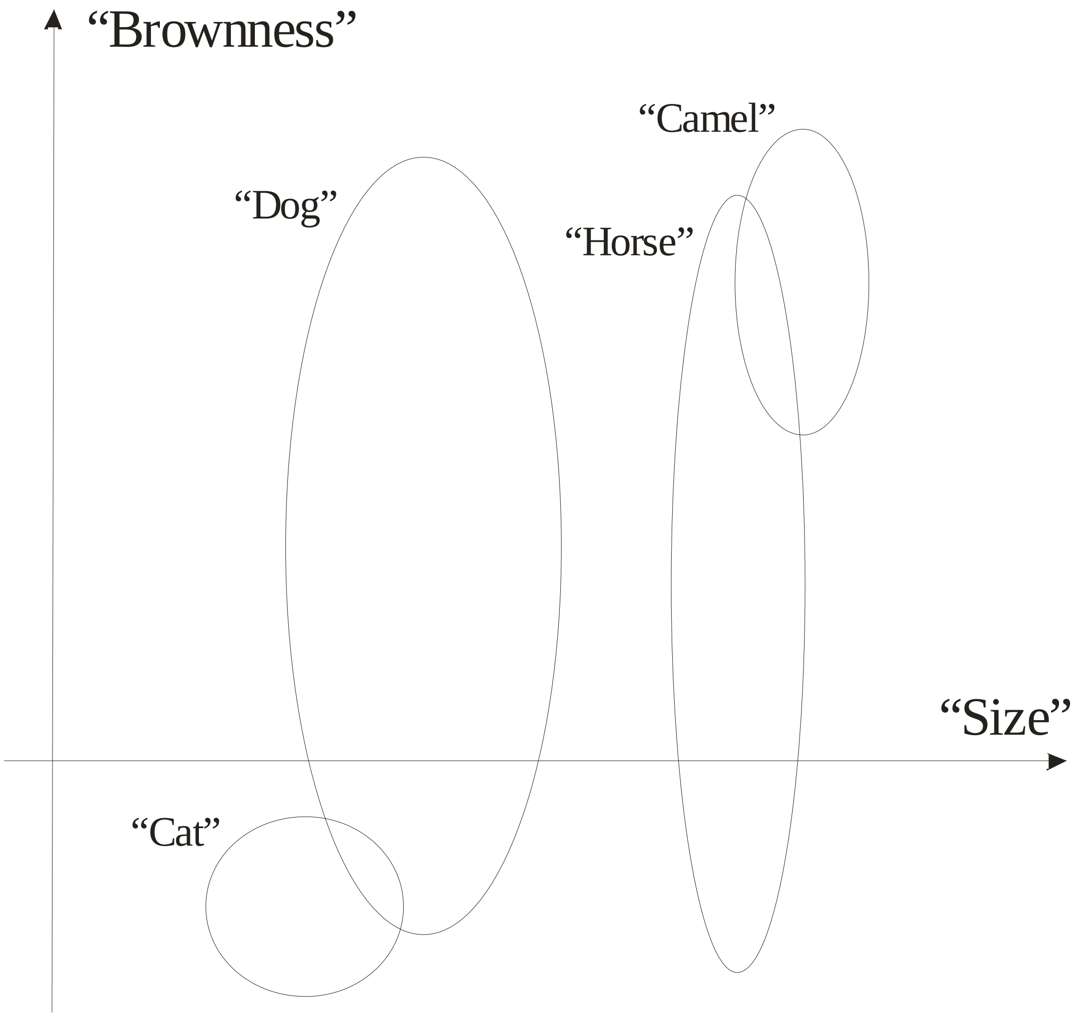






- Chess is a ”banana fly” of cognitive science: Many of the interesting phenomena are visible in not too complex form
  - Experiments with human subjects have shown that, when a chess board is shown to them for a short period of time, the experts can recall all the pieces, whereas beginners can only remember a few pieces. What is interesting is that this is so *only if the shown chess configurations are characteristic to chess*; for random boards the recall rate did not differ significantly. The experts must have an internal model of what the board may look like.
- The experiments revealed that the qualitatively the same behaviors were obtained with the cybernetic model
- What is interesting is that the *errors* that the model made were cognitively credible.

Extensions needed …



- Unimodal data = only one cluster (assume normally distributed) – direct connection to linear models
- This expressive power is not enough for real domains
- Multimodal data = many clusters – *nonlinearity* needed (*sparse coding*)

Sparse coding

- Linear model = A single Gaussian distribution = a single data cluster = a single ”category” can be implemented

  How to implement multiple categories in the same structure?

- One needs to have a mechanism to implement *alternative structures* on demand

  A simple way to implement multiplicity is *sparse components*

- Sparse coding: The goal is not extreme compression, or the minimum number of model components (as it normally is) – The goal is *minimum number of simultaneously active model components* – only a *subset of latent variables is non-zero*

- Sparse coding is mathematically complicated, necessitating nonlinearity, and defying explicit, non-iterative methods
- It has been shown that sparse coding is physically well motivated, giving ”natural-looking” underlying features
- Sparsity results in ”sharing” of components: Input data are decomposed into a set of ”building blocks”
- Sparse component analysis seems to be rather robust – the role of variable weightings is not so acute

- Let N denote the ”sparsity level”, number of simultaneously active components, $N << n$
- The number of combinations, structural alternatives is $\binom{n}{N}$.

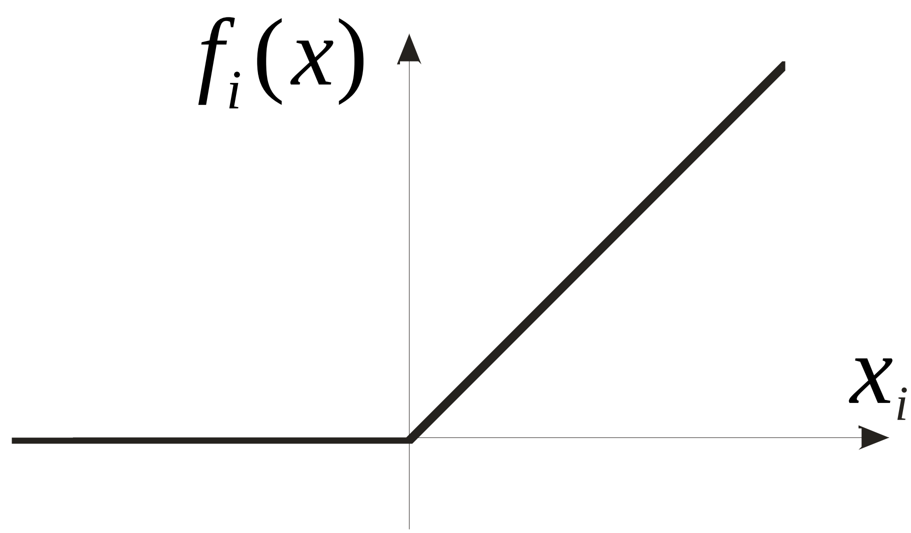
Relation to cognition?

- Traditional theory: Cognitivistic observations
  - Only some 4 – 7 different items can be kept in *short-term memory* (STM) simultaneously; these items are addressed in the “all-or-nothing” manner
  - The physical limit for STM cannot be essentially extended, whereas there are no such acute limitations for the size of *long-term memory* (LTM)
  - The STM capacity can only be extended through employing more appropriate ”items” to be stored (”expert chunks”)
- Cybernetic model: Interpretation of cognitivistic observations
  - Now n = LTM and N = STM
  - The vectors ϕ_i are the long-term memory elements, constituting a structure connecting the m incoming signals together appropriately
  - There are no separate localized physical STM memory registers; rather, short-term memory is implemented in terms of on-line associations of LTM elements through individual neurons (as explained in Lec. 12)
  - References to LTM units are not binary but ”non-negative”

CUT function

- Linearity starting point – gives intuitions in which directions to extend the framework
- A simple example of nonlinear extensions: CUT function
- If variable is positive, let it through; otherwise, filter it out

$$f_i(x) = \begin{cases} x_i, & \text{kun} \quad x_i > 0 \\ 0, & \text{kun} \quad x_i \leq 0. \end{cases}$$



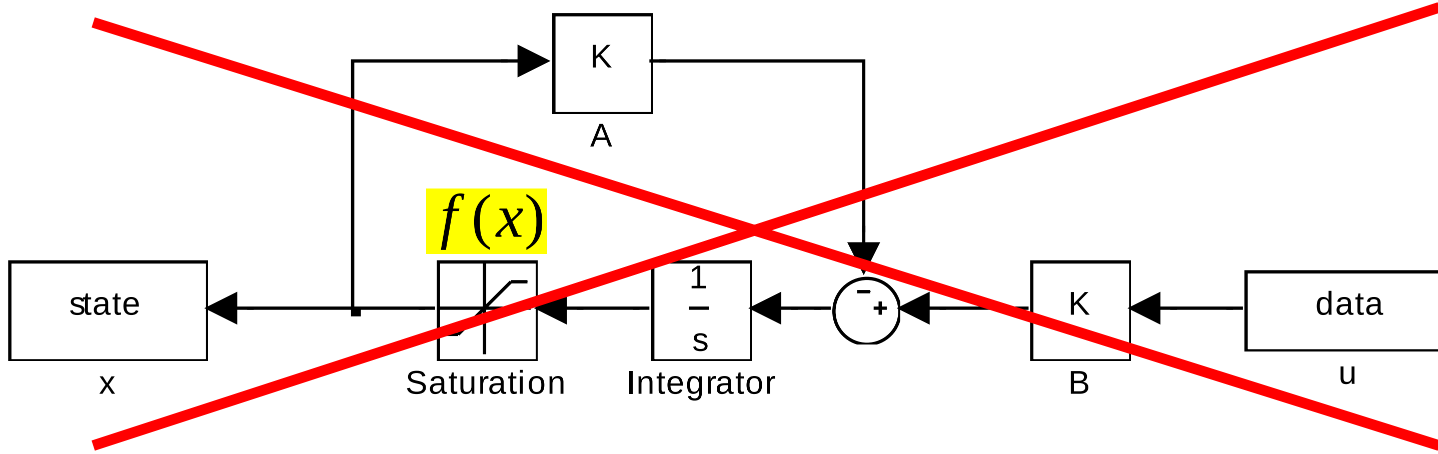
Negative signals are not ”visible”

CUT function properties

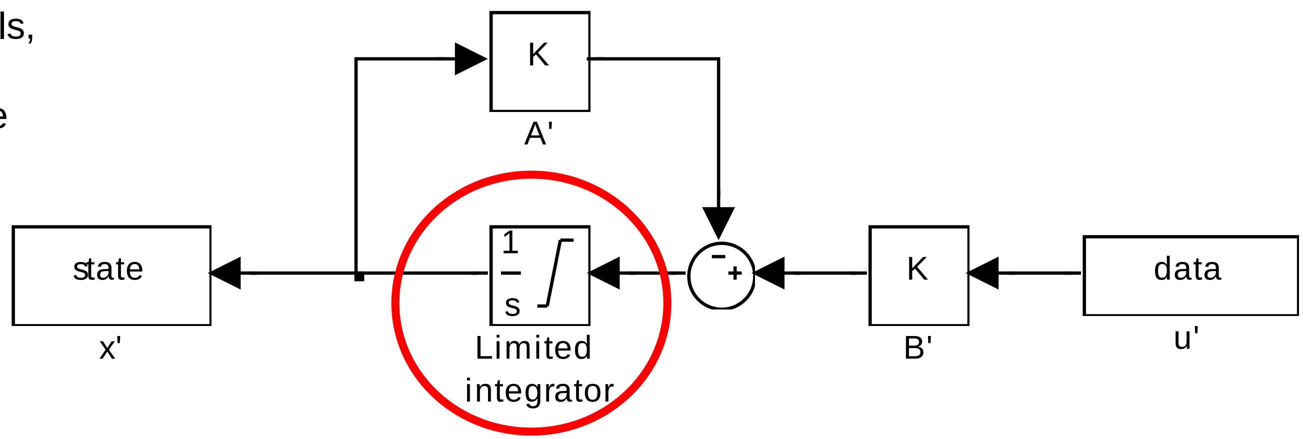
- Direct extension of linearity: Need two cut variables to represent a strictly linear variable
- Theoretical benefits: Functions are piecewise linear – however, still very complex (remember Lec. 3)!
- Physical plausibility: Many real signals are non-negative, but still continuous and unbounded from above:

- Number of individuals cannot become negative (populations)
- Frequencies cannot become negative (neuron systems)
- Concentrations cannot become negative (chemical systems)
- Powers cannot become negative (energy systems)
- Activations cannot become negative (cognitive systems)

Implementation of the nonlinearity



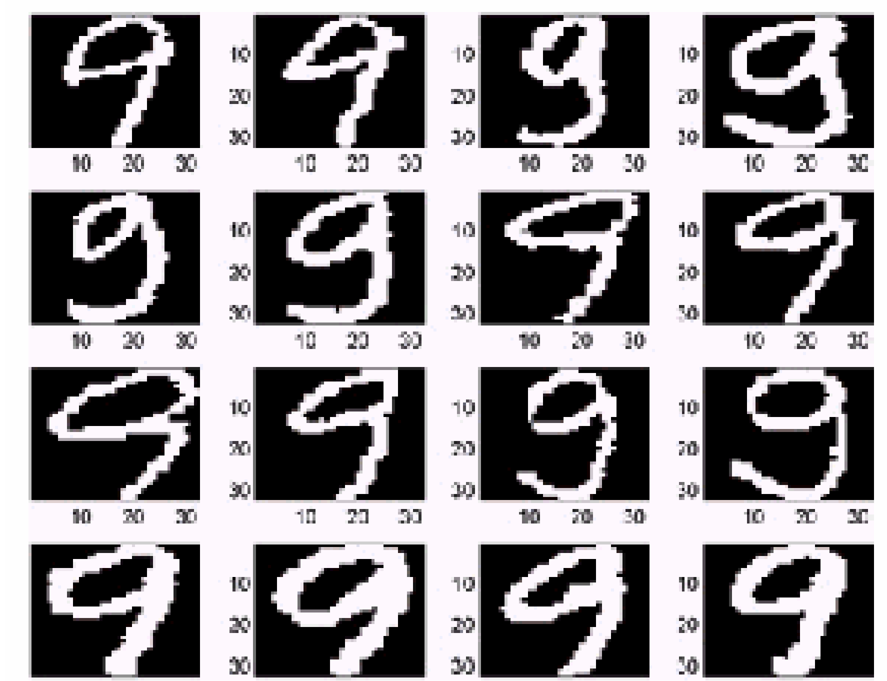
To have bounded signals,
the integrated variables
have to be non-negative



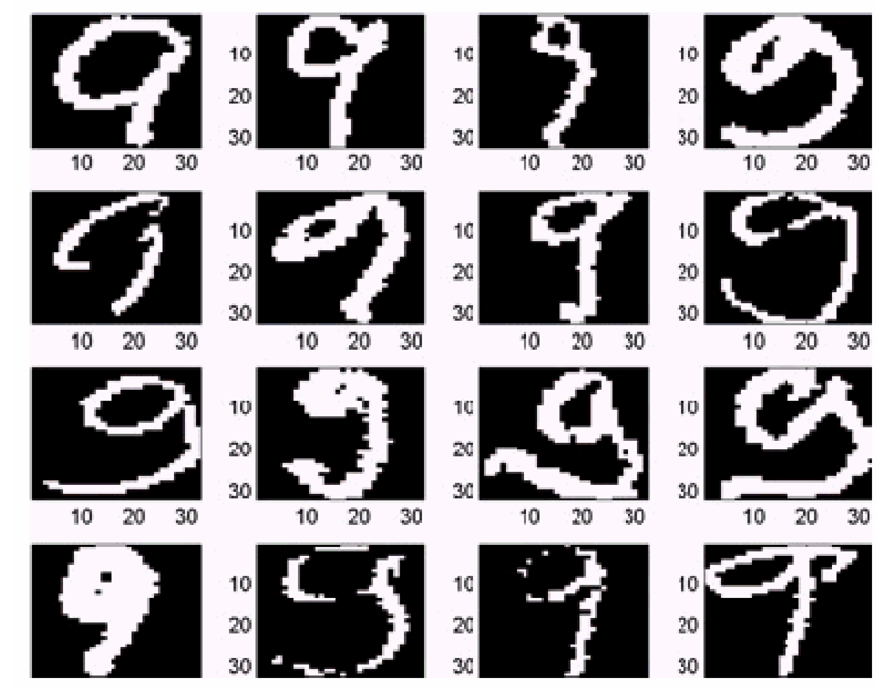
Example: Hand-written digits

- There were a large body of 32x32 pixel images, representing digits from 0 to 9 (thanks to Jorma Laaksonen)

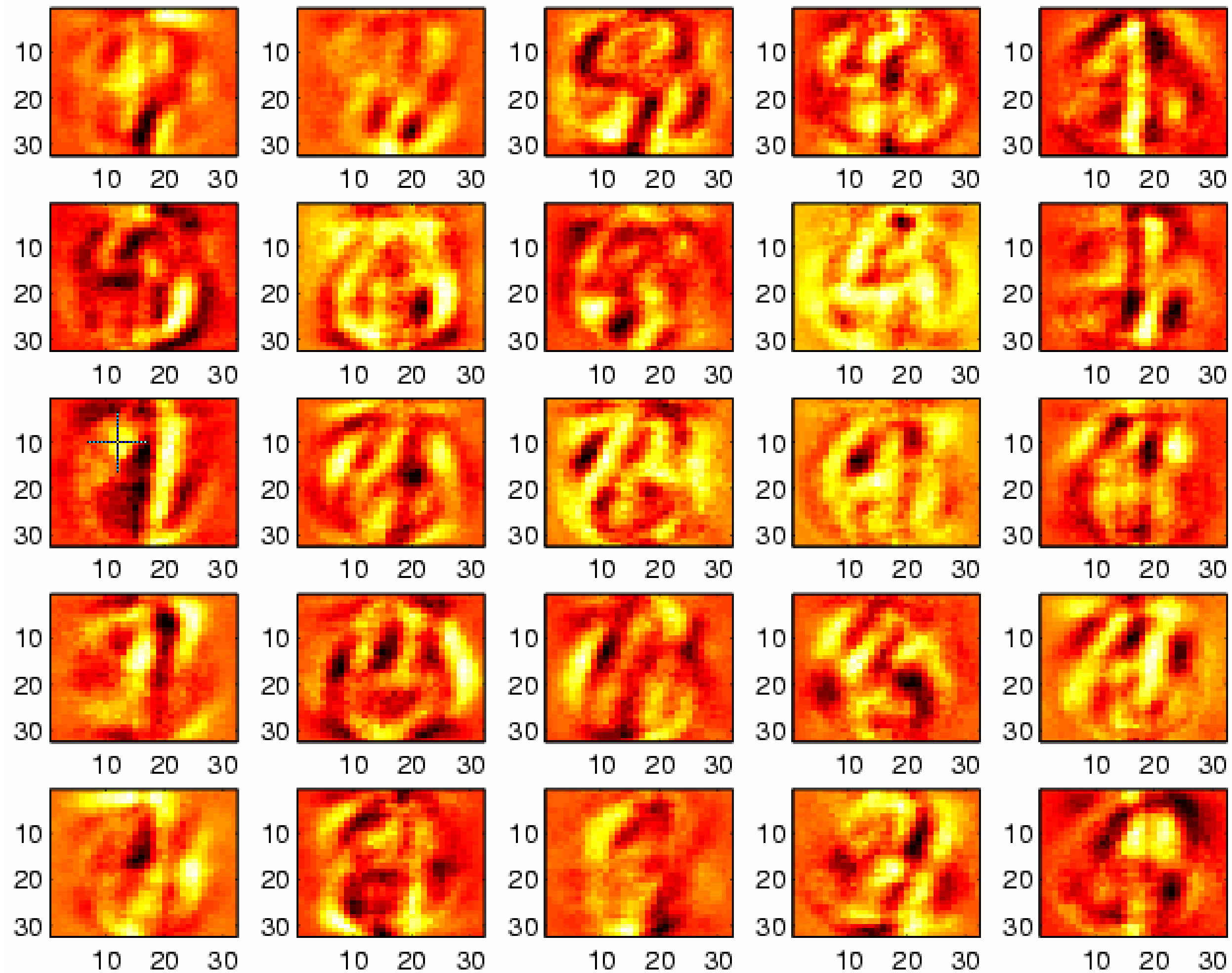
Examples of typical ”9”



Examples of less typical ”9”



- Converged 25 nonlinear features
- Still, it seems that is only the principal subspace that is extracted



- The sparsity level N (the number of non-zero latent variables) has to be controlled by some additional parameters

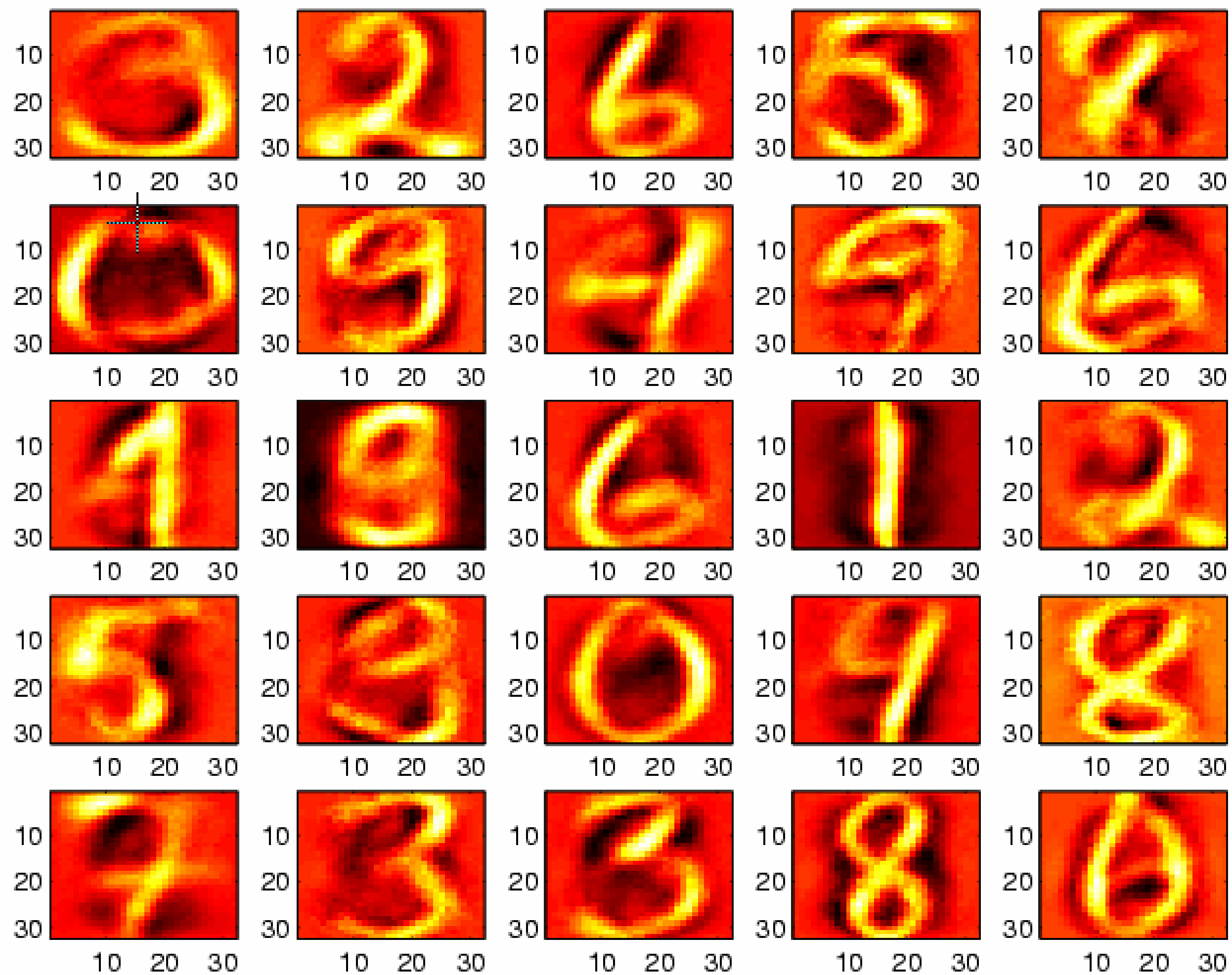
  How to motivate extra parameters?

- Due to sparsity, the correlations can become biased if calculated in the standard way
- One can approximate the ”correct” correlation matrix as

$$A = \mathrm{E}\left\{ \overline{xx^T} \right\} + \bar{A}$$

- Adjusting the additional matrix makes it possible to affect adaptation: More positive definite = more sparse coding
- However, it is difficult to control sparsity this way

- Average sparsity level set to 10
- Clearly, intuitively appropriate features are localized better



- Again, as nonlinearity has been introduced in the structure, the dynamic processes become complicated
- Instead of applying the dynamic process for determining the latent variables, in practice it is easier to try to extract the sparse components directly

Goal: Determine an algorithm that –

- Abstracts the dynamics away, concentrating on the (assumed) final pattern directly
- Optimizes the sparse presentation to explicitly match the input data, minimizing the criterion
- Is an extension of linear principal component algorithms, so that now various *overlapping sequences of principal components are extracted*

GGH Algorithm

- Select each of the data vectors u one at a time, and for the selected vector apply the following iteration:

- Choose the prototype ϕ_c best matching the data:

  $$c = \arg\max_i \left\{ \left| \phi_i^T u \right| \right\}$$

- Apply the *self-organizing map* (SOM) algorithm to store u around ϕ_c, and after that normalize all ϕ_i to unit length
- Eliminate the contribution of ϕ_c out from the data:

  $$u \leftarrow u - \left(\phi_c^T u \right) \phi_c$$

- Repeat the above deflation process until the sparsity goal has been reached.

After extraction of the candidates, weights can be refined (if they are not orthogonal)

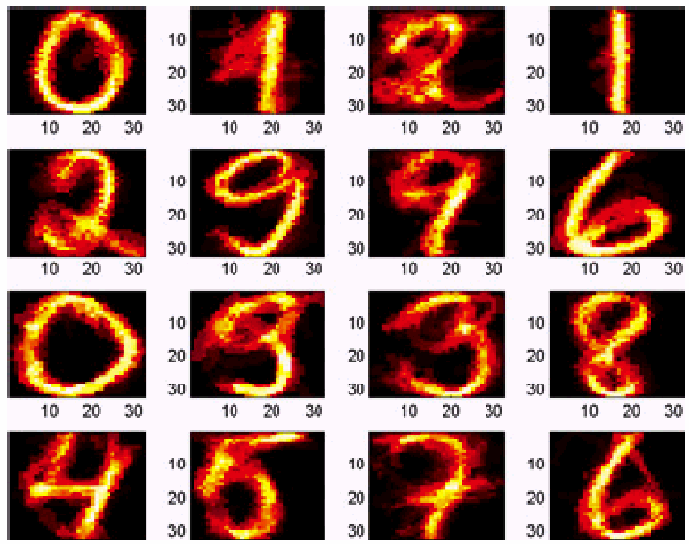
$m = 1024$

LTM

$n = 16$

STM

$N = 1$:



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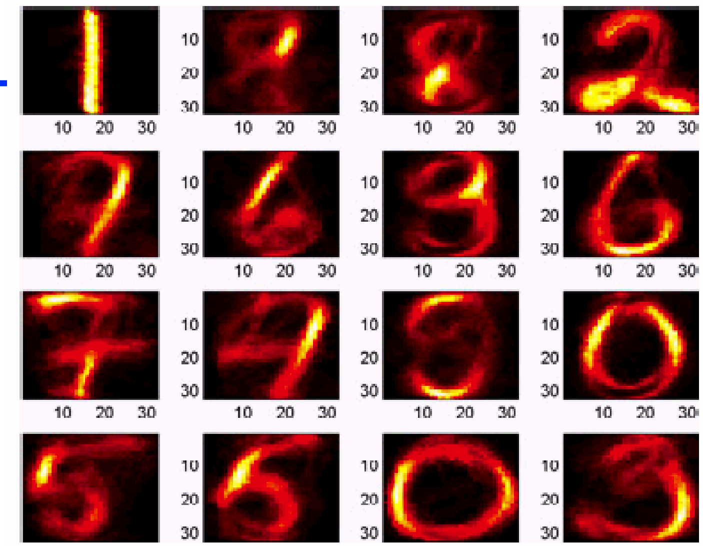

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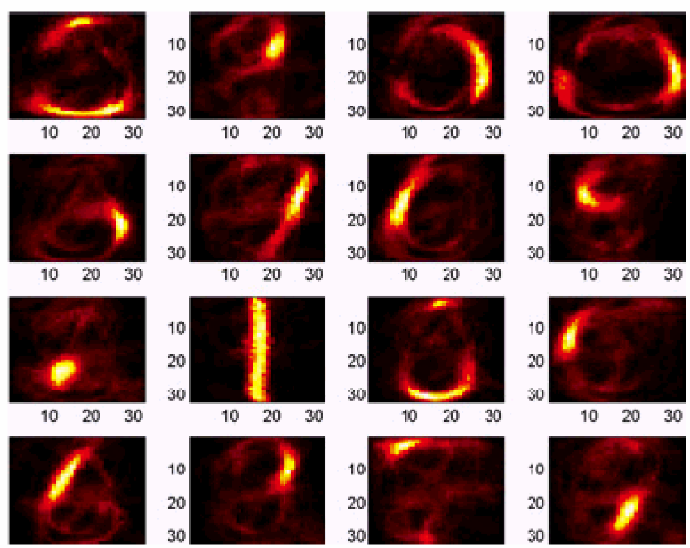

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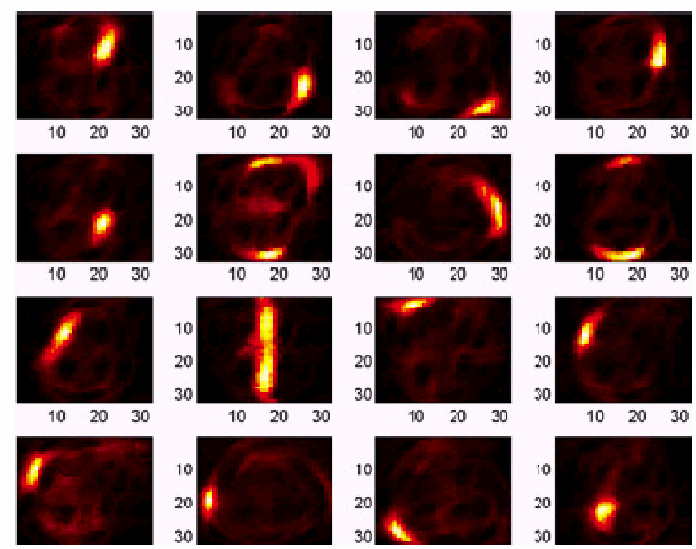
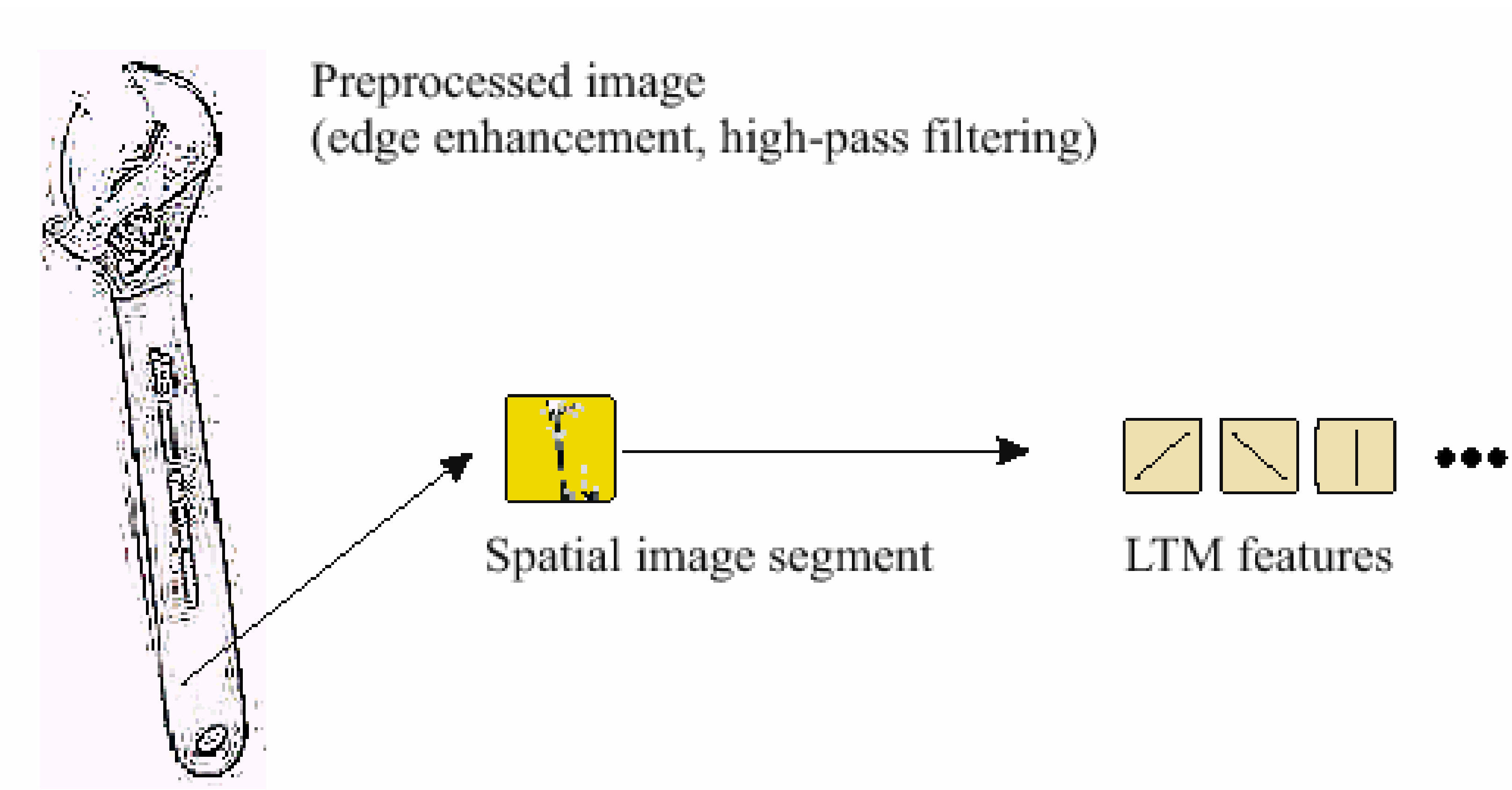


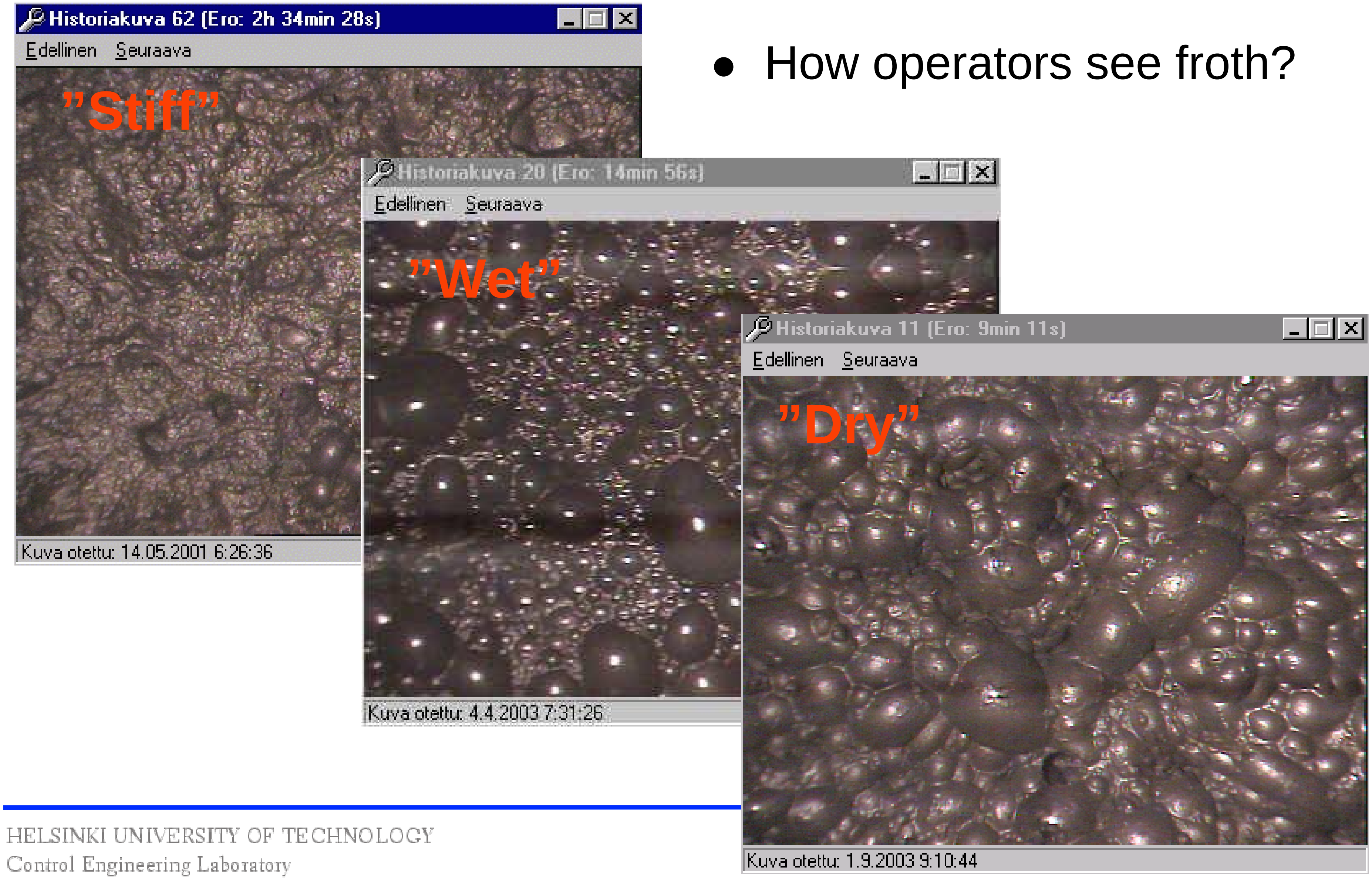
- Visual V1 cortex seems to do this kind of decomposing!



Further experiments

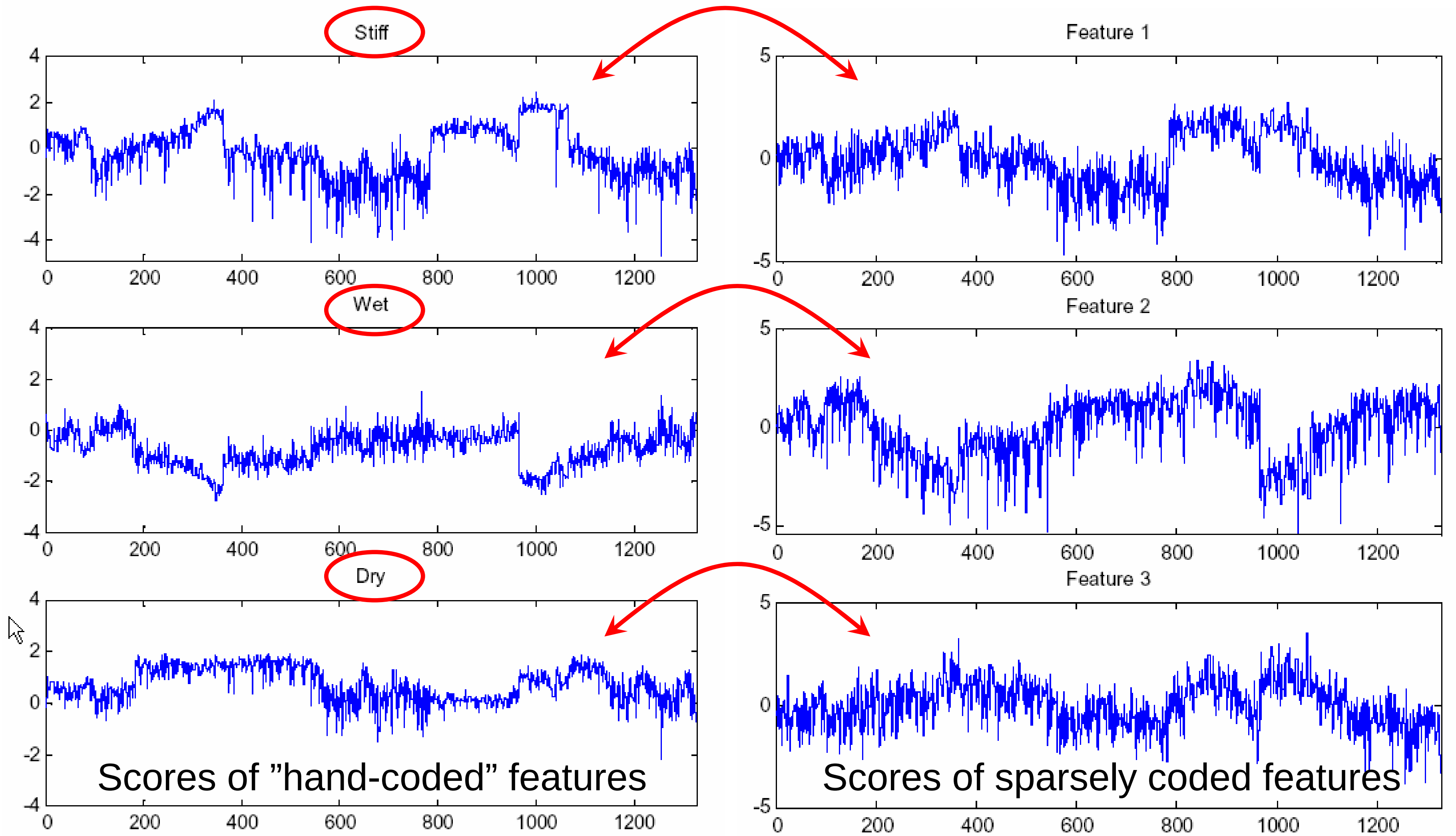
- Pyhäsalmi zinc concentrator: Image analysis is applied to extract information of a frother cell
  - Extracted variables: Bubble size and ”load”, color, intensity, speed, ...
- Operator queries were carried out at the flotation plant:
  - ”What are the main types of flotation froth?”
  - ”How would you characterize those froth types?”
- The characterizations were hand-coded in a classifier
- Independently, the available data was modeled applying GGH Algorithm, automatically extracting sparse structure
- The sparse components were also applied in a classifier ...

”Conceptual froth types”



- How operators see froth?

Sparse coding captures cognitive essence?



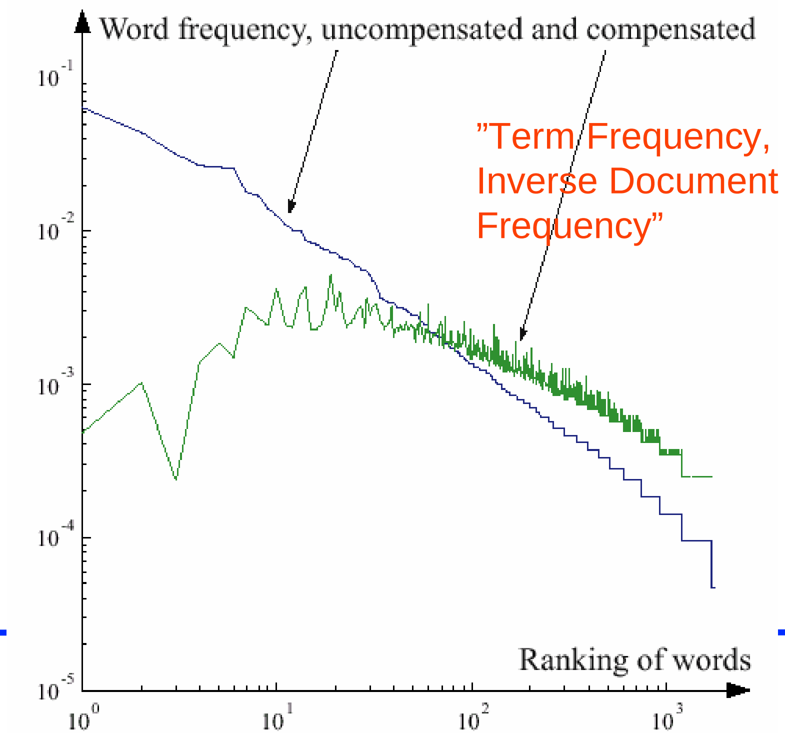
Real-life scale applications

- Real test for cognitive model plausibility – truly big systems

  Data mining & exploratory analyses of textual documents

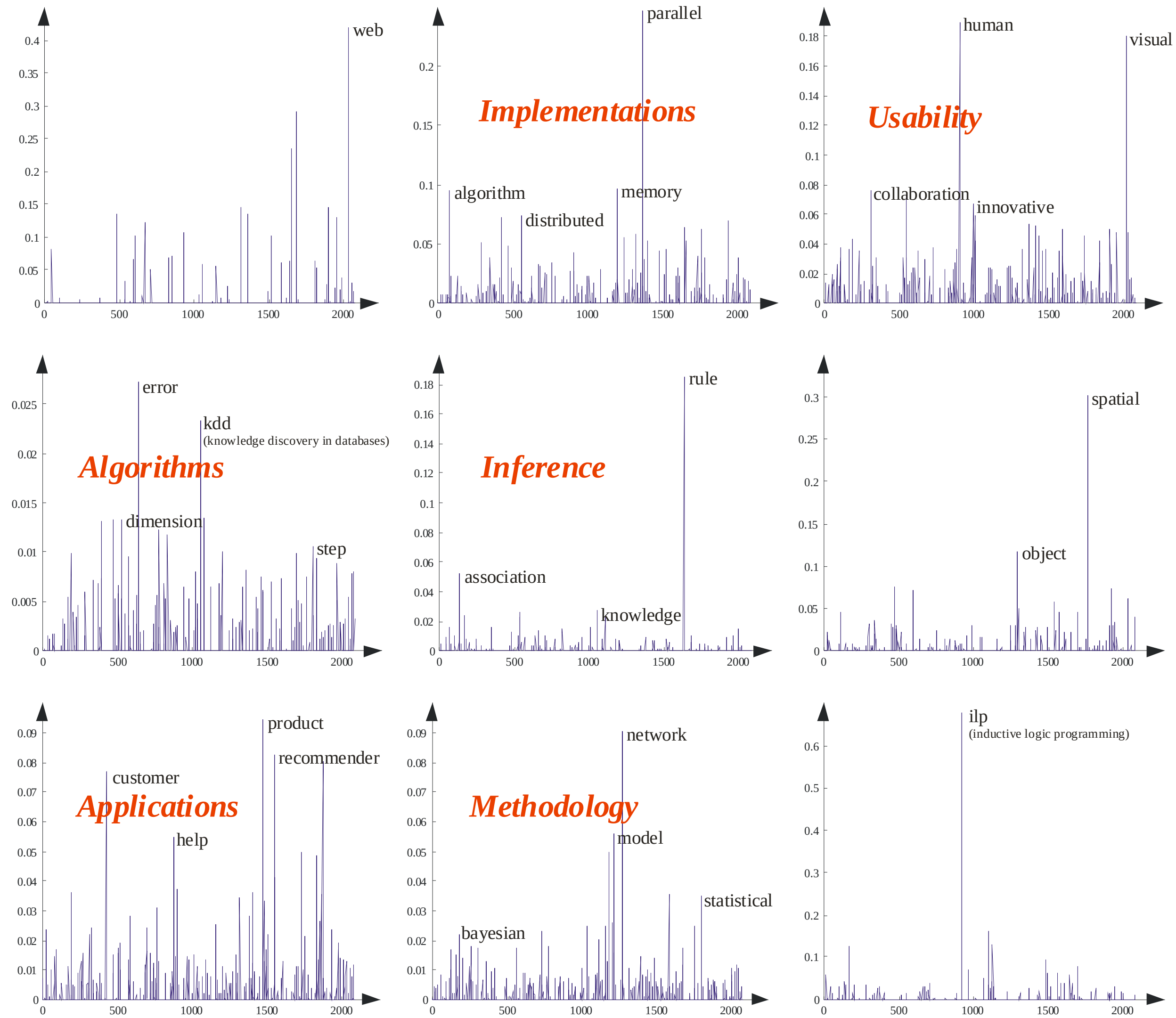
- There is a continuum from dense to sparse models:
  - WEBSOM (textual SOM) is *extremely sparse*, all documents being represented by only one of the prototypes
  - LSI (latent semantic indexing) is *extremely dense*, all documents being represented by all of the prototypes
  - Natural representations are between the extremes, being *relatively sparse*?
- Potential of sparse document models:
  - Sparse components are ”generalized keywords” characterizing documents
  - Automatic ”table of contents” into the text material is constructed
  - Applications: Structuring, search, collaborative filtering, ...

- Data material from INSPEC search: ”knowledge mining”
  A few hundred documents, a few thousand words ...
- Words in the document abstracts used as individual inputs
  Very little preprocessing of data, only TFIDF weighting
- Modeling *document fingerprints* = Histograms of term contents
- Common words determine similarity between texts (no deeper semantic analysis)
- Data is ”static”: No succession between texts observed, etc.



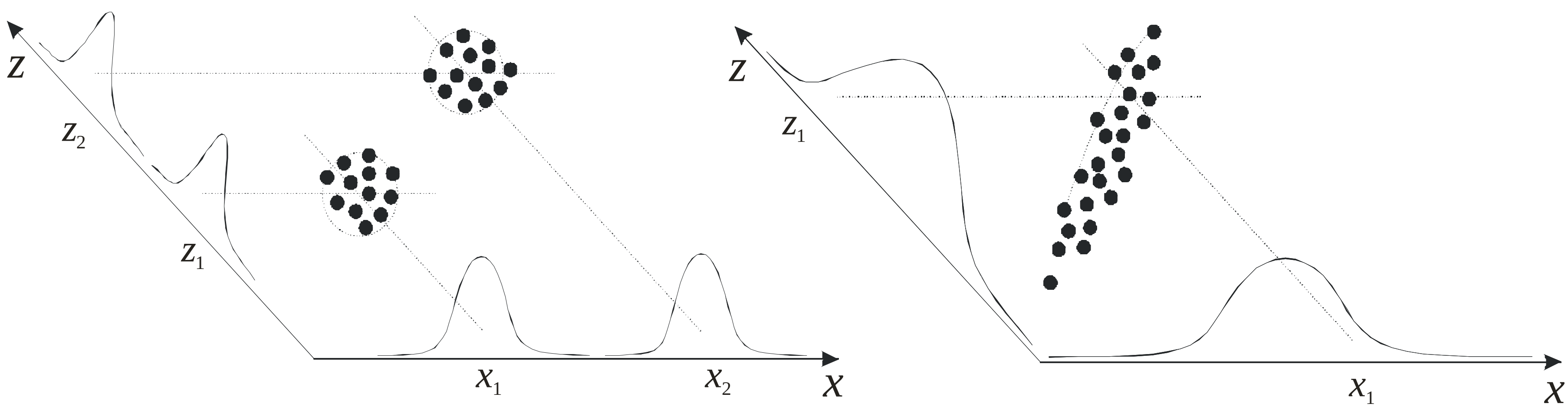
”Generalized keywords”

- $N = 3$, $n = 9$
- Visualization of the keywords shows which words are the most relevant
- Each document reconstructed approximately as a weighted sum of three such keywords



About *expertise*

- Reasoning = associative pattern matching of incomplete data
- Relation to *Case-Based Reasoning* (CBR): Now the patterns have continuous fine structure
- Relation to *expert systems*: Rules are projections of the high-dimensional data onto some distinct dimensions



Here rule systems work (IF $x = x1$ THEN $z = z1$, etc.) ... But here they do not

About *knowledge*

- Traditional definition of **knowledge**:
  1. Motivated,
  2. true
  3. belief

  Instead of *one* concept to be defined now there are *three*!

  Symbolic grounding is necessarily *hermeneutic*

- In neocybernetic framework the deepest concepts become matters of scientific study
- Instead of *truth* the essential thing now is relevance: Do there exist appropriate data structures in data
- Counterintuitively:

  Making ”truth” *relativistic* it becomes *universal*!

About *wisdom*

Wisdom vs. intelligence:

”A clever person can manage in situations where the wise one never falls into”

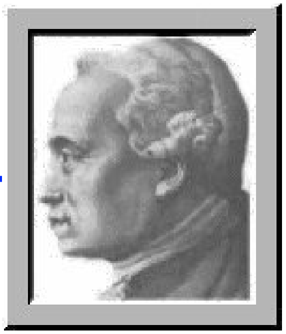
Another way to put this:

The clever has the possibility of constructing such models of the environment that the wise one already *has*

About *consciousness*

- The most challenging problem is that of *consciousness*
- There are different kinds of theories:
  - Consciousness is simply manifestation of the ”soul” – only for humans!
  - Consciousness is manifestation of infinite recursion, ...
- There are also contradictory intuitions:
  - Essence of consciousnes = ability to feel pain
  - ... But then, rather than being topmost in cognitive hierarchy, it is the simplest!
- Cybernetic interpretation: It is about agent’s modeling ability, consciousness = the capability of constructing sophisticated enough models where there is distinction between ”self” and the environment
  - Consciousness is gradual; animals are conscious in varying degrees
  - *Small children are not conscious*?!

About *deep questions*



- Human understanding is necessarily limited by our senses and our cognition machinery

How can we know that we share the same views as other people?

What is the relation among subjective worlds?

What can we know about the world beyond our senses?

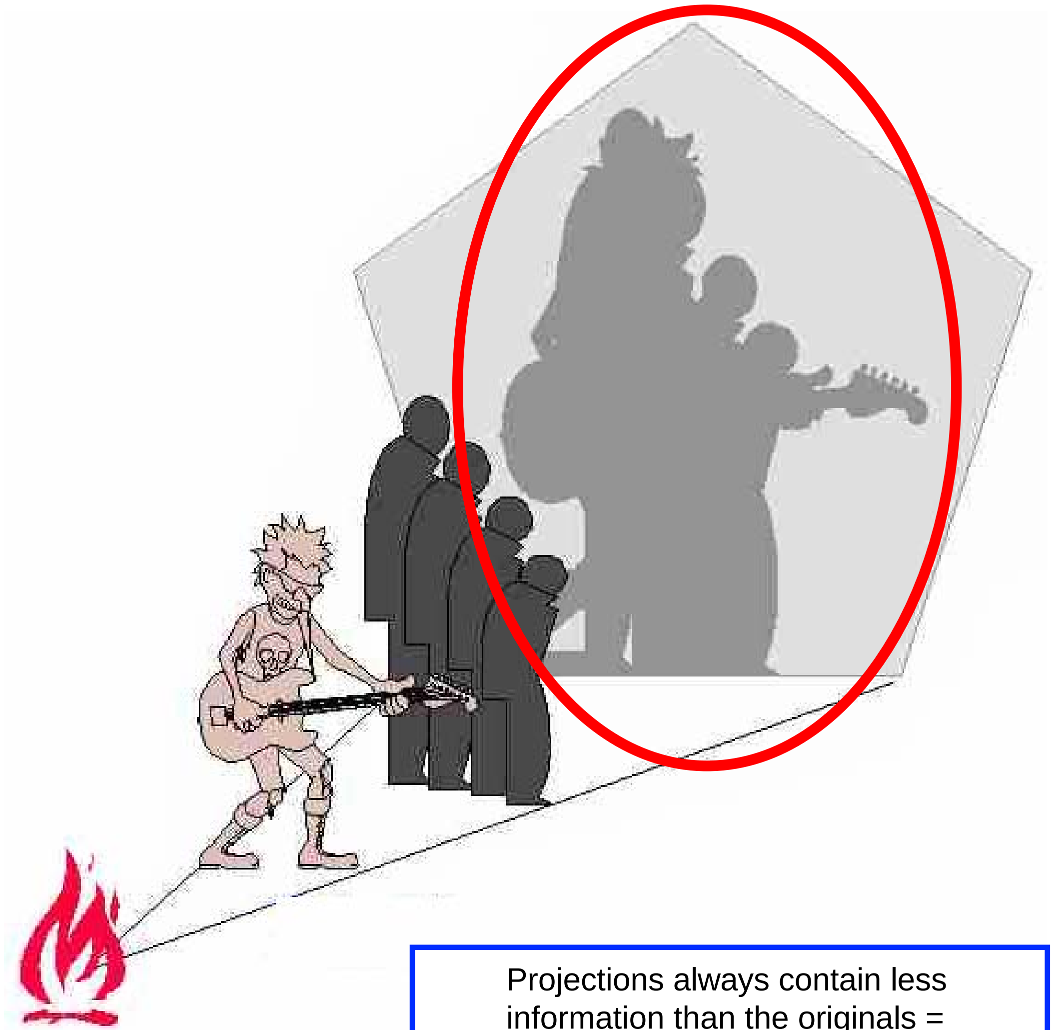
How are the subjective and the objective related?

World as data

- Plato's "Cave Metaphor"

  The observations are a projection of the high-dimensional reality onto the space spanned by our senses
- Put in another way: Observation processing systems only see data

  ... And one can never escape this fact



Projections always contain less information than the originals = there are many ways to interpret observations ...

And this applies not only to visual images but truly *everything*!

Models vs. reality

- Traditional complex systems pessimism
  - Curse of complex systems: Sensitivity to initial values and parameter values, small deviations finally explode
  - ”Cardinality” of systems is higher than that of possible models – there exist more systems than there are models
  - Reality is fundamentally ”non-modellable”, all models necessarily give false predictions (compare to weather forecasts, etc.)
- Neocybernetic optimism
  - Because of local stability assumption, system converges to the same state from within a basin of attraction, even if the initial state is inaccurate
  - Models are optimal and unique *to an extent*, reflecting the properties of the environment, so that there exists a similarity between models and systems
  - Modeling machinery can be implemented in very different domains without changing the results

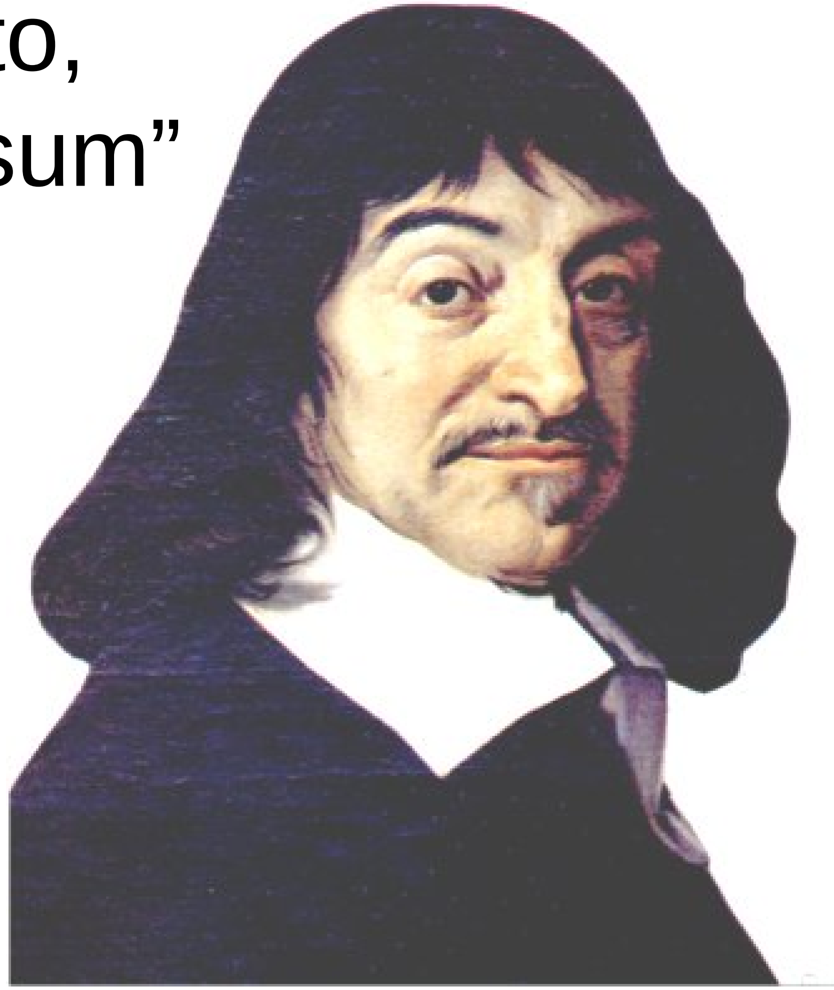
Subjective worlds

- The data modeling machinery essentially dictates what will be expressed in the model
- Immanuel Kant: perception is a construction, largely a property of the mental system

  = The real mental model is also only a model of the world
- This is the reality we live in: What is left outside will forever remain there – and we have no way to know what it is

- What can we then know about other people’s worlds?
  = Can there ever be real understanding among people?
- Further – can there ever exist “understanding” among humans and computers?

”Cogito,
ergo sum”



”Cogitas,
ergo sum”

Intersubjectivity

- Kant: Humans share the same modeling principles
- Assumption now: These principles are cybernetic – uniqueness (?) means that the model structures the same

- Humans also can share same world view, same concepts
- What is more – if a human and a computer share the same sensory environment, the resulting models again are similar – a computer and a human can share the same world view

- What is then *objective* reality?

  For any application that one can imagine, it does not matter – *everything* is, after all, only meaningful in *subjective* reality

But there is more ...

Interobjectivity

- Tradition: ”Humans are just constructing models of nature” = ”The true essence of natural systems cannot be captured”
- But it is also Nature that is constructing models to implement cybernetic systems

The natural system IS a model!

The model IS a natural system?

- If we can find the appropriate model structure for a system, the constructed model can capture its true *essence*

Philosophical convergence

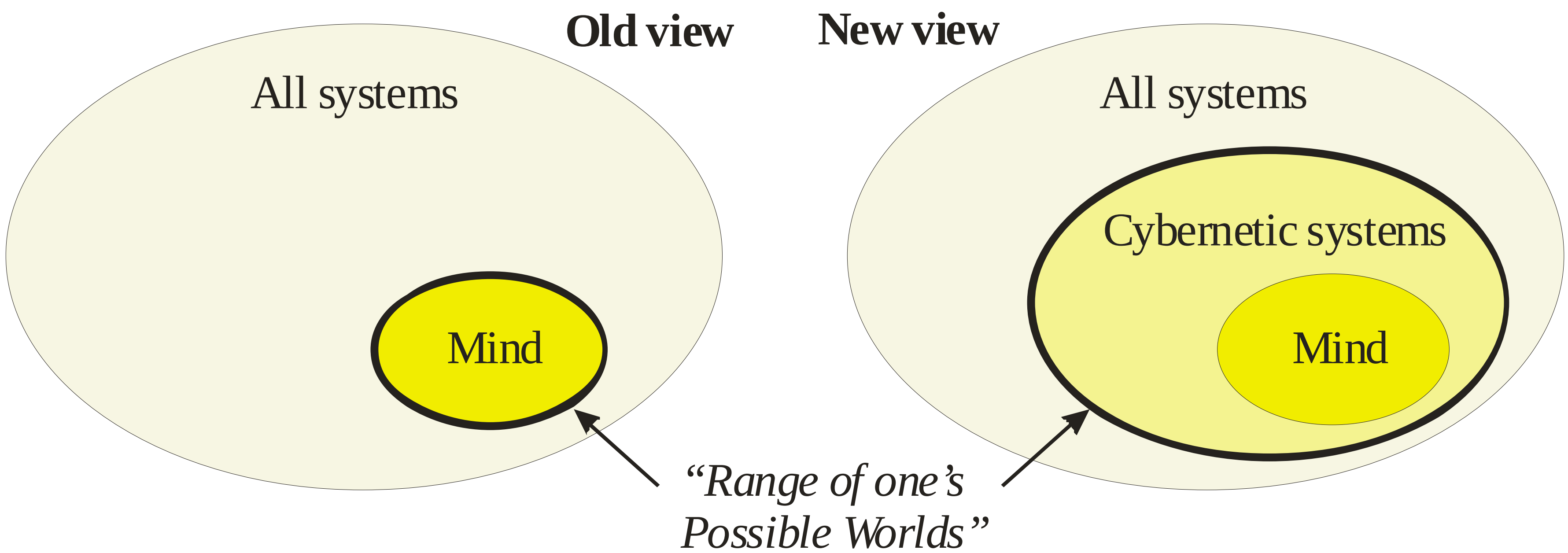
- The connection between intersubjectivity and interobjectivity can be rephrased also in another way:

  Ontology = Study of *what there exists in the world*

  Epistemology = Study of *what one can know about it*

- It is the same processes that take place outside the mind and inside it
- The only difference between ontology and epistemology is the point of view
- *Note that basic physics, etc., are not necessarily cybernetic processes, and may remain outside (remember Feynman)*

- Not all physical systems are cybernetic – but the most interesting and relevant ones *are*
- Such systems can extend our mental realms

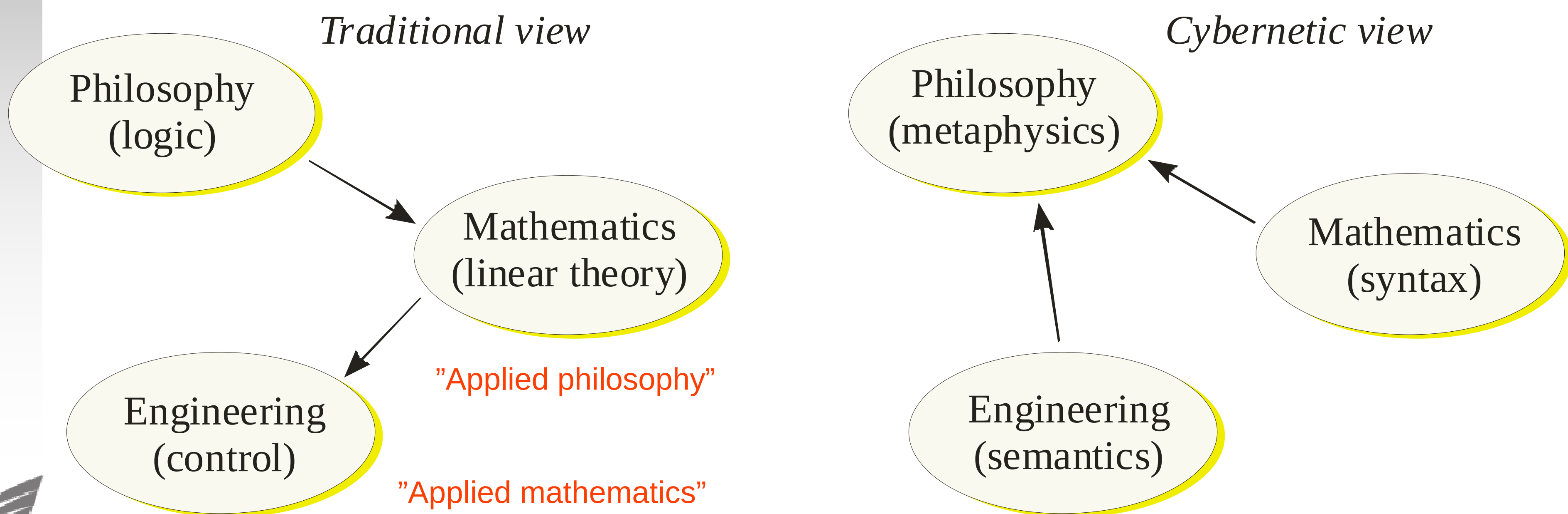


Further consequences

- Second-Order Cybernetics (Heinz von Foerster): ”The mind (a cybernetic system) cannot understand systems of the same level of complexity
- Now opposite view: Human can be liberated from the loop, there are powerful conceptual tools for ”understanding” the inner and outer processes alike:
- Claim #1: *Modeling theory is the key towards understanding the structure of complex systems*
- Claim #2: *Control theory is the key towards understanding the behavior of complex systems*

Control engineering rehabilitated

- Mathematics gives the language for discussing philosophies
- Control understanding gives the *meaning* and *relevance* to the philosophical discussions



Example intuition: *Adaptive control*

- Adaptation is the key property in truly cybernetic systems = they are *adaptive control systems*, trying to implement more efficient controls
- This is yet another benefit if one has control engineering background: One can understand what happens in truly cybernetic systems
- Why are adaptive controllers notorious in control engineering? Why do they behave in a pathological way?
- The reason for ”explosions” is *loss of excitation*: Good control eliminates information (variation) in data
- This takes place in all loops of simultaneous model identification and control that is based on that model

Power of mathematics

- It has always been wondered why (simple) mathematics is so powerful in representing Nature
- There are now some fresh points of view available –
- To start with, the cybernetic phenomena *are* simple, being characterized in terms of correlations, etc.
- But what is more fundamental – it seems that system complexity and analyzability go hand in hand:

  If Nature has been able to construct sophisticated model structures, why not us?
- The positivistic claim here also is that *cybernetic systems can always be modeled*

Cybernetic thinking offers many new intuitions to modeling work

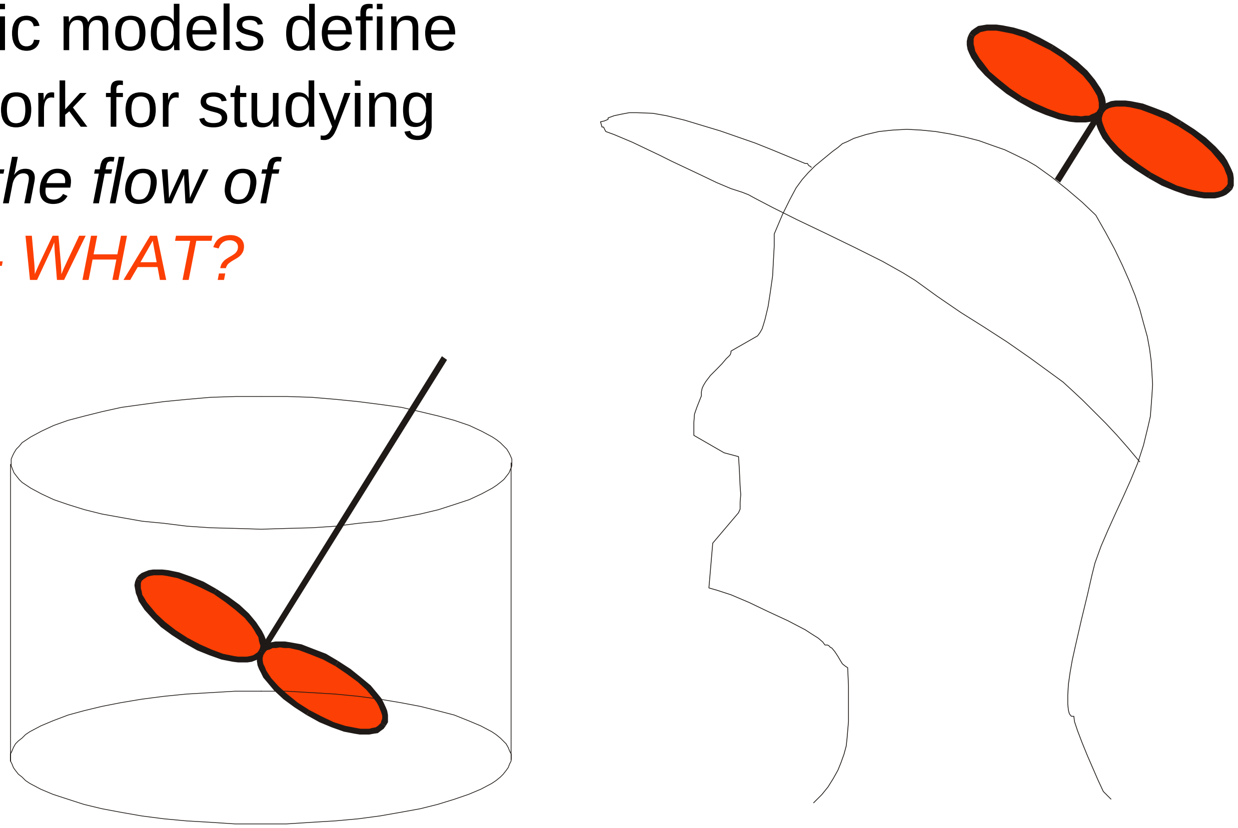
Further: *Ockham's razor*

- When constructing models, there are many presuppositions that seldom are explicitly stated
- One of such presuppositions is *Ockham's razor*, telling that the simpler explanation is **"more true"** than a complex one
- This is of course pragmatic, the only realistic starting point – otherwise the models become clumsy and "less aesthetic"
- Ockham's razor is seldom questioned – however, in the cybernetic framework *this principle can be motivated*:

- A cybernetic system exploits all available resources in an (more or less) optimal way – seen in another way, this means that the resulting systems *are* as simple as possible

Further: *Ideal mixers vs. idea mixers*

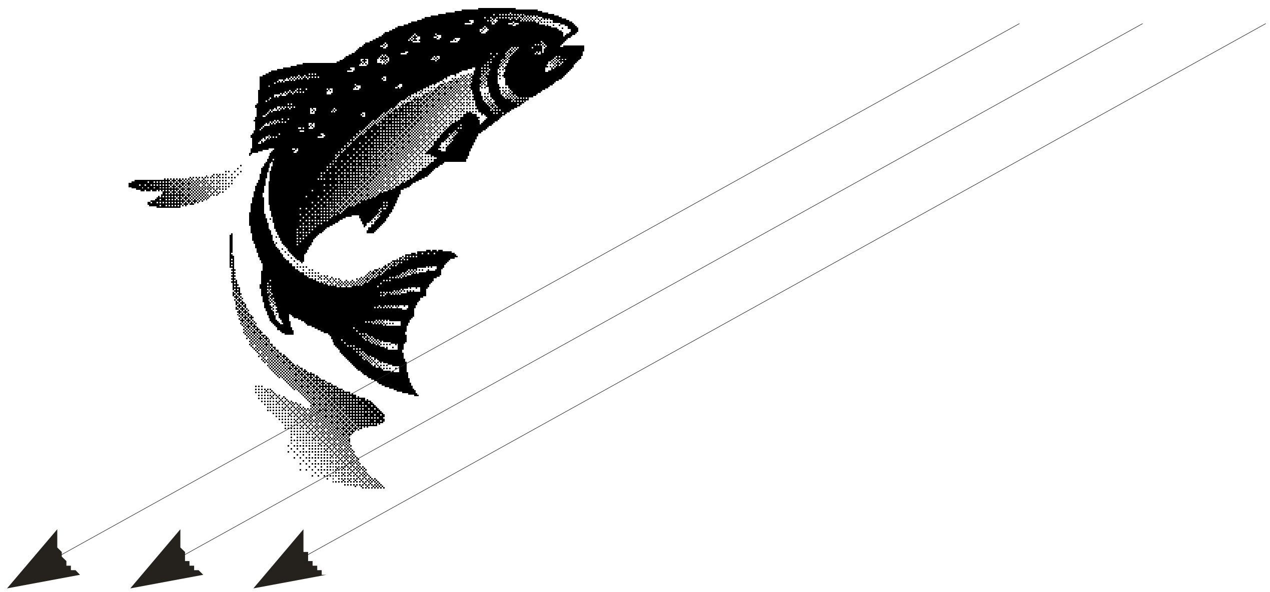
- Cybernetic models define a framework for studying *whirls in the flow of entropy* – WHAT?



- *Many systems with cumulating improbability can be studied*

Paradox of entropy

- Two classes of systems – *normal* and *abnormal*: Either energy is exhausted for *increasing* or *decreasing* entropy
- Compare to *sublunar* and *translunar* physics: Planetary motions are divine?



CLOSED vs. OPEN systems?

Entropy

- Study the cybernetic systems from another point of view – there are some principles governing all systems:
  - First law of thermodynamics: The total *amount* of energy in an isolated system remains constant
  - Second law of thermodynamics: The ”quality” of the energy becomes worse, or *entropy* in the system increasing
- The ”energy quality” is its ability to do work – if there finally are no differences in potential, it is the ”thermal death”
- There are different interpretations of entropy:
  - Thermodynamic entropy: System goes towards more probable states
  - Information theoretic entropy: System goes towards less information

”Cybernetic systems feed on information, producing entropy”

- There are some intuitive misconceptions
  - Entropy ever increases = ”arrow of time” !!
  - ”Universe must be expanding – otherwise time would go backwards” ??
- For example, is *symmetry* a sign of entropy or neg-entropy?
  - First intuition: Symmetry means *structure* and *order* – negative entropy
  - However, a completely unordered set of particles – meaning high entropy level – is most symmetric, as any of the particles can be interchanged
- Intuitions are problematic and contradictory
  - Simplicity of symmetric patterns is an illusion, being caused by our mental machinery that exploits existing mental models to interpret symmetries
- The thermodynamic and information theoretic entropia seem to be mutually incompatible – but now these will be united ...

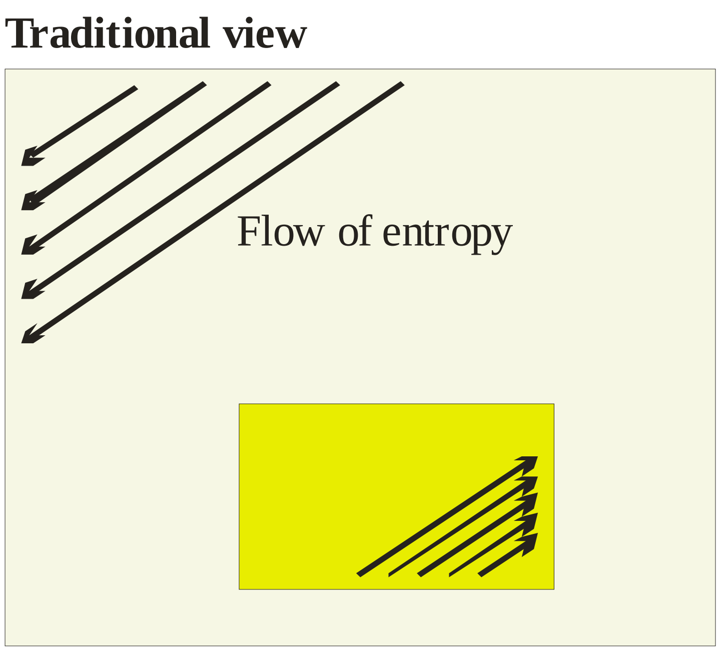
! ! !

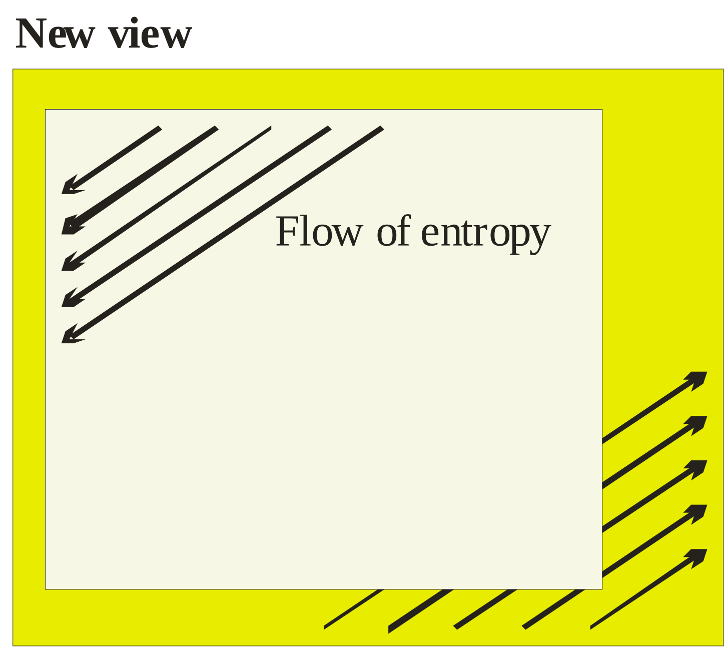
- In a cybernetic system information = variation, or deviation from balance
- Goal of cybernetic system: Balance = loss of information = maximum probability = (local) heat death on the lower level
- The control structure implemented by the cybernetic system thus boosts entropy – the faster, the better the control is
- Emergence of structure on the higher level is also **not** against the arrow of entropy – on the contrary:

Emergence of structures is *caused* by entropy pursuit

this entropy being equally meaningful in the thermodynamic and information theoretic setting.

- It seems that all systems, including cybernetic ones, are thermodynamically consistent: When seen in the correct perspective, *entropy increases in all subsystems*





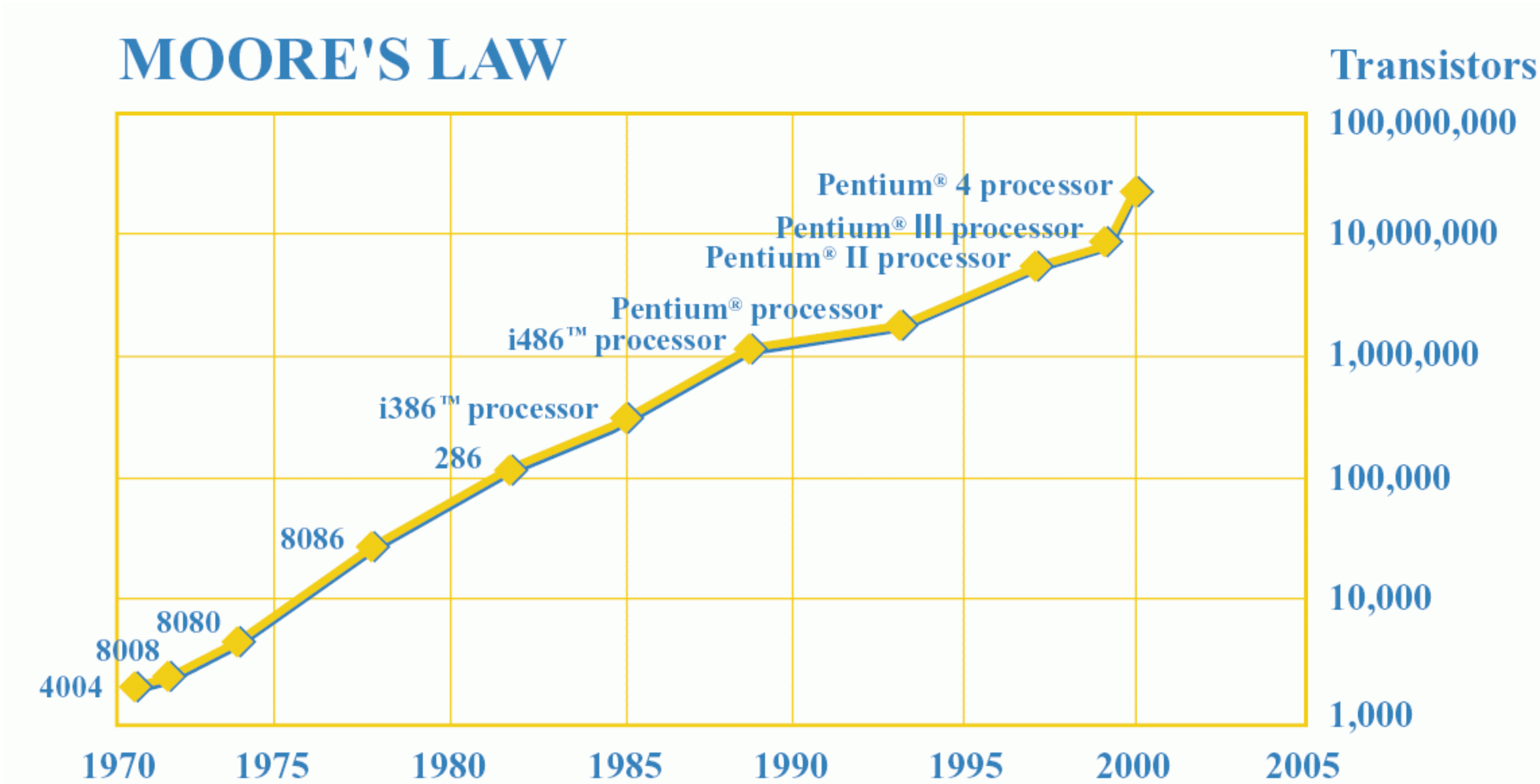
”Maximum entropy pursuit”

- The strong modeling framework gives additional benefits ...
- Previously, static models between u and x were constructed
- Now, the consistency of entropy behavior can be exploited:

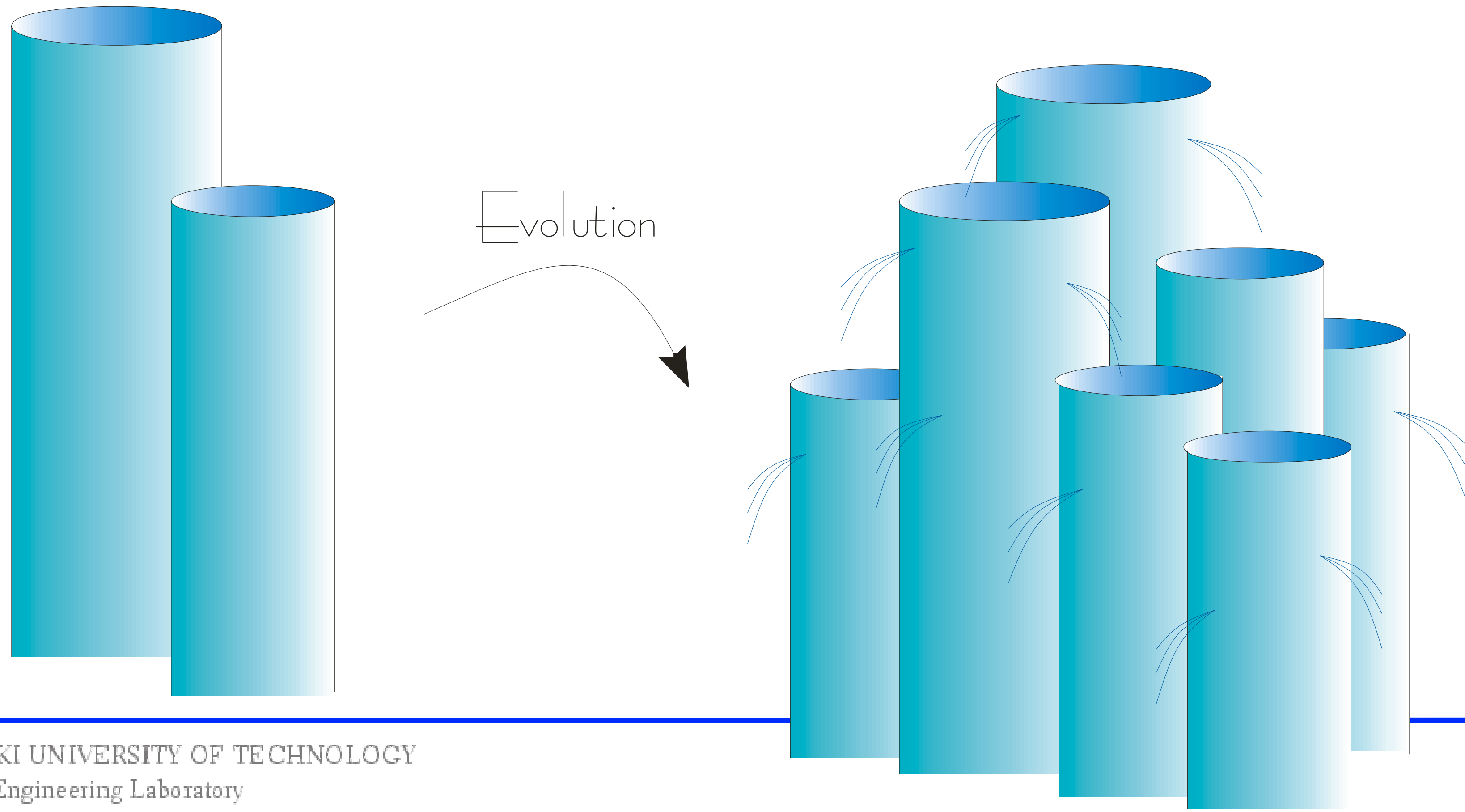
  It can be assumed that entropy not only increases, but it *increases at the maximum rate*
- This means that dynamic models become readily available; one can speak of *generalized diffusion processes*
- In the neocybernetic standard models, the speed of dynamics can be interpreted in this framework: If the adaptation factors are selected as $\Gamma = \mathrm{Var}\{xx^{\mathrm{T}}\}^{-1}$, the diffusion rate is scaled by observation reliability

= ”Principle of least difference”?

- Diffusion towards goal state is (asymptotically) exponential
- Exponential speed growth = exponential decay of slowness

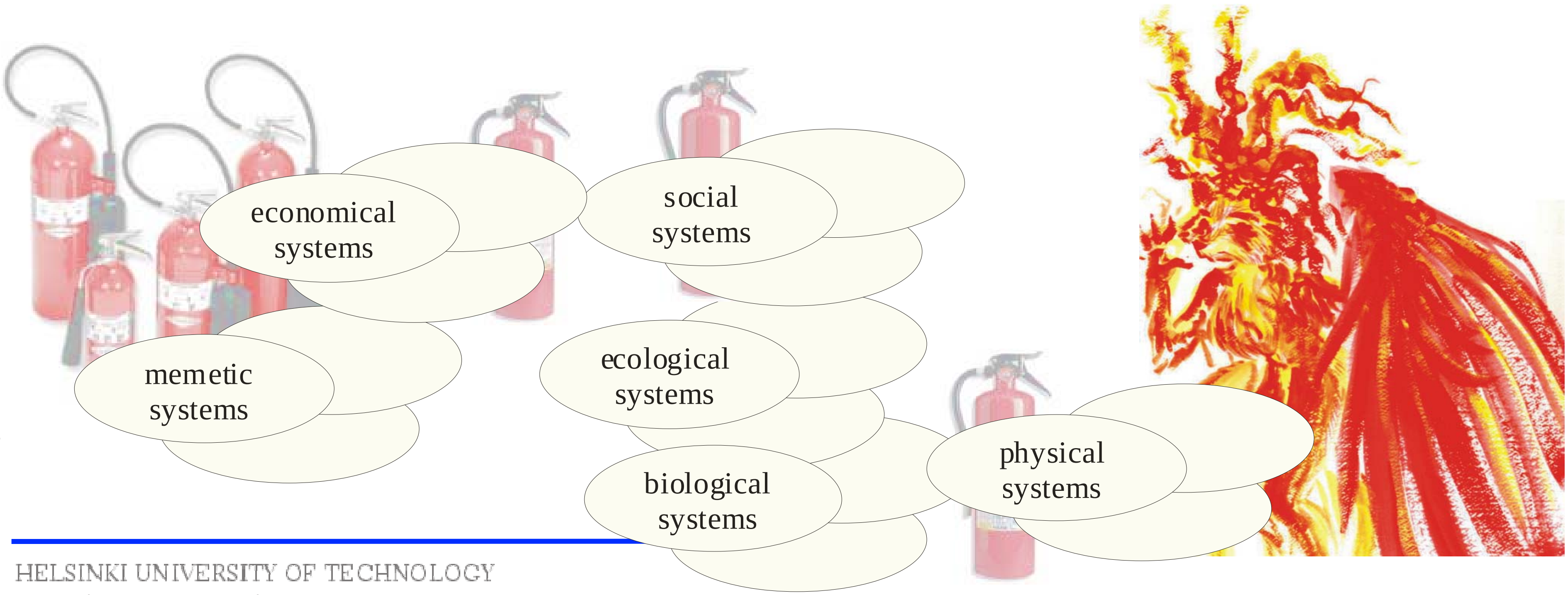


- How the reservoirs become exploited, and how differences vanish, ”drops in potential” becoming smooth and continuous



Some teleology ...

- Heraclitus' *Logos* is not "fire" but "fire extinguisher": The incoming variation is being eliminated by the systems
- There is no "Intelligent Designer" but a "Hardworking Idiot": The local optimizations result in extreme inconsistency



... and some teology

- The unconscious *thinking patterns* need to be emphasized
- The religious ideas are among the most fundamental patterns of thought
- For example, the Western science struggles with these –
  - One implicitly implements idea of centralization without seeing alternatives
    - Huge amount of complexity in models (orbitals, etc.) is needed just to compensate for the absence of a framework where a distributed structure can be maintained
  - One explicitly (aggressively) tries to eliminate all divine-looking explanations
    - Unfortunately, categorically avoiding teleological and finalistic explanations results in simply incredible models (message-RNA transferring information, ...)
- As there exists no planning or centralized control, *pantheism* would be more appropriate – but centralized, engineering-like thinking has been the necessary intermediate step!

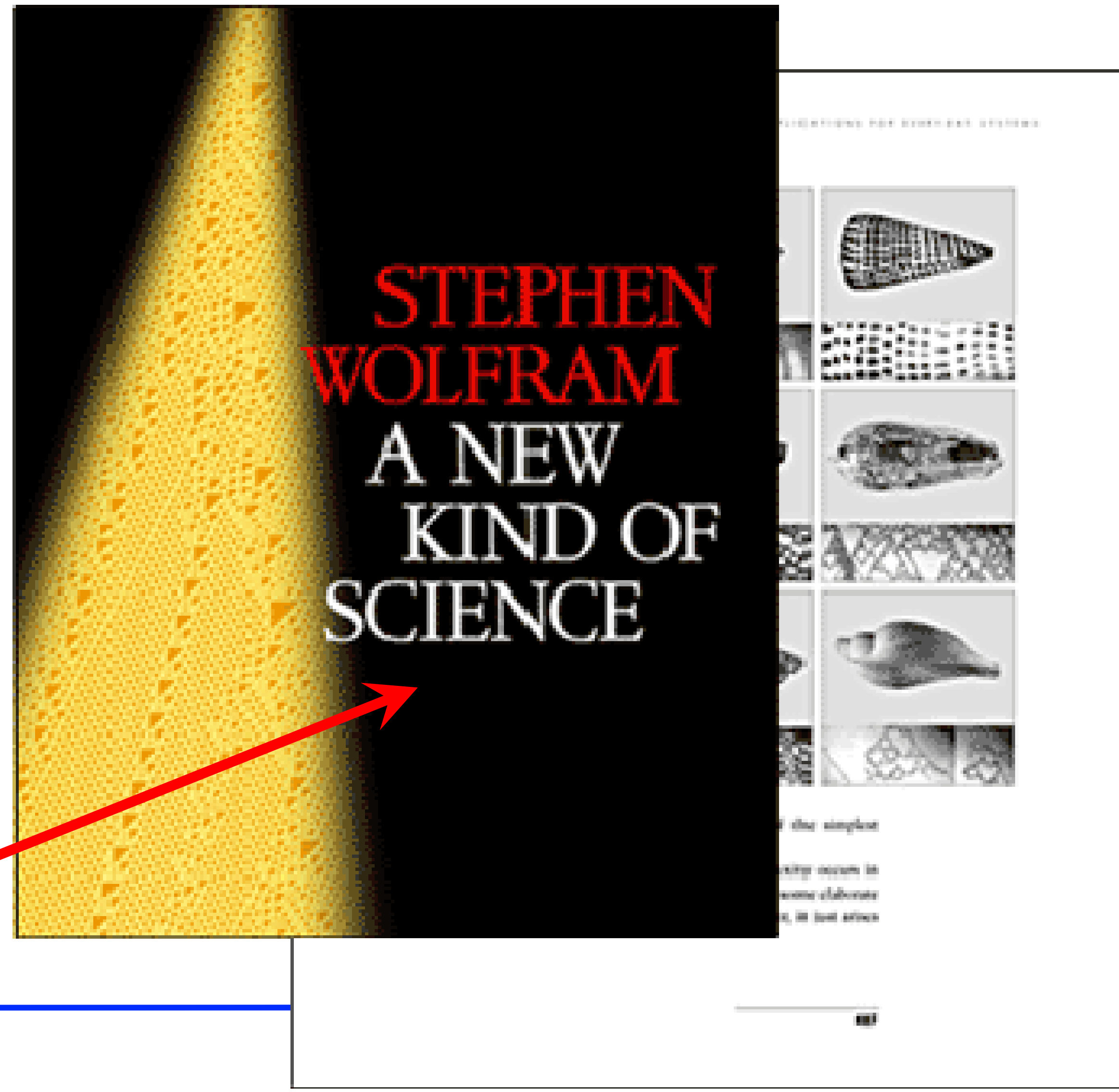
J.-P. Sartre: *”Even the most radical irreligiousness is Christian Atheism”*

”Principles of Cybernetism”

- *Why there is **evil**, why there is **poverty*** in the world?
  - These are just the other end of the continuum – always somebody is the poorest; if there were no differences, the heat death would have been reached. – Is extreme equality a sustainable goal in a society?
- *Why there is **suffering*** in the world (Schopenhauer)?
  - Of course, this is the basic property of a cybernetic system and organism; if there are no *real* obstacles or problems, these will be imagined
- *What is the **purpose** of life*?
  - It is entropy maximization! – *Prosper and exploit the world! Consume more!*
- *What is **death***?
  - It is dropping out from the dynamic equilibrium to the static balance (compare to power outages)

"A New Kind of Natural Philosophy"

- **Old Science** (mathematics, modeling, etc.) still applies
- There will be a **New World**
  – The ways of interpreting the observations of the environment need to change
- Compare to …



Cybernetics Rules!

... But what are those rules?

Let us find it out!

`http://www.control.hut.fi/cybernetics`