AS-74.4192 Elementary Cybernetics

Lecture 5:

Association to Populations

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Recap: Neocybernetic models

- **First-order cybernetic system**: Assume (for stable A)

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

- **Truly cybernetic system**: In the case of "smart" adaptation

$$\frac{dx}{dt} = -\Gamma\,\mathrm{E}\left\{\overline{x}\overline{x}^T\right\}x + \Gamma\,\mathrm{E}\left\{\overline{x}u^T\right\}u$$

- Completely local operation results in *self-organization, self-regulation*, and *second-order balance*
- The set of profiles ϕ_i spans the *principal subspace* of data u

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

Extensions?

The symbols can also be interpreted in different ways:

- x vector represents *population sizes* (or *biomasses*, or *activities*, ...)
- u is the vector of available *resources*
- A, B matrices (and Q) 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?*

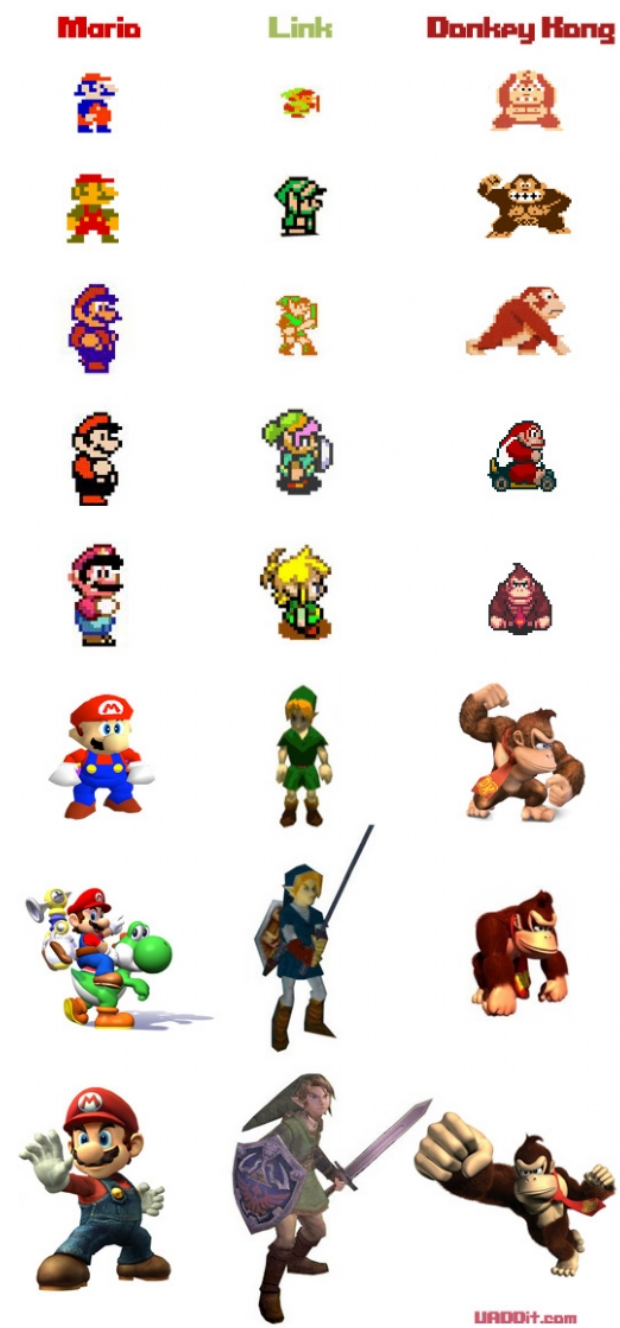
Counterarguments

- Criticism #1: The dynamic underlying processes are very 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; for example, interactions among agents cannot be captured.
  - Answer: In balance, the number of variables is less, and only the activity levels are of relevance; what is more, the interactions need not be modeled, only the exploitation of the environment (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!

Individuals / species do not have evolutionary advantage – only the *system as a whole* has

Key assumption

- If u stands for resources, principal subspace model can maximally match (exploit) these resources
- Species with an optimal strategy outperforms others, resulting in more biomass + more probable survival
- What one observes afterwards, in the evolutionary (local) balance, is only examples of such best strategies
- Conclusion: Species (ecosystems) that are still there today, implement the neocybernetic strategy!



Is the cybernetic model structure *true*?

- Theodosius Dobzhansky:

  "Nothing in biology makes sense without reference to evolution"

- Cybernetic realms:

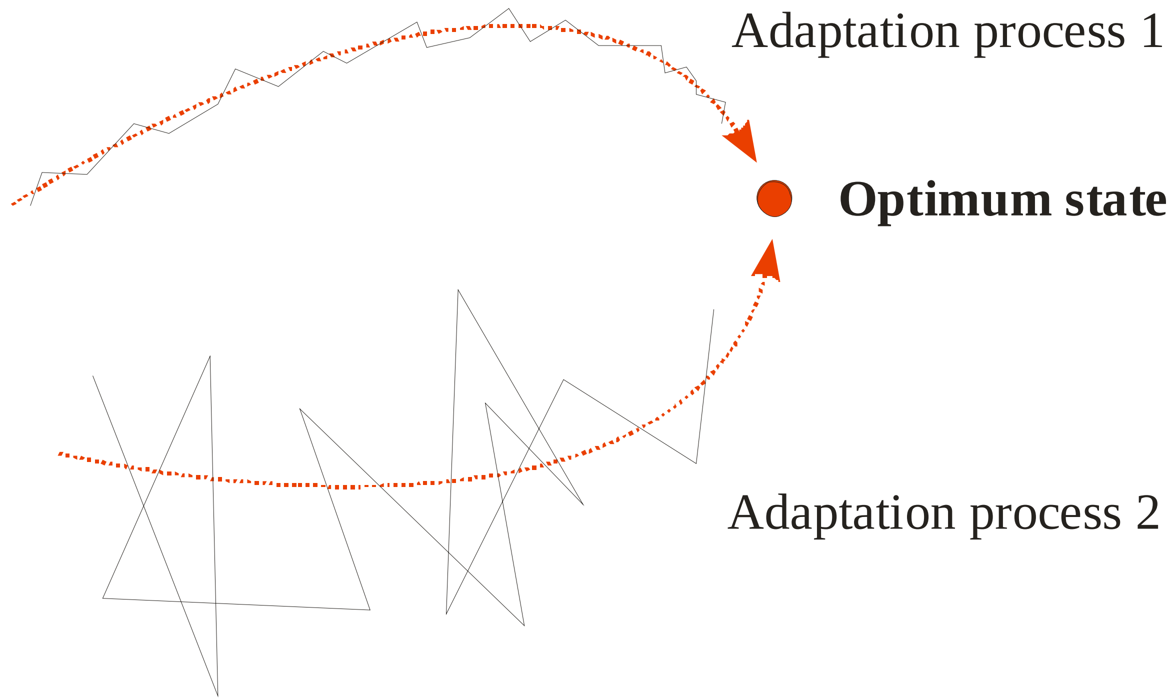
  "Nothing in complex systems (biology, ecology, economy, ...) makes sense without ... evolution"

- Evolution is a matter of belief – no verification nor falsification
- But if this starting point is accepted – then the neocybernetic model is a logical next step!
- Biology can become a *real science*, turning from description of taxonomies ("what?") to study of mechanisms ("how?") ... and even *beyond science*, to analysis of goals ("why?")

Humanistic "sciences": questions of the form "who?" !

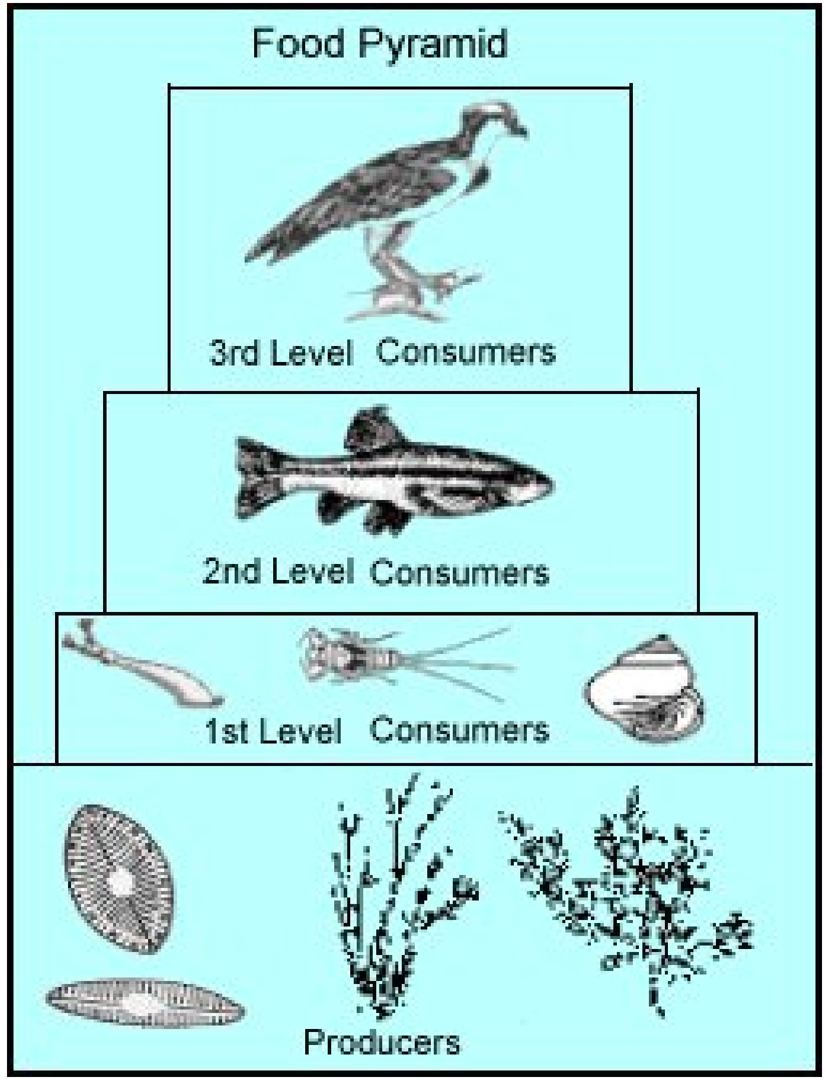
From Heraclitus' ideas to Platonian ideals?

- Again: ignore individuals, abstract time axes away
- The (hypothetical) final state can be identical no matter what are the details of the more or less random adaptation process



Example #1: Ecological system

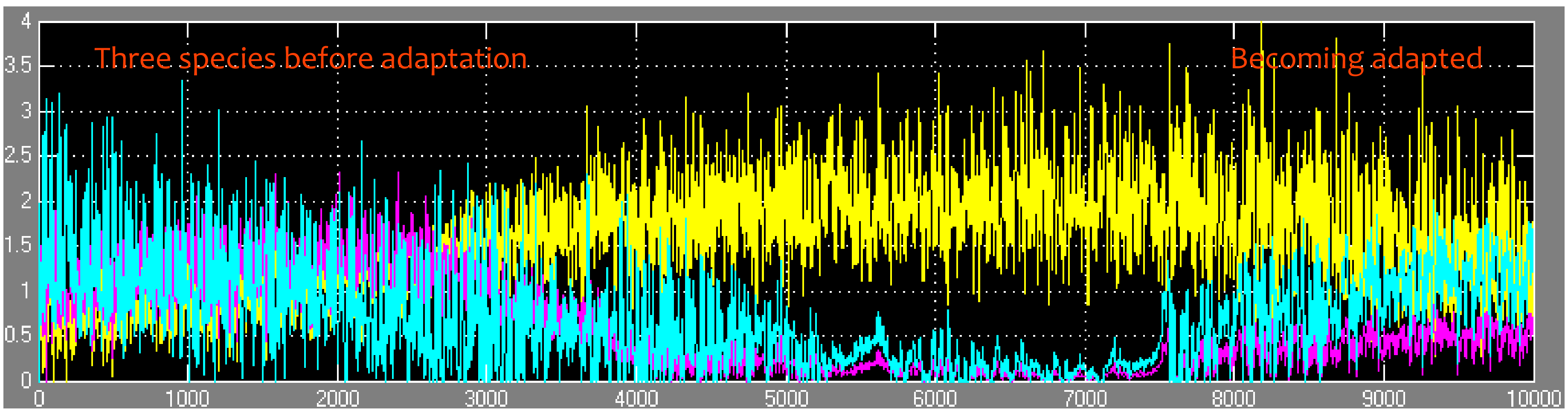
- Actors: Individual animals
- Variables x_i: Population sizes in species i (actually, *activities*)
- Input u: Available food (or other environmental conditions)
- Model ϕ_i: *Forage profile* for i, revealing the range of prey (or other environmental demands)
- Learning of the system based on Darwinian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



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

Models for the "edge of chaos"

- 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"



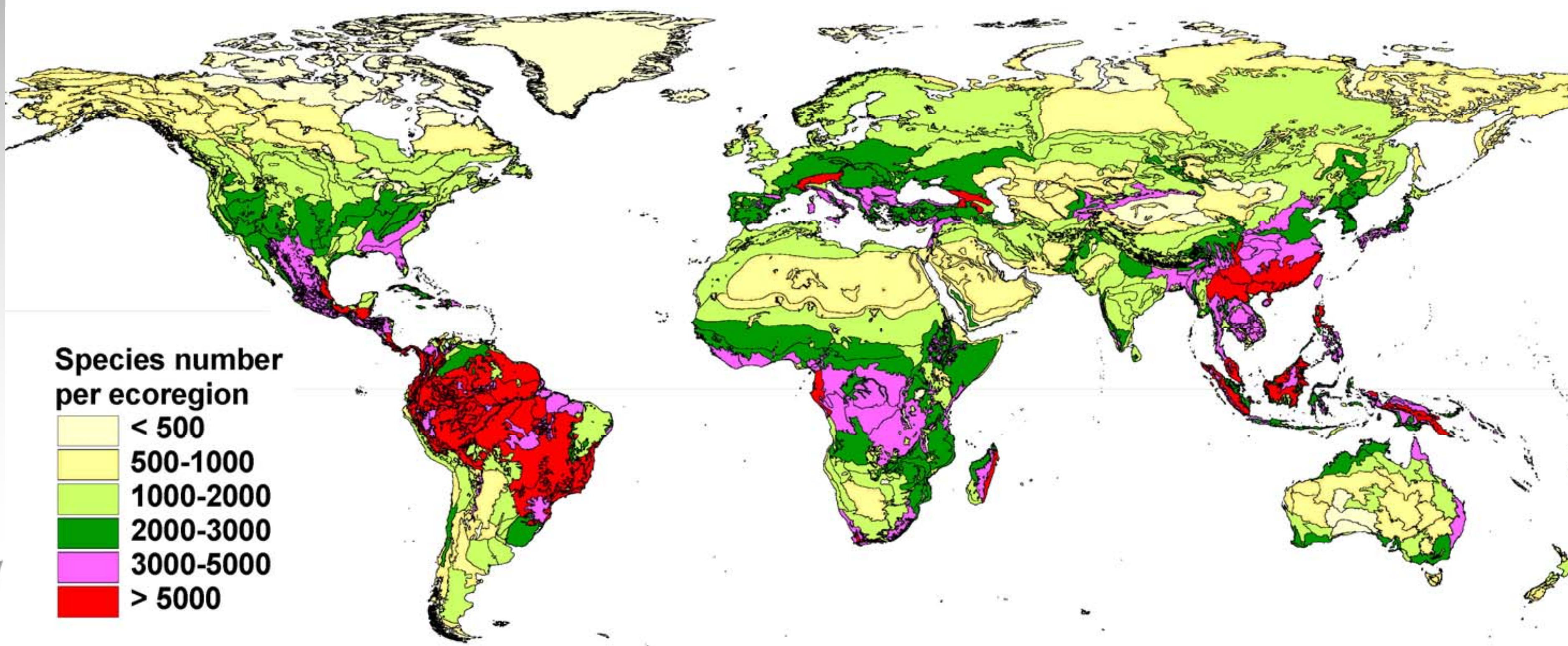
Some intuitions offered by the new model

- 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
  - Traditional models of multi-species ecologies typically end in non-natural results: extinctions, and single-species dominance – now not.

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

Biodiversity

- Claim: *Niches are determined by resource variation structures*
- Invariance in conditions would ruin it all (cf. Heraclitus' flows!)



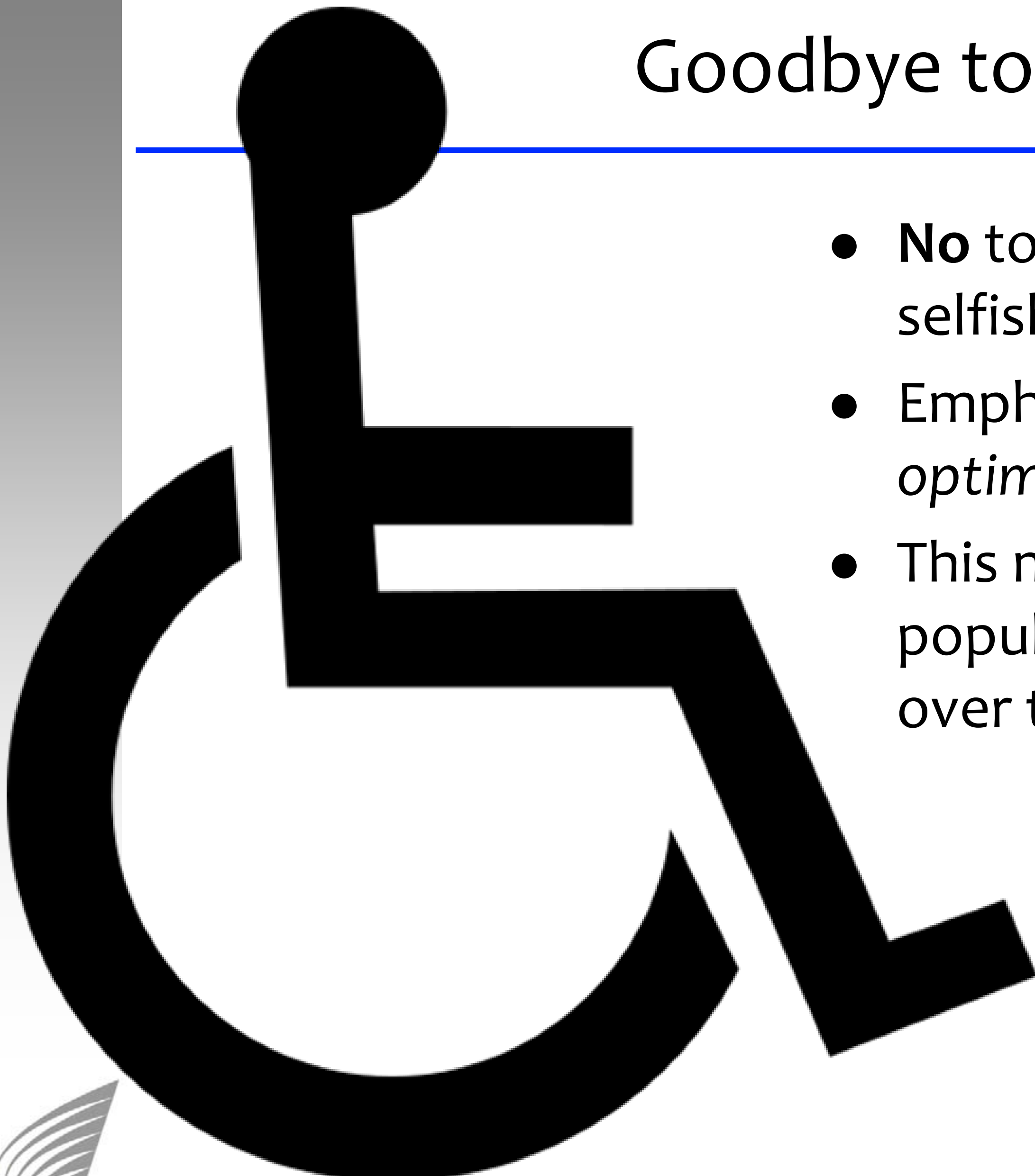
- There are also lesser observations that can be studied from a fresh point of view, for example

  Hardy-Weinberg law:

  > "In a large, random-mating population, the proportion of dominant and recessive genes tends to remain constant from generation to generation unless outside forces act to change it"

- This balance in "non-optimum" can directly be explained in terms of "surplus variation" in the environment beyond the among-species level variation
- Remember that the artificial *genetic algorithms* operate in a different way: They can be paralysed as the variation among the population completely vanishes

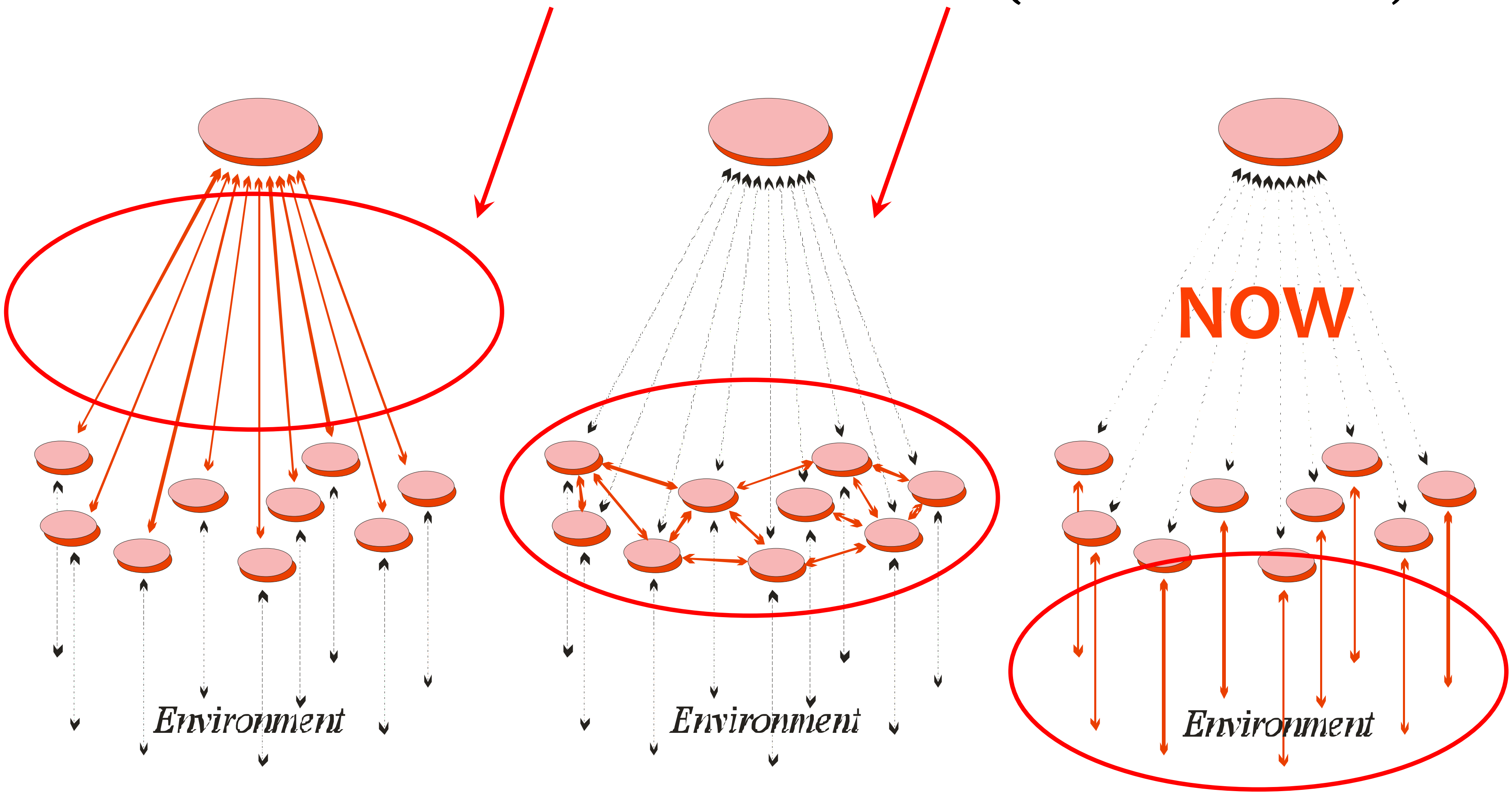
Goodbye to Social Darwinism?



- **No** to "selfishness of genes", **no** to selfishness of individuals
- Emphasis from the *individual optimality* to the *system robustness*
- This means optimality on the population level over individuals and over time instants

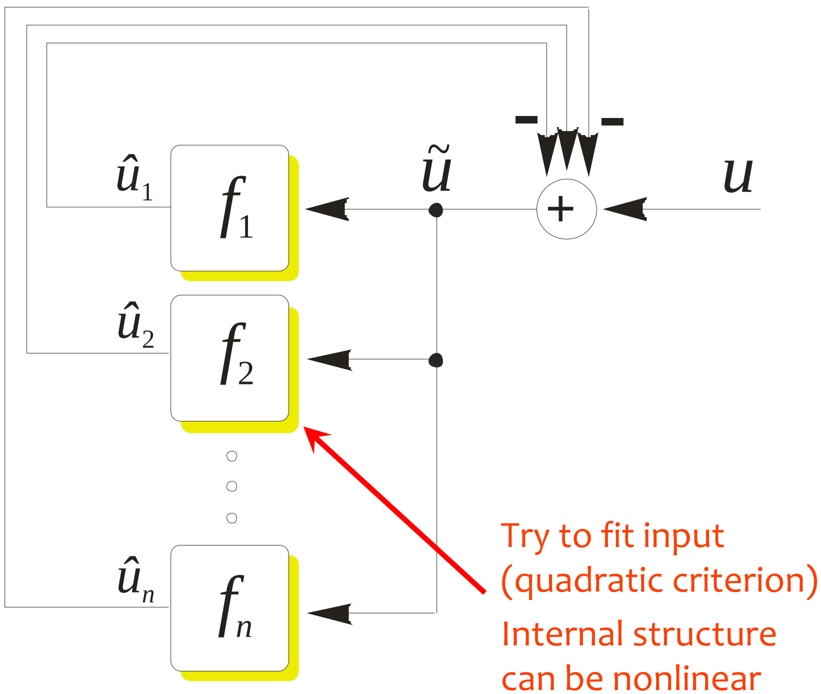
New schema for agent communication

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



Population of general local agents

- No matter what is inside an agent and how it adapts, it can be integrated with others when its estimate $\hat{u}_i$ to u is known
- Self-organization emerges as u is changed to $u - \hat{u}_1 - \ldots - \hat{u}_n$



- Each agent only sees its immediate input and tries to reconstruct it
- In agents fewer degrees of freedom than in data
- End result: Agents represent a set of features
- Map of solutions union of $\hat{u}_i$

Step aside: About programming languages

- Programming language is a tool for modeling and simulating reality (as it is seen at a moment!)
- The language should reflect reality to be modeled, supporting the relevant structures and concepts
- Evolution of languages: Monolithic (Fortran etc.) – procedural (Pascal etc.) – object-oriented (Java etc.) – *agents-based*
- What will the future programming language maybe look like? Cybernetic intuition (for *special purposes*):
  - **Ultimate distribution of control**. Agents are independent computational entities, perhaps implemented in a fractal way, trying to reproduce the input; coordination of agents is trivial, based on exhaustion of the input
  - **Autonomous adaptation**. Agents evolve to better match the local data; there is self-organization of the features if input is variable enough.

Hierarchy & distribution among functionalities makes the overall system robust and faster adapted (see H. Simon: "Architecture of Complexity")

Further: - The challenge being faced

How to represent a complex object as data?

- Compare to computer (war) games: State of the player is coded in a single variable – "health"
- Here, too – it must be assumed that such a coding exists, and interactions among the low-level systems can be formalized, as well as their inner functions
- Now the model structure is fixed – the problem is to represent the essential features of the domain area in the required form as data

Biosemiotics

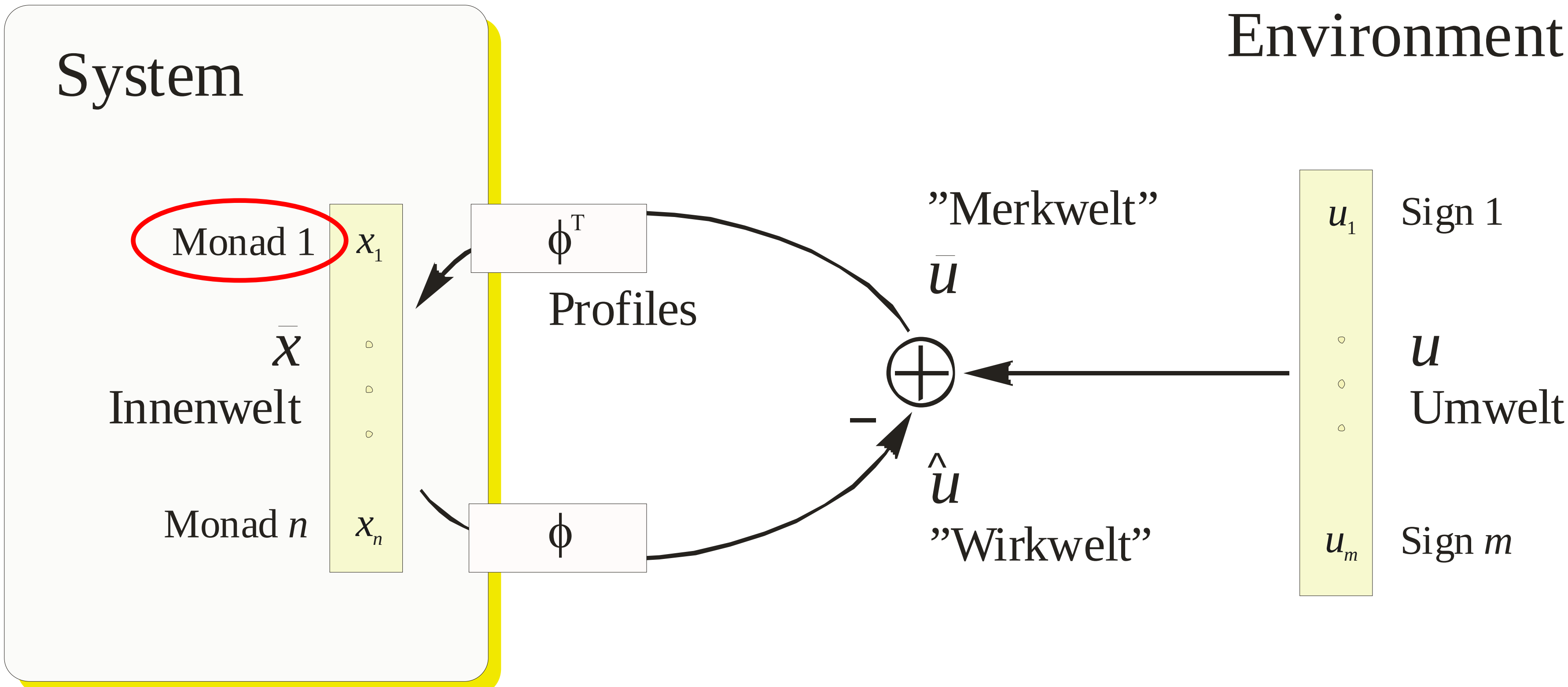
- Semiotics = general study of sign processes (semiosis), or signification and communication…, including the study of how meaning is constructed and understood
- Memetics = Narrower view of the above, constrained to the analysis in *ideasphere*
- Biosemiotics = semiotics in *biosphere*:

    1. The study of signs, of communication, and of information in living organisms
    2. Biology that interprets living systems as sign systems
    3. The scientific study of biosemiosis.

- Now, this boils down to the question of *how variables are selected* and *how they are weighted* – after that, the "semiosis" takes place more or less automatically (PCA!).

Semiotic system = system interpreting / constructing *meanings*

- Applying the established terminologies, one can here write...



"Biosemantics"

- The inputs of a system determine its subjective "world" – the model structure determines its "induced interpretation"
- Atoms of semantics are buried in the formulas $\mathrm{E}\{x_i u_j\}$ denoting *elementary interactions among the environment and the system*
- In the adaptation process, the above is transformed into analysis of the formulas $\mathrm{E}\{u_i u_j\}$ meaning *elementary connections within the environment*
- Again, operator E couples emergent levels, defining semantics through "compacted experience"
- The system is also dictated by observations of the environment ("Umwelt") – now this can be elaborated on

Another concept getting involved: *Information*

- *For some reason*, in identification theory matrix $\mathrm{E}\{uu^{\mathrm{T}}\}$ is called *(Fisher) information matrix ...*

$$\mathrm{E}\left\{uu^T\right\} = \begin{pmatrix} \mathrm{E}\left\{u_1u_1\right\} & \cdots & \mathrm{E}\left\{u_1u_m\right\} \\ \vdots & \ddots & \vdots \\ \mathrm{E}\left\{u_mu_1\right\} & \cdots & \mathrm{E}\left\{u_mu_m\right\} \end{pmatrix}$$

"Atom" of mutual information
= Unit of "neg-entropy"

- Neocybernetic model structures (correlation matrices) – Compact storages of information (as seen in interactions)
- Covariances are always > 0, and they are directly summable for independent data – axioms about information fulfilled
- Note: statistically relevant $\mathrm{E}\{x_i u_j\}$ is now information, instantaneous $x_i(k)\, u_j(k)$ is only data
- So – Information becomes captured maximally by PCA

Information **emerges** from *data* – remember $\mathrm{E}\{x^2\}$

- Thing to remember: Emergence may be found when expectation of merged variables is calculated

$$\mathrm{E}\left\{\mathit{merge!}\right\}$$

$$\mathrm{E}\left\{\mathit{colony}\right\} = \mathrm{Ecology}$$

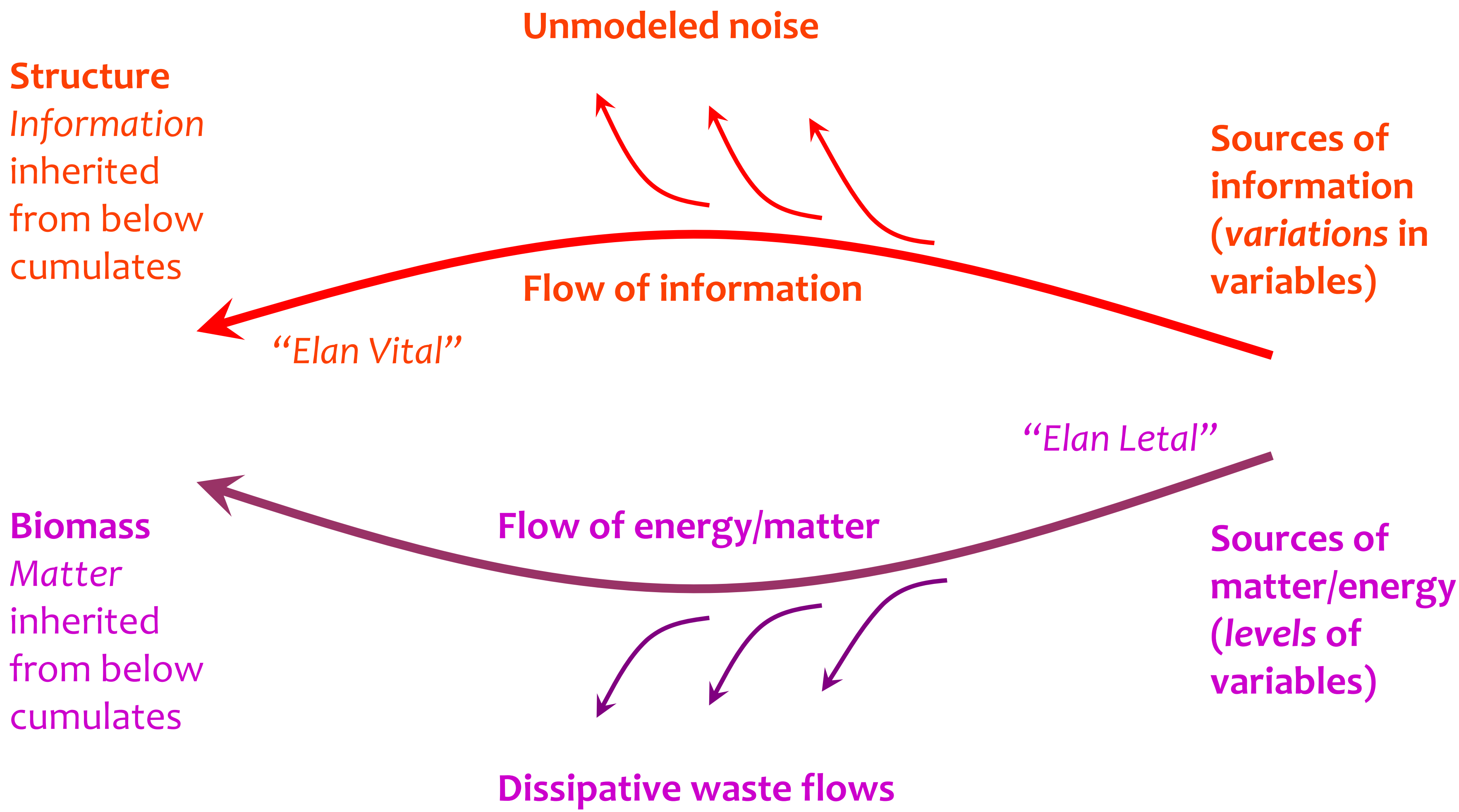
- Perhaps the buzzwords with “e-” can be updated to “E-”

From "data modeling" to "system modeling"

- Shannon's Information Theory, and
  Kolmogorov / Chaitin (algorithmic) Information Theory:
  - Strictly syntactical, no domain area semantics involved
  - Extreme universality thus reached
  - Intuitively paradoxical:
    - What you expect, contains no information
    - Noise has the highest information content?
- Neocybernetic Information Theory:
  - "Semantics" included in manipulations, thus non-universal
  - Universality only among all cybernetic systems
  - Intuitively appealing:
    - What is expected, is the most characteristic
    - Noise (consisting of unique events) has no relevance!

Uncorrelated noise: Information whose structure has not *yet* been found

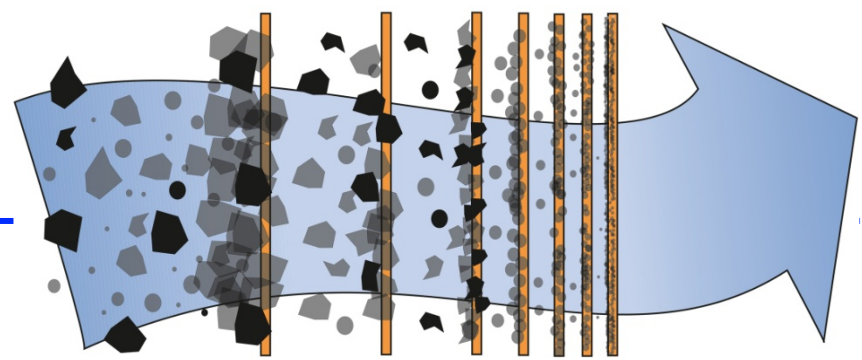
Abstract flows in a cybernetic system



Case 1: Information weighting

- Another way to express behaviors in a cybernetic system – *emergent illusion*: “Systems are hungry for information”
- A concrete definition of this information makes it possible to find new (holistic) ways for system analysis
- Power spectrum now expresses the information distribution along the frequency axis
- Filtering of information offers a practical way of weighing the variables and changing the view of the environment
- Different time scales become implicitly modeled, revealing the “frequency-domain environment” of the system

Similarly in spatial domain ...?



Linear filters

- Simple first-order linear filter: $$\frac{du}{dt} = -\mu u + \mu u_{\text{in}}$$
- Corresponding transfer function: $$F(s) = \frac{\mu}{s+\mu} U_{\text{in}}(s)$$
- Power (information) transfer: $$H(\omega) = \frac{\mu^2}{\omega^2 + \mu^2} H_{\text{in}}(\omega)$$
- Higher-order linear filters: $$F(s) = \frac{\mu^d}{(s+\mu)^d} U_{\text{in}}(s)$$
- Characterization in frequency domain: Cut-off frequency μ
- Characterization in time domain: “decaying memory”, exponential “forgetting horizon”

Distribution of information (variation)

- Upper level = *Environment*

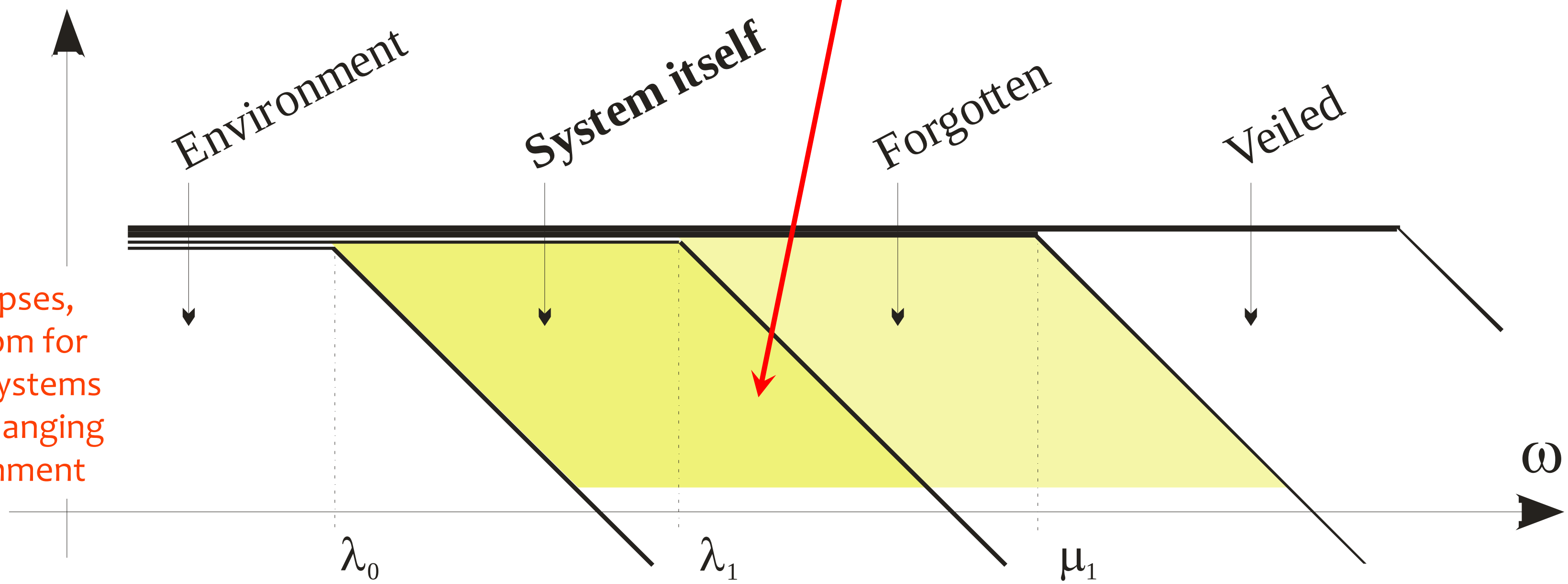
$$\frac{du_e}{dt} = -\mu_0 u_e + \mu_0 u_{in}$$

$$\frac{d\hat{E}\{\bar{x}_e u_e^T\}}{dt} = -\lambda_0 \hat{E}\{\bar{x}_e u_e^T\} + \lambda_0 \bar{x}_e u_e^T$$

- Lower level = *The system*

$$\frac{du_s}{dt} = -\mu_1 u_s + \mu_1 u_{in}$$

$$\frac{d\hat{E}\{\bar{x}_s u_s^T\}}{dt} = -\lambda_1 \hat{E}\{\bar{x}_s u_s^T\} + \lambda_1 \bar{x}_s u_s^T$$



As time elapses, there is room for ever new systems on top – changing the environment

Note linearity on the log/log axis = "power law" !?

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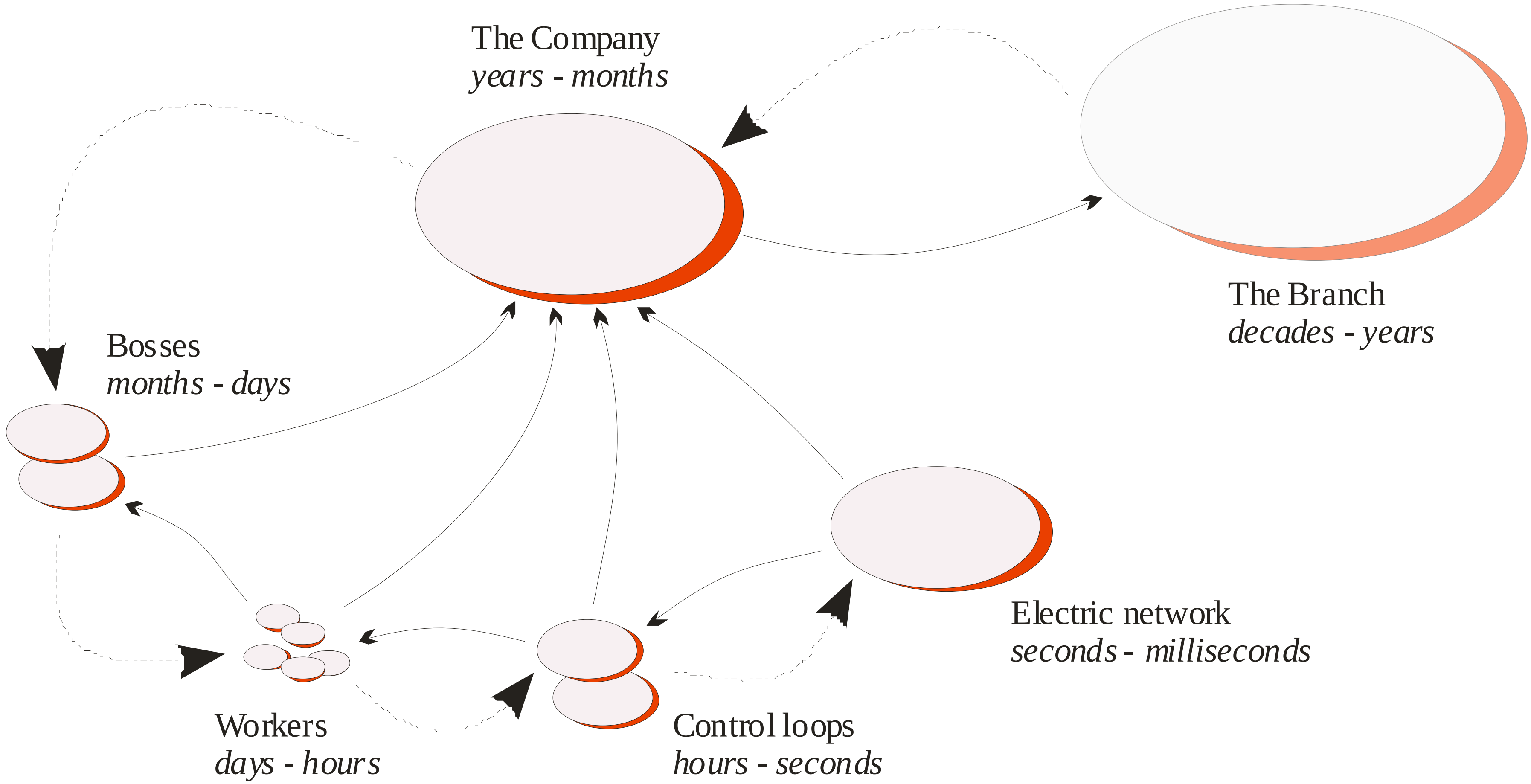
- “Upper system” = Slower dynamics
- Interactions as seen from the upper system:
    - The lower system adjusts itself (more or less) immediately to the upper level variables
    - From the point of view of environmental dynamics and balances, the lower system is seen as *static*
- “Lower system” = Faster dynamics
- Interactions as seen by the lower system:
    - The upper system gives “reference values”, more or less fixed constraints, determining the environment where the system has to operate and adapt
    - From the point of view of system dynamics and balances, the upper system is again seen as *static*

When optimizing, the levels get tangled (as in “quartal capitalism”)

Example: Electric company



Each subsystem is also cybernetic optimizing in scarcity of information

Case 2: Data selection

- Again: The information in the environment is presented as data, and this data is coded in real-valued signal vectors
- Key point when trying to affect the results:

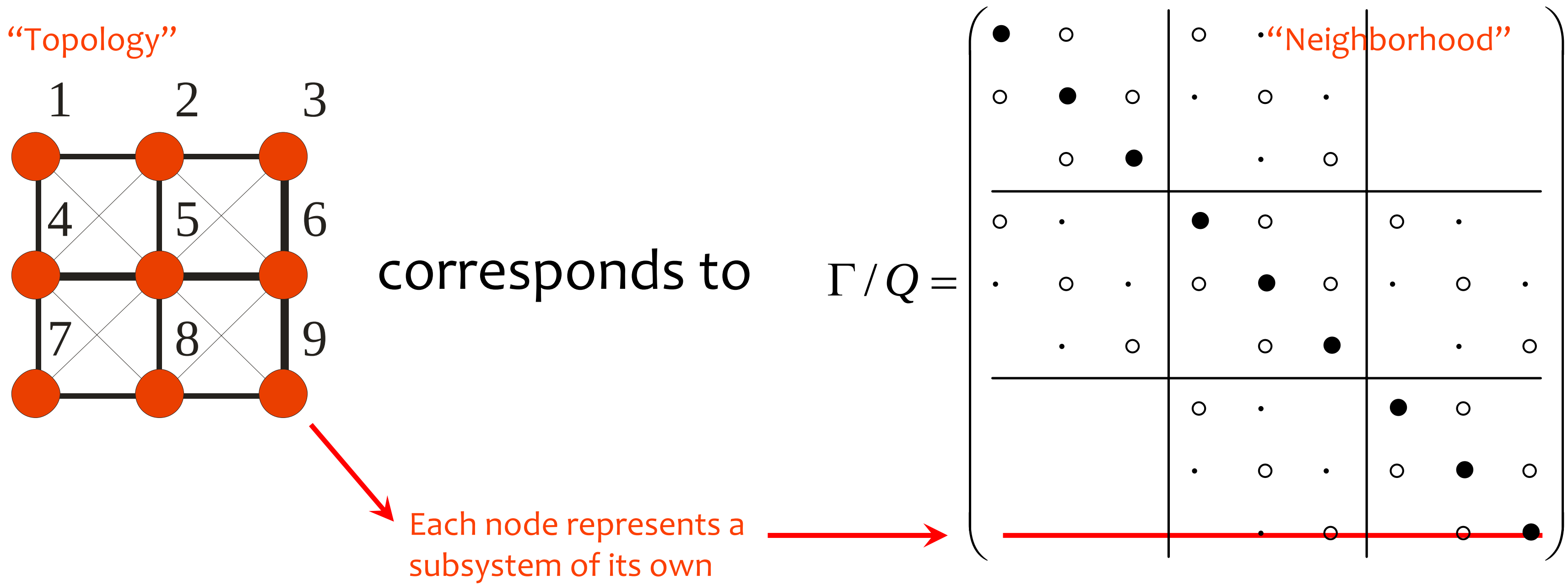
  Selection of variables to be included in input data
- Special challenge in higher-level systems, where the space of candidate variables is potentially infinite
- The more there exist available variables, the more there are interpretations = projections = different views of the world
- Remember the "Barnum effect": Compare to horoscopes, numerology, ... and humanistic sciences ... (?)
- A consistent model can be constructed from any starting points

Temporal data augmentations

- Earlier, the mapping from u to x was assumed to be static: There was no connection to succession of variables
- However, in nature there exists inertia – how to model this?
- *Assume* that there exist longer-living species, perhaps experiencing various generations of shorter-living ones
- The input data has to be augmented with earlier time-series data (own species information + other species)
- Intuition from traditional identification: Model over time-series data = dynamic model
- It turns out that static PCA turns to "dynamic PCA": The system can carry out *subspace identification* of the data – Dynamic state space model (implicit) is constructed

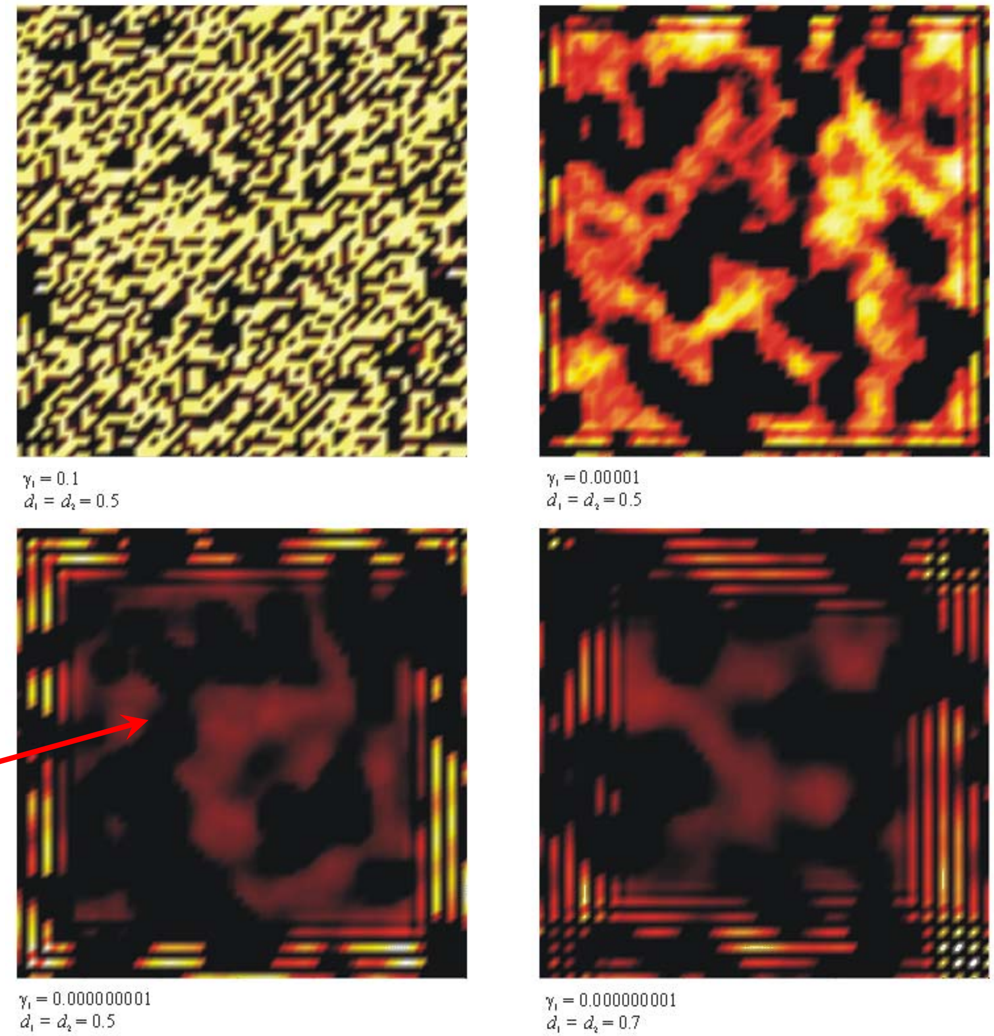
Spatial data augmentations

- Sharing information between systems (isolated populations), for example SOM (self-organizing map) can be emulated
- Note: The final state can differ if the actual adaptation mechanism is nonlinear so that there are alternative minima



- Application: Modeling of surface patterns (see “step3.pdf”)

A grid of 70×70 “cells” with competing “color genes”; interactions of neighbors dictates the “winner gene”



Information blockages: Example

- "Ideal" cybernetic model with clever agents implements principal subspace analysis
- "Nonidealities" make it possible to implement *differentiation* among variables
- For example, explicit PCA is carried out if the covariance matrix structure is forced to be non-symmetric:

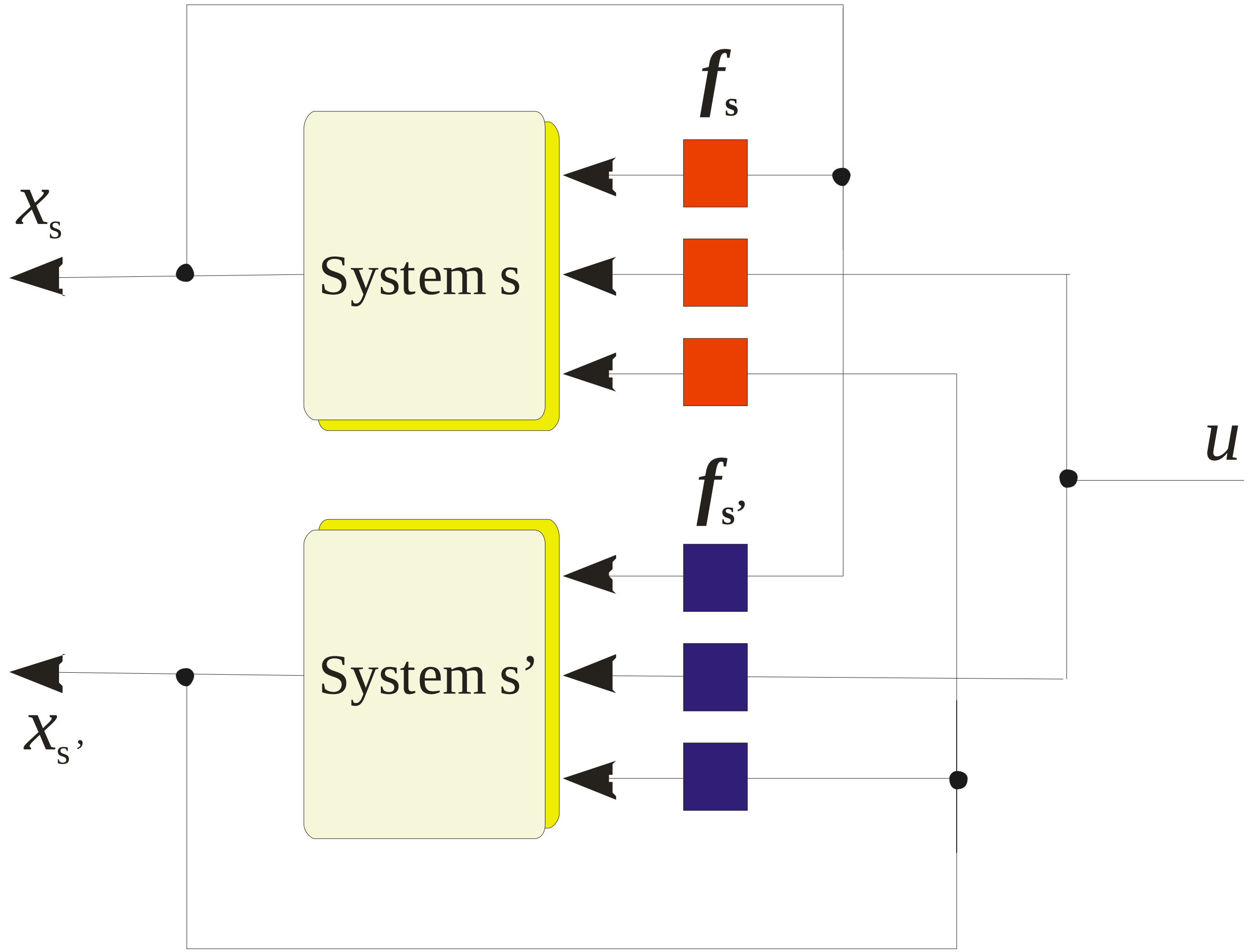
$$A = \begin{pmatrix} \bullet & & & & \\ \bullet & \bullet & & & \\ \bullet & \bullet & \bullet & & \\ \bullet & \bullet & \bullet & \bullet & \\ \bullet & \bullet & \bullet & \bullet & \bullet \end{pmatrix} \leftarrow \text{Triangular masking}$$

Data modification

- *Sensors are censors*, determining what is seen of the environment by the system
- For example, nonlinearities can give new views to the *same* data
- Later: *It is assumed that real-life nonlinearities are collected in this feature extraction phase*

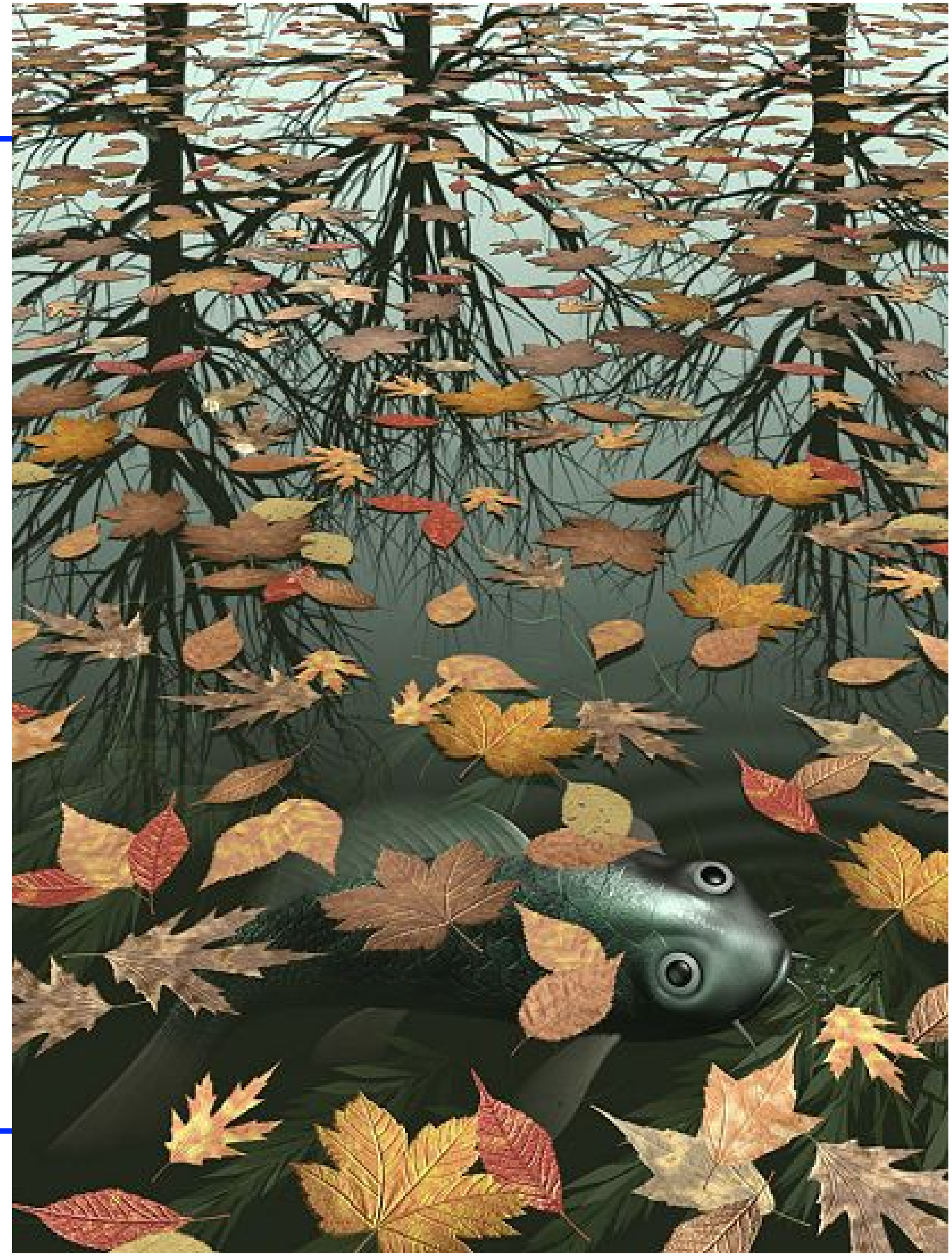
Feature extraction

- Modified or appropriately selected data can be seen as *features*
- Differing features, differing properties
- The system implements *pattern search*



Key challenge

- How to focus:
  Which variables to select, how to weigh them?



When views differ

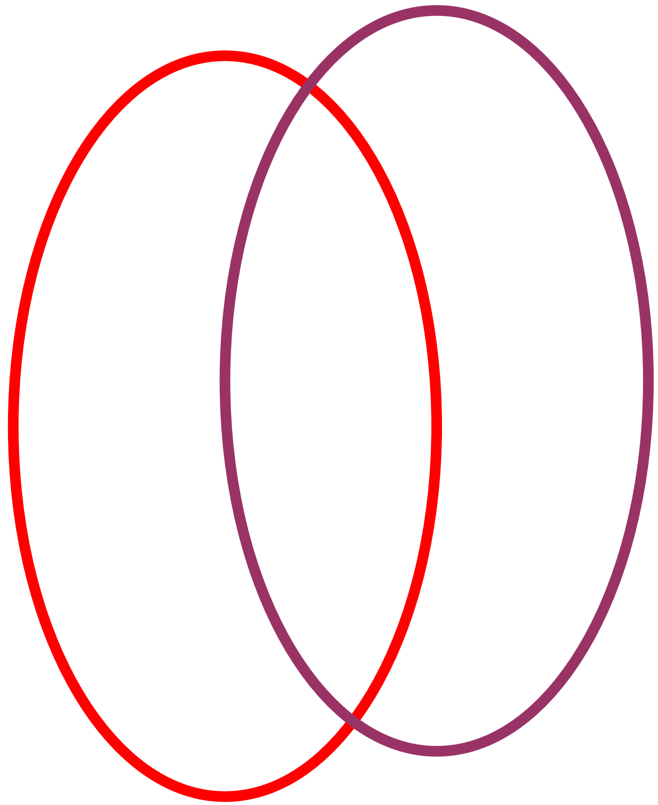
- There are coexisting consistent cybernetic subsystems
- They seem to reside in “parallel universes” – example TKK:

Scientific view

Criteria: Anarchy,
non-formality,
non-optimality

Emergent structures:
Invisible “hierarchy
in substance”

Functioning:
finding questions,
answering them



Administrative view

Criteria: Efficiency,
optimality, money,
formal frameworks

Prior structures:
Organizational
hierarchies

Functioning: Courses,
projects, meetings,
strategies

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 (or squares of these!) 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 also exist many interleaved subsystems

- There is no “good” or “bad” in nature (or in economy) – it is the cruel blind laws of nature that rule:
- Role of money
  - All variables have to be structureless and dimensionless – money offers a nice measure for making *all* things commeasurable
  - When the role of money is generally accepted, the system can become more efficient and streamlined, more transparent and more unique
  - “Everything has its price” – this is the truth; it is irrelevant whether or not this is ethically sustainable
- Role of individuals
  - It is statistically irrelevant how resources are distributed among actors (companies) – however, for a single company, this makes a *big* difference
  - An individual company may prosper or suffer, or get extinct; in that case the system soon substitutes it with others – there is nobody to mourn

Systems of humans

- Special challenge: Humans as agents in a system
- 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.
- A human (to some extent) can choose one's neighborhood and company, changing one's inputs
- A human is good at inventing new ways to see things – making it possible for the system to find new input variables
- How about free will? – Remember that one is now NOT interested of individuals!

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

Learning in "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
    - 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"
    - Success typically means that *more emphasis* is put on that behavior, and repeated failure results in *compensation* – this all can be interpreted as Hebbian learning
  - "Resources" (variables) among humans are typically *functionalities*

Relation to *pragmatism*

- Pragmatism: Practical consequences or real effects are vital components of both meaning and truth

- The relation between a system and its environment is not one-directional: There is not an excess of resources, there is *need* of resources
- A system becomes relevant in environment (for surrounding systems) through its *function*, its actions, when it offers new variables, new resources
- In complex systems, there is active search for variables
- Inversely: ability to offer new variables makes you needed, it is the easiest way to assure there is a niche – specialization

- Environment: mainly other systems
- System: a functional entity
- Symbiosis – systems offer nourishment (information) to each other

Towards cooperation

- System = functional entity, seen as functions from outside (Sum of parts does not implement those functions!)
- System = fractal structure of functions characterized by its attributes
- System goal = find new functions = make it valuable for others = make it survive in evolution together with others

Evolution is needed also in a constant environment as neighboring sytems change

- 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 environment, crude survival of the fittest ("Adam Smith style")
- *Some* level of intelligence: Additionally, avoid competition
  - Feedback implemented already in the survival strategy (modern market style)
- Local intelligence: Balance among a network of neighbors
  - Try to directly implement local equilibria (welfare state objective)
- Global intelligence: Directly optimize over the whole system
  - Design a system implementing global equilibrium (utopia!)

- More intelligent strategies: From *competition* to *cooperation*

"Memetic systems"

- Memes = "Genes of the infosphere", "idea atoms" to be appropriately combined
- Emergent structures in infosphere are theories or paradigms (in science), isms (in politics), and religions
- Humans are needed as *signal carriers* – the systems evolve following their own dynamics (remember Hegel / *Weltgeist*)
- Goodness criteria: Match with observations – depending on how the world is seen, as constructed by humans
- Hebbian learning fully implemented in science:
  - Successfull branches become "hot", they get more financing, and more researchers – making that branch evolve even faster
  - Compare to companies in an economy: "Do not fix it if it works!"

About (pheno)spheres

- Geometrical intuition extended: As the size of a sphere grows (its "diameter"), the surface grows *slower* than the volume (number of systems therein), no matter what is the dimension (the number of variables)
- More and more systems are connected only to other systems, not to the outside world
- Finally, the systems model each other, not the outside world, and the direction of adaptation is no more clear (a "stubborn" enough system can make its environment yield)
- Specially in complex enough "noospheres", like in humanistic sciences, one ends in *postmodern relativism*: No explanation is essentially better than the others

Final note – Application of intuitions: *Politics*

- Why democracy seems to prosper even though it is less efficient than a dictatorship (the Platonian system)?
  - Assuming that there is complete information available in the society, democracy represents the *most cybernetic* political system
  - Parties determine profiles ϕ of opinions; many parties = pluralistic society?
  - Party popularity (number of votes x_i) reflects specific needs u_j in the society, and this is reflected in its possibilities of implementing party visions
- Why representatives?
  - Higher level in the cybernetic hierarchy
  - Faster and more frequent reactions to acute issues, etc.
- Is the current system the best possible?
  - Just a single vote – too crude, all politicians/parties becoming "generalists"
  - Why not allow the voter to give a "spectrum" of votes, so that a vote could be distributed among various candidates (sum of vote fraction squares = 1)?

Downfall of the Soviet: Loss of information?

- There were problems in –
  1. Data input:
     - Statistics were forged and not accurate
  2. Control output:
     - Commands could not be enforced
  3. Info transfer:
     - Communication block (no faxes, censorship, ...)
  4. Sampling:
     - Too long (5 years) intervals between data

Cybernetics solving political disputes ...?

- Poland has been claiming that its number of representatives in the European Parliament should be increased ... they say that the numbers of representatives from different member states should be related to *square roots of the populations*.
- The Poles say that this principle has worked well in the USA, but they have no better justification for the claim.
- Surprisingly, it seems that the Poles may have a point there. Remember that the cybernetic "stupid agent" model gives the following square root form relationship between the levels:

$$\mathrm{E}\left\{\overline{x}\overline{x}^T\right\} = \frac{1}{\sqrt{q}}\left(D^T\theta^T\ \mathrm{E}\left\{uu^T\right\}^{1/2}\theta D\right) - \frac{1}{q}\, I_n$$

Threshold

Thresholds are inherent in cybernetic systems

- Without strong enough coupling (if q is too low), variation gets filtered out
- Often, this is good (?) when noise can be avoided (compare to dissidents in politics and in science)
- Sometimes this is bad: Even good ideas have hard time breaking through all by themselves