Complex Adaptive Systems and Agent Based Modeling

of Industrial Network Growth

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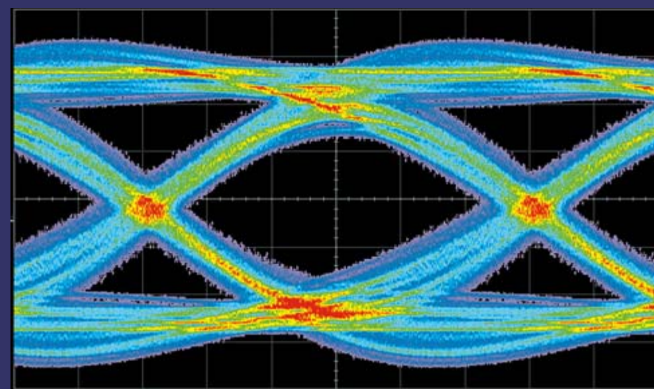
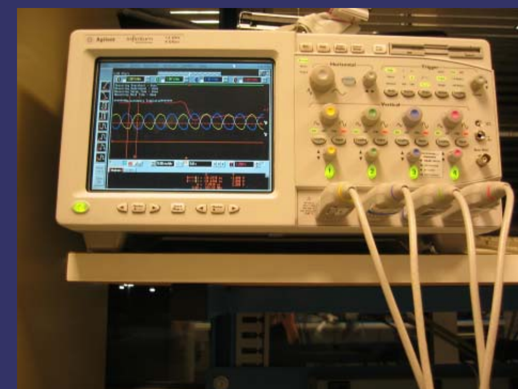
Who am I, and why am I here ?

Chris Davis

- Previously an engineer at Dell
  - Signal Integrity/Electrical Analysis

MSc in Industrial Ecology

Thesis on combining Life Cycle Analysis within Agent Based Modeling

Currently doing my Doctoral research at TPM / TUDelft, section Energy and Industry

I will talk to you about :

- Complex Adaptive Systems
- Industrial Networks
- Agent Based Modeling

Take Home (meta)Message

- The world around is Complex, both the biosphere and the Technosphere
- Any activity within both must acknowledge this, or fail miserably
- Complex Adaptive Systems is a Meta-Theory, that gives you a world view and enables cross-disciplinary knowledge sharing.
- These are very powerful tools to understand / model the world, but are not mainstream yet.
- You don't need to understand everything now, but you will know how to find it, when you need it...

- Yes, you can fall asleep now...


MAGGIE
AND THE
FEROCIOUS BEAST
LET'S PLAY A GAME!
FUN AND GAMES WITH MAGGIE AND HER FRIENDS!
DVD

Defender – Attacker game

- Lets clear the tables, and stand in a big circle...
- Randomly select 2 people :
  - A: *The Defender*
  - B: *The Attacker*
- *You are The Target !*
- Move so that you always keep *The Defender* between you and *The Attacker*

- *Source, Eric Bonabeu, http://www.icosystem.com/game.htm*

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STOP !

- *The Defender* is now the Target
- You are *The Defender !*

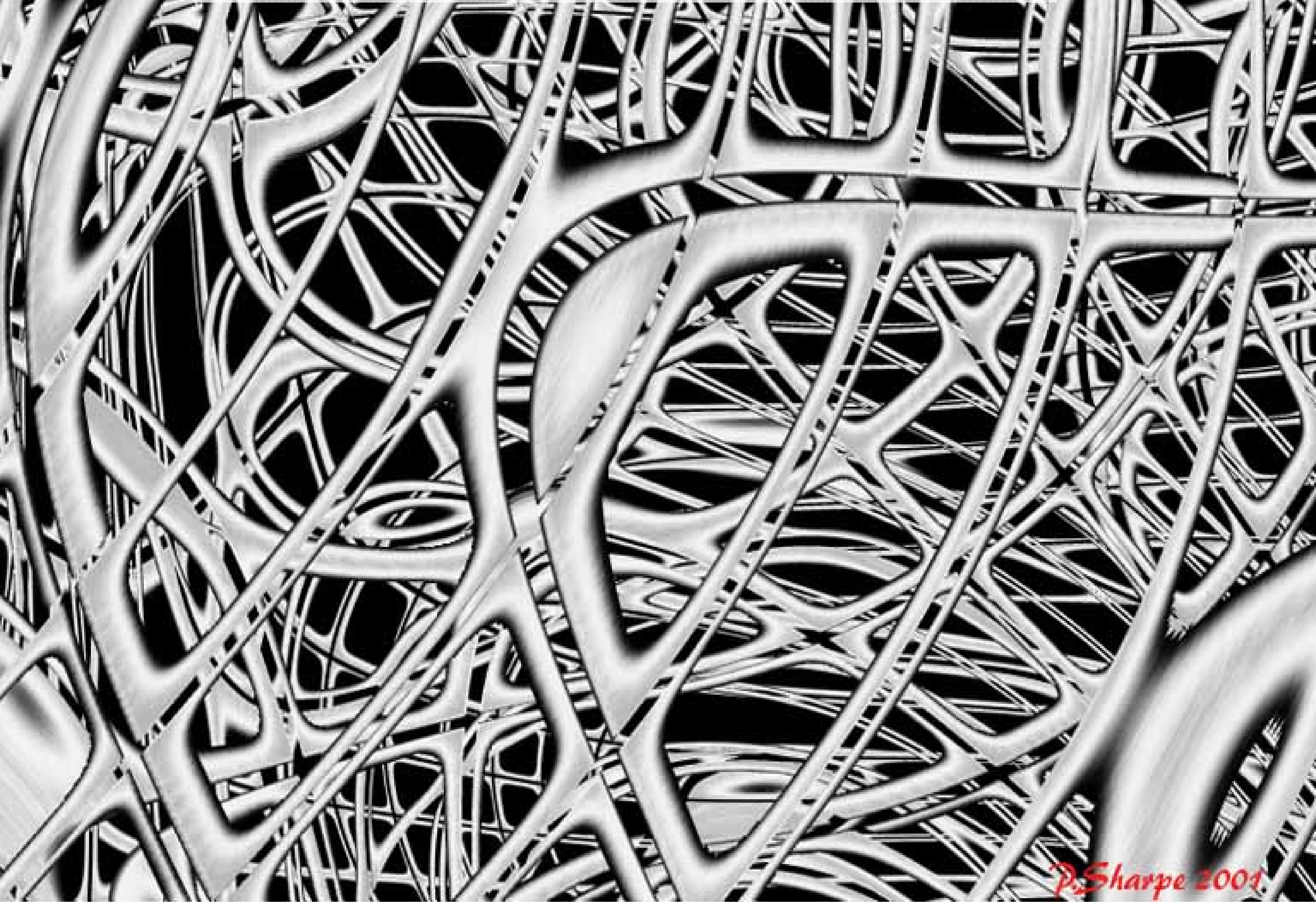
- Move so that you keep yourself between *The Attacker* and *The Target*.

What the heck just happened ?

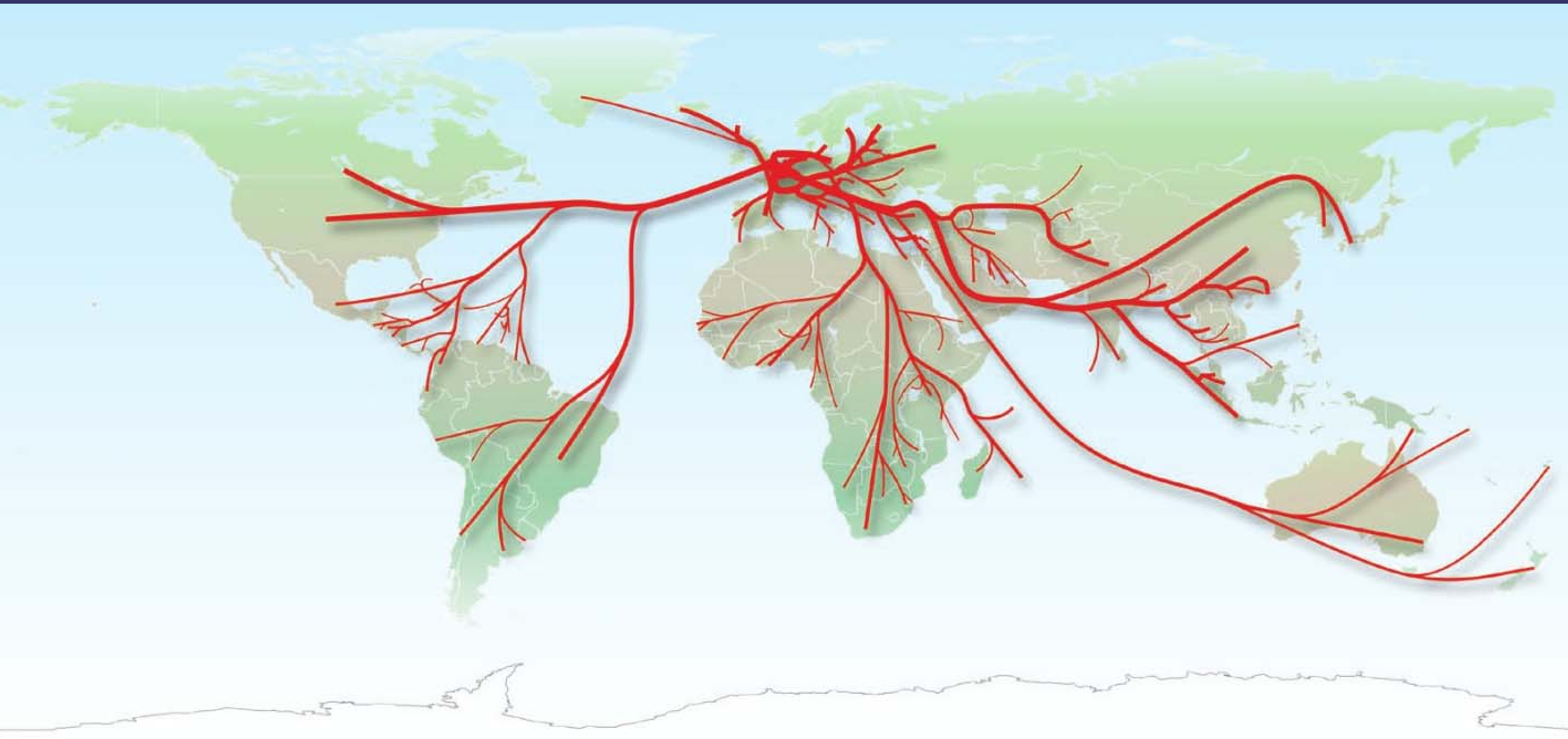
Take Home Message

- Simple rules of individual behavior can lead to surprisingly coherent system level results.
- Small changes in rules or in the way they are applied can have significant impact on the system level results.
- Intuition can be a particularly poor guide to prediction of the behavior of complex systems above a few levels of complexity (here we have only 3).
- Simulation is a powerful tool for understanding the dynamics of complex systems.
- Source : http://www.icosystem.com/game.htm

Complexity



Do We Know What We're Doing?



The UK Interdependence Report:
How the world sustains the nation's lifestyles and the price it pays

http://www.neweconomics.org/gen/z_sys_PublicationDetail.aspx?pid=220

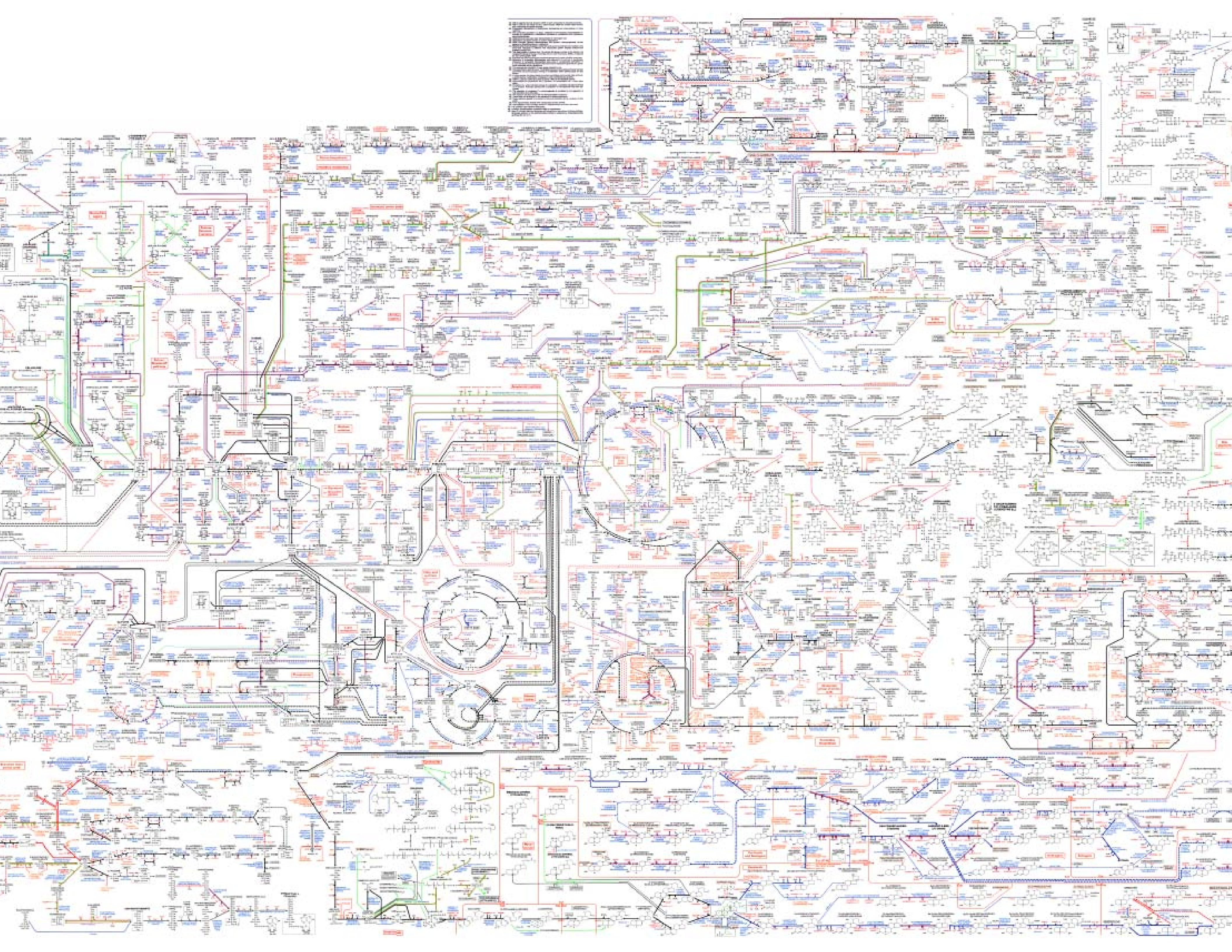
Who's in Control?

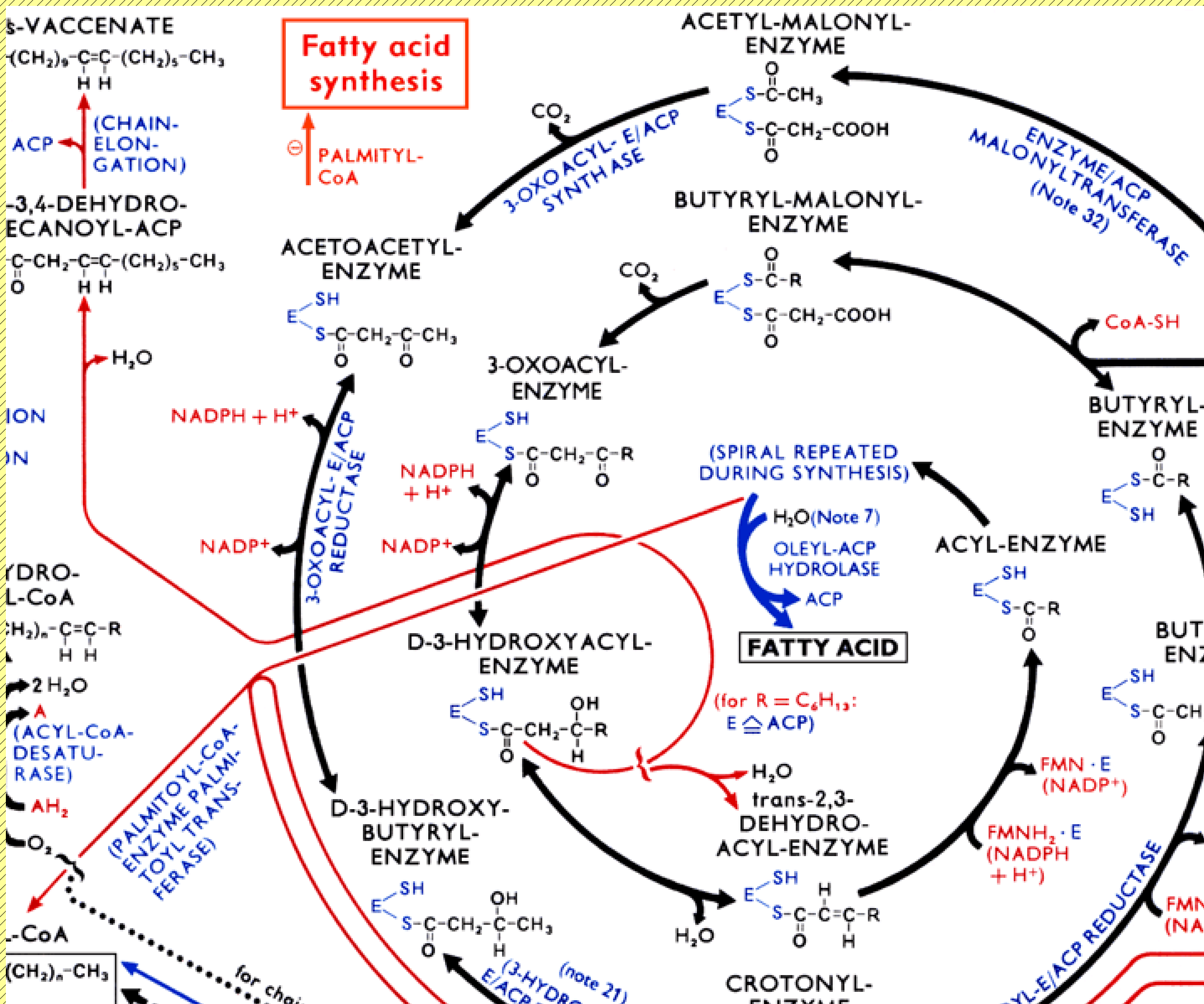
The economic problem in general, as well as that of environmental protection is...

'... how to secure the best use of resources known to any of the members of society, for ends whose relative importance only these individuals know. Or to put it briefly, it is a problem of utilization of knowledge which is not given to anyone in its totality'

F. A. von Hayek

"Economics of life cycle assessment: Inefficiency of the present approach" by S. Schaltegger quoting "Use of Knowledge in Society" by F.A. von Hayek





Fatty acid synthesis
PALMITYL-CoA
ACETYL-MALONYL-ENZYME
3-OXOACYL- E/ACP SYNTHASE
ENZYME/ACP MALONYLTRANSFERASE (Note 32)
BUTYRYL-MALONYL-ENZYME
CoA-SH
ACETOACETYL-ENZYME
3-OXOACYL-ENZYME
BUTYRYL-ENZYME
3-OXOACYL- E/ACP REDUCTASE
NADPH + H+
NADP+
(SPIRAL REPEATED DURING SYNTHESIS)
H2O(Note 7)
OLEYL-ACP HYDROLASE
ACP
FATTY ACID
ACYL-ENZYME
D-3-HYDROXYACYL-ENZYME
(for R = C6H13: E ≙ ACP)
H2O
trans-2,3-DEHYDRO-ACYL-ENZYME
FMN · E (NADP+)
FMNH2 · E (NADPH + H+)
D-3-HYDROXY-BUTYRYL-ENZYME
CROTONYL-
(CHAIN-ELON-GATION)
-3,4-DEHYDRO-
ECANOYL-ACP
(ACYL-CoA-DESATU-RASE)
AH2
(PALMITOYL-CoA-ENZYME PALMI-TOYL TRANS-FERASE)
(note 21)

Systems are :

- a regularly interacting or interdependent group of items forming a unified whole.
- an organized set of doctrines, ideas, or principles usually intended to explain the arrangement or working of a systematic whole.
- manner of classifying, symbolizing, or schematizing
- harmonious arrangement or pattern or order

merriam-webster dictionary

Systems View

Yaneer Bar-Yam : http://necsi.edu/guide/concepts/system_perspective.html

- Taking into account all of the behaviors of a system as a whole in the context of its environment is the systems perspective.
- While the concept of system itself is a more general notion that indicates separation of part of the universe from the rest, the idea of a systems perspective is to use a non-reductionist approach to the task of describing the properties of the system itself.

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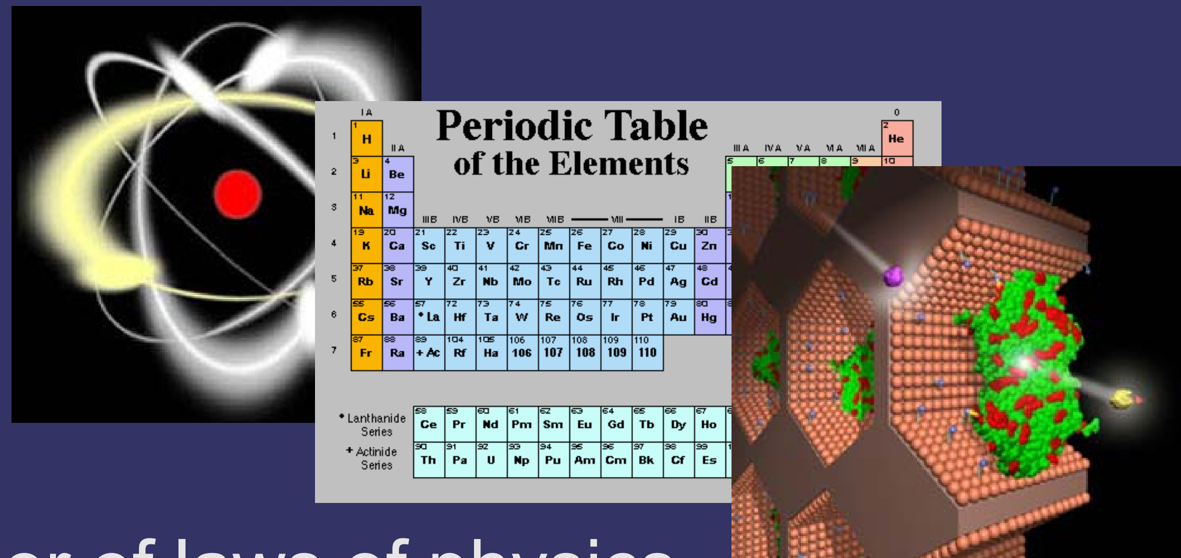
Systems View *cont.*

- In the systems perspective, once one has identified the system as a separate part of the universe, one is not allowed to progressively decompose the system into isolated parts.
- Instead, one is obligated to describe the system as a whole. If one uses separation into parts, as part of the description of the system properties, this is only part of a complete description of the behavior of the whole, which must include a description of the relationships between these parts and any additional information needed to describe the behavior of the entire system.

An Analogy



- Physics
  - Basic laws
- Chemistry
  - Emergent behavior of laws of physics
- Biology
  - …
- Psychology
  - …
- Sociology
  - …

www.sciencemuseum.org.uk / www.unm.edu / www.sc.doe.gov

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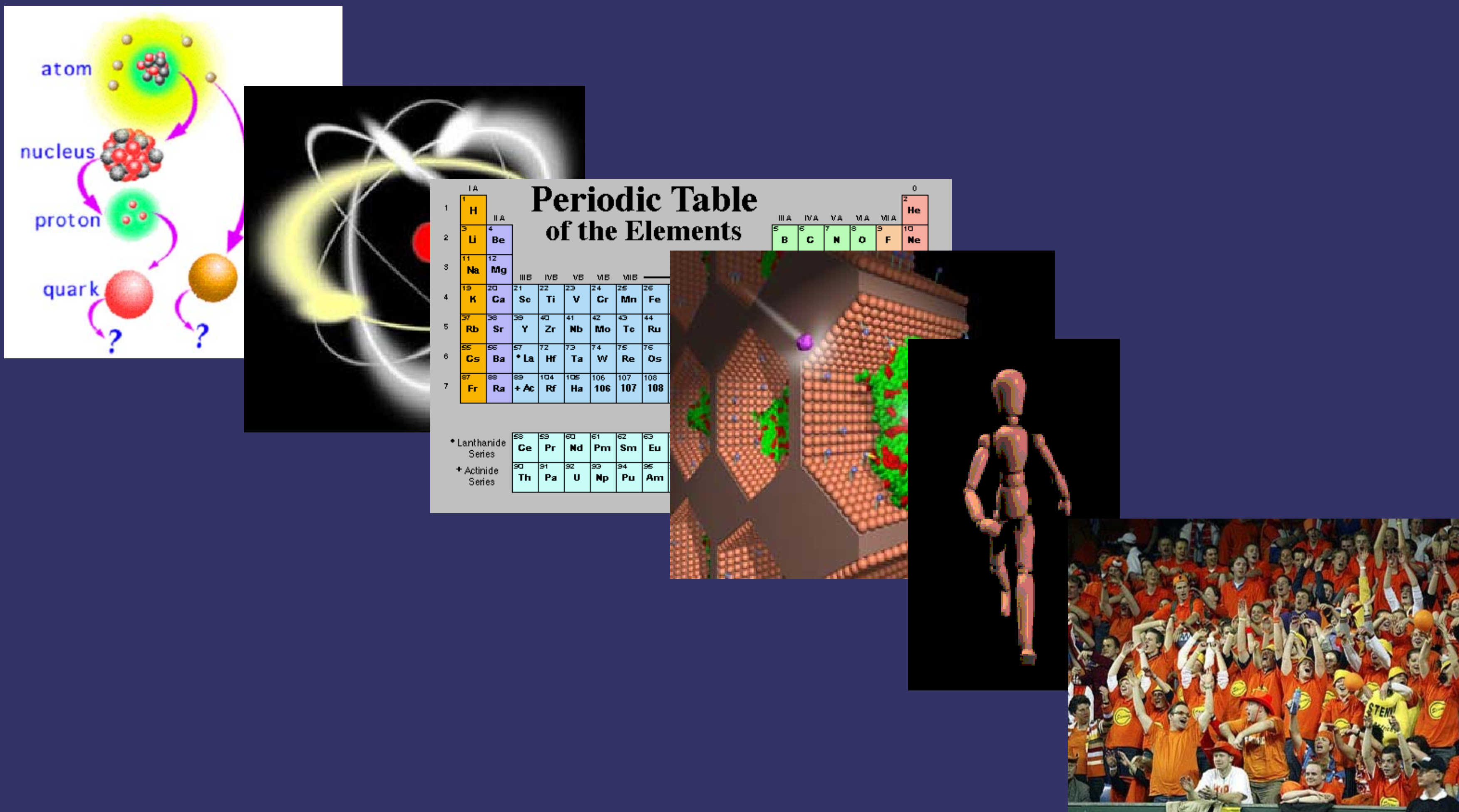
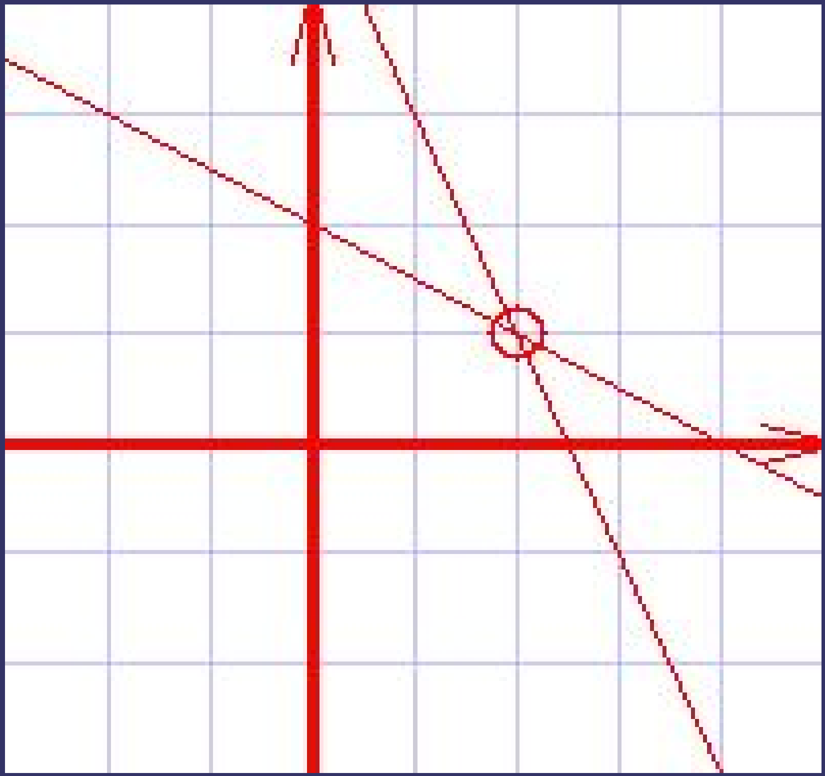
Levels



Levels do not exist in the real world: continuum of ‘levels’.
It’s all in the eye of the beholder…

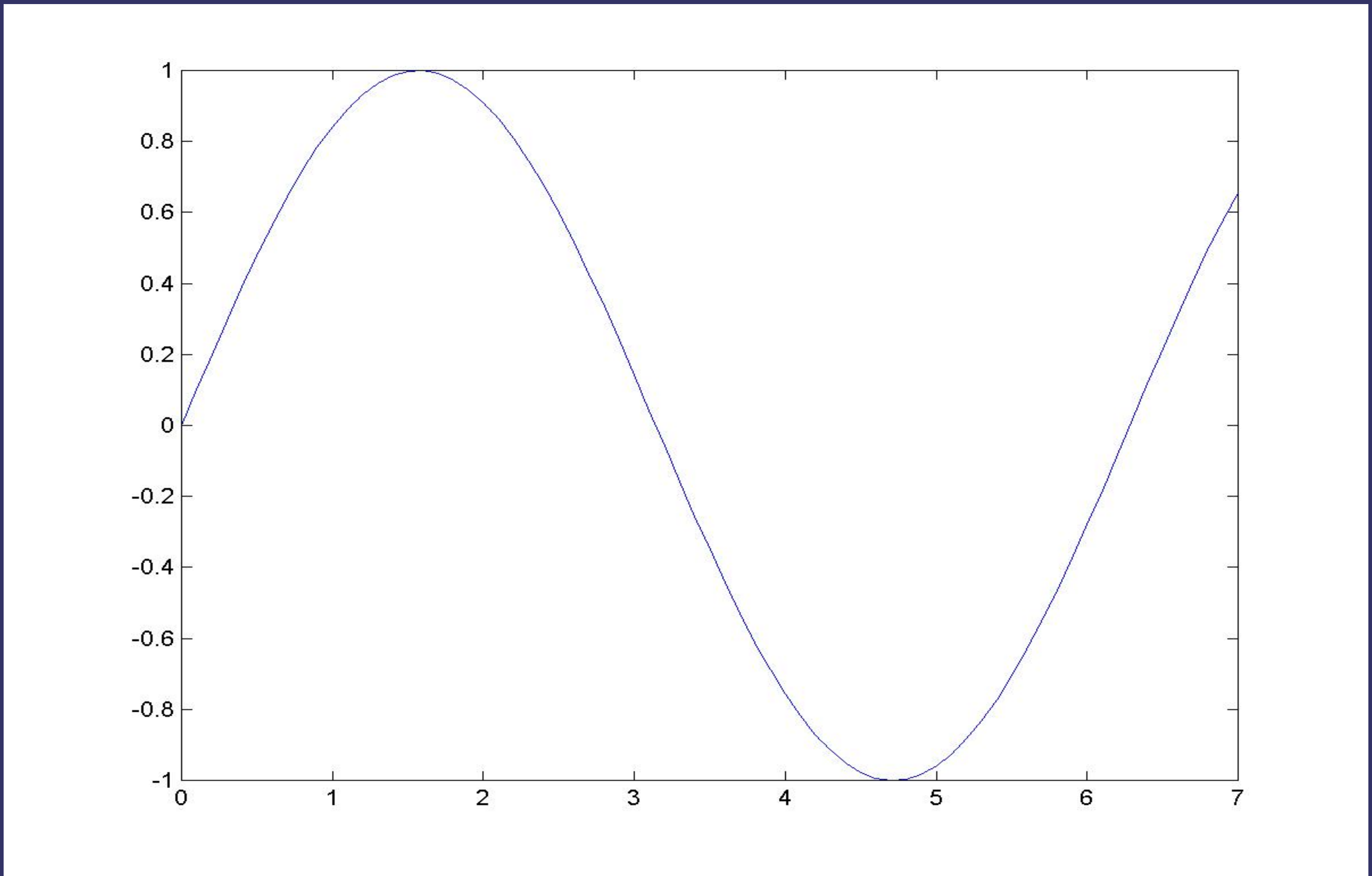
Linear Systems

- Linear systems are ``simple''. An change in the systems setting results in a system response linearly proportional to the input. (y=Ax+B)
  - often used as an approximation of more complicated systems because they are easy to calculate. (matrix inversion)



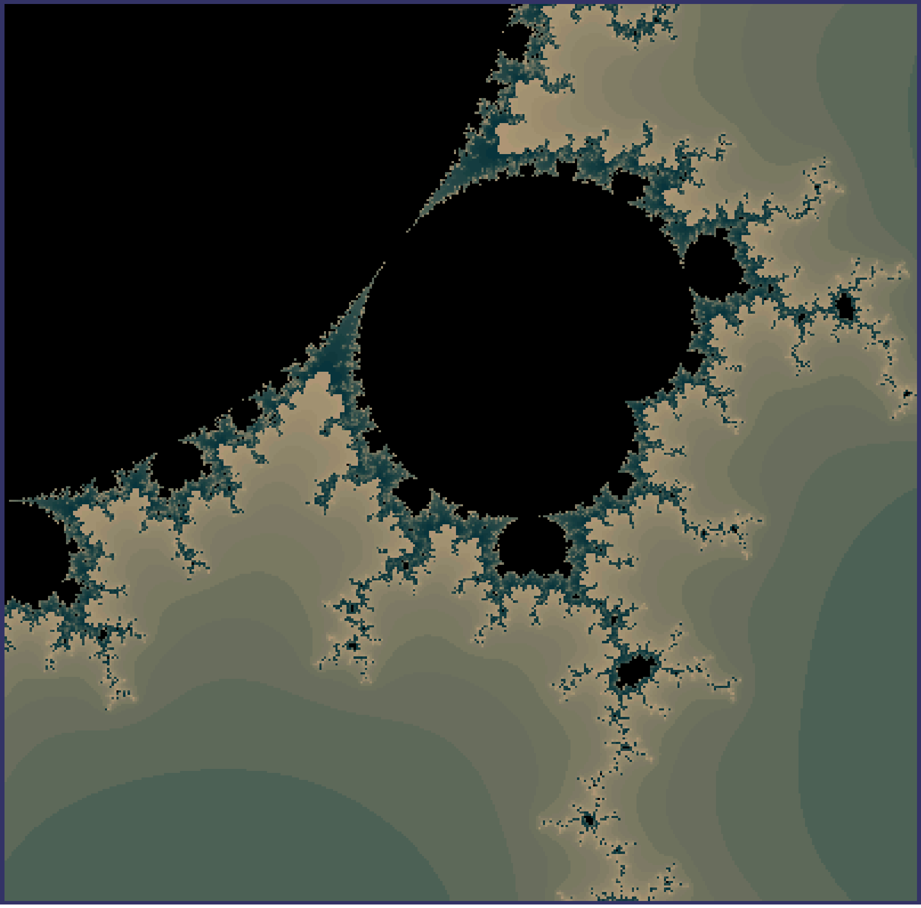
Nonlinear systems

- Nonlinear systems have a response that is not proportional to the input.
  - can be straightforward and predictable (y = sin x)

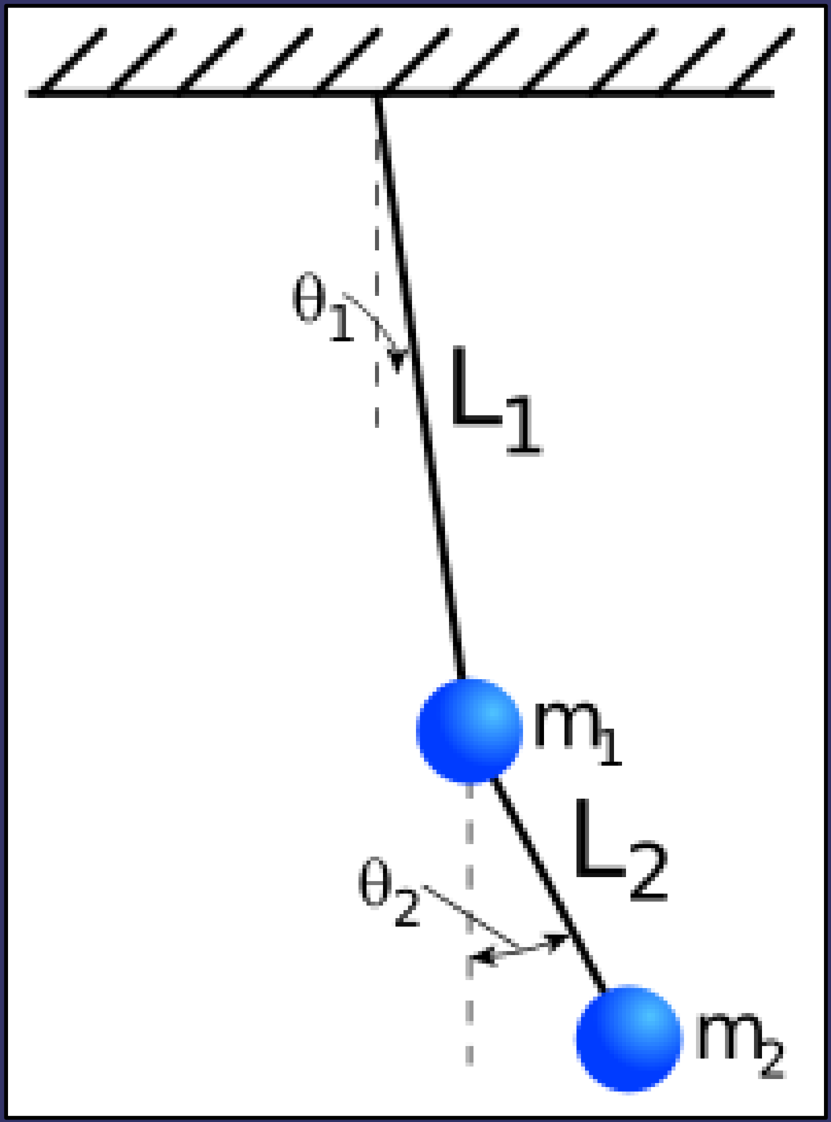


Nonlinear chaotic systems

- Some non-linear systems express Chaotic behavior.
  - That is, extreme sensitivity to initial conditions, as in case of Z = Z^2 + Ci

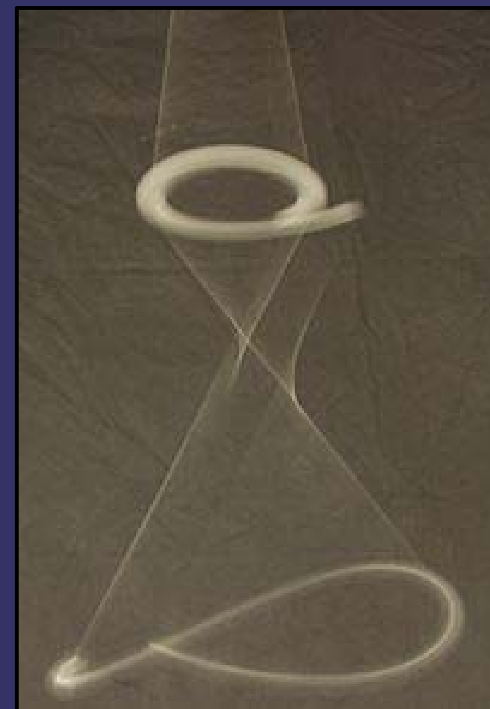


Double Pendulum



Double Pendulum

- A simple system with chaotic behavior



Complexity

- Complexity is the property of a real world system that is manifest in the inability of any one formalism being adequate to capture all its properties.
- It requires that we find distinctly different ways of interacting with systems.
- Distinctly different in the sense that when we make successful models, the formal systems needed to describe each distinct aspect are NOT derivable from each other.

- D. C. Mikulecky

Measuring Complexity?

We shouldn't expect to be able to come up with a single universal measure of complexity.

The best we are likely to have is a measuring system useful by a particular observer,
in a particular context,
for a particular purpose.

T. Carter, CSSS 2002

Complex Adaptive Systems

- A Complex Adaptive System (CAS) is a dynamic network of many agents (components) acting in parallel, constantly acting and reacting to what the other agents are doing.
- The control of a CAS tends to be highly dispersed and decentralized.
- If there is to be any coherent behavior in the system, it has to arise from interaction (competition, cooperation etc.) among the agents themselves.
- The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents.
- (source: John H. Holland, Complexity: The Emerging Science at the Edge of Order and Chaos)

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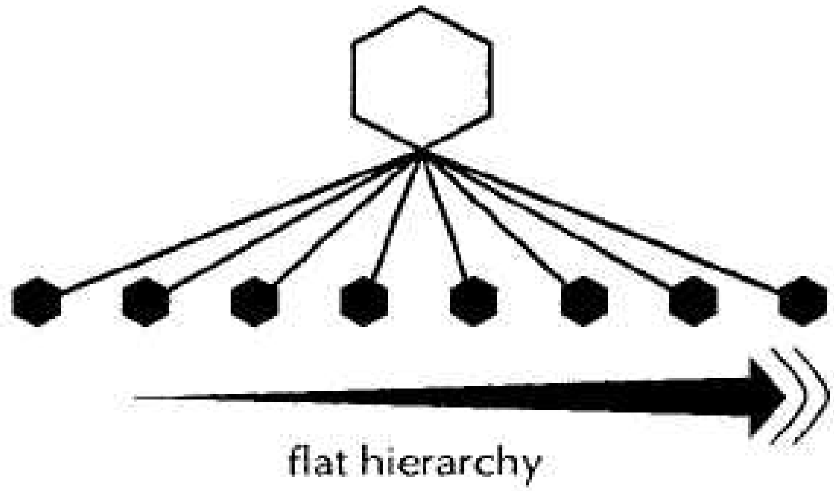
Complex vs. Complicated

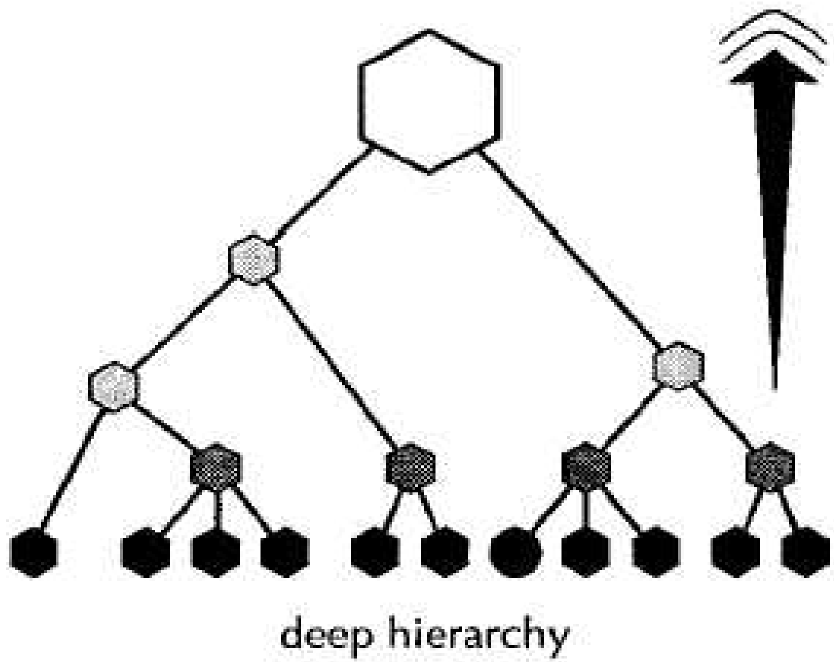
Horizontal Differentiation

Elaboration of structure solves problems and moves on to the next problem, leaving structure behind. Evolution makes COMPLICATED structure that is difficult to control, predict, or mend. It causes horizontal differentiation.



Vertical Differentiation

Elaboration of organization creates energy dissipative far from equilibrium structures. It causes COMPLEX structure with many levels. Behavior becomes simple but energetic cost is high. Emergence causes vertical differentiation.



Supply side sustainability, Hoekstra, Allen and Tainter, Systems research and Behavioural Science, 16, 403-427,1999

(some) Properties of CAS

- Emergence
- Chaos
- Observer Dependence
- Path Dependence
- Adaptiveness
- Non Linearity
- Robustness
- Instability
- Diversity
- Self Similarity
- Context Dependency
- Intractability
- ...

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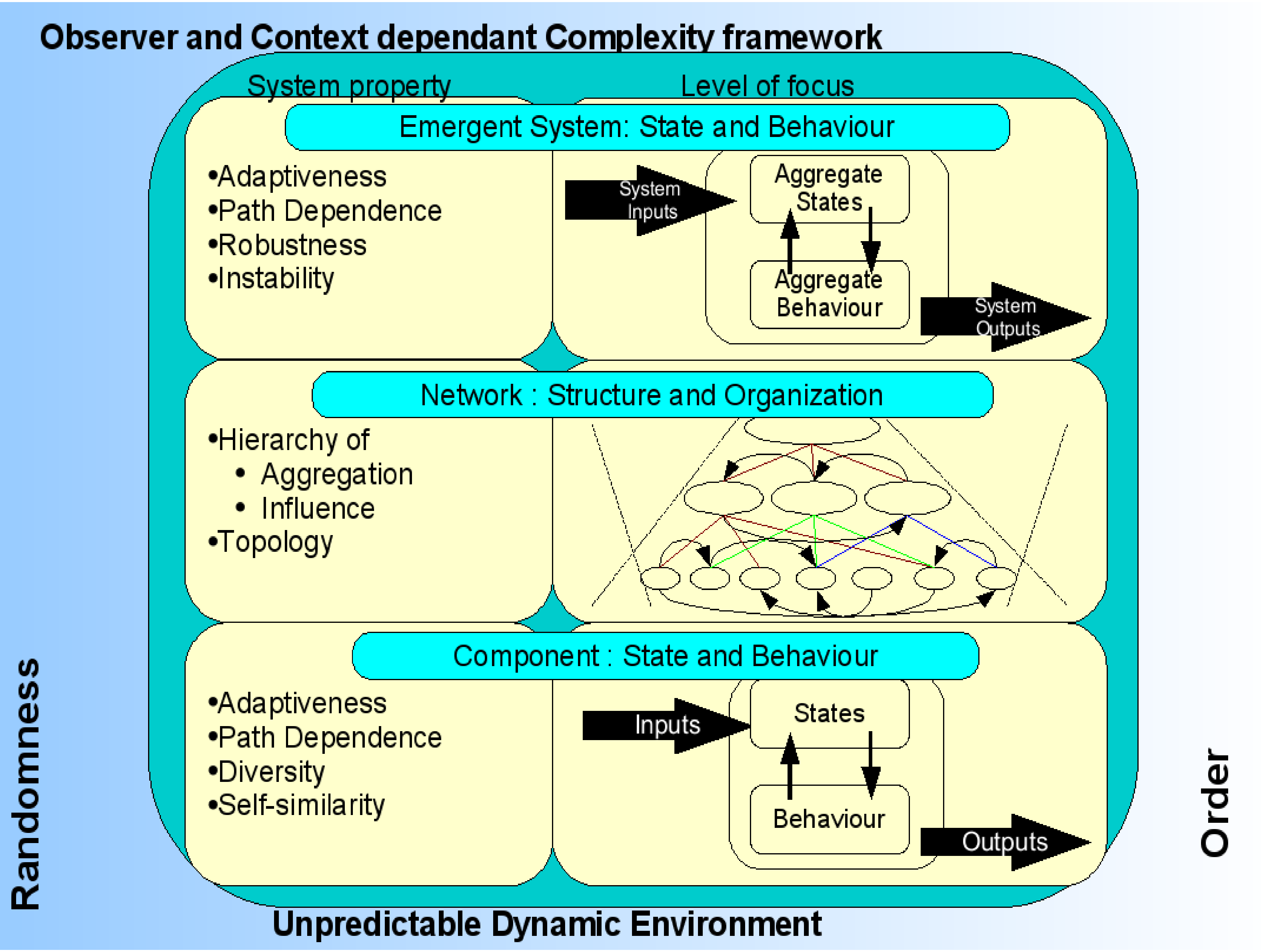

Observer and Context dependant Complexity framework
System property
Level of focus
Emergent System: State and Behaviour
•Adaptiveness
•Path Dependence
•Robustness
•Instability
System Inputs
Aggregate States
Aggregate Behaviour
System Outputs
Network : Structure and Organization
•Hierarchy of
• Aggregation
• Influence
•Topology
Component : State and Behaviour
•Adaptiveness
•Path Dependence
•Diversity
•Self-similarity
Inputs
States
Behaviour
Outputs
Unpredictable Dynamic Environment
Randomness
Order

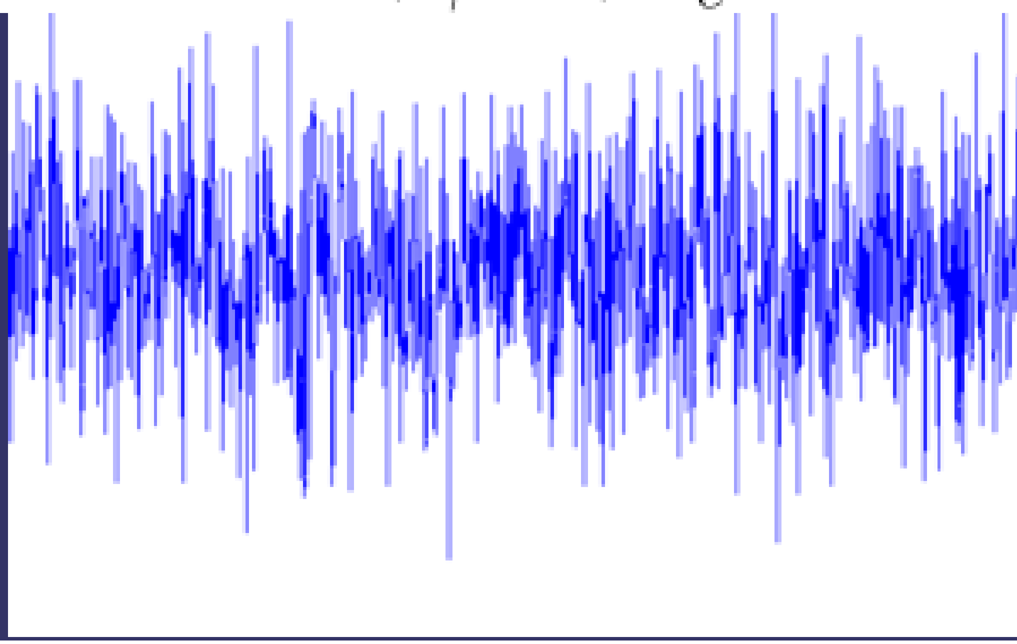
Chaotic vs. Random

- State of a dynamic system changes over time, according to some rule or procedure (linear or not). Such a system is called deterministic.
- Fractals are deterministic systems that are chaotic. That means that their dynamic is very sensitive to small variations in initial conditions of the parameters.
- They are however NOT random.
- Random things can not produced by any system (model). Only (suspected) true random thing known to man is the decay of radioactive atoms.

Randomness

- True Randomness has NO cause !
- Your computer CAN NOT make a random number...
- Get your random numbers here :http://www.fourmilab.ch/hotbits/
- Randomness contains NO information !
- Drives mutation in nature !

$$^{137}\mathrm{Cs} \xrightarrow{30.17\mathrm{y}} {}^{137\mathrm{m}}\mathrm{Ba} + \beta^- + \overline{\nu_e} \xrightarrow{156\mathrm{s}} {}^{137}\mathrm{Ba} + \gamma$$



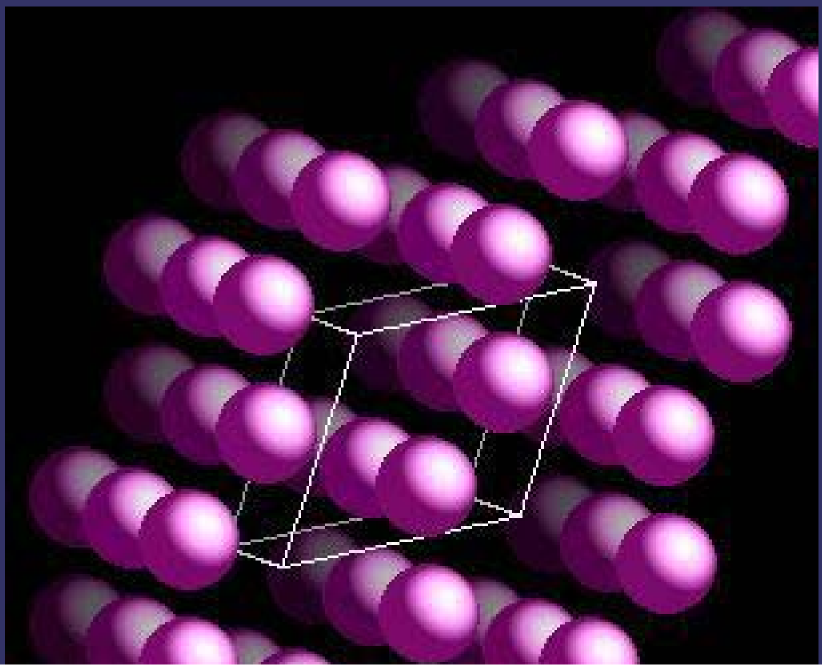
Radiation and DNA

- Just think about it for a second....
- The most information-loaded molecule, allowing for all known life, producing very highly ordered structures, **DNA** is extremely sensitive to THE random source in universe, nuclear decay....

Order

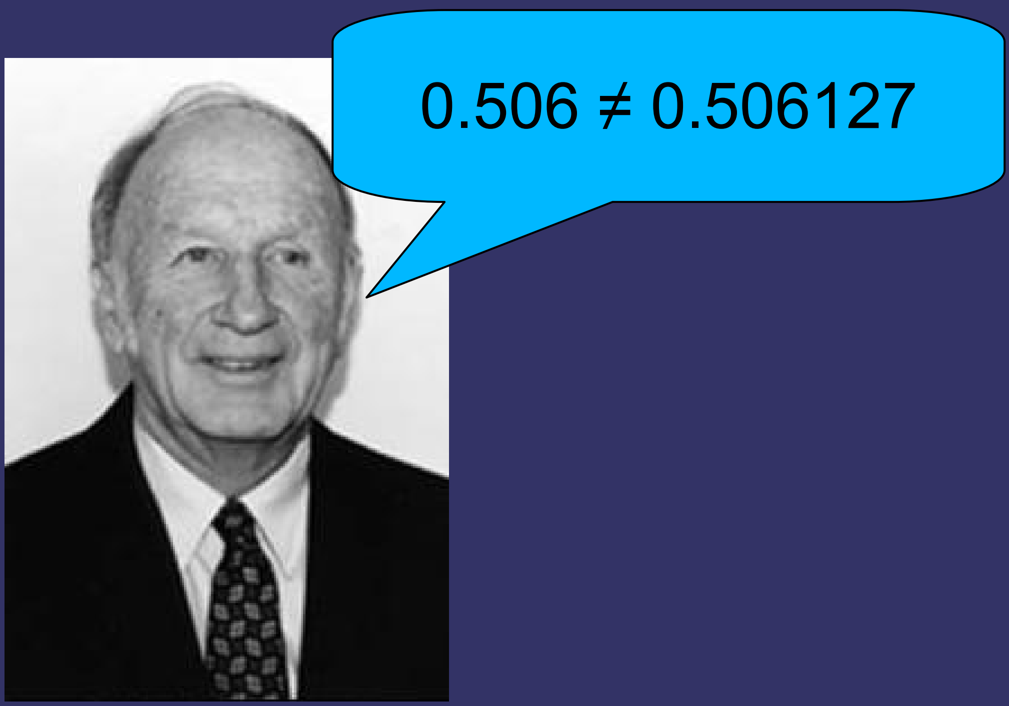
- 111111111111111111111111111111111

- Perfect order has NO information
- Crystals are almost fully ordered.
- Kauffman : Life between Order and Chaos

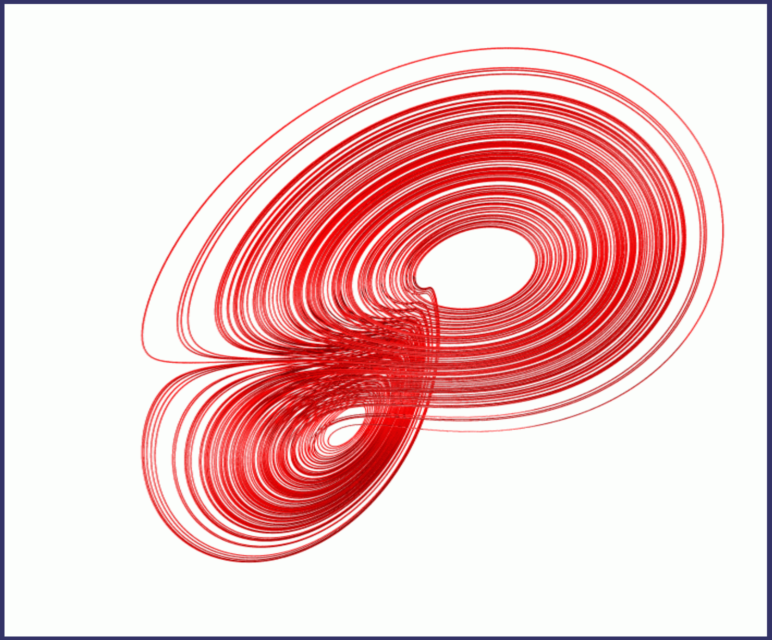


Chaos

- Complex behavior, arising in a deterministic non-linear dynamic system, which exhibits two special properties:
  - sensitive dependencies in initial conditions
  - characteristic structures

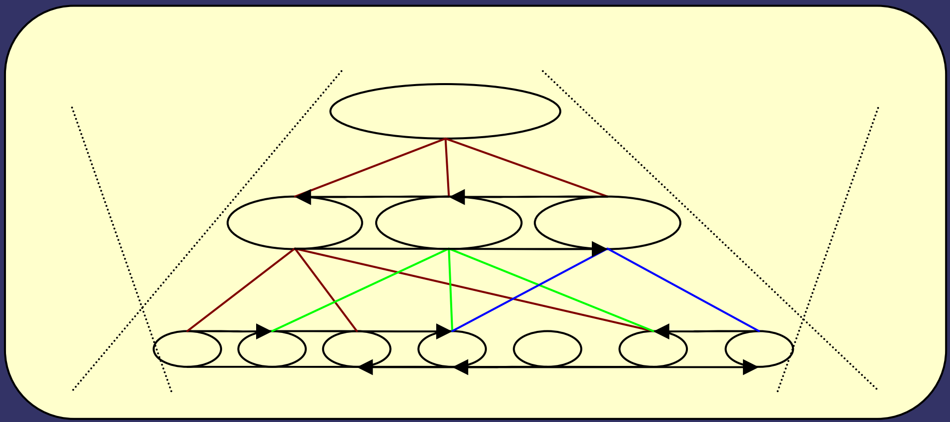


Edward Lorenz



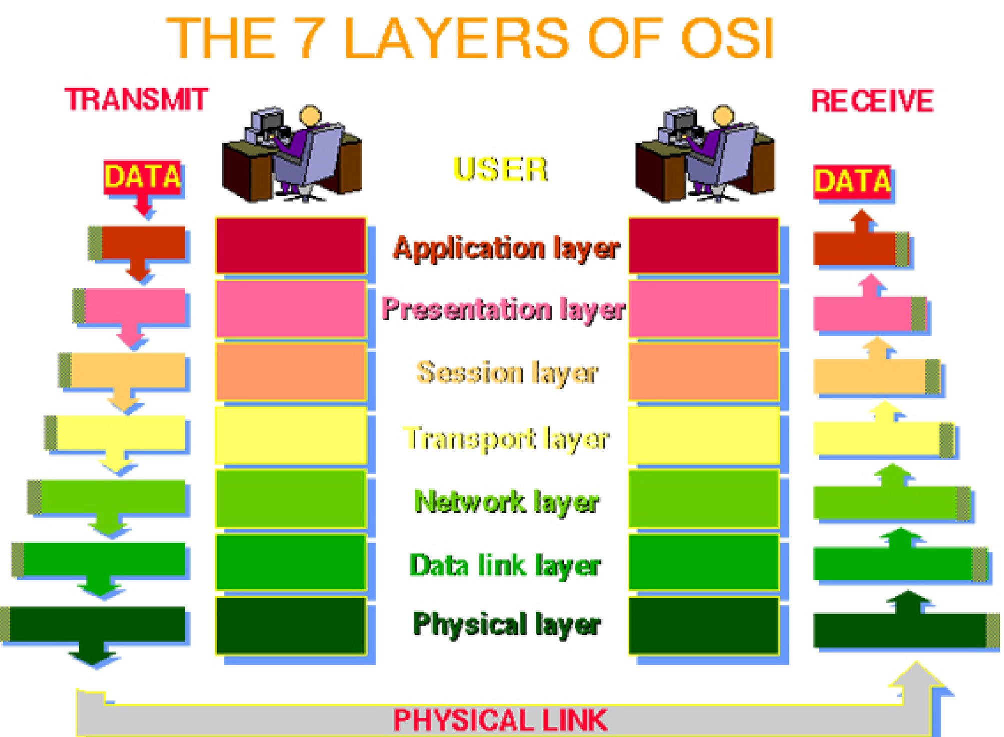
Context Dependency

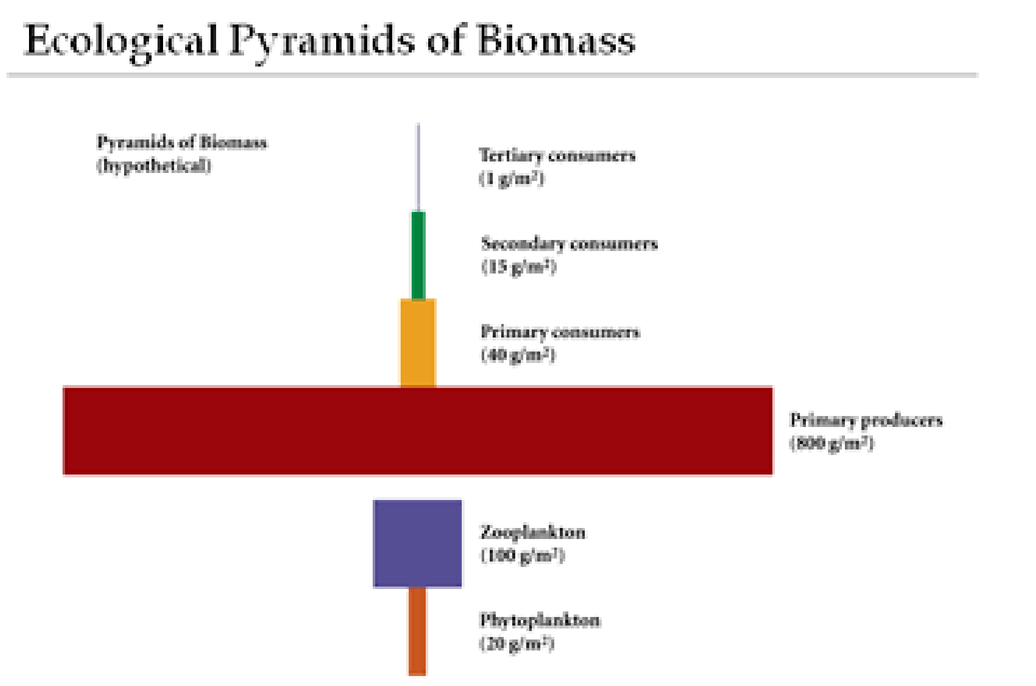
- Most complex systems have an elaborate hierarchical organization where the upper levels constrain the actions of the lower levels.
  - Low level system components provide all the possible behaviors that a system can have.
  - Higher systems levels set the boundaries to behavior.
- This creates an interlocking limitations between the levels that determine the overall system behavior.



Context Dependency examples

- trophic levels of food webs (grass / grazers / predators / humans)
- the Internet (cables / protocols / data / music sharing / RIAA lawsuits)





Sustainability example

- Rules for CFC banning work within the Western world. China is the biggest growth market since the ban.
- A gene that makes plants resistant to insects can cause devastation if it enters the wrong population.

  - *Why is this property important ?*
- it is not only the thing you do, it is where you do it.
- Realize that nothing exists in isolation

Emergence

- Emergent high-level properties are interesting, non-obvious consequences of low-level properties. They are more easily understood in their own right than in terms of properties at a lower level.
  - Emergence is not a thing, but a process.
  - Emergence is a measure of surprise we get from observing the system. It is a function of our ignorance.

1929

2008

Sustainability example

- Global overconsumption
- Ever increasing pollution
  - *Why is this property important ?*
- Only solving the consequence itself does not solve the problem.

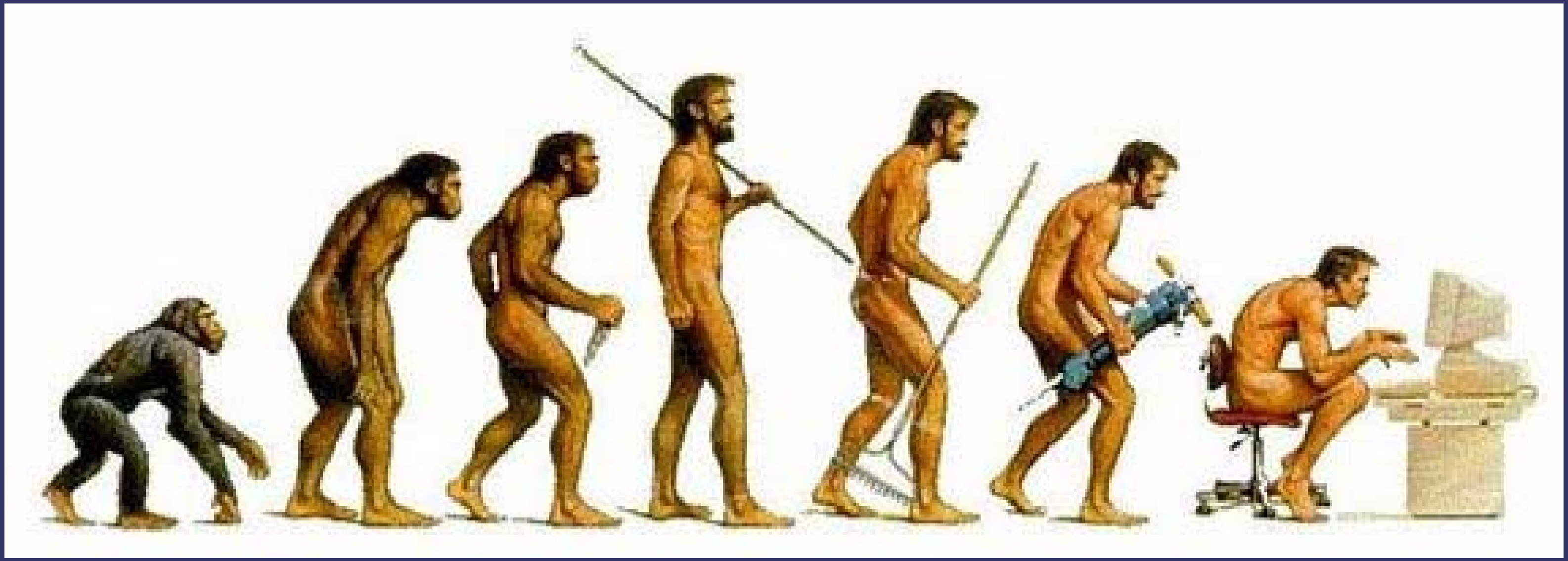
Observer Dependence

- When the observer has a good predictive/explanatory model of system behavior, she will understand the system behavior and not be surprised by its dynamics or characteristics.
- Observer with a less good model will perceive a number of behaviors and states as emergent, since they can not be predicted or understood by the model.
  - Swarming behavior of birds was/is considered emergent until it was discovered that they follow 3 simple rules.

Questions ?

Path Dependence

- The state and dynamics of a Complex systems depend on its previous states and dynamics. Complex systems have a "memory" or path that is of influence on their behavior.
  - Once a society has chosen a certain technology, it can not easily change from it.
  - Evolution is more and more variation on less and less themes. eg. four limbs in vertebrates...



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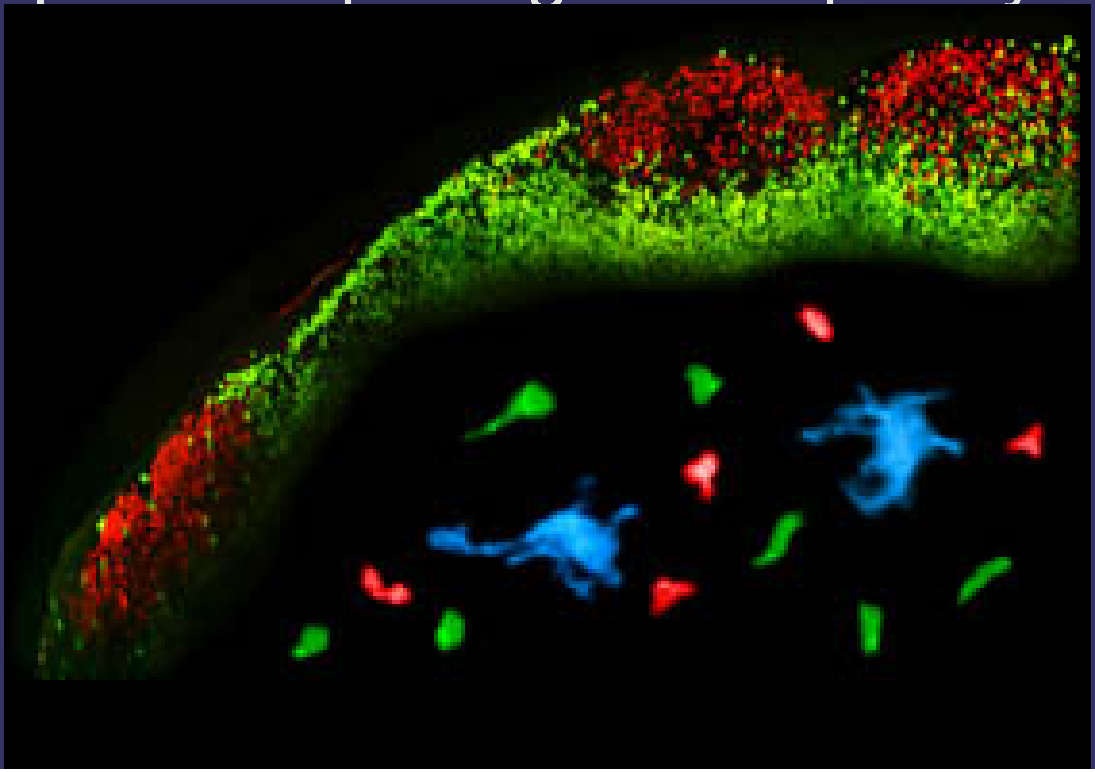
Sustainability Example

- The famous example of the oil-barons in the beginning of the 20th century bought all the light rail (tram) companies in cities and tore out the tracks. This “forced" the US to become totally car dependent.
  - *Why is this property important ?*
- Be aware of the possibility of bifurcation.
- Make your choices very carefully !

Adaptiveness

- As an influence of the surroundings or internal states, a Complex system can change its behavior. The change is towards a more "optimal" or "fit" state. Complex systems posses a notion of "learning"
  - Immune system becomes more responsive after it has been exposed to pathogens frequently.



Sustainability Example

- If a field is sprayed with herbicides for a long time, tolerant weeds will appear.
- Long term application of antibiotics is causing a worldwide resistance (eg. TBC)
  - *Why is this property important ?*
- Be aware of the pressures you exert. System may adapt !
- The world is not static !

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Diversity

- Complex systems exhibit a high degree of diversity in their subsystems.
  - Ecosystems consists of different species and Society consists of many types of people.

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Sustainability Example

- Great biological diversity protects from disease (see the problem of monoculture and pests)
- Technological diversity can cause inefficiencies (incompatibilities in electricity nets)

  - *Why is this property important ?*
- Lack of it makes systems fragile
- Too much of it make system inefficient

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Self-Similarity

- Most components of a system share a common quality, properties or behavior. Components must be similar enough to be able to interact.
  - All organisms in an ecosystems metabolize and grow. Ecosystems themselves can be seen as such organisms.
  - Society as a whole reflects many properties of a person, eg. need for security.

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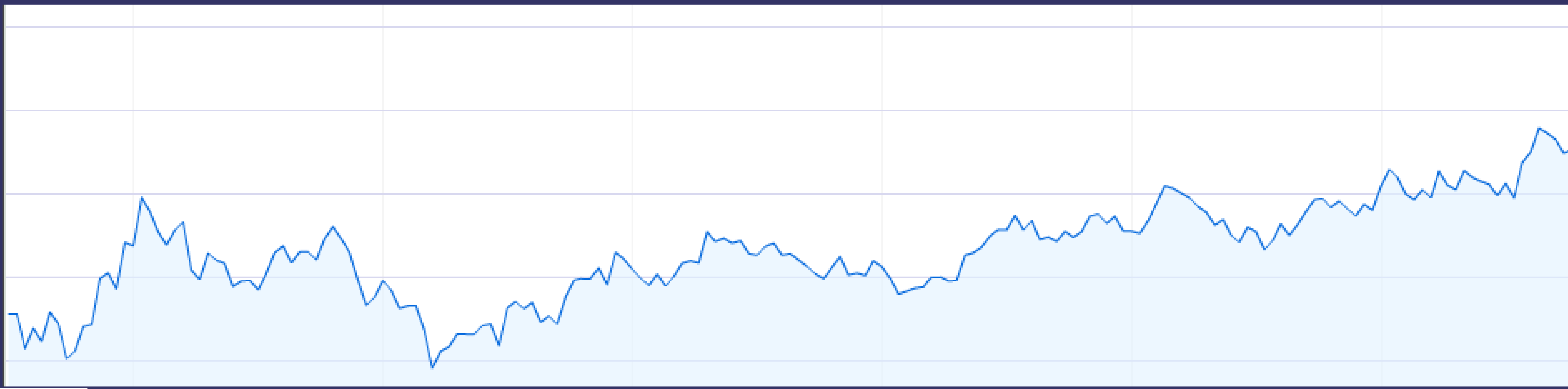
Self-Similarity

- Ex: Dow Jones Industrial Index graphs
- What are the different time scales?



Self-Similarity

Sustainability Example

- Most people respond to financial incentives (environmental subsidies and taxes)
- Income distribution : species distribution
  - *Why is this property important ?*
- If you look right, you might find a common approach to very different set of problems

Robustness

- Complex systems are often very robust to change. The effect needed to cause a system to change can be very large.

- Ecosystem can lose a large proportion of its species before becoming unstable
- A brain can still be functioning, even after large portions of it have been attacked by stroke.

Sustainability Example

- Attempts to restore eutrophied lake ecosystems were unsuccessful
- Consumer preferences about eco-friendly products are very difficult to change
  - *Why is this property important ?*
- There is no quick fix !

Instability

- Most complex systems posses more than one "Attractor". That is, they posses more than one "Steady State"that attracts the system towards it.
- Changing a system parameter, rule or structure results in a system response that is not be proportional to the change (even though it might). Nor is the causality of an modification guaranteed.

- Your heartbeat can double as a result of you being scared by a loud noise in a few seconds
- Shouting "Free Beer!" on a student party causes an stampede and a rush in the corridors.

Sustainability Example

- Remember the oil baron example? Small action can have very large effect.
- Removal of keystone species can cause an ecosystem collapse.

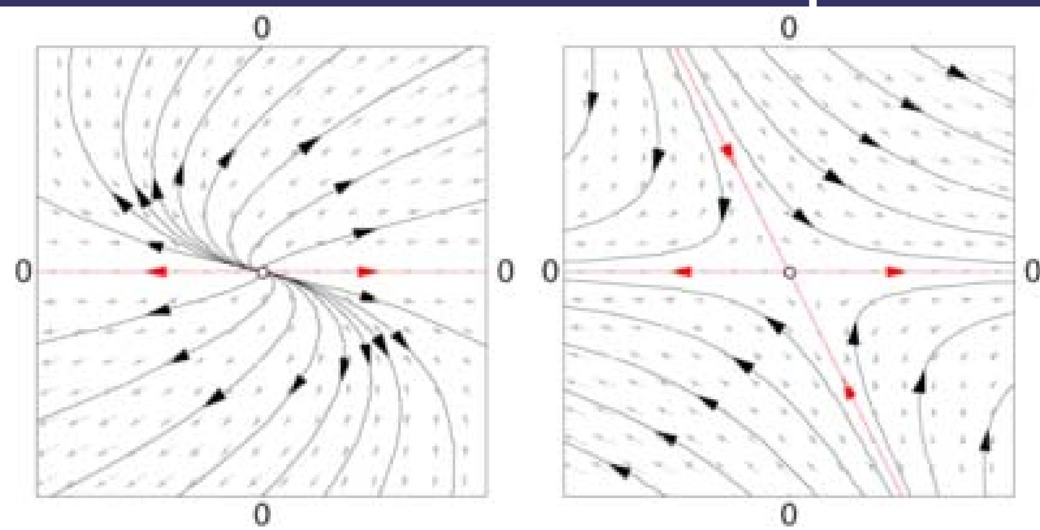
  - *Why is this property important ?*
- Complex system can behave chaotically.
- Be careful what you do to them.

Statistical Thermodynamics

- Studies the aggregate state of all the components in a system
  - pressure
  - temperature
  - entropy
  - free energy
- Deserts are hotter than rainforests, even though they get the same amount of sunlight

Non-linear dynamics : studying chaos

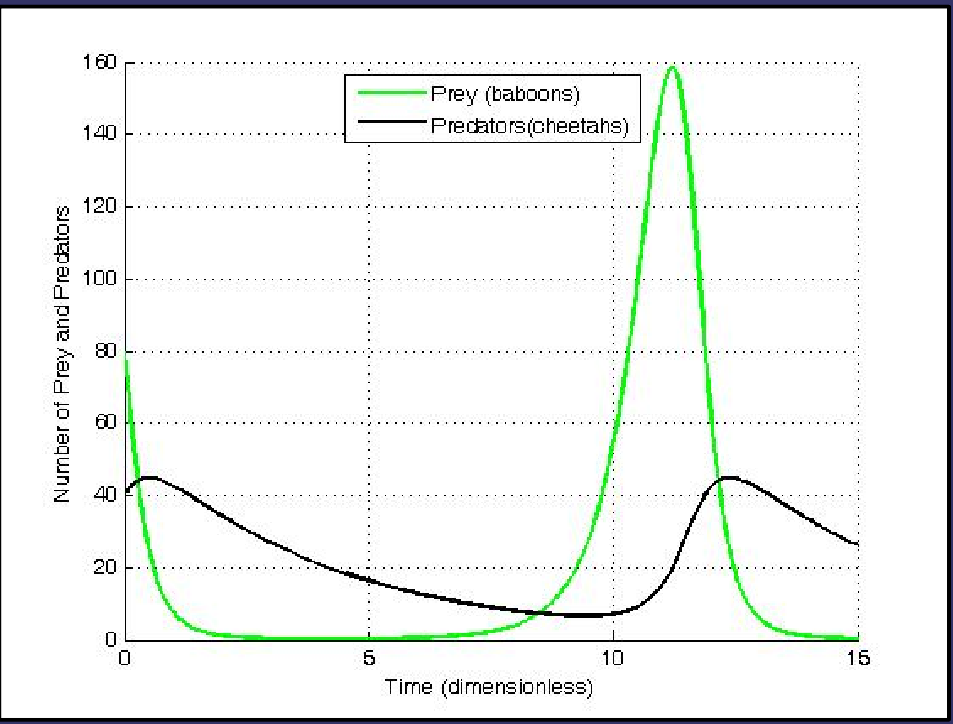
- Attractor maps



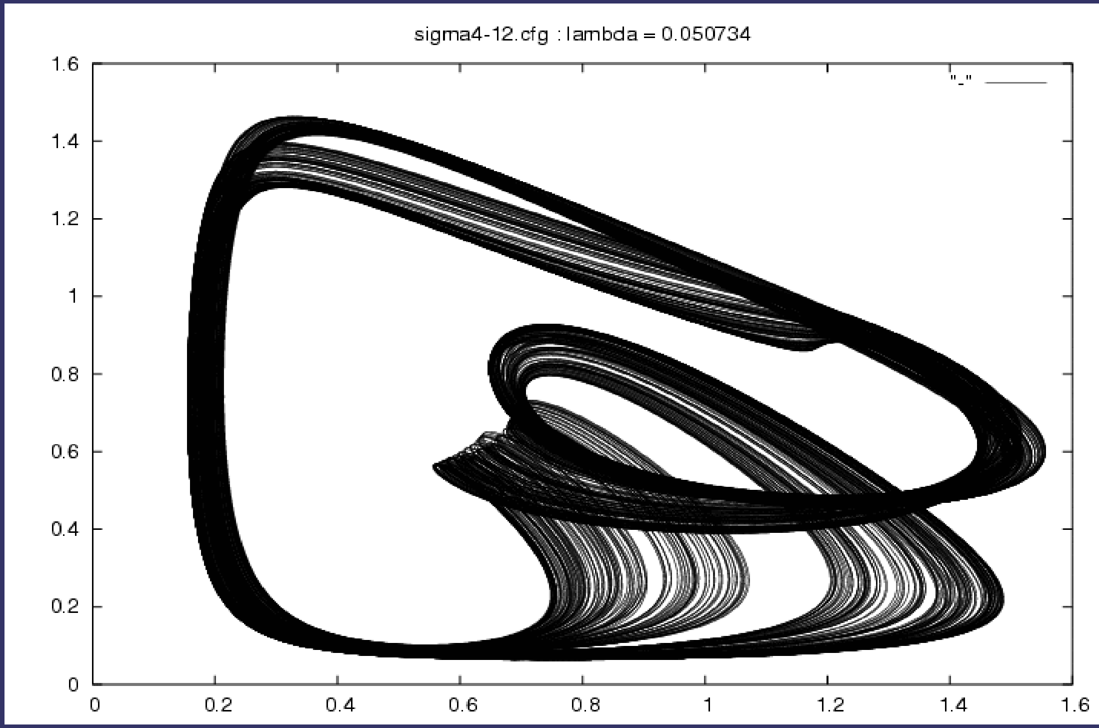
- Bifurcation maps

Attractor Map

- Predator-Prey Relationships

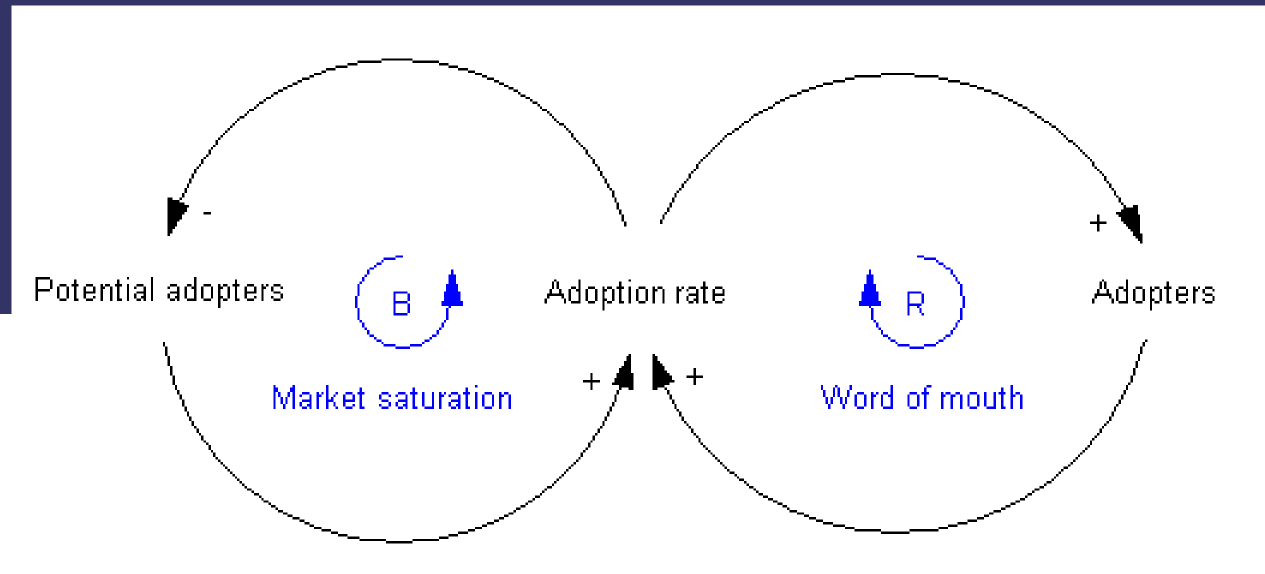


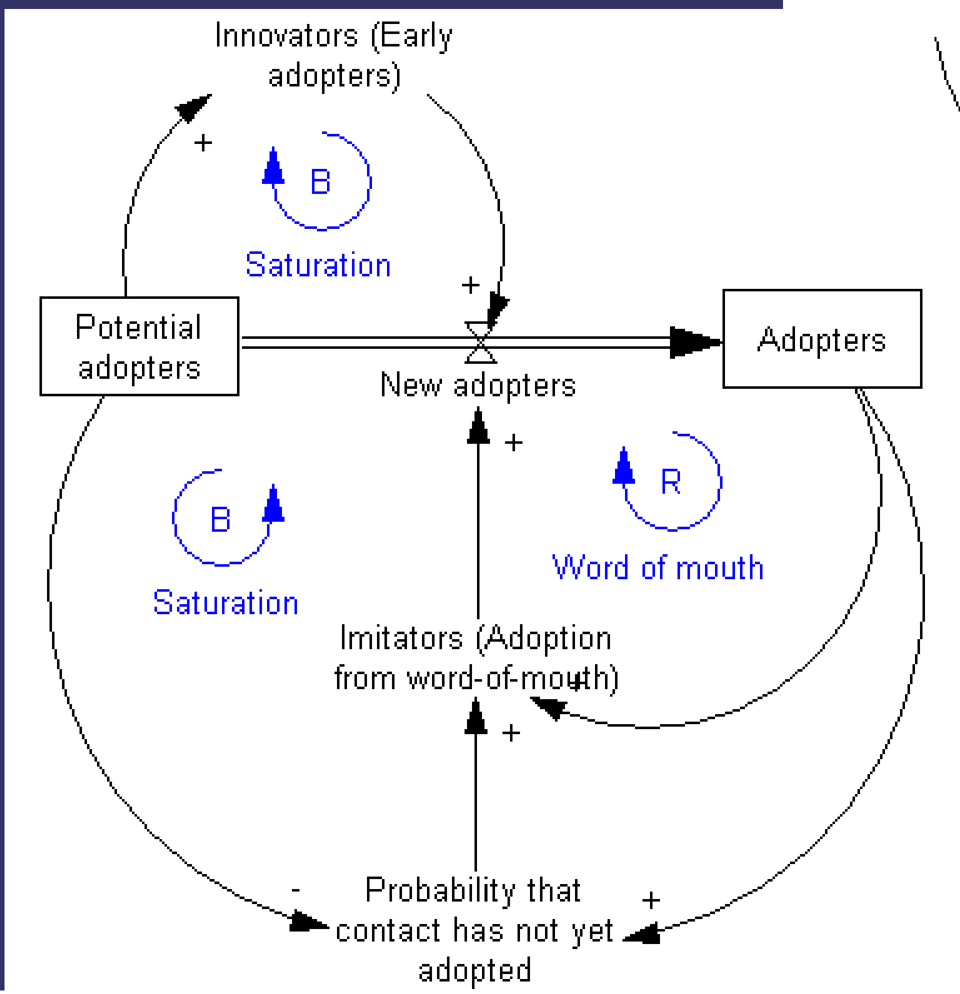
http://en.wikipedia.org/wiki/Lotka-Volterra_equation



http://www.joakimlinde.se/projects/LVmaps/

System Dynamics

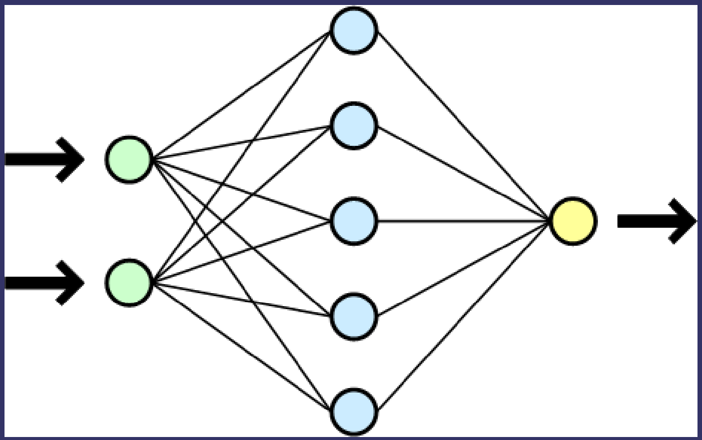




- Top-Down description of systems behaviour
  - Stocks and Flows
  - Causal Loop diagrams
- Can be chaotic...

Neural Network

- is a system of interconnecting neurons in a network working together to produce an output function. The output of a neural network relies on the cooperation of the individual neurons within the network to operate.
  - Biological (Brain !)
  - Artificial
- Used for pattern creation and recognition



- an interconnected group of artificial neurons that uses a mathematical or computational model for information processing based on a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network.

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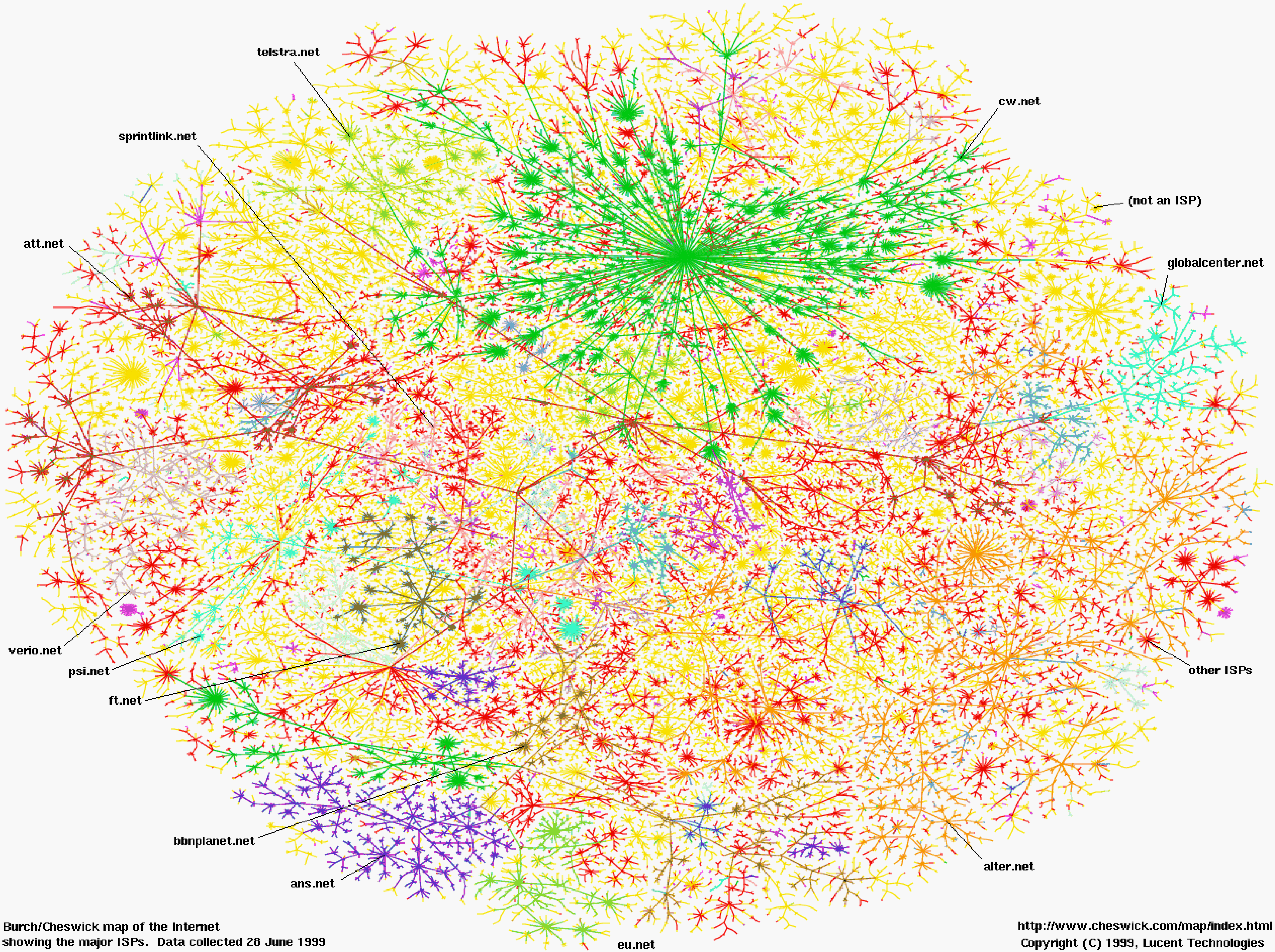
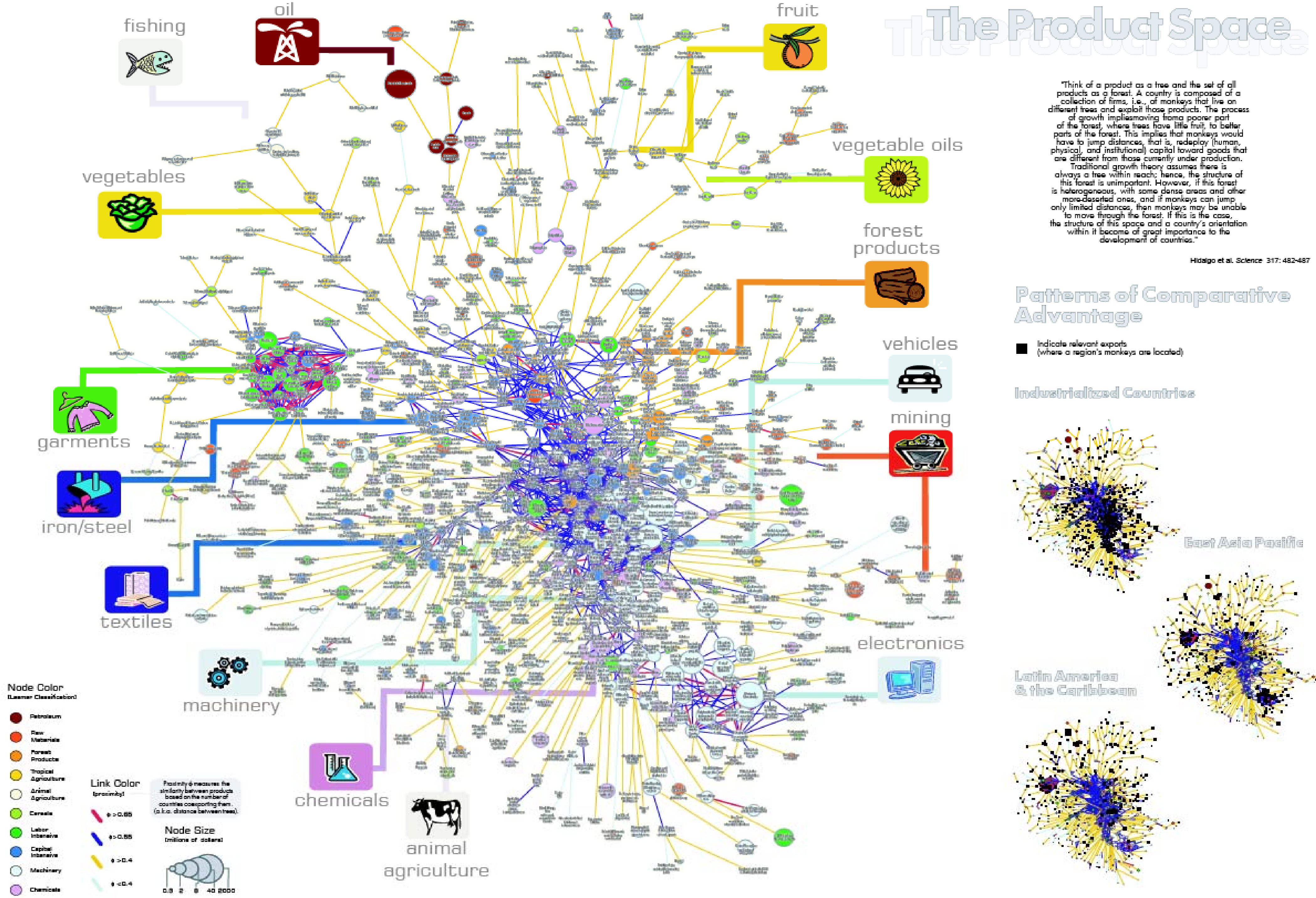
Network (Graph) theory

- graph theory is the study of graphs, mathematical structures used to model pairwise relations between objects from a certain collection.
- Everything is an Node or an Edge.
- Characterization and growth of networks.



Burch/Cheswick map of the Internet
showing the major ISPs. Data collected 28 June 1999

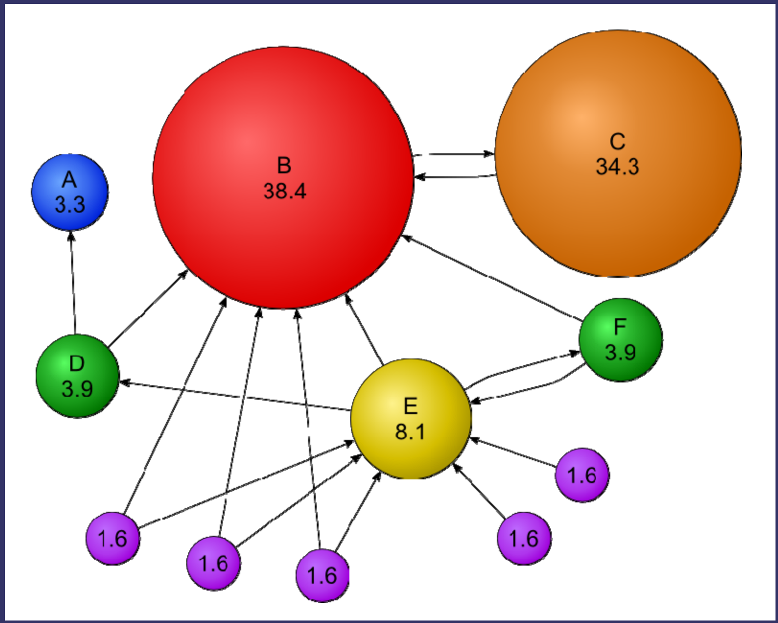
http://www.cheswick.com/map/index.html



CA Hidalgo, B Klinger, A-L Barabasi, R Hausmann.
The Product Space Conditions the Development of Nations. Science (2007)

Network Analysis - PageRank

- Led to Google's domination of search market
- Finding other applications, ecosystem analysis
  - ”a species is important if it points towards important species.”



Agent Based Modelling

- construct the computational devices (known as agents with some properties) and then, simulate them in parallel to model the real phenomena.
- The process is one of emergence from the lower (micro) level of the social system to the higher level (macro).
- *We will get into much more detail later !*

Genetic Algorithms

- Create many random frogs
- Select the fittest
- Mutate and breed them
- Select the fittest
- etc.

Frog as an Agent

1=Yes
0=No
#= Don't care

The string with least "Don't Care" governs the action
Selection to "Life & Death
Genome is "Evolved"

Frog Genome :

Moving	On the ground	Large	Far	Striped	Flee !	Pursue !

If Object Is Moving: Flee !

1	#	#	#	#	1	0

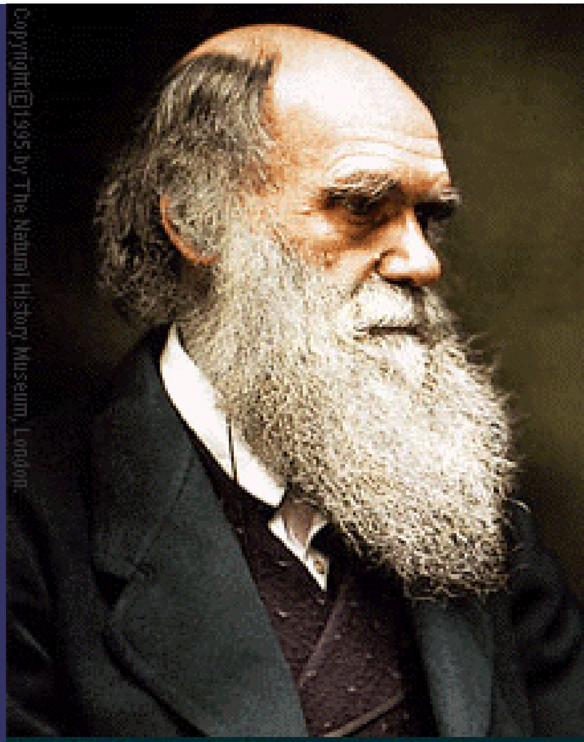
If Object Is Moving, Is In The Air, Small And Near: Pursue !

1	0	0	0	#	0	1

If Object Is Moving, Is In The Air, Small, Near And Striped:Do Nothing!

1	0	0	0	1	0	0

Evolution



Charles Darwin (colourized B&W print)

- Charles Darwin, 1859
  " The Origin of Species"
  - "Live, vary, multiply, let the strongest live and the weakest die"
- Evolution is an algorithmic process.
  - It is a answer to the how question
  - Not the why or where !

(Dennet, DC, Darwin's Dangerous Idea: Evolution and the Meanings of Life, Simon & Schuster; Reprint edition (June 12, 1996), ISBN: 068482471X)

Some properties

- Evolution is NOT teleological
  - no "*Grand Purpose*"
- Evolution is a local optimizer
  - survival of the most suited organism for the current situation
- Evolution is path dependent
  - more and more variations on less and less themes
- Evolution does not now know *sunk cost*
  - dinosaurs evolved over millions and gone in a few thousand years. How about us ?

Evolution in human systems

- Seems to have a goal
  - Never stopping economic growth ?
- Seeks the optimum
  - But what is an optimum ?
- Is path Dependant
  - Think fossil fuels
- Very sunk cost aware !

- Careful what to learn and what not to learn from nature, when thinking about society

Evolution is intractable

Problems that can be solved, but not fast enough for the solution to be usable *(Hopcroft, et al, Introduction to Automata Theory, Languages, and Computation 2007: 368)*

That is, it is <u>not</u> NP complete...
It exists in the EXPTIME/space

$$\text{EXPTIME} = \bigcup_{k \in \mathbb{N}} \text{DTIME}\left(2^{n^k}\right).$$

Chess, Go, Checkers are examples of EXPTIME problems

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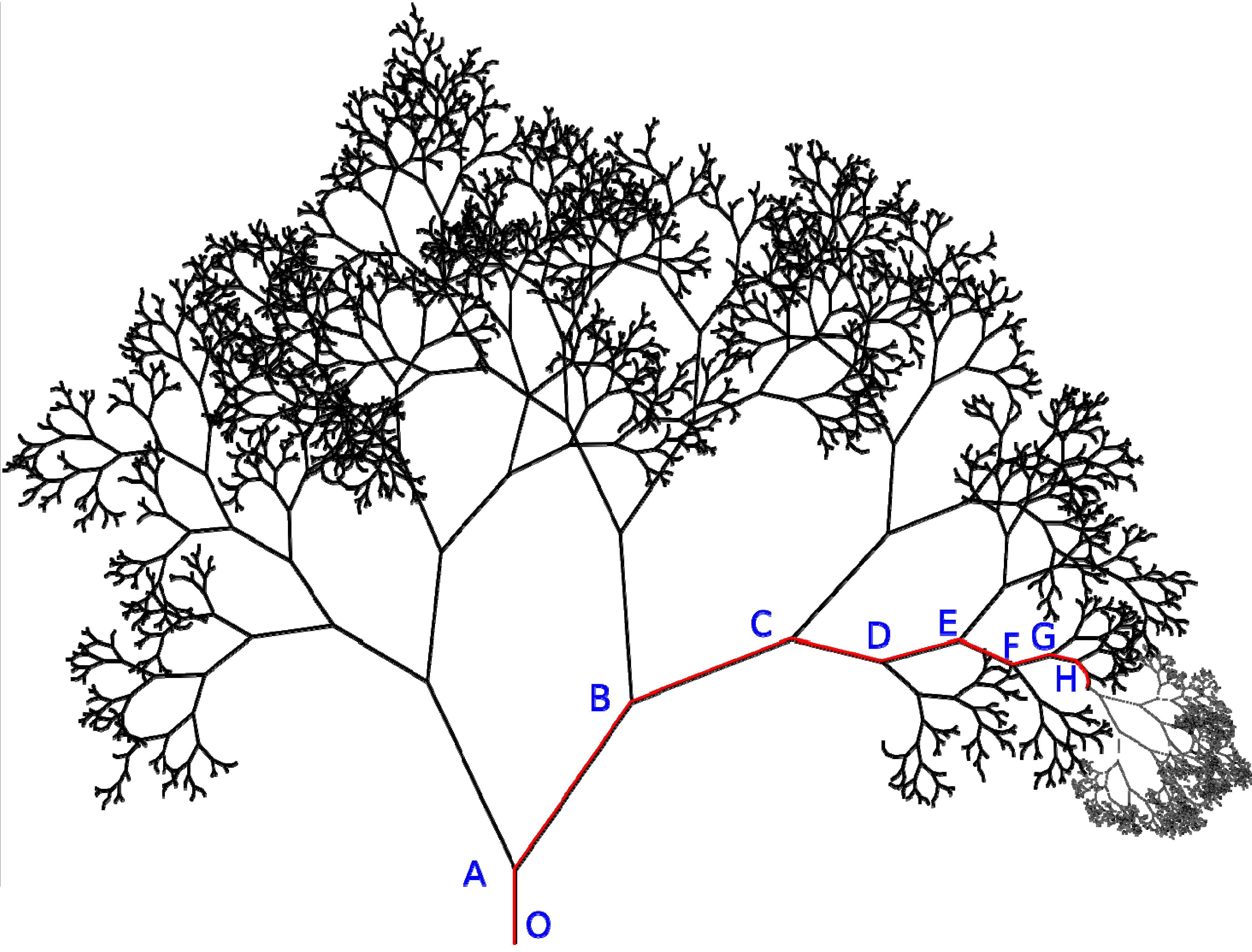
A
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Sense of scale

- each electron in the universe (10^{79})
- computational power of today's fastest supercomputer instructions per second (10^{12})
- worked for the life of the universe (10^{17}) seconds
- 10^{108} computations
- evolutionary process with 100 variables, evaluated over 100 time steps.
- examine all possibilities to predict the outcome in advance would take
- $2^{100^{100}} = 2^{10000}$ calculations >> 10^{108}

Inherent deep uncertainty

- In evolution, only one thing is certain: *uncertainty*

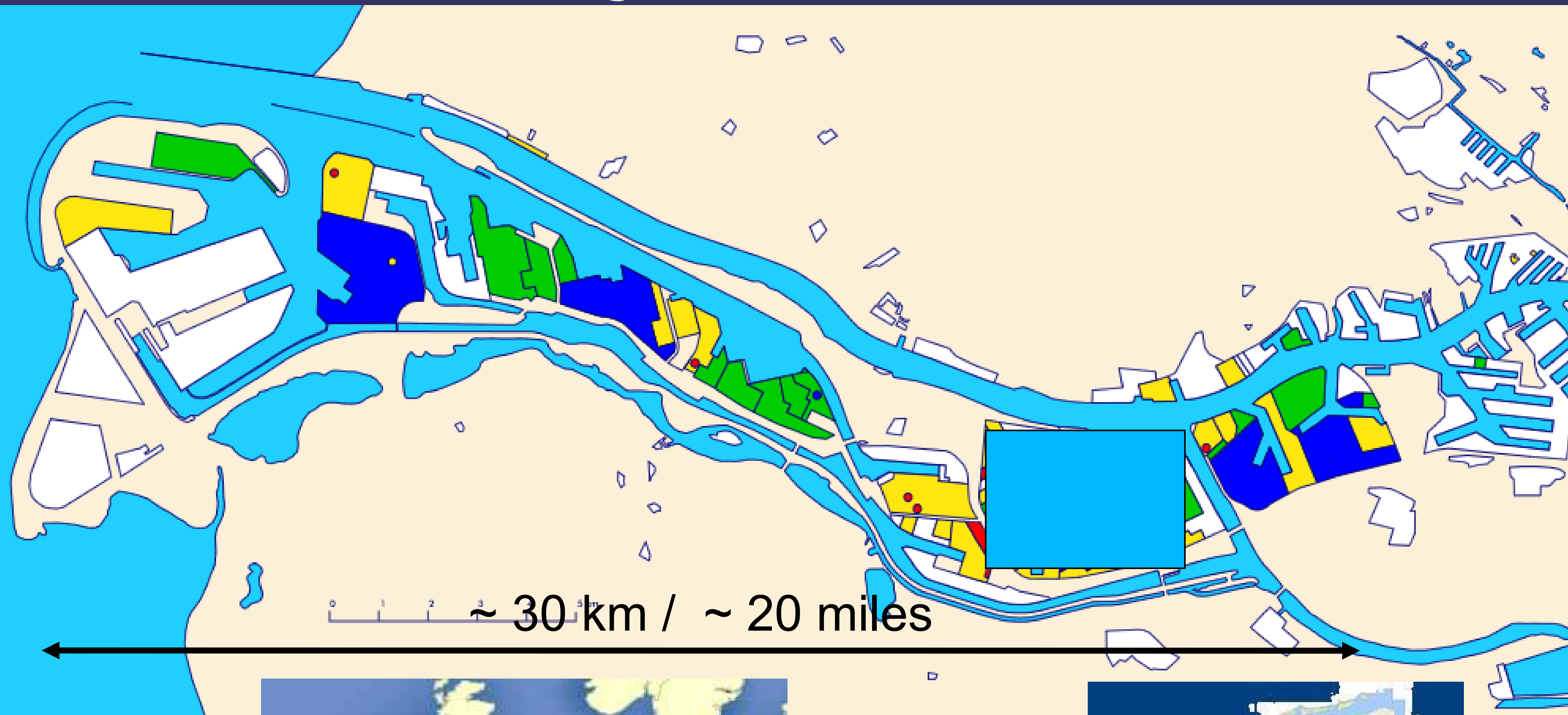
- Of the value of parameters
- Of the system structure

- Nature solves this by modular, interoperable, multi-functional component and interaction design

Some corollaries

- Evolution is a distributed, parallel adaptive dynamic design process
- Two extremes of evolutionary strategies :
  - Bacteria : Live fast, surf the evolutionary wave
  - Elephants: Live slow, control the environment
- Evolution needs both source of order and randomness: Control and Innovation
- Gardening instead of bridge design.
- Uncertainty as a driving force ?

Rotterdam Rijnmond industrial area



System characteristics

- Economics
  - Capital intensive, huge investments
    - 1990-Today □ > 7 bn. US$; Total >30 bn. US$;
  - Labor extensive, high skill-level
    - 12,000 direct FTE, 60,000 indirect FTE
  - Long lifespan, low margins
    - Payout 10-15 years; Installations: 20-30 years; sites > 90 years
  - Science-based;
    - Technological know-how is key

- Resulting Dynamics
  - Discrete events: Design
    - (e.g. Lyondell PO-11, Shell Hycon, Cogen)
  - Cluster: Evolution
    - Entrapment & interdependencies
    - Infrastructure dependent; mutual dependent
  - Slow / intermittent
  - Shaped by external pressures

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Complexity and Industrial Systems

- Large Scale Socio-Technical Systems (LSTS)
  - long lifespan (>> 15 - 30 y.)
  - high investments (>> 50 M Eur)
- Multiple actors/agents shape the system
  - Private Decision-Making
    - past investments = huge sunk costs, entrenchment
  - Public Interest & Decision-Making
    - society nurtures and depends on the activities
- result is a Complex Adaptive System
  - tuned for economic efficiency
  - resistant to change
  - .... and <u>no single steering wheel !</u>

Sustainability Challenge

- reduction of dependence on cheap gas, oil and metals
- Increasing environmental and economic constraints
- Transition required:
  - in order to survive, industrial regions such as Rotterdam – Rijnmond, or the Groningen seaports must undergo a transition towards sustainable networked industry- infrastructure
- How to <u>shape</u> such a transition?
- Increase understanding of **Large Scale *Socio-technical systems***

Modeling LSTS

- Ashby's law of requisite variety : a model system or controller can only model or control something to the extent that it has sufficient internal variety to represent it
- LSTS :
  - consist of many discrete, interacting components, acting in parallel
  - exhibit evolutionary behavior
  - require multiple formalisms to be fully described
- Eating your own dog food
  - Adaptive Agent Based Model
  - Socio-technical co-evolutionary process of creating models
  - Created by many people

Requirements for the modeling process

- **Non-Functional Requirements**
  - *Open Source :* Enables radical interdisciplinary collaboration
  - *Sufficient community diversity :* You can not model CAS alone
  - *Organically growing :* Internally driven, robust growth
  - *Recorded history :* Allows backtracking at mistakes
  - *Enforceable authorship :* Who did what, when
  - *Modular :* Scientific LEGO, analogous to nature
- **Functional Requirements**
  - *Useful :* Socially determined
  - *Testable :* Repeatable and falsifiable

ABM development in 30 seconds...

- Take many different types of experts
- Create a shared, formal language (Ontology)
- Make description of a synthetic firms' (Agents) that have a realistic :
  - (portfolio of) Technology
  - Decision making processes
- Let them interact under many scenarios (economic, technical, legal)
  - Agents buy and sell, live and die..
- Industry and infrastructure networks emerge and evolve.

<u>*Understanding*</u> *and* <u>*Shaping*</u> *the Evolution of λ-systems*

- The Challenge:
  - How to reorganize industries and infrastructures for continuity, surviving the challenges posed?
- Why is this a problem?
  - Lack of <u>understanding</u> the co-evolution.
  - No single actor steers the process.
  - Unexpected feedbacks disrupt the <u>shaping</u> of
- Problem owners
  - Regional Development Authority
  - National Government
  - Industry Association, Shareholders, Employees
  - Local Community
- • How to fix it ?

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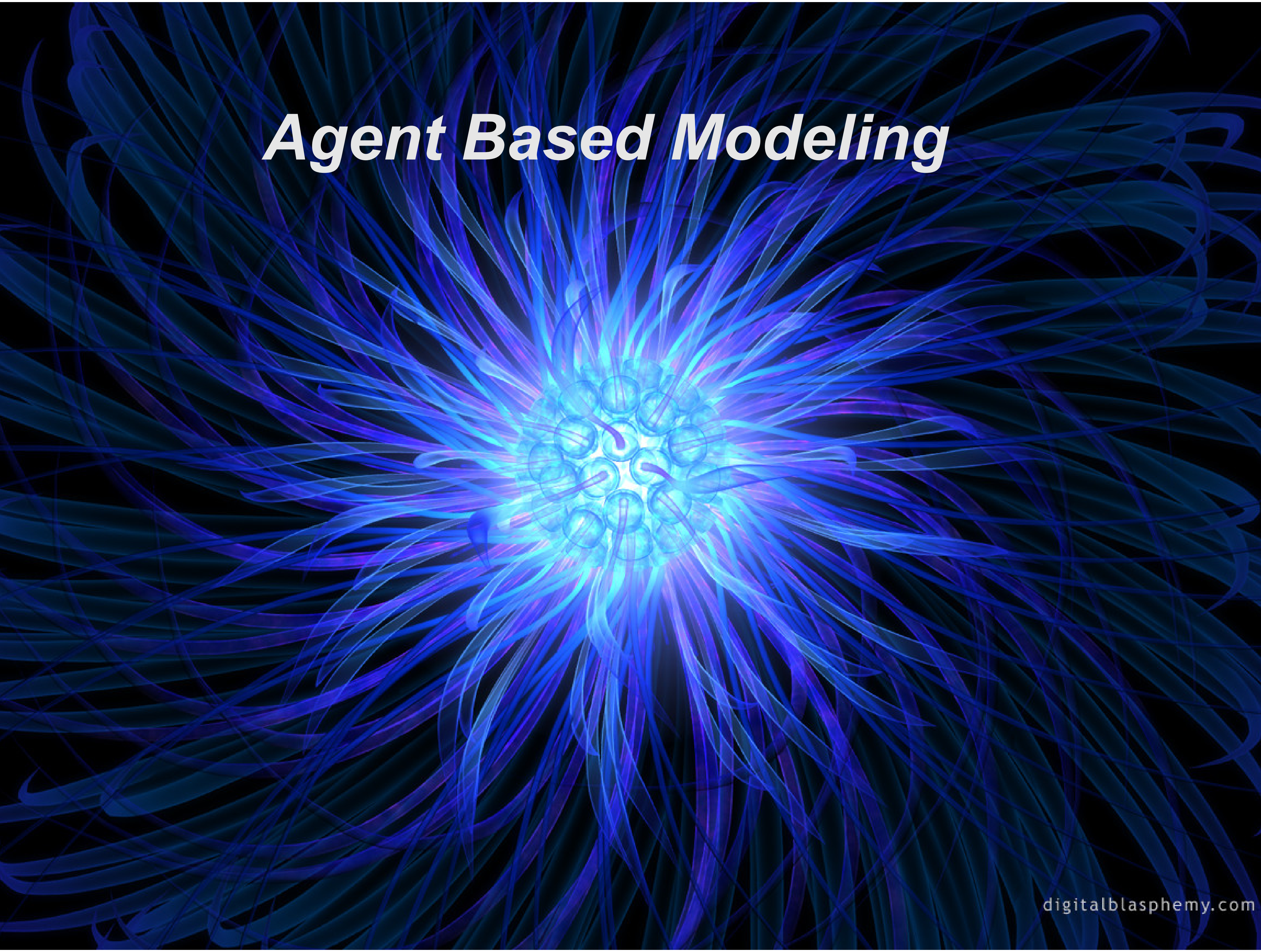
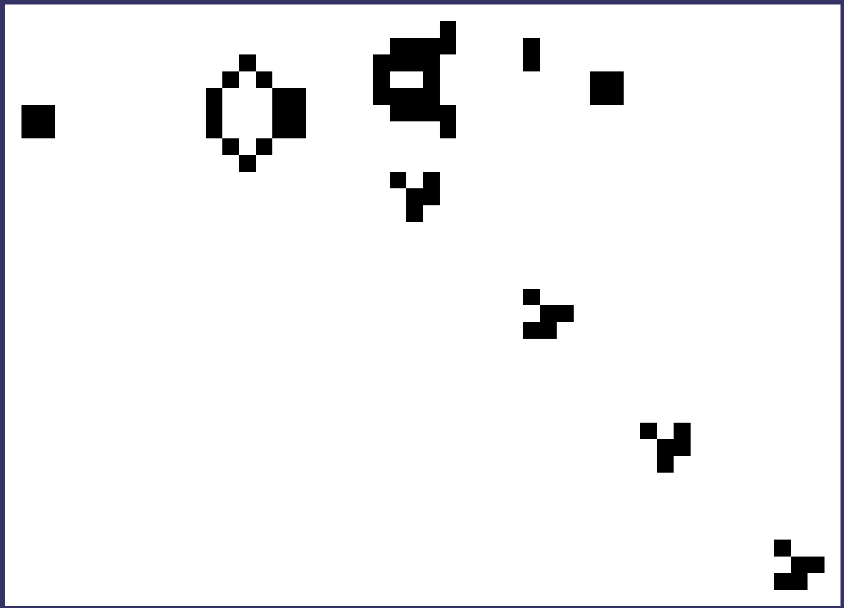
Agent Based Modeling



The Great-Granddaddy

- It all started with Cellular Automata and Conway's Game of Life
- Rules:
  - Any live cell with fewer than two live neighbours dies, as if by loneliness.
  - Any live cell with more than three live neighbours dies, as if by overcrowding.
  - Any live cell with two or three live neighbours lives, unchanged, to the next generation.
  - Any dead cell with exactly three live neighbours comes to life.
- Patterns:
  - Gliders, Spaceships, Still lifes, Eaters, Reflectors

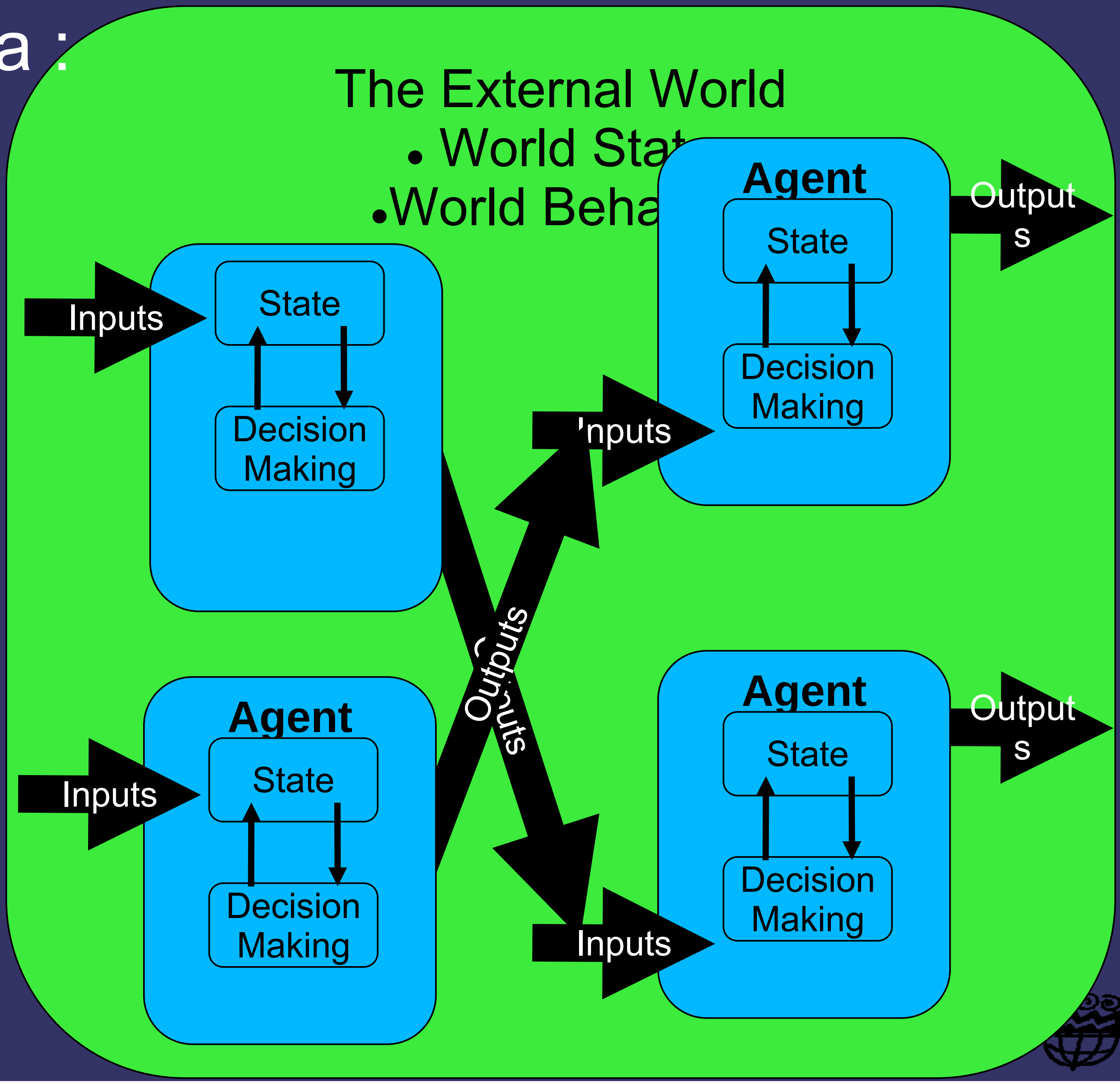


Agents

- An agent is a persistent thing which has some state we find worth representing, and which interacts with other agents, mutually modifying each others' states. The components of an agent-based model are a collection of agents and their states, the rules governing the interactions of the agents, and the environment within which they live. *(C. R. Shalizi "Methods and techniques of complex systems science: An overview,")*
- An agent is a thing that does things to other things *(Stuart Kauffman)*

Generic Model layout

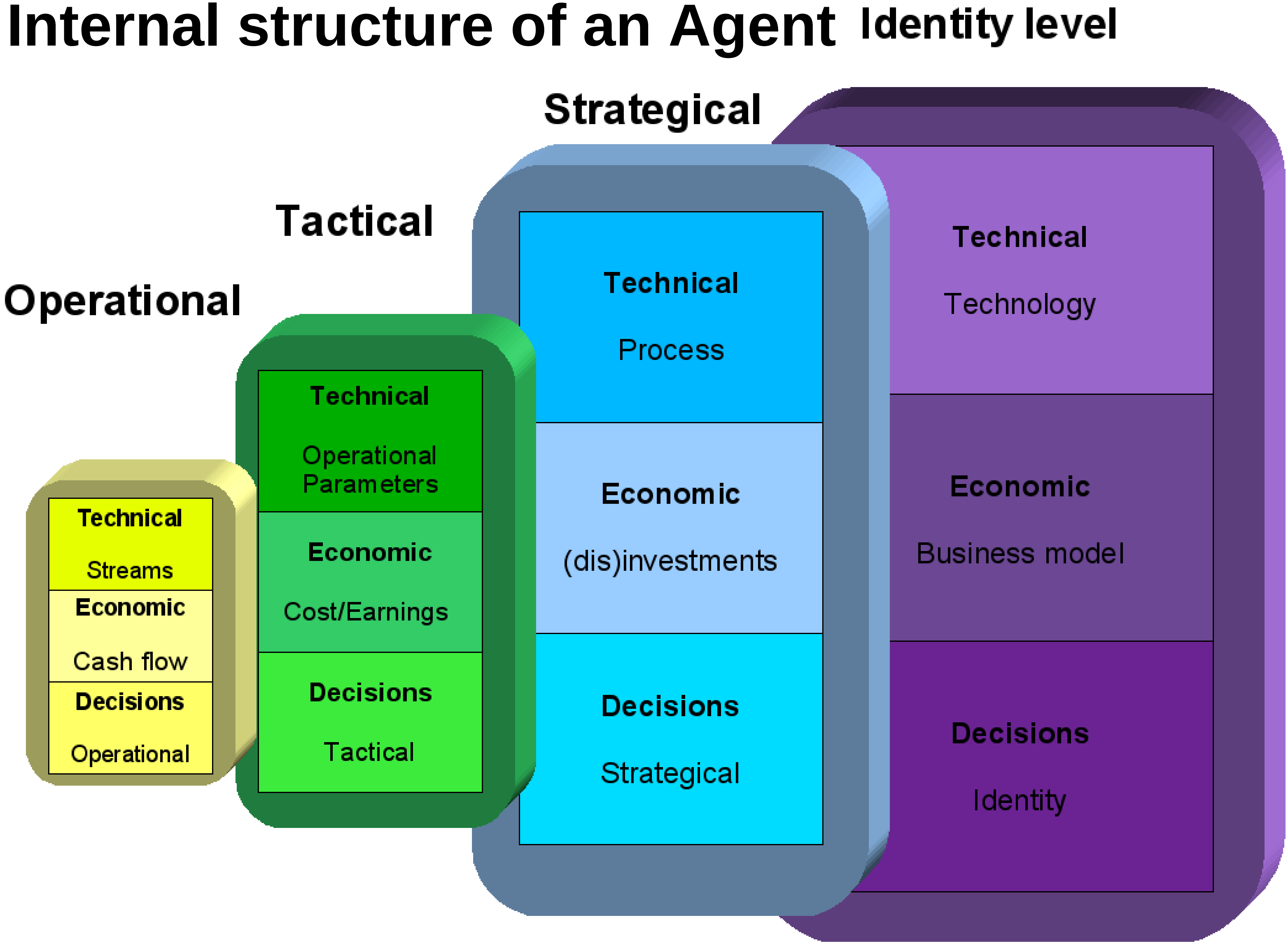
- Agents can be in a :
  - Grid
  - GIS coordinates
  - continuous space
  - network
  - soup
  - ...



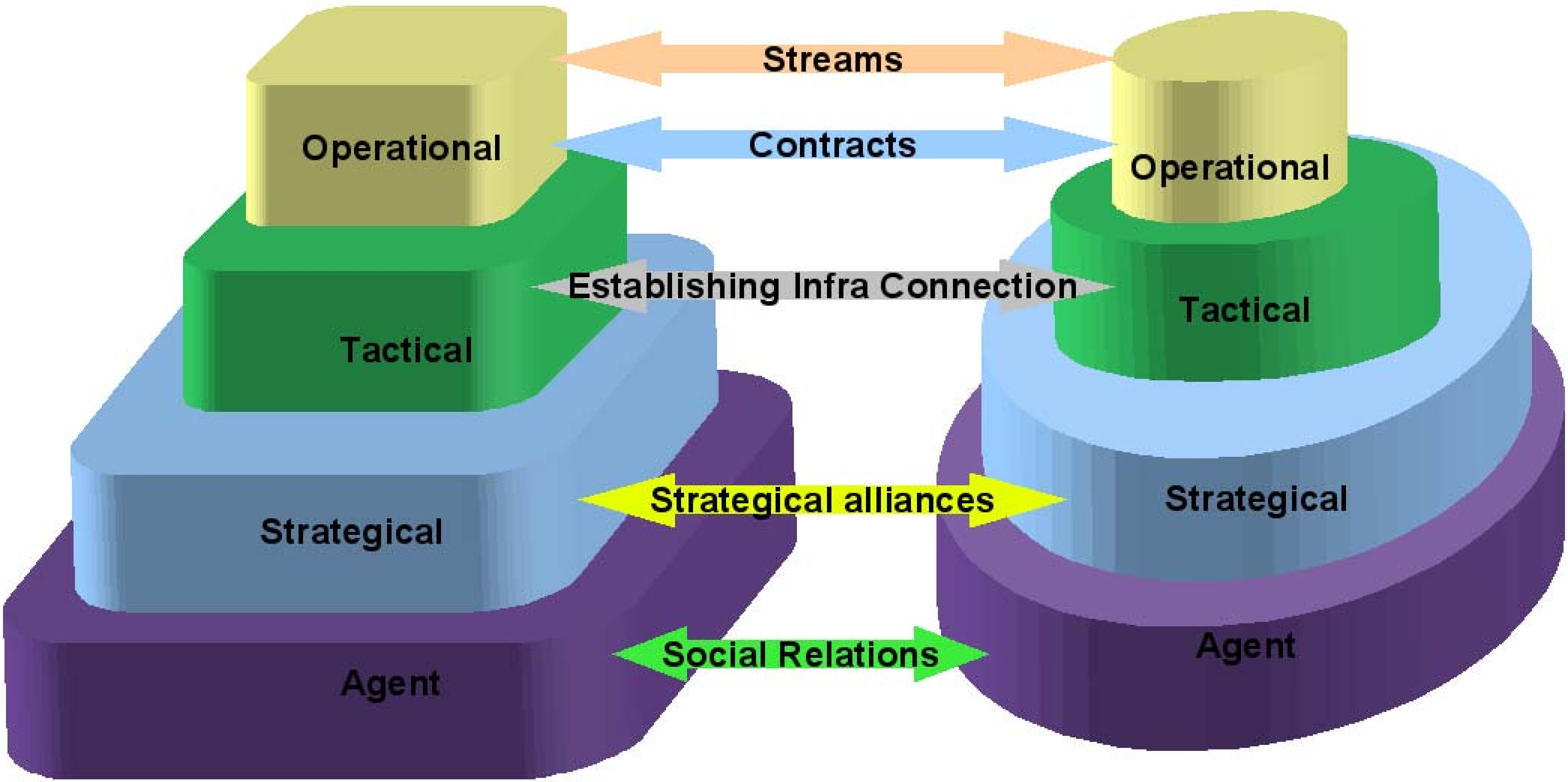
Amazing !
Works upside-down too !

- In an ABM, everything is a Agent, even the External World
- One is free to keep the External World fixed, and let the agents behave/adapt to it
- But it is perfectly ok to fix the agents, and evolve the External World to make it fit the agents.

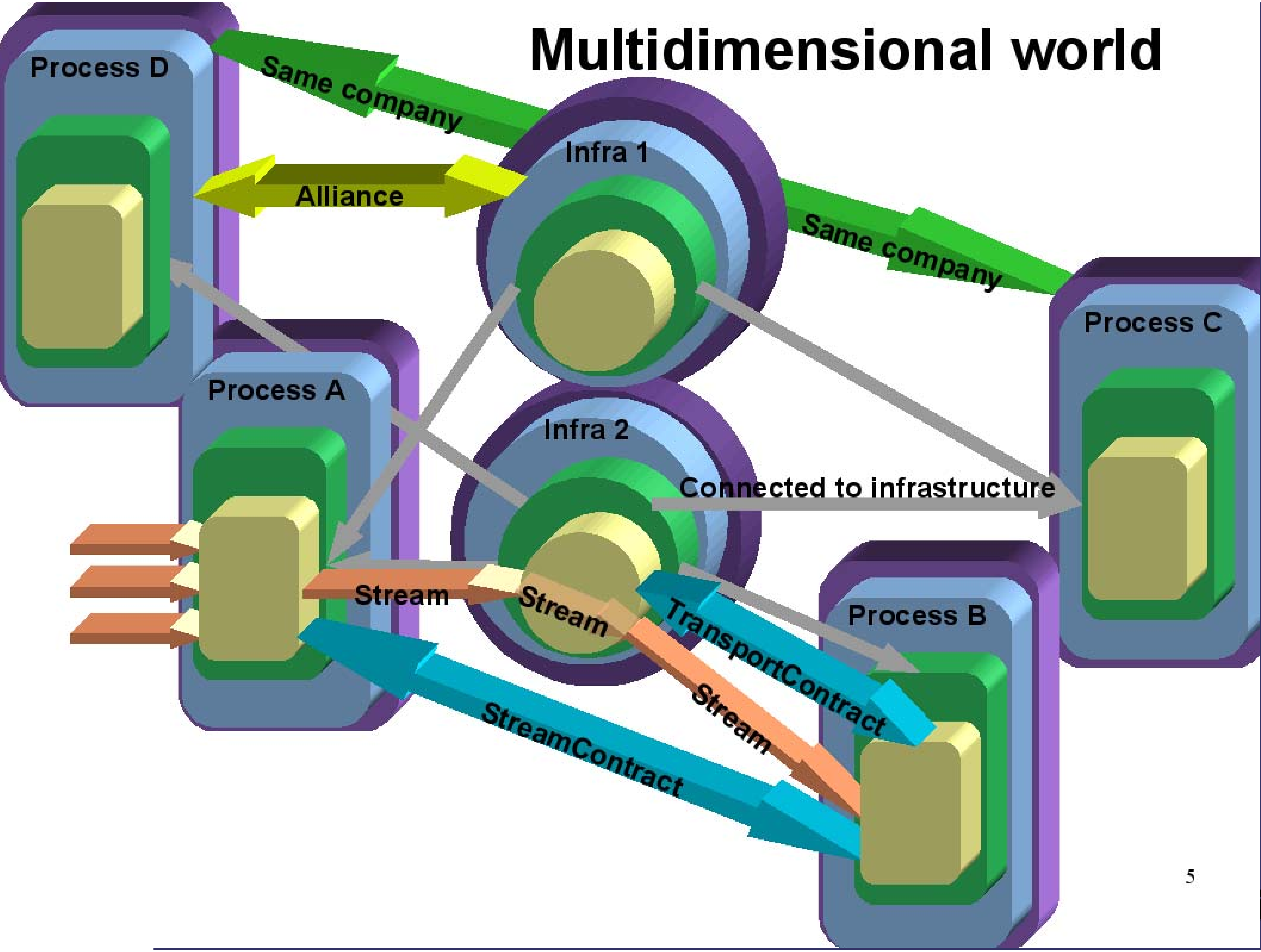
Internal structure of an Agent



Typical connections between Agents



Multidimensional world

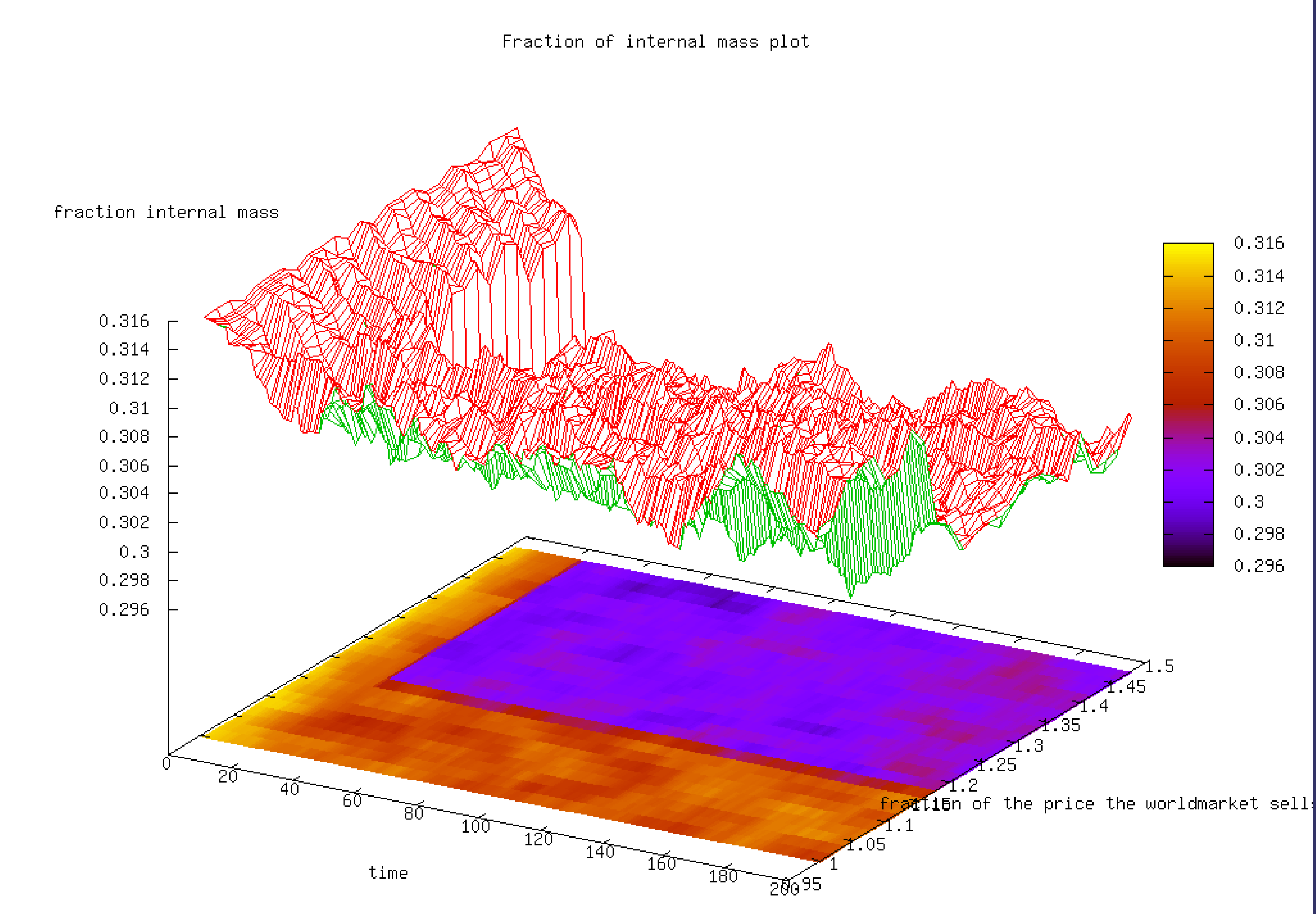


Thus: an enormous Design Space!

- There are very many possible technologies
  - Laws of nature limit the possible
- There are unlimited ways to make a decision
  - Current economic reality limits what is possible now...

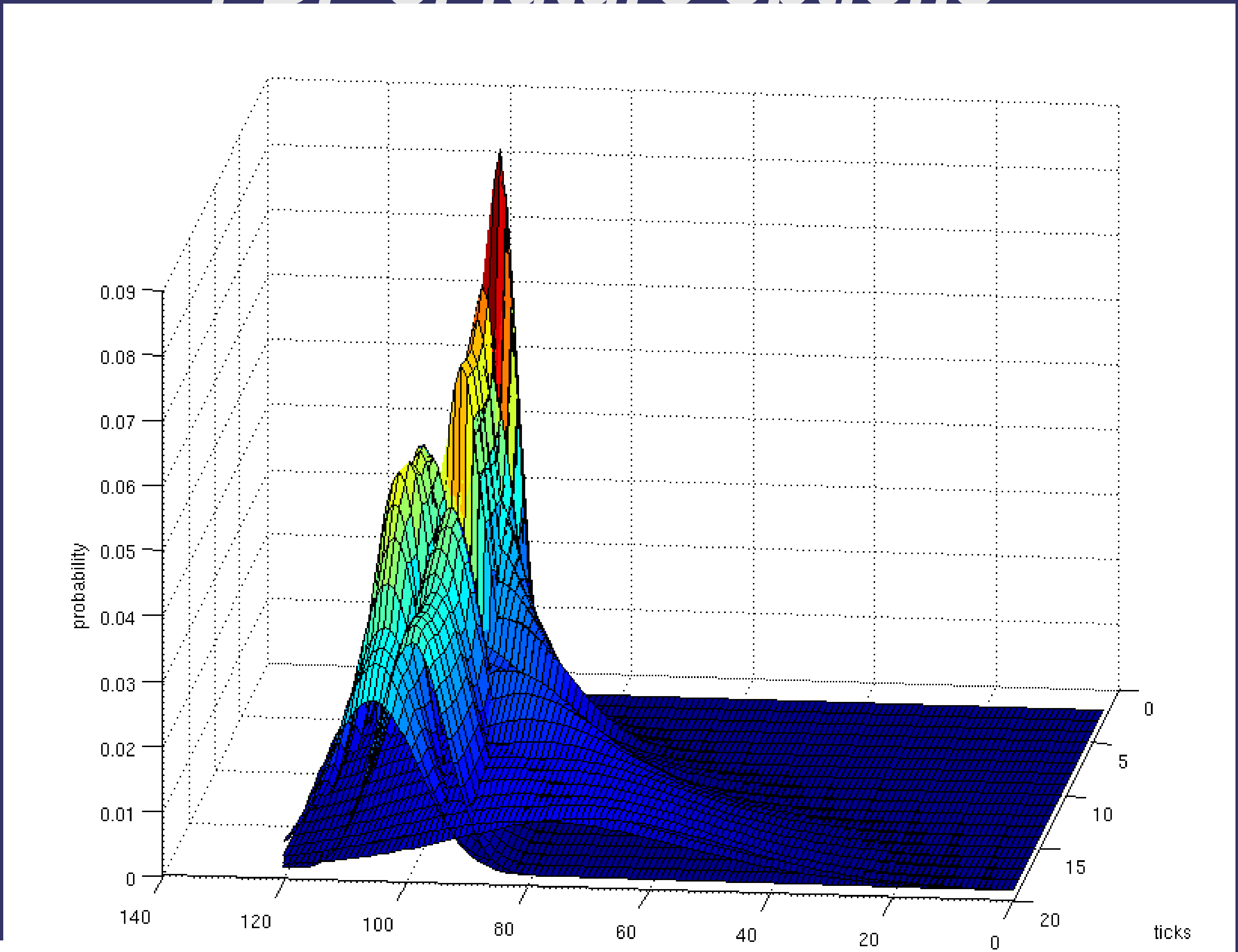
- Agents that can adapt and respond to the changing environment
- ... surf the dynamic fitness landscape on the sea of possibilities...

Example parameter space



Work with S. Blokker

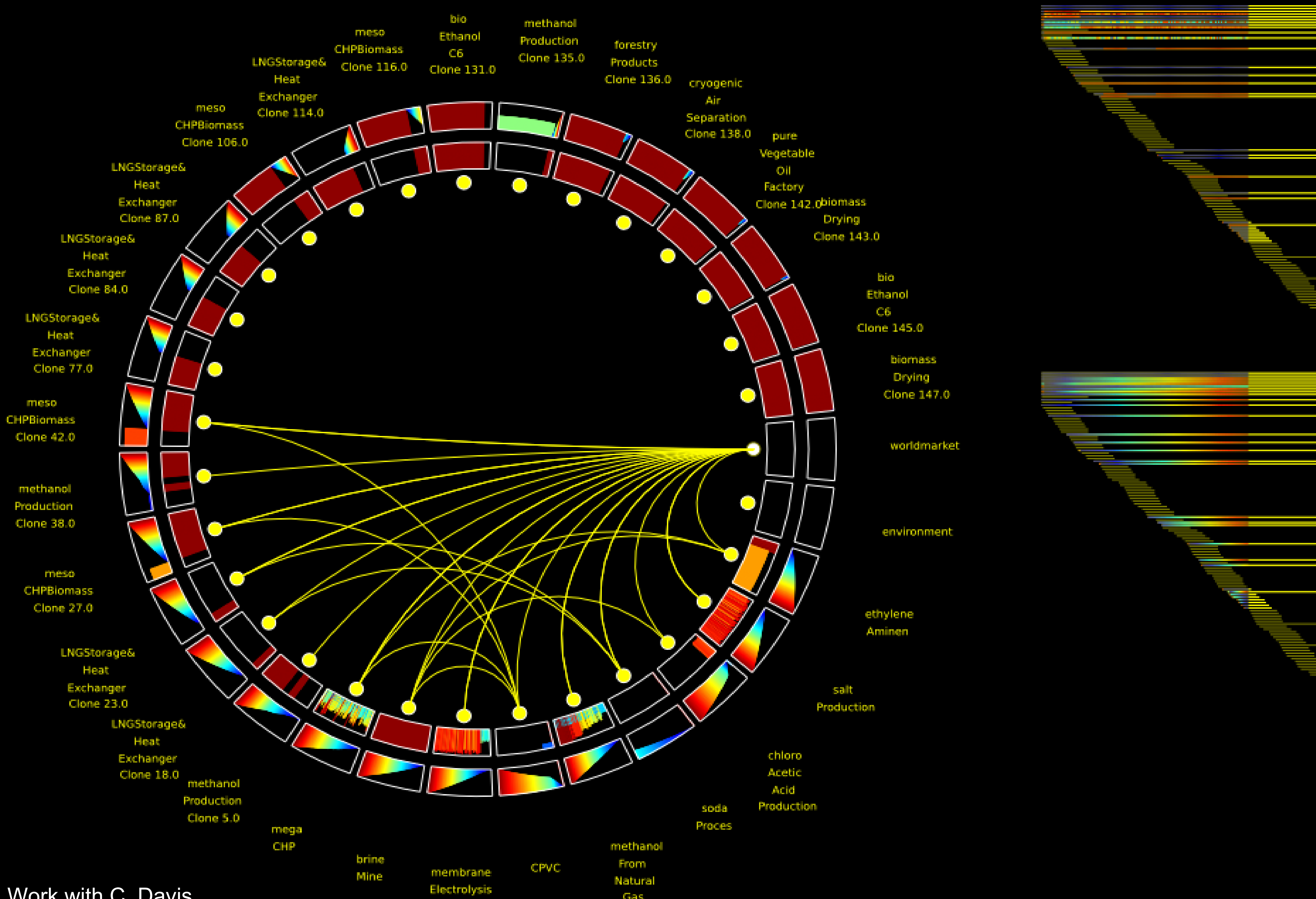
PDF of future options



Work with Chris Davis

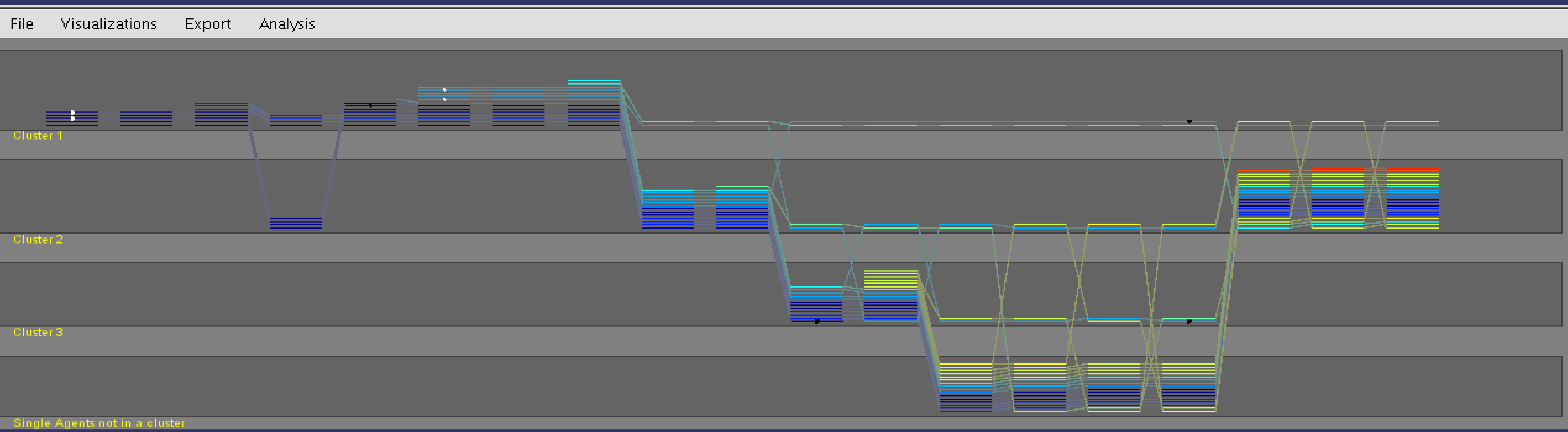
Cluster structure evolution

This is a image generated by the AgentBasedModel of industrial Network Growth Developed by Igor Nikolic.
The models raw data output was processed by Chris Davis.



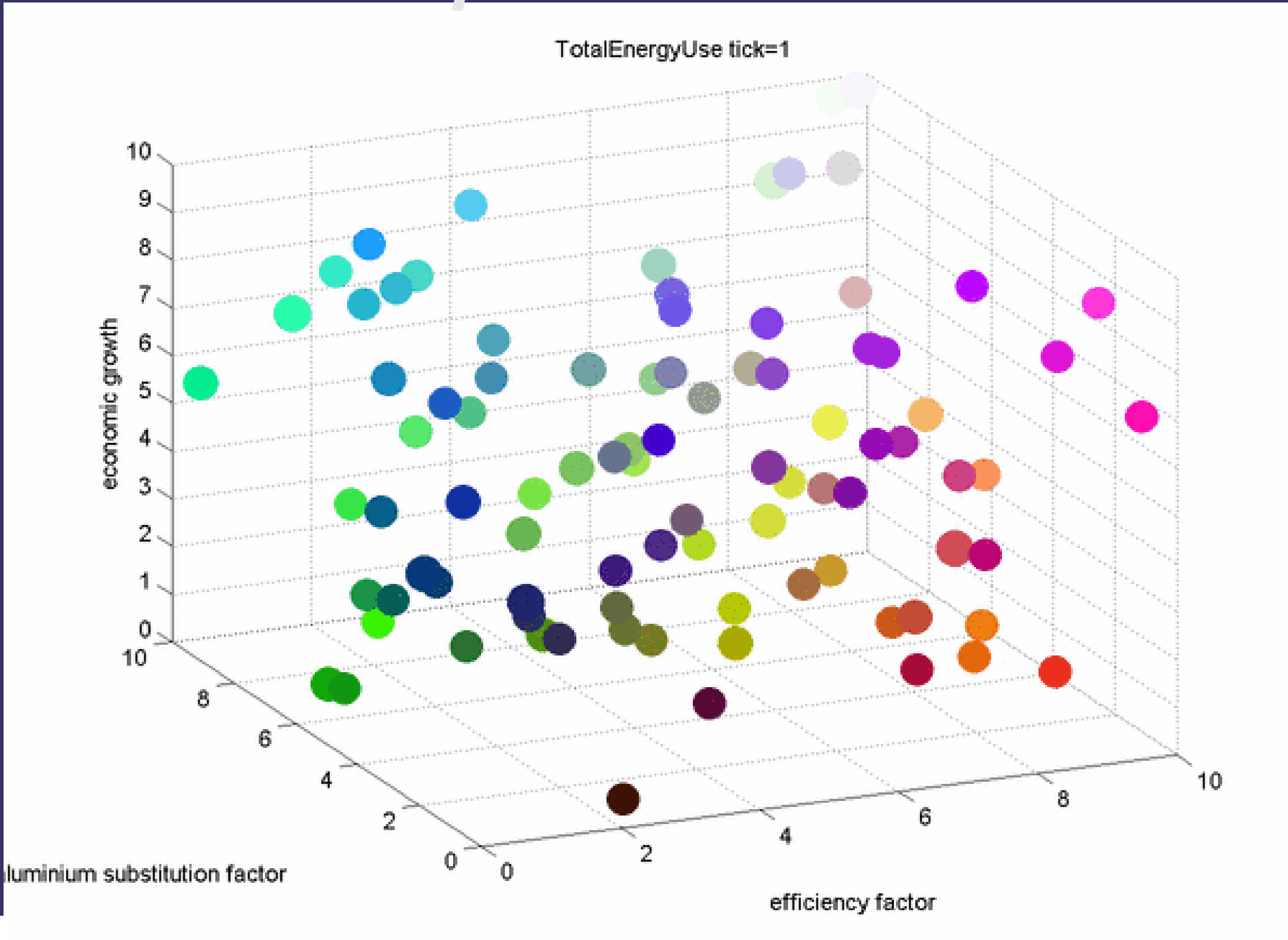
Work with C. Davis

Cluster structure evolution II



Work with C. Davis

Cluster production evolution



Work with Chris Davis and Kridtaya Sakamornsnguan

Generic Lessons learned

- Useful for many different problems
- Coupling of “soft “ human behavior with “hard” physical modeling
- Excellent for
  - testing “gezond boeren verstand”
  - “voeten op tafel” introspection
- Disadvantage
  - The client/user needs to “get it”
  - Lots of data needed for quantitative prediction

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Lessons learned II

- Technology + agent identity + start situation
  - Creates networks with
    - a given sustainability profile
    - a given earning profile
    - a given decision behavior
- What-if scenario testing :
  - Which technological, behavioral, policy options will make the overall cluster better

- **The "best / optimal" network structure cannot be objectively determined. It is a context dependent societal decision.**

Policy /societal relevance

- **Avoid** “obvious” mistakes
- **Test** possible outcomes of policy
- **Design** policy
- **Involve** stakeholders early in development

Towards Generative Science...

If you didn't grow it, you didn't explain it

– Joshua Epstein

Generative science

J. Epstein, "Agent-based computational models and generative social science," Complexity, vol. 4, no. 5, pp. 41-60, 1999.

- complex behaviors are seen as generative processed
- The central principle is that all phenomena can be described by interconnected networks of (relatively) simple units.
- In this approach deterministic and finite rules and parameters of natural phenomena interact with each other to generate complex behavior.

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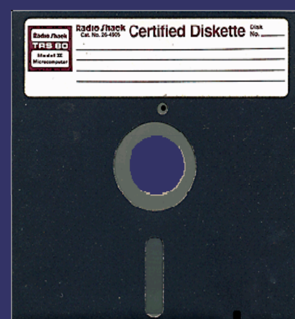
Compression

Willow Seeds

=



800K

=

- Habitat
- Erosion control
- Microclimate
- Air purificiation
- Soil production
- Food
- Medicine
- Products

Gardening the Technosphere?

Take Home (meta)Message

- The world around is Complex, both the biosphere and the Technosphere
- Any activity within both must acknowledge this, or fail miserably
- Complex Adaptive Systems is a Meta-Theory, that gives you a world view and enables cross-disciplinary knowledge sharing.
- These are very powerful tools to understand / model the world, but are not mainstream yet.
- You don't need to understand everything now, but you will know how to find it, when you need it...

A note from the sponsors...

- I am looking for students for various projects
- MSc thesis
  - Yes, I want to work with this stuff !
- Literature review papers
  - Yes, I would like to read more about this stuff !
- *Capita Selecta* subjects
  - Yes, I want to do something, but I don't know what !

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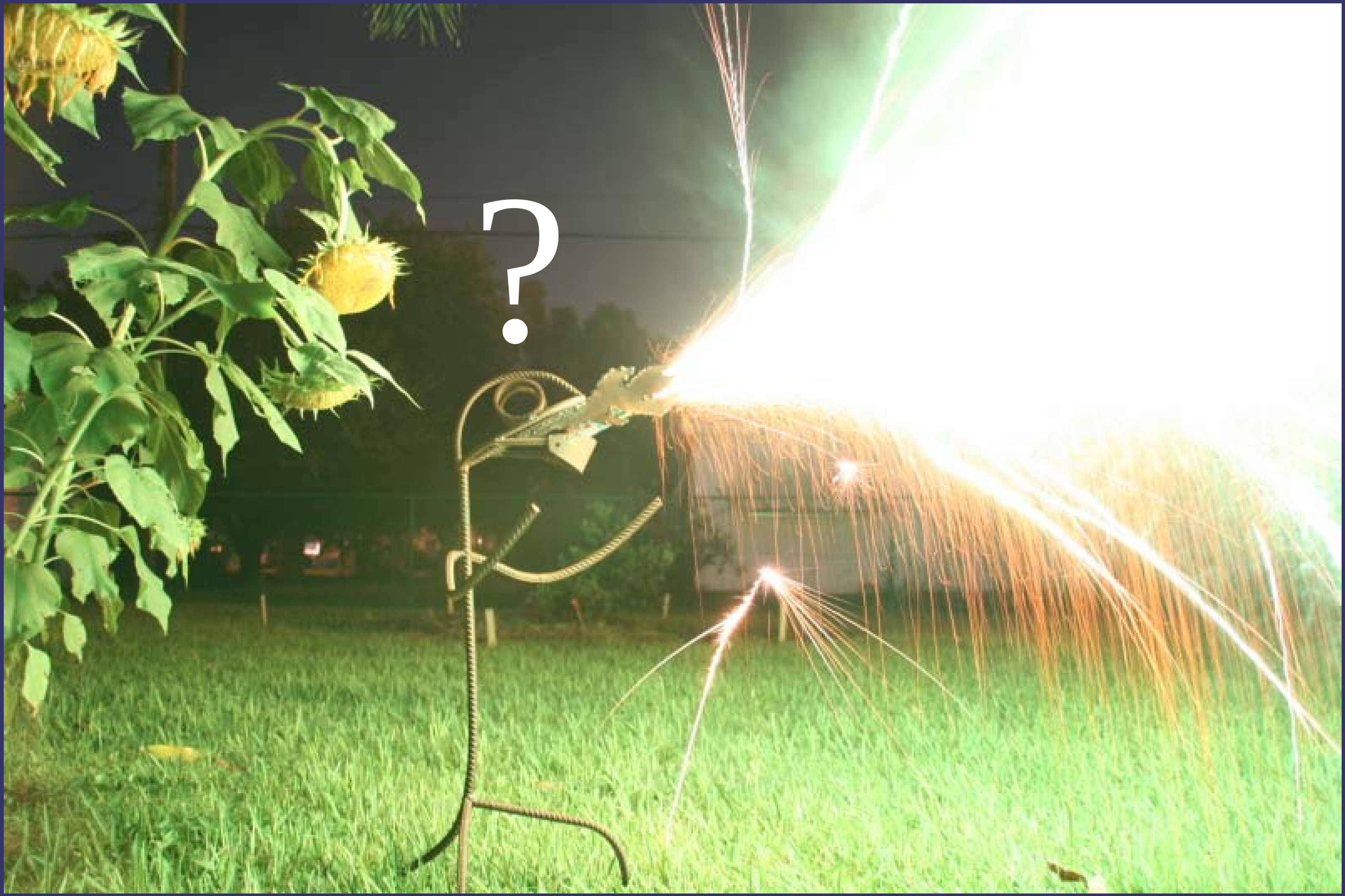
Oh yeah, the wiki

- wiki.tudelft.nl
- Going live... TU Delft wide... Nov 3rd
- Log on using your netID
- See what we've been doing the last four years
- Add to the interlinked web of science
  - Notes
  - Presentations
  - Articles
  - Concepts
  - Research

Questions?



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