Industrial Operations / Information Processing Convergence

Control Chain Management Body Of Knowledge

MI - Science for Enterprise Systems

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Agenda

- Enterprise as a system
- Entropy
- Chaos
- Complexity
- Information
- Linguistics

Systems theory studies Open, Complex systems

- **System theory is not exactly a science**
  - "A set of theories - automata theory, linear systems theory, control theory, network theory, general Lagrangian dynamics, etc. - unified by a philosophical framework"
  - a holistic approach to reality
- **System:**
  - Set of elements in dynamic interrelation that are organised for a given purpose (J. De Rosnay)
- **Open system: Interacts with its environment**
  - =/ Closed system: no matter/energy I/Os
- **Feedback loops on internal and external variables (Cybernetics)**
- **Complex system: the whole more than its parts, chaos…**
- **Opposes to (or complements) Cartesian, analytic approach**
- **Particularly applied in sociology, biology and environment**

Types of systems

- **Biological systems use membranes**
  - (Cell, tissues, body) to insulate components and handle interactions.
  - They keep their structure, but renew at the cell level et reproduce
  - Slow, supra-genetic (Darwinian) evolution
- **Artificial systems composition is generally variable**
  - Social, mechanical, IT
  - Their structure can evolve rapidly in reaction to internal and external pressures
  - Meta models of these systems evolve like biological systems
    - Democracy, monetary system, transportation, computers, telephone
  - Shared components
    - People can be parts of several organizations
    - They can be employees and shareholders in the same company

The 10 commandments of Systems control

- **Preserve variety**
- **Do not "open" regulatory loops**
- **Look for the points of amplification**
- **Re-establish equilibriums through decentralization**
- **Know how to maintain constraints**
- **Differentiate to integrate better**
- **To evolve, allow aggression**
- **Prefer objectives to detailed programming**
- **Know how to use operating energy**
- **Respect response times**

(J. De Rosnay)

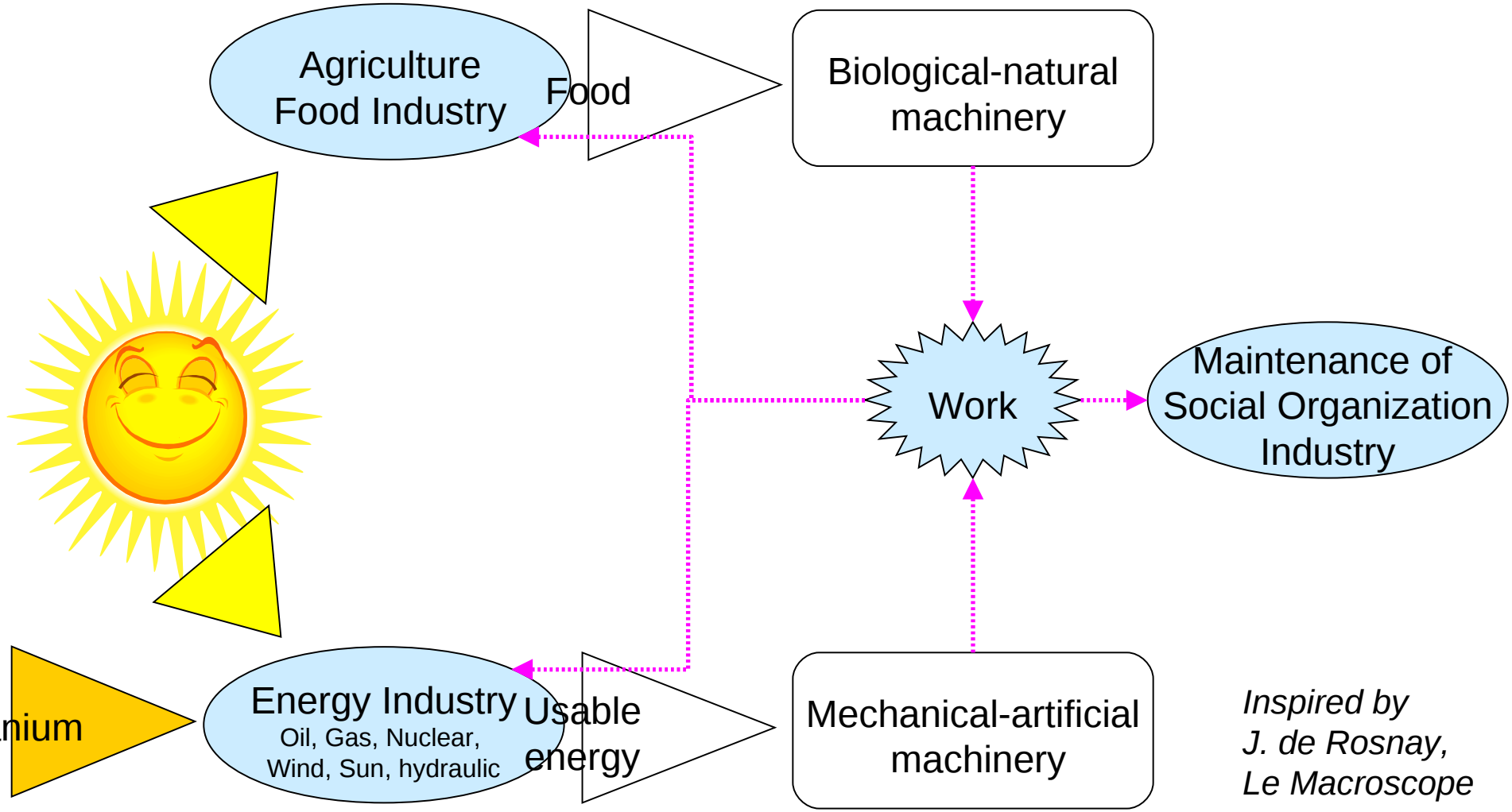
A cosmic view of the World

- **We know nothing about where we come from, where we go**
  - More we learn about Nature, more we become conscious of our understanding shortness
- **Different possible scales of the Unniverse**
  - The human Era
    - from great apes evolution to final (eg. nuclear) self destruction
  - From Big Bang to Apocalypse
    - From energy soup to pure spirit
  - Part on an infinite cycle
    - Big bang succeeded to a previous cyle
  - Multidimensional
    - Other +/- parallel Worlds
- **We evolve in a very narrow space-time spot!**
  - Let’s build our own little story about industrial enterprises…

Enterprise is an Open, Complex System

- **Physical interactions:**
  - Earth, other Enterprises, internal Resources
- **Noospherical interactions:**
  - Goals of the World, Humanity, Humans, Owners, other enterprises
- **Social interactions:**
  - Nations, NGOs, Trade unions, Family
- **A thermodynamic entity**
  - Consumes energy, applies it on matter
  - “Heat” (waste energy) when badly controlled (thermal entropy)
- **Industry is a major component in the Earth eco-system**
- **Fast rise of enterprises « Social Responsibility » concern**
  - Cares about social, environmental and economical footprints
  - Various motivations

Industry eco-system (anthropo-centric!)



Inspired by
J. de Rosnay,
Le Macroscope

Relevant sciences for Enterprise systems

- **An enterprise is a complex, dynamic system**
- **As such, it is well covered by science and philosophy**
  - applying for its understanding and control
- **Though the applicable knowledge is rather unlimited, we will concentrate on some significant topics**
  - seemingly helping best in our search of supporting the enterprise as an evolving organism within a harsh, constraining environment
  - This is an ongoing discovery work to highlight and leverage existing knowledge for improving enterprise sutainability
- **This study concerns only the system aspects of an enterprise**
  - Does not address specific business related mechanics
    - Physical transformations
    - Marketing and sales theories
    - Scheduling and financial management technics
    - …

Enterprise as a scientific subject

- **Largely studied subject**
  - Academic studies often stays at the “Valid philosophy” stage
  - Intuitive, simple, common sense approaches (6 Sigma, Lean management, Theory of Constraints) more successful
- **Enterprises intuitive management**
  - Constraints from Market, Shareholders, bankers, environmentalists, global economics
  - => genial – or lucky – intuitive managers?
- **Leveraging relevant physics principles**
  - Help achieving short term “reasonable” objectives & long term sustainable evolution
  - Converge to Information

Agenda

- **Enterprise as a system**
- **Entropy**
- **Chaos**
- **Complexity**
- **Information**
- **Linguistics**

Entropy

- **3 meanings**
  - Irreversibility: the 2nd law of Thermodynamics
  - Measure of the disorder: Kid's room, engineer desk…
  - Measure of ignorance: We are part of the system: Disorder prevents understanding
- **Entropy of an open system can increase or decrease**
  - Increasing = decrease of order, information
  - Decreasing = increase of order, information
- **Can entropy be negative?**

Entropy 1: Irreversibility (entropy macro observation)

- **The 2nd law of Thermodynamics - Sadi Carnot (1824)**
  - Based on observation of heat engines
  - over time, differences in temperature, pressure, and density tend to even out in a physical system that is isolated from the outside world.
  - Entropy is a measure of how far along this evening-out process has progressed
- **Interpretations**
  - In a system, a process that occurs will tend to increase the total entropy of the universe
  - Heat generally cannot spontaneously flow from a material at lower temperature to a material at higher temperature.
  - It is impossible to convert heat completely into work in a cyclic process - Engines produce unrecoverable heat
  - The Arrow of Time: Closed systems entropy always increases as the Universe's

Entropy 2: Disorder (generalized entropy definition)

- **Fundamental definition**
  - Entropy = the number of the possible microscopic configurations of the system
  - Entropy is maximal when all microstates are equaly likely
- **Boltzmann (1896)**
  - Statistical mechanics Entropy S function of W?
  - S = k log W
- **Schrödinger (1944)**
  - Linked entropy S to « state of disporder » D or « order » Or
  - S = k log D => -S = k log Or

Entropy 3: Information

- **Hartley (1928)**
  - « Quantity of information » H of a message of N signs in an alphabet of S signs
  - H = N log S
- **Shannon (1948)**
  - “Information Entropy” The minimum length of a message for a given meaning
  - Information inversely proportional to probability
    - Affected by coding, noise, redundancy
    - The entropy of a text in english is 1,0 – 1,5 bit/letter
    - More information = less probability, more complexity, more “chaos”, more entropy

Entropy 3: Information

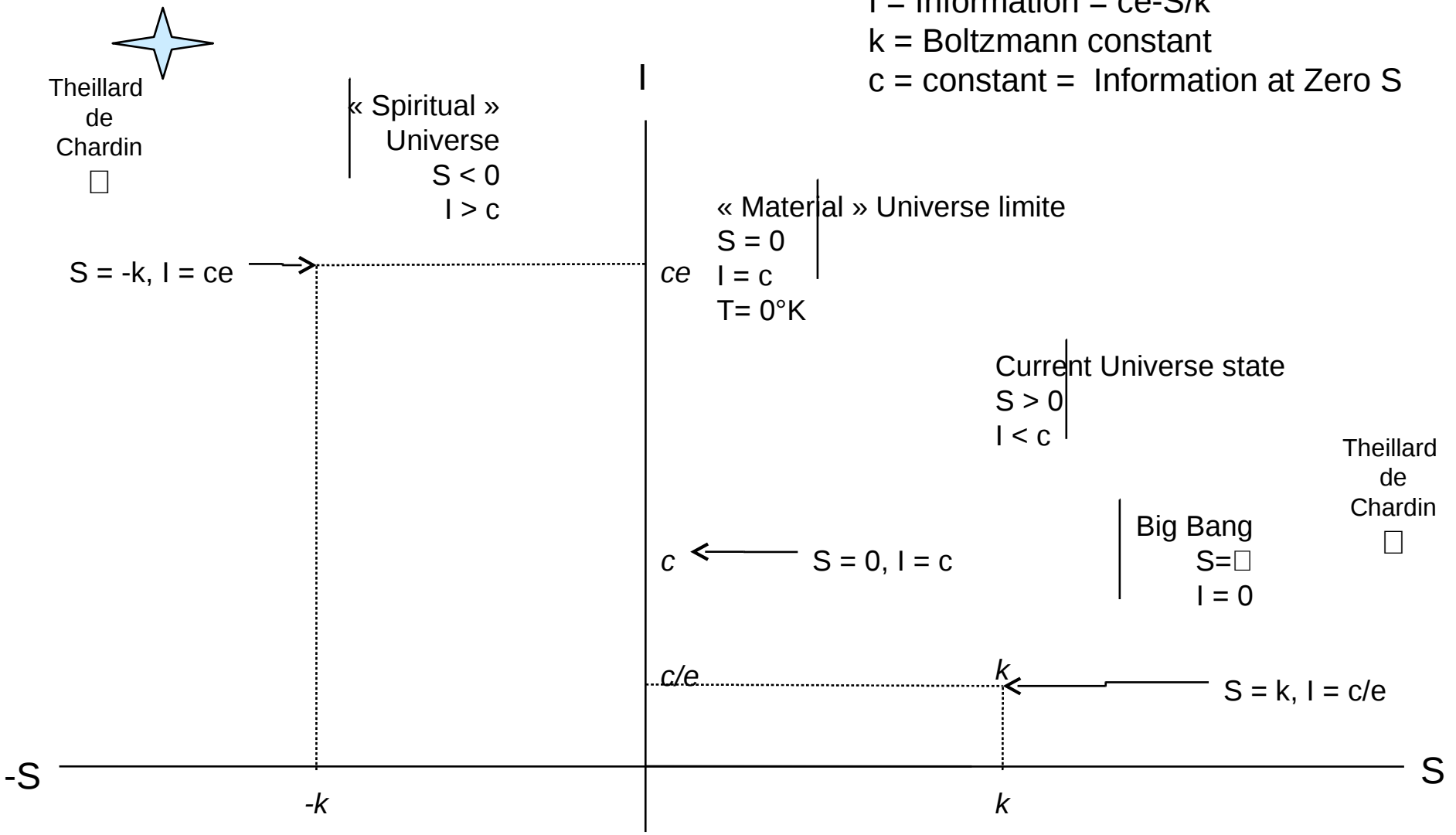
- **Wiener (1948), Brillouin (1951)**
  - The “opposite” Shannon’ theory
  - amount of information = measure of its degree of organization,
  - entropy of a system = measure of its degree of disorganization
  - Information = Negative entropy (Wiener) = Negentropy (Brillouin)

Entropy 3: Information

- **Stonier (1997)**
  - The relation between entropy and information is not a direct linear relationship
  - From Boltzmann and Schrödinger
    - (1) S = k log Or
  - Direct relationship between information I and organization (or)
    - (2) I = c (Or) c to be defined
  - From (1) and (2)
    - (3) I = c e-S/k
  - “c” appears to be the information content I0 of a system when absolute entropy S= 0
    - (4) I = (I0) e-S/k
    - Compare to the direct entropy / information relationships I = -aS
  - One entropy unit 1J/K = 1023 bits

Information / Entropy relationship

S = Entropy = k log c/I
I = Information = ce-S/k
k = Boltzmann constant
c = constant = Information at Zero S



Discussion

- **How Enterprise relates to entropy?**
  - What does Entropy means ofr Enteprises?
  - How to measure Enterprise entropy?

Enterprise entropy

- **Many different forms of energy**
  - Thermal, chemical, Electrical, Radiant, Nuclear, Magnetic, Elastic, Acoustic, Gravitational…
- **Many different forms of entropy**
  - Human resource: inefficiency, errors, tiredness, aging, illness, discontent ..
  - Equipment resource: wear & tear, inefficiency, breakdown...
  - Material & energy resource: waste, energetic balance, uselessness (decreasing relevancy)…
  - Conflicting resource collaboration
- **High entropy may satisfy short term financial goals**
  - Earth system feedback loops will correct or eliminate offenders

Jane Carbone's criterias of Entropic IT (1)

- **Weakening interactions with users**
  - Most funded projects are fun to build, but do not directly support key business drivers
  - The corporate data model just celebrated year ten of its development, but the only cake-eaters were the corporate data modelers…
- **Increasing redundancy and over quality**
  - The quality improvement process has become so internalized that a high percentage of funded projects are creating very high-quality redundant functions, data stores and interfaces
  - To support "Buy Vs. Build," each Line of Business has purchased its own trouble-reporting system — and server to host it
  - There are at least several effective, well-managed work intake processes, with highly trained project managers each tracking their own overlapping, competing projects

Jane Carbone's criterias of Entropic IT (1)

- **Increasing shortsightedness**
  - No one has noticed the linkage between the measurements used to indicate the overall health and success of the organization — shareholder value, high quality/low error rates, customer satisfaction — with the 22 inconsistent, overlapping customer data stores and the high level of customer complaints about receiving duplicate mailings
  - When projects are late/over budget/irrelevant, there is usually stunned surprise (How could this have happened?)
- **Deprecating organization**
  - There is a formal Systems Development Methodology — somewhere…
  - There is a governance process, but basically, any tall person with a loud voice can build a new customer data store
  - The IT organization structure looks like a bad module design

Sanidas's Entropy-related factors/variables in conducting business

Increasing entropy	Decreasing entropy	Increasing or decreasing entropy
Waste	Innovations	Culture
Inertia	Experience	Attitudes
Lack of information	Vision	Procedures
Decreasing constraints	Leadership	Risk taking thinking
Deregulation	Tolerance	
Lack of collaboration	Objectives	
Stress level	Production line	
Fatigue	Knowledge	
Conformity/convention	Links with outside	
Uncertainty	Planning	

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- **Complexity**
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- **Linguistics**

3 types of systems

- **Deterministic systems**
  - Can be modeled, totally predictable
- **Random – stochastic – systems**
  - No equation, no model, no prediction are possilbe
- **Chaotic systems**
  - Tend to be « attracted » by a complex « figures »
  - Deterministic, but no predictable

Chaos

- **Mathematical chaos applies to deterministic, dynamic systems**
  - As the term “Chaos” seems to contradict
  - These systems are characterized by a high sensitivity to initial conditions: perturbations are exponentially amplified
    - The resulting behaviour is “random”
    - Do not mistaken with Disorder
  - Natural and artificial system all can exhibit chaotic behaviour
- **Chaos in space**
  - What is the length of French Brittany shores? (Benoit Mandelbrot)
  - Scale invariant behaviour
- **Chaos in Time**
  - The “Butterfly Effect” “*Predictability: Does the Flap of a Butterfly’s Wings in Brazil set off a Tornado in Texas?* (Edward Lorenz 1972)

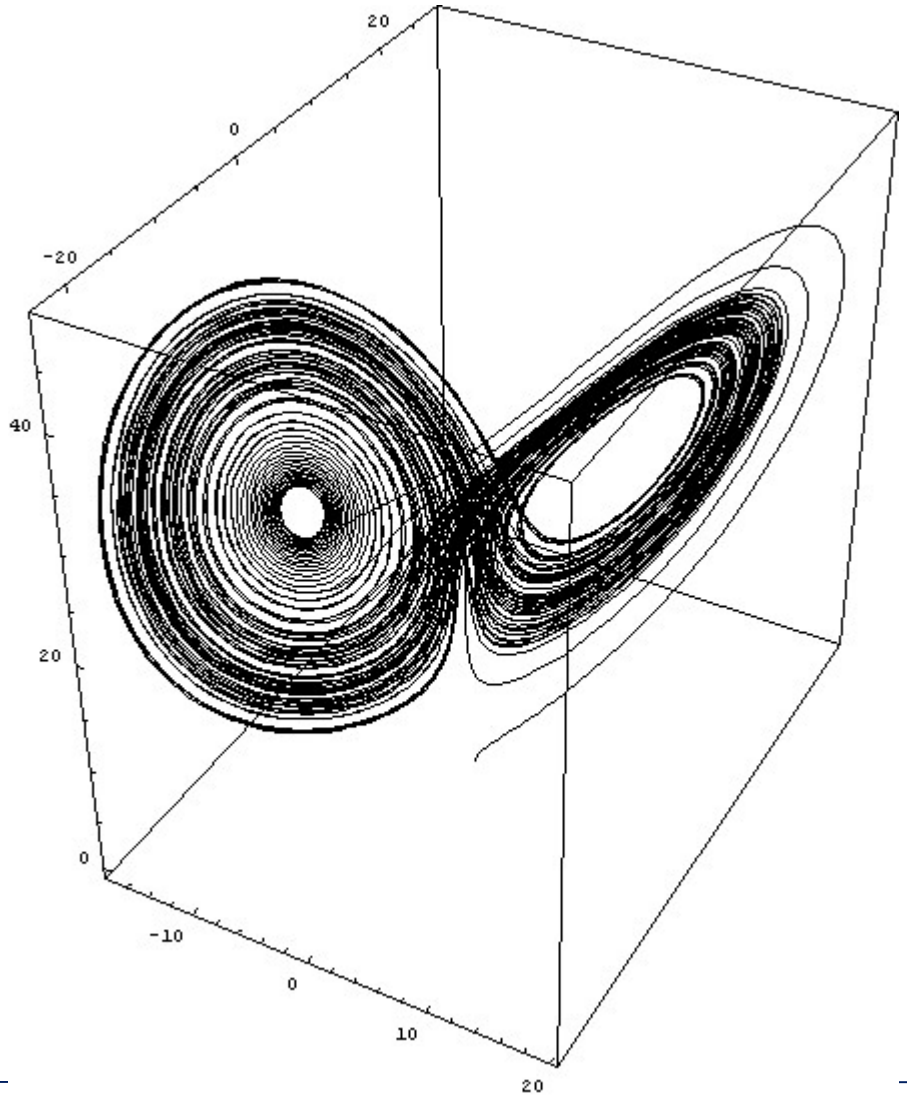
History

- **A Recent science**
  - Henri Poincarré (1905 - *Leçons de mécanique céleste*)
  - E. Lorenz (1961 - « Deterministic non-periodic flow » on weather prediction)
  - James Gleick(1987 - “Chaos: Making a New Science”)
  - Refers now to “Non linear systems”
- **“Chaology” is a paradigm shift**
  - Challenges classical concepts (Laplace)
  - in mathematics, topology, physics, population dynamics, biology, biology, meteorology, astrophysics, information theory, computer science, economics, engineering, finance, philosophy, physics, politics, psychology, and robotics

Chaotic system

- **3 AND conditions**
  - Sensitivity to initial conditions: Butterfly effect
  - Topologically mixing: Overlap may happen (“chaos” popular sense)
  - Dense periodic orbits: Recurrent patterns –
    - PO = type of solution for a dynamical system which repeats itself in time. (a stable periodic orbit is an oscillator)
- **Attractor : a particular phase space**
  - Irreversible tendency of an unsolicited system evolution
    - A pendulum can be plotted as its position against its velocity
      - *Moving = a closed curve Resting = a point*
    - Chaotic behaviour can take place on an attractor
  - Strange attractors: Complex attractors typical in chaotic systems
- **Edge of Chaos**
  - a region between order and chaos, where the complexity is maximal
  - The edge of chaos is an organizational state that allows systems to have high levels of responsiveness, variety, creativity and vitality

Lorentz's strange attractor



Discussion

- **How Enterprises relate to Chaos ?**

Chaos in Enterprise

- **Enterprise is chaotic**
  - Unpredictable events, Unexpected outcomes, Murphy's law
  - Various Internal and external happenings:
    - Ideas, Decisions, errors, environment aggression
- **These events can**
  - Modifying structurally the system
  - Change the energy/matter/information balance
- **Resulting in**
  - Damage or entire destruction of the system when it is not resilient enough
  - Triggering quantum leap improvement

Chaos in Enterprise

- **Opportunistic intelligence – « Edge of Chaos »**
  - Chaos suggests that some non predictable events can be leveraged for performance improvement
  - Enterprises at EOC exhibit self-organizing characteristics
    - operating within EOC provides them with high responsiveness to their environments opportunities,
    - but enough structure to act and perpetuate themselves.
    - compromise between structure and surprise
- **Process improvement**
  - Apparent random behaviour actually aren't
  - 'Chaos theory in quality control of spring wire"
    - M.Muldoon, M.Nicol, and L.Reynolds, University of Warwick 1995
- **Operations and Project Risk management**
  - Localizing the attractors can help to manage the risk

Events, Opportunity, Evolution and chaos

- **Beside its instant operations, a system is submitted to**
  - Internal errors
  - Ideas
  - Environment aggression
- **These events can damage or definitively destroy the system**
  - When it is not resilient enough
- **These events can also make a quantum leap in improvement**
  - Reducing entropy
  - Increasing the energy flow
  - Information is the key

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Complexity

- **Disorganized vs Organised Complexity”**
  - Large number of parts, Random interactions, statistically studied behaviour
  - Vs correlated interactions between parts, can be modelled
- **Complication vs Complexity**
  - Complication is a matter of understanding
  - Complexity is independent of the intellectual capability of the observer
- **Complexity applies to:**
  - Behaviour: relates to emergence and self-organization, Chaos’s sensibility to initial conditions as a possible cause
  - Mechanisms: relates to complex adaptative systems
  - Data: relates to compression difficulties
  - Systems

Complex systems characteristics (1)

- **Are usually open**
- **Have many components**
- **Are structured with Variations**
  - Spanning several scales : Plants, Area, Work centres, Units, Drives
  - Can be nested: systems of systems
- **Display fuzzy boundaries of the system itself and its parts**
  - Observer's choice
- **Interactions**
  - non linear
  - Feedback loops
- **Have memory**

Complex systems characteristics (2)

- **Realize emerging properties / behaviour**
  - properly driven machine and appropriate knowledge can elaborate a product unknown from the machine perspective
- **Are ever evolving**
- **Exhibit "intelligence"**
  - Self organization, adaptability, survivability, ultimately self-reproduction
- **Involve Cooperation/Competition, Internally/Externally**
- **Are Chaotic**
  - Chaos complexity closely related
  - Scale invariance, Sensibility to initial conditions,
  - Self-organized criticality (SOC)
    - Possiblity of brutal collapses or emergence of features of the whole system or parts of it - Avalanches, Earthquakes, financial markets

Complex systems and Information

- **Systems consume, produce, transmute energy, matter and information**
- **Systems tend to deteriorate with time**
  - Becoming unable to turn Energy into more ordered outcome
    - Unable to create Value
- **Information provides order, organization**
  - Complex systems have the ability to process information and evolve
- **Information generates “negative entropy”:**
  - Makes Energy/Matter/Information transmutation effective
    - to transform Energy in Matter
    - To elevate Matter ordering
    - To improve knowledge
  - Increases intelligence
    - Ability to survive and reproduce

Enterprise complexity

- **The Enterprise organism keeps morphing itself**
  - Achieving the Darwinian process of its existence by developing objective knowledge to its advantage
  - Fighting entropy, securing survival, enabling progress
  - Ensuring that thinking people and machines understand each other and the system they live in
- **Auto-organization is an attribute of complex systems**
  - Hypercritical complexity – quantity and quality of interactions - spouts “emerging properties”
  - Developing new, higher ranking behavior - not deductible from their individual components

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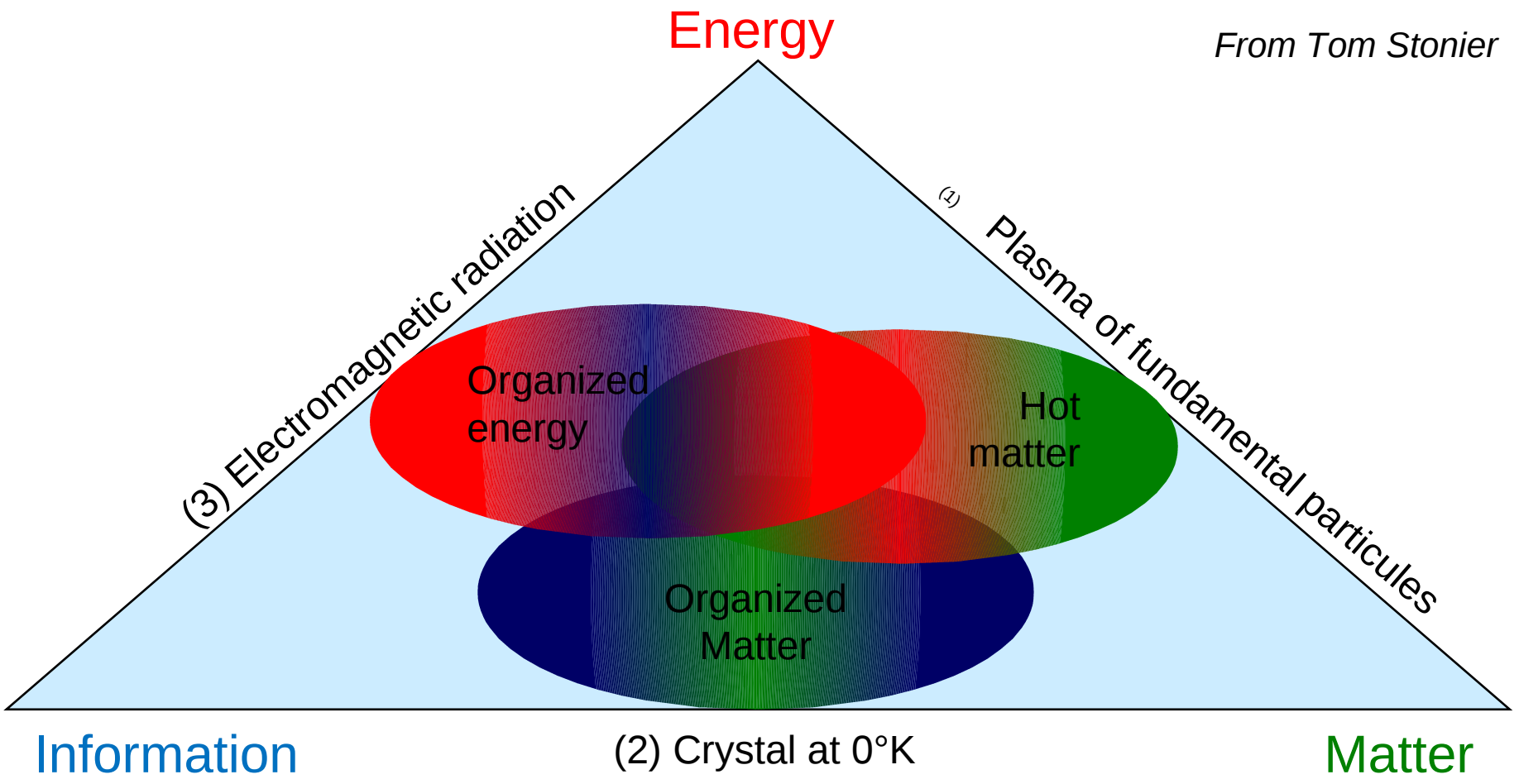
Information Physics

- **Information is the ultimate meta-science**
  - Any science is a information derived class
- **Information is one of the primary material of the Universe…**
  - Global Energy → Material → Information
    - Evolution of our universe
  - Particles interactions, “particles” themselves…
    - An integral part of the Quantum Theory
  - The ultimate outcome of universe from big bang pure energy to pure information through the material and life stages
  - The opposite of Time
    - Time = Ignorance = Lack of information (Grinbaum)

Information Physics

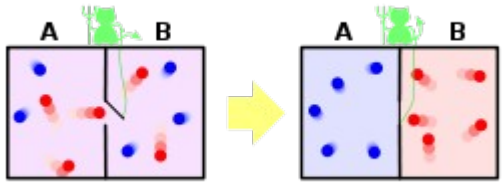
- **Information has a tangible reality**
  - Independently of the observer
  - Its meaning depends on the context
- **Information exists independently of the observer**
  - Kinetic information
    - is produced / consumed » by the system in action
  - Structural, Potential information
    - is embedded in the assembly of the system considered statically (fundamentally the whole story of science and engineering that led to the existence of the system

Energy – Matter – Information trilogy



Maxwell's Demon

- Can the 2nd law of thermodynamics be violated?
  - .. if we conceive of a being whose faculties are so sharpened that he can follow every molecule in its course, such a being, whose attributes are as essentially finite as our own, would be able to do what is impossible to us. For we have seen that molecules in a vessel full of air at uniform temperature are moving with velocities by no means uniform, though the mean velocity of any great number of them, arbitrarily selected, is almost exactly uniform. Now let us suppose that such a vessel is divided into two portions, A and B, by a division in which there is a small hole, and that a being, who can see the individual molecules, opens and closes this hole, so as to allow only the swifter molecules to pass from A to B, and only the slower molecules to pass from B to A. He will thus, without expenditure of work, raise the temperature of B and lower that of A, in contradiction to the second law of thermodynamics."



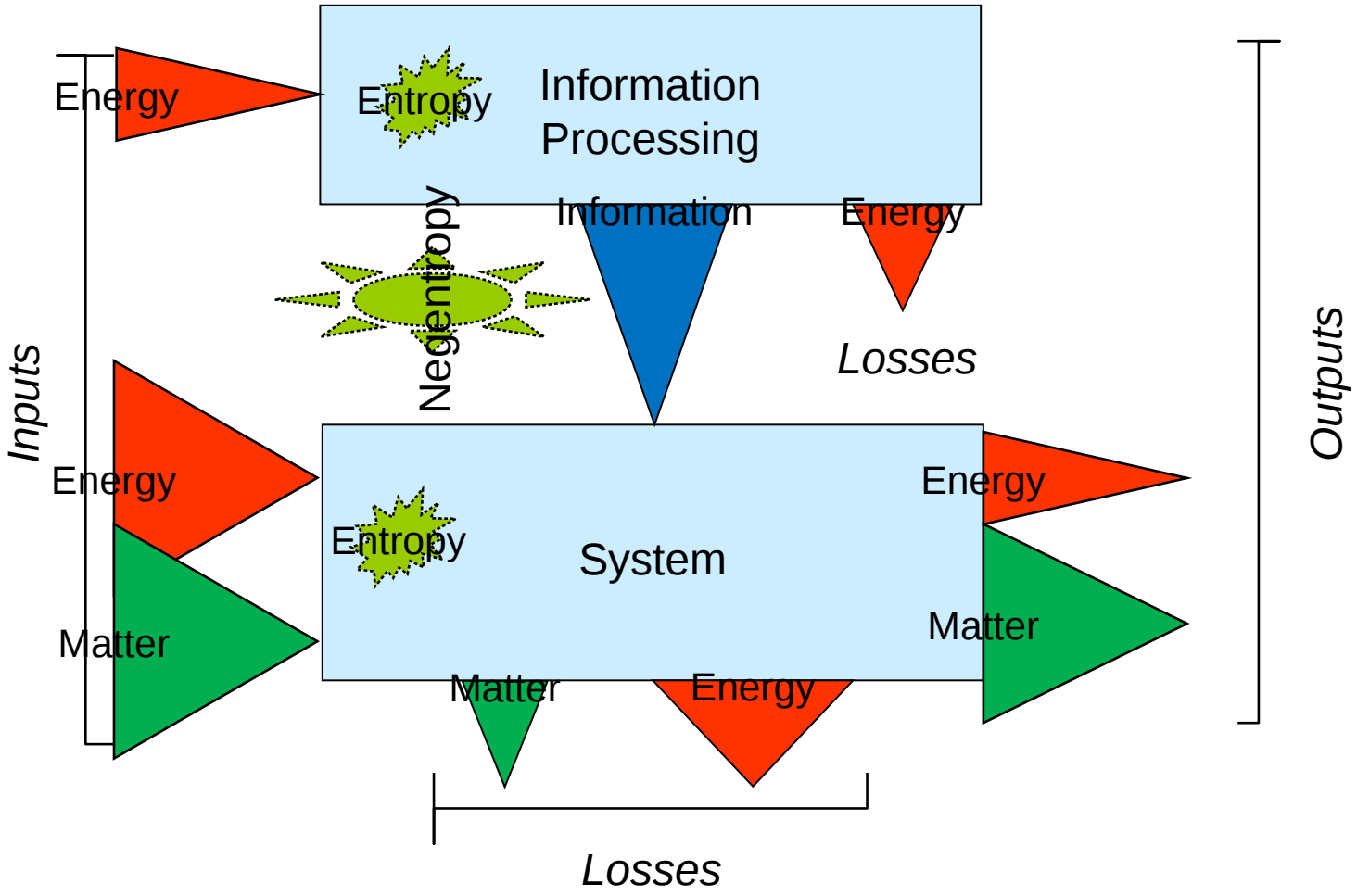
Landauer's principle

- **It costs no energy to copy information - What about erasing?**
- **Landauer's principle:**
  - "Any logically irreversible manipulation of information, such as the erasure of a bit or the merging of two computation paths, must be accompanied by a corresponding entropy increase in non-information bearing degrees of freedom of the information processing apparatus or its environment"
    - Energy W to erase 1 bit = kTln2
      - *k is Boltzmann's constant*
      - *Ln2 comes from binary encoding.*
    - minimum increase in entropy of the system per bit erased
      - $\Delta S = k \ln 2$
- **This resolve the Maxwell's demon paradox**
  - As the demon needs to store information and will need to erase it at some point

Energy and Information

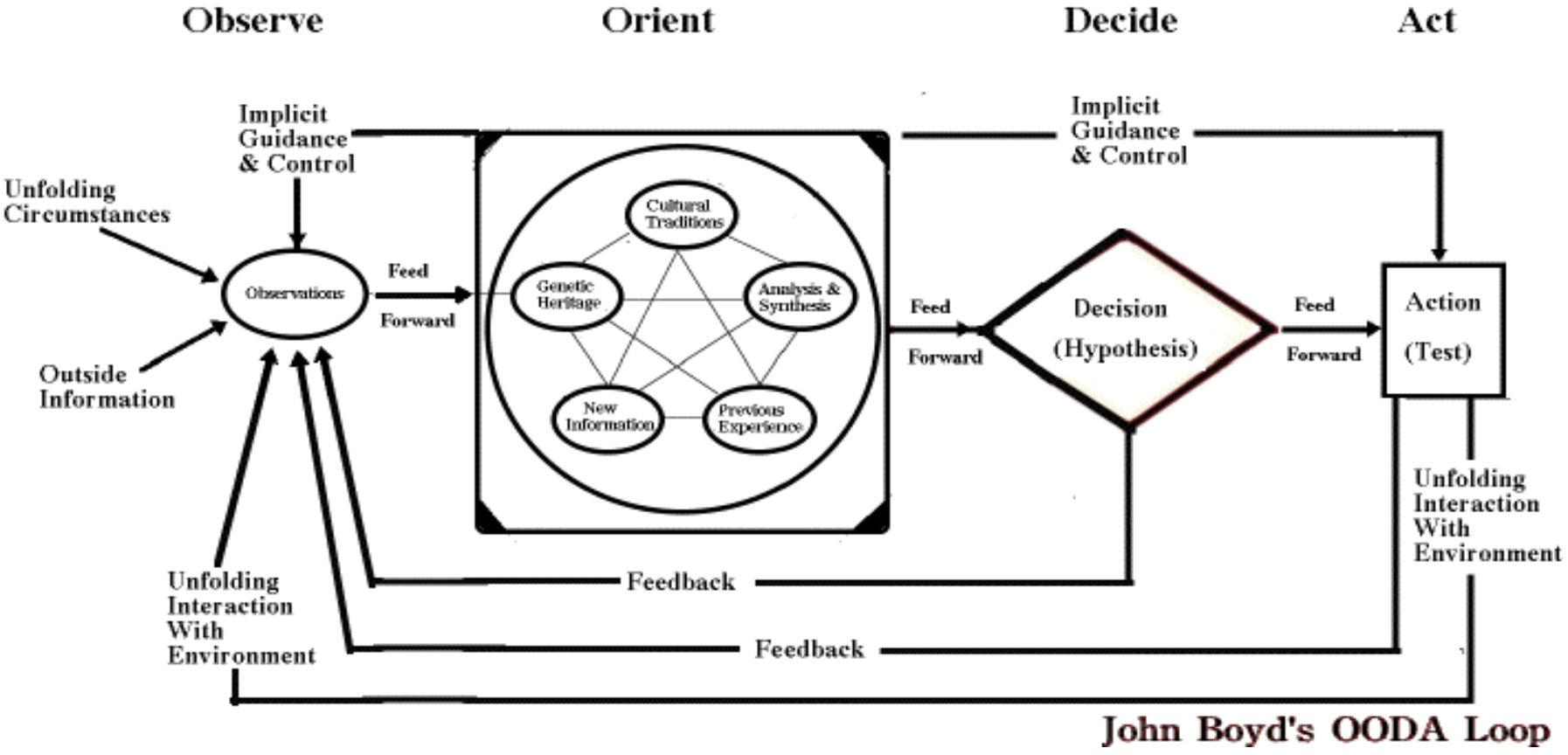
- **Information processing consumes energy**
  - Uses, but does not produce usable energy:
    - thermodynamic entropy of information processing systems is maximum
    - Landauer: destroying information consumes energy
- **Complex systems**
  - Systems consumes and produce energy
  - Any complex system deteriorates with time – the Entropy fate.
    - Becoming unable to turn Energy into Value
    - Entropy is essentially about disorder
- **Information conveys ordering power, "Negentropy"**
  - Information provides order, supports/enables organization.
  - Information "applied" to a system
    - Generates "negentropy"
    - increases its knowledge, its order = reduces its entropy

Information / energy / matter relationship in complex system



Information and Decision

- **Decision consumes and produces information,**
  - Information allows decision, which triggers action
  - The outcome of a decision is a new information leading to subsequent action, and ultimately changing the physical world



Information and Time

- **Real time information :**
  - knowledge of the current situation
- **History information :**
  - memory of the past experiences
- **Prospective information :**
  - extrapolation of the future based on history, RT information and acquired knowledge
- **Time somewhat compensates for the lack of universal, extensive knowledge, information**
  - Information is Knowledge - Time is Ignorance… (Alexei Grinbaum)

Discussion

- **What Information means for Enterprises**
  - What information covers?
  - How IT relates to Information?
  - How information can affect the enterprise?

Information in Industrial Enterprise

- **Common paradigm**
  - Computer + network + databases + software = IS
  - Information System serves the Enterprise system

- **Need for a symbiotic approach**

Information and IT

- **IT HW/SW only addresses one part of the information handling**
  - Beside Sound, Vision, Smell, Telepathy, Waves, Quanta…
- **Information manifests itself in**
  - Business process execution
  - Organization design
  - Idea processing
  - Decision making
  - Monitoring and Control
  - ...

Relative importance of IT in Enterprises

- **Services, Banks, Insurance companies**
  - The sold items are virtual = intrinsically Informational
  - IT is the production asset = investment
    - Objective return on investment
- **Industry**
  - The purpose of Industry is to produce Goods, not Information
    - The sold items are physical
  - IT is a supporting utility = operating expense
    - How to justify expenses? Feeling, assumptions, hopes…
    - Hard benefits of early automation: eliminated biological workforce (and associated costs)
  - What is the true IT importance?
    - IT involves intimate parts, supporting elements of “purpose” systems, that create value

Information & Systems in Industry

- **Information is an integrated part of any system,**
  - Information is both Structural (the knowledge that made up the system) and kinetics (making the system changing)
- **An "Information System" is an abstract concept to handle the information aspects of a given "real system"**
  - It cannot exist independently of this system
  - Information Technology is a media to reveal more information, as well as Sound, Vision, Smell, EM Waves, Telepathy…
- **IT solutions can be called "Information Processing Artifacts"**
  - IT solutions are merely subsystems dependent of the actual systems they support

Information Processing

- **Information processing deals with several dimensions**
  - Real time processing, Transactional processing, data storage, knowledge management, analytics, modelling, simulation and optimization, collaboration…
  - MRP, DBR or PID are examples of computational methods to achieve particular decision processes
    - Operations planning, Operations optimal scheduling, Physical measurement control
- **Information processing purpose**
  - Acquire Knowledge, Learn from experience
    - Capture explicit and implicit knowledge
    - Detect events and correlations
  - Apply / enforce acquired knowledge
  - **Carry on Intelligence**

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- **Linguistics**

Language at the roots of knowledge and intelligence

- **Information is associated with different concepts**
  - Bit and bytes flowing into electical wires or stored in an SSD drive
  - Meaningful messages exchanged between collaborative partners
  - Universal objective knowledge that can be stored, retrieved, developped independently of its users (Popper)
- **Between the physical, real world**

Conditions of intelligence

- **A product of complexity, Intelligence raises from several factors**
- **Ability to develop knowledge**
  - Enabling cycling between subjective experience and objective knowledge
- **Ability to share knowledge**
  - Enabling seamless storage and access to relevant knowledge
- **Ability to interact**
  - Enabling understandable communication between components
- **Individual intelligence**
  - Sophisticated components performing locally
  - At the advantage of the whole system

Language

- **Objective reality and knowledge are out of reach as such**
  - Reality - Things and facts - cannot be directly captured and influenced
  - Knowledge exists independently of its actual understanding – by human, machines
- **Language is the means for handling knowledge and reality**
  - Language defines atomic symbols (number, alphabets), basic concepts (vocabulary, emoticons) and rules (grammar) for representing reality and expressing knowledge
- **Language is a pre-condition for intelligence**
  - Enables individual intelligence – thinking, computing
  - Enables systemic intelligence – communications
- **« Natural » languages for handling by biological entities**
- **« Computer » languages for handling by artificial entities**

Enterprise knowledge

- **Covers many domains**
- **Addresses tangible and intangible information.**
- **For Industrial facilities operations**
  - Tangible knowledge
    - Resources and capabilities (equipment, people, material, energy…)
  - Intangible knowledge
    - Know-how to handle resources in order deliver main or support product and services

Enterprise language

- **A language provides support for meaningful, non ambiguous representation for**
  - Knowledge exchange, storage, retrieval
  - Describing enterprise structural and behavioral aspects on the time scale
- **Must serve both Human and IT relationship**
  - Understandable by people and machines
  - Machine, being notably stupid, need extended, precise formalism to understand

Elements of the enterprise language

- **Natural language accommodates most of human interactions**
  - Body language often completes the lexical message
- **Machines need more formalism**
- **The enterprise language is a formal ontology**
  - A semantic tree
  - Defining concepts associated with lexicon (translations, synonyms,)
  - Structured successively in
    - simple abstract concepts i.e. « Identifier » « Description »
    - General concepts i.e. « « activity », « Resource »
    - business concepts as references for actual business entities mentioned in messages
  - Describing relationships and value domains