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SYSTEMS SCIENCE & COMPLEXITY MANAGEMENT

Complexity

Real, Absolute

- Variety
- Connectivity
- Convolution

Perceived, Relative

- Does not resolve easily into (Platonic) shapes
- $f(\text{familiarity})$
- Shapes in clouds, fortunes in tea-leaves

Systems Complexity

Nature's complex, nonlinear systems:

- Greater power densities, self-healing, auto adaptation, self-replication... etc.
- Use Nature's examples to greatly improve man-made systems...

Complexity \Rightarrow *Life*

Cambrian Life-form, c. 500MY BPE



Complexity \Rightarrow *Life*

- For 4.5 billion years, Earth produced v. simple life: bacteria; plankton; multi-cellular algae.
- Then: 530 million years ago:
 - Cambrian Explosion!!
 - Extravagance of weird, bizarre, fractal life forms: sex!
 - Evolution of eyes \Rightarrow Predator/Prey “arms” race
 - All today’s body plans/architectures created...
- Cambrian marked by c.3 *mass extinctions*, followed by continual resurgence of...
- ...*Complexity \Rightarrow Continual Emergence of Life*

Complexity \Rightarrow Life

CD-ROM. “Oceans: The Origins of Life”



Swimming animal is *anomalocaris*, top predator. The apparent “plants” are fractal animals – life too deep under the sea for photosynthesis...

Life, Order and Disorder...

- Evidently, *complexity auto-generates...*
- ...Complexity \Rightarrow order *and disorder...*
 - Big Bang \Rightarrow stellar systems; galaxies; clusters; super-clusters... *Black Holes*
 - *Hymenoptera/Isoptera* \Rightarrow hives; colonies; bivouacs... *swarms*
 - *Homo sapiens sapiens* \Rightarrow families; societies; cultures; civilizations... hierarchies which eventually *collapse*, often spectacularly

Systems Lifecycle Theory

Theory for Addressing Issues

Theory for Developing System Concepts

Theory-base for Systems Engineering

Premise: Interconnected systems driven by an external *energy* source will tend to a *cyclic* progression in which:

- system *variety* is generated,
- *dominance* emerges to *suppress* the variety,
- the dominant mode *decays* or *collapses*, and
- survivors regenerate *interconnected variety*...

Complexity



Unified Systems Hypothesis (HUSH)

Unified Systems Hypothesis

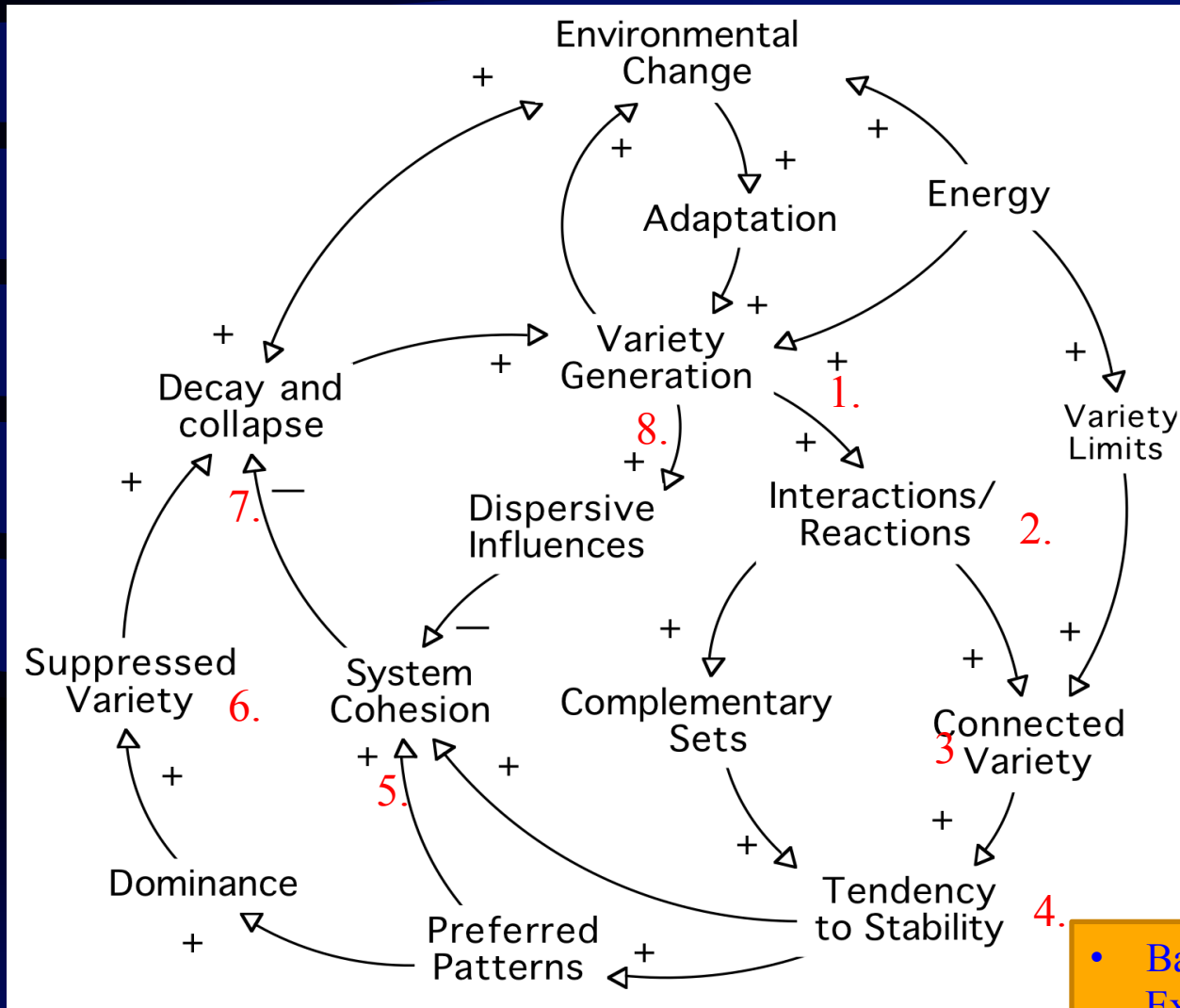
- *That open systems form, develop, sustain, collapse/decay and reform continually – “entropic cycling”*

‘Law of Cyclic Progression:’

“Open interacting systems’ entropy cycles continually at rates, and between levels, determined by available energy”

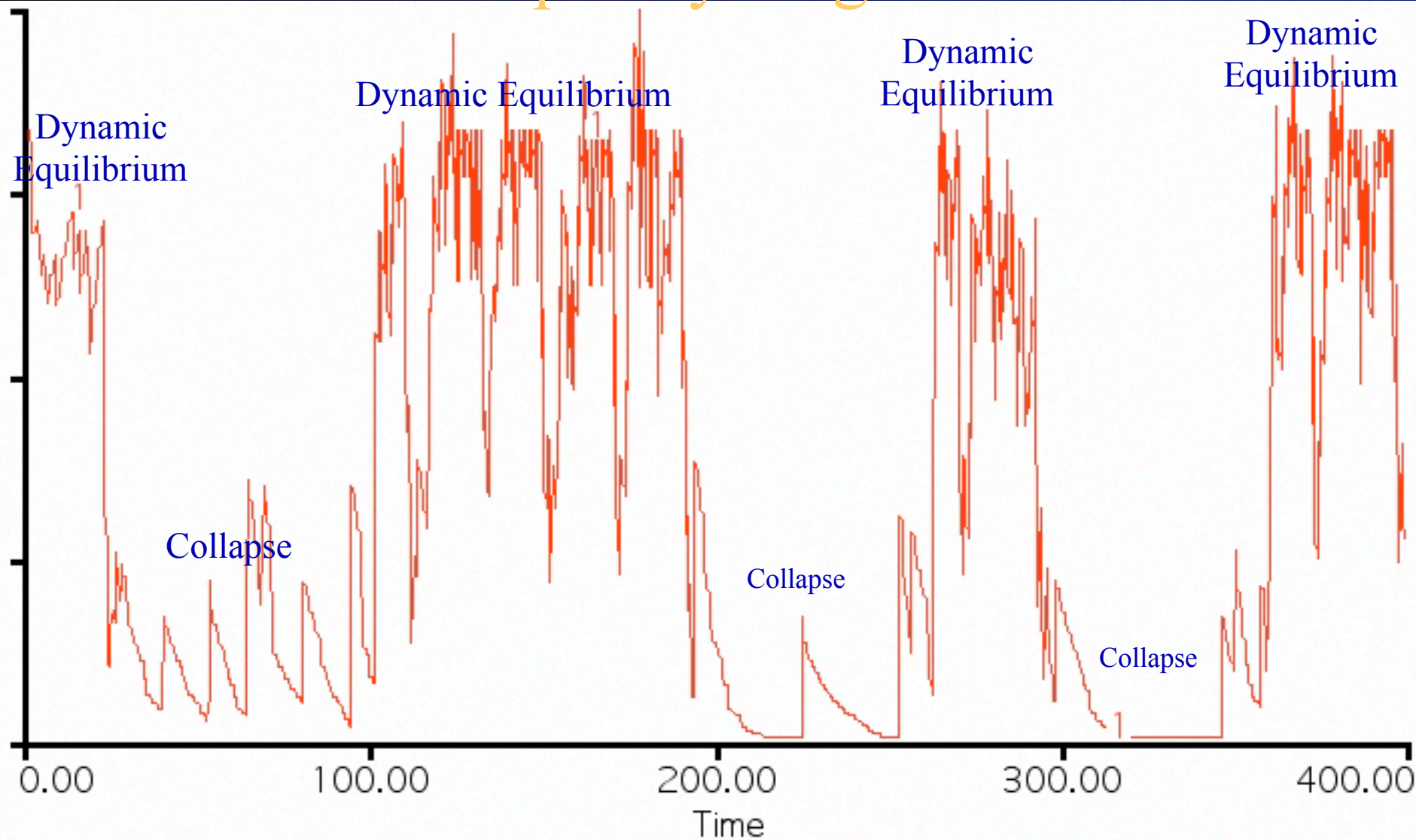
“Systems Engineering: A 21st Century Systems Methodology,” D K Hitchins, 2007, John Wiley

Unified Systems Hypothesis (HUSH)



- Basis for Cambrian Explosion?
- Endemic today?

USH Entropic Cycling Simulation



USH – Global Warming

- *(Weather) Systems' entropy will cycle continually at rates, and between levels, determined by available (increasing) energy.*
- USH predicts that global warming will result in more extreme weather conditions, more frequently:
 - more severe storms,
 - more downpours, floods, BUT
 - more extended calms,
 - more extreme droughts
- Weather systems are chaotic: impossible to predict individual events or locations

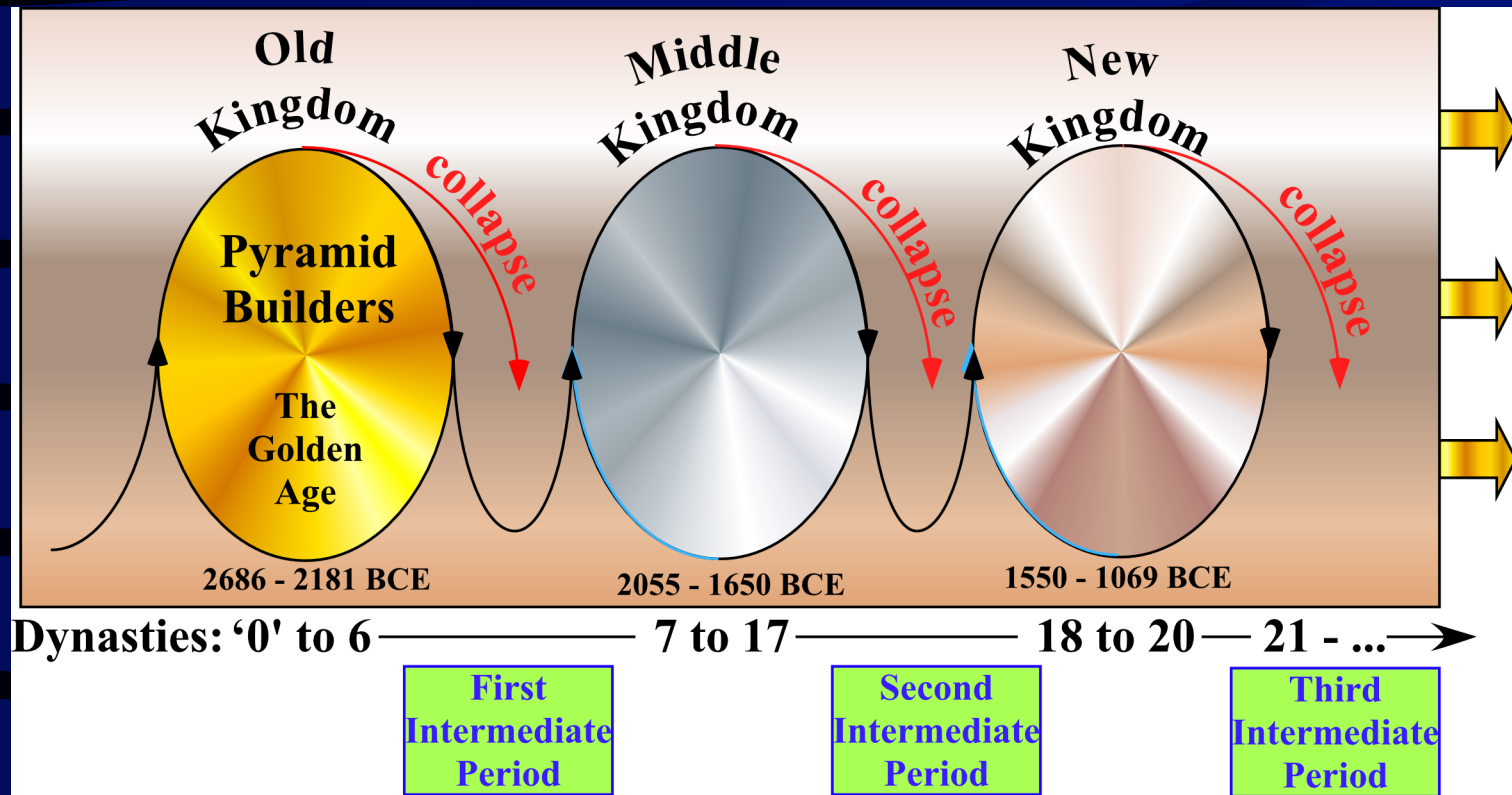
USH “Use Cases”

USH is Universal, Scale-independent, understandable, useful

- ***Revolution***; Bolshevism; Stalinism; domino-collapse of Soviet Union
- ***Politics***: left-wing; right wing; continual switching is stable... *dominant* leader who expels dissidents (‘wets’) from cabinet reduces *variety*, heralds own *collapse*
- International *economic* cycles (Kondratieff)
- *Bureaucracies* that “exist, like aircraft carriers, mainly to defend themselves” exemplify preferred patterns
- *Accountants* destroy companies by *shedding variety* to survive economic winter...
- Ancient Egypt ‘cycled’ through 3 unified ‘epochs,’ with ‘intermediate’ periods of relative disorder...

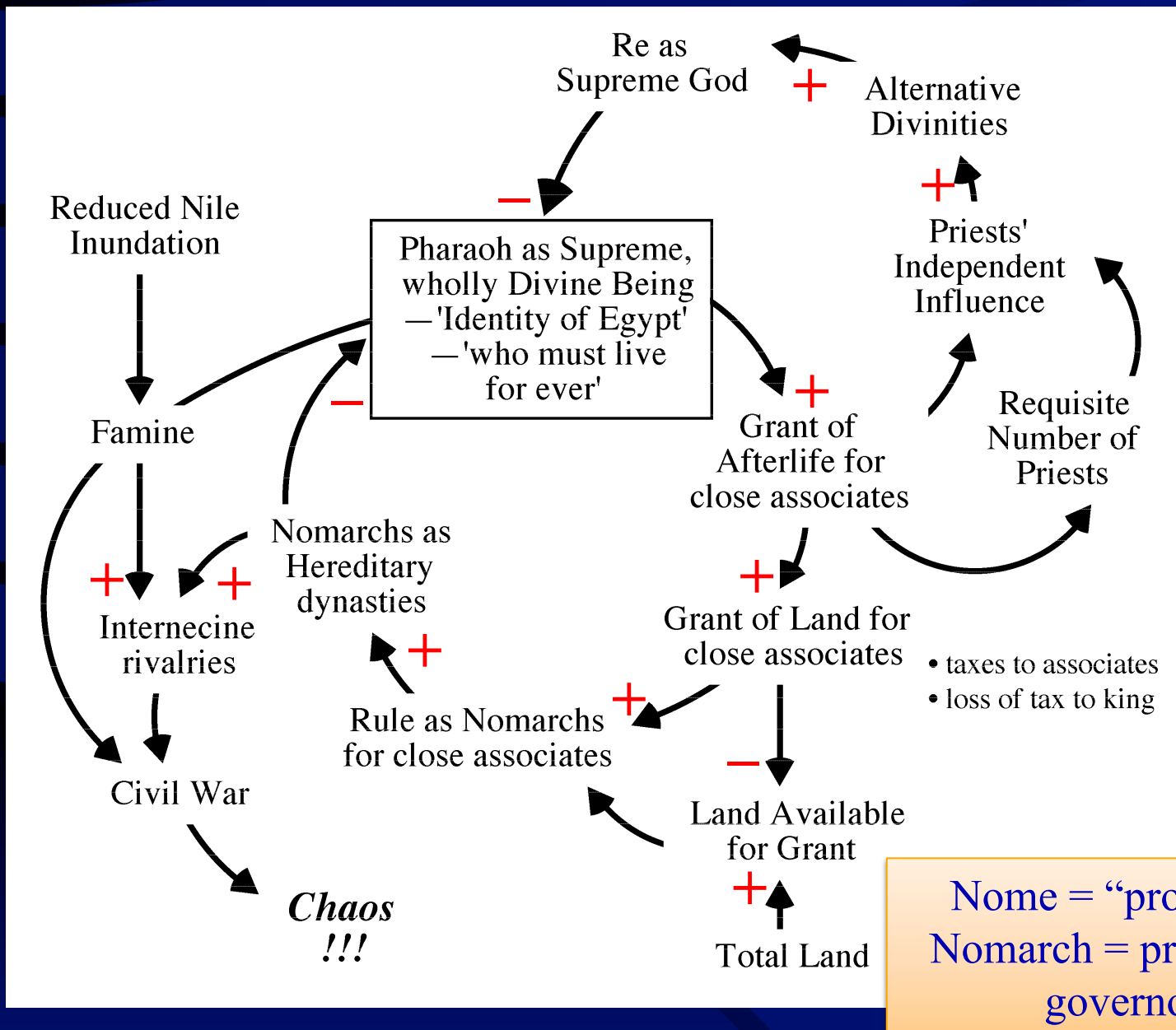
D K Hitchins, *Advanced Systems Thinking, Engineering and Management*, 2003, Artech House, Boston.

USH and Ancient Egyptian Epochs



- Each oval represents an epoch in the ancient Egyptian civilization
- ... *and* a rotating USH lifecycle map
 - Each epoch built society slowly, established, then collapsed...
 - Each new epoch built on the residues from its predecessor
 - ⇨ Entropic Cycling in social history? *Faint echo* of Cambrian Explosion?

Causal Loop Model – Demise of the Pyramid Age



USH in Systems Engineering

- Unique approach to complex systems engineering –
 - *natural, social and sociotechnical systems!*
 - ~~*Mechanistic*~~ \Rightarrow *Organic, “Biological” paradigm*
 - *Principles* – *holism* – *synthesis* – *organicism*
- Anticipates continually changing *environment*
- Maintains/increases *connected-variety* to accommodate changing *environments*
- Promotes *harmony* through *synthesis*
- Continually refreshes *connected-variety* for *homeostasis/dynamic equilibrium*

Complexity – Levels of Organization

LEVELS OF ORGANIZATION

Biology/Anatomy *Man-made Systems*

Community ↔ Company

Population ↔ Group

Organism 5 Platform

Organ System 4 System

Organ 3 Subsystem

Tissue 2 Composite

Cell 1 Component

* Population - all the organisms that belong to the same species, in the same geographical area

** Community - a group of interacting living organisms sharing a populated environment

Complexity – Levels of Organization

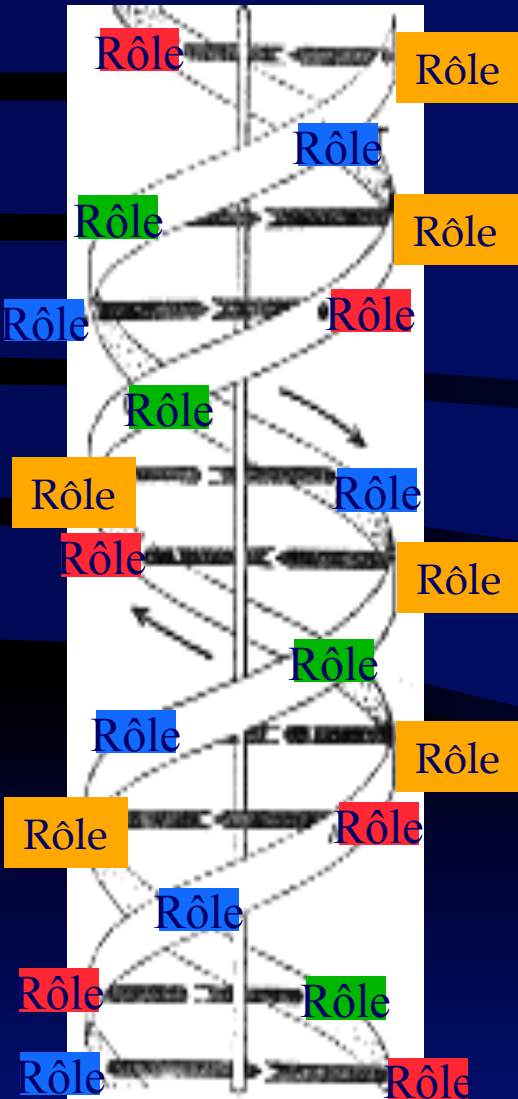
LEVELS OF ORGANIZATION

<i>Biology/Anatomy</i>		<i>Man-made Systems</i>	SE Layer
Nation	9	Nation	<i>Socioeconomic/societal SE</i>
Region	8	Organization	<i>Industry Systems Engineering</i>
Community	7	Company	<i>Business Systems Engineering</i>
Population	6	Group	
Organism	5	Platform	<i>Project Systems Engineering</i>
Organ System	4	System	
Organ	3	Subsystem	
Tissue	2	Composite	<i>Artefact Engineering</i>
Cell	1	Component	

* Population - all the organisms that belong to the same species, in the same geographical area

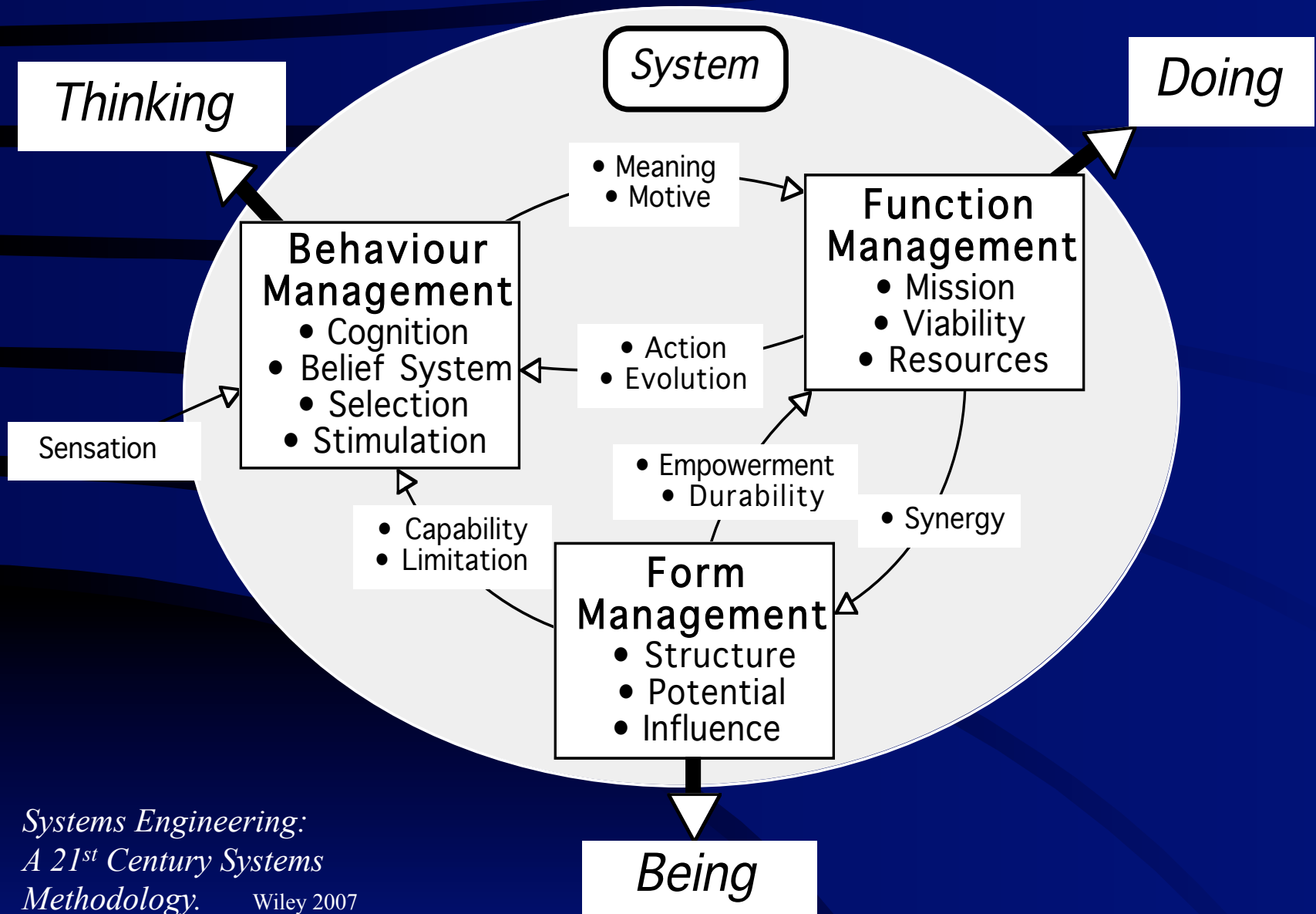
** Community - a group of interacting living organisms sharing a populated environment

The Social Genotype®—Basis of Identity, Culture and Adaptive Social Behaviour



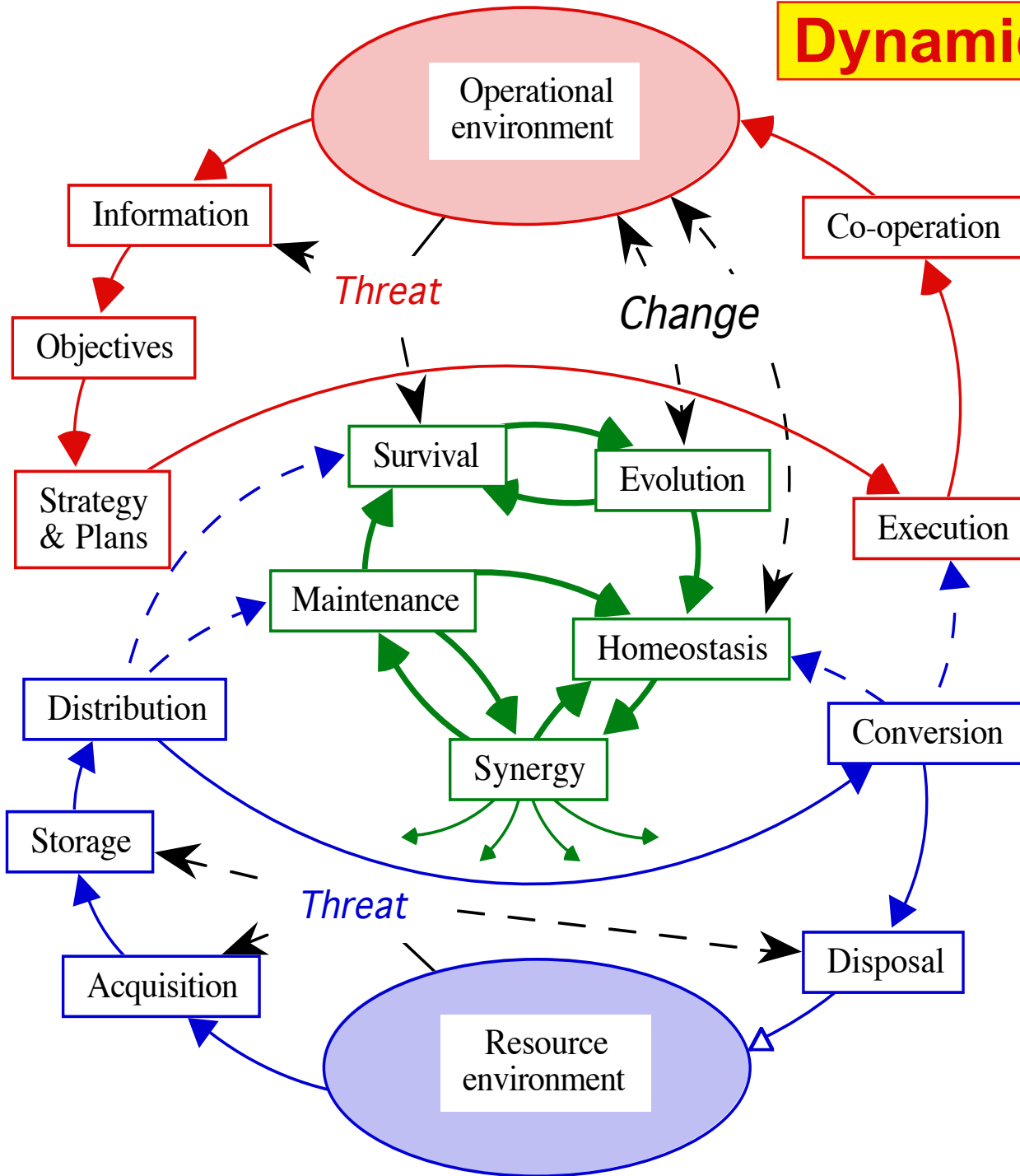
- Analogue/extension of DNA which expresses identity of *individual*.
- Social Genotype expresses identity/culture of *social group*
- Rôles/groups and relationships form stable, palpable structures
 - Rôle more determined by relationships and interactions with other rôles, less by rôle-holder
- Relationships mediated via common, shared *belief system*—shared attitudes, viewpoints/*weltanschauungen*, ethics, morals
 - which may be *very different* from those of the individual fulfilling the rôle! (Jung)

The Generic Reference Model



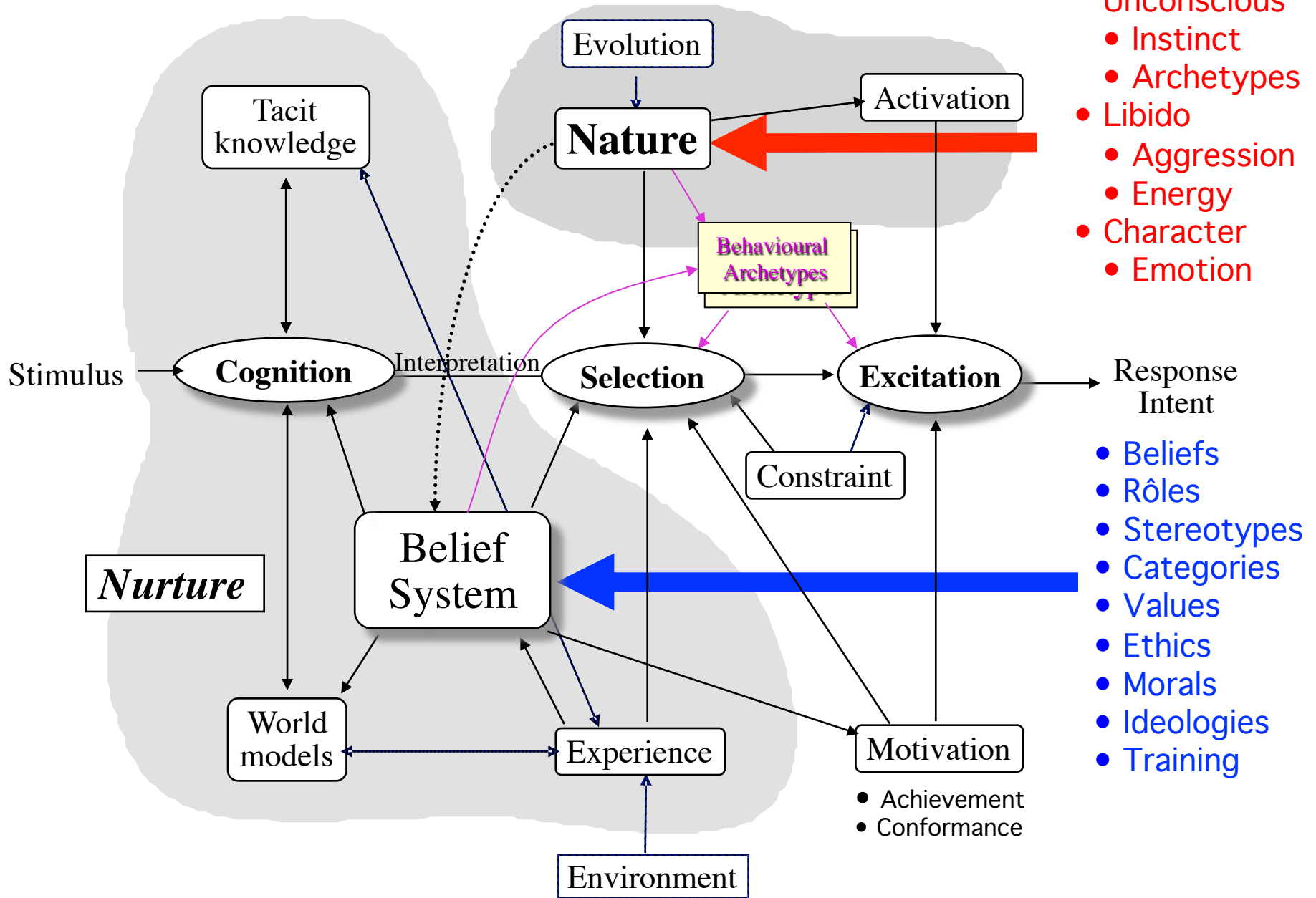
*Systems Engineering:
A 21st Century Systems
Methodology.* Wiley 2007

Dynamic GR(Function)M



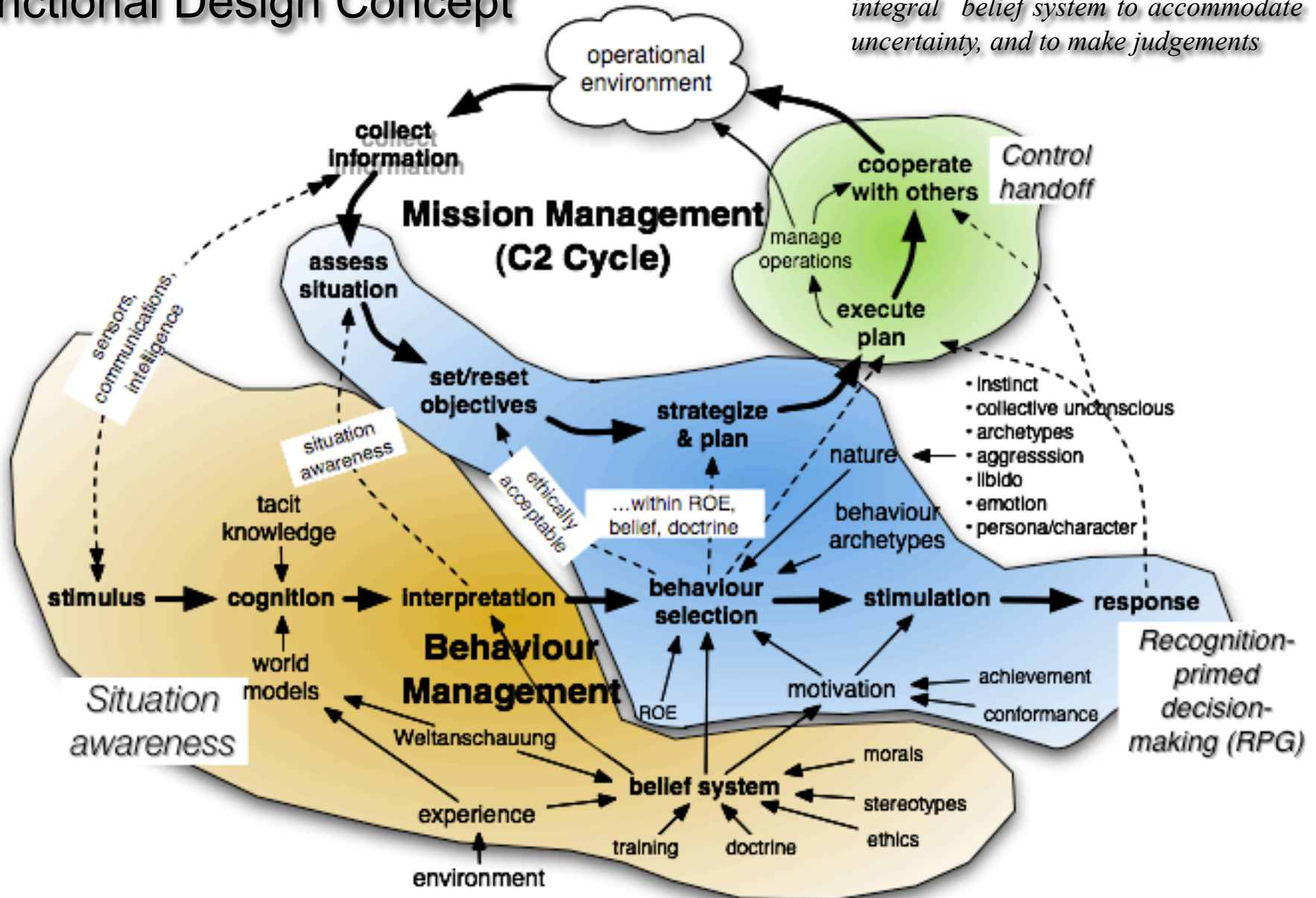
- 3 elements seen in respective “environments”
- Viability provides platform for Mission Management
- Resources provide energy & materials for Viability and Mission Management
- Threats to Mission Management, & Resource Management
- Change challenges Homeostasis (resist) and Evolution (adapt)

GRM: Behaviour Management

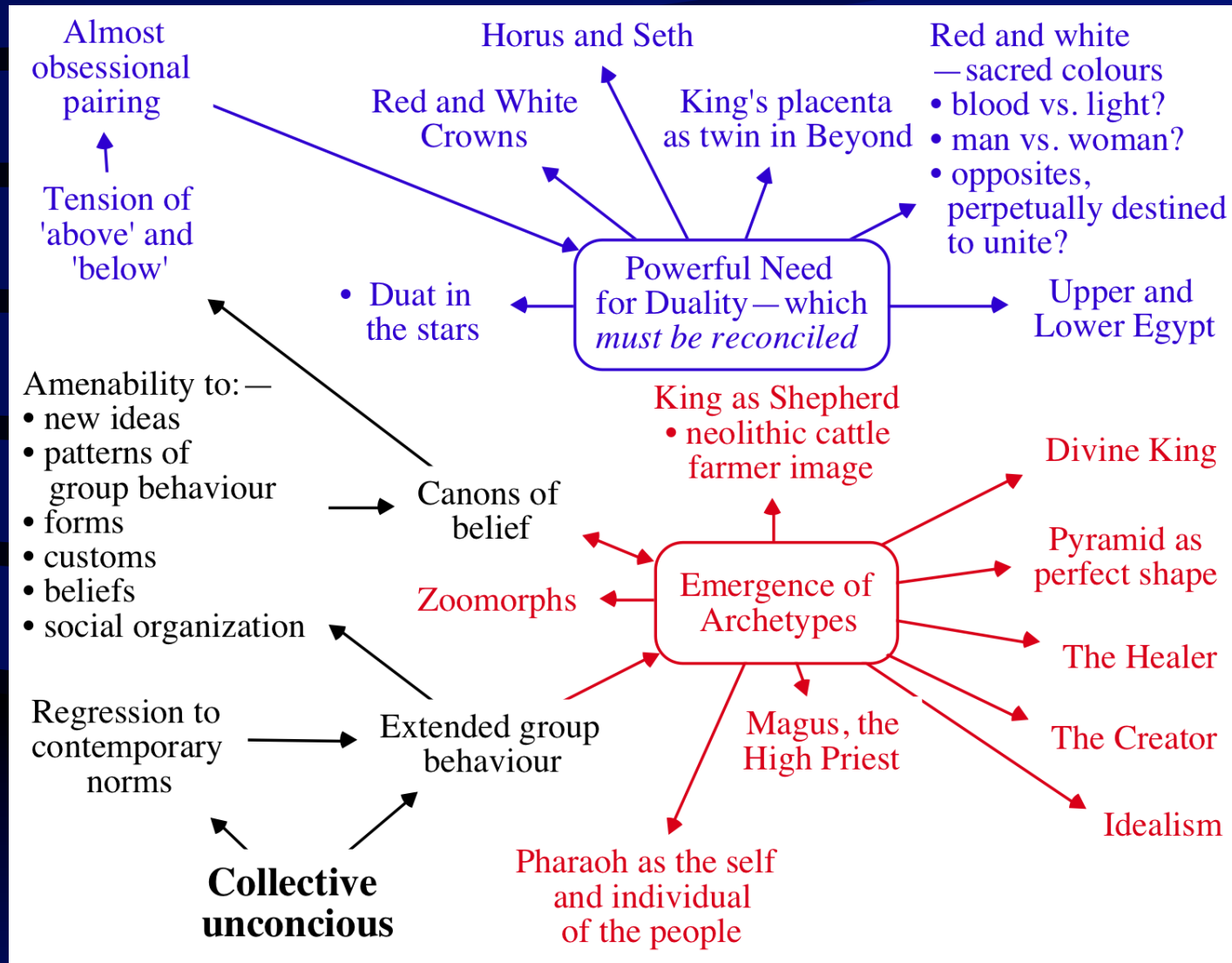


Autonomous Peace Officer Functional Design Concept

Autonomous systems will behave ethically, morally and will need an integral belief system to accommodate uncertainty, and to make judgements



Behavioural Archetypes - Ancient Egypt



Shepherds of their Flocks – Shepherd Archetype through the Ages

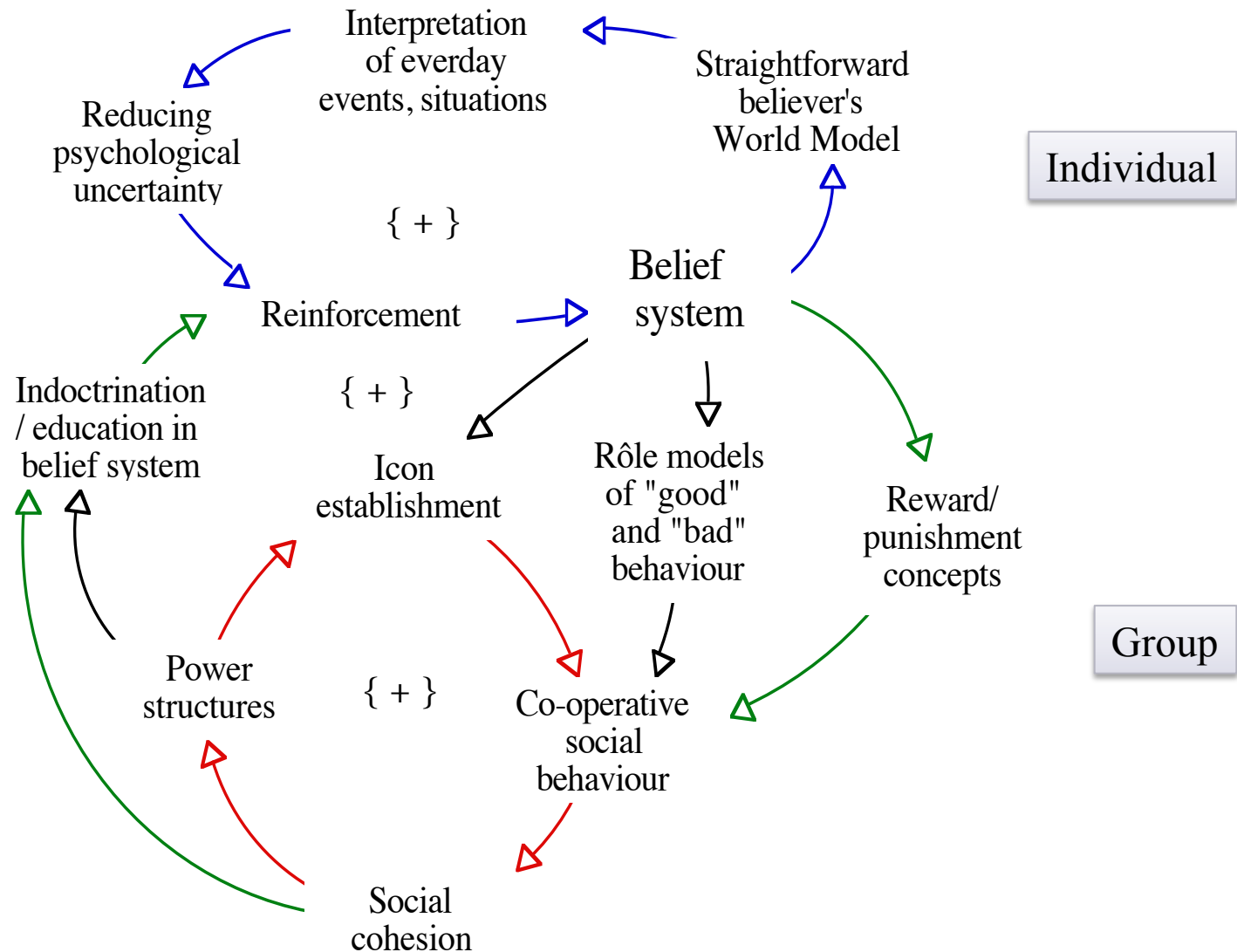


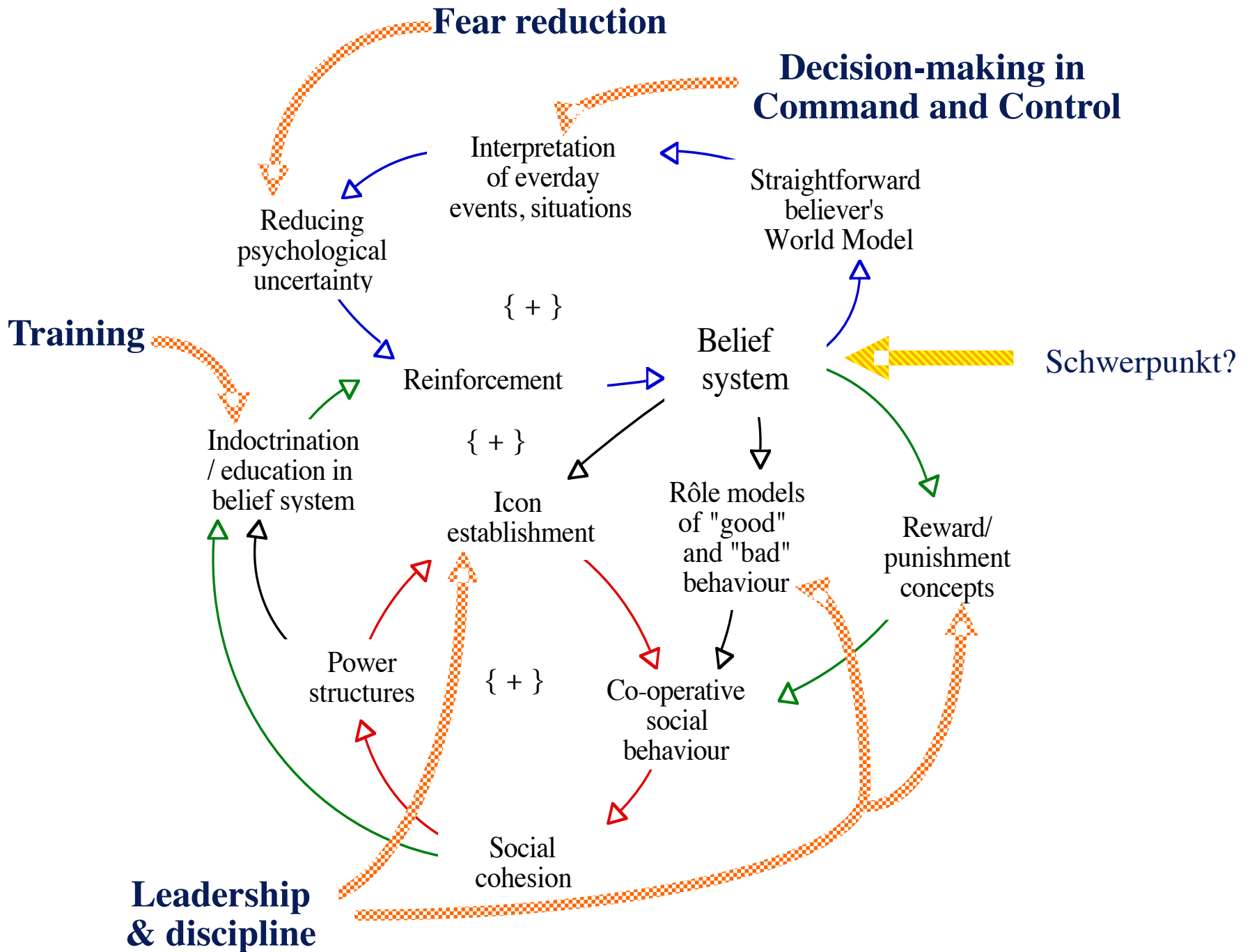
Crozier



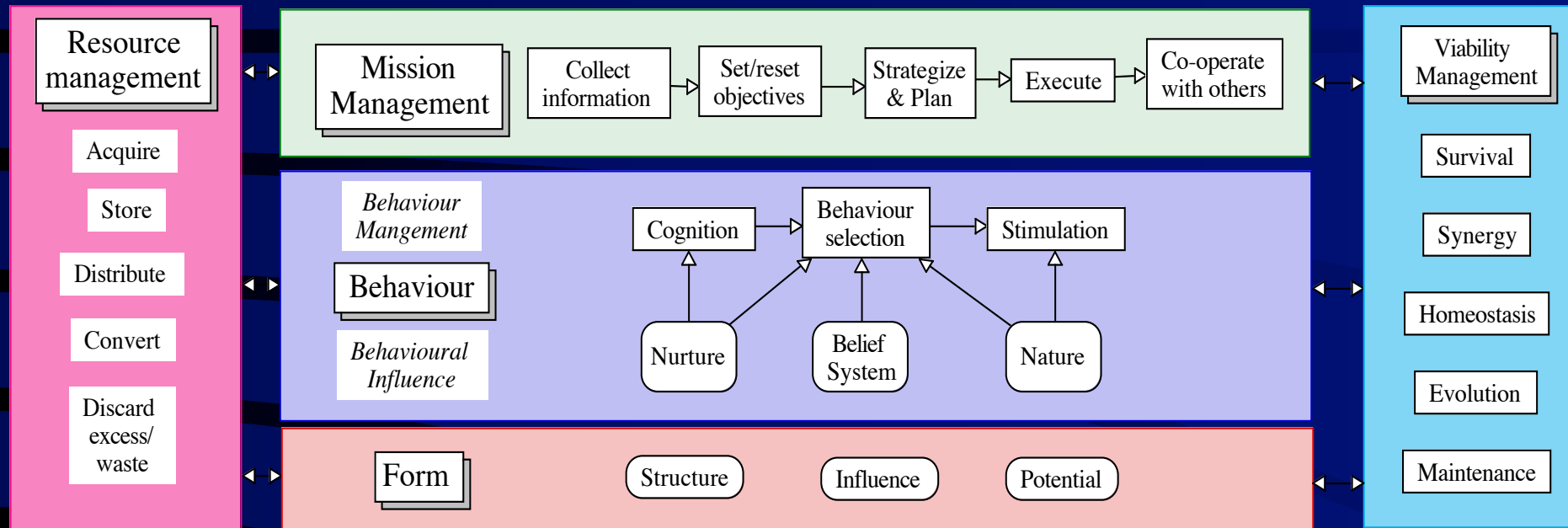
Crook

Maintaining/ reinforcing the belief system—1

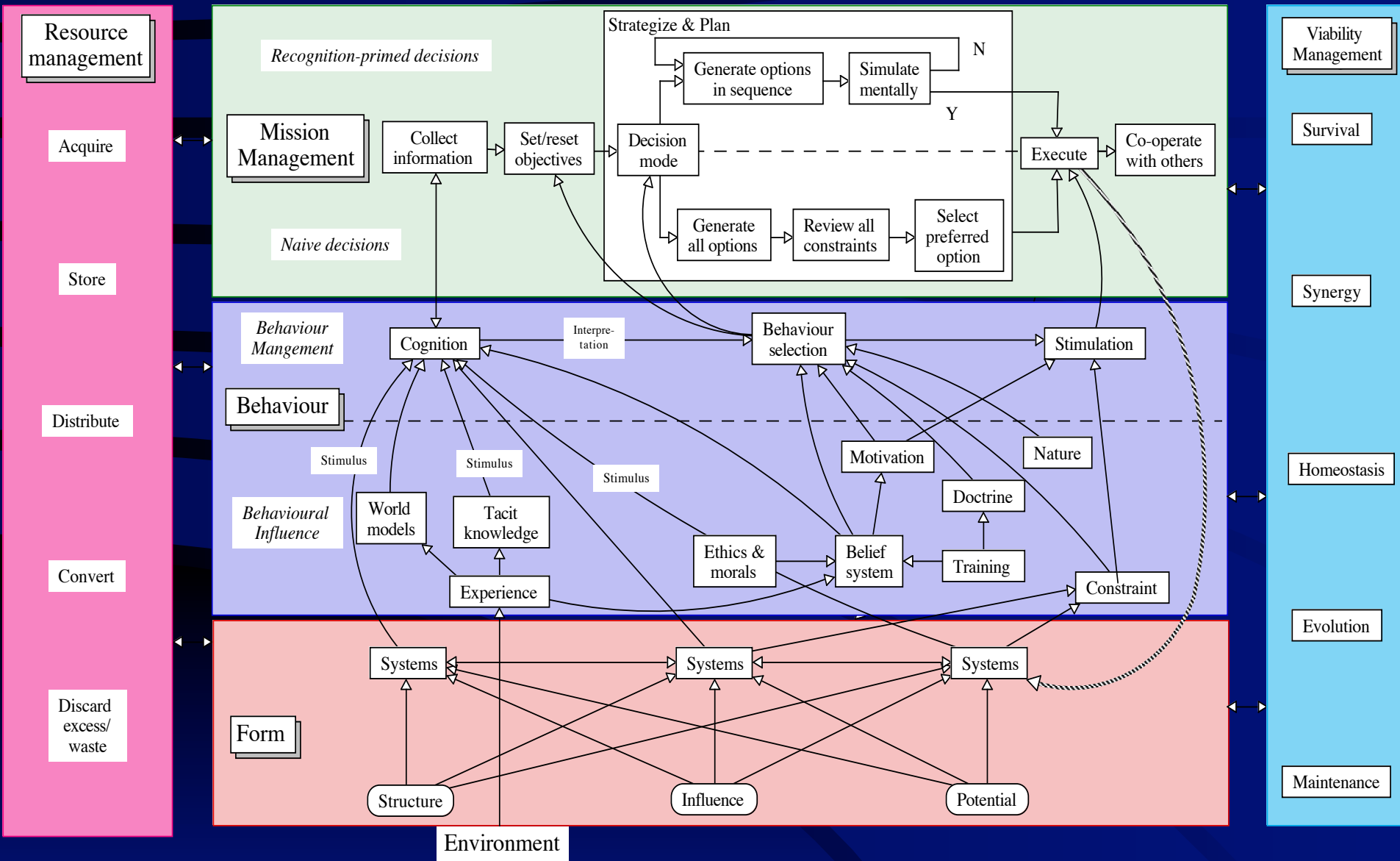




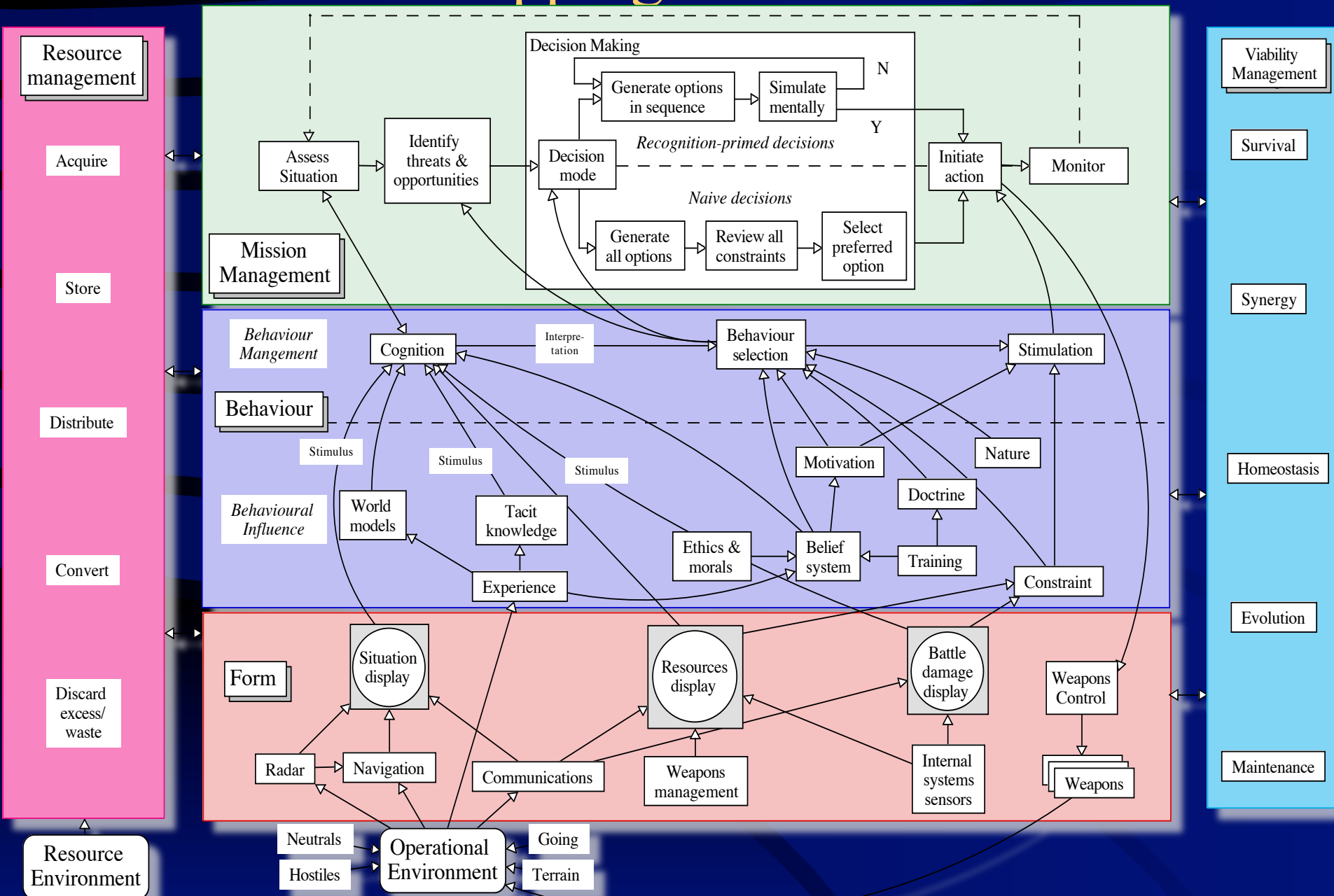
GRM in Layered Virtual Machine Format



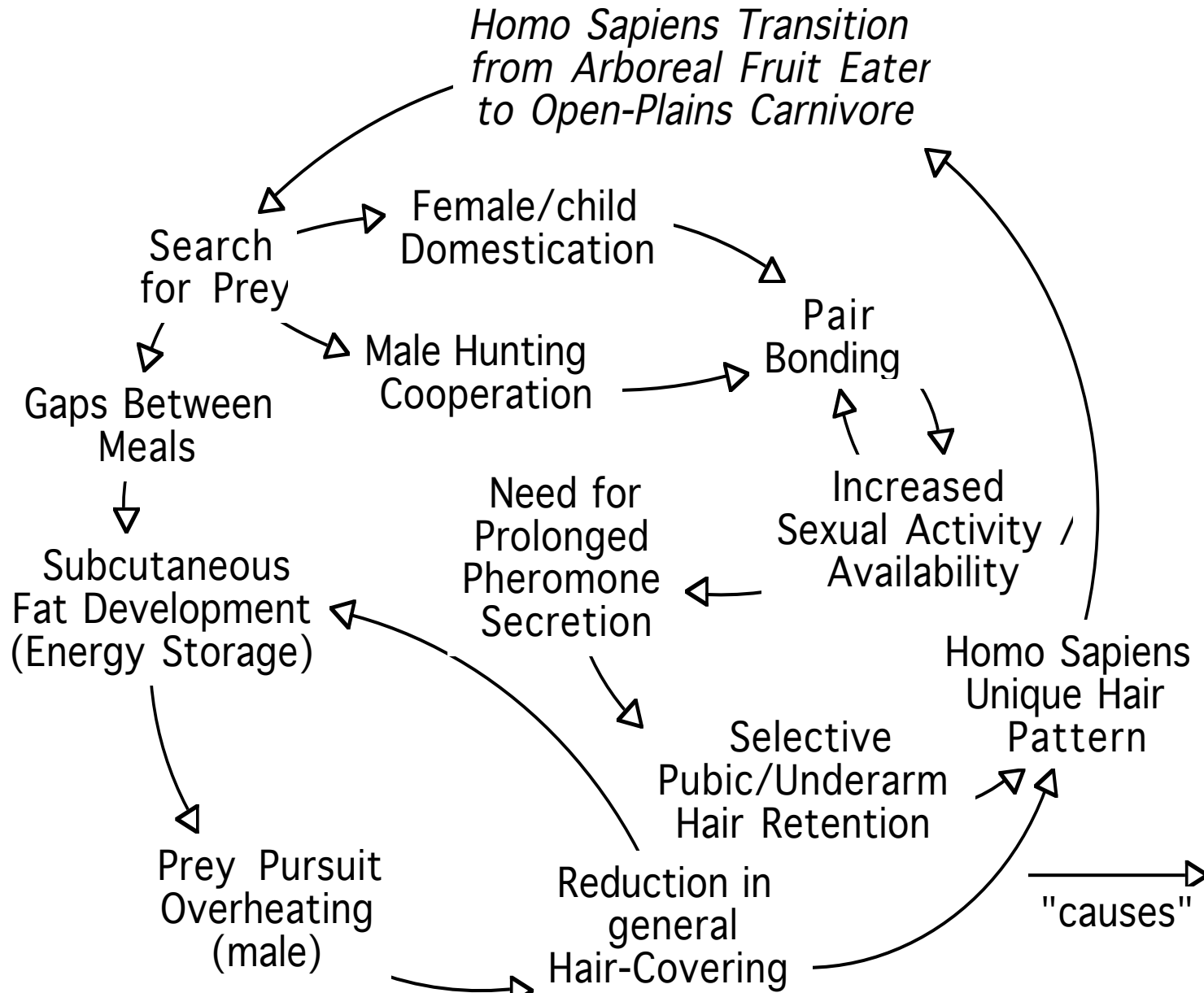
One Level of Layered GRM Elaboration



Mapping on to C³I



Causal Loop Model for Homo Sapiens Hair Growth

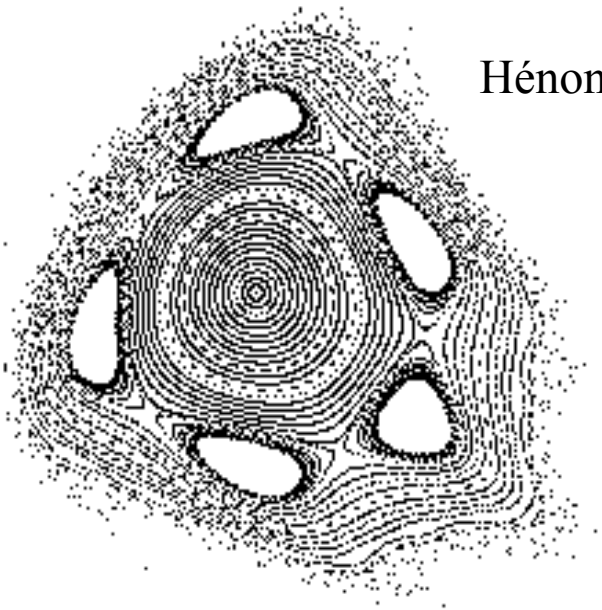


Deterministic Chaos

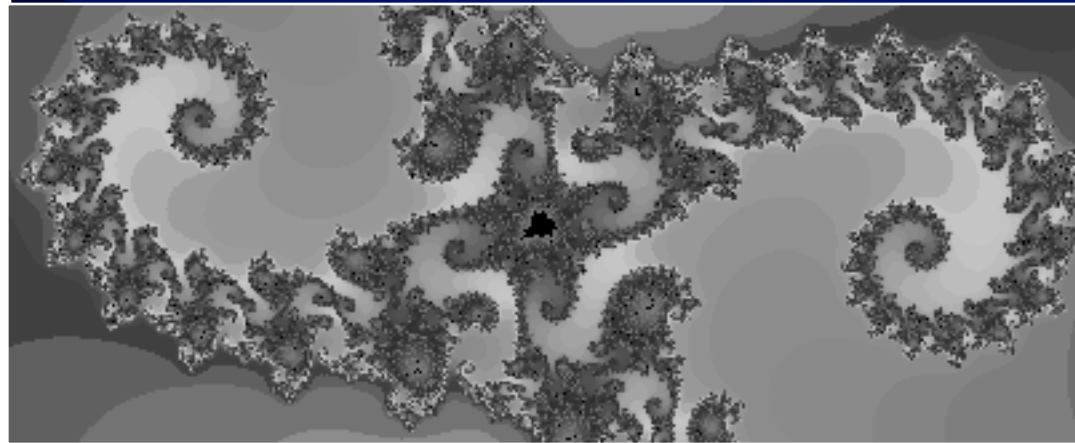
Chaotic Phenomena

- Two main varieties:
 - Deterministic Chaos – exponential growth in uncertainty
 - Weak chaos – power law growth in uncertainty
 - shared with fractals and self-organizing criticality...
 - .. suggesting some phenomenological commonality
- Chaos is organized, structured, bounded –sic!!

Hénon Chaos

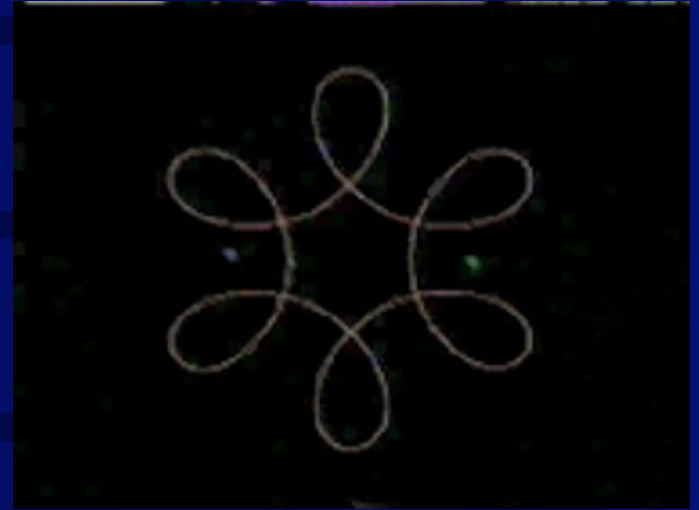


The Julia Set (fractal)



Deterministic Chaos – Poincaré (1887)

- French mathematician
 - 3-body celestial problem - how do ‘bodies’ behave in space?
 - Poincaré won international maths competition: upper video clip:
 - regular, repeating, but incomplete. However...
 - .. different starting conditions give different result...
 - ...corrected error only *after* winning!
 - ‘Close-coupled’ behavior in lower video clip!
 - Never repeats
 - chaotic!
 - Poincaré: ‘father’ of chaos
- N.B.** Apparently simple, Newtonian systems can exhibit complex behaviour!



From Channel 4 Equinox program: Chaos

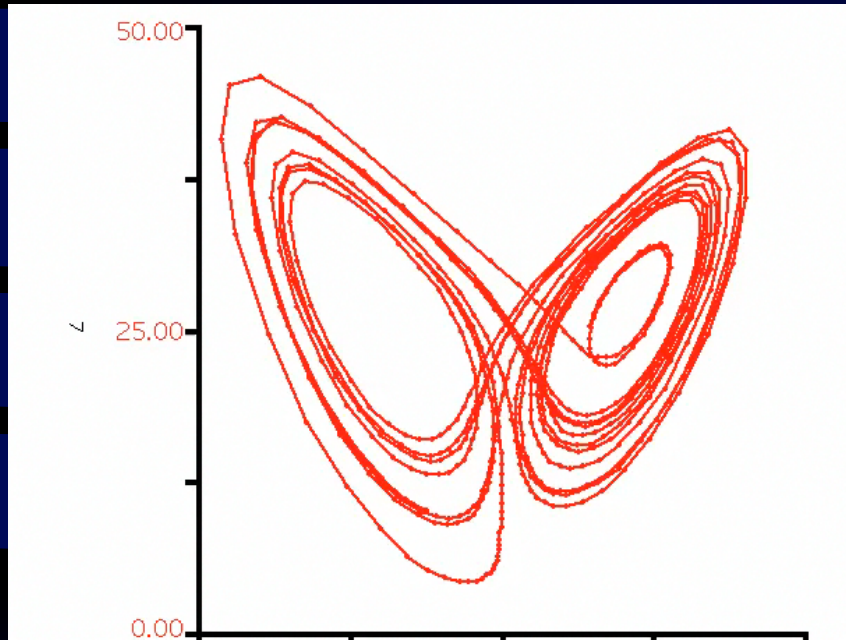


Lorenz's Weather – Deterministic Chaos

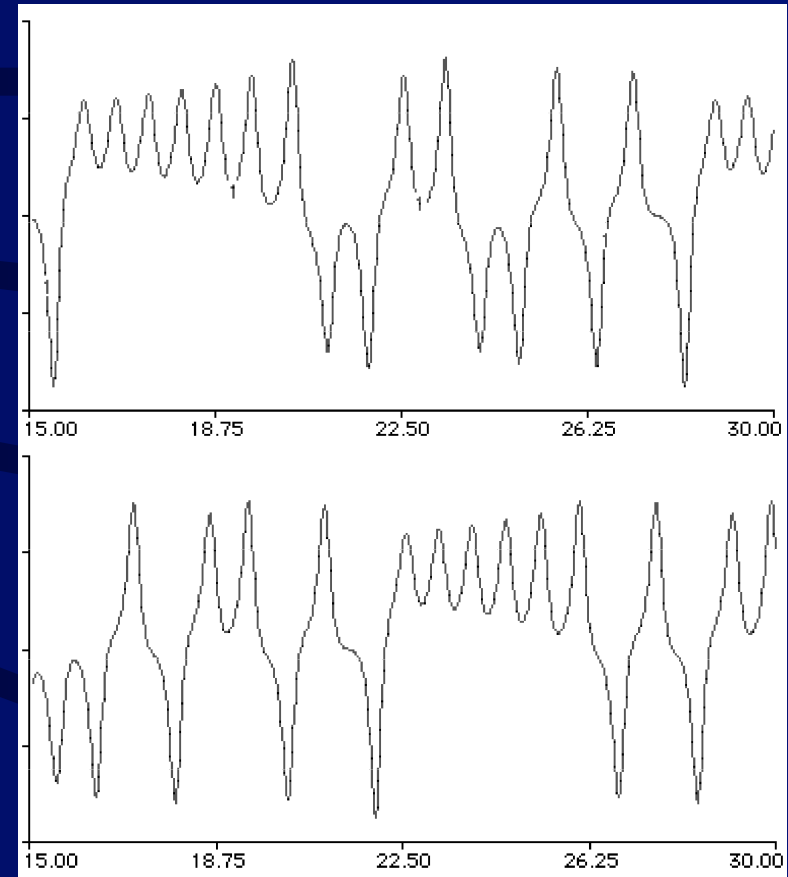
$$dx/dt = -10x + 10y$$

$$dy/dt = 28x - y - xz$$

$$dz/dt = -8z/3 - xy$$



Lorenz's Butterfly – “*strange attractor*”
-never repeats, never overwrites, never
goes outside bounds – represents ‘climate’
–*Signature of ‘pure’ deterministic chaos*



Different starting conditions create
different, but very similar, patterns

Coupling & Chaos

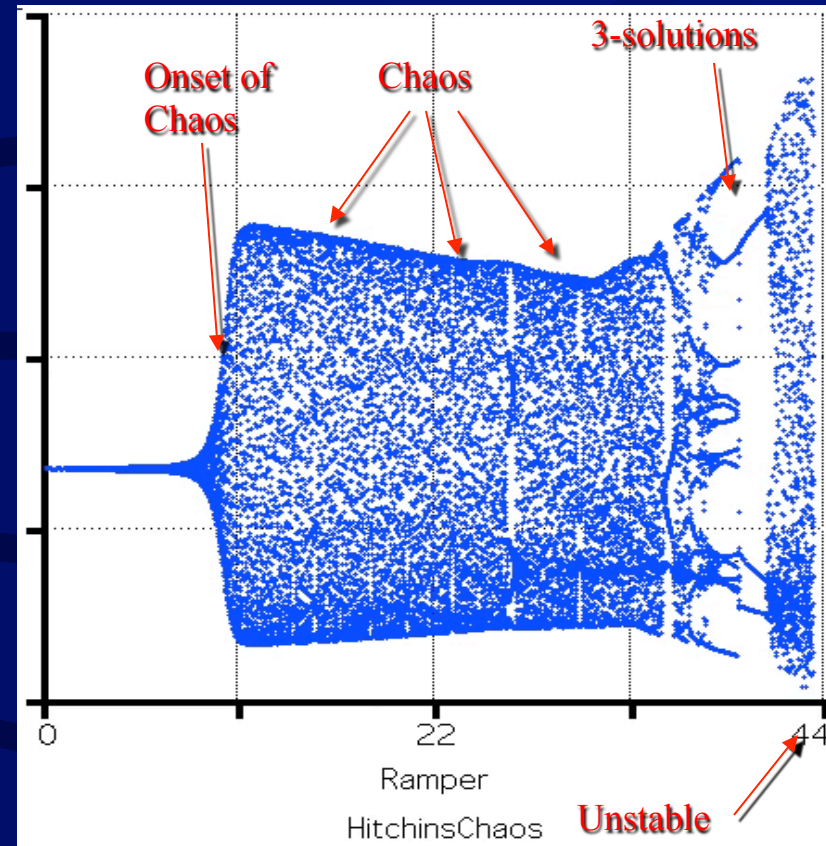
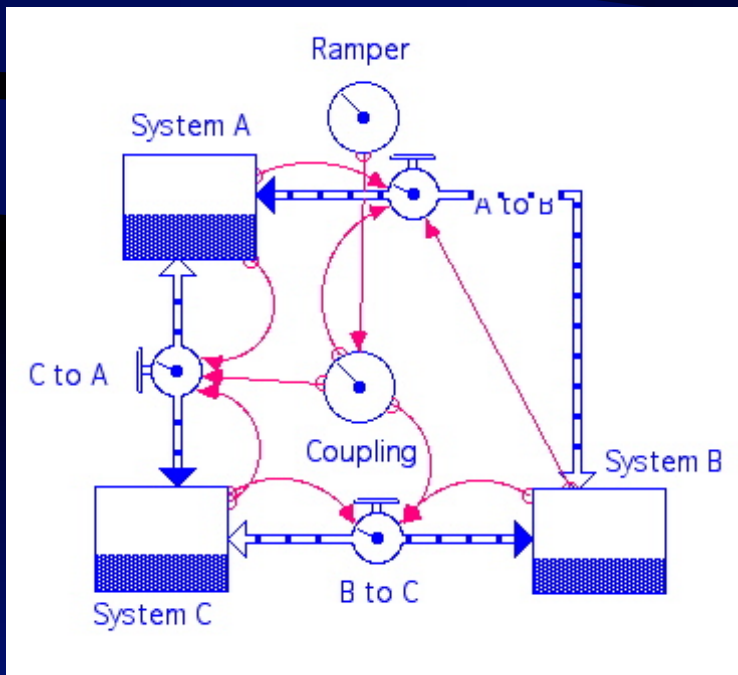


*Video feedback: TV camera pointed at screen showing picture from TV camera - 'strike a light' and –
dynamic chaotic patterns...*

- Increased coupling between elements in 3-body problem caused *deterministic chaos*.
- Tight coupling between subsystems as parts of some whole may cause *deterministic chaos*, too
- Shown in simulations...
- Beware:
 - .. of over-tight *coupling* between systems in systems *design* and in systems *integration*...
- .. “sailing close” to the ‘far edge of chaos’

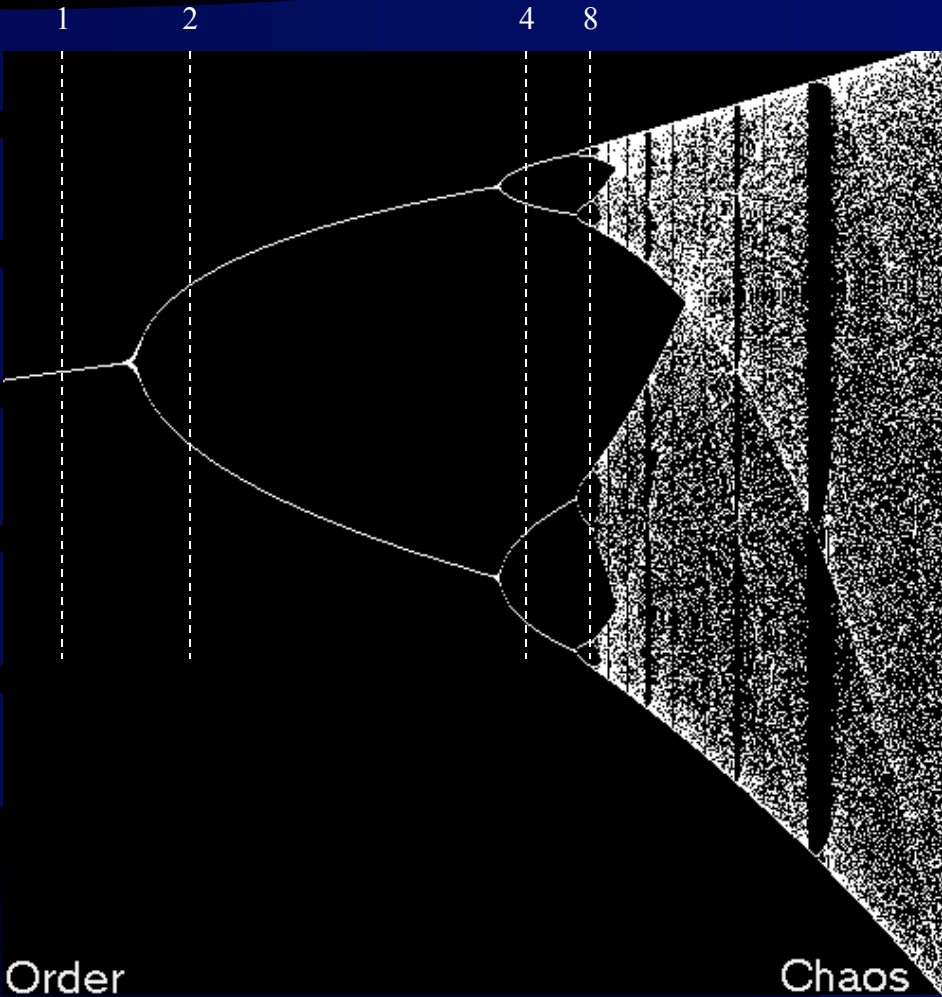
“Simulated Chaos”

- The simple, 3-coupled reservoir model (c.f. 3-body problem) illustrates development of chaos...



- ...complex behaviour can emerge from simplest of systems – without designer/owner/user knowledge

.. doubling...



Logistic Bifurcation Diagram
(iterate $x_{n+1} = a \cdot x_n(1 - x_n)$)

The *Edge* of Chaos...

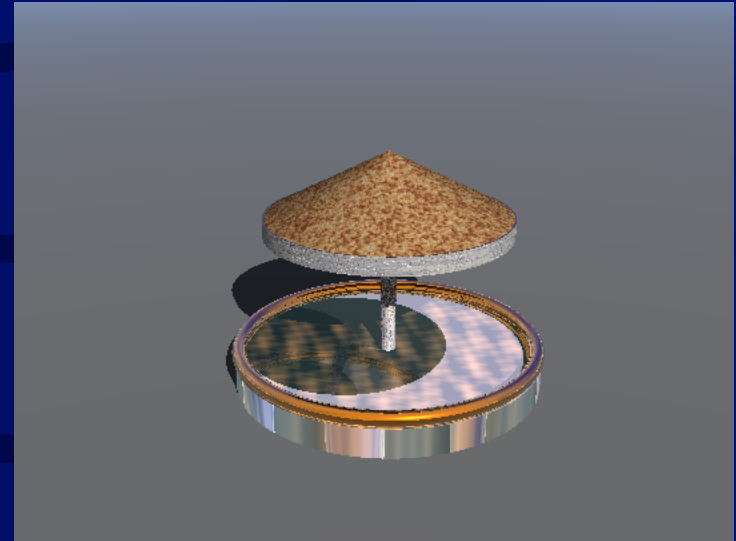
- Many real world systems may exist on the “edge of chaos:” between order and disorder/chaos...
- Some view ‘complexity’ as between order and chaos
- Logistic/sigmoid *very common equation* in biology, engineering, population growth...

Weak Chaos:

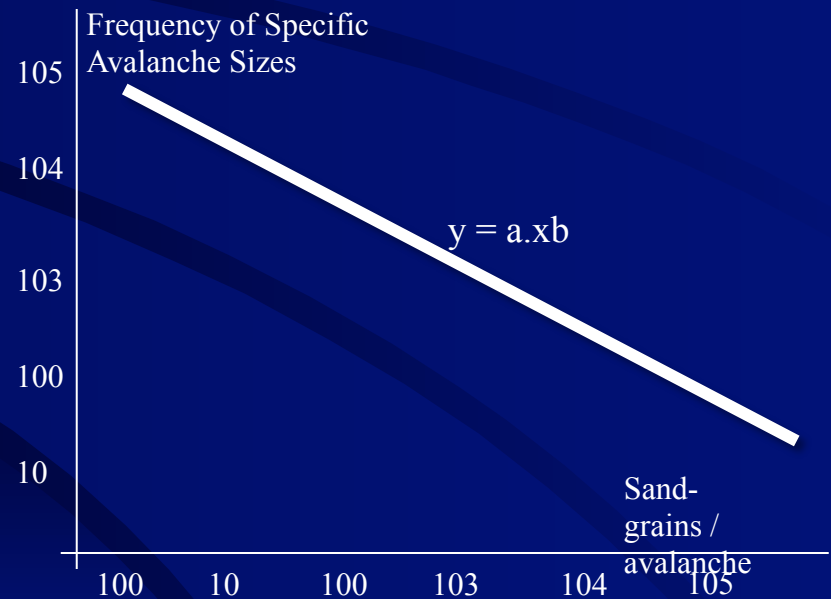
Self-Organized
Criticality

Weak Chaos: Self-organized criticality

- 6 cm plate; drop grains of sand on plate; cone forms
- Cone \rightarrow critical height
- Above critical height; avalanches reduce height
- Height varies above and below critical
- Measure number of grains falling off plate in each avalanche
- Many small avalanches; few large avalanches...
- Log (grains/avalanche) Vs. log (specific avalanche frequency) = straight line...
 $\log y = \log x + C$

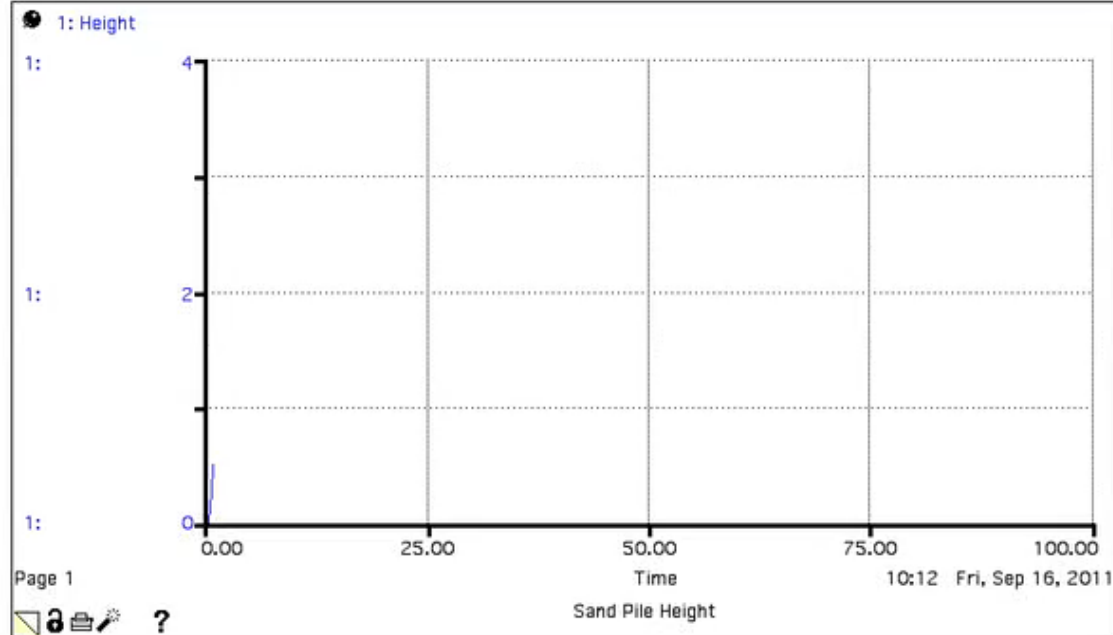
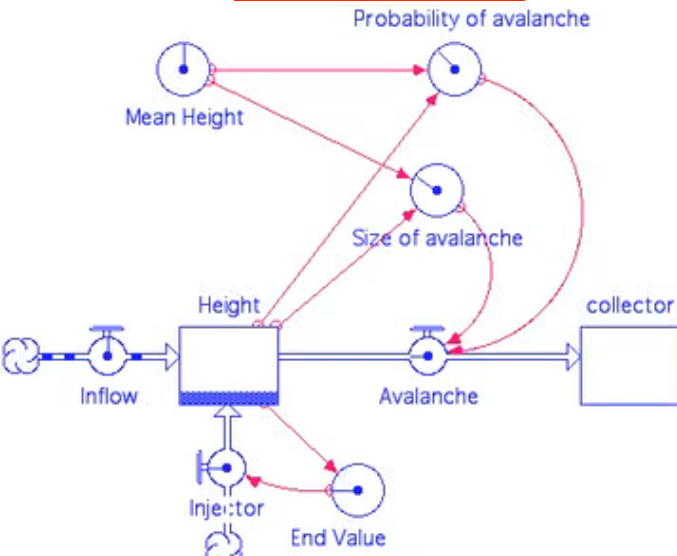


Investigating Earthquakes:
Bak & Chen's Sand Pile

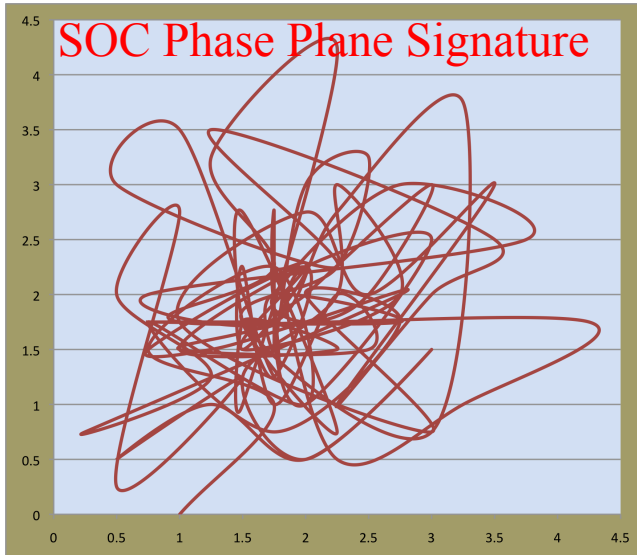


Self-organized Criticality Simulation

Stella™ Model



SOC Phase Plane Signature



Model based around Bak & Chen's sandpile concept, which they used to explore plate tectonic/earthquake patterns.

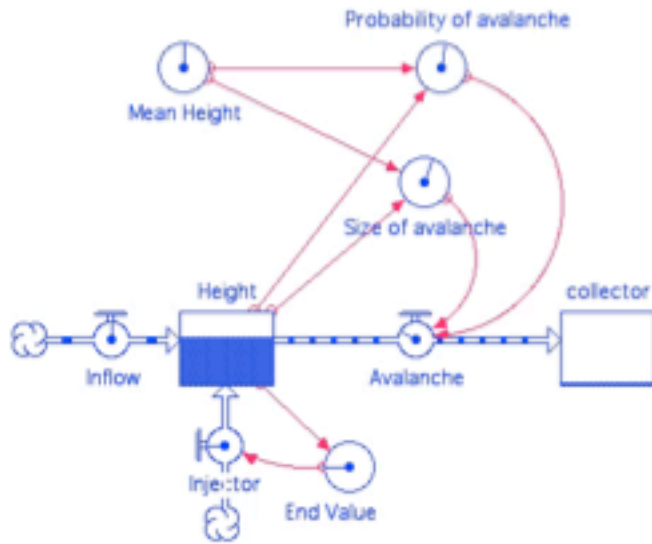
Model gives reasonable facsimile of self-organized criticality.

Graph could represent: Earth seismic readings, earthquakes; size and frequency of meteorites; stock market fluctuations; $1/f$ noise; crime statistics; deaths in conflicts; encephalographs; traffic movements; etc; etc.

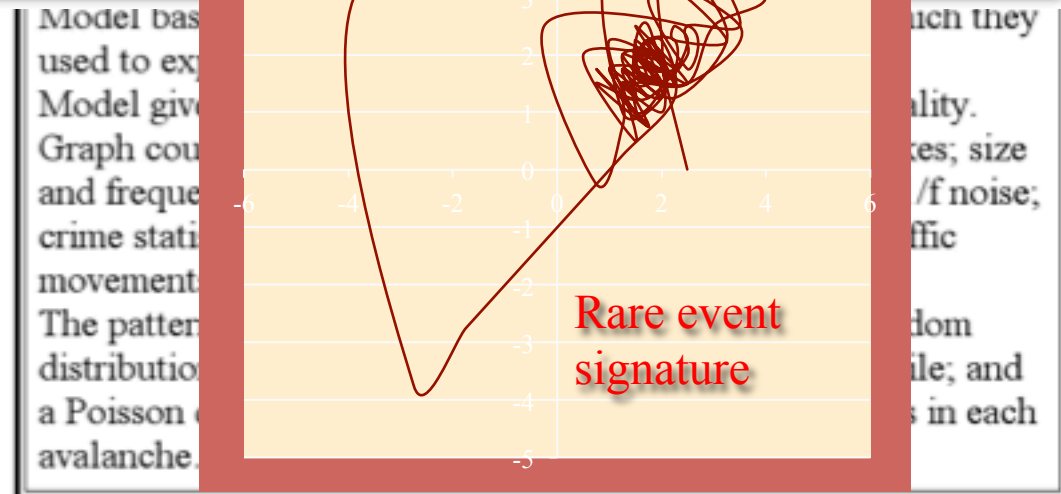
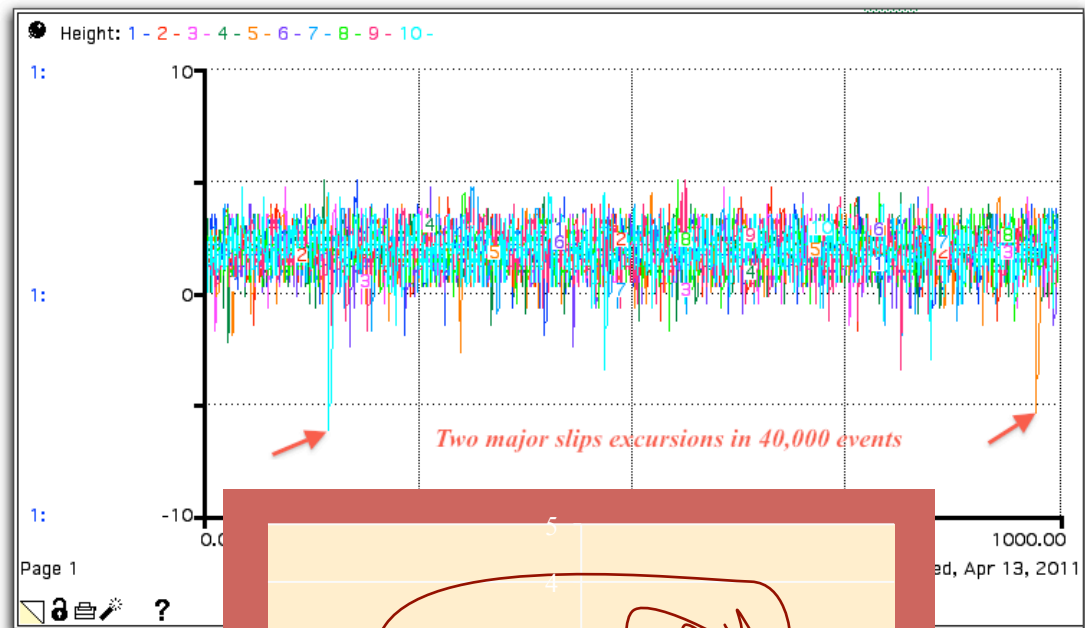
The pattern derives from two distinct distributions: a random distribution representing the height buildup of the sandpile; and a Poisson distribution representing the number of entities in each avalanche...

Self-organized Criticality Simulation

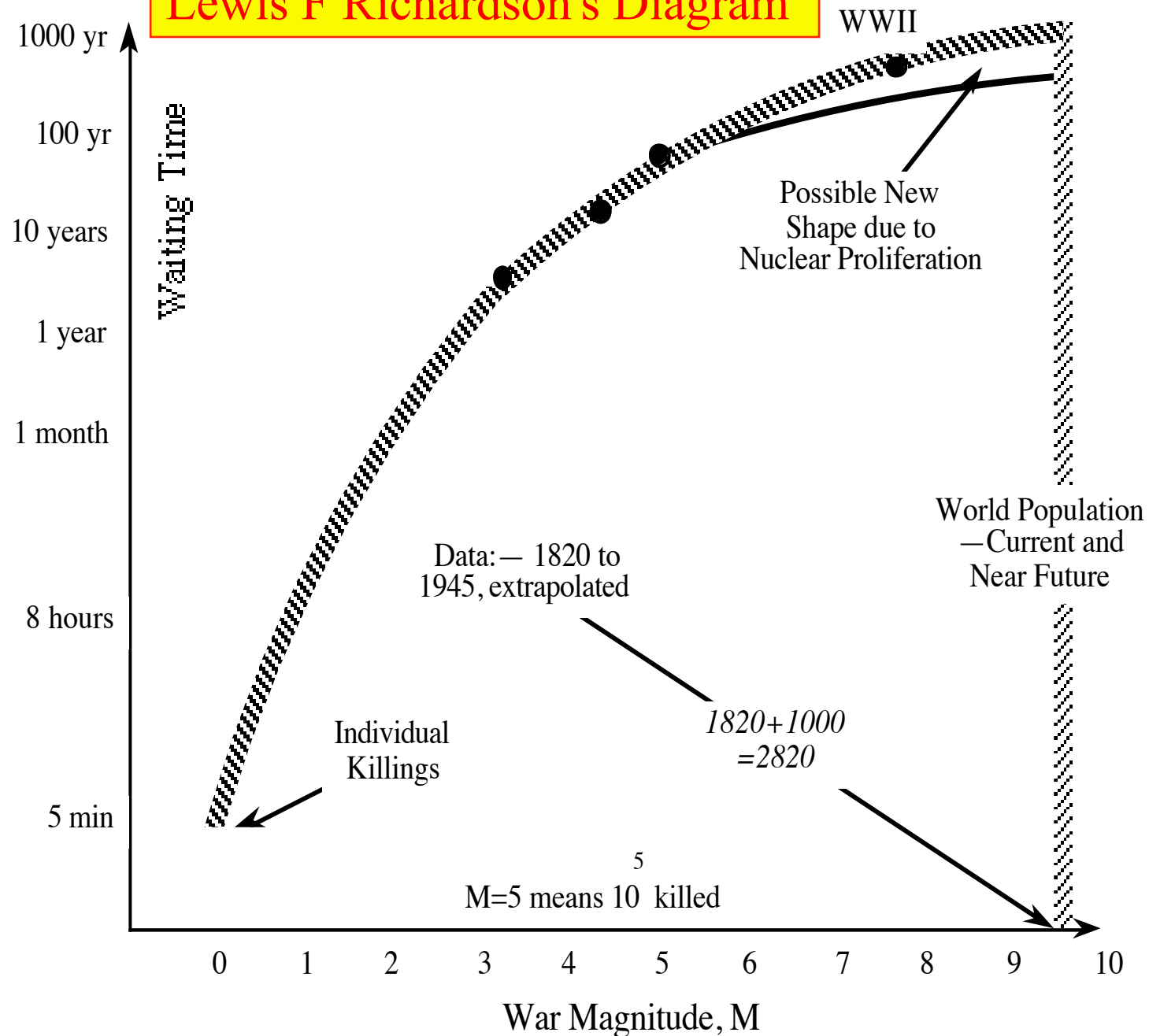
Stella™ Model



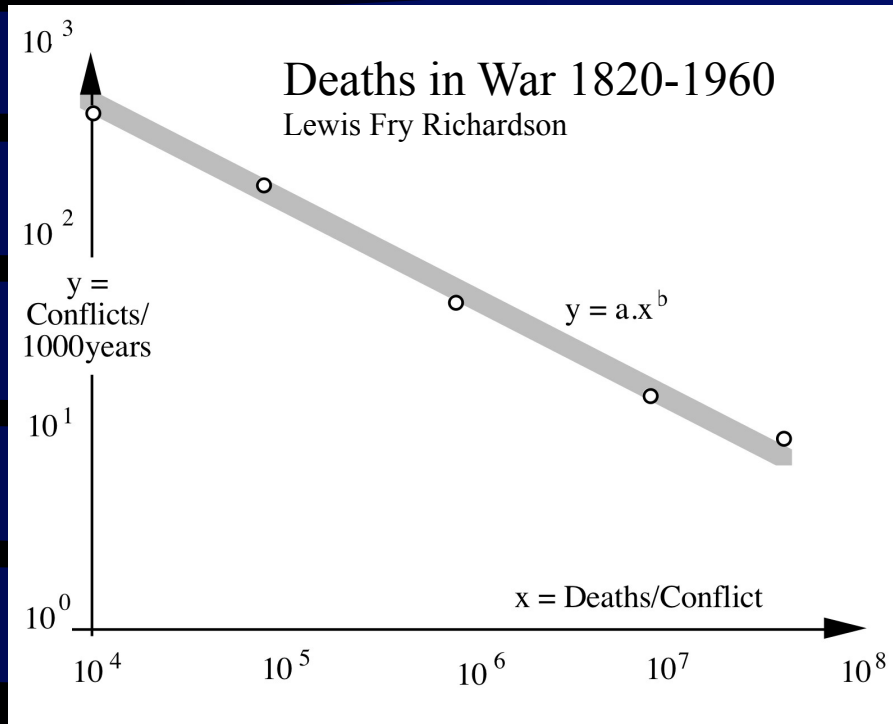
Graph shows rarity of major slippage (result from 10+ runs). Implies that the *occurrence* of such rare events may not be predictable, but their *frequency* of occurrence *is*! ...c.f. Taleb's notion of "Black Swan Events"



Lewis F Richardson's Diagram



Weak Chaos...

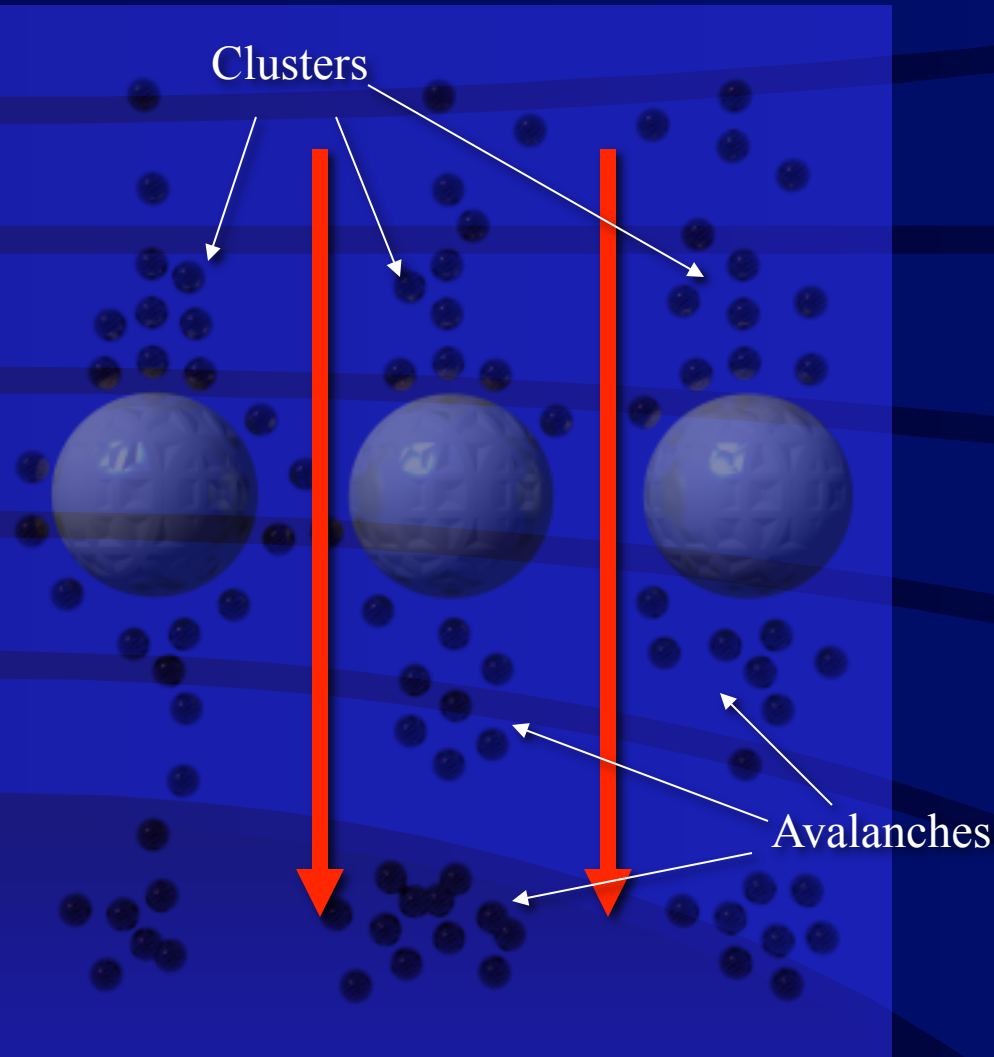


Fractal Pattern/weak chaos arises *widely* in Nature, and in the “affairs of Man.”

Arises where ‘free’ flow is hampered or constricted

- Bak & Chen’s sand pile
 - tectonic plate movement, earthquake patterns
- Weak chaos found widely
 - stock exchange price movements
 - 1/f ‘noise’ in conductors
 - ‘fixed’ ion grid, electron flow
 - distances between cars
 - asteroid size and frequency
 - crime statistics
 - Deaths in War
 - machine gun, tanks, gas, atomic bomb... do not cause deviation from straight line...!

‘Constricted Flow:’ Conceptual Model

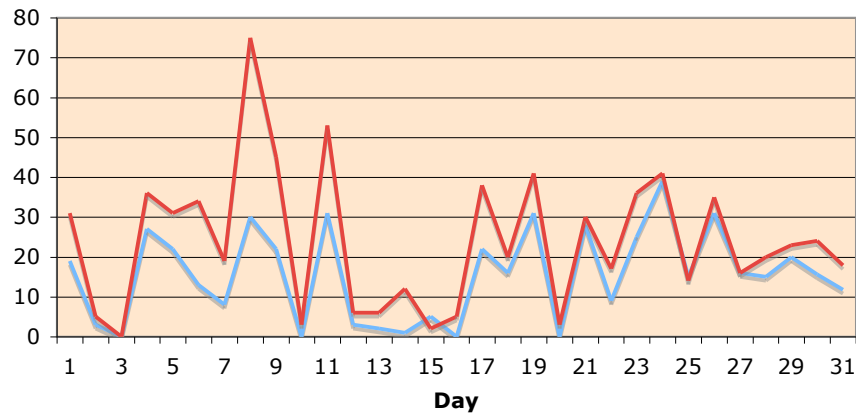


- ‘Marble’ flow is constricted by ‘Golf-balls’
- ‘Marbles’ jostle, cluster up-stream of ‘Golf-balls:’ cluster builds-up ‘pressure’
- Pressure forces release of ‘marbles’ as variously sized avalanches...
- Analogous behavior in many real-world situations
 - Criminals Vs Police
 - Turnstiles/checkouts
 - Economics
 - Turbulence
 - Production; etc., etc.

Compare with ‘sand-pile’ model

Relative Aircraft Losses:
8th August - 5th September

— RAF Losses — German Losses



BoB: on the Edge of Chaos?

- Top chart:
 - Daily aircraft losses
- Bottom chart:
 - Day-to-day variability in aircraft losses...
 - ...is there a hint of a butterfly shape?
- Was the BoB right on the Edge of Chaos?

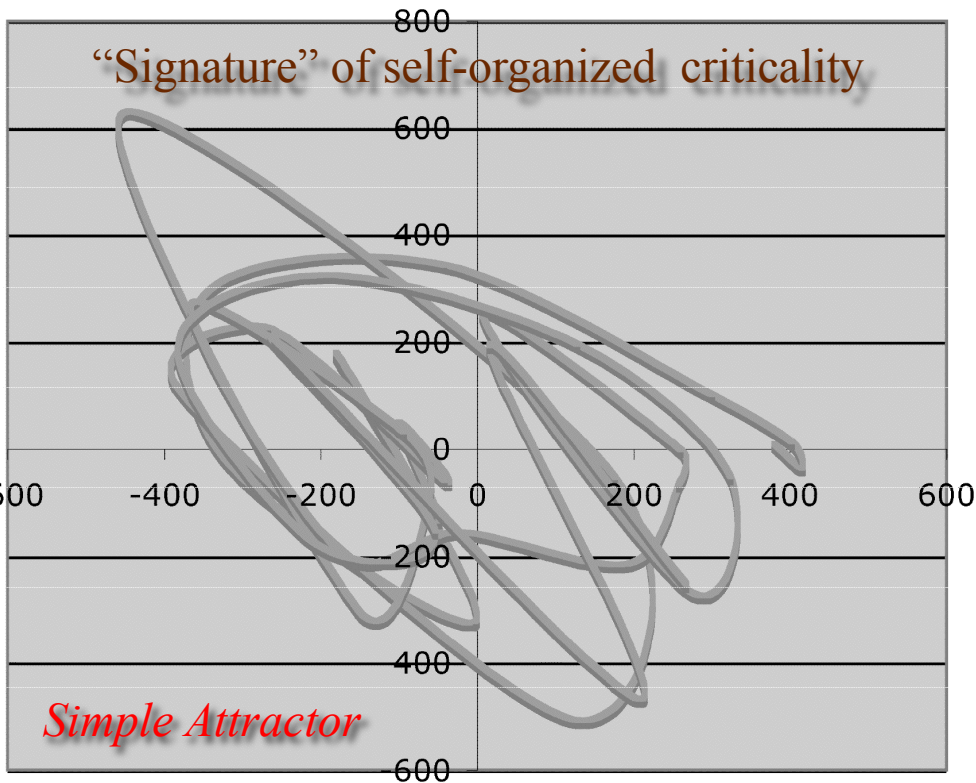
Combined RAF and LW A/C Losses
– Phase Plane Chart



Ancient SoC

- Is there a relationship between Deterministic Chaos and Self-organized Criticality?
- Ancient Egypt depended on annual Nile Inundation for good crops
 - Good inundation - good yield
 - Too high OR too low, poor yield...
- Inundation 'driven' by weather to South - deterministic chaos?
- Population rose during 'good' inundation
- Poor inundation ➡ famine ➡ population fell...

Self-organized Criticality



'Metaphor for the planet's impending problems'

Stele showing effects of famine in the Nile Valley ⇒ *Louvre* 



Summary

- Complexity *gives* life: is a *fact* of life!
- Systems science seeks to understand, manage, and *exploit* complexity – not to *avoid* it!
- *Embracing* complexity...
 - ..offers capability, intelligence, *flex- adapt*-ability
 - self-replication/healing/repair, power-density...
- “Nature’s systems engineering:” took 530My to evolve present efficient, intelligent organisms...
- Perhaps SE should adopt an evolutionary, *biological* paradigm, rather than its current *mechanistic* one...
 - but *evolve* solutions to problems rather *more quickly!!* We may not have much time left!