AN INTRODUCTION TO
SYSTEMS THINKING

Derek Hitchins

What is *"Systems Thinking?"*

- Well, simply thinking about the world around us, about situations and problems, and "how things (might/could/should/do) work:"
  - As open, interacting systems, networks of systems and hierarchies of systems…
  - …of material or immaterial things
- Surprisingly revealing!
- Thinking about emergent properties, capabilities and *behaviours*, how they come about, what benefit they might be, what problems they might create…
- Unravelling the inner workings of complex systems… esp. non-linear—so, real world!

What about the *"Systems" in Systems Thinking*

- But, first, what is a system?
  - Many definitions, try:
  - *A complex organized whole of interacting material or immaterial things…*
    - ***complex—organized—whole—interacting***
  - So, a script, car with driver, person, organization, solar system
  - Systems exist, function, behave, show emergent properties…
    - Properties of the whole that cannot be exclusively attributed to any of the parts
      - "the whole is greater than the sum of the parts, the part is greater than a fraction of the whole" Aristotle, *Composition Laws*
    - *…cornerstone of systems thinking!*

What about the *"Systems" in Systems Thinking*

- There are different "aspects" of systems
  - Open/closed, hard/soft
  - Self-organized, man-made…
- Closed system has an impenetrable boundary—a theoretical concept used e.g. in thermodynamics
- A hard system is one made from material things, technology, whereas…
- ".. soft" implies human and immaterial, e.g. organizations, human activity systems (HASs), teams…
  - may not always do the same thing, perform the same way, as in "human…"
- 'Self-organized' implies naturally-occurring
  - Solar system, flora and fauna, ecosystems, you and me…
  - So, is an organization of people hard, soft or self-organizing?
- Is a car without a driver a system?
  - Or an artefact, a tool to serve a human's purpose?
- Or is a *car plus driver* a system?
  - This combination is autonomous and purposeful, so…
  - .. could it be a sociotechnical system?

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

- Evident parallel between self-organizing, natural systems (left) and…
- Corresponding man-made systems at right

1. *Tissues* formed from emergent properties (EPs)of groups of *cells*.
2. *Organs* formed from EPs of groups of *tissues*
3. *Organ systems* formed from EPs of groups of *organs*
4. *Organism* formed from EPs of groups of *organ systems*…

- Manmade systems correspond…
- Suggests biological metaphor for systems engineering…

What about the *"Systems" in Systems Thinking*

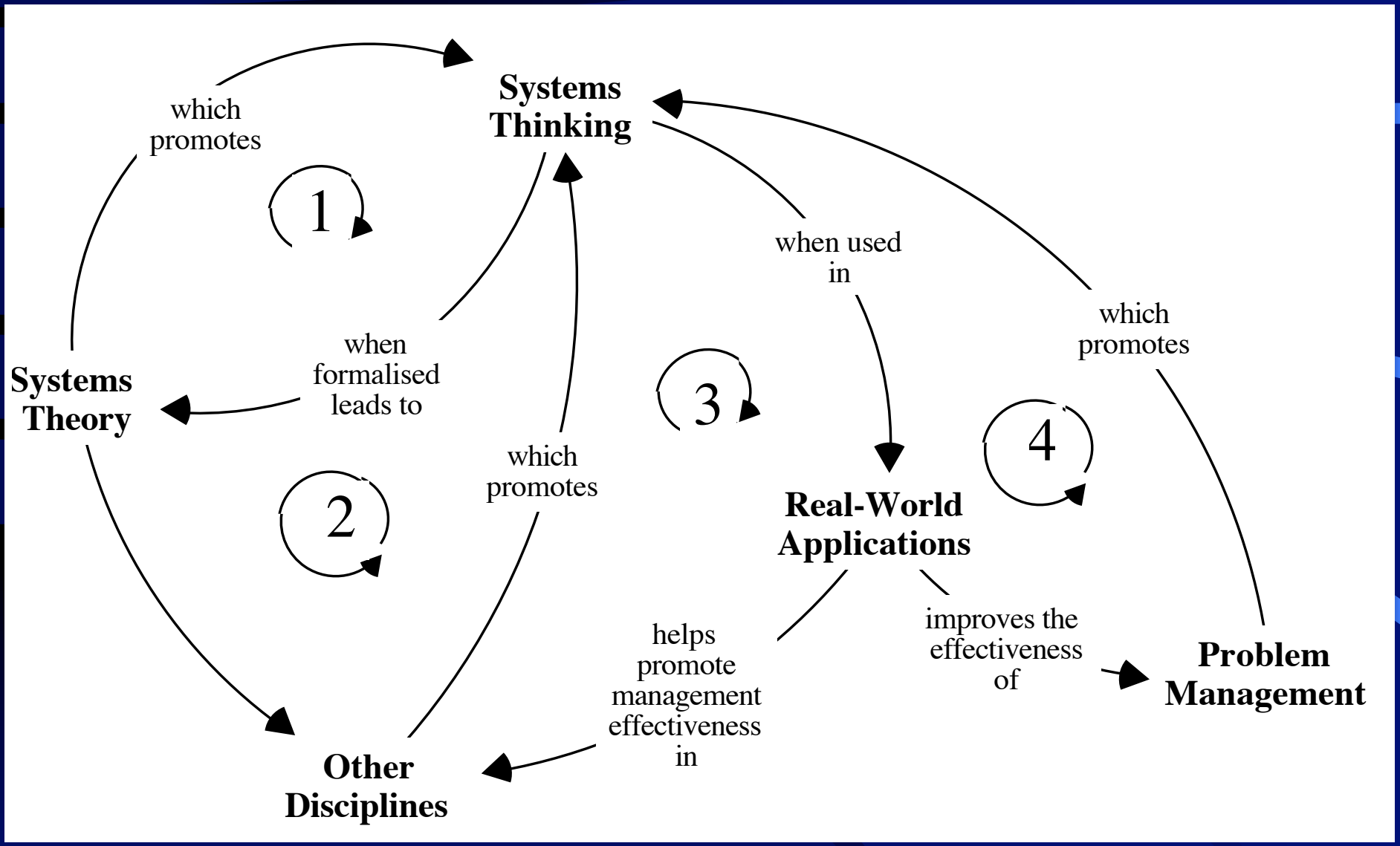
- Systems are generally open, exchanging *energy, information and substance* with other, similarly open, systems
  - so, *a continual flux* through the system
- Systems adapt to the interchange…
- So, systems form networks of interacting systems—systems form hierarchies of systems within systems within systems…
  - .. and all dynamic, shifting, shimmering…

The Point/Value of Systems Thinking?

- Understand complex/complicated things/ situations/problems:
  - Hence explain emergence, behaviour, resolve problematic situations
- Establish systems design requirements:
  - Cooperation, coordination, complementation, concinnity, control—of and between subsystems
  - Flux of energy, information, substance…
- Explain counter-intuitive behaviour, unintended consequences…
  - with a view to avoiding / exploiting!
- Get to the *heart* of the matter!

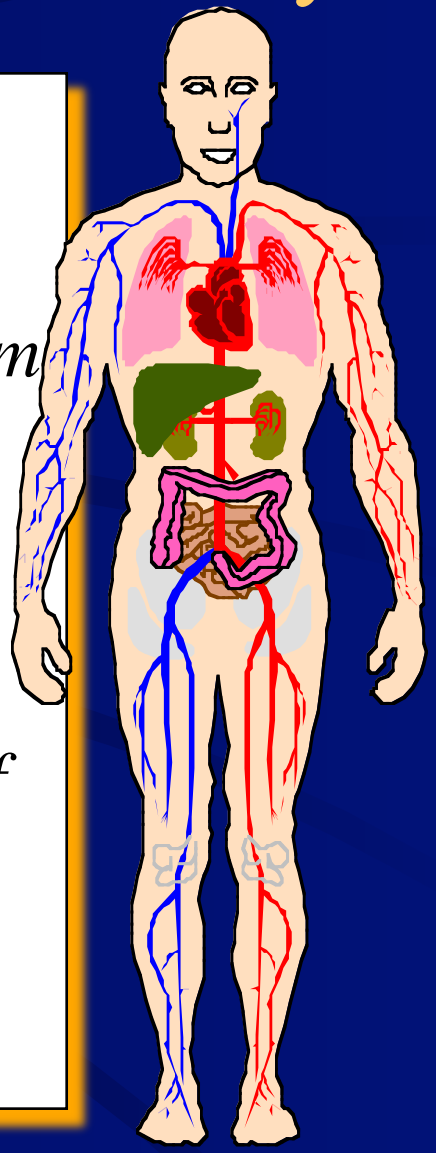
The Point/Value of Systems Thinking?

Academic viewpoint…



The First System Principle and its Corollary

- **First Principle of Systems: —**
  - *The properties, capabilities and behaviours of a system derive both from its parts **and** from the interactions between those parts.*
- **Corollary to the First Principle**
  - *Altering the properties or behaviour of any of the parts, or any of their interactions, affects other parts, the whole system and interacting systems*



How to go about systems thinking…

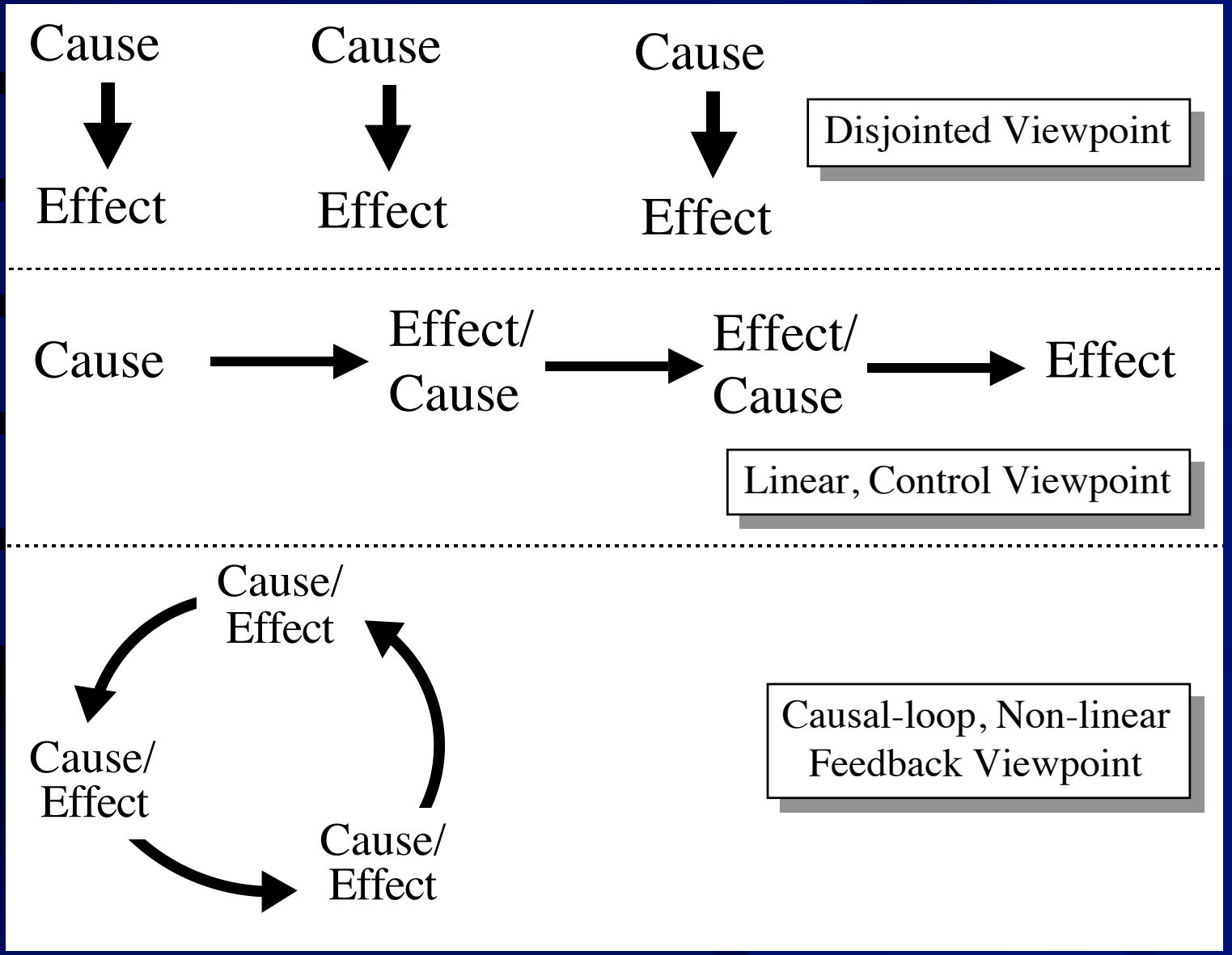
METHODS AND METHODOLOGIES

CAUSAL LOOP MODELLING

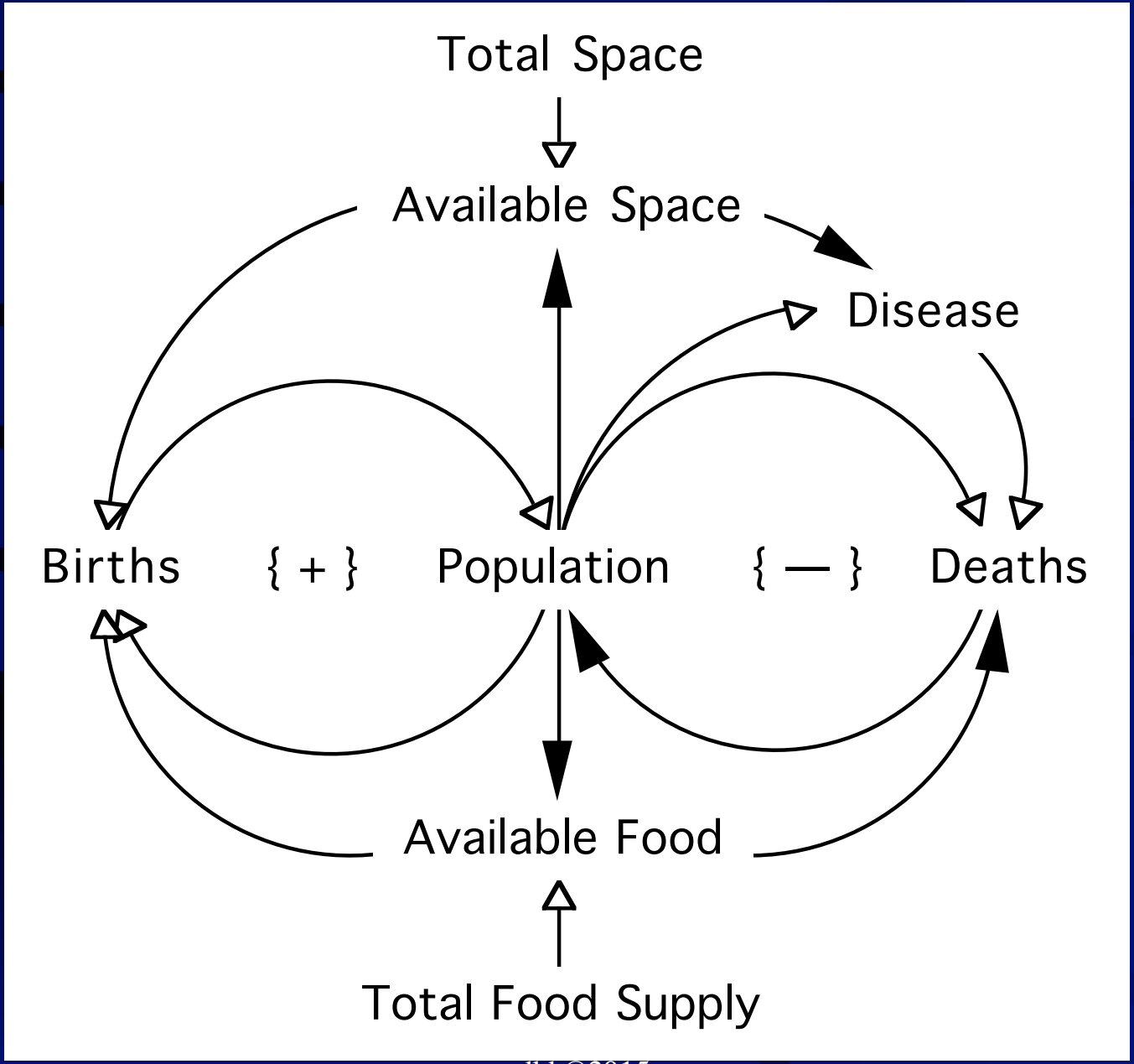
…key method for "systems thinking:"

formulating, sharing, improving, completing!

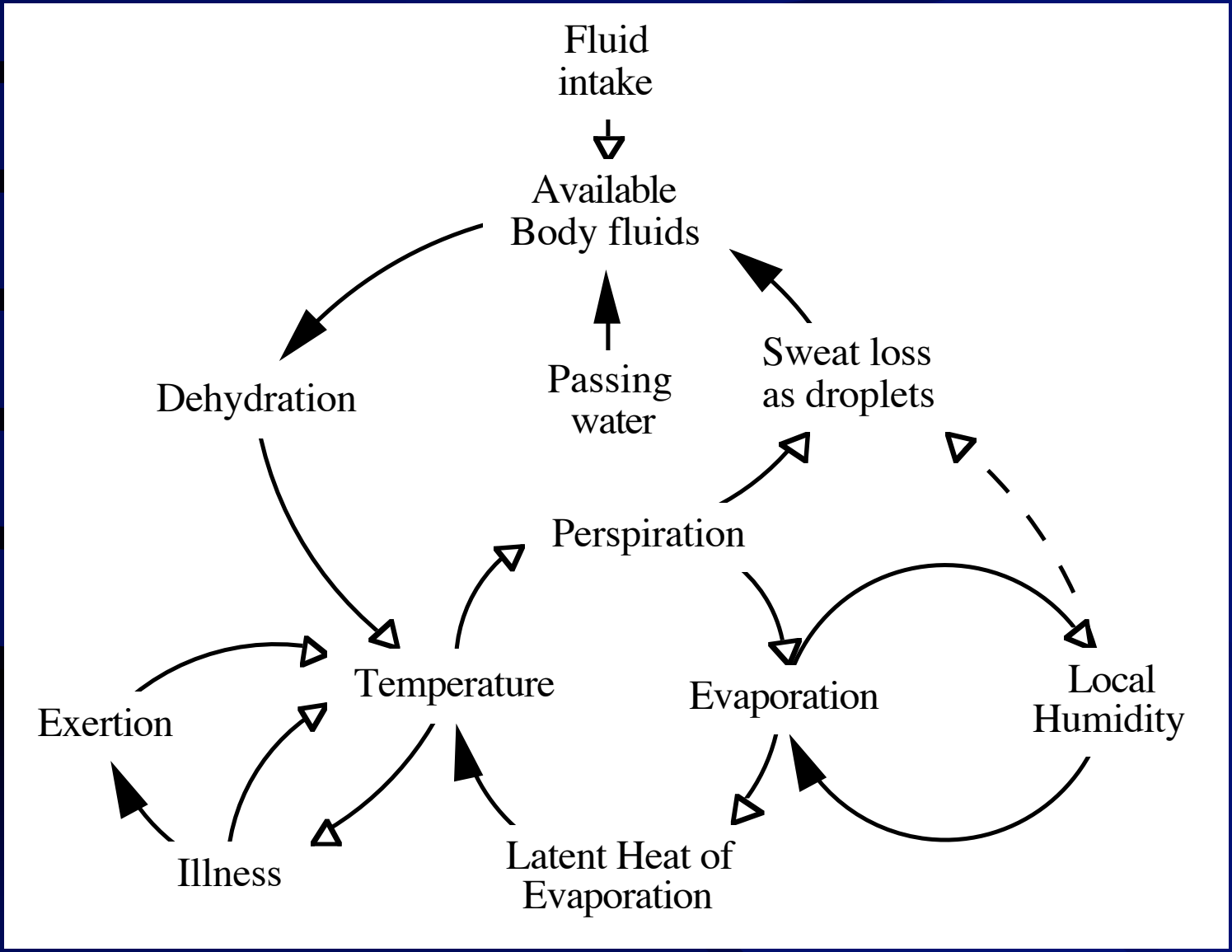
Cause and Effect

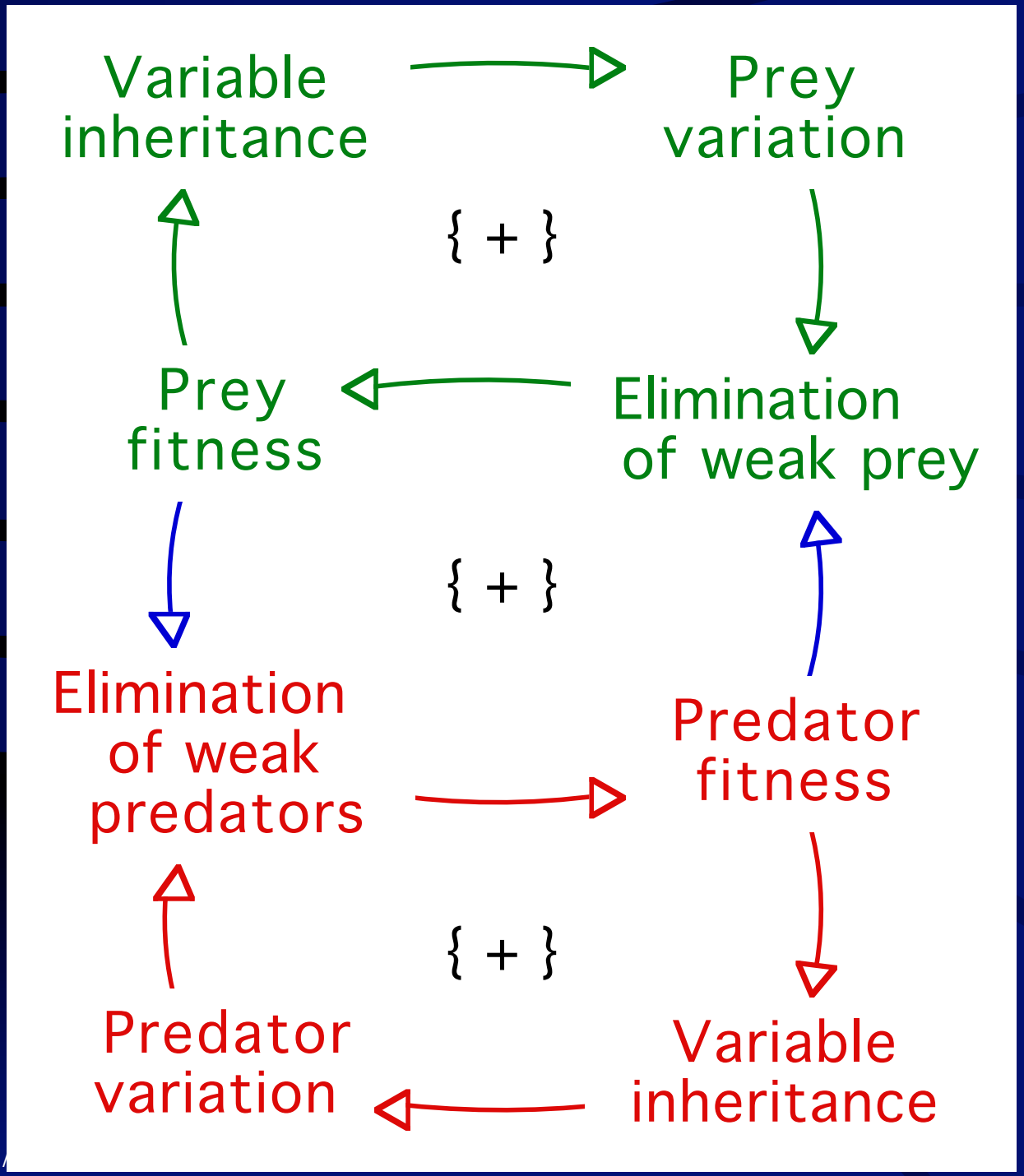


Systems Thinking – *Resources*



CLM of Body Temperature Regulation

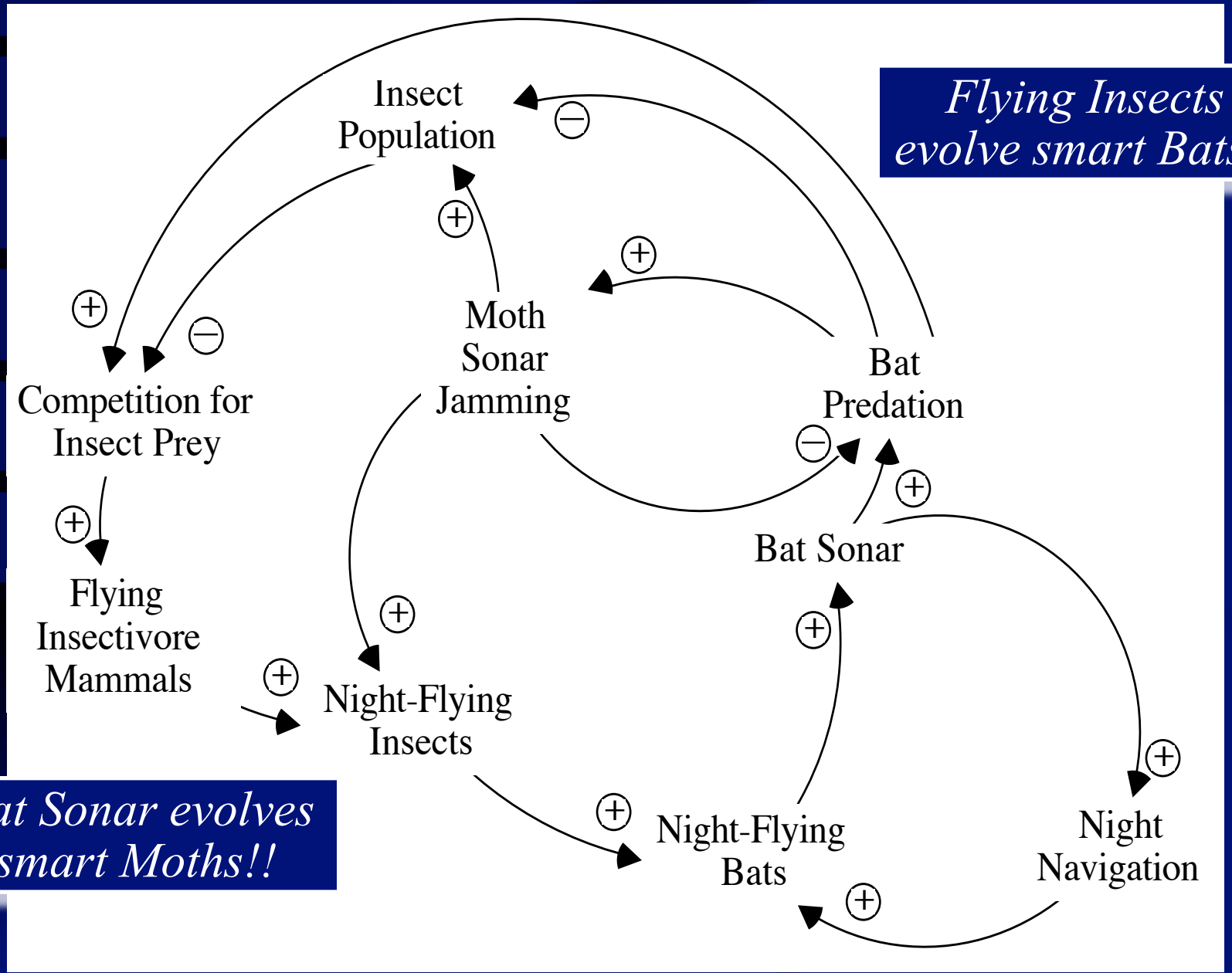


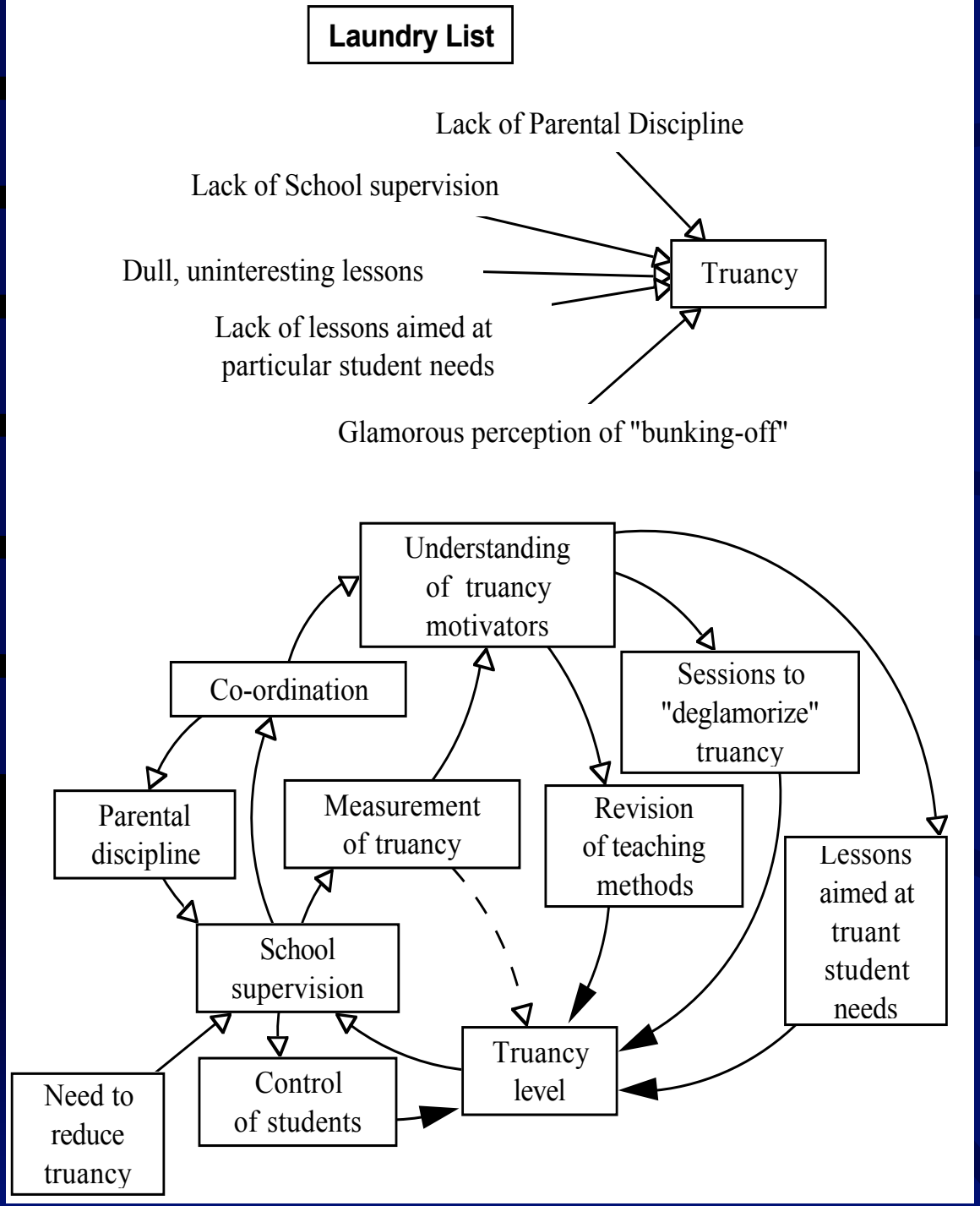


Darwin

Survival of the Fittest

Nature's Co-evolution – Moths & Bats

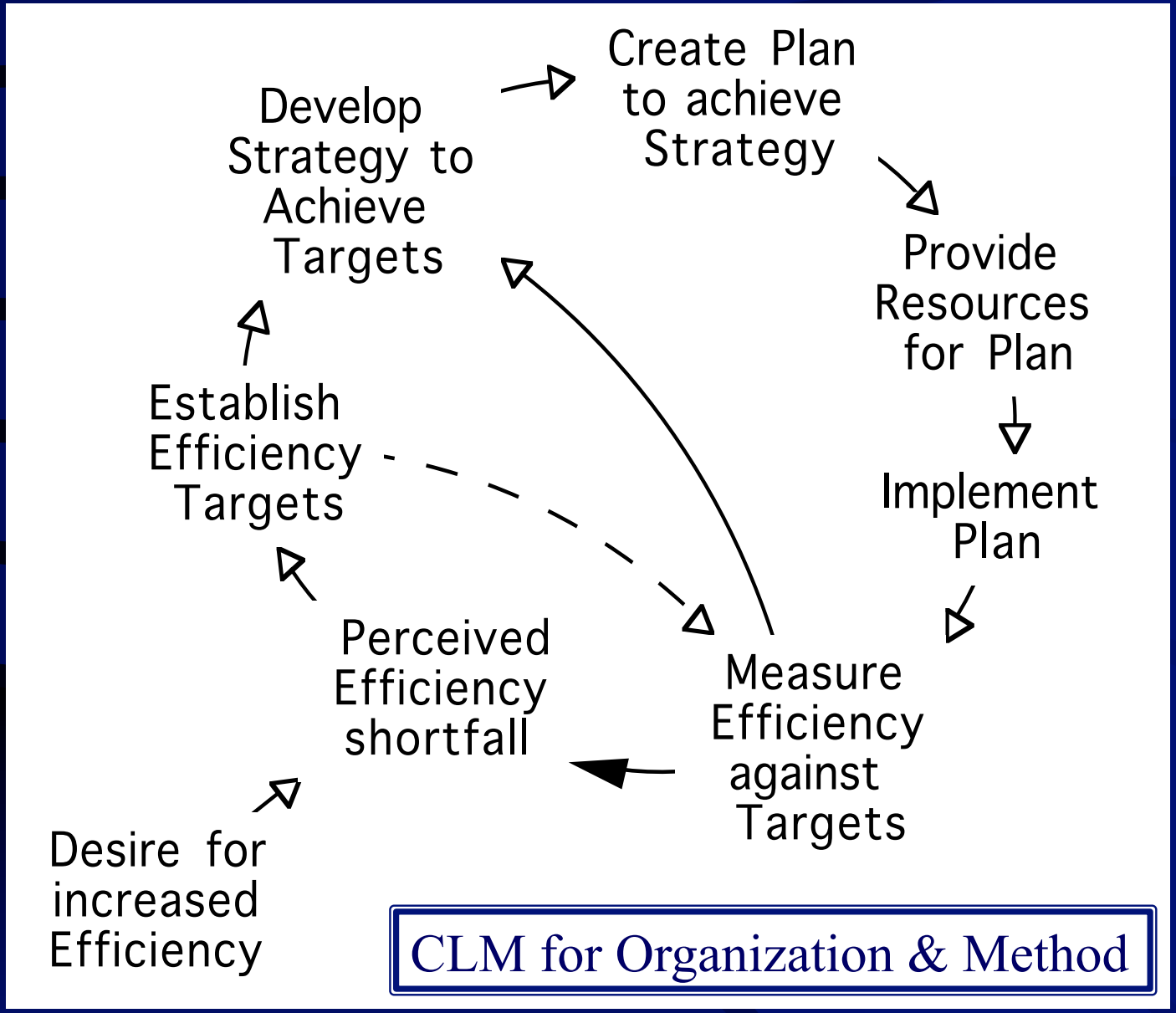


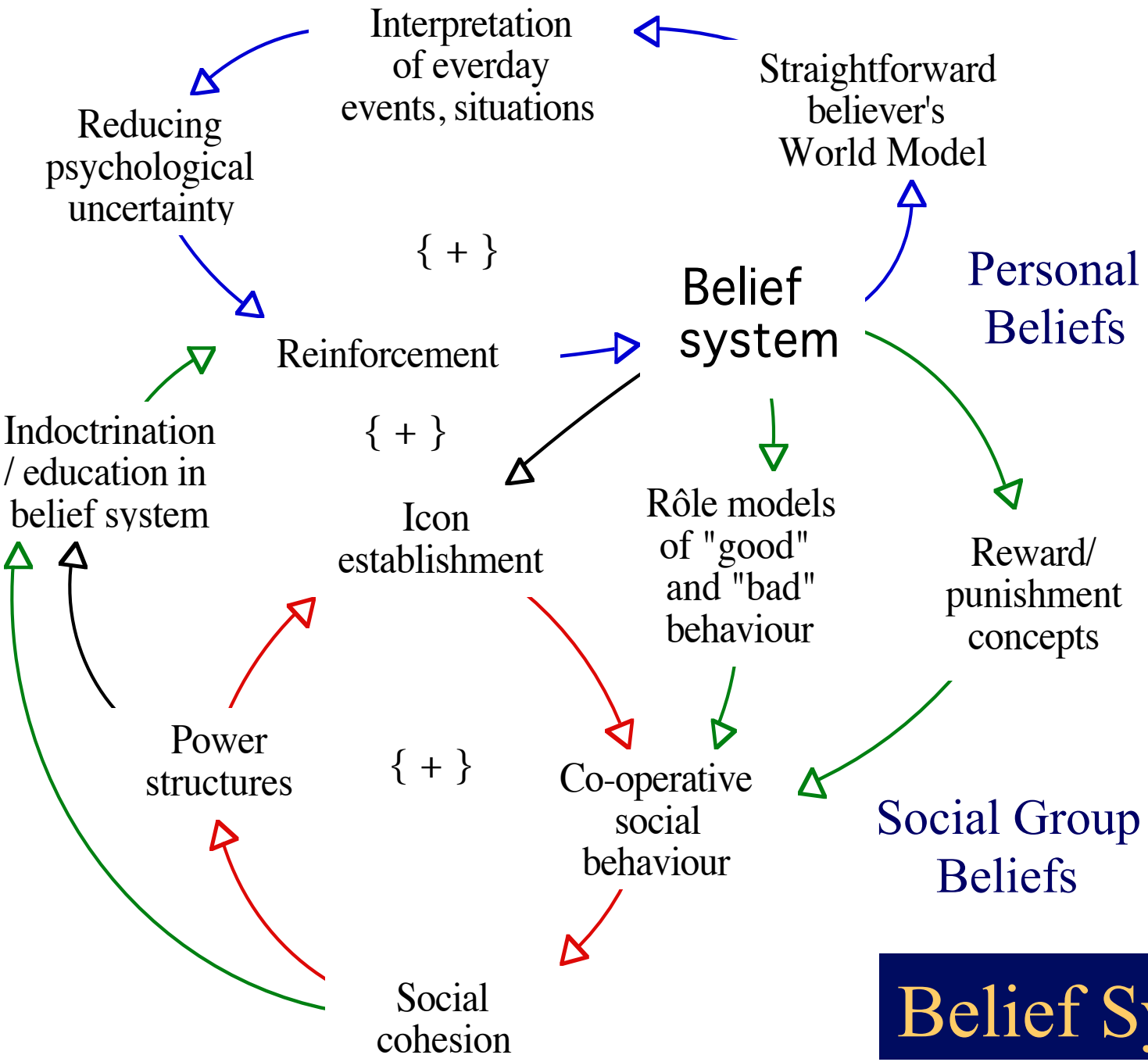


Truancy

- CLM developed to explore possible solution to school truancy.
- A model of "how it might work…"

Efficiency


Create Plan to achieve Strategy
Provide Resources for Plan
Implement Plan
Measure Efficiency against Targets
Perceived Efficiency shortfall
Desire for increased Efficiency
Establish Efficiency Targets
Develop Strategy to Achieve Targets
CLM for Organization & Method



Belief Systems

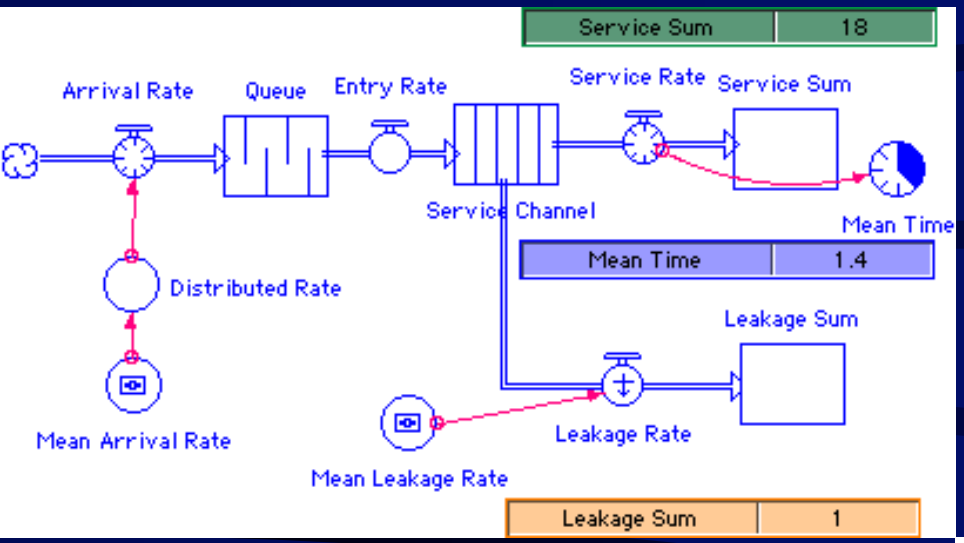
Systems Thinking – *Queues*

- Simplified and generalized…
  - No mention of any technology…
  - No mention of who or what is queuing…
- Concerned only with:
  - What a queue *is*
  - Different ways in which queues can *behave*
  - *Outcome* from differing behaviours
- So, systems thinking about queues applicable to:
  - Supermarket checkout, Wimbledon…
  - Serial data highways, data links…
  - …anything where queues form…

Systems Thinking – *Queues*

- Traditionally used mathematics:
  - λ mean arrival rate of items in the queue
    - (exponential distribution)
  - μ mean rate of items being serviced
    - (exponential distribution)
  - Mean channel utilization = $\lambda/\mu = \rho$
- Then, number in Q = $\rho/(1-\rho)$
  - E.g. if $\rho = 0.5$ then Q contains 1 item on average
- And, number in Q *and being serviced* is $1/(1-\rho)$
  - E.g. if ρ is 0.5 then = *number in system* is 2.
- But, when $\lambda = \mu$, then $\rho = 1$, and $Q = \infty$
- Maths for multiple Qs can get tricky…

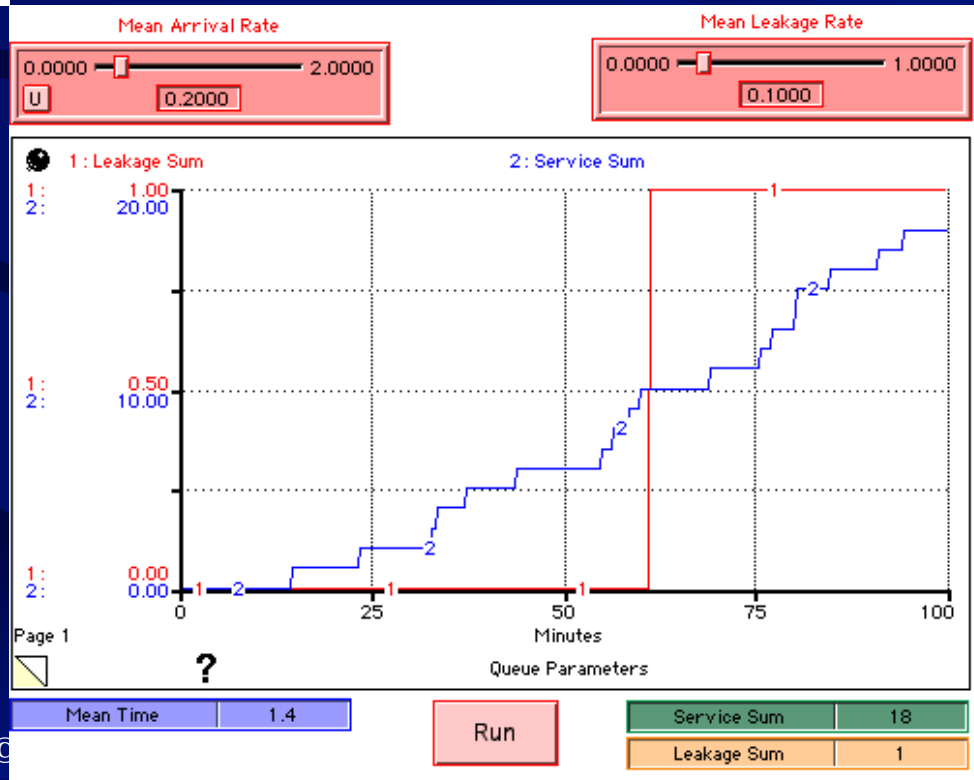
Systems Thinking with STELLA™ – *Queues*



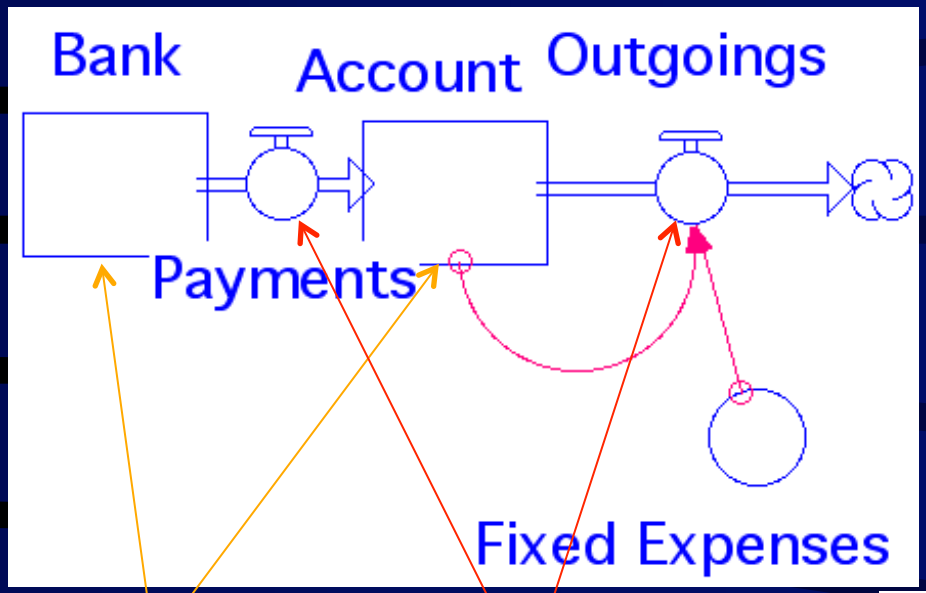
- Simple FIFO Queue, but with "leakage" from "conveyer:"
  - E.g. discard faulty part…
- Poisson distribution to represent arrivals distributed around mean arrival rate, λ

- Control panel at right:
  - Vary λ and Mean Leakage Rate

  ➔Mean Service Rate, μ
- Graphs for Service & Leakage Sums
  - Graph for Mean Time end-to-end.
  - Graph for number in conveyer
- Experiment with various queuing parameters and many runs.
- Hence build models of serial / parallel queues for more complex applications…



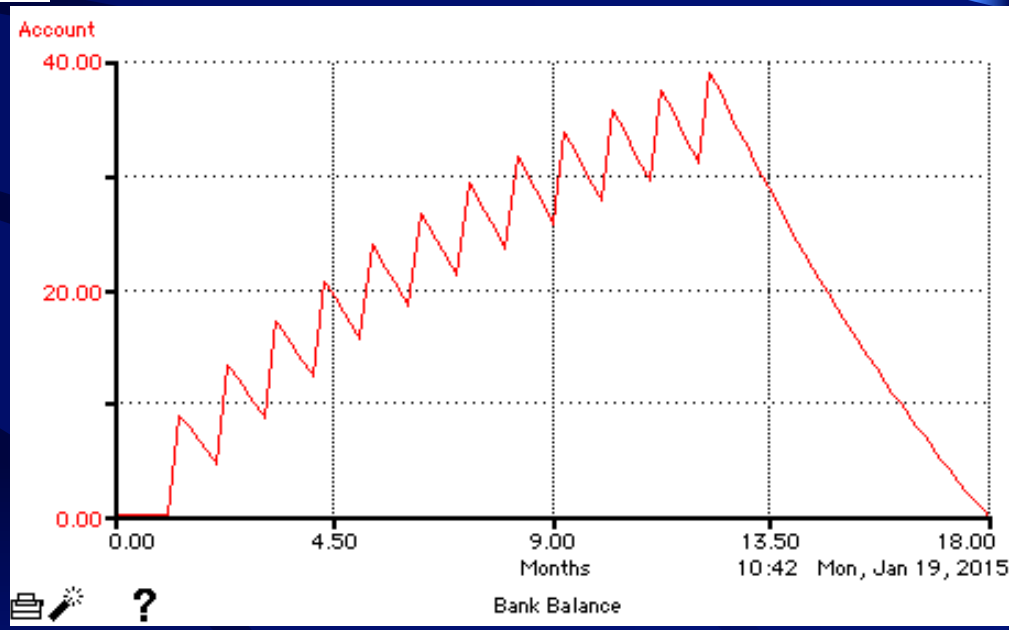
System Dynamics…



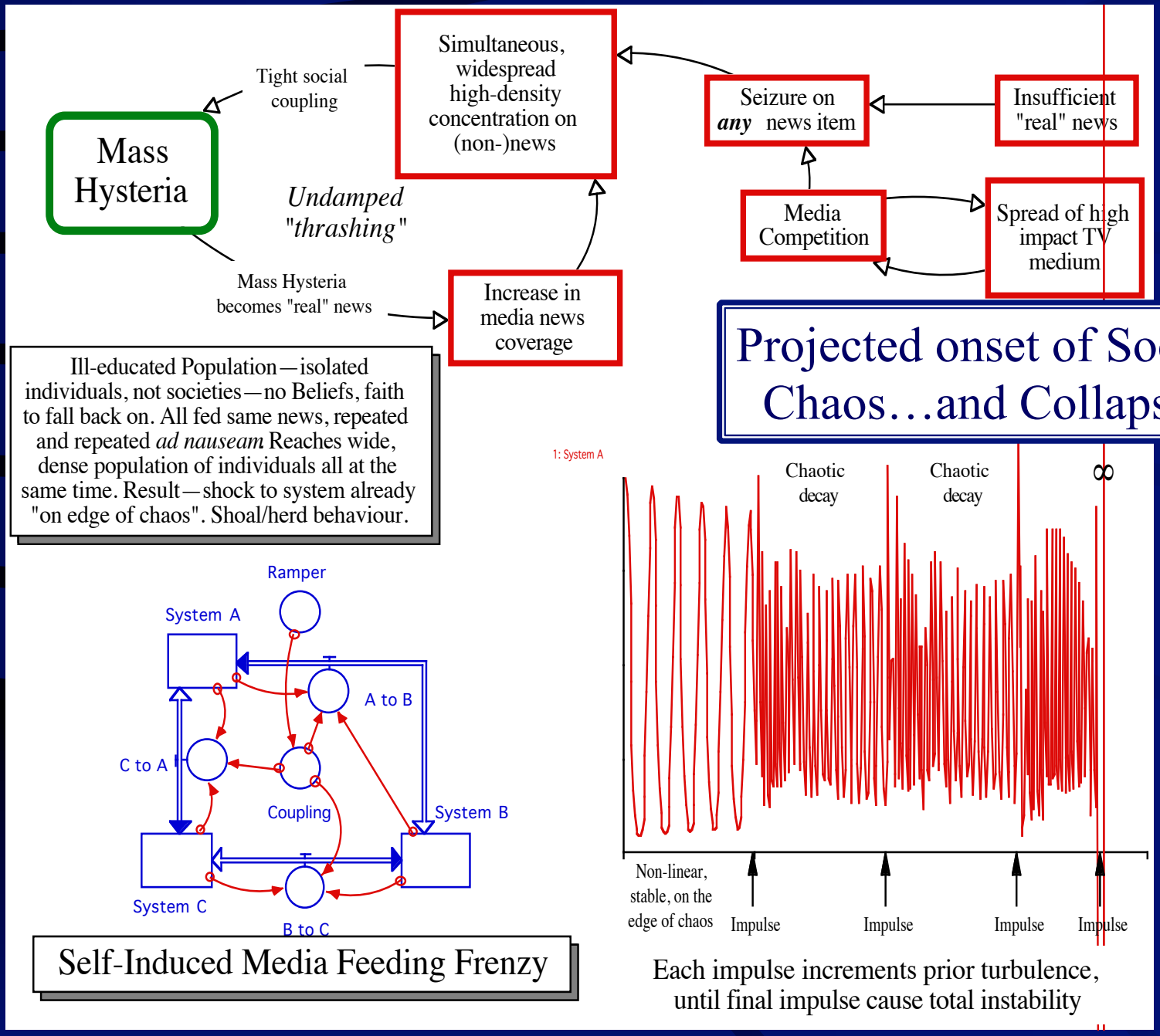
- …using STELLA™
  - Systems Thinking Environment and Learning Laboratory Approach
  - …says it all!

Reservoir

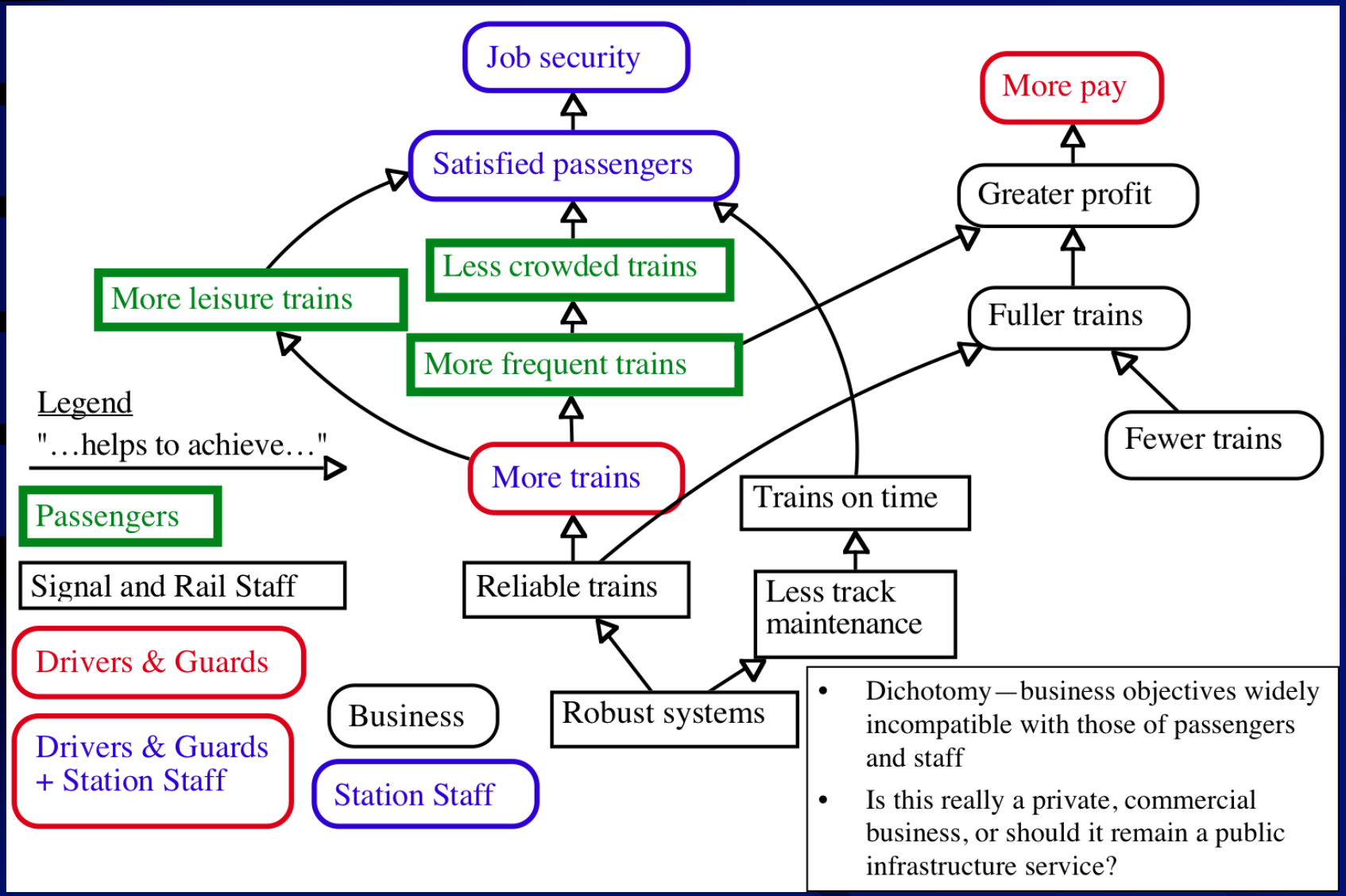
Tap
(flow control)



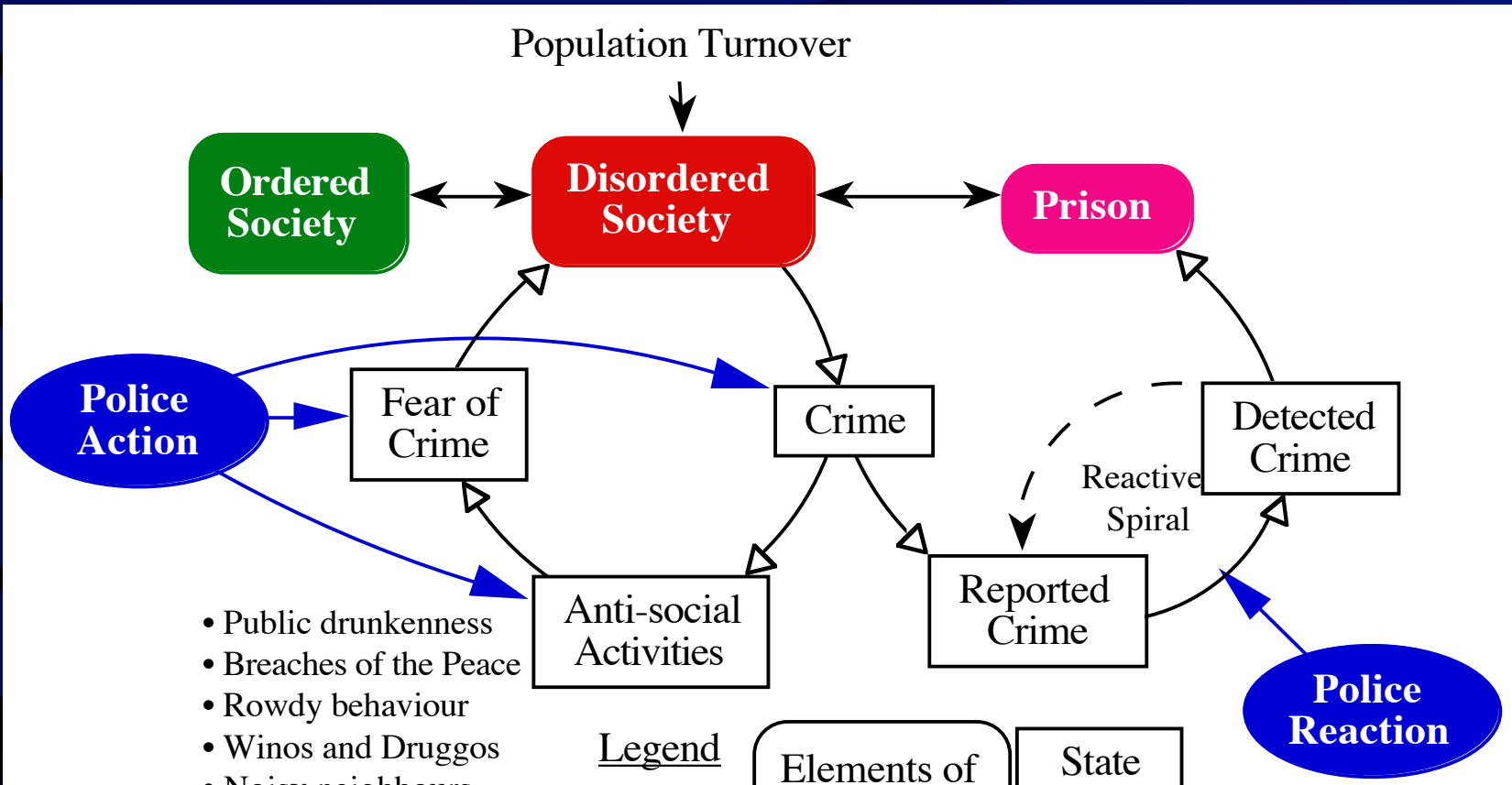
- Broke! …got a job!
- 12 equal end-of-monthly payments,
- Fixed monthly outgoings.
- Broke again(!) in 18 months!


Mass Hysteria
Tight social coupling
Simultaneous, widespread high-density concentration on (non-)news
Seizure on *any* news item
Insufficient "real" news
Media Competition
Spread of high impact TV medium
Undamped "thrashing"
Mass Hysteria becomes "real" news
Increase in media news coverage
Ill-educated Population—isolated individuals, not societies—no Beliefs, faith to fall back on. All fed same news, repeated and repeated *ad nauseam* Reaches wide, dense population of individuals all at the same time. Result—shock to system already "on edge of chaos". Shoal/herd behaviour.
Projected onset of Social Chaos…and Collapse!
1: System A
Chaotic decay
Chaotic decay
∞
Non-linear, stable, on the edge of chaos
Impulse
Impulse
Impulse
Impulse
Ramper
System A
A to B
C to A
Coupling
System B
System C
B to C
Self-Induced Media Feeding Frenzy
Each impulse increments prior turbulence, until final impulse cause total instability

Interpretive Structural Modelling: Railways–Stakeholder Analysis!



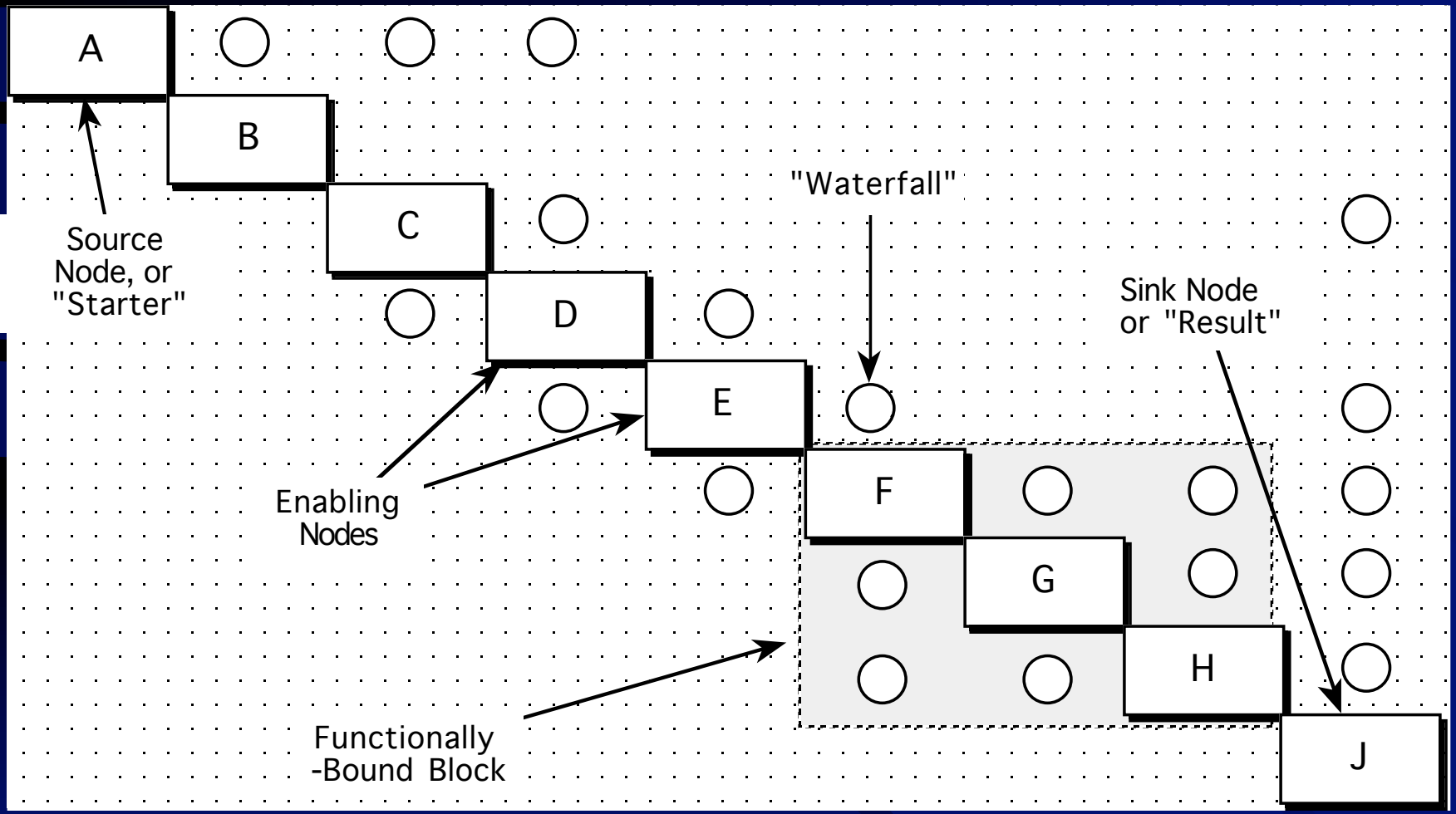
Modern Policing



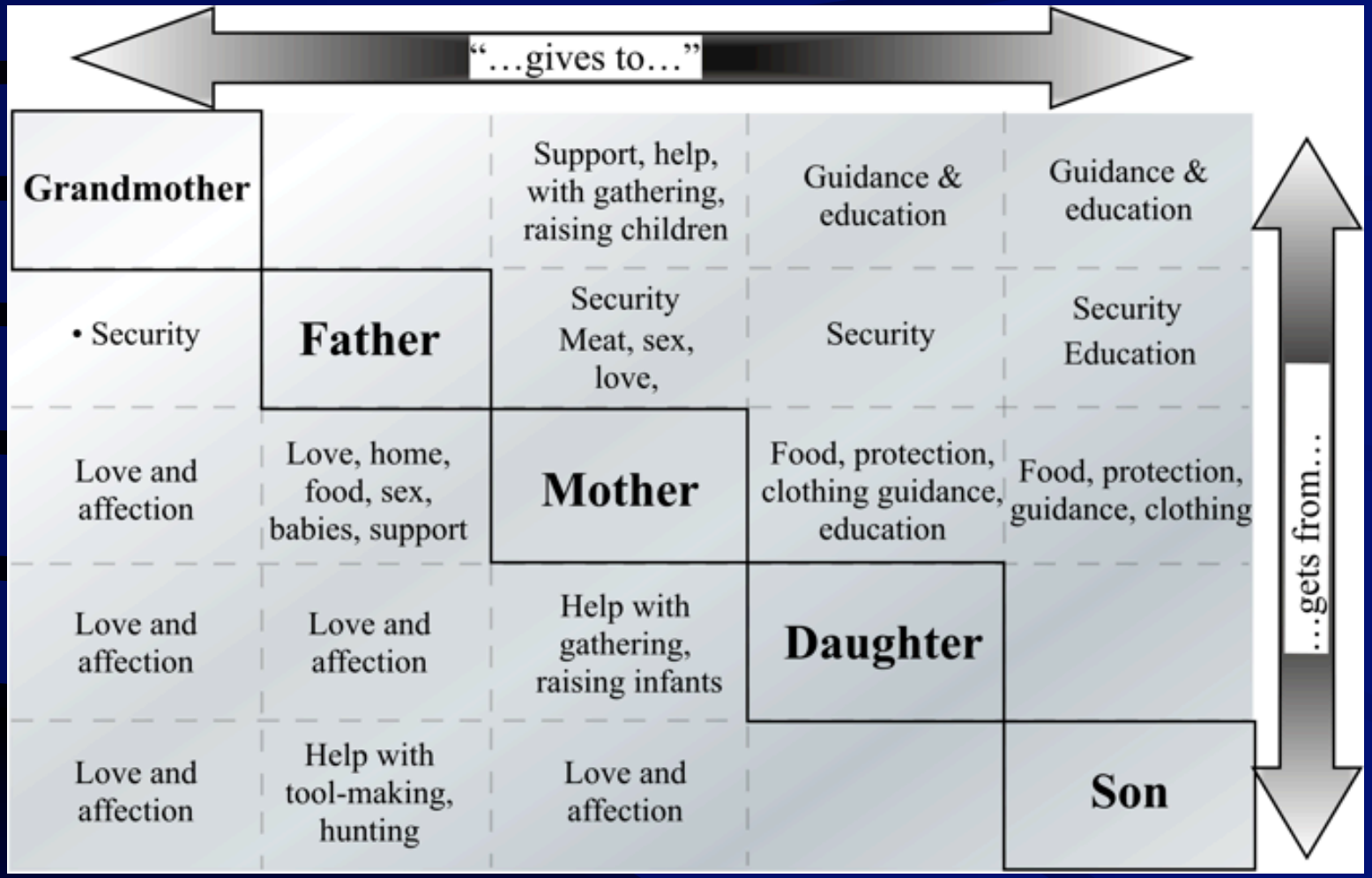
$$\text{Disordered Proportion, } p = \frac{\text{Disordered Society}}{\text{Ordered Society} + \text{Disordered Society}}$$

N2 Chart Interface Patterns…

- Leading diagonal shows *internal* functions/subsystems of one system…
- Circles represent interfaces; border represents permeable boundary
- Whole represents functional architecture of system-in-context



Example N2 Chart…Hunter-Gatherer Family



- Overview of whole system of interacting (sub)systems… shows "how it works as a whole, how they work together, cooperate…to create secure family home."

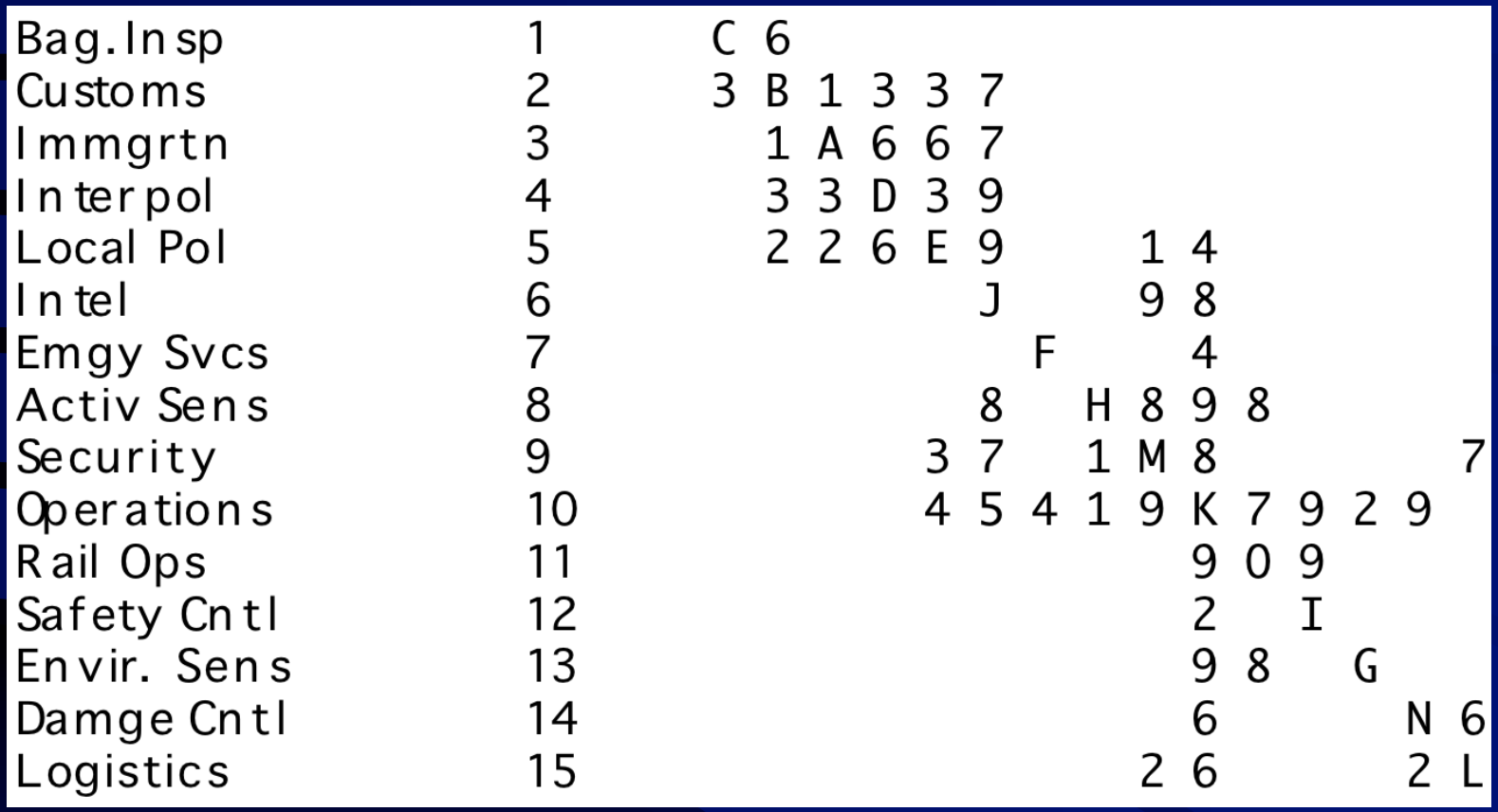
Unclustered N2 Chart

- Channel Tunnel N2 Chart for notional Crisis Management System (1988)
- Direct readout from CADRAT© Tool

Damge Cntl	1	N								6					6
Interpol	2		D			3				9		3	3			
Activ Sens	3			H					8	8					8	9
Envir. Sens	4				G				8							9
Customs	5		3			B	3			7		1	3			
Bag.Insp	6					6	C									
Safety Cntl	7							I								2
Rail Ops	8							9	0							9
Intel	9									J					9	8
Logistics	10	2									L				2	6
Immgrtn	11		6			1				7		A	6			
Local Pol	12		6			2				9		2	E		1	4
Emgy Svcs	13													F		4
Security	14			1						7	7		3		M	8
Operations	15	9		1	2			9	7	5			4	4	9	K

Clustered N2 Chart

- Minimized configuration entropy – reveals functionally bound blocks (candidate subsystems) and Operational Node at Operations, 10-K

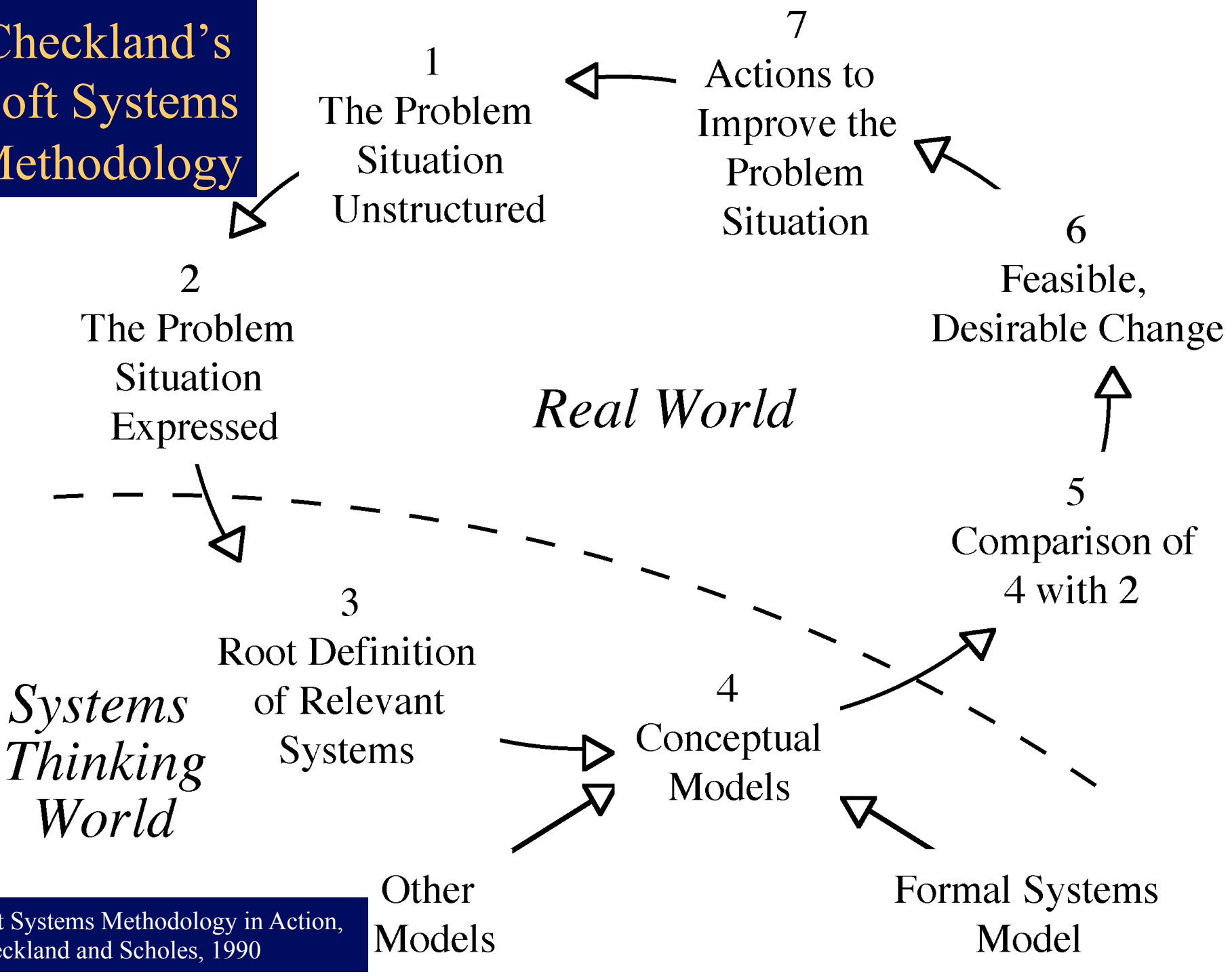


Clustering method employed genetic algorithm to "tease out" optimum configuration, revealing architecture

A few of a wide variety of…

METHODOLOGIES…

Checkland's Soft Systems Methodology



Soft Systems Methodology in Action, Checkland and Scholes, 1990

Checkland's SSM

- SSM: built around seven-stage model. Analyst addresses problem situation from two perspectives: what is actually happening in the situation being analyzed (the Real World); and what could/would/should be happening in an Ideal World.
- 2. Picture of the problem situation—precursor to possible purposes for a system: can either be a new system designed to alleviate the problem or a redefinition of an existing system
- 3. A ***root definition*** is developed for each system that describes six key aspects of that system, CATWOE:

  'Customers' of the system –victims or beneficiaries of transformation that system carries out.

  *'**A**ctors'* within the system – those who carry out the transformation.

  *'**T**ransformation process'* carried out by the system –in converting input to output.

  ***W**eltanschauung* –worldview that makes transformation meaningful in context of the system.

  *'**O**wners'* of the system – those with the authority to stop the transformation process.

  *'**E**nvironmental constraints'* – elements outside the system that it takes as given.
- 4. Each root definition elaborated to produce *conceptual activity model:* includes core activities to service needs of root definition.
  - Elaboration: results of systems thinking rather than of explicit reference to existing organizations and processes; exposes only those activities that are logically necessary.
- 5, 6, 7 Feasible actions to improve situation…based on differences between Real & Ideal

Hitchins' Rigorous Soft Methodology
RSM—Seven Steps to…

Step 1. Appreciate broad area of concern

Step 2. Find the symptoms causing concern

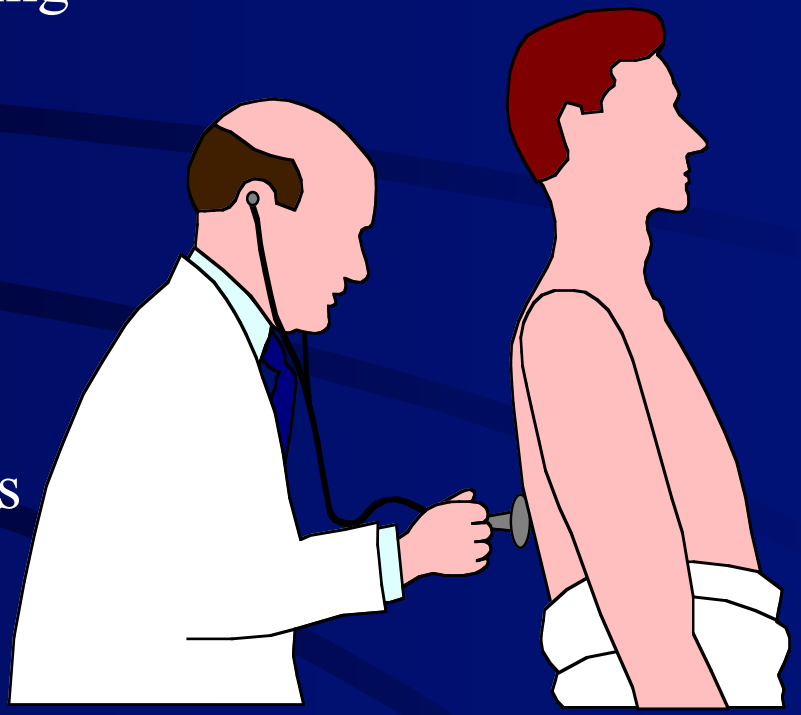
Step 3. Find suspect *implicit* systems (c.f. organ systems)

Step 4. Group suspect *implicit* systems into sets

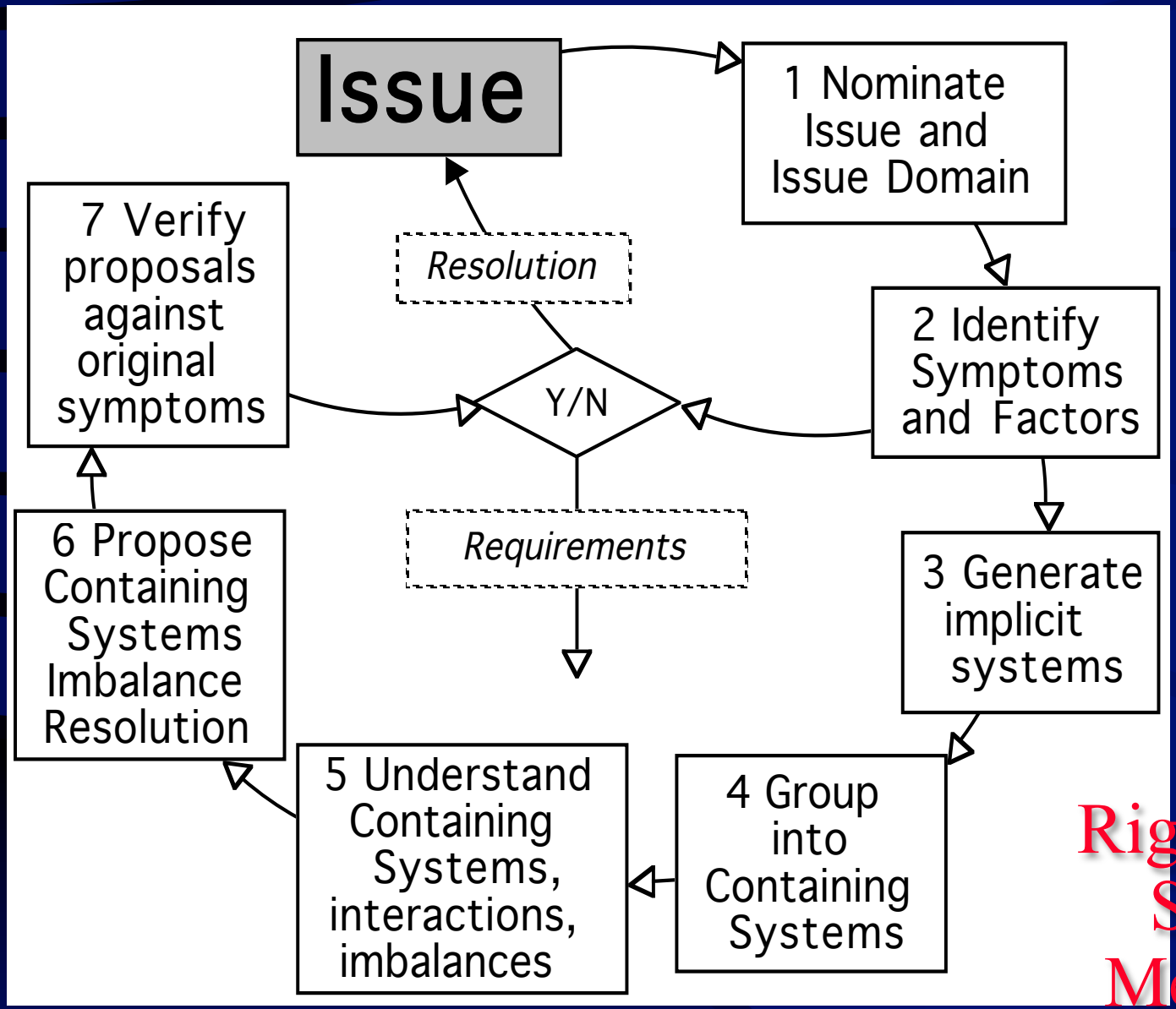
Step 5. Highlight set deficiencies compared with ideal

Step 6. Propose remedy

Step 7. Check remedy eliminates *all* symptoms



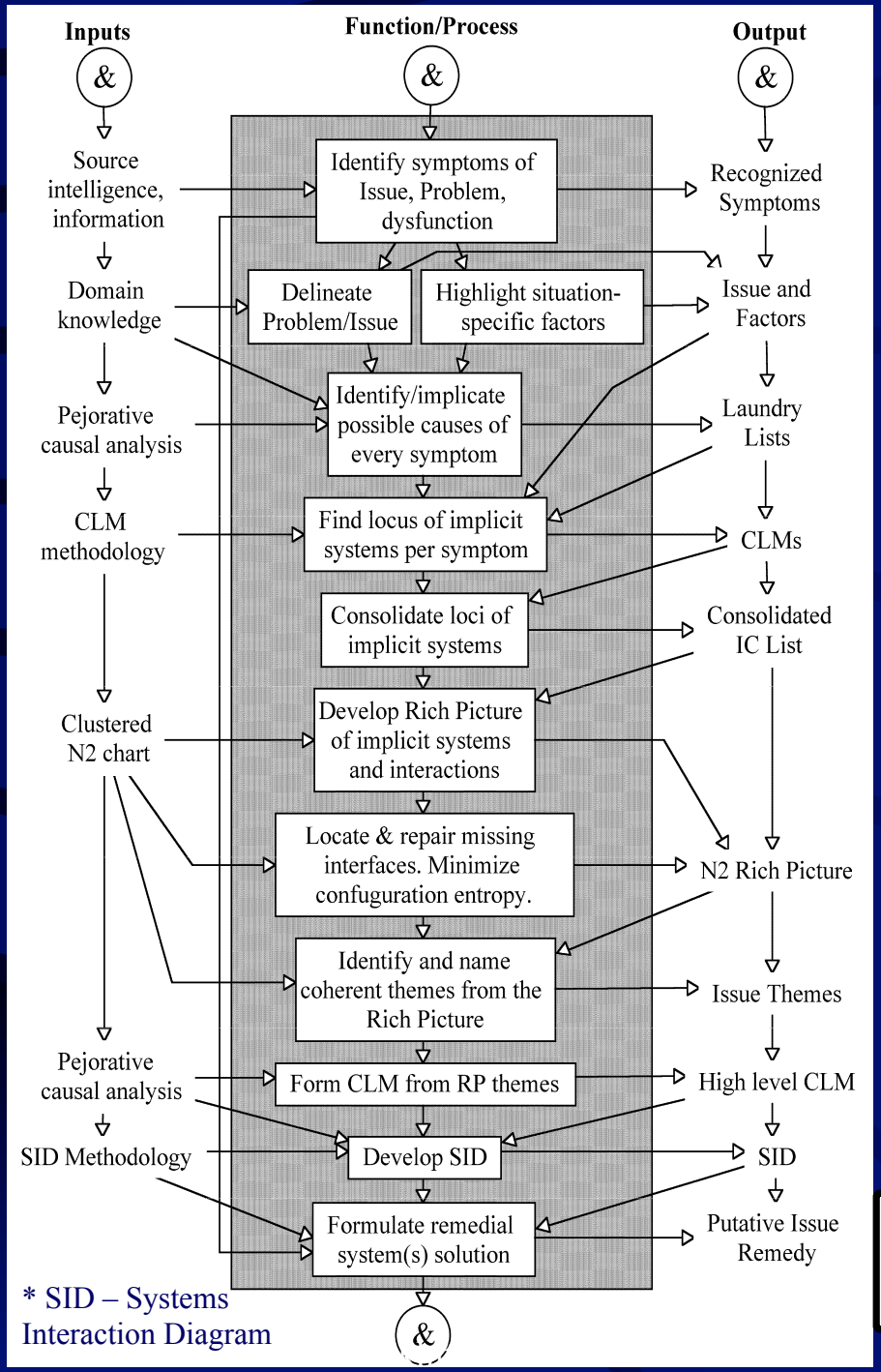
"THE GP APPROACH"



Rigorous Soft Method — Graphic

Systems Engineering: A 21st Century Systems Methodology
Derek Hitchins, 2007

- Horizontally, a sequence of IPO (Input-Process-Output) figures
- Vertically, a column of functions/activities forming a central process
- Input column shows data, tools and methods
- Output column shows Deliverables
- Whole may be elaborated, with each level forming a new Behaviour Diagram…
- Altogether exceedingly powerful method of thinking, and expressing!

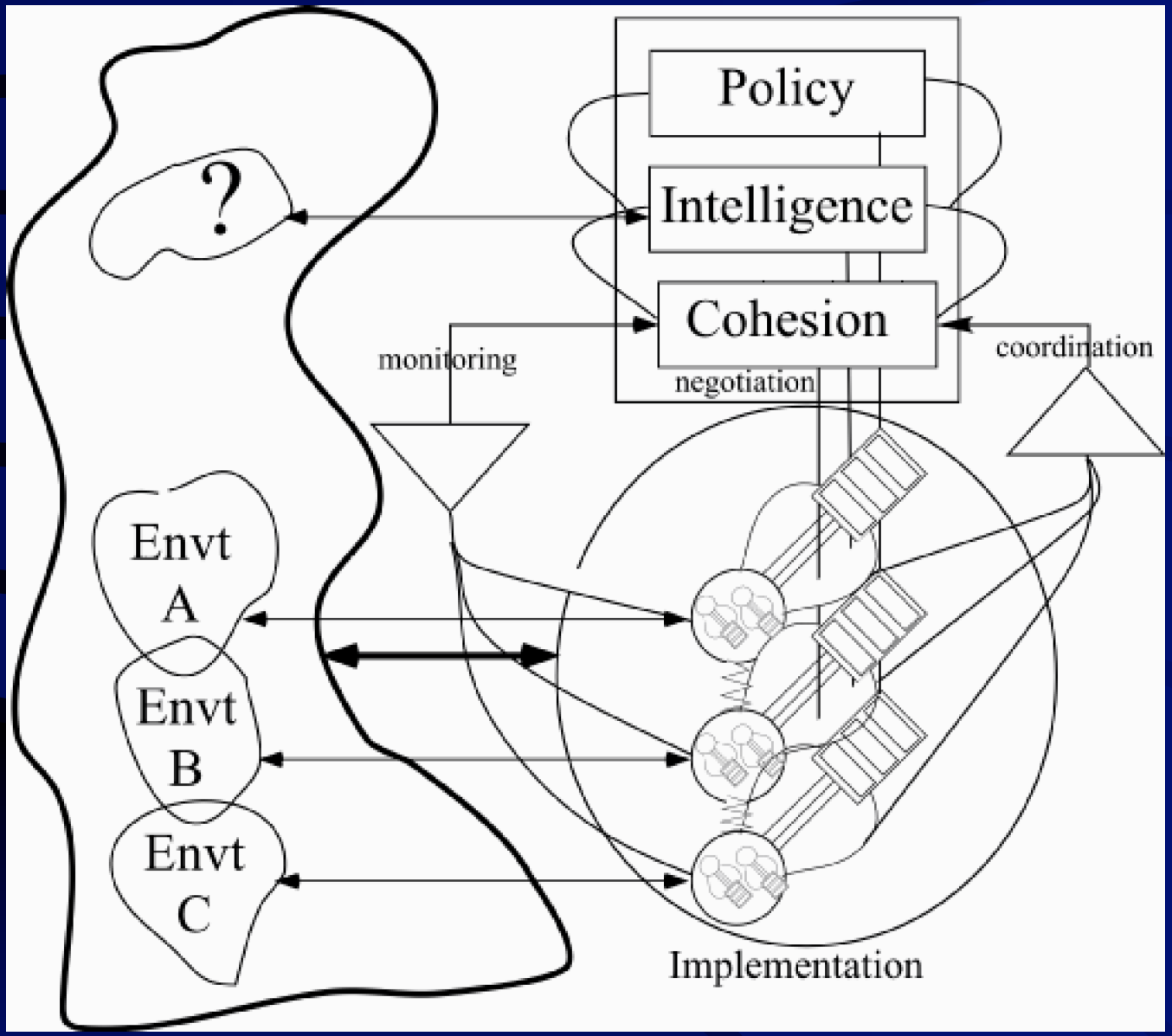


RSM as a Behaviour Diagram

(another approach to systems thinking)

Systems Engineering: A 21st Century Systems Methodology
Derek Hitchins, 2007

Beer's Viable Systems Model

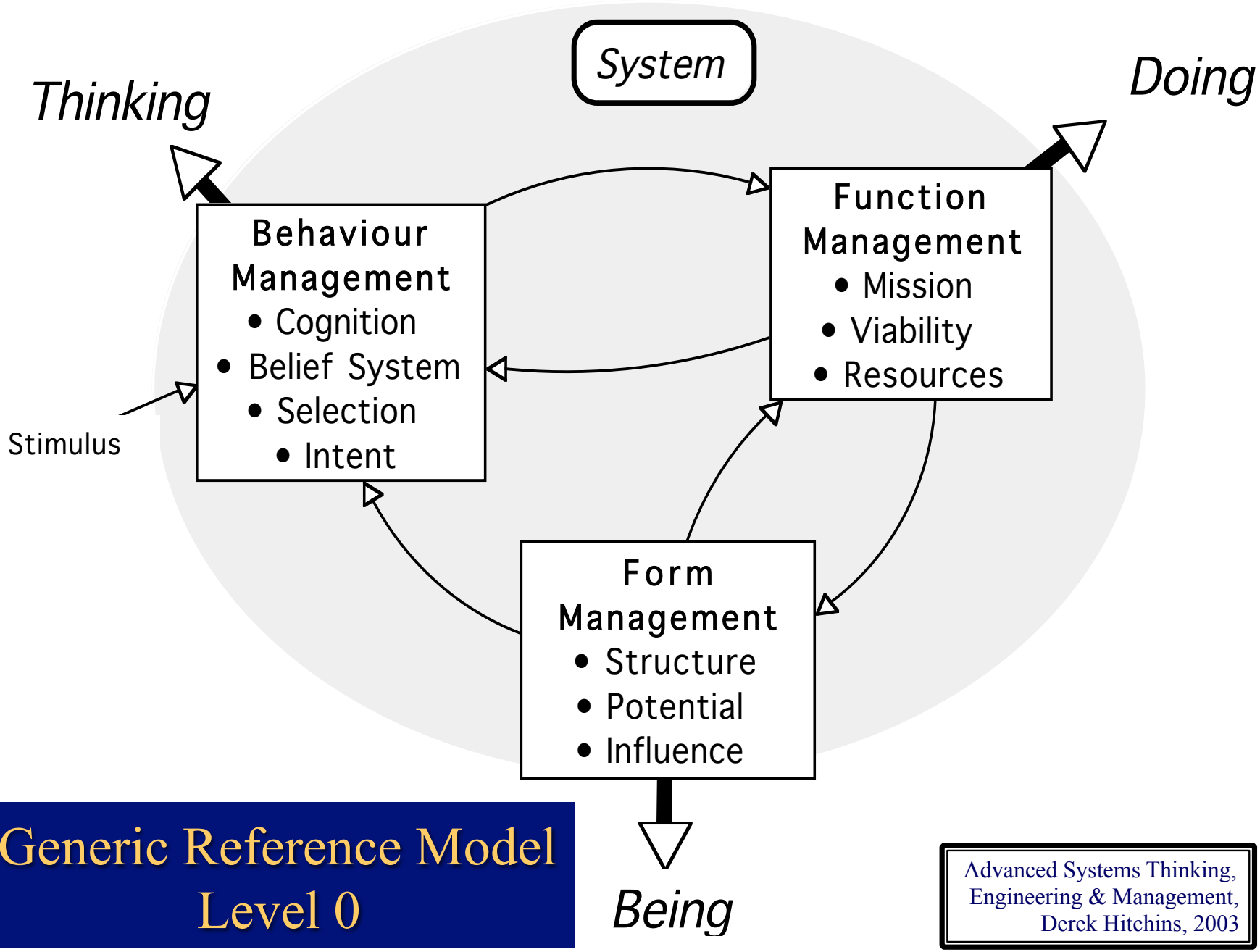


Beer's VSM

- Beer developed a model of management control based on his understanding of the human nervous system: this is the Viable Systems Model (VSM), for an autonomous system. The model is recursive:
- The large circle represents **System 1** of the five systems.
- **System 2,** 'Coordination,' coordinates System 1 (Upward Arrow)
- **System 3** is about overall Cohesion .
- **System 3* is about** monitoring. (Downward Arrow)
- **System 4 (Intelligence)** is concerned with looking forward into some future environment (question mark in the figure).
- **System 5**'s (Policy) functions include setting context, establishing corporate identity and 'providing closure to internal dialogues.'

Hitchins' Generic Reference Model

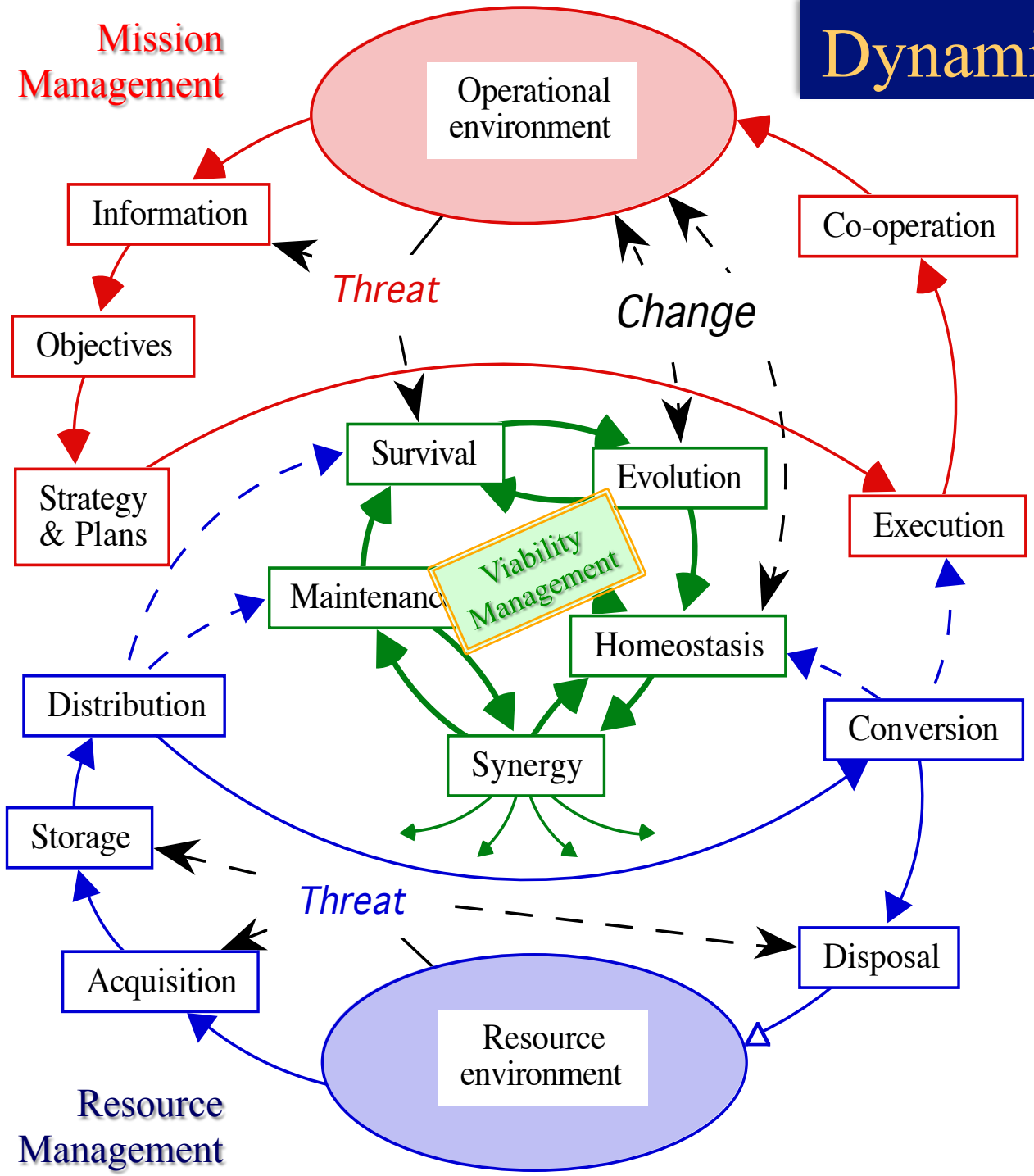
- Reference Model of any system
- All systems Exist, have Being
  - Solar system
- Some systems also Do things, Function
  - Elevators, transport, clocks, generators…
- …and some systems Think and Behave…
    - respond to stimulus, Nature Vs. Nurture…
  - Humans, Elephants, Cetaceans, car-with-driver…
- Any system is a selection/combination of the three: Being, Doing and Thinking/Behaving
- Open Systems face continuing *flux* of energy, information and substance, yet maintain *Viability*
    - ability of a thing to maintain itself or recover its potentialities.



Generic Reference Model Level 0

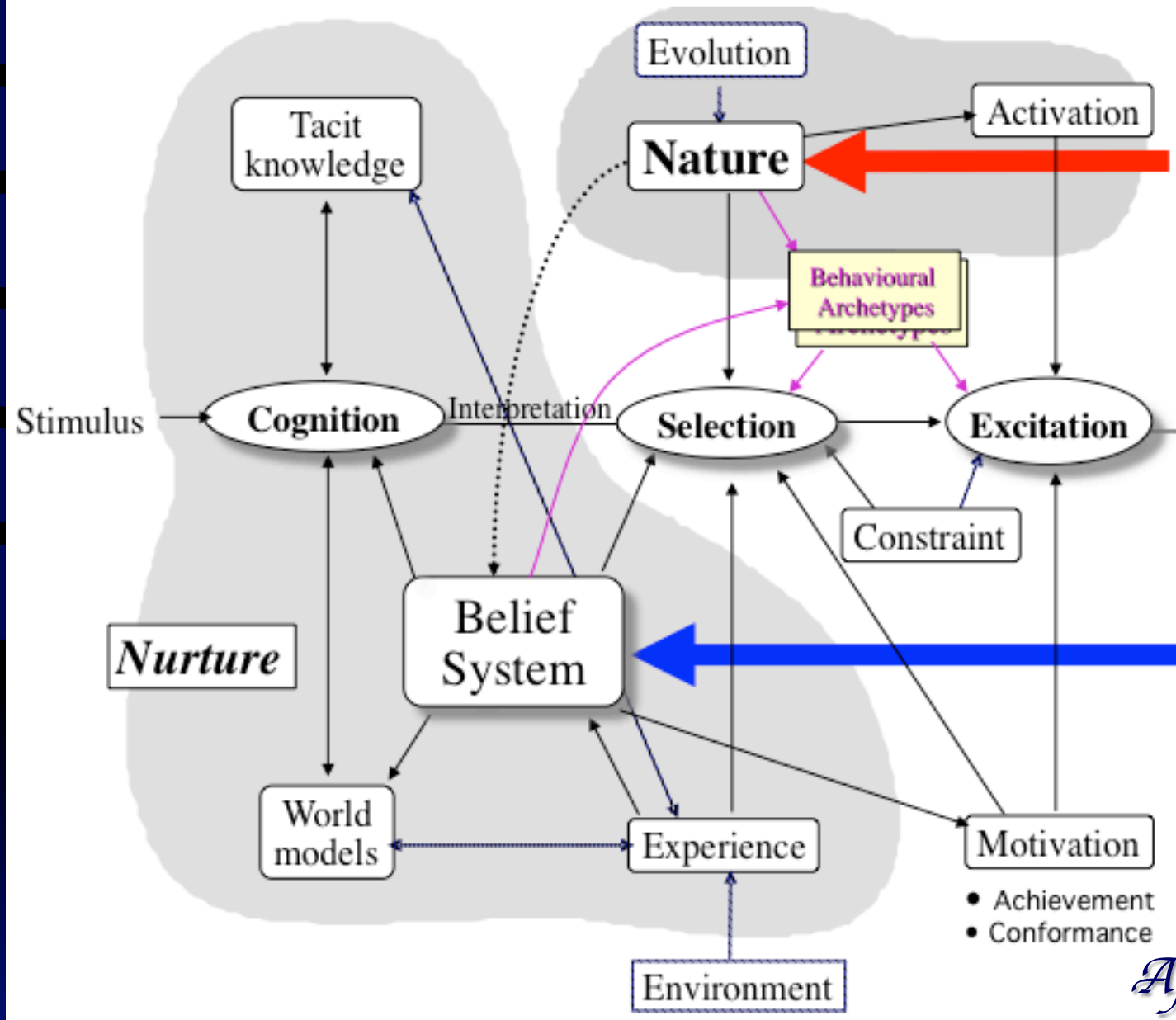
Advanced Systems Thinking, Engineering & Management, Derek Hitchins, 2003

Dynamic GR(Function)M



- 3 elements seen in respective "environments"
- Viability provides platform for Mission Management
- Resources provide energy & materials for Viability and (internal) operations
- Threats to Mission Management, Resource Management
- Change challenges Homeostasis (resist) and Evolution (adapt)
- Open System ***Flux*** of energy, information and substance "managed" in Mission and Resource Management

GRM Behaviour Model

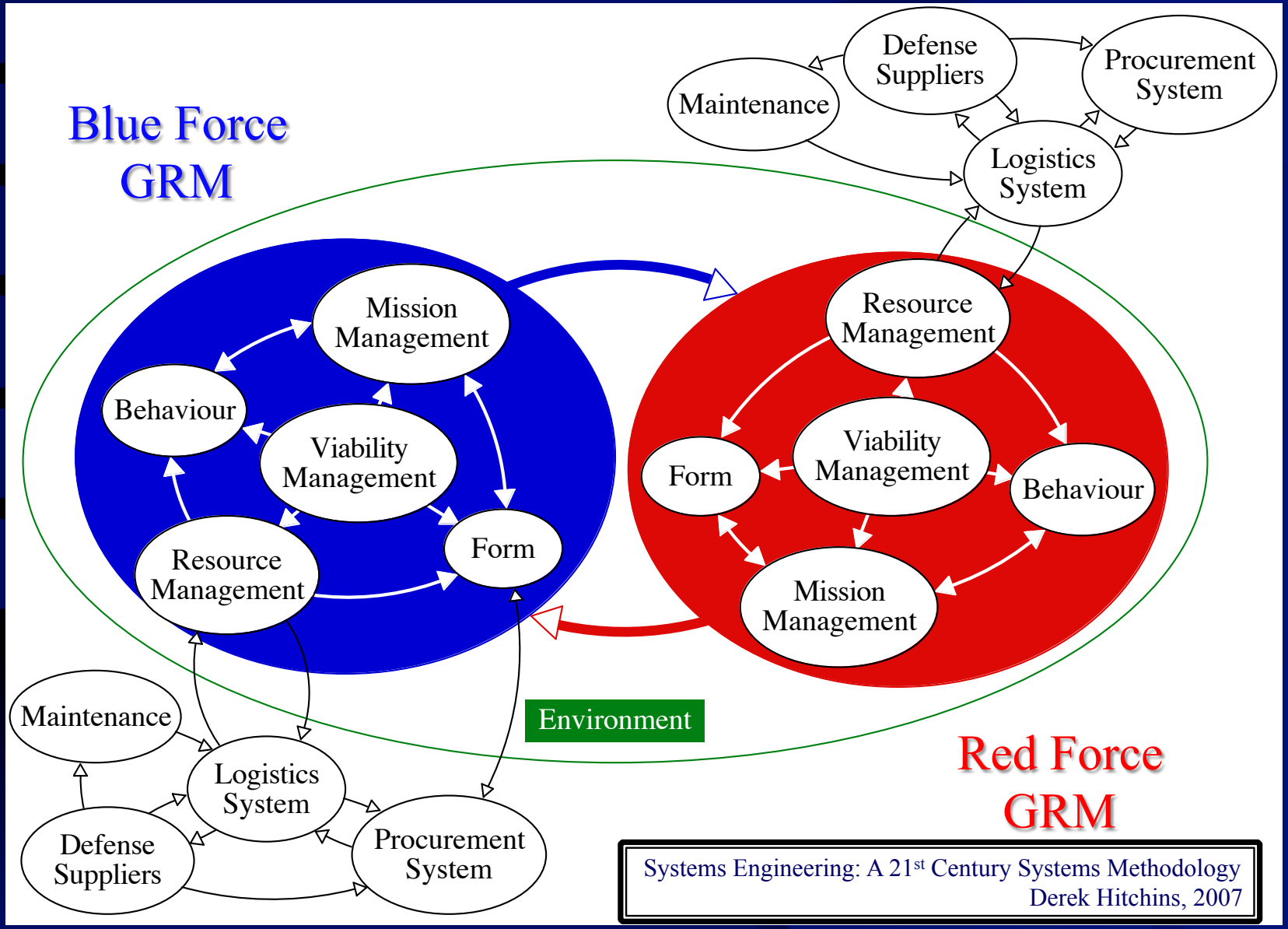


- Collective Unconscious
  - Instinct
  - Archetypes
- Libido
  - Aggression
  - Energy
- Character
  - Emotion

- Beliefs
- Rôles
- Stereotypes
- Categories
- Values
- Ethics
- Morals
- Ideologies
- Training

After Carl Jung

Hitchins' Generic Reference CLM in Conflict…



Conflict Simulation

- CLM Red and Blue Forces each represented by a full GRM in STELLA™, instantiated with appropriate values for combat
- Forces, one GRM each, then interconnected through a representative environment…
- …let (simulated) battle commence…

Conclusion

- Systems Thinking—vast subject
  - surface only scratched here
- Principal ideas and methods and methodologies shown, but…
- There are many more to be discovered, some rigorous, others less so…
  - challenge: to get to the *heart* of the matter
- However, a most rewarding and *useful* exercise…