


Integrating systems thinking, systems science and systems engineering – understanding the difference and exploiting the synergies

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Many views on

- Systems science, Systems thinking, Systems engineering
- Hard and Soft systems, etc etc etc

Relationship between them uncertain

- or at least not widely agreed

My Purpose

- Present a proposal for relationship between SS, ST, SE that is both practical and rigorous
- Point out some of the simplifications and clarifications that follow

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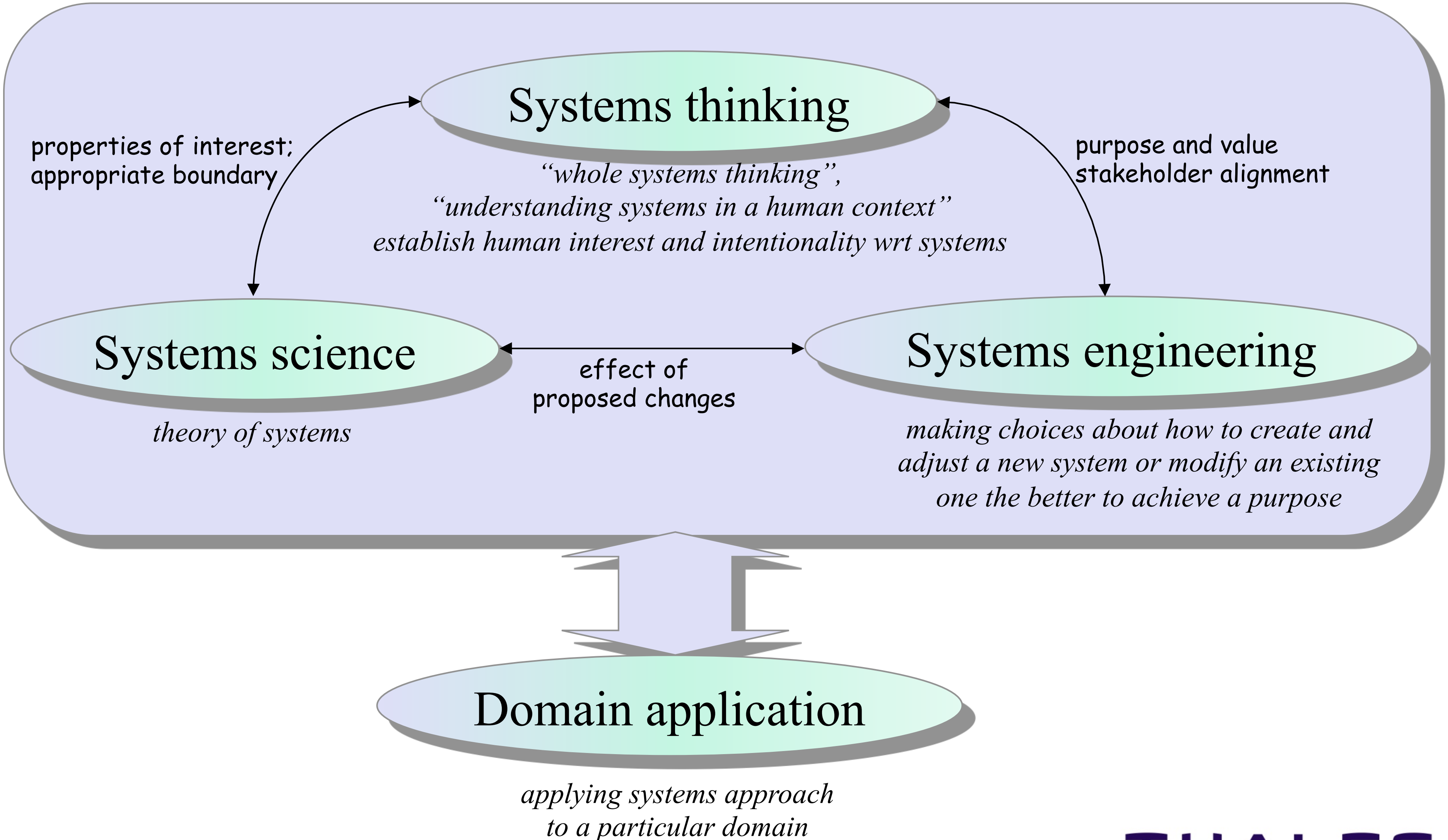
The proposition



Definitions of "science"

Science:

- a systematic enterprise that builds and organizes knowledge in the form of testable explanations and predictions about the universe.
- - - "science" refers to the body of reliable knowledge itself, of the type that can be logically and rationally explained".

Working scientists usually take for granted a set of basic assumptions that are needed to justify the scientific method:

1. that there is an objective reality shared by all rational observers; ("positivist")
2. that this objective reality is governed by natural laws;
3. that these laws can be discovered by means of systematic observation and experimentation."

Modern science is based on the Scientific Method, which can be summarised as:

- observe the real world,
- form a theory as to why things as they are (or as they appear to be),
- form a hypothesis that allows us to test the theory by experiment,
- depending on the result, reject, adapt or provisionally accept the theory.

When there is sufficient evidence to support a theory, it can be used to make predictions.

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"There is nothing new to be discovered in physics now;
all that remains is more and more precise measurement;"
"X-rays will prove to be a hoax."

So remember - scientific theories are always "provisional",
because new experiments may reveal limits to accepted theories.

But he also said:

"In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it.

- *I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it;*
- *but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind;*
- *it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of* Science, *whatever the matter may be."*

Lord Kelvin, late 19th century

Purpose of systems science in the systems approach:

“to provide useful and relevant theories about systems to inform systems practice”.

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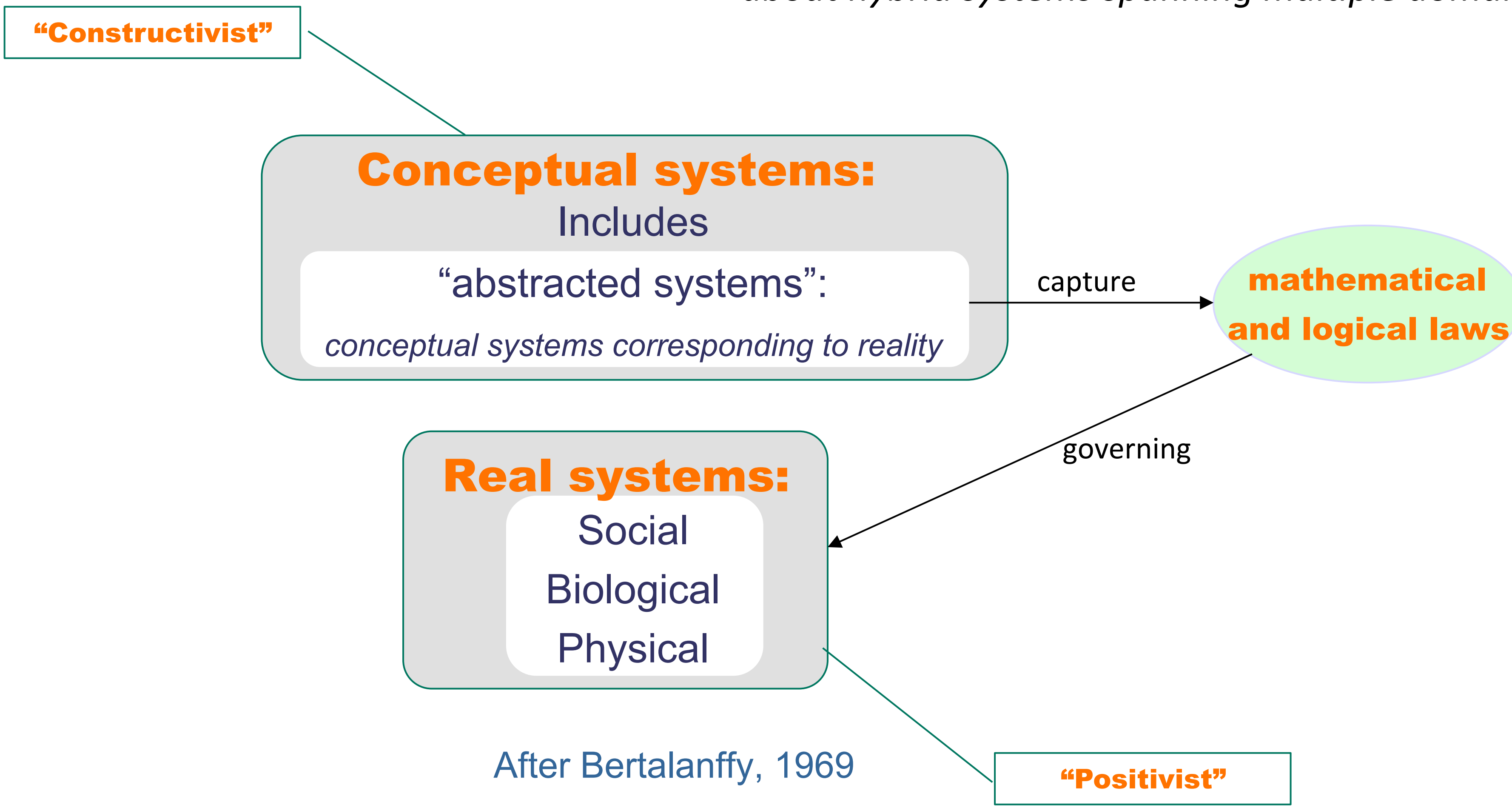
Generic "system laws" are required to unify thinking about hybrid systems spanning multiple domains



After Bertalanffy, 1969

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2 interesting questions about systems

What is different about different kinds of system?

This question leads to "reductionist" enquiry

Leads to wide diversity of concepts, taxonomies, dimensions of variation; with correspondingly wide diversity of practice, experience and opinions

Intriguing: but not always useful!

What is similar about different kinds of system?

This question encourages us to see similarities not differences

allows re-use of patterns, insights and models:
in different domains;
to integrate across domains.

The subject of systems science – which underpins SE and ST

Overloaded and inconsistent terminology, mismatched mental models, and human desire to be different, all impede recognition and exploitation of common patterns

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Many people have discussed general systems theories and models:

- Hitchins
- Dori
- Blockley
- Hubka & Eder (Theory of technical systems)
- And many others - -

Most seem to relate to ideas from 3 primary sources

- Bertalanffy, “general systems theory”, e.g. 1969
- Hall, A.D. 1962
- Ashby (ca 1950)

- Bertalanffy emphasises “isomorphy of laws in different fields”

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Common or generic reference model of "system"

A system exists within a wider "context" or environment.

- The environment includes "operational", "threat" and "resource" environments

A system is made up of parts that interact with each other and the wider environment.

A system has system-level properties ("emergent properties") that are properties of the whole system not attributable to individual parts.

A system has

- Structure
- Function
- Behaviour
- A lifecycle
- performance

A system both changes, and adapts to, its environment when it is deployed.

Systems contain multiple feedback loops with variable time-constants so that cause and effect relationships may not be immediately obvious or easy to determine.

A system may exist independent of human intentionality

A system may be part of one <u>or several</u> wider "containing systems".

A system may be self sustaining, self organising, dynamically evolving

A system may offer "affordances" – features that provide the potential for interaction by "affording the ability to do something"

Affordances will lead to interactions whether planned or not, e.g. the affordance of a runway to let planes land and take off also leads to a possibly unintended affordance to drive vehicles across it

A system may be

clearly bounded and distinct from its environment (solar system, Earth, planes, trains, cars, ships, people)

closely coupled with/embedded in its environment (bridge, town, runway, cardiovascular system, internet)

of fluid and dynamic make-up (club, team, social group, ecosystem, flock of geese, internet)

A system may be technical (requiring one or multiple disciplines to design), social, ecological, environmental, or a compound of any or all of these.

Don't all systems have purpose?

Opposing worldviews:

- "systems must have purpose, by definition"
- "real systems" occur in nature with no (or no human) purpose.

Arguments between these become (in my view) unhelpfully metaphysical.

- and trip up on undisclosed differences in philosophy e.g. Positivist vs Constructivist

I think:

- Engineered systems are engineered for a purpose.
- Some human-made systems are "accidental systems"
  - have unforeseen interactions that lead to unintended consequences.
  - created by humans by accident when deploying or modifying a system for another purpose.
- Natural systems exist, persist and evolve because they provide some stability or viability benefit to the constituent parts of the system.
  - Good examples of this include the many symbiotic relationships in biological systems.
  - Such systems are better understood in terms of "mutual benefit" rather than "purpose".

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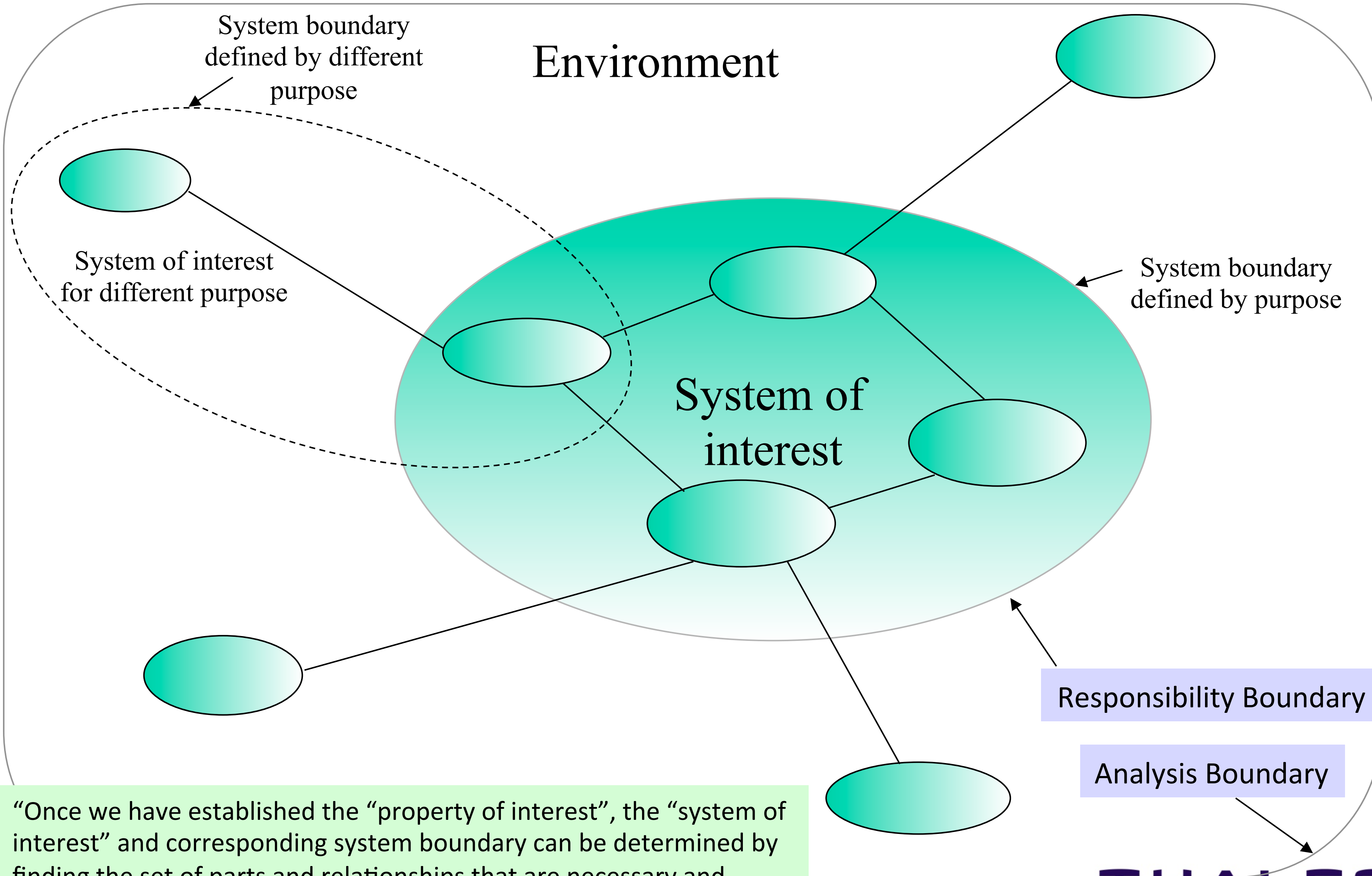
Boundary paradox



"Once we have established the "property of interest", the "system of interest" and corresponding system boundary can be determined by finding the set of parts and relationships that are necessary and sufficient to account for the property or properties of interest."

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Key role of Systems Thinking:

- "establish the purpose and value of the system of interest"

Key outputs of systems Thinking:

- correct choice of problem
- correct identification of stakeholders and their concerns
- correct choice of system properties of interest
- correct choice of system boundary, or criteria for making that choice
- alignment of stakeholder purpose, values and incentives
- identify those parts of problem to "managed" and those to "solve"
- correct programme construct for a complex system development
- define purpose and value for each set of systems engineering activities.

Choices

- The function, behaviour and performance we believe are required to achieve purpose, satisfy stakeholders, and avoid unintended negative consequences
- The structure, behaviour and performance attributes of the system of interest and of its components
  - (may include people, processes, services etc);
- Making, or providing evidence to support, value-driven trade-offs between different approaches and solution options
- Those variables in the external environment of the system that will be explicitly measured by the system;
- How susceptible the system is to environmental variables we have chosen not to explicitly measure
- How to prove system meets stakeholders' needs & expectations, and is fit for purpose

Activities

- Get the system working as a system and delivering the intended benefits
- Define the parts and their interfaces and associated processes and behaviour of
  - The operational system
  - Enabling systems including:
  - The development organisation
  - The test system
  - The manufacturing system and supply chain
  - The setting to work system
  - The support system
  - The decommissioning system
- Document these, and related process, practices and assumptions, so the system can be replicated and managed through life

prove the design will work at as early a stage in the project as possible, to avoid building a flawed design, or solving the wrong problem.

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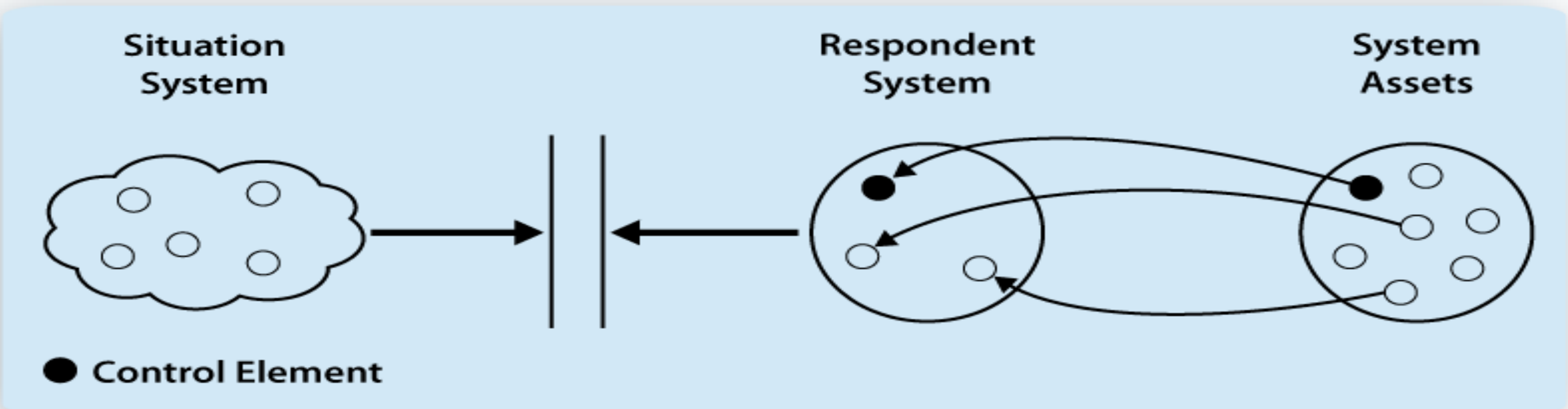
Systems Approach example 1: System Coupling Diagram



Bud Lawson, 2010

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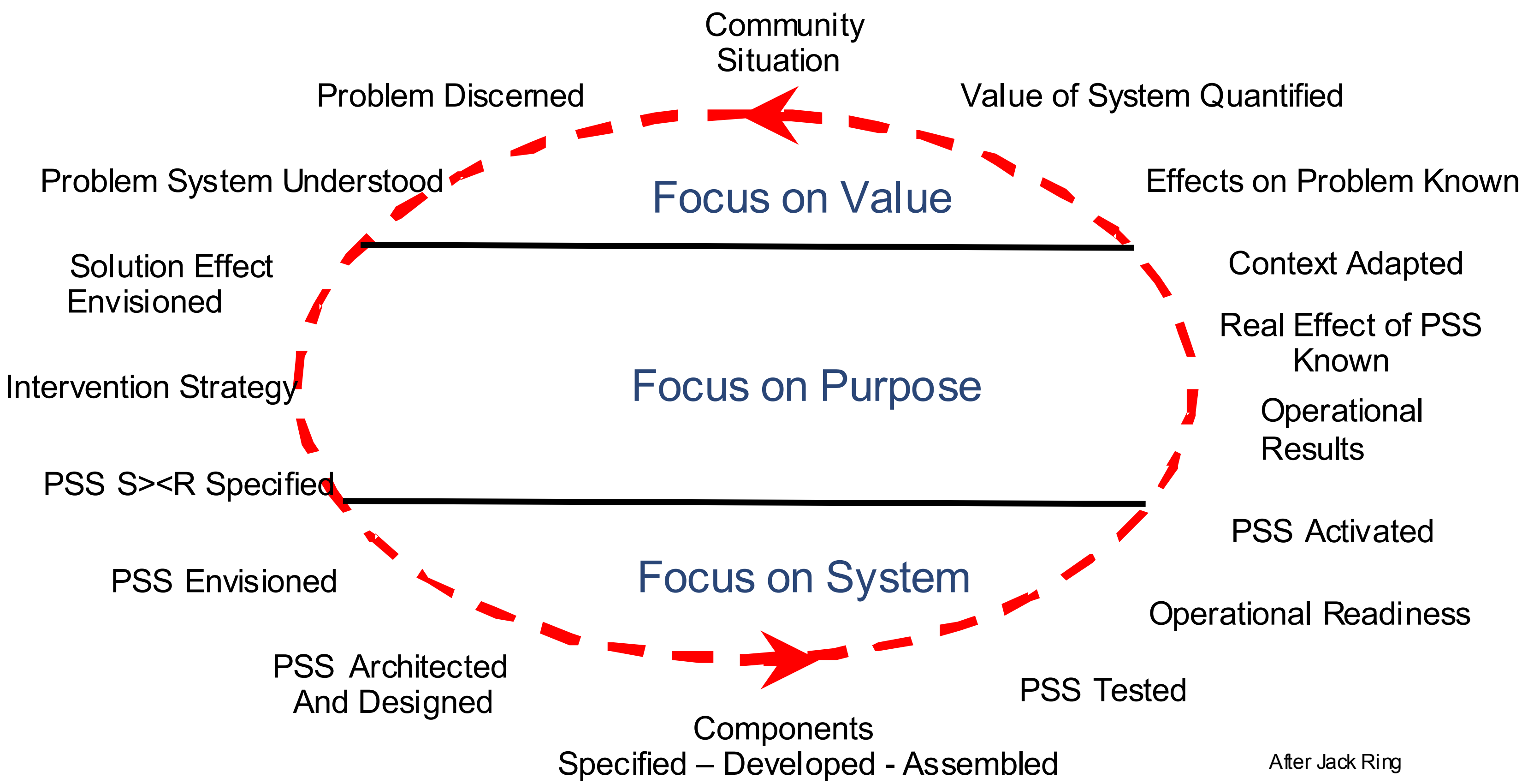
Systems Approach example 2 – system value cycle



PSS = "problem solution system"

Jack Ring, 1998 & 2004

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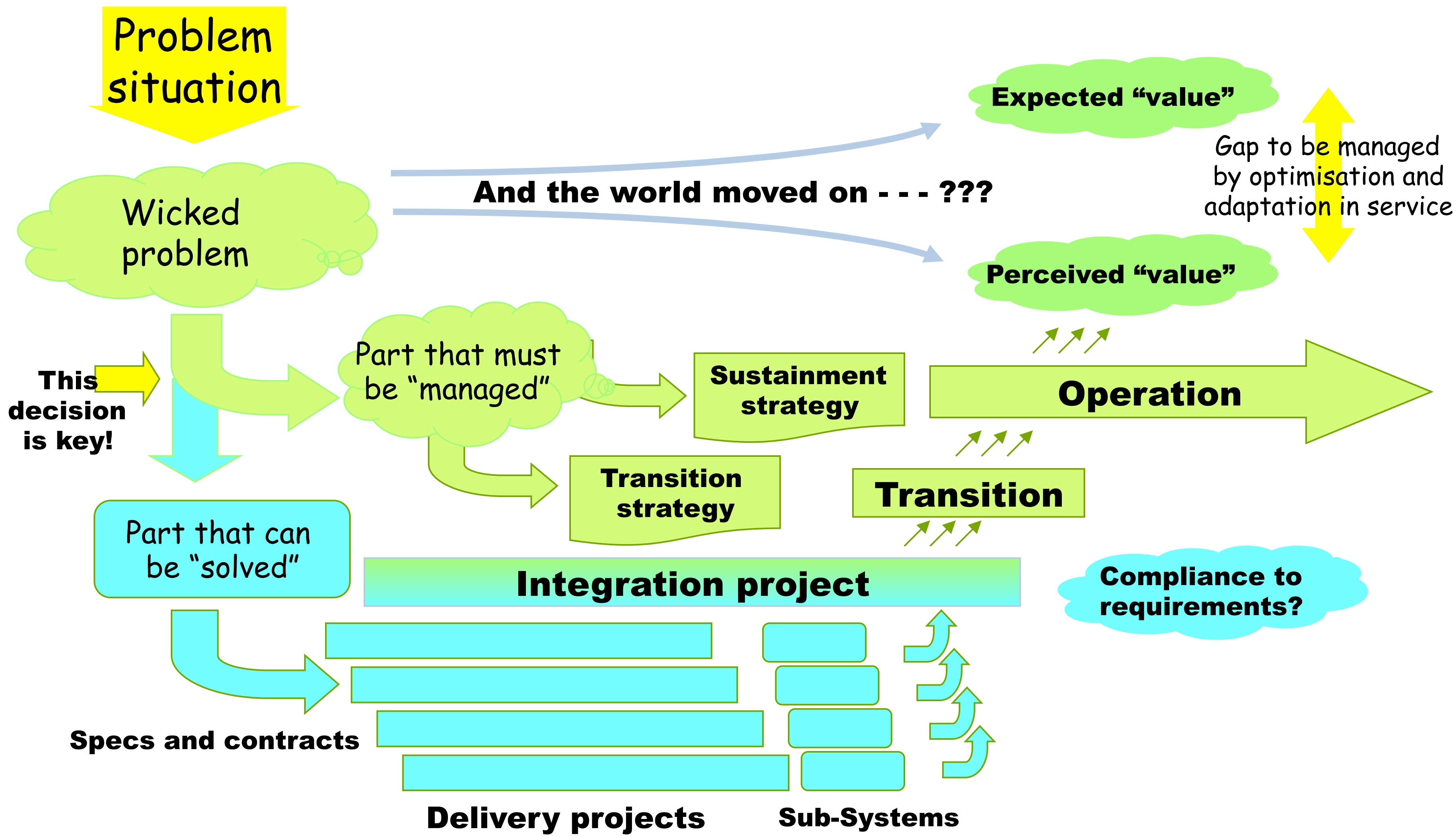
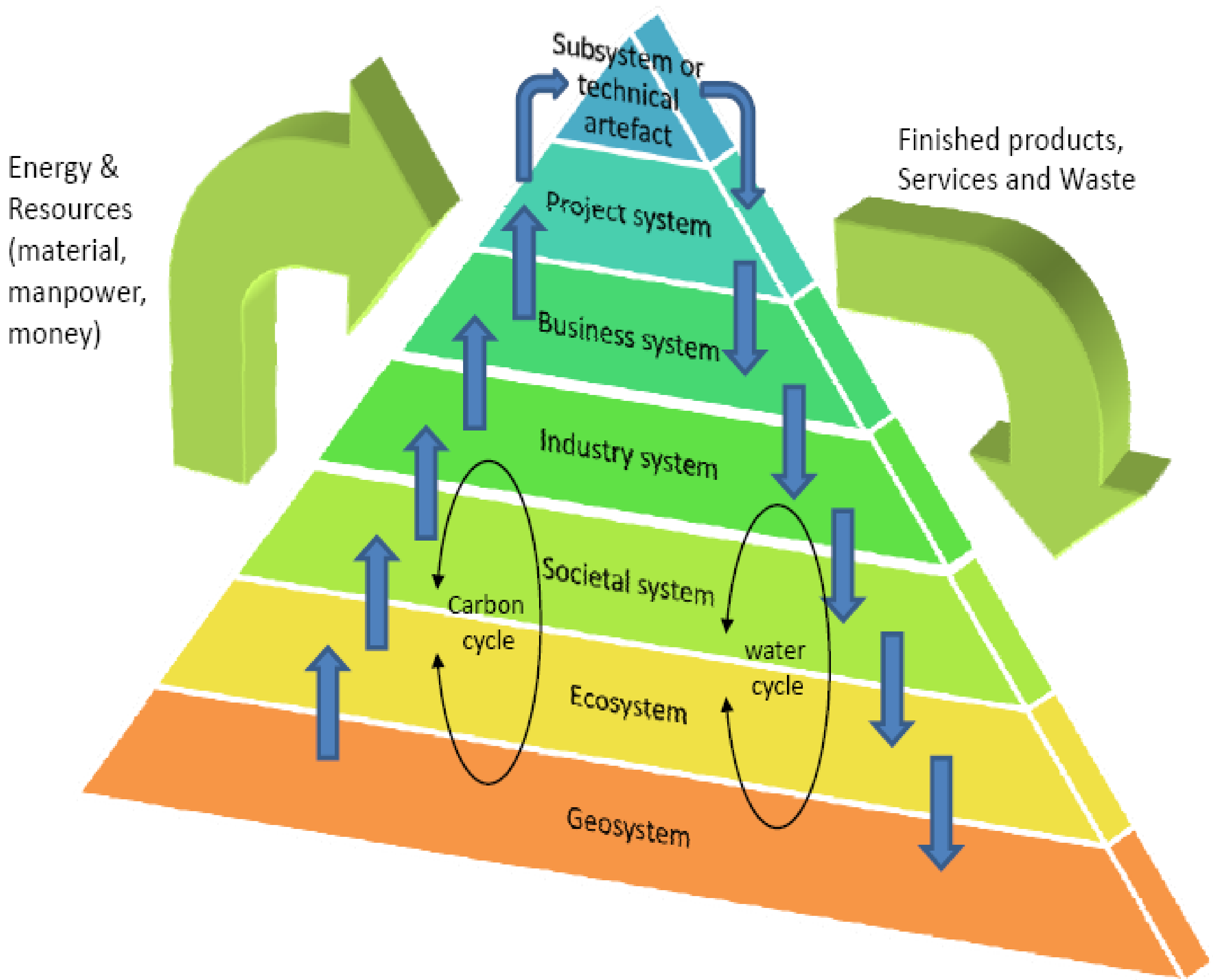
Example 3: “Soft and hard”



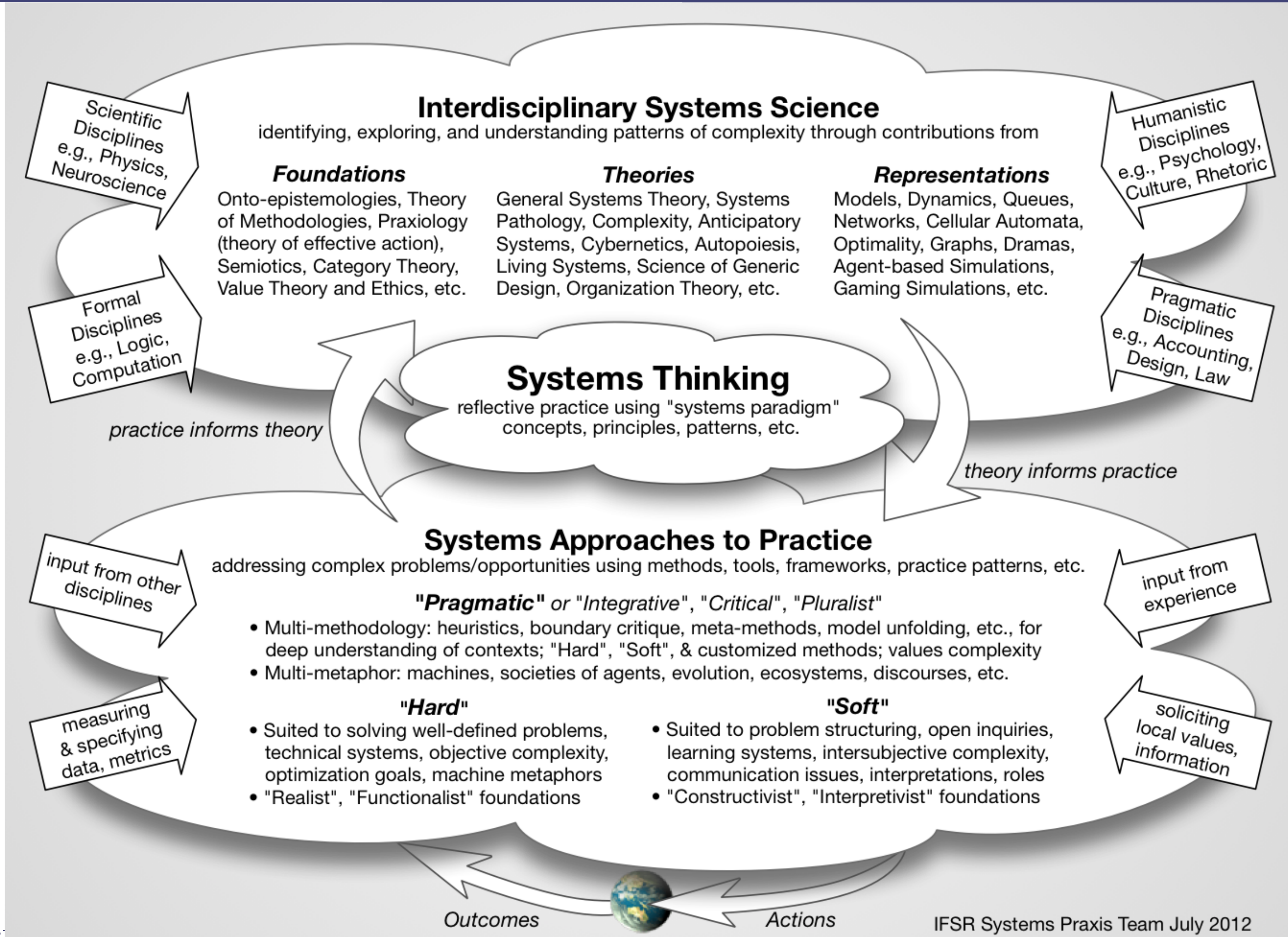
Hillary Sillitto, 2009-10

Example 4: Closed cycles in nested layers of subsystems



Derek Hitchins 1990's, extended by Sillitto & Godfrey, 2009

Example 5: Getting to Unified (trans-disciplinary) Systems Praxis



Domain specific systems approach

A systems approach in a particular domain will apply these general principles within the context of existing knowledge about the particular domain.

This may include

- an understanding of domain problems, constraints, risks and opportunities;
- the best order to tackle issues as we approach a problem in the domain.

Domain experts

- understand the degrees of freedom and appropriate design approaches
- know how to do the specific analyses relevant to standard functions and performance.

The advantage of a domain-specific approach:

- better efficiency based on risk-aware replication of known practices and proven design rules.

Potential disadvantages are

- blindness to cross-domain opportunities and issues,
- risk of the "wrong-problem syndrome", solving the problems that interest domain experts rather than what is needed to resolve the problem situation.

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Conclusions

Systems engineering depends on

- systems thinking to identify purpose and value and appropriate programme portfolio and stakeholder alignment;
- systems science for a fundamental understanding of the nature and characteristics of systems

So

- systems thinking is used to establish strategies for systems engineering.

If systems science can be correctly codified it allows us to

- develop useful domain independent system concepts, abstractions, principles and models
- that will aid the practice of systems engineering.

Domain specialisation adds specific knowledge of

- key constraints, functions and performance parameters in the domain.

Systems engineers need to understand elements of systems science and systems thinking to be able to operate as effective systems engineers.

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Thank you for your attention.
Any questions?

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