Leveraging System Science When Doing System Engineering

Richard A. Martin

INCOSE System Science Working Group

and Tinwisle Corporation

System Science and System Engineering Synergy

- Every System Engineer has a bit of the scientific experimenter in them and we apply scientific knowledge to the spectrum of engineering domains that we serve.
- The INCOSE System Science Working Group is examining and promoting the advancement and understanding of Systems Science and its application to System Engineering.
- This webinar will report on these efforts to:
  - encourage advancement of Systems Science principles and concepts as they apply to Systems Engineering;
  - promote awareness of Systems Science as a foundation for Systems Engineering; and
  - highlight linkages between Systems Science theories and empirical practices of Systems Engineering.

Engineering or Science

- "Most sciences look at certain classes of systems defined by types of components in the system. Systems science looks at systems of all types of components, and emphasizes types of relations (and interactions) between components." George Klir – past President of International Society for the System Sciences

- Most engineering looks at certain classes of systems defined by types of components in the system. Systems engineering looks at systems of all types of components, and emphasizes types of relations (and interactions) between components.

Engineer or Scientist or Systemist

Engineers and Scientists have a lot in common:

- Construct and test models and theories
- Congregate to tell their peers about the work they do, successes and failures
- Fragmented into domains of expertise
- Use specialized languages and symbols to communicate among themselves
- Few practitioners, the systemists, actually looking at the whole picture

And some differences:

- Phenomenon of interest (natural / human-made)
- Primary value of method use (knowledge / operational capability)

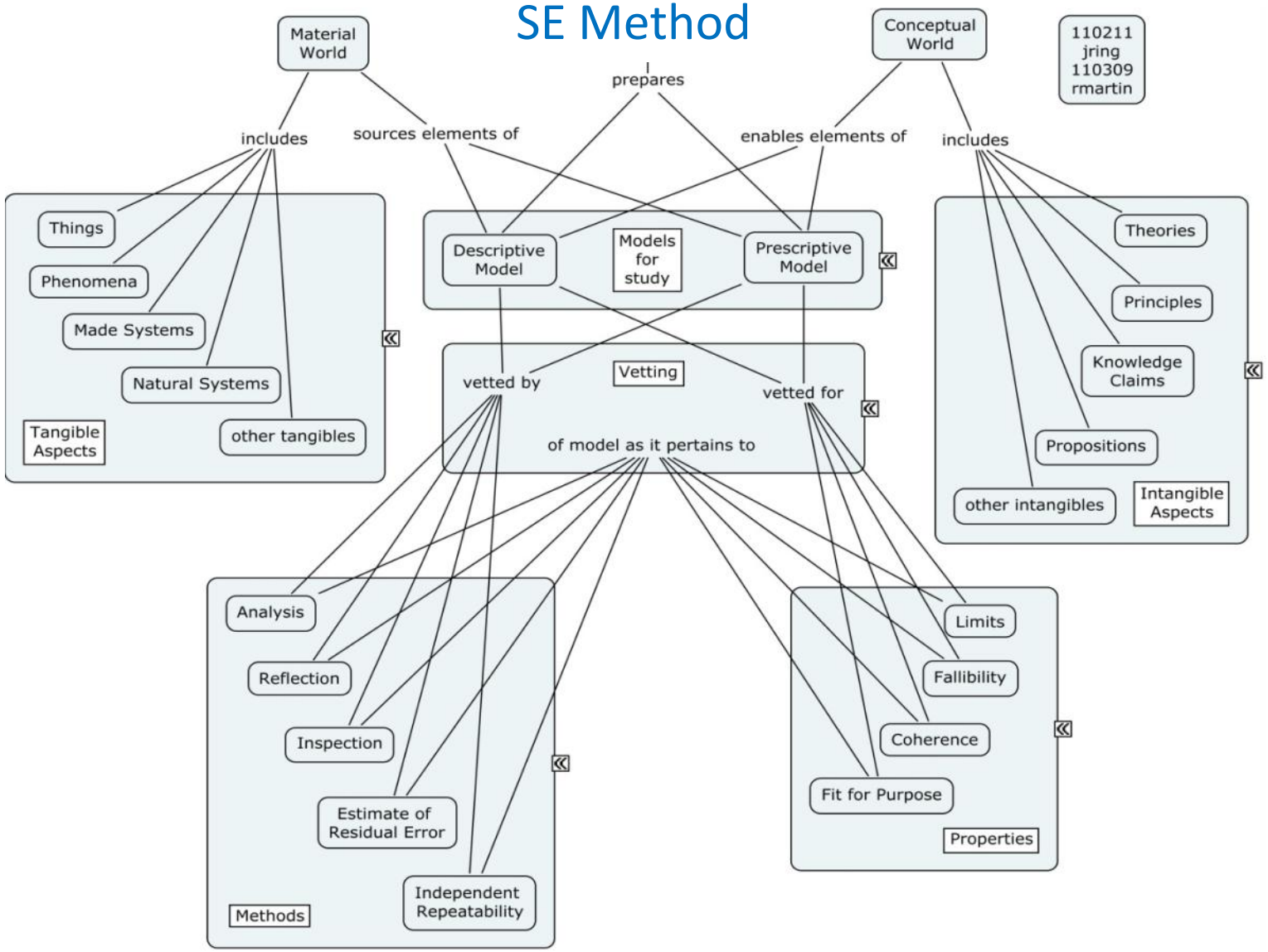
SS Landscape*

- Chaos theory
- Complex systems
- Complex system
- Cybernetics
  - Biocybernetics
  - Engineering cybernetics
  - Management cybernetics
  - Medical cybernetics
  - New Cybernetics
  - Second-order cybernetics
- Control theory
  - Affect control theory
  - Control engineering
  - Control systems
  - Dynamical systems
  - Perceptual control theory
- Operations research
- Systems biology
  - Computational systems biology
  - Synthetic biology
  - Systems immunology
  - Systems neuroscience
- System dynamics
  - Social dynamics
- Systems ecology
  - Ecosystem ecology
- Systems engineering
  - Biological systems engineering
  - Earth systems engineering and management
  - Enterprise systems engineering
  - Systems analysis
- Systems theory in anthropology
- Systems psychology
  - Ergonomics
  - Family systems theory
  - Systemic therapy
- Systems theory
  - Biochemical systems theory
  - Ecological systems theory
  - Developmental systems theory
  - General systems theory
  - Living systems theory
  - LTI system theory
  - Sociotechnical systems theory
  - Mathematical system theory
  - World-systems theory
- Systems theory in sociology
  - Talcott Parsons
  - John N. Warfield
  - Niklas Luhmann
- Etc…

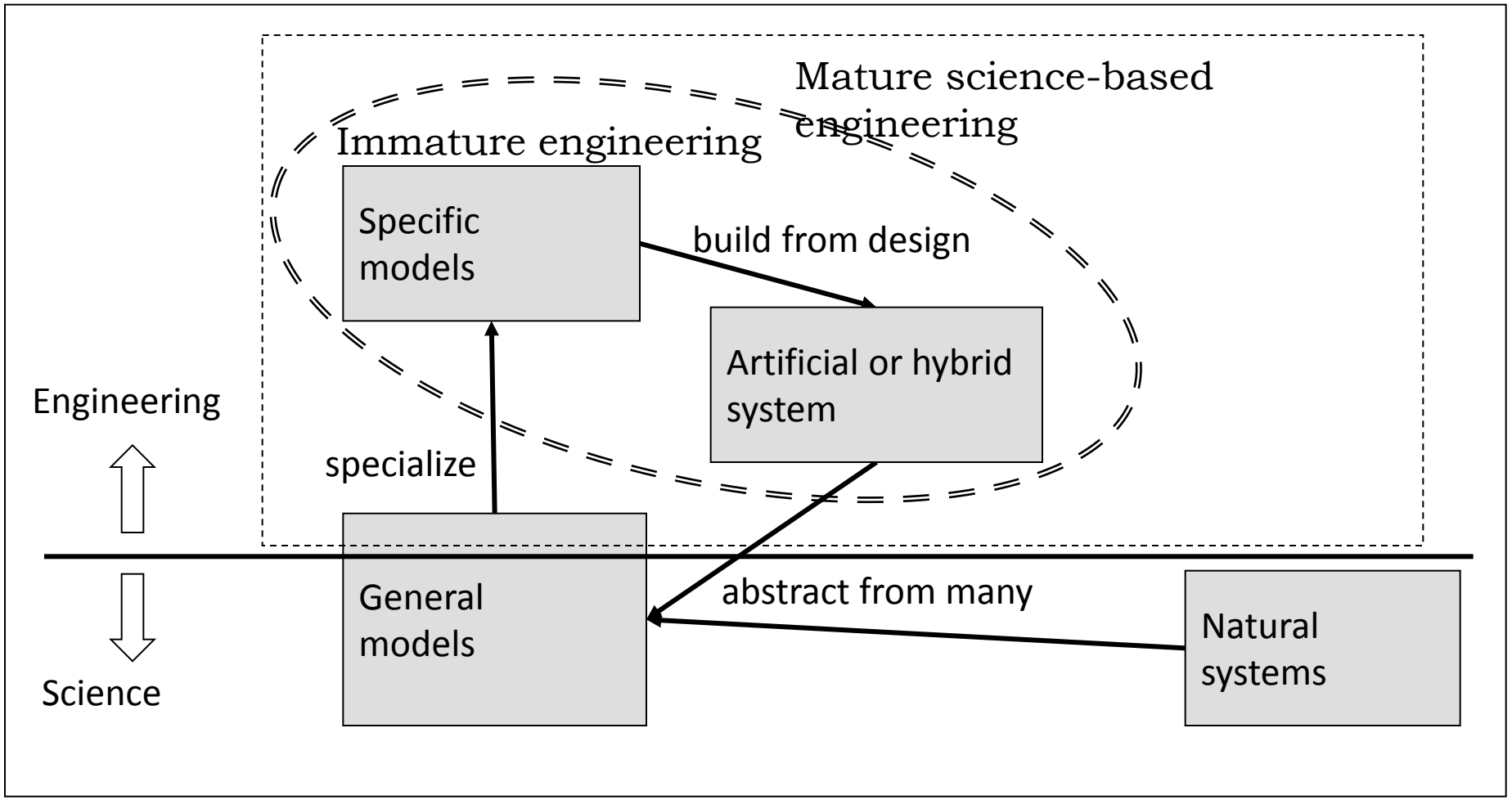
* According to Wikipedia (separate Wikipedia article on each topic listed)

James Martin – IW13

Similar Methodology



Science supports engineering



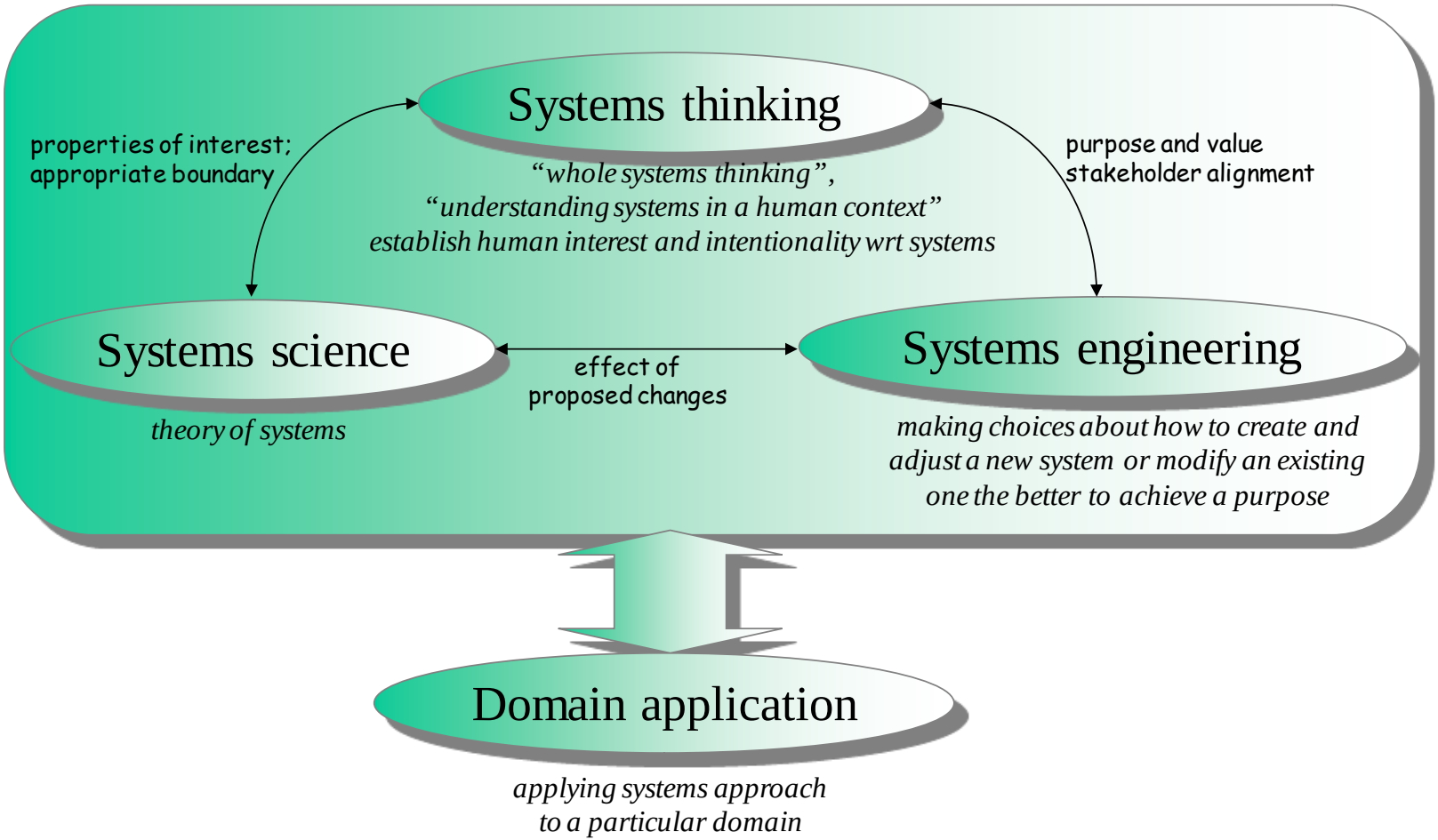
Duane Hybertson, IW13

SysSciWG Projects

WG leaders – James Martin & Duane Hybertson

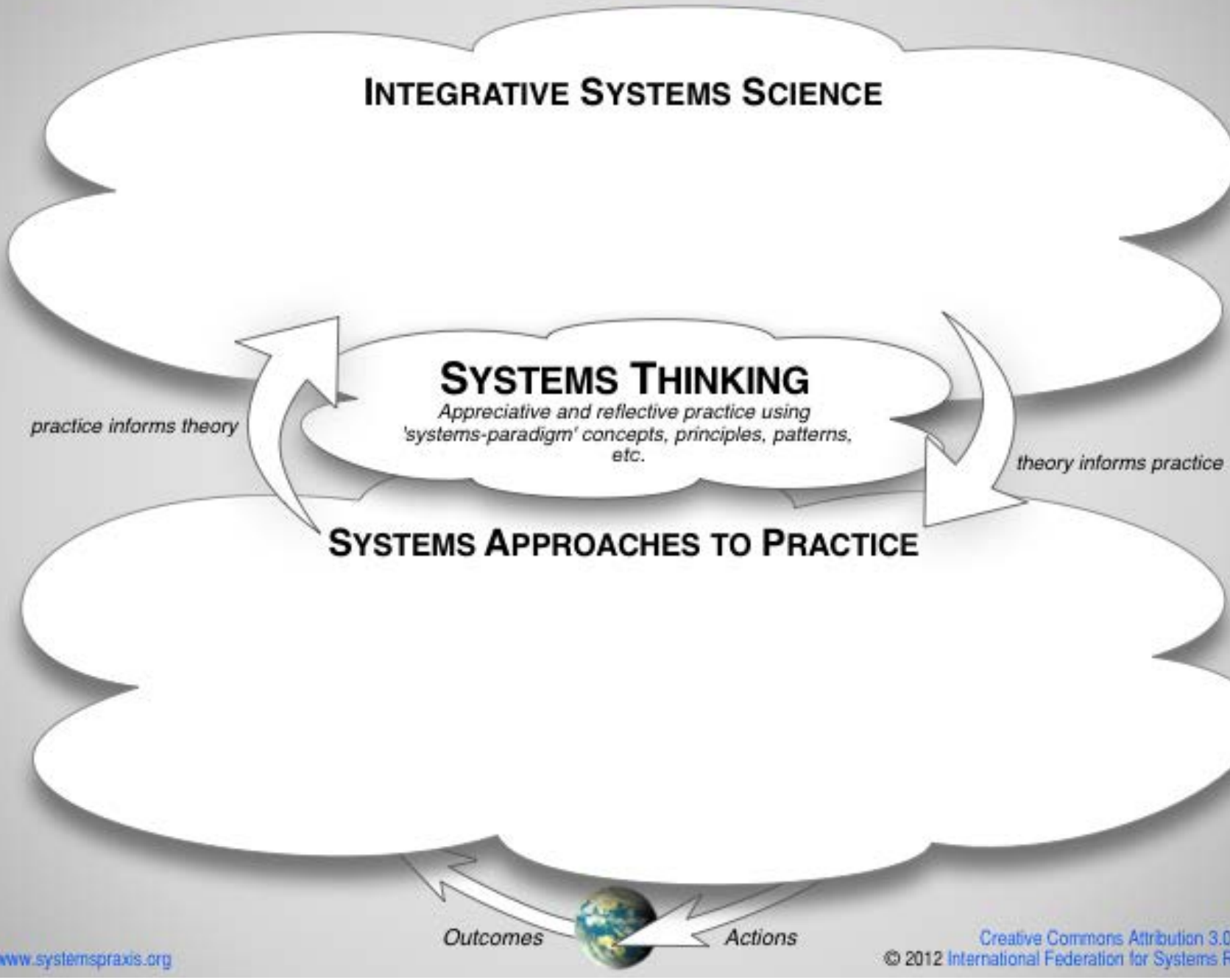
- System Praxis Framework – Janet Singer, Hillary Sillitto, et. al.
- Unified Systems Science Theory - Len Troncale, et. al.
- Systems of Innovation/ System Pathologies - Bill Schindel & Bruce Beihoff
- Unifying Ontology for Systemists (suspended)- Jack Ring & Richard Martin
- Basic Structural Modeling – Joe Simpson
- Synergizing Systemists – Jack Ring
- SEBOK Part 2 – Rick Adcock and James Martin
- IFSR Conversation ’14 – James Martin and Gary Metcalf
- SS/SE Synergies white paper – Duane Hybertson, et. al.

Integrated Systems Approach



Sillitto, H., "Integrating Systems Science, Systems Thinking and Systems Engineering: understanding the differences and exploiting the synergies". INCOSE International Symposium, Rome, July 2012

The Systems Praxis Framework, a joint project of the International Council on Systems Engineering and the International Society for the Systems Sciences



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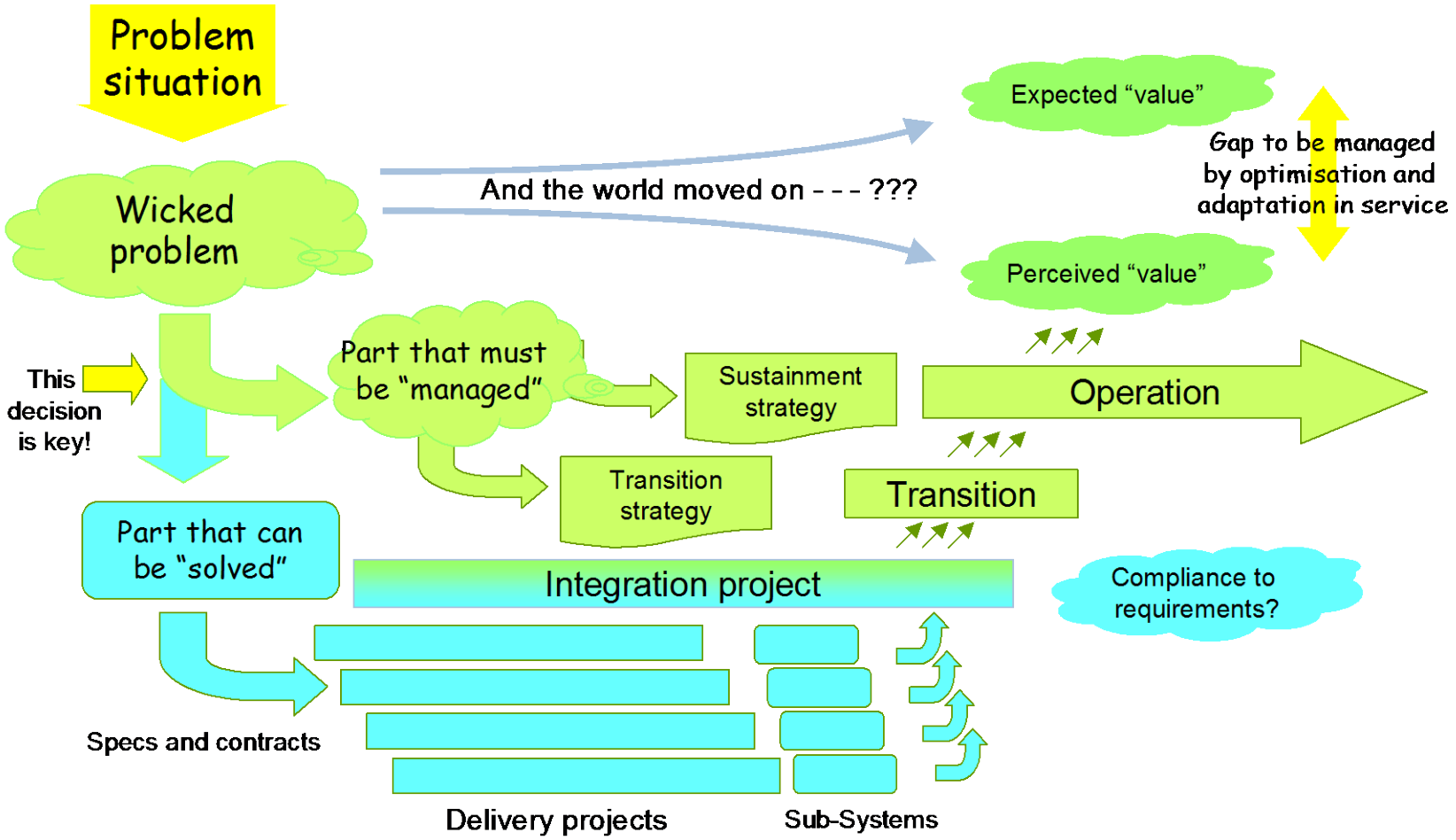
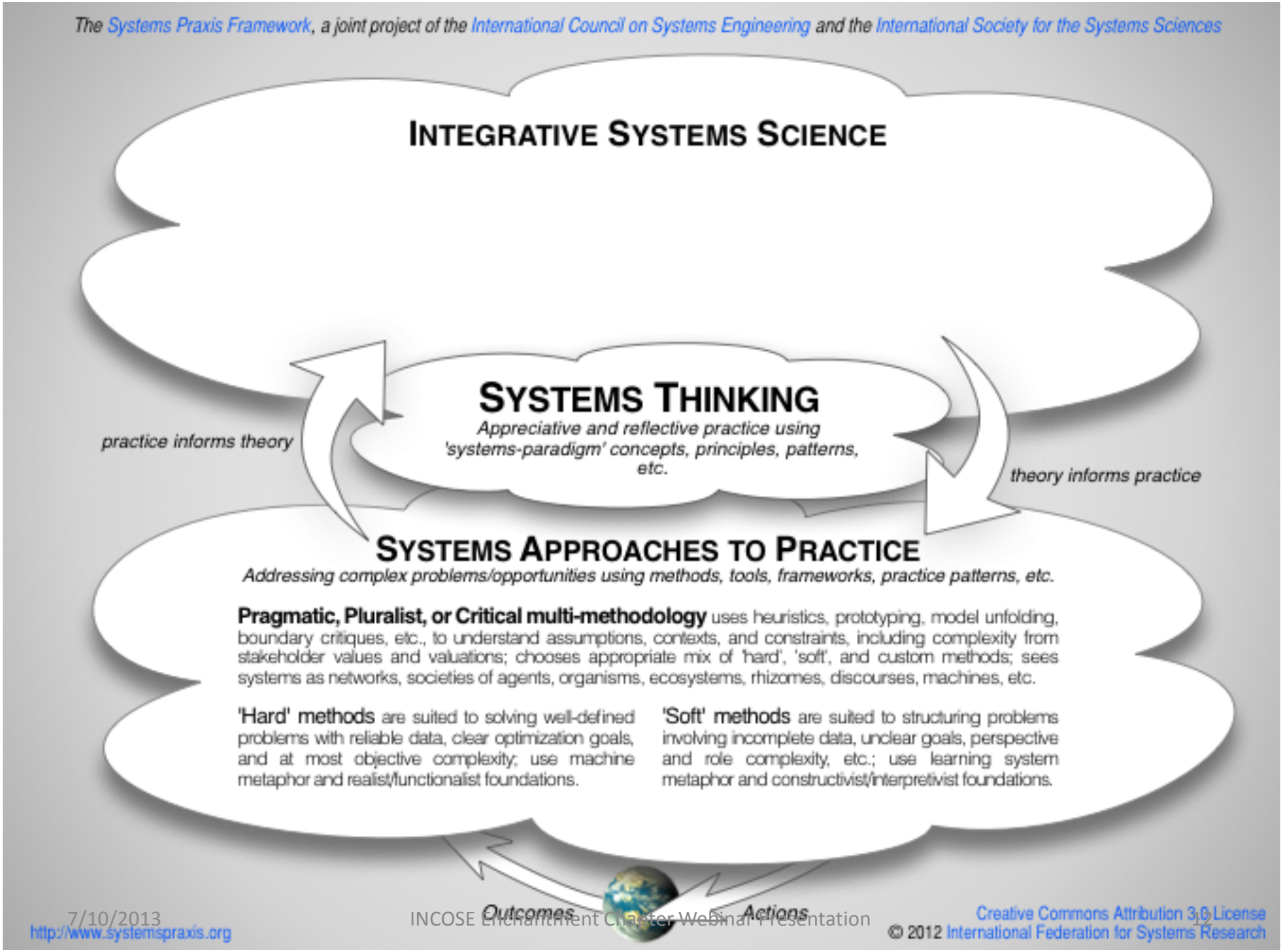
Hard and Soft Aspects



Hillary Sillitto, 2009-2010


The Systems Praxis Framework, a joint project of the International Council on Systems Engineering and the International Society for the Systems Sciences
INTEGRATIVE SYSTEMS SCIENCE
SYSTEMS THINKING
Appreciative and reflective practice using 'systems-paradigm' concepts, principles, patterns, etc.
practice informs theory
theory informs practice
SYSTEMS APPROACHES TO PRACTICE
Addressing complex problems/opportunities using methods, tools, frameworks, practice patterns, etc.
Pragmatic, Pluralist, or Critical multi-methodology uses heuristics, prototyping, model unfolding, boundary critiques, etc., to understand assumptions, contexts, and constraints, including complexity from stakeholder values and valuations; chooses appropriate mix of 'hard', 'soft', and custom methods; sees systems as networks, societies of agents, organisms, ecosystems, rhizomes, discourses, machines, etc.
'Hard' methods are suited to solving well-defined problems with reliable data, clear optimization goals, and at most objective complexity; use machine metaphor and realist/functionalist foundations.
'Soft' methods are suited to structuring problems involving incomplete data, unclear goals, perspective and role complexity, etc.; use learning system metaphor and constructivist/interpretivist foundations.
Outcomes
Actions
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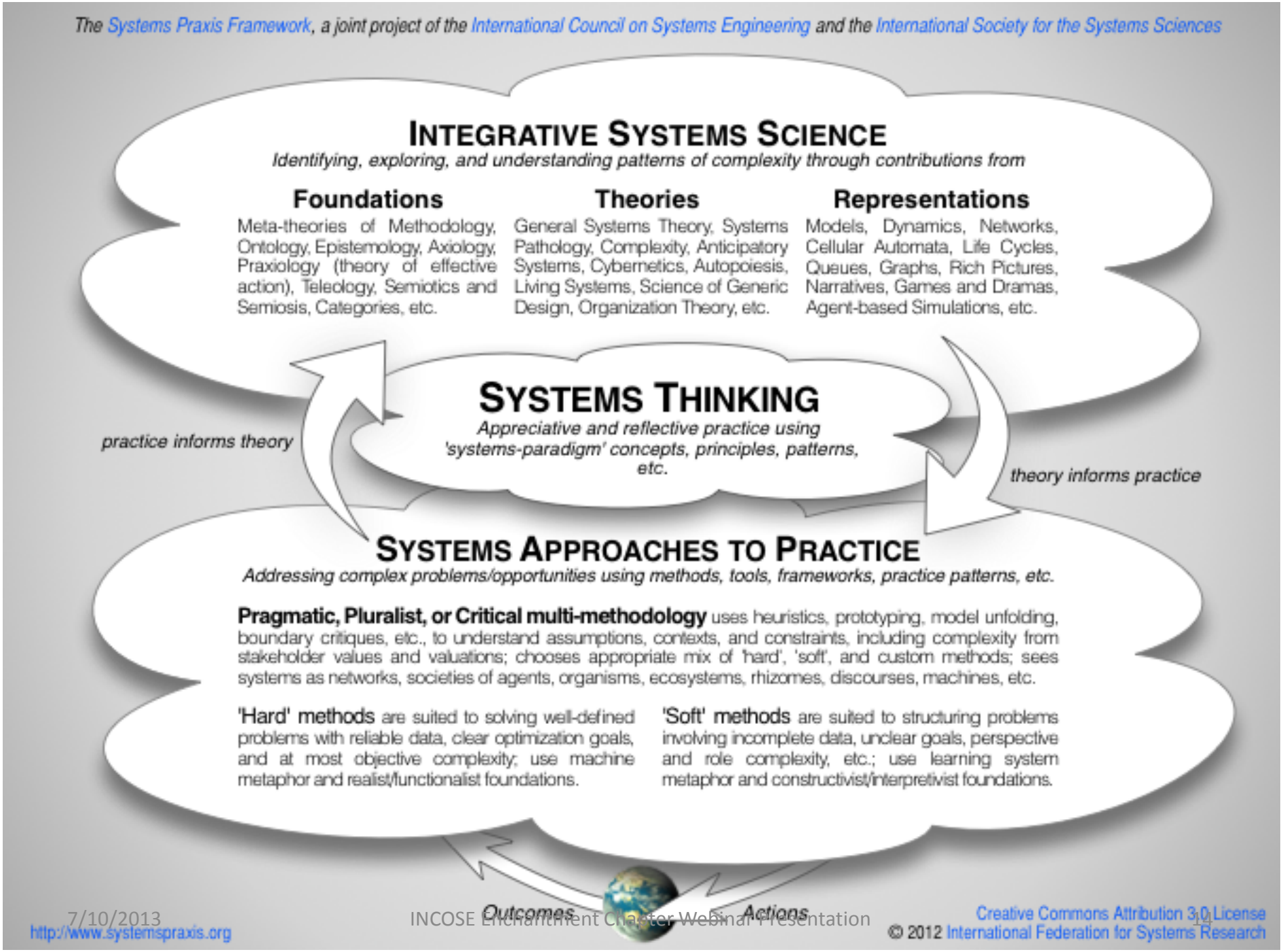
Elements of the Three Cultures

(following Cross 2001)

Culture	Phenomena	Methods	Values
Science	Natural world	• Controlled experiment • Classification • Analysis	• Objectivity • Rationality • Neutrality • Concern for 'truth'
Humanities	Human experience	• Analogy • Metaphor • Criticism • Evaluation	• Subjectivity • Imagination • Commitment • Concern for 'justice'
Design	Man-made world	• Modelling • Pattern-formation • Synthesis	• Practicality • Ingenuity • Empathy • Concern for 'appropriateness'


The Systems Praxis Framework, a joint project of the International Council on Systems Engineering and the International Society for the Systems Sciences
INTEGRATIVE SYSTEMS SCIENCE
Identifying, exploring, and understanding patterns of complexity through contributions from
Foundations
Meta-theories of Methodology, Ontology, Epistemology, Axiology, Praxiology (theory of effective action), Teleology, Semiotics and Semiosis, Categories, etc.
Theories
General Systems Theory, Systems Pathology, Complexity, Anticipatory Systems, Cybernetics, Autopoiesis, Living Systems, Science of Generic Design, Organization Theory, etc.
Representations
Models, Dynamics, Networks, Cellular Automata, Life Cycles, Queues, Graphs, Rich Pictures, Narratives, Games and Dramas, Agent-based Simulations, etc.
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Scientific Disciplines e.g., Physics, Neuroscience

Humanistic Disciplines e.g., Psychology, Culture, Rhetoric

INTEGRATIVE SYSTEMS SCIENCE

Identifying, exploring, and understanding patterns of complexity through contributions from

Foundations

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Representations

Models, Dynamics, Networks, Cellular Automata, Life Cycles, Queues, Graphs, Rich Pictures, Narratives, Games and Dramas, Agent-based Simulations, etc.

Pragmatic Disciplines e.g., Accounting, Design, Law

Formal Disciplines e.g., Math, Logic, Computation

practice informs theory

SYSTEMS THINKING

Appreciative and reflective practice using 'systems-paradigm' concepts, principles, patterns, etc.

theory informs practice

SYSTEMS APPROACHES TO PRACTICE

Addressing complex problems/opportunities using methods, tools, frameworks, practice patterns, etc.

direct input from disciplines

measured and specified data, metrics, etc.

Pragmatic, Pluralist, or Critical multi-methodology uses heuristics, prototyping, model unfolding, boundary critiques, etc., to understand assumptions, contexts, and constraints, including complexity from stakeholder values and valuations; chooses appropriate mix of 'hard', 'soft', and custom methods; sees systems as networks, societies of agents, organisms, ecosystems, rhizomes, discourses, machines, etc.

'Hard' methods are suited to solving well-defined problems with reliable data, clear optimization goals, and at most objective complexity; use machine metaphor and realist/functionalist foundations.

'Soft' methods are suited to structuring problems involving incomplete data, unclear goals, perspective and role complexity, etc.; use learning system metaphor and constructivist/interpretivist foundations.

input from experience and legacy practices

solicited local values, knowledge, etc.

Outcomes

Actions

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100+ Systems Processes

…mechanisms or isomorphies...

1. Allometry Patterns
2. Anergic Mechanisms
3. Ashby's Conjecture (Requisite)
4. Attractors (Point, Periodic)
5. Autopoiesis, Allopoiesis
6. Bifurcations
7. Boundary Conditions
8. Catastrophe Processes
9. Closed Systems
10. Competitive Processes
11. Cooperative Processes
12. Counterparity Mechanisms
13. Coupled Feedback Processes
14. Couplings, Interactions
15. Cycles and Cycling
16. Decay Processes
17. Deutsch's & Dollo's Conjecture
18. Dev't Patterns & Laws
19. Dissipative Str Processes
20. Duality Mechanisms
21. Emergence Processes
22. Energy Flow Processes
23. Entropy
24. Equilibrium Processes
25. Ergodic Processes
26. Evolutionary Processes
27. Exclusion Principle
28. Feedback Processes
29. Feedforward Processes
30. Fiegenbaums Constant
31. Field Dynamics
32. Fractal Structure, Time, & Process
33. Fragmentation Processes
34. Flows, Generic Rules
35. Growth Patterns & Laws
36. Hierarchical Structure & Process
37. Homeostatic Processes
38. Hypercycles
39. Input Mechanisms
40. Information Flow Processes
41. Integration Processes
42. Instability Mechanisms
43. Least Action/Energy Principles
44. Lifestage Cycles
45. Limit Cycle Processes
46. Limits, Physical
47. Limits, Informational
48. Lotka-Volterra Substitutions
49. Lyapunov Functions
50. Maximality Principles
51. Meta-Heterarchical Str & Processes
52. Minimization Principles
53. Morphodynamic Processes
54. Negative Entropy
55. Negative Feedback Mechanisms
56. Network Dynamics
57. Non-Equilibrium Thermodynamics
58. Open Systems
59. Oscillations
60. Output Processes
61. Periodic Processes
62. Phases
63. Plenitude, Principle of
64. Positive Feedback Mechanisms
65. Potential Spaces or Fields
66. Power Spectrum of Physics
67. Replication-Recursive Mechanisms
68. Restructuring Rules
69. Self-Organizing Processes
70. Singularities
71. Soliton Theory (Long Waves)
72. Spin Processes
73. Stability Processes
74. States
75. Steady State Mechanisms
76. Strings, Generic Systems
77. Symmetry, Systems-Level
78. System Identification, Sub-, Super
79. Taxonomy, Systems
80. Transgressive Equilibrium
81. Variation Mechanisms
82 .Zipf's/Pareto's Conjecture

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Natural Science Literature

Case Studies

"Not only the usual natural sciences that serve as a source of info. for our new sys of sys process theory, it is the new systems-based versions of those sciences. They have recently discovered their obligate complex systems natures."

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Sample SPT Linkage Propositions

- Transitions/Phases/Modes are in part the result of Symmetry Breaks in Linkages.
- Symmetry Breaking is a partial cause of Scalar Emergence.
- Hierarchical Structure is a partial result of Scalar Emergence.
- Coupled Negative & Positive Feedbacks are a partial cause of Dynamic Equilibrium
- Non-Equilibrium Thermodynamics is a necessary condition for Diffusion Limited Aggregation.
- Diffusion Limited Aggregation is a partial cause of Fractal Structure.
- Non-Equilibrium Thermodynamics is a necessary condition for Fractal Structure.

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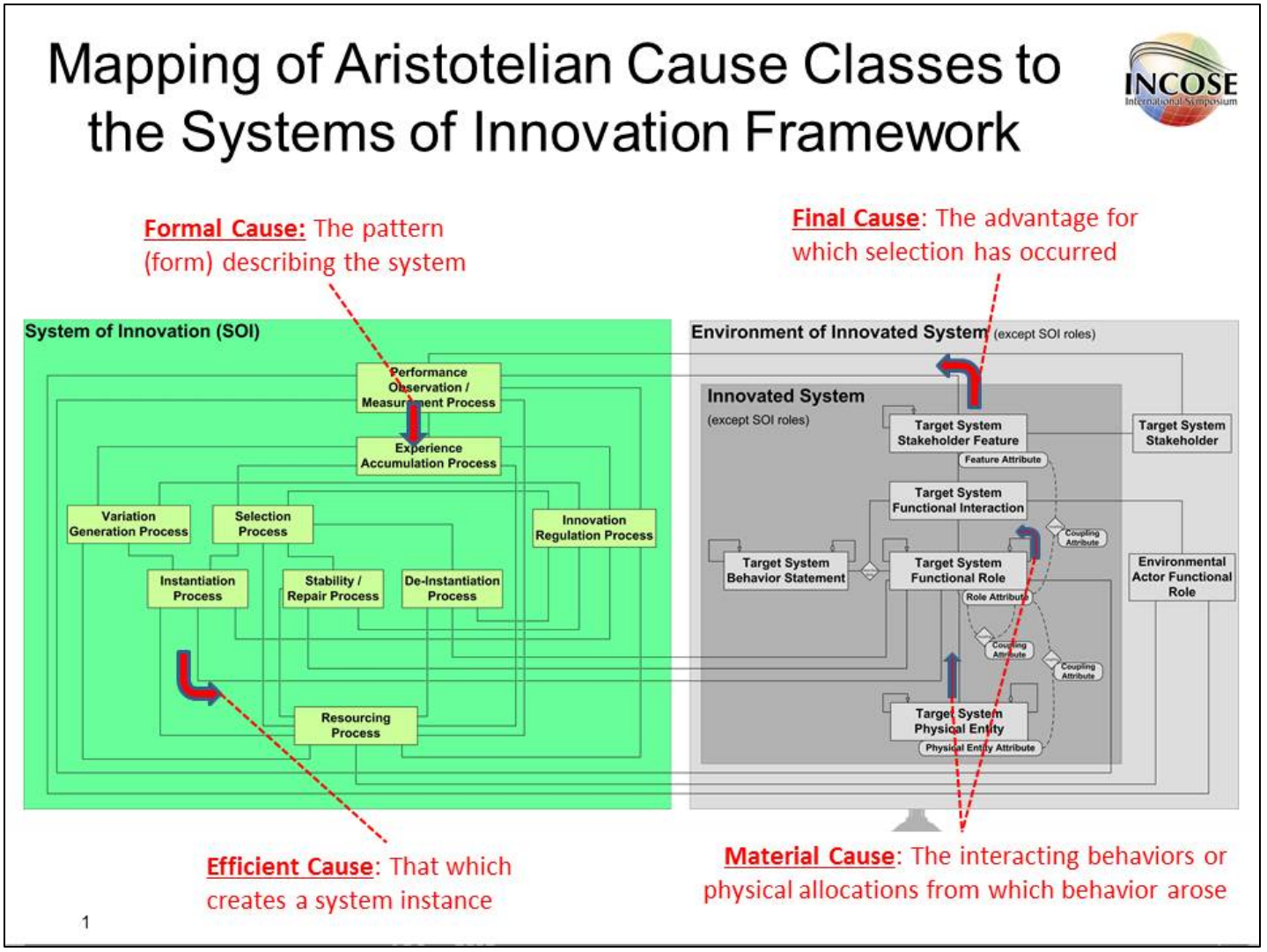
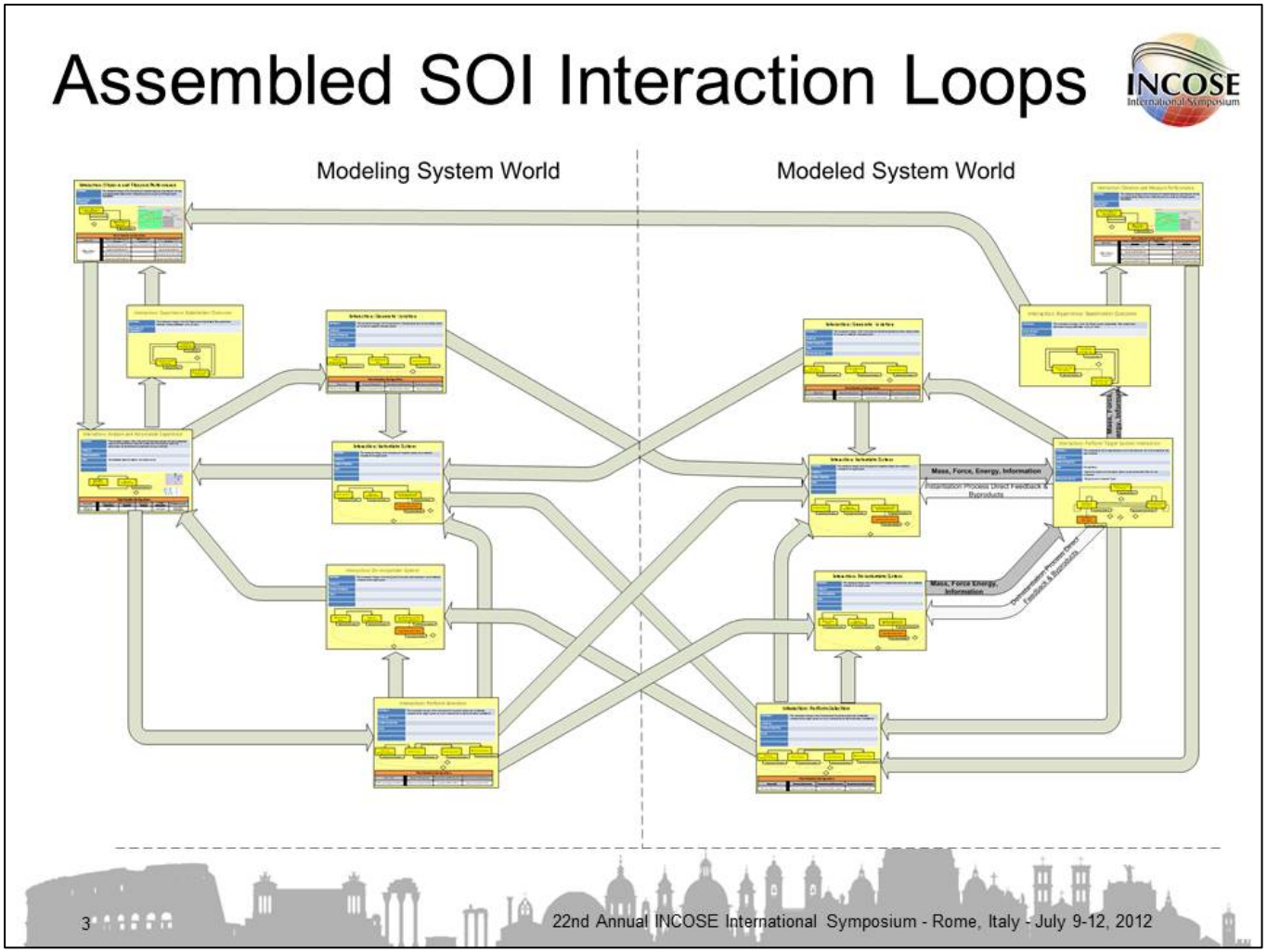
Systems of Innovation



Bill Schindel & Bruce Beihoff – IW13

Interacting Loops of Innovation



Bill Schindel & Bruce Beihoff – IW13

Relational Complexity Theory

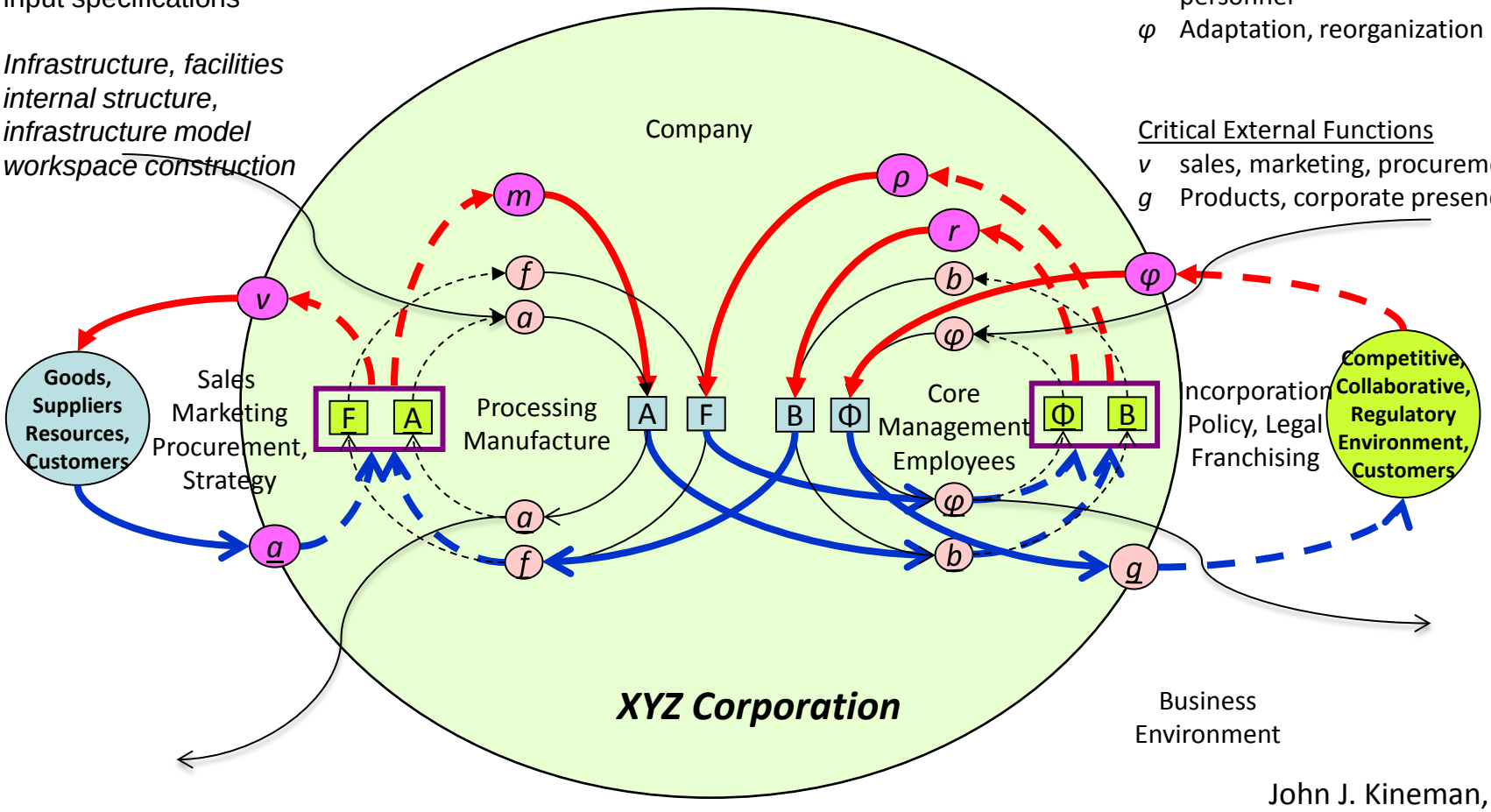
Components
- *A* *Stockpile of raw materials*
- *a* waste
- *A* resource model
- *a* input specifications

- *B* *Infrastructure, facilities*
- *b* *internal structure,*
- *B* *infrastructure model*
- *b* *workspace construction*

- *F* *Operations*
- *f* *QA tracking*
- *F* *Operational model*
- *f* *Jobs, tasks, etc.*

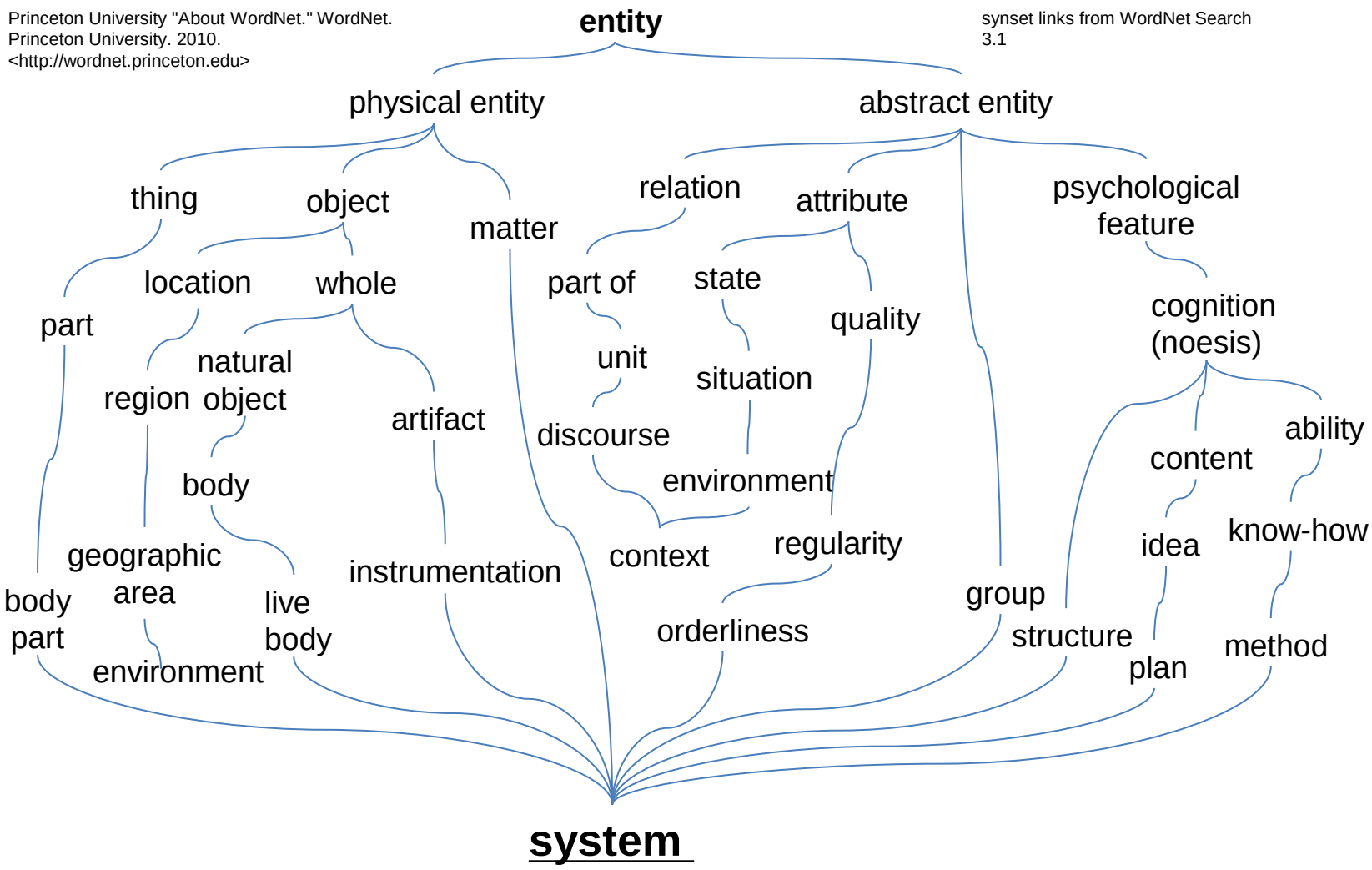
Critical Internal Functions
- *m* Milling the wood
- *ρ* Replication
- *r* Quality Control, maintenance, personnel
- *φ* Adaptation, reorganization

Critical External Functions
- *v* sales, marketing, procurement
- *g* Products, corporate presence

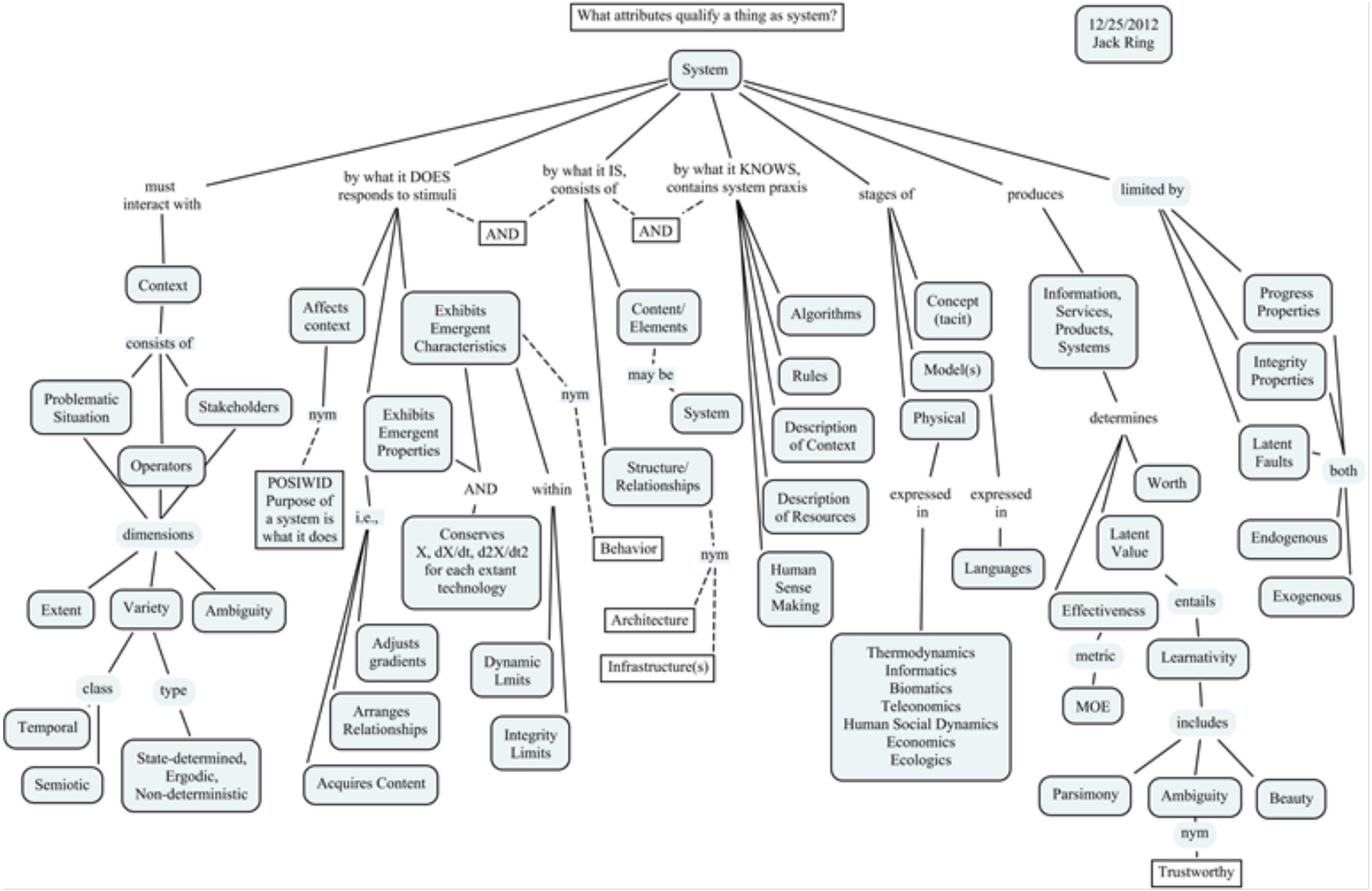


John J. Kineman, IW12

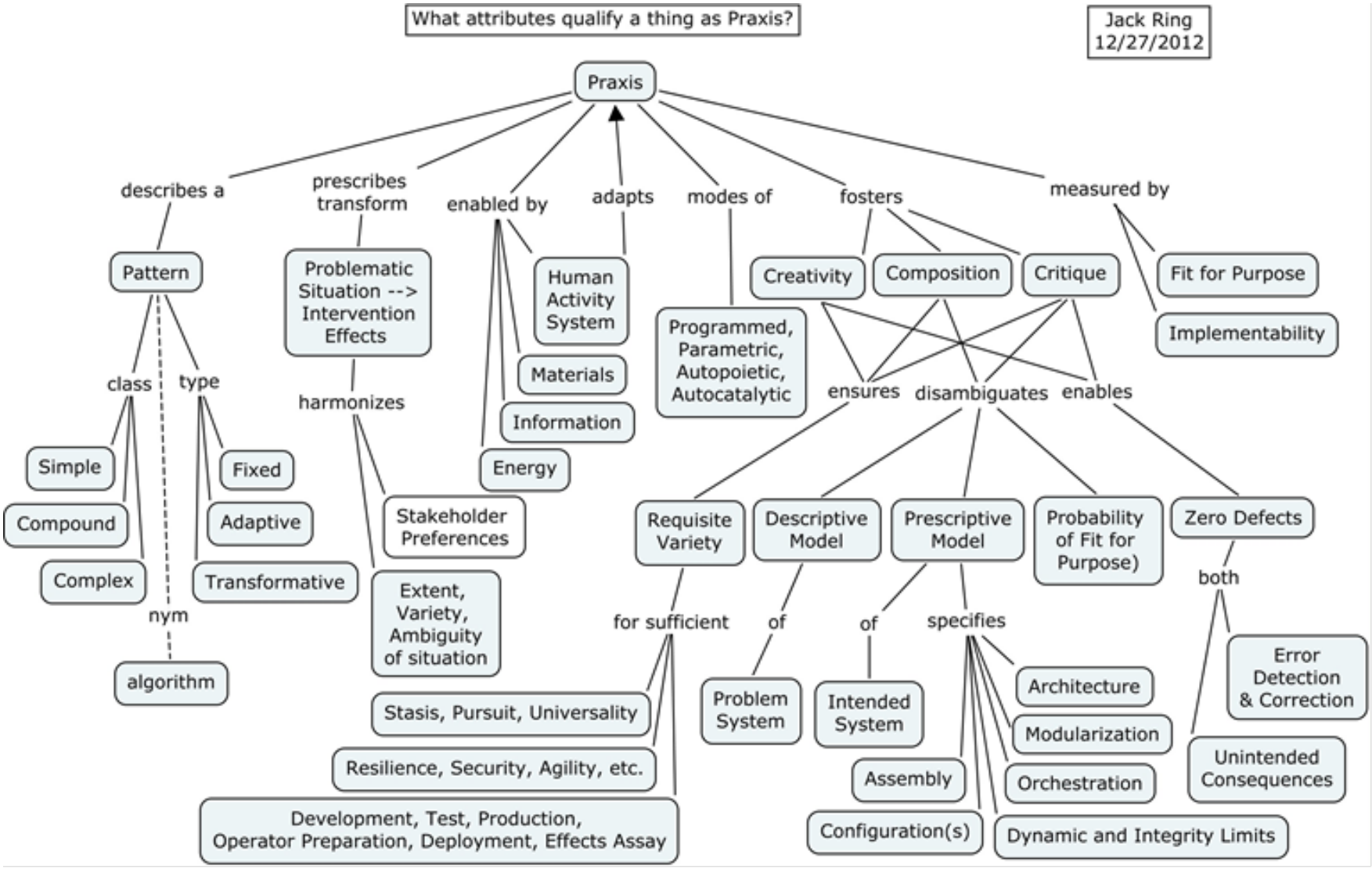
a **system** for everyone



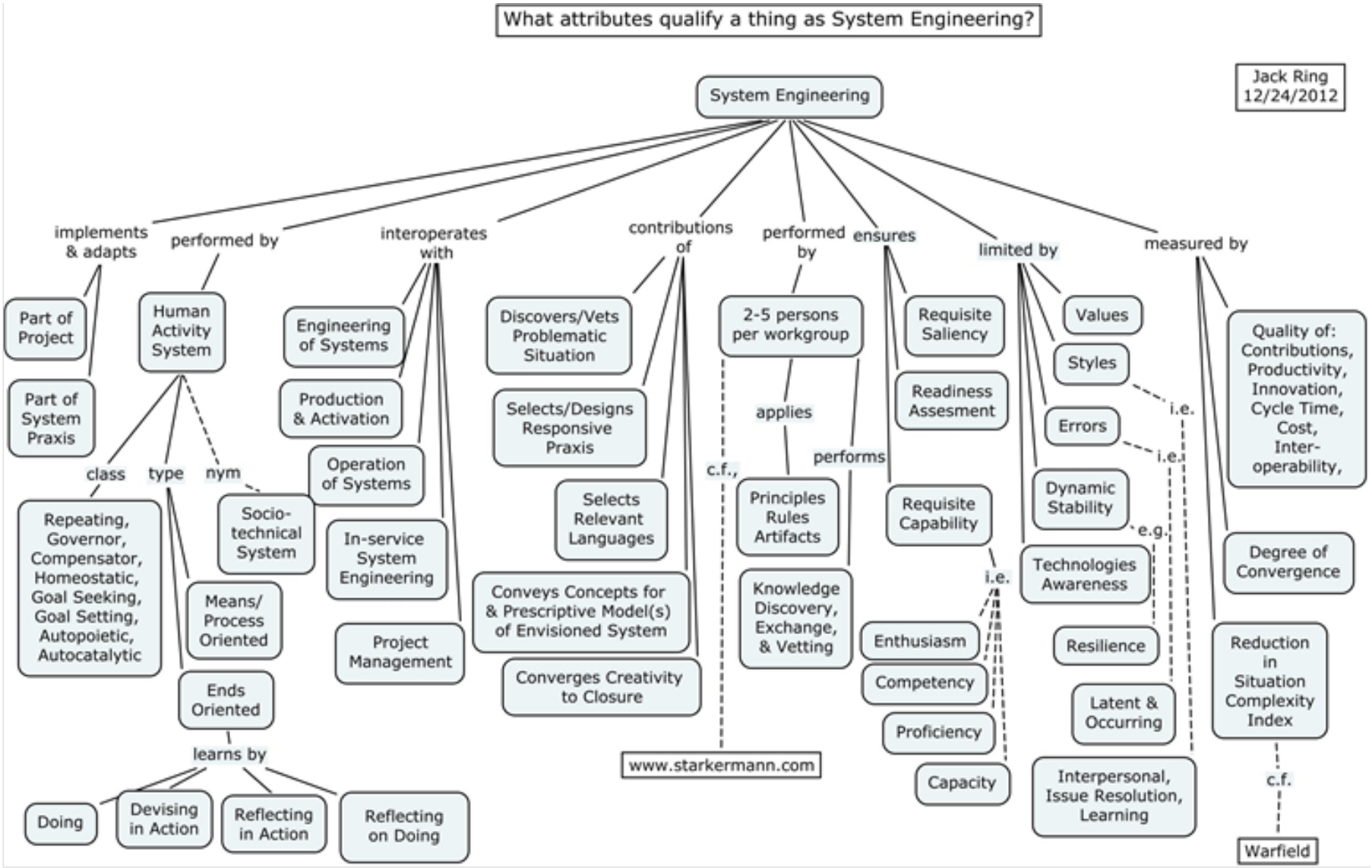
Concept Map - System



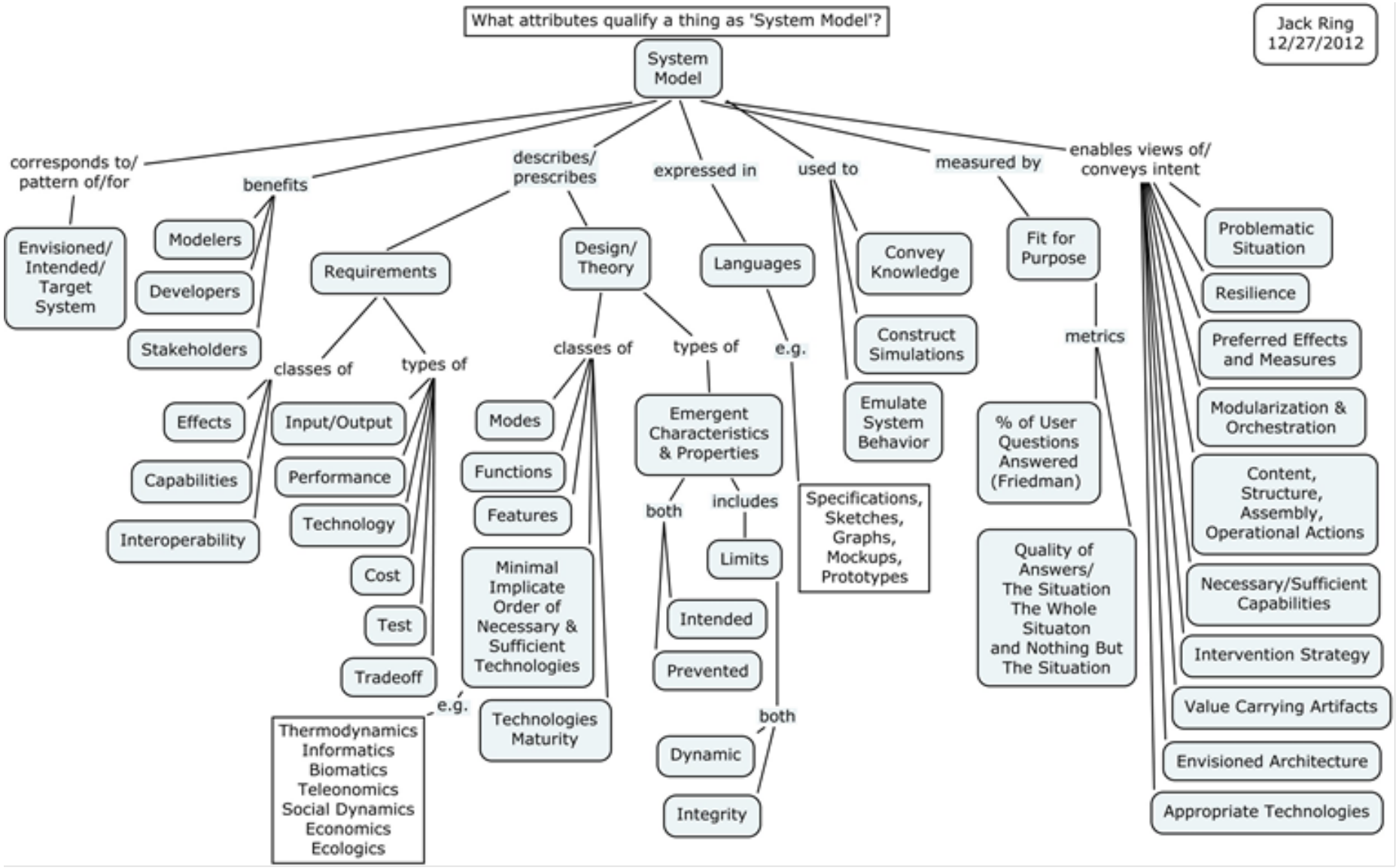
Concept Map - Praxis



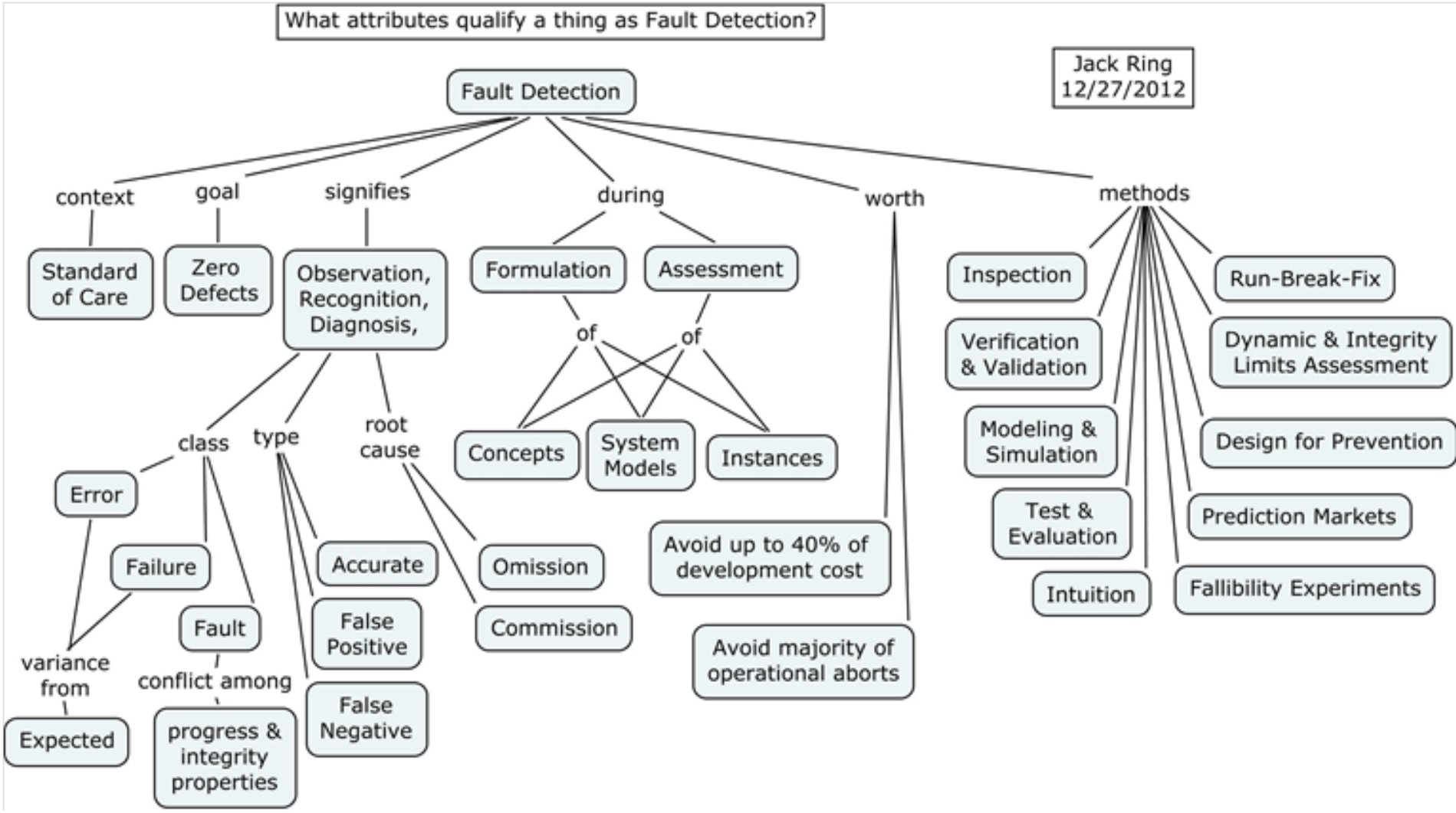
Concept Map – System Engineering



Concept Map – System Model

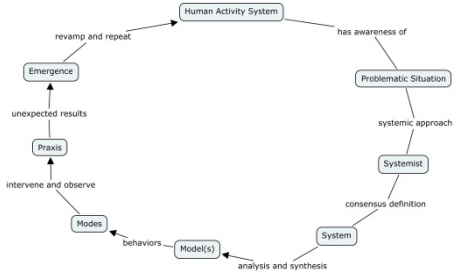


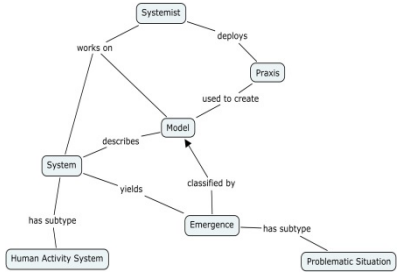
Concept Map – Fault Detection

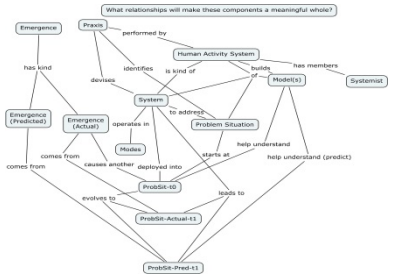


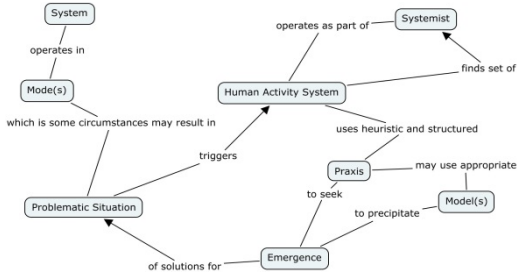
The ontology conundrum

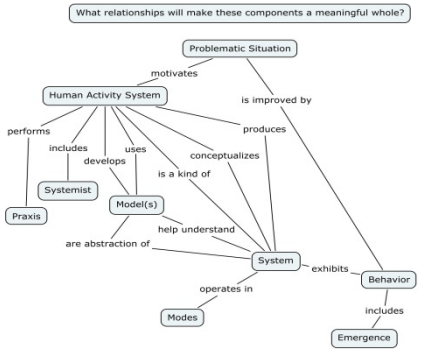
8 participants and 8 terms - emergence, human activity system, model, modes, praxis, problematic situation, system, systemist

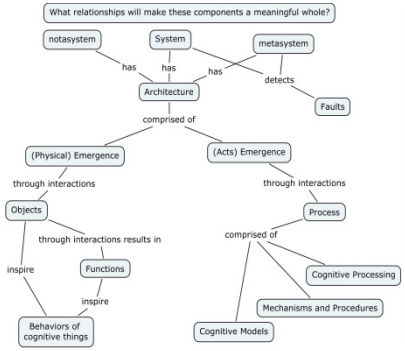


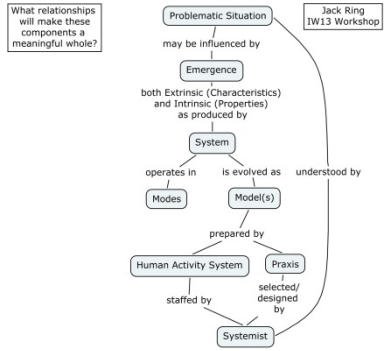


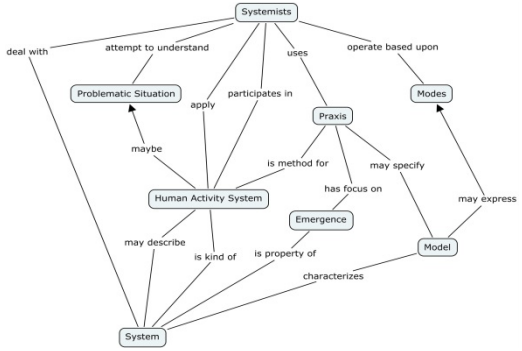








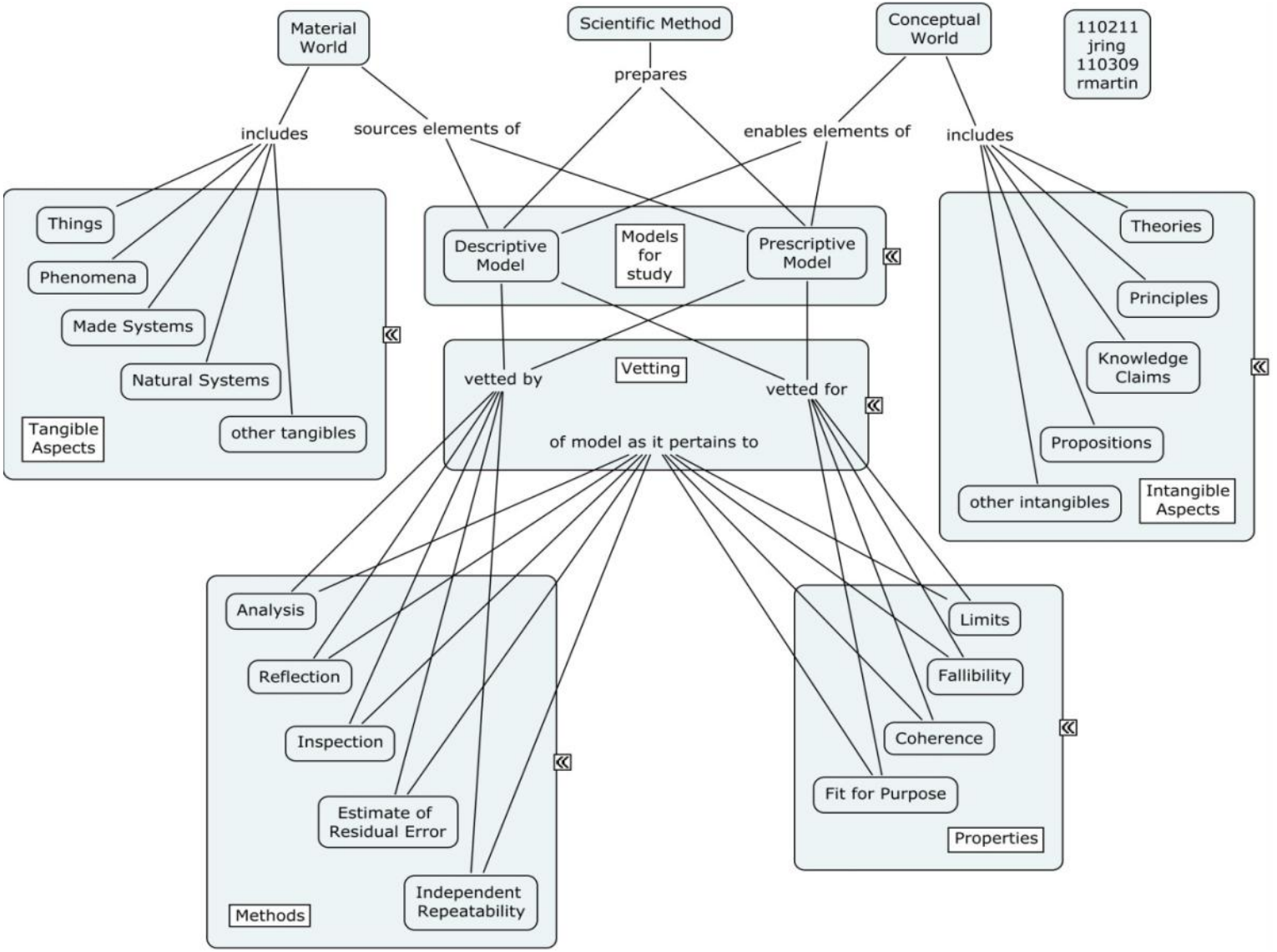




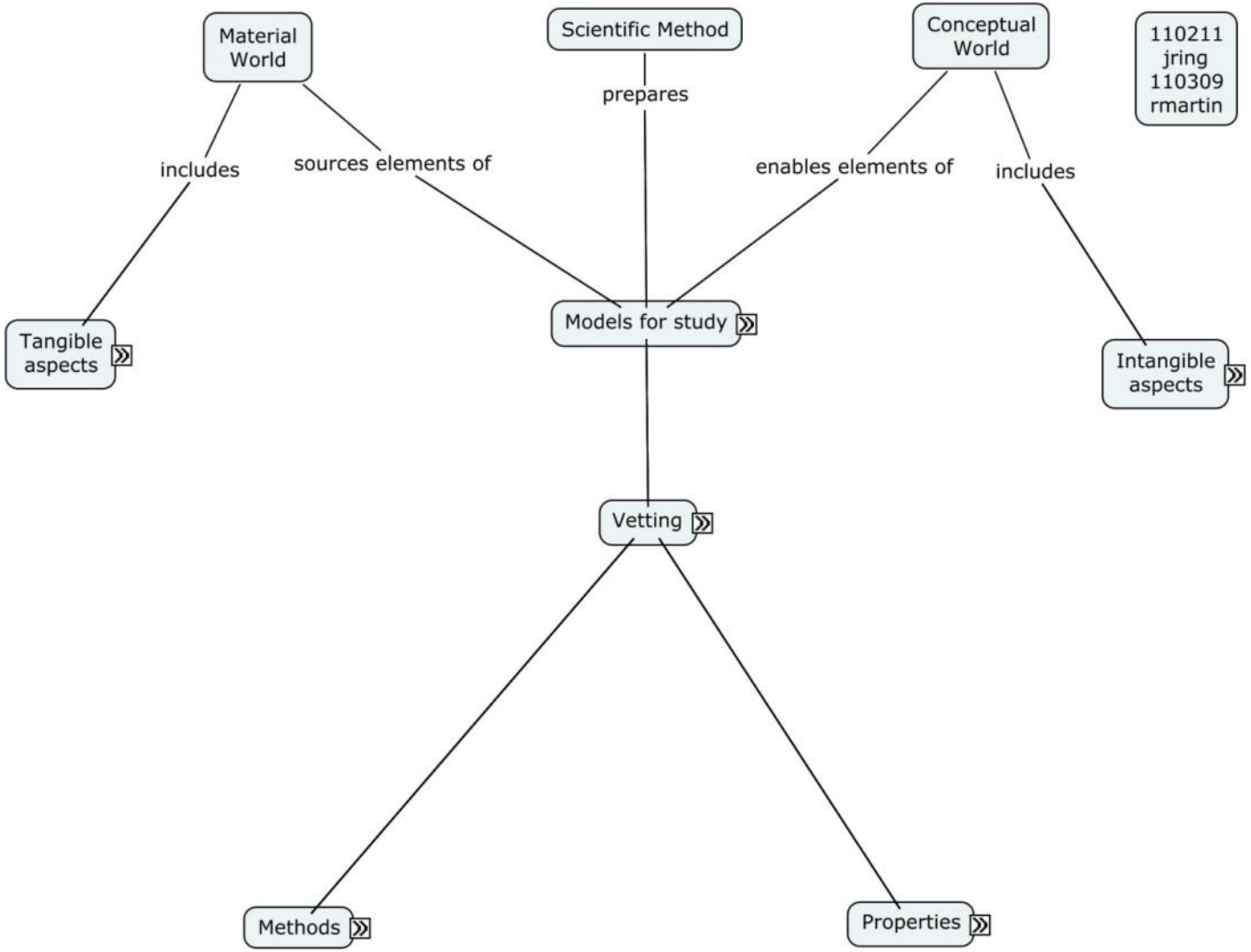
yields 104 propositions (99 distinct), 27 of which include another term

Spreadthink reigns supreme!

Similar Methodology?



Or just a Use Case Actor?



SysSciWG Admin

- Members of the Systems Science Working Group meet twice a year at the INCOSE International Workshop and the International Symposium.
  - Contact Systems Science Working Group (Systems-Science@incose.org) for additional information or to join this group.
- Collaboration
  - http://groups.google.com/group/syssciwg (about 120 members)
  - https://sites.google.com/site/syssciwg2013 (SSWG wiki site-**NEW**)
  - http://syscoi.com/commons/ (Systems Community of Inquiry)
  - http://cmapspublic.ihmc.us/rid=1275487929775_861803180_25975/SSWG (cmap sharepoint site)
  - ~~SS-discuss@incose.org~~ (discontinued)