Australian National University

COMP3530/6353
Systems Engineering for Software Engineers

Systems Engineering

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Outline

- We will take a helicopter view of Systems Engineering **key concepts** using the *Systems Engineering Body of Knowledge (SEBoK)* as a guide

SEBoK

http://sebokwiki.org

Outline

Introduction

- Systems Engineering overview
- Economic value of Systems Engineering
- Systems Engineering and other disciplines

Foundations of Systems Engineering

- The Systems Praxis Framework
- System Fundamentals
- Systems Science
- Systems Thinking

Systems Engineering and Management

- Lifecycle processes
- Lifecycle models

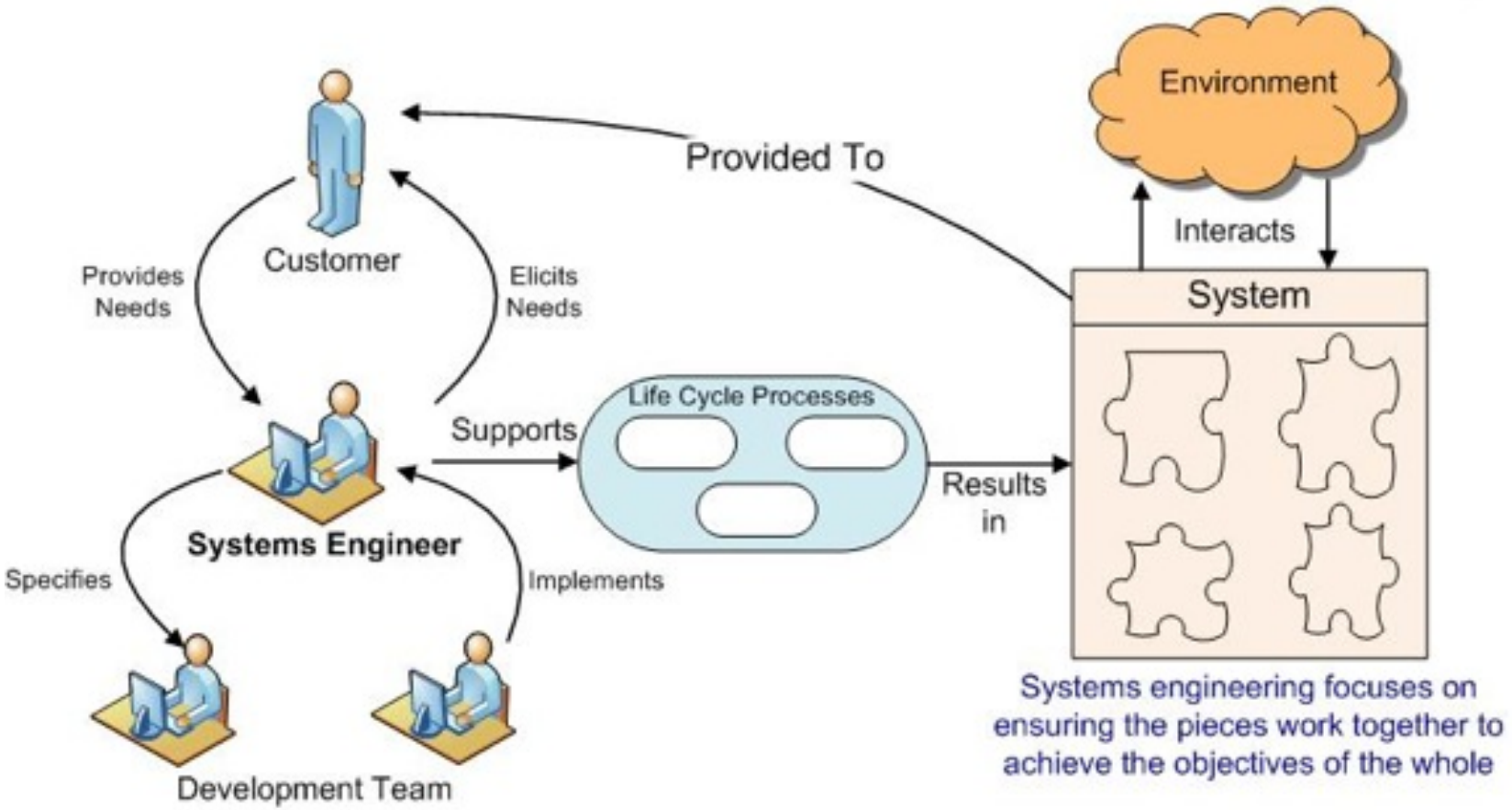
Introduction – *SE Overview*

SE is an interdisciplinary approach and means to enable the realization of successful systems.

- Products
- Services
- Enterprises
- Systems of Systems (SoS)

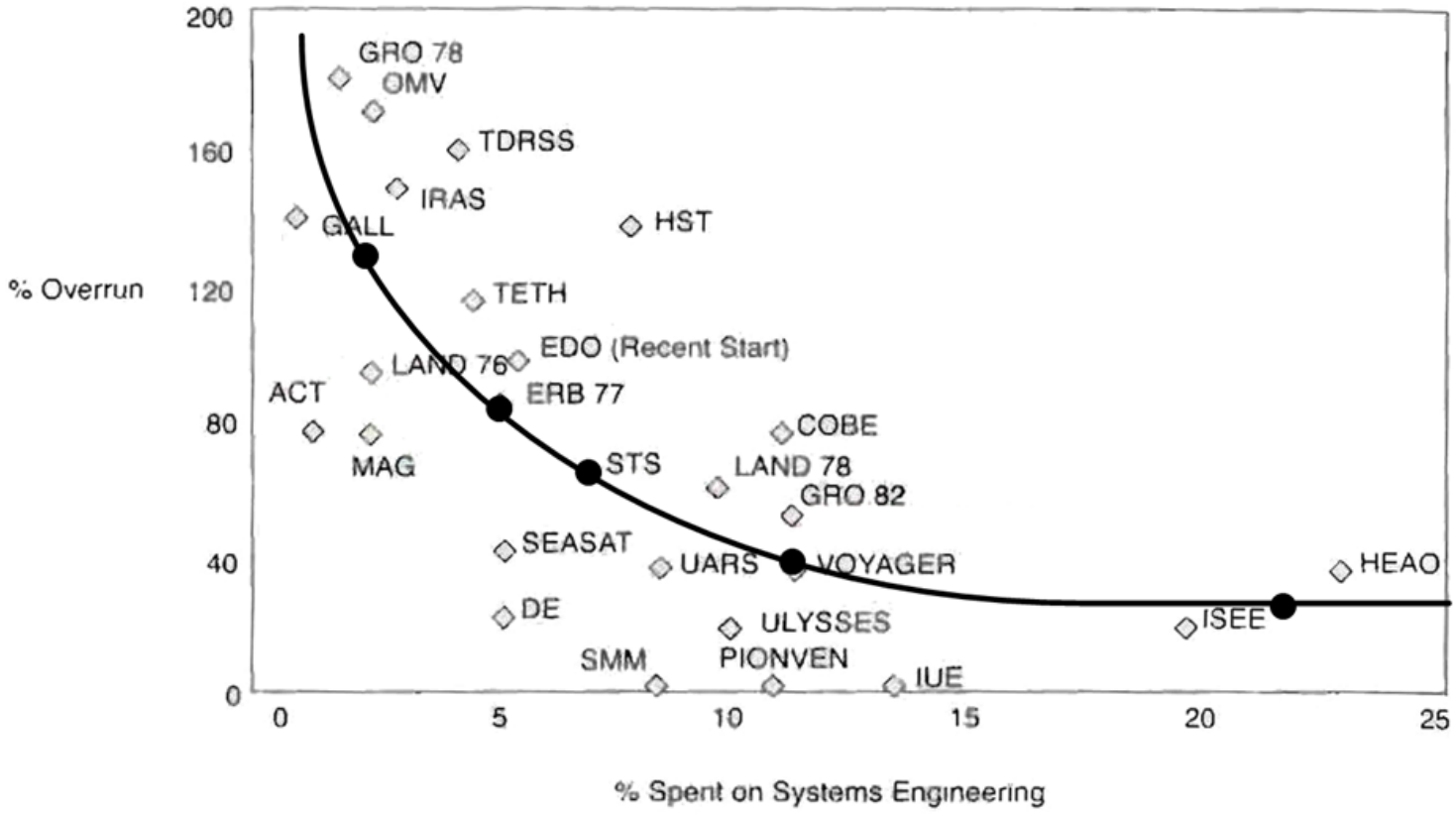
Successful systems must satisfy the needs of their customers, users and other stakeholders.

Introduction – *SE Overview*



http://sebokwiki.org/wiki/File:SE_Key_Concepts.jpeg

Introduction – *Economic Value of SE*



*Source: Werner M. Gruhl, Chief Cost & Economics Analysis Branch, NASA Headquarters

Introduction – *SE and other Disciplines*

SE and Software Engineering

SE and Project Management

SE and Specialisations

- Reliability
- Human Systems
- Safety
- Security
- Manufacturing
- Environment

Introduction – *SE and other Disciplines*

Non-Engineering Disciplines

- Art
- Economics
- Law
- Psychology
- Science
- Sociology

Foundations of SE – *The Systems Praxis Framework*

Praxis

- integrating theory and practice

Systems Praxis

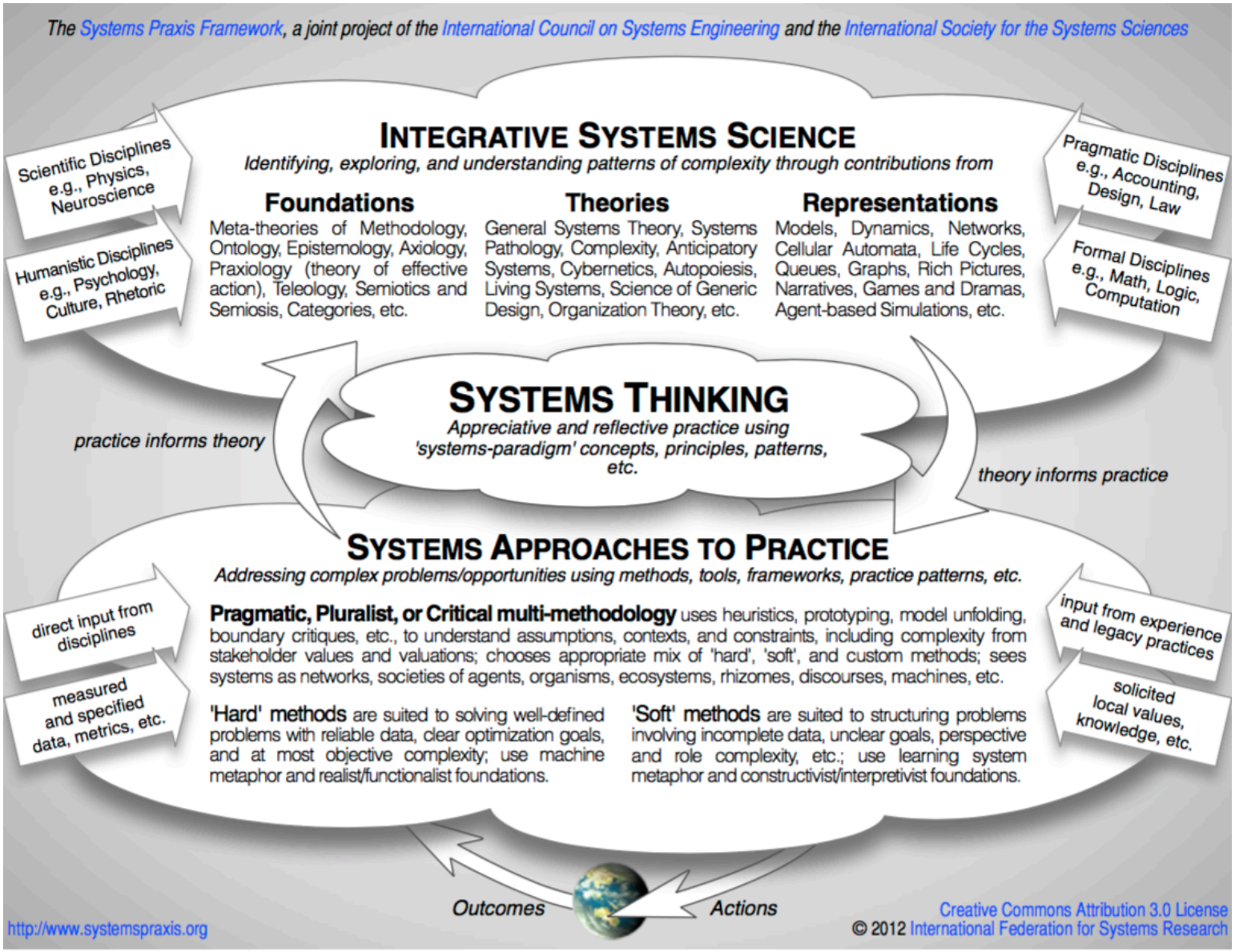
- the entire intellectual and practical endeavor of creating holistic solutions to complex system challenges.

Foundations of SE – *The Systems Praxis Framework*

The Systems Praxis Framework

- Jointly developed by
  - *International Council on Systems Engineering* (INCOSE) and
  - *International Society for the System Sciences* (ISSS)

- Integrates Systems Science and Practice via Systems Thinking


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
Scientific Disciplines e.g., Physics, Neuroscience
Humanistic Disciplines e.g., Psychology, Culture, Rhetoric
Pragmatic Disciplines e.g., Accounting, Design, Law
Formal Disciplines e.g., Math, Logic, Computation
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.
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
http://www.systemspraxis.org
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Foundations of SE – *System Fundamentals*

A System is a set of elements in interaction

(Bertalanffy, L., von. 1968. General System Theory: Foundations, Development, Applications, rev. ed. New York, NY, USA: Braziller.)

- The elements of a system may be *Natural, Social, Abstract or Technical.*
- Interaction may involve *influence, flows of materials, flows of information*

Foundations of SE – *System Fundamentals*

Systems Hierarchy

- A system comprises a set of elements that exists within the context of a larger system
- The elements of a system are systems themselves
- An 'endless' hierarchy

System of Interest (SoI)

- Defined by a boundary around a set of elements
- For a specific purpose
  - study, development, explanation ….

Foundations of SE – *System Fundamentals*

System Environment

- "The surroundings (natural or man-made) in which the system-of-interest is utilized and supported; or in which the system is being developed, produced or retired."

(INCOSE Systems Engineering Handbook, version 3.2. San Diego, CA, USA: International Council on Systems Engineering (INCOSE), INCOSE-TP-2003-002-03.2.)

Foundations of SE – *System Fundamentals*

Open Systems

- exchange inputs and outputs with their environment

Closed Systems

- Have no interaction with their environment
- Useful for abstract systems and for some theoretical system descriptions

Foundations of SE – *System Fundamentals*

Open System Domains

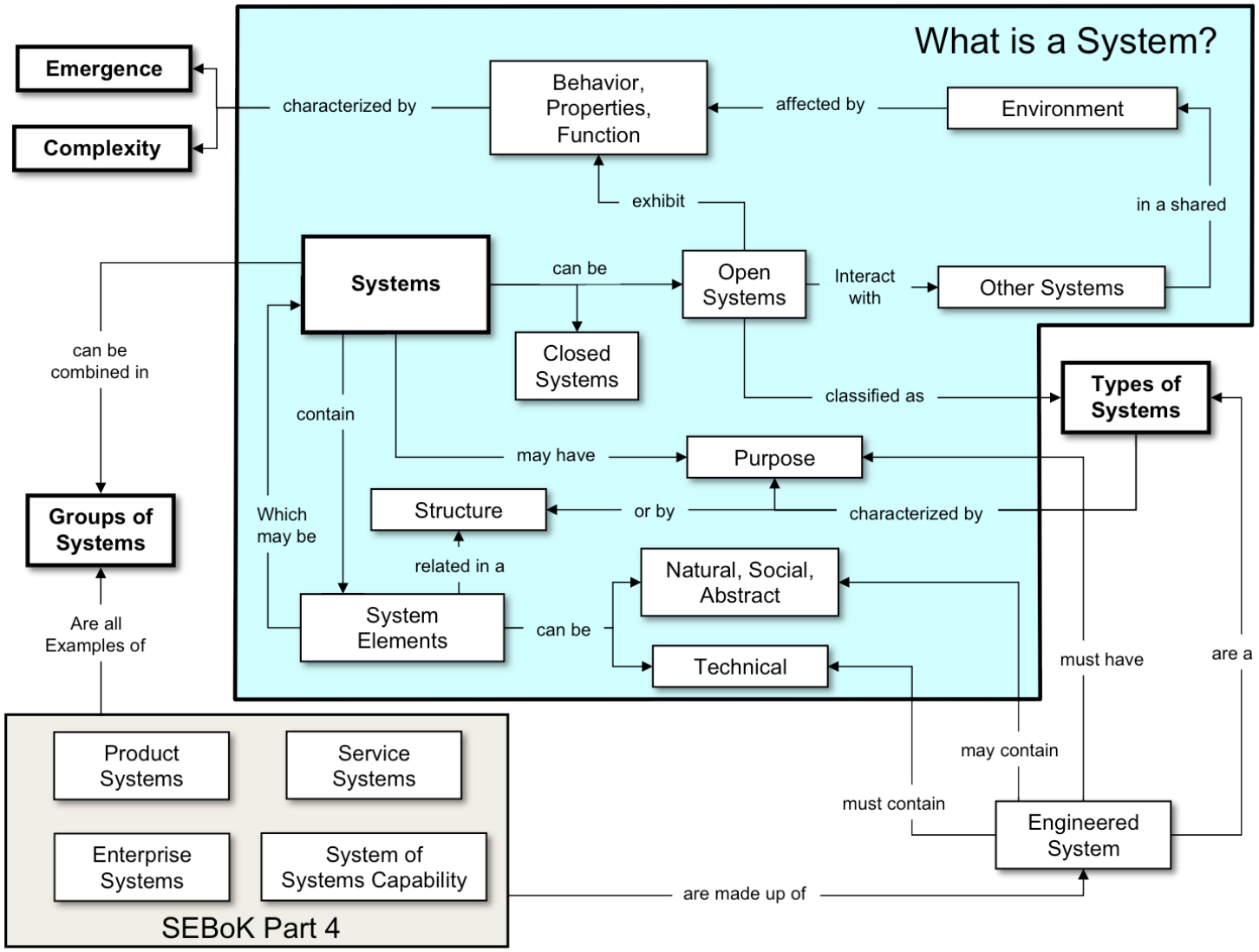
- Natural Systems
  - Solar System
  - Weather system
  - Digestive system
- Social Systems
  - UN Security Council
  - Business
  - The Research School of Computer Science
- Engineered Systems
  - Bridges
  - Aircraft
  - Software

Foundations of SE – *System Fundamentals*

Other taxonomies

- **Boulding, K.** 1956 “General Systems Theory: Management Science, 2, 3 (Apr. 1956) pp.197-208; reprinted in General Systems, Yearbook of the Society for General Systems Research, vol. 1, 1956.
- **Bertalanffy, L. von**. 1968. *General System Theory*. New York, NY, USA: Brazillier.
- **Checkland, P.B**. 1999. *Systems Thinking, Systems Practice*. Chichester, UK: John Wiley & Sons Ltd.
- Many many more …

Foundations of SE – *System Fundamentals*



Foundations of SE – *System Fundamentals*

Complexity

- "A measure of how difficult it is to understand how a system will behave or to predict the consequences of changing it"

(Sheard, S.A. and A. Mostashari. 2009. "Principles of Complex Systems for Systems Engineering". Systems Engineering, 12(4): 295-311.)

Forms of Complexity

- Structural Complexity
- Dynamic Complexity
- Socio-Political Complexity

Foundations of SE – *System Fundamentals*

Emergence

- "The principle that whole entities exhibit properties which are meaningful only when attributed to the whole, not to its parts."
  (Checkland, P. B. 1999. *Systems Thinking, Systems Practice*. Chichester, UK: John Wiley & Sons Ltd.)

- Emergent system behavior can be viewed as a consequence of the interactions and relationships between system elements rather than the behavior of individual elements.
  (SEBoK)

Foundations of SE – *System Fundamentals*

Emergence

- System behaviour emerges from a combination of the behavior and properties of the system elements and the systems structure or allowable interactions between the elements, and may be triggered or influenced by a stimulus from the systems environment.
  (SEBoK)

Examples

- Hydrogen + Oxygen = Properties of a Water Molecule
- {Water Molecule} = Properties of a Liquid
- Life
- Consciousness
- The World Wide Web

Foundations of SE – *System Science*

Systems science, is an integrative discipline which brings together ideas from a wide range of sources which share a common systems theme.
(SEBoK)

Foundations of SE – *System Science*

General Systems Theory

- Attempt to formulate general principles applicable to all open systems – focus on relationships and system as a whole

Cybernetics

- studies the flow of information through a system and how information is used by the system to control itself through feedback mechanisms. (SEBoK)

Operations Research

- considers the use of technology by an organization.
- It is based on mathematical modeling and statistical analysis to optimize decisions on the deployment of the resources under an organizations control.
- It arises from military planning techniques developed during World War 2. (SEBoK)

Foundations of SE – *System Science*

Systems Analysis

- was developed by RAND Corporation in 1948.
- "… a systematic examination of a problem of choice in which each step of the analysis is made explicit wherever possible." (http://www.rand.org/content/dam/rand/pubs/research_memoranda/2006/RM1678.pdf)

System Dynamics (next week's lecture)

- Uses some of the ideas of cybernetics to consider the behavior of systems as a whole in their environment.
- System Dynamics was developed by Jay Forrester in the 1960's. He was interested in modeling the dynamic behavior of systems such as populations in cities, industrial supply chains. (SEBoK)

Foundations of SE – *System Science*

Hard Systems Thinking

- views of the world are characterized by the ability to define purpose, goals, and missions that can be addressed via engineering methodologies in an attempt to, in some sense, “optimize” a solution
- In hard system approaches the problems may be complex and difficult, but they are known and can be fully expressed by the investigator. (SEBoK)

Foundations of SE – *System Science*

Soft Systems Thinking

- considers a world characterized by complex, problematical, and often mysterious phenomena for which concrete goals cannot be established and which require learning in order to make improvement.
- Such systems are not limited to the social and political arenas and also exist within and amongst enterprises where complex, often ill-defined patterns of behavior are observed that are limiting the enterprise's ability to improve.
- Soft system approaches reject the idea of a single problem and consider problematic situations in which different people will perceive different issues depending upon their own viewpoint and experience.
- These problematic situations are not solved, but managed through interventions which seek to reduce "discomfort" among the participants.

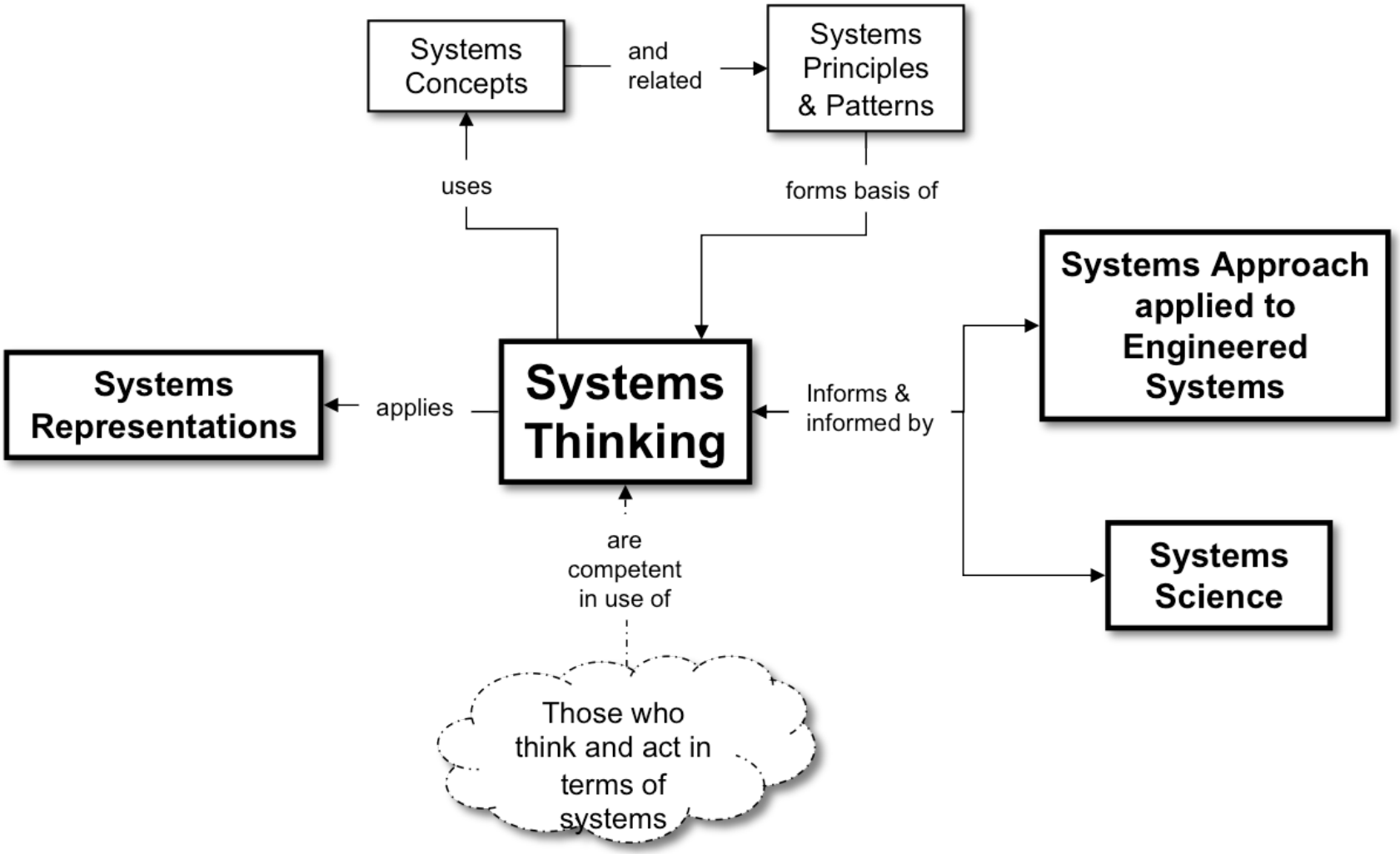
Foundations of SE – *Systems Thinking*

Systems thinking is concerned with understanding or intervening in problem situations, based on the principles and concepts of the systems paradigm.

Systems thinking considers the similarities between systems from different domains in terms of a set of common systems concepts, principles and patterns

- eg. Our own research looking at SCRUM vs Mental Health Research and General Administration – similarities in problem situations and approaches to dealing with them.

Foundations of SE – *Systems Thinking*



Foundations of SE – *Systems Thinking*

Other thoughts on Systems Thinking

- "a discipline for seeing wholes ... a framework for seeing interrelationships rather than things ... a process of discovery and diagnosis ... and as a sensibility for the subtle interconnectedness that gives living systems their unique character"
  [Senge, P.M. 1990, 2006. The Fifth Discipline: The Art and Practice of the Learning Organization. New York, NY, USA: Doubleday Currency.]
- "Systems thinking is the art of simplifying complexity. It is about seeing through chaos, managing interdependency, and understanding choice. We see the world as increasingly more complex and chaotic because we use inadequate concepts to explain it. When we understand something, we no longer see it as chaotic or complex."
  [Gharajedaghi, J. 1999. Systems Thinking: Managing Chaos and Complexity: A platform for designing. 1st ed. Woburn, MA: Butterworth-Heinemann.]
- Many more …

Foundations of SE – *Systems Thinking*

Separation of Concerns

- A key strategy for dealing with complexity- nicely described by Dijkstra:
  - *"Let me try to explain to you, what to my taste is characteristic for all intelligent thinking. It is, that one is willing to study in depth an aspect of one's subject matter in isolation for the sake of its own consistency, all the time knowing that one is occupying oneself only with one of the aspects. We know that a program must be correct and we can study it from that viewpoint only; we also know that it should be efficient and we can study its efficiency on another day, so to speak. In another mood we may ask ourselves whether, and if so: why, the program is desirable. But nothing is gained —on the contrary!— by tackling these various aspects simultaneously.* ***It is what I sometimes have called "the separation of concerns", which, even if not perfectly possible, is yet the only available technique for effective ordering of one's thoughts, that I know of.*** *This is what I mean by "focussing one's attention upon some aspect": it does not mean ignoring the other aspects, it is just doing justice to the fact that from this aspect's point of view, the other is irrelevant. It is being one- and multiple-track minded simultaneously."*

[Dijkstra, Edsger W (1982). "On the role of scientific thought". Selected writings on Computing: A Personal Perspective. New York, NY, USA: Springer-Verlag. pp. 60–66. ISBN 0-387-90652-5. Available from http://www.cs.utexas.edu/users/EWD/transcriptions/EWD04xx/EWD447.html]

Foundations of SE – *Systems Thinking*

I see Separation of Concerns in a broad sense

- Discipline or Specialisation
- Decomposition
- Abstraction
- Life-cycle processes

Each of these points of view focus attention on some aspect of a problem while remaining aware of other aspects (as per Dijkstra's writings above)

Foundations of SE – *Systems Thinking*

SoC – Discipline or Specialisation

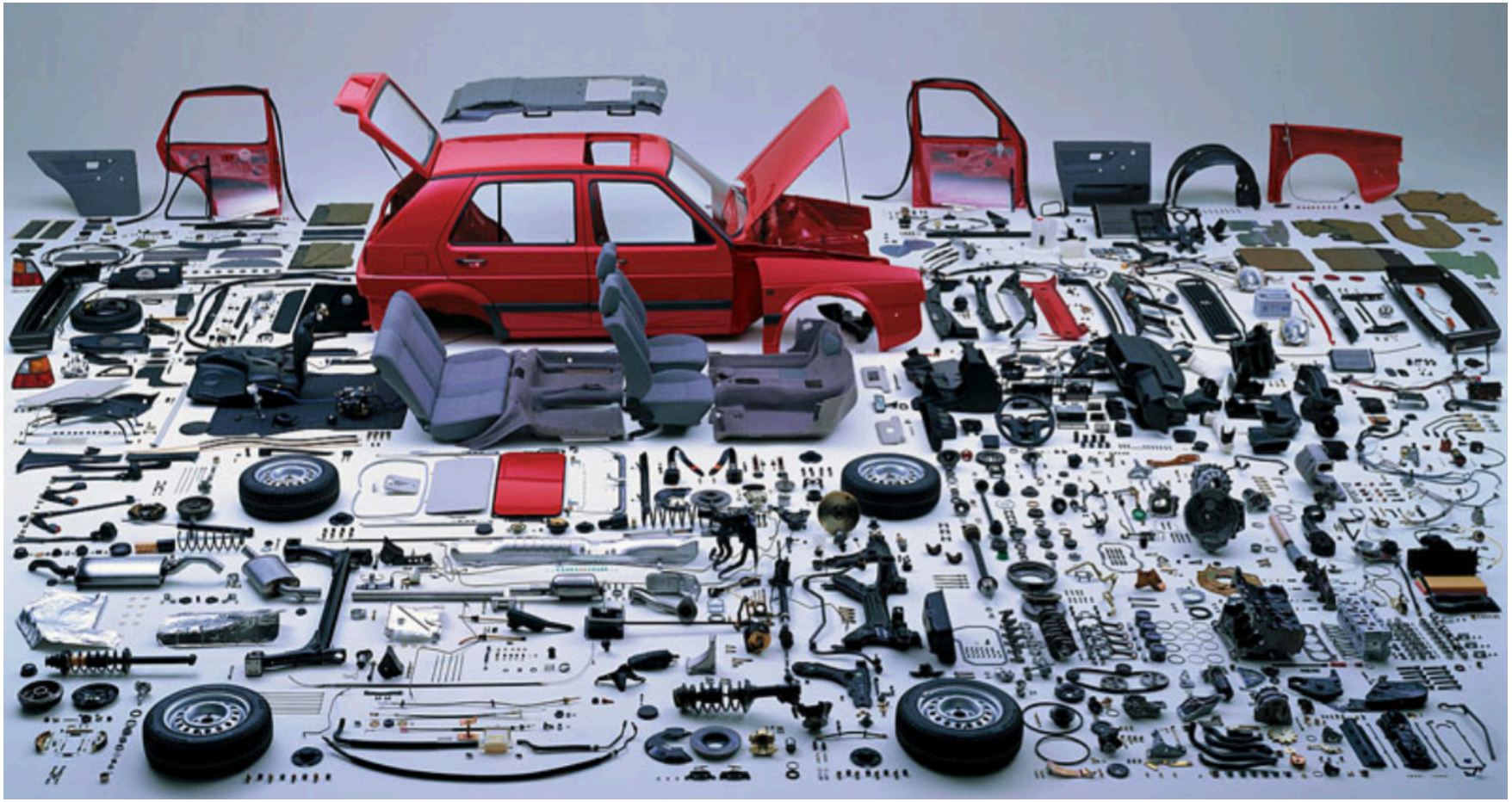
- Engineering
  - Aeronautical
  - Civil
  - Communication
  - Electrical
  - Mechanical
  - Chemical
  - Software
  - …
- Artists
- Lawyers
- Economists

Foundations of SE – *Systems Thinking*

SoC – Decomposition

Foundations of SE – *Systems Thinking*

SoC – Decomposition



Foundations of SE – *Systems Thinking*

SoC – Abstraction

- Removes detail for a specific purpose

A nice paper on abstraction:

- Zucker J-D. A grounded theory of abstraction in artificial intelligence. *Philosophical Transactions of the Royal Society B: Biological Sciences*. 2003;358(1435):1293-1309.

SE and Management – *Lifecycle Processes*

ISO Standard 15288:2015
Software and Systems Engineering – System Lifecycle Processes

Organises processes into four groups

- Agreement processes
- Organisational project-enabling processes
- Technical management processes
- Technical processes

SE and Management – *Lifecycle Processes*

Technical processes

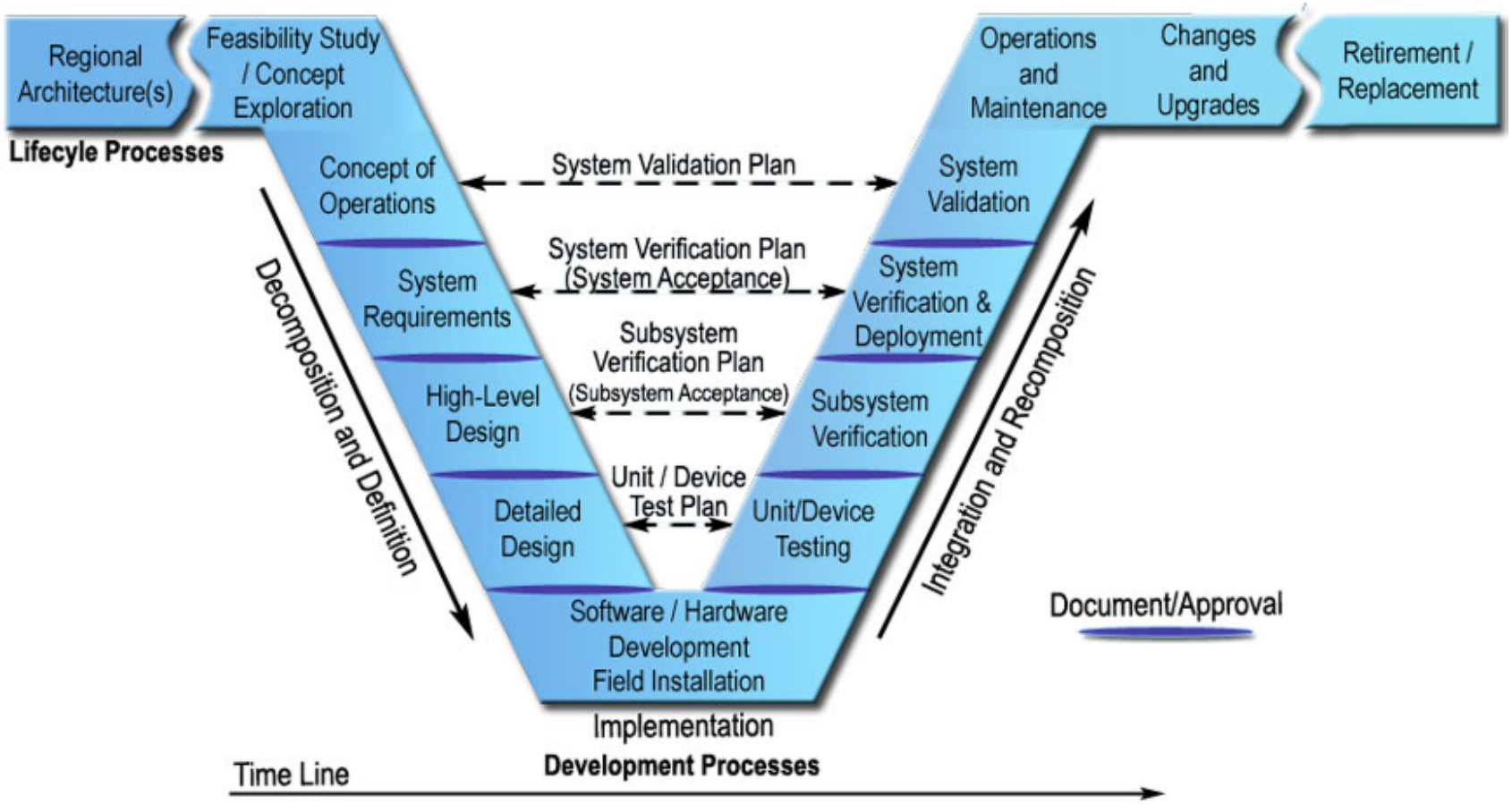
- Business or mission analysis
- Stakeholder need and requirements definition
- System requirements definition
- Architecture definition
- System analysis
- Implementation
- Integration

SE and Management – *Lifecycle Processes*

Technical processes (continued)

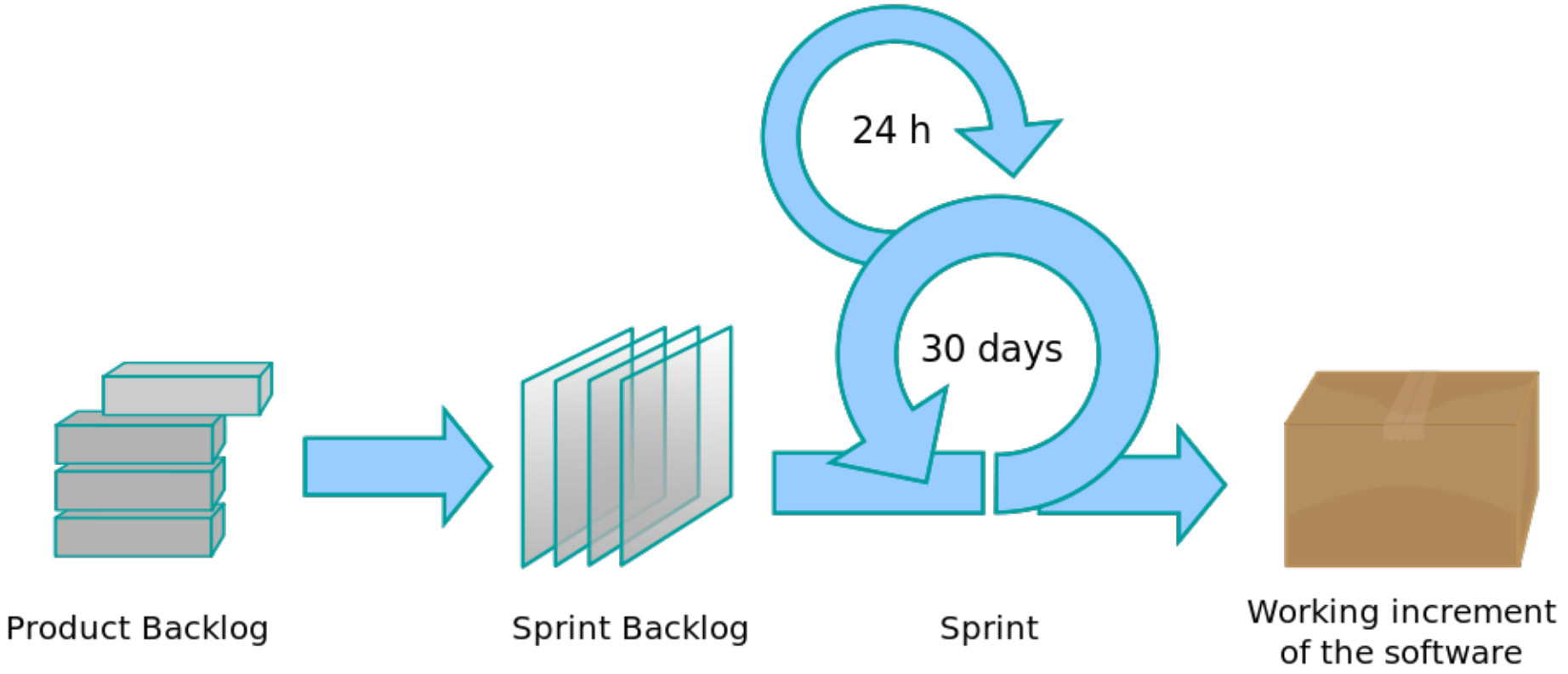
- Verification
- Transition
- Validation
- Operation
- Maintenance
- Disposal

SE and Management – *Lifecycle Models*



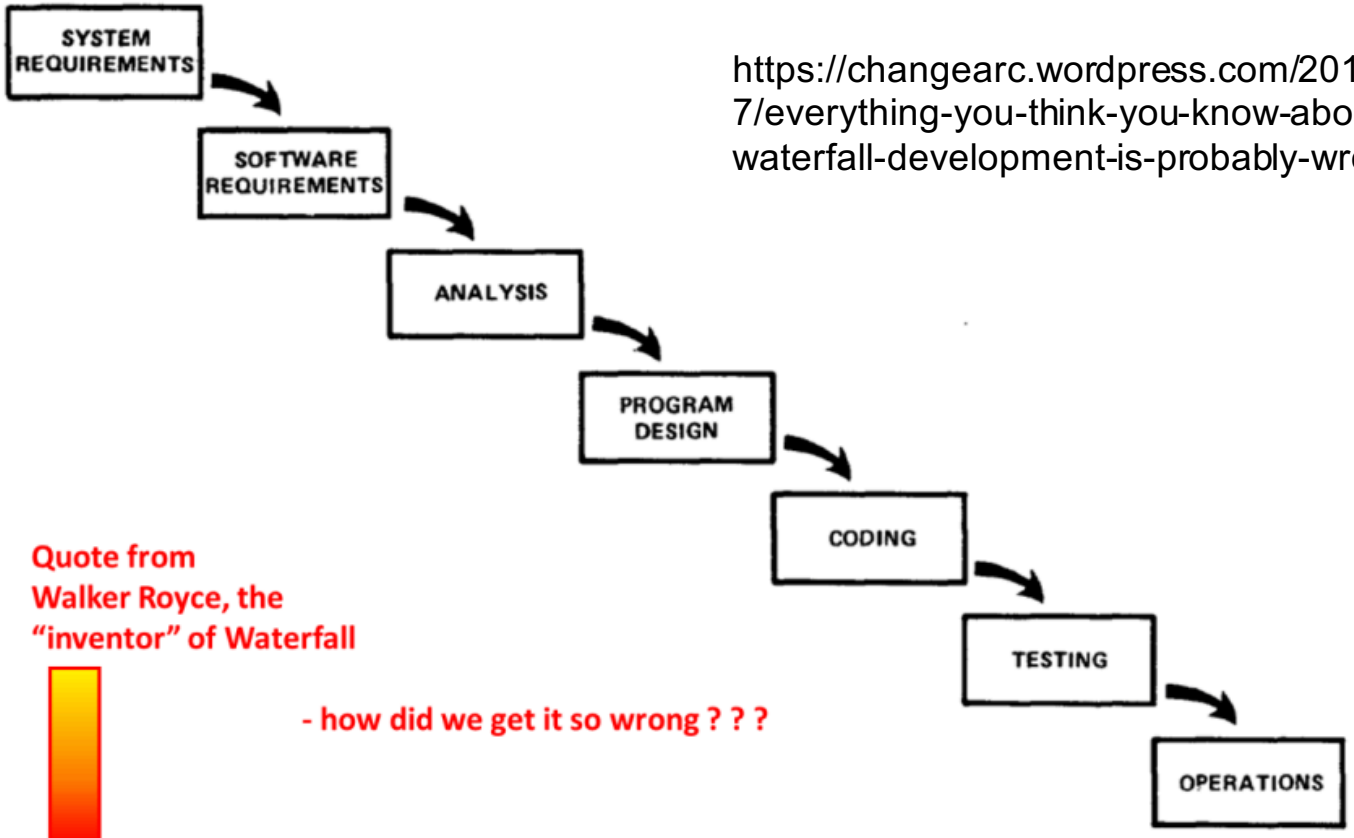
http://ops.fhwa.dot.gov/publications/seitsguide/section3.htm

SE and Management – *Lifecycle Models*



https://en.wikipedia.org/wiki/Scrum_(software_development)

SE and Management – *Lifecycle Models*



https://changearc.wordpress.com/2013/03/17/everything-you-think-you-know-about-waterfall-development-is-probably-wrong/

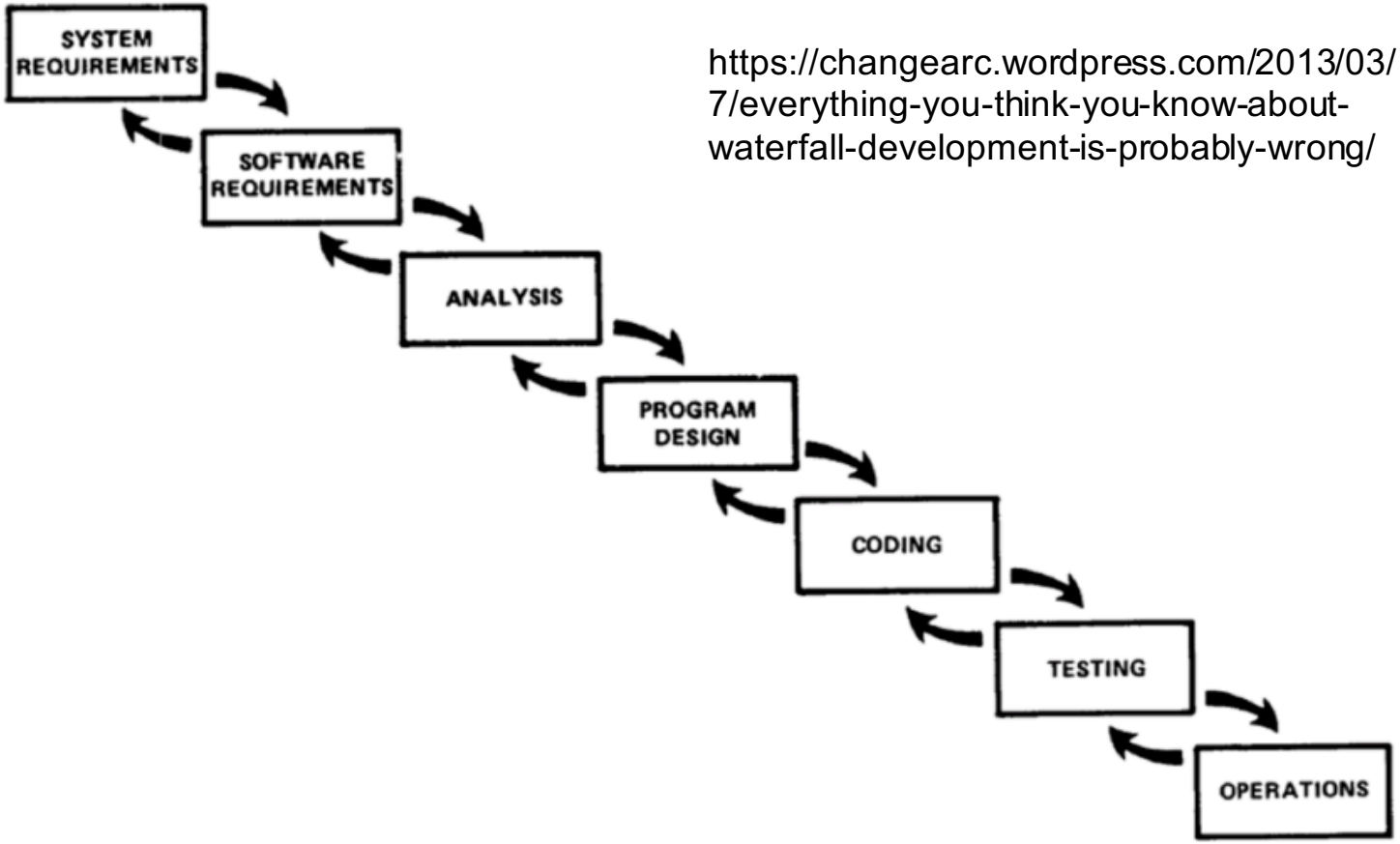
Quote from Walker Royce, the "inventor" of Waterfall

- how did we get it so wrong ? ? ?

Figure 2. Implementation steps to develop a large computer program for delivery to a customer.

I believe in this concept, but the implementation described above is risky and invites failure.

SE and Management – *Lifecycle Models*



https://changearc.wordpress.com/2013/03/17/everything-you-think-you-know-about-waterfall-development-is-probably-wrong/

Figure 3. Hopefully, the iterative interaction between the various phases is confined to successive steps.

SE and Management – *Lifecycle Models*

"Yes, that's right, Walker Royce, acknowledged as "one of the leaders in software development in the second half of the 20th century" essentially invented Iterative Development* and not Waterfall in 1970 over 40 years ago. If only people had read the paper fully and looked at the diagram after the first one."

https://changearc.wordpress.com/2013/03/17/everything-you-think-you-know-about-waterfall-development-is-probably-wrong/

Some other interesting ideas

Massachusetts Institute of Technology
Engineering Systems Division

ESD aims to solve complex engineering systems problems by integrating approaches based on engineering, management, and social sciences—using new framing and modeling methodologies.

- https://esd.mit.edu
- https://esd.mit.edu/Headline/ESD_StrategicPlan2011.pdf

Some other interesting ideas

Ultra-Large-Scale Systems

Ultra-large-scale (ULS) systems will be interdependent webs of software-intensive systems, people, policies, cultures, and economics.

- http://www.sei.cmu.edu/uls/
- http://resources.sei.cmu.edu/library/asset-view.cfm?assetID=30519

A final question for your Learning Portfolio

- One response to 911 was to strengthen cockpit doors
- This did not prevent MH370
- Is there a better way to deal with cockpit doors?

Hints: Use a systems thinking approach
Consider Ashby's *'Law of Requisite Variety' – Google it.*

That was a lot of stuff …

But I hope that many of the ideas have disturbed your world view.

A set of concepts that underpin the remainder of the course

Questions?