Understanding and Designing Complex Sociotechnical Systems

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Some problems are so complex that you have to be highly intelligent and well informed just to be undecided about them.

Lawrence J. Peter (of Peter Principle fame)

TWO LINKED CONCEPTS

CRITICAL CONTEMPORARY ISSUES

AND

COMPLEX SOCIOTECHNICAL SYSTEMS

Critical Contemporary Issues (CCI)

- Global Climate Change
- Energy/Environment
- Developing Country Megacities
- Global Economy
- National Security
- Productivity
- Mobility and so forth

Lady Bird Johnson found that in dealing with highway beautification it was like “picking up a tangled skein of wool; all the threads are interwoven – recreation and pollution and mental health. And the crime rate, and rapid transit and the war on poverty, and parks... everything leads to something else.”

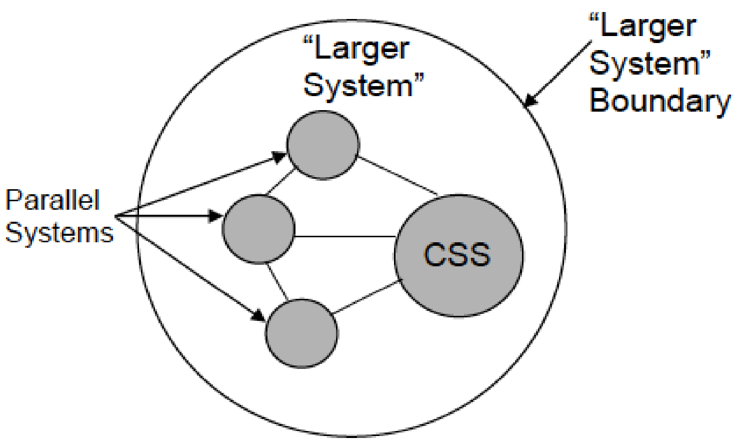
Lady Bird Johnson's Obituary in the Economist, July 21, 2007

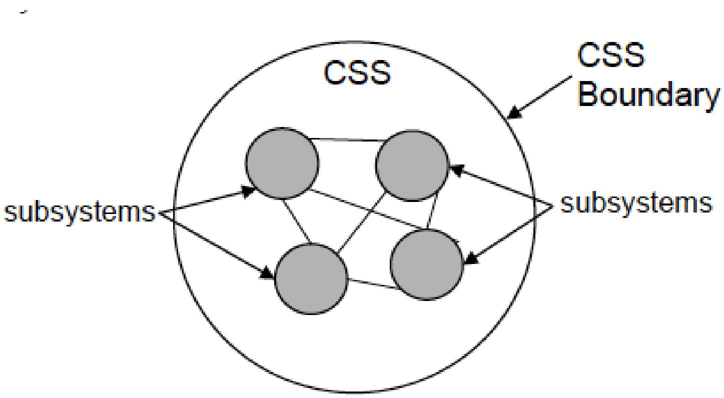
Complex Sociotechnical Systems

Let's parse this

Systems

- Composed of interconnected components and subsystems
- Often structured in a hierarchical manner
- Usually Interacts with the environment external to it





Sociotechnical

- Containing technology subsystems and components central to its performance

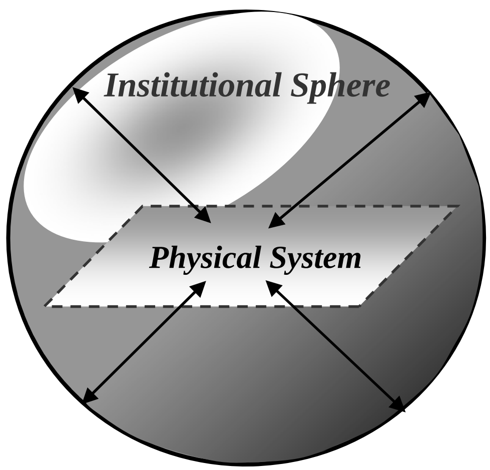
and

- Having societal/ political/ economic relevance and impact

Some Types of Complexity

- *Structural complexity*
  - The number of components in the system and the network of interconnections between them
- *Behavioral complexity*
  - The type of behavior that emerges due to the manner in which sets of components interact
- *Evaluative complexity*
  - The competing perspectives of stakeholders who have different views of "good" system performance
- *Nested Complexity*
  - The interaction between a complex "physical" domain and a complex "institutional" sphere

Nested Complexity



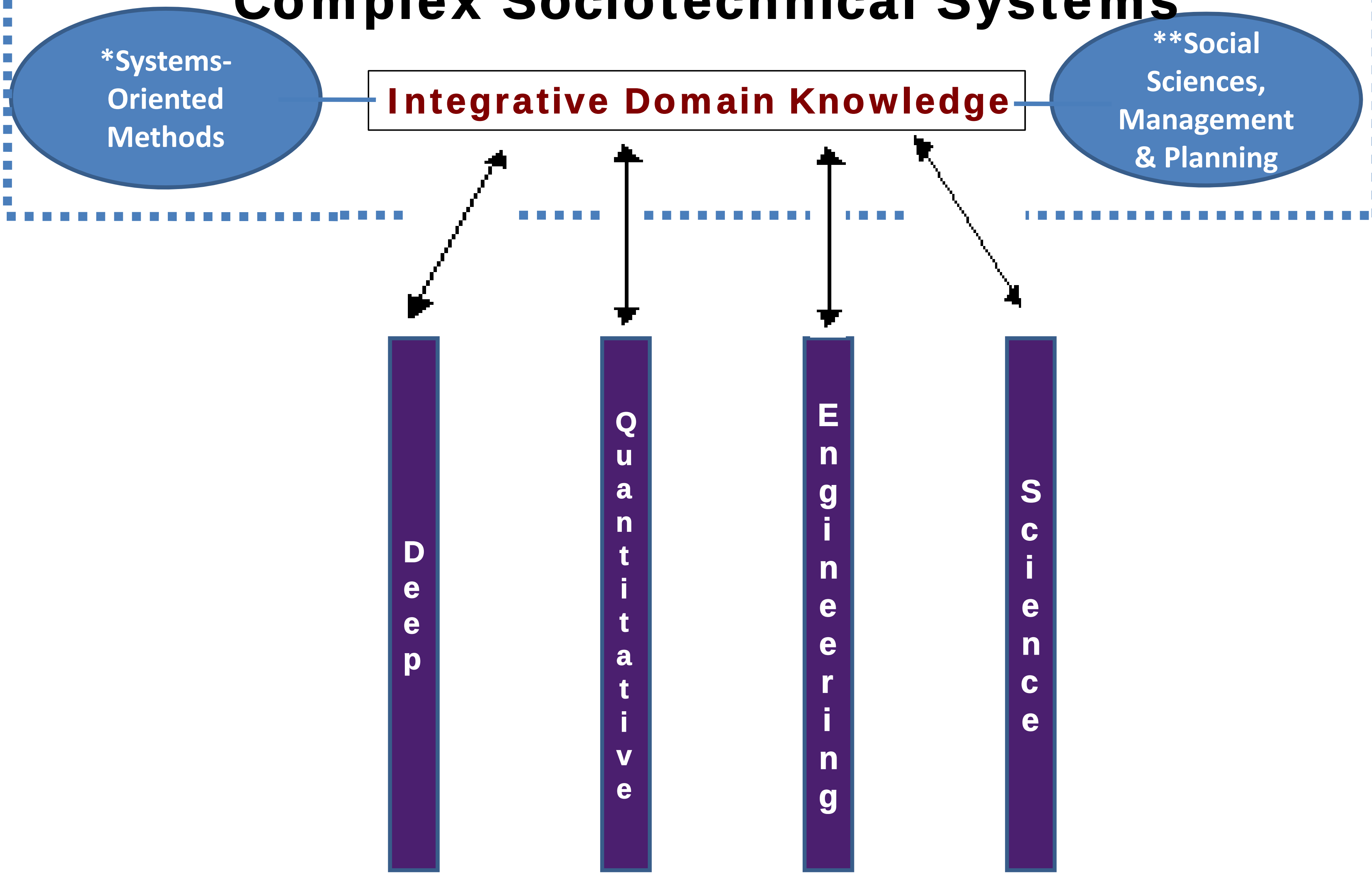
- Physical system
  - More quantitative principles
  - Engineering & economic models
- Institutional "sphere"
  - More qualitative in nature and often more participatory
  - Stakeholder evaluation and organizational analysis
- Different methodologies are required
  - within the physical system
  - between the institutional sphere and the physical system
  - within the institutional sphere

Herbert A. Simon

H.A. Simon, ‘Rational choice and the structure of the environment’, Psychological Review, vol. 63 (1956), pp. 129-38

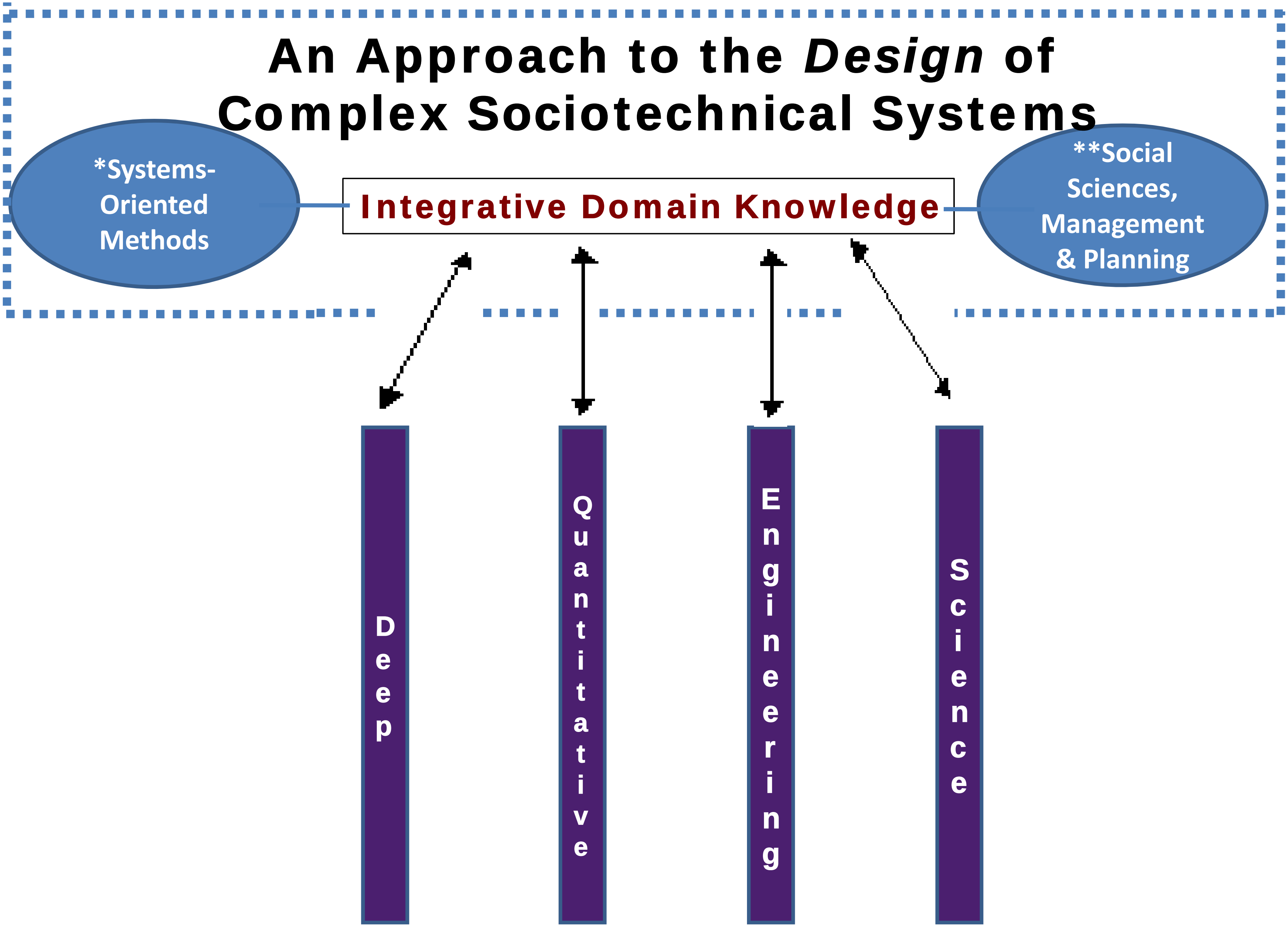
People Making “Rational” Choices → System → Performance

An Approach to the Study of Complex Sociotechnical Systems



BEYOND "STUDY" TO "DESIGN"

- We are not simply observers
- Our Complex Sociotechnical Systems are purposeful
- We have a normative view – what does good performance mean?
- We have a prescriptive view – how do we make our system perform better?
- But humility needs to be part of this process


An Approach to the *Design* of Complex Sociotechnical Systems
*Systems-Oriented Methods
Integrative Domain Knowledge
**Social Sciences, Management & Planning
Deep
Quantitative
Engineering
Science

The Intellectual Content of Integration I

An integrated view of a domain (e.g. transportation or energy.....)

The integration of various methodologies

- Systems-oriented methods
- Social Science, Management and Planning
- Engineering Science

So, is there intellectual content here?

MEXICO CITY: Transportation and the Environment

- One of the largest megacities in the world and the economic engine of Mexico
- Severe mobility problems, with productivity implications
- Important Technological Aspects
- Severe environmental problems, with health issues
- Social equity issues
- The institutional sphere is complex indeed and sometimes dysfunctional

The Intellectual Content of Integration II

- There would seem to be little question that there is intellectual content in integrating when one considers problems of the scale and complexity of Mexico City
- But there is a *more important test*: Are there principles and core underlying concepts for creating this integrated approach *across* domains? Is there a transferable "residue"?

Principles and Concepts: A Work in Progress I

- The micro/macro question
- The enterprise viewpoint
- Life-cycle properties --the “ilities”
- A flexibility/resilience perspective
- Sustainability as an overarching design principle

Economic Development,
Environmental Protection and Social **E**quity

Principles and Concepts: A Work in Progress II

- Using qualitative and quantitative methods rigorously and in tandem
- Focusing on feasibility – optimality is beyond the pale
- Understanding and measuring complexity in a sociotechnical context
- Using system architecting as an organizing principle

Principles and Concepts: A Work in Progress III

- Identifying and quantifying uncertainties and creating strategies for dealing with them
- Recognizing system safety as an emergent property
- Recognizing the importance of context

“Only Connect”

“Only connect” was the constant admonition of the great English novelist, E. M. Forster........... ***the ability to connect thus to raise the yield of existing knowledge is learnable.....***

Peter Drucker

Complex Sociotechnical Systems

- This field of study did not fall from the sky
- There is a significant history with distinguished progenitors

Simon, Weiner, Forrester, Schumpeter, von Neumann

Collected Papers of Jay W. Forrester

Foreword by Dean Gordon Brown

"This book might appropriately be titled *'Seeking to Understand Today's Complex Society.'*"

"stated succinctly, we live in a world where everything affects everything else"

"Scholars in many disciplines have addressed themselves to seeking solutions to these dilemmas. The disciplines of operations research, econometrics, behavioral science, statistics –to name a few – have been developed and applied. But our problems escalate. New and more powerful approaches are urgently needed."

So why now?

People have talked for decades about cutting across disciplines to study Complex Sociotechnical Systems – why is it especially important now?

- Critical Contemporary Issues framed as Complex Sociotechnical Systems are endemic and can only grow in importance
- We have the tools, technologies, and some principles and concepts to work effectively across disciplines

Engineering Systems

> They are, by our definition **Complex, Sociotechnical Systems**
  - *Technologically enabled* networks which transform, transport, exchange and regulate Mass, Energy and Information
  - *Large-scale*
    - large number of interconnections and components
  - *Sociotechnical aspects*
    - social, political and economic aspects
  - *Exhibit Nested complexity*
    - technical complexity nested within institutional complexity
  - *Dynamic*
    - involving multiple time scales, uncertainty & lifecycle issues
  - They require deeply rigorous quantitative and qualitative approaches

Examples I

- Transportation and Air Quality in Mexico City
- Extracting Information from Blogs for Strategic Planning in Advanced Technologies (e.g. Cloud Computing)
- Cape Wind-- Off-shore Renewable Energy in Nantucket Sound: Understanding Stakeholder Views
- Organizational Infrastructure and Technology for Air Combat

Examples II

- Provision of Broadband Telecommunication Services by Municipal Electric Utilities (MEUs)
- Regional Strategic Transportation Planning (RSTP) as Coupled to Supply Chain Management (SCM)
- Providing High-Speed Broadband Internet Access in Developing Countries: The Case of Kenya

The Future of Engineering Systems/ Complex Sociotechnical Systems

> We address critical contemporary issues using the Engineering Systems/Complex Sociotechnical Systems world view

> This integrated interdisciplinary approach is a pathway for relevance of universities ***in a society where relevance is demanded of all institutions***

> Only by considering Engineering Systems/Complex Sociotechnical Systems as a **field of study** can we make continuing contributions to critical contemporary issues

Thank you for your attention.

Any comments or questions?

BACKUPS

The *CLIOS* [Complex, Large-Scale, Interconnected, Open, Sociotechnical] Process

A three-stage structured process.

- Representation
- Design, Evaluation and Selection
- Implementation

1. Representation

"Defining the problem may be the most important element in making effective decisions ... The right answer to the wrong problem is very difficult to fix … once the problem has been correctly defined, the decision itself is usually pretty easy."
Peter Drucker

2. Design, Evaluation and Selection: develop ***bundles of strategic alternatives*** and select among them

3. Implentation: develop bundles of strategic alternatives and select among them

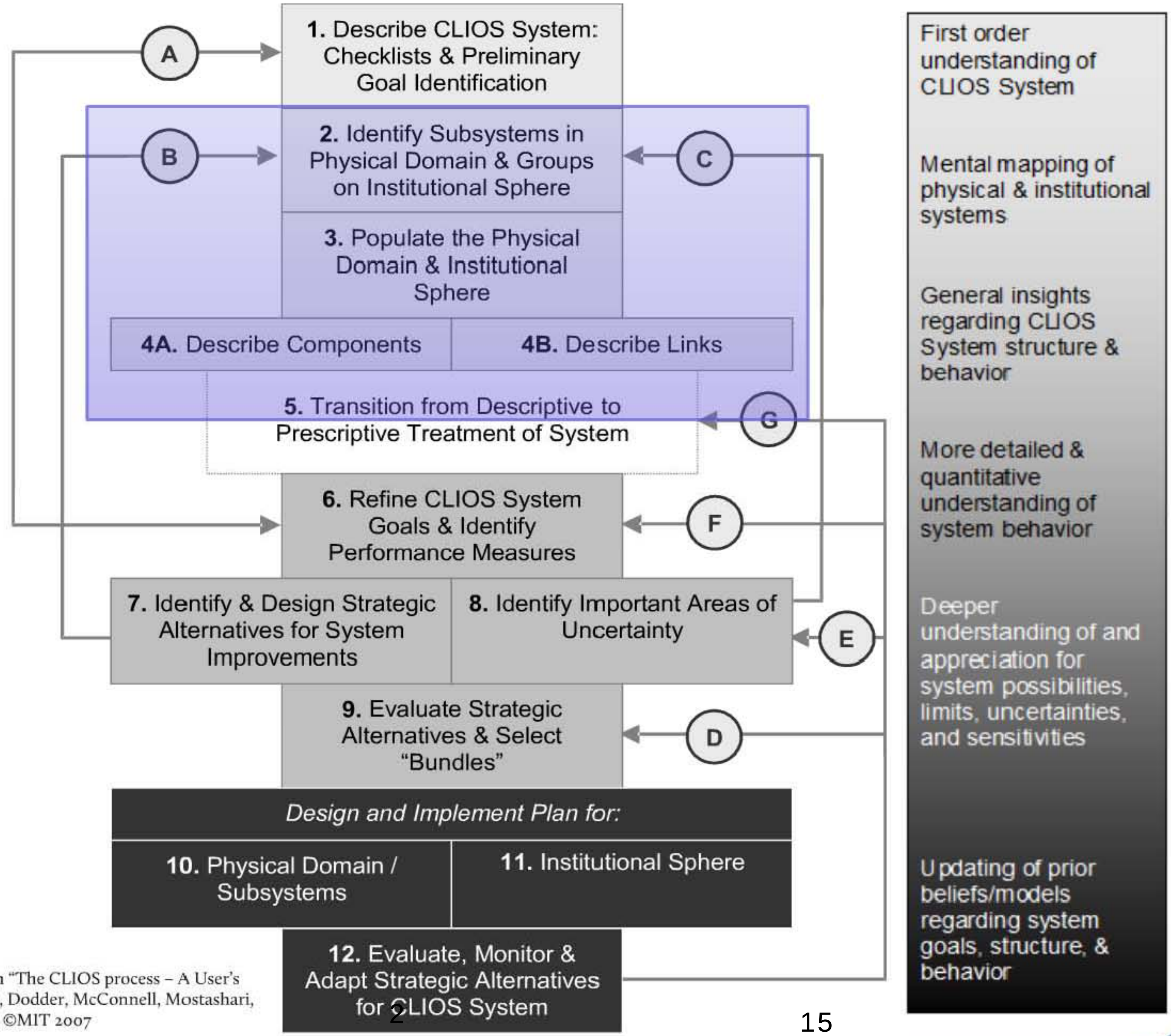
Implicitly, there is iterative behavior throughout

The CLIOS Process

PHASES

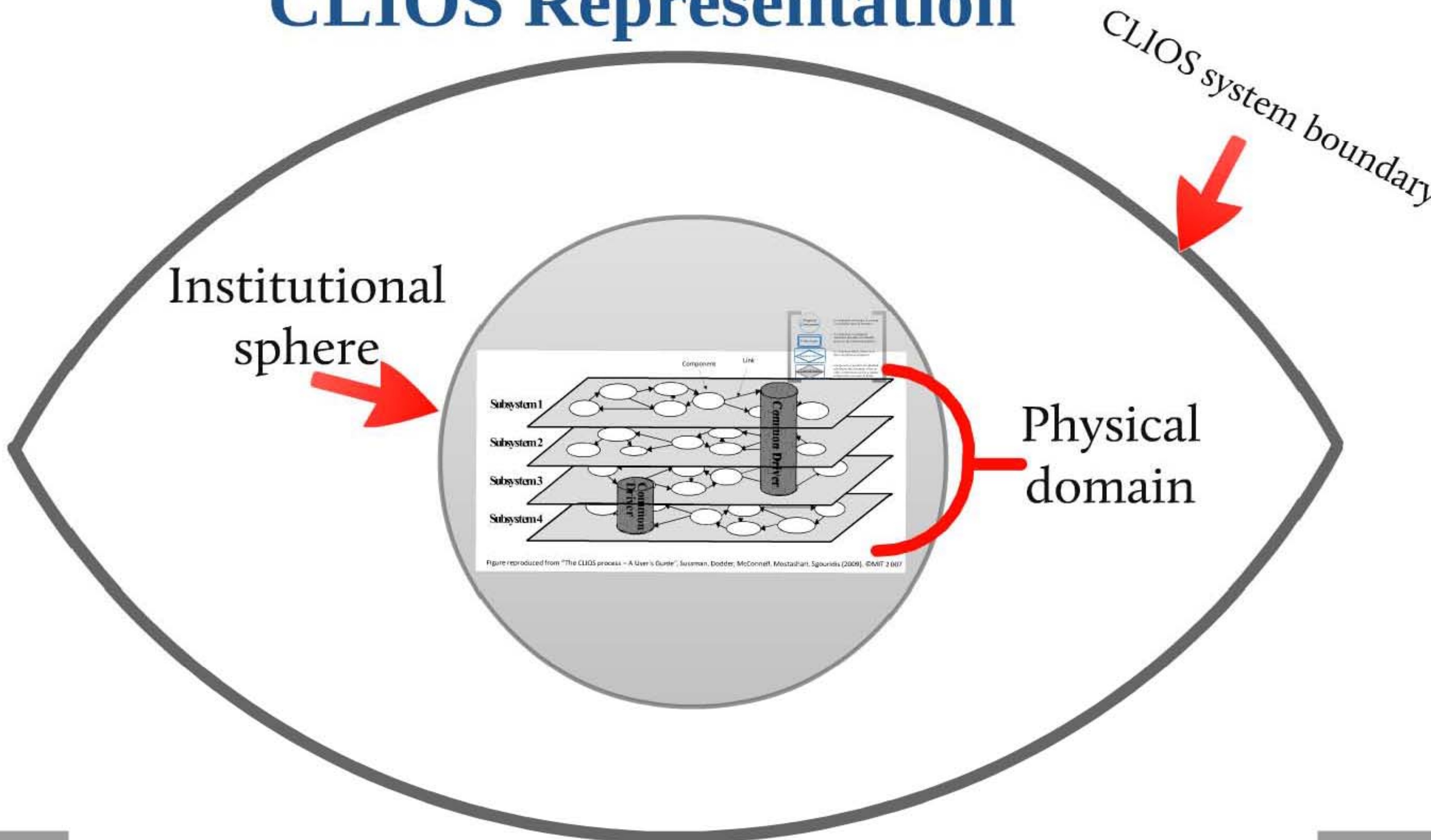
- REPRESENTATION
- DESIGN, EVALUATION, & SELECTION
- IMPLEMENTATION & ADAPTATION

Complex
Large
Interconnected
Open
Sociotechnical



Reproduced from "The CLIOS process – A User's Guide", Sussman, Dodder, McConnell, Mostashari, Sgouridis (2009), ©MIT 2007

CLIOS Representation



Mirroring Hypothesis

The *Mirroring Hypothesis* (Carliss): Aligning the "technical architecture" with the "organizational architecture" leads to better system performance

CLIOS Process Ideas I

- Sustainability as an overarching design principle
- Separate “organizations” from other components – CLIOS Process world view
- Distinguish between representation and modeling

  Representation related to visualization

  Think carefully about when to quantify – when to “model”
- Recognize different kinds of complexity
- Emphasis on dealing with uncertainty

CLIOS Process Ideas II

- Emphasis on stakeholder roles
- Strategic alternatives
- Robust bundles of strategic alternatives
- Strategic alternatives are needed for implementation as well
  - In the physical domain
  - On the institutional sphere -- change management
- Monitoring the outcomes is central to the CLIOS Process
- The CLIOS Process as iterative among all the stages

3.11 from a Complex Sociotechnical Systems (CSS) Viewpoint V

Was 3.11 an "unknown unknown"?

A "this changes everything" event?

Dealing with High Impact, Low Probability

Events

PRINCIPLES FOR PROCESS FORMATION FOR COMPLEX SOCIOTECHNICAL SYSTEMS

Principles for Process Formation for Complex Sociotechnical Systems I

- Keep institutional changes on the agenda (recognizing the difficulties)
- Optimization is a will-o'-the wisp
- Too hard to find an optimum
- Oft-times not even sure what we are optimizing
- Uncertainty dominates
- Known unknowns
- Unknown unknowns

Principles for Process Formation for Complex Sociotechnical Systems II

- Understanding Structure is Vital
  - Don't rush to quantify
- There is no silver bullet
  - Bundles of strategic alternatives
- Thinking about flexibility
- Explicit consideration of stakeholders at all stages of the process
- The need for iteration of the process: revisiting earlier work and decisions
- Scale and Scope, Function, Structure, Temporality (de Weck, Roos and Magee)