



Solution Elements for Studying Complex Systems

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Recherche et développement
pour la défense Canada

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Summary

1. Introduction

- Complexity and CxS
- Sources of complexity
- The Study of CxS

2. Solution Elements

- State-of-the-art on CxT, CxS and chaos
- Commonalities in the scientific literature – two perspectives
- Four modalities for studying CxS
- The recommended approaches, processes

3. Application to NCO C2

4. Conclusion

Used acronyms:

CxS: Complex System

CxT: Complexity Theory



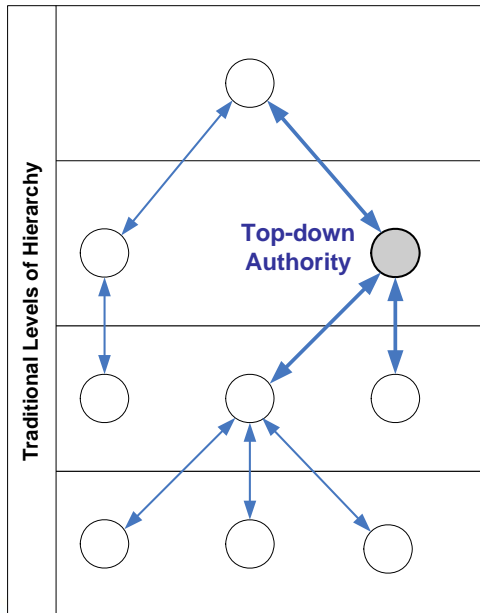
1 Introduction

Complexity and Complex Systems

The notion of “**System**” is **recursive** [12]. A system: may include: software, hardware, **human** [17], process, doctrines, etc.

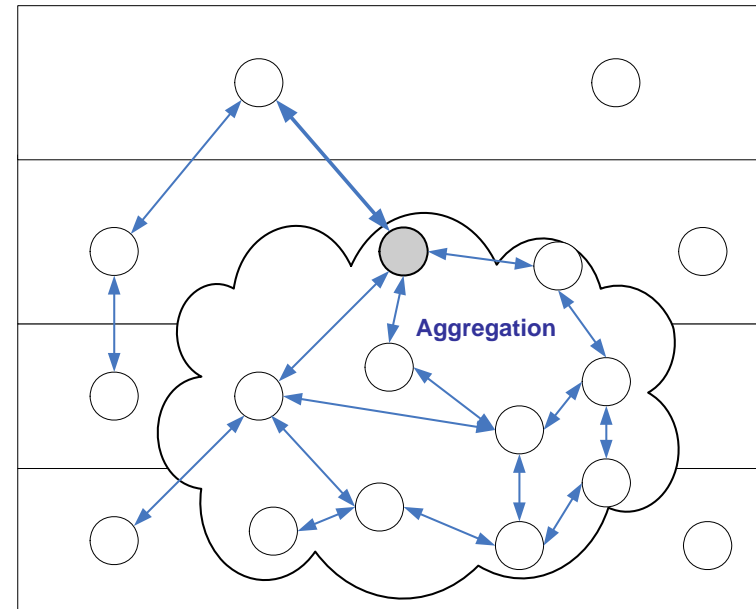
CxS: many components and links, intricate interactions, re-organization, adaptation

Hierarchy



Usually **tightly coupled**, linear

Both hierarchy and network

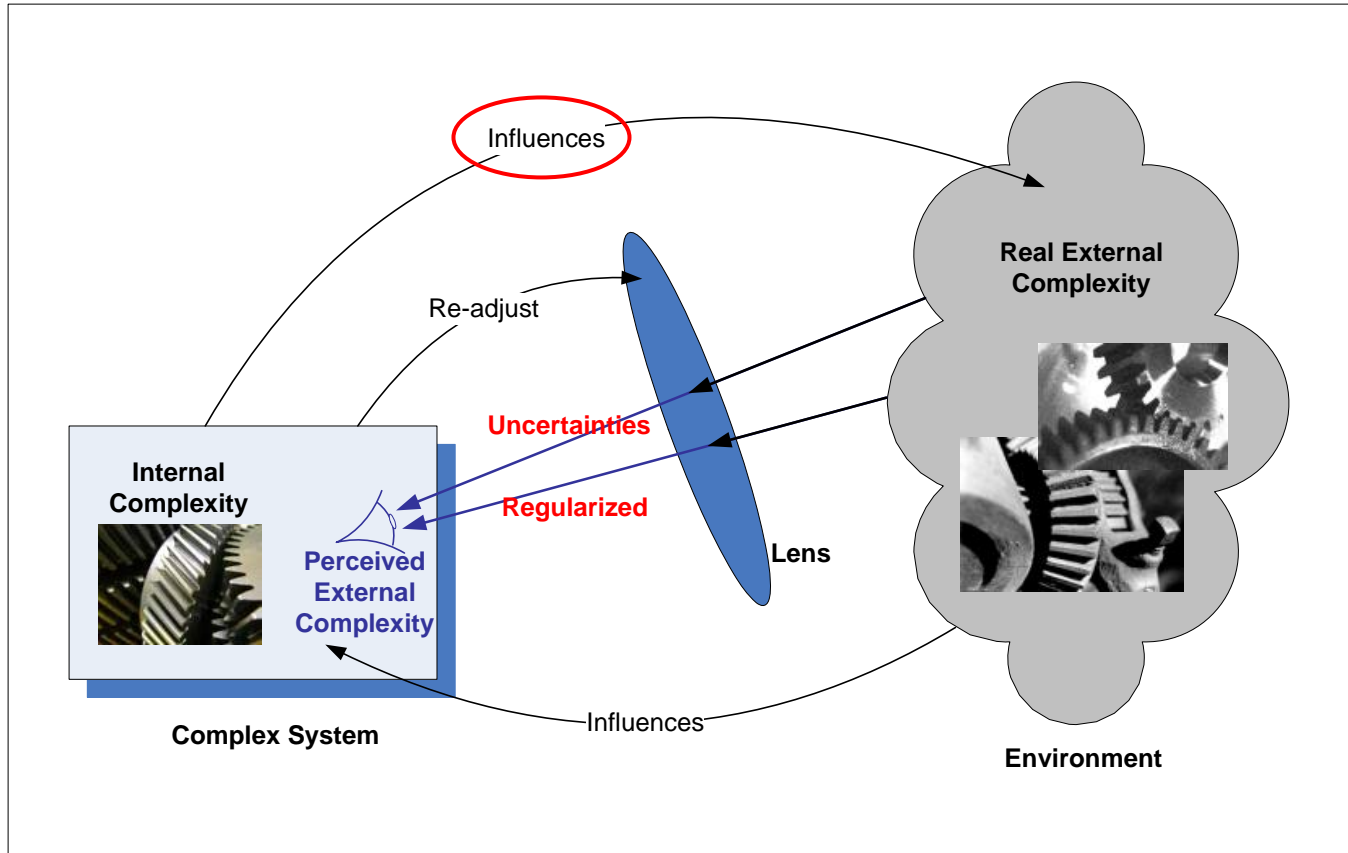


Usually **loosely coupled**, less hierarchic, more decentralized, flexible, and non-linear



1 Introduction

Complex systems “in” their Environment



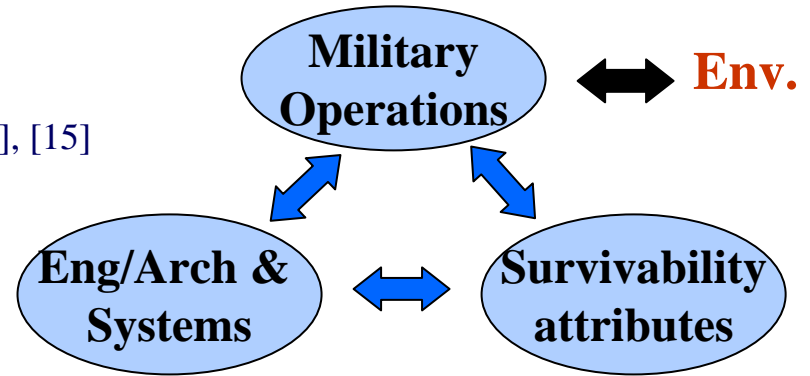
From [12] and [15]



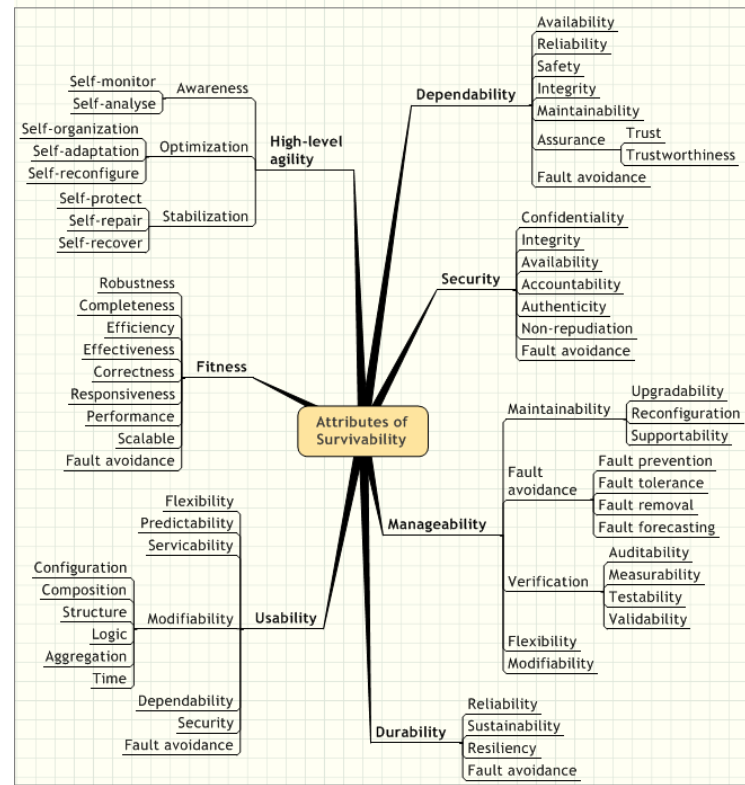
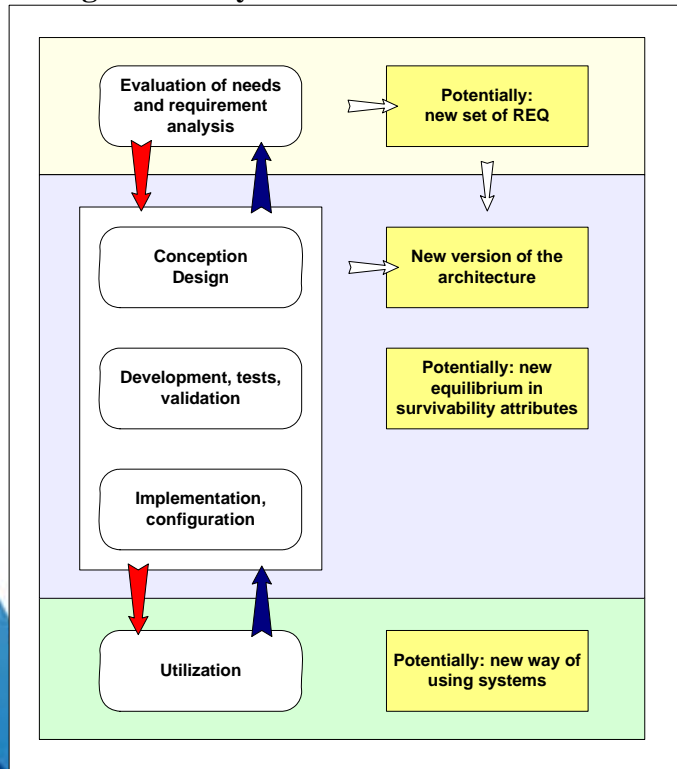
1 Introduction

Main Sources of Complexity [16], [15]

(Mil. Ops)



Eng/Arch & Systems



Ops: Beech [6], Calhoun [8], many others. Eng/arch: [18], [7], [3], many others



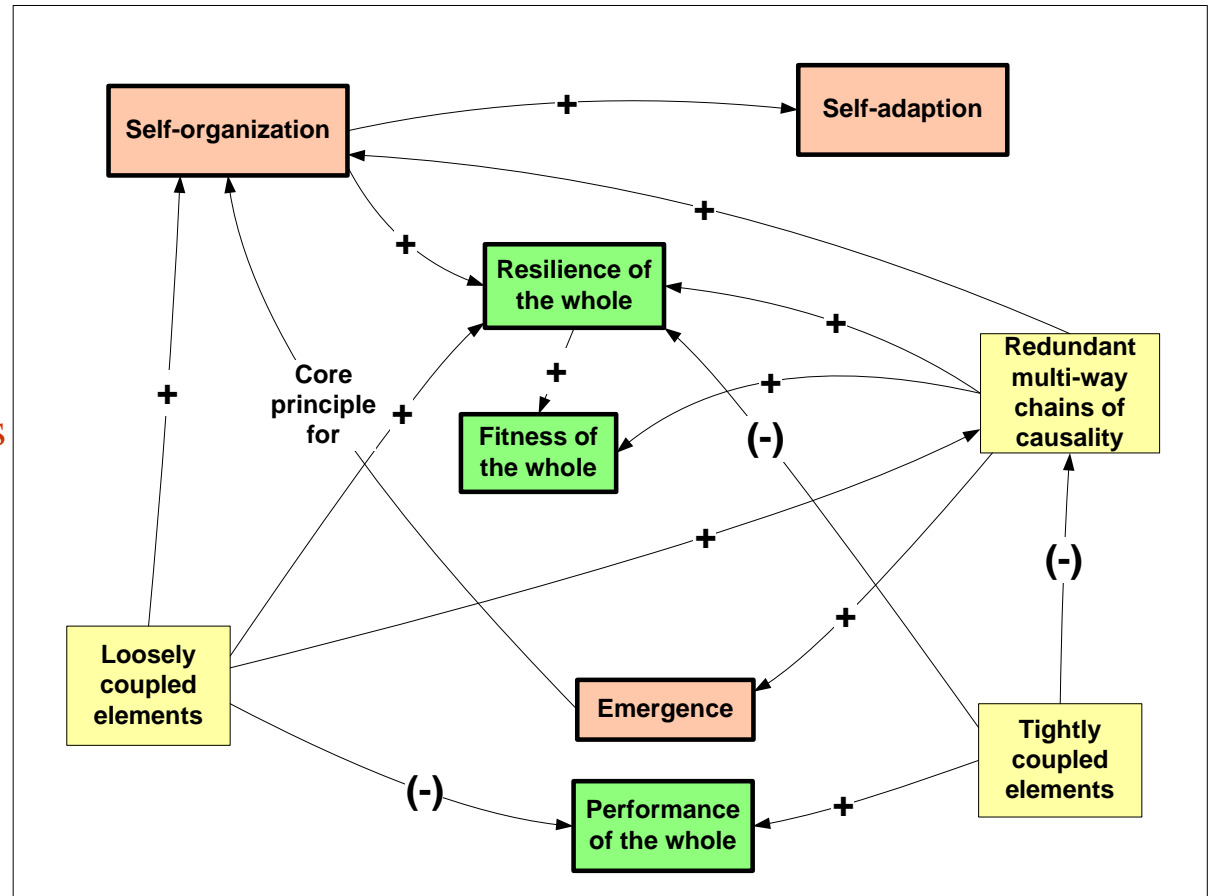
1 Introduction

The Study of CxS and Complex Problems

The task is not easy.

As shown later, **interaction diagrams** may help

- +/- contributions
- Cause-effect interrelationships
- Focus on selected aspects
- Does not depend on domains



Interaction diagram [12]

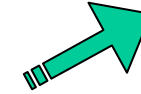


2 Solution Elements

State-of-the-Art on CxT, CxS and Chaos

1- List of Works, Experts, Organizations, Projects, Journals, Conferences and Tools

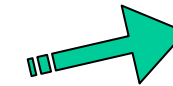
[9]



471 references + 713 additional Internet addresses + abstracts

2- Formulations and Measures of Complexity

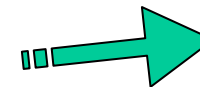
[10]



64 formulations and measures of systems' complexity

3- Glossary

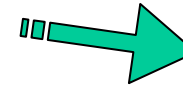
[11]



335 key words defined by different authors

4- Overview of Theoretical Concepts

[12]



Review of concepts

5- Solutions

[to be published].



Solutions (...)



2 Solution Elements

State-of-the-Art on CxT, CxS and Chaos

SOTA; as we all know:

- CxT is currently the object of intense R&D all around the world
- Huge literature
- Vocabulary is still evolving
- Concepts related to CxT are abstract; often not easy to grasp

Aim of this work:

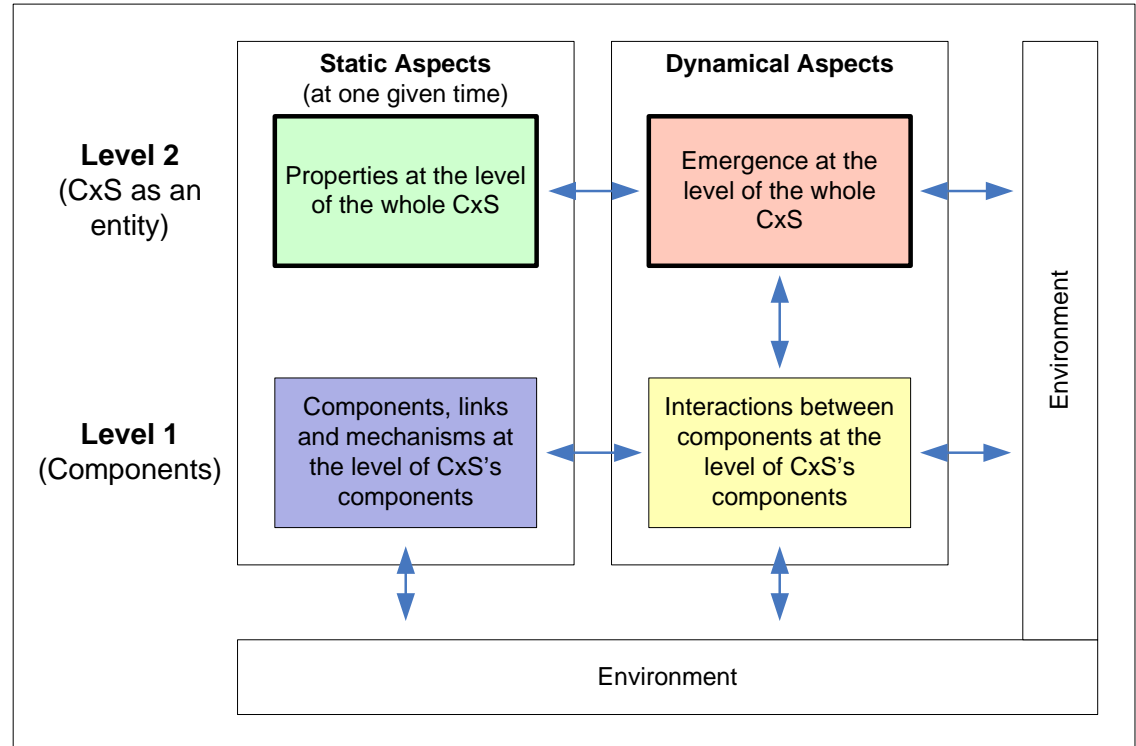
- Propose some **elements of solution** that may help the study of CxS and complex problems
- It is an on-going work (please send us your comments/suggestions)



2 Solution Elements

Commonalities in the Scientific Literature – Two Perspectives

Two **perspectives** can be extracted [13]:



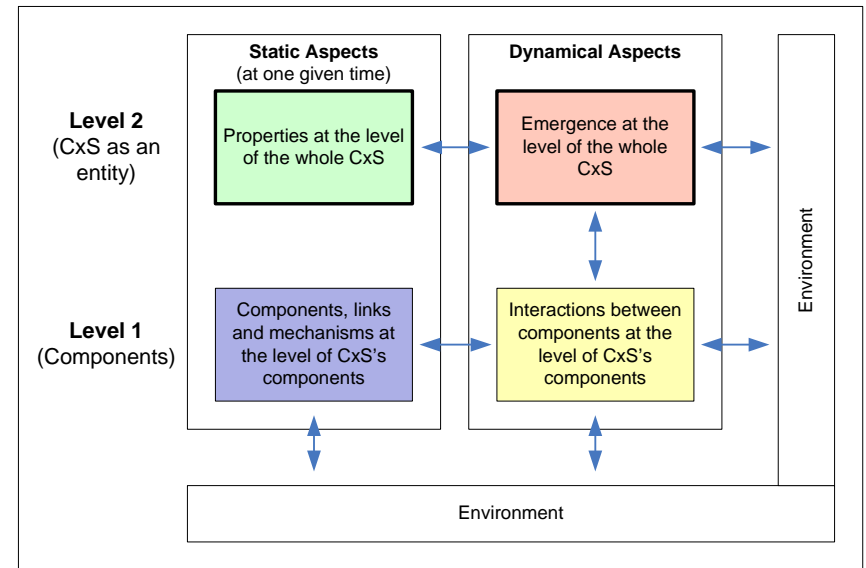
- Perspective 1:** Allows to discriminate between conceptual levels of CxS
- Perspective 2:** Allows to discriminate between static and dynamic aspects



2 Solution Elements

The Four Modalities

From these two perspectives:
we identify **4 modalities** [13] that
may be used to study CxS



Modality: a pre-defined **condition**.

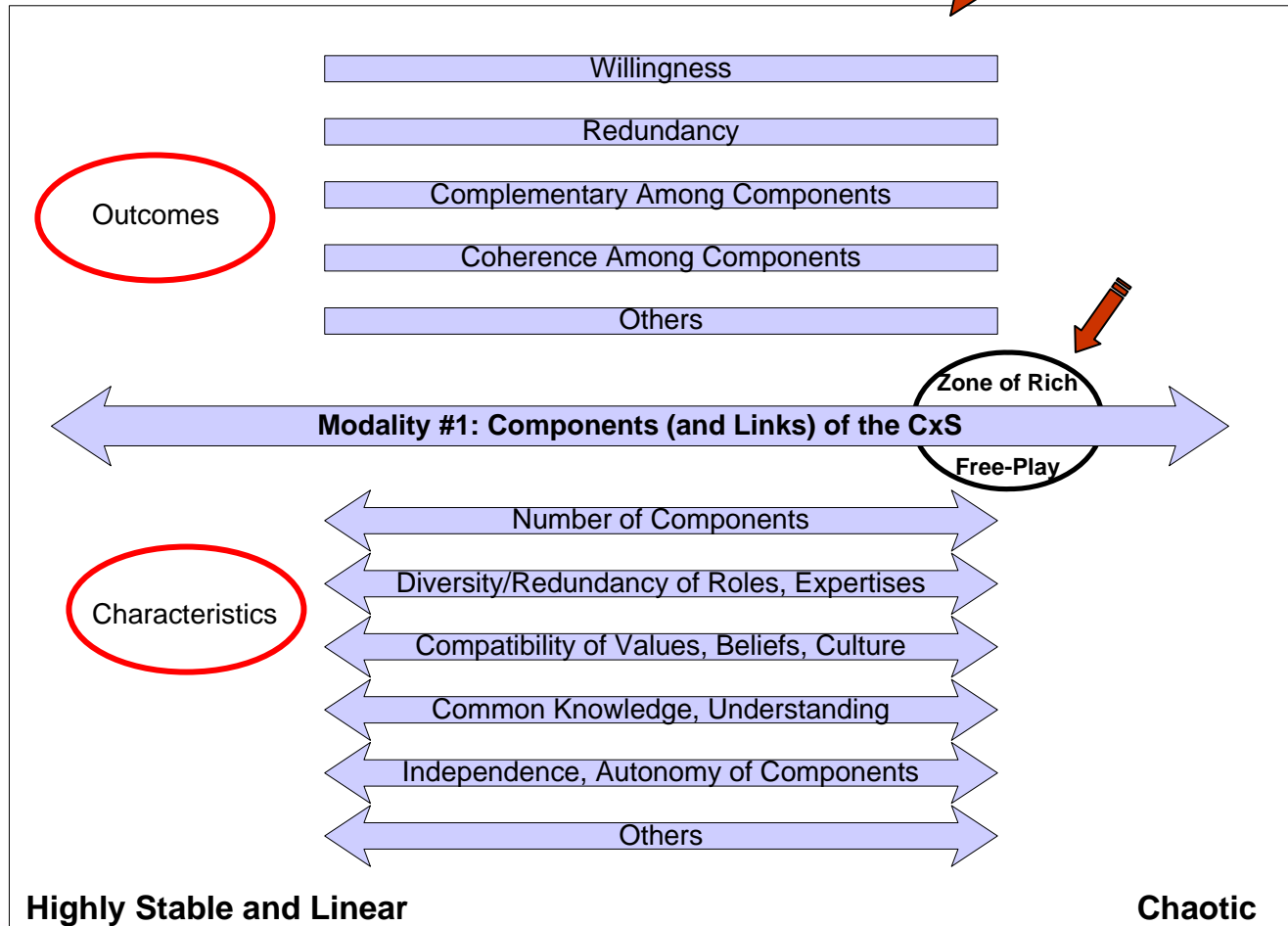
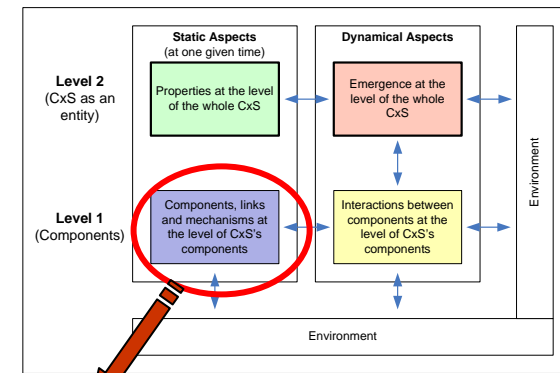
→ Modalities allow the classification of concepts, phenomena (etc.)
according to pre-defined conditions.

The four proposed Modalities → ...



2 Solution Elements

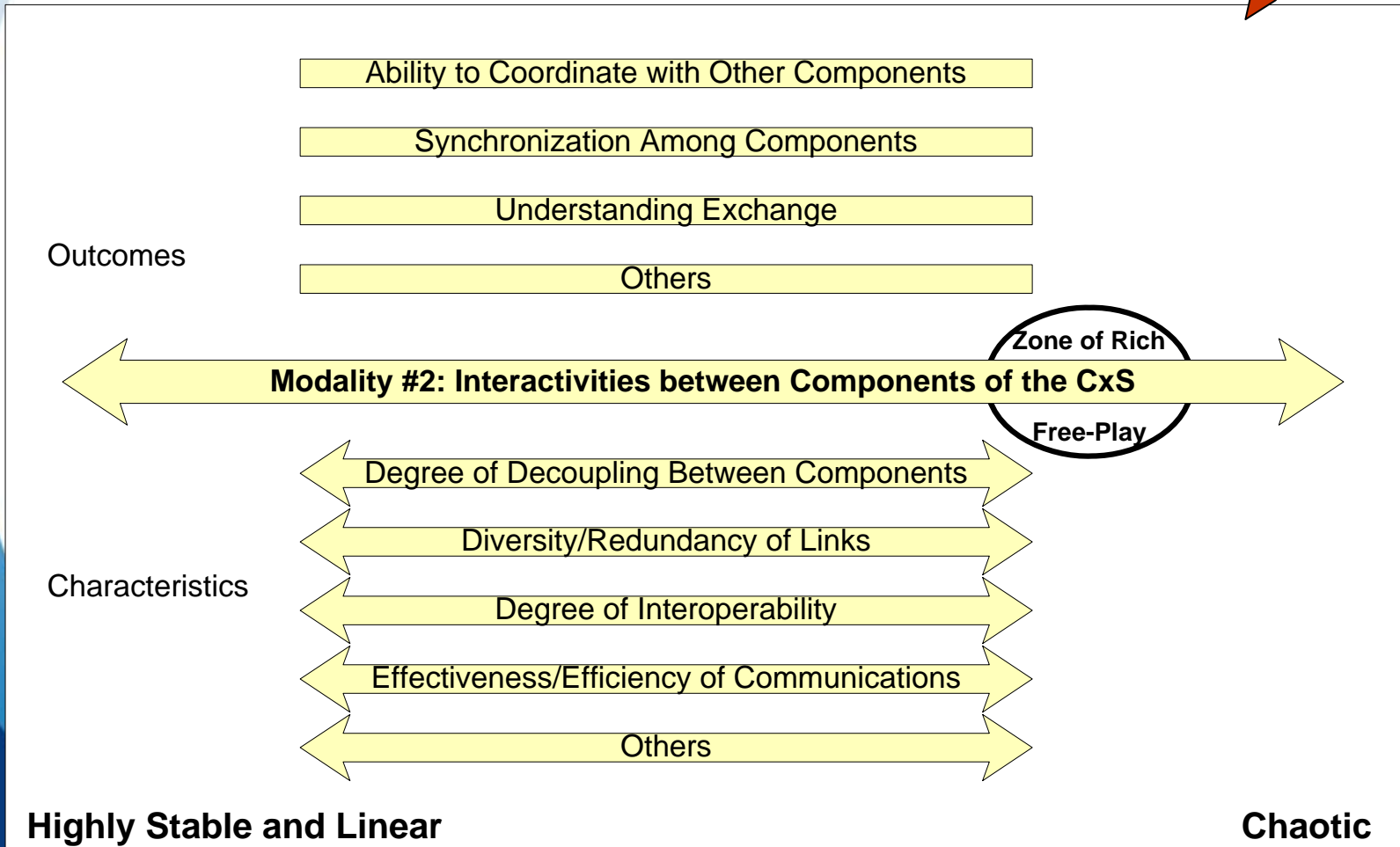
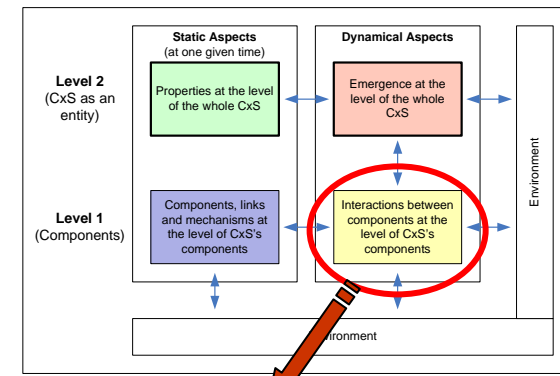
Modality 1: Internal Components (and Links)





2 Solution Elements

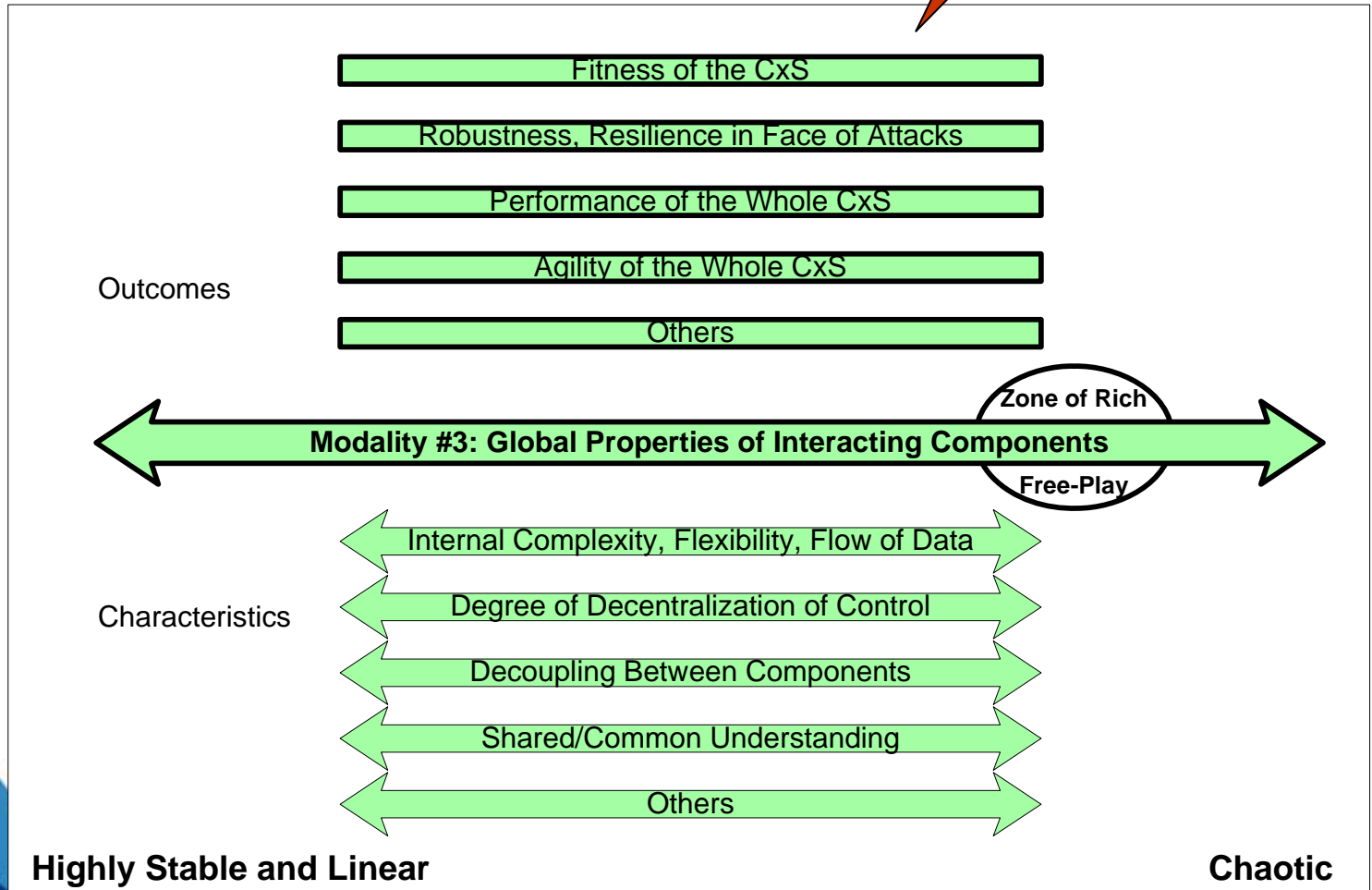
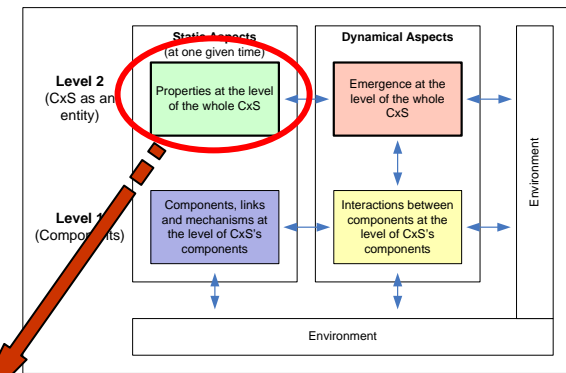
Modality 2: Internal Interactivities





2 Solution Elements

Modality 3: Global Properties of CxS



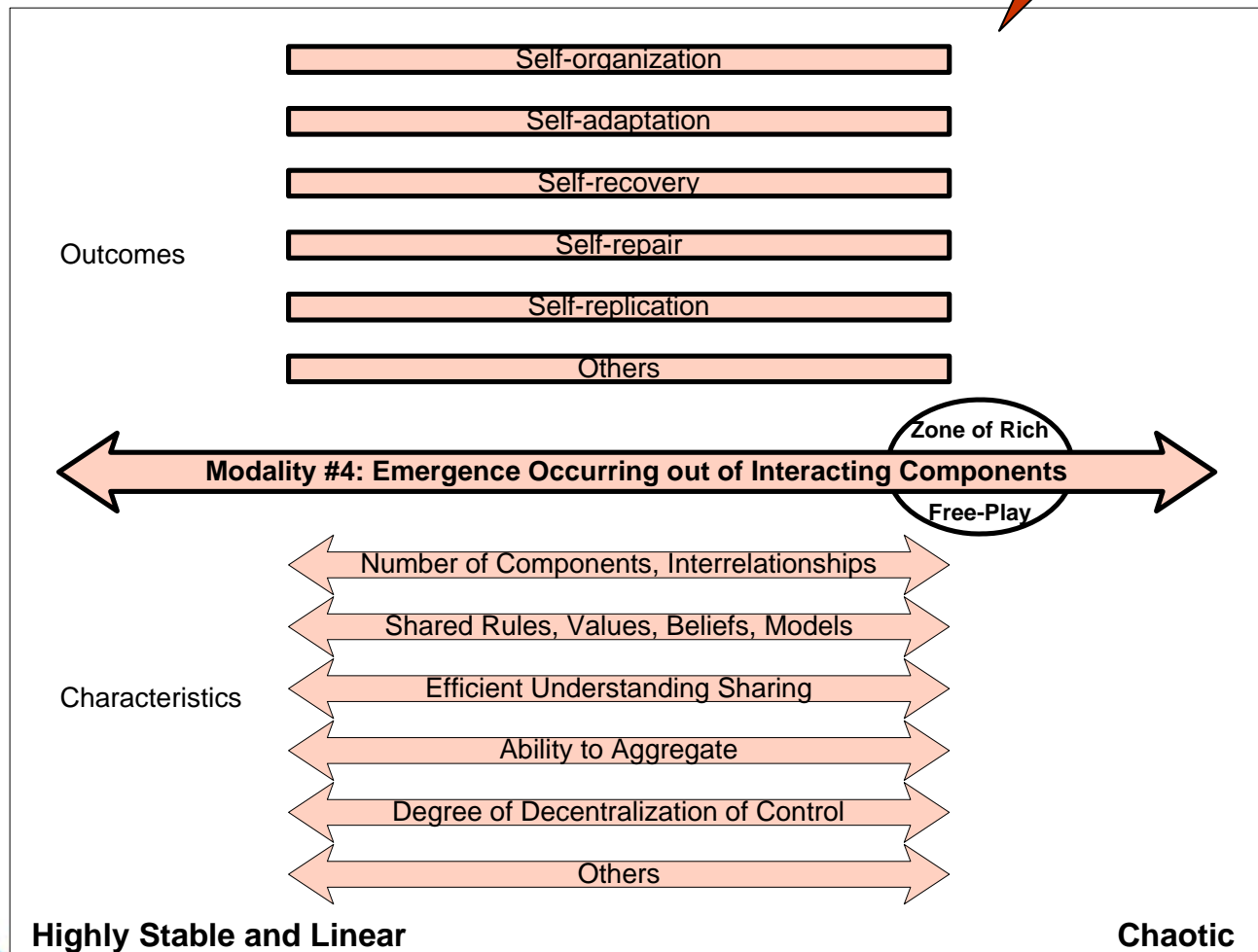
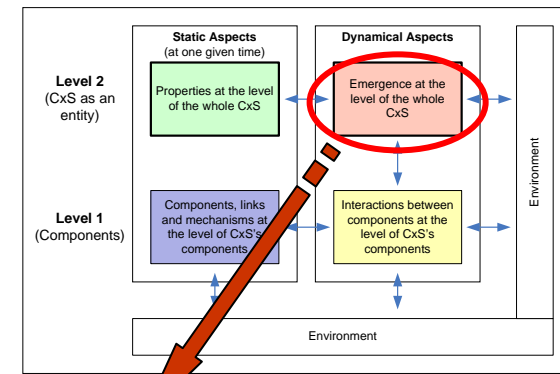
Highly Stable and Linear

Chaotic



2 Solution Elements

Modality 4: Emergence

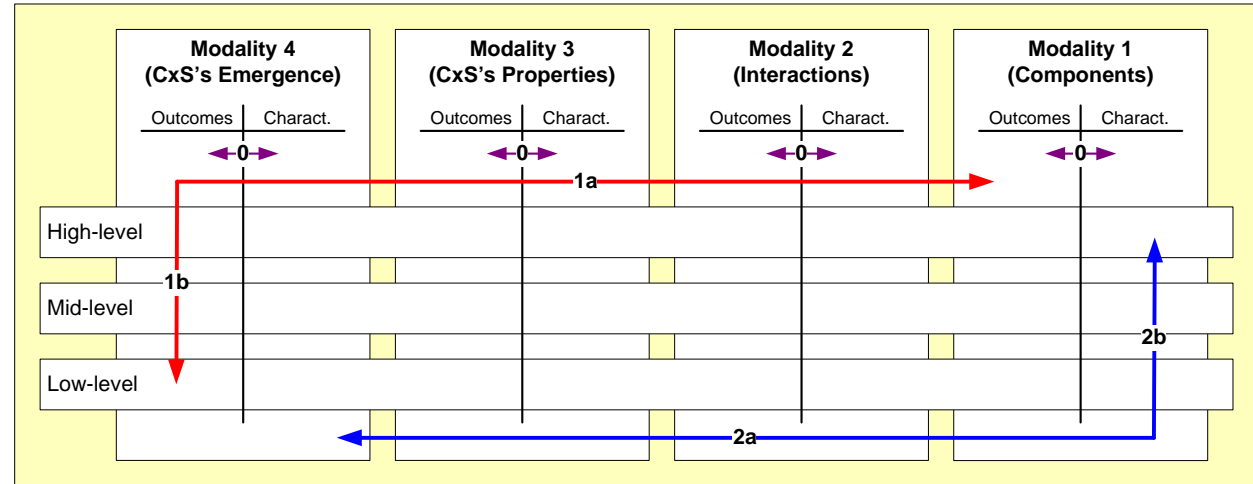




2 Solution Elements

Recommended Approaches, Processes

Discovery process
[17], [5]



The recommended approaches:

- **Holism → Holon**; a system is a whole in itself as well as a part of a larger system
- **Classical & Evolutionary engineering:** [17], [5] among others
- (1) **Top-down:** [2] among others
- (2) **Bottom-up:** [2] among others
- **Multiscale Analysis:** [4], [5]

→ **Cause-effect relationships** must be studied (**independently of domains**)



3 Application to NCO C2

The Use of Modalities

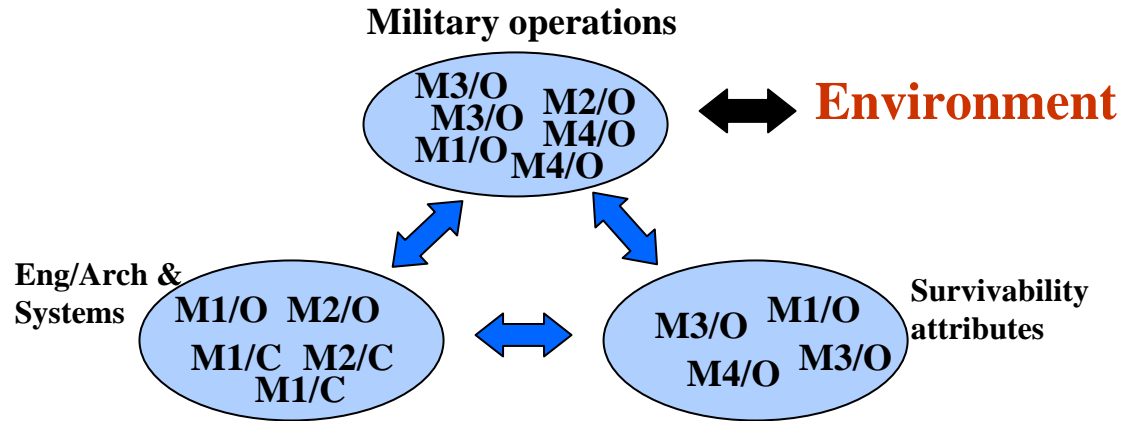


M1: Components, links

M2: Interactivities

M3: CxS's properties

M4: CxS's emergence



For instance, M1/C means Modality #1, Characteristic

All relevant **cause-effect relationships** must be studied (independently of domains)

- Modalities can be used (characteristics and outcomes)
- Holism, top-down and bottom-up approaches
- Multiscale analysis, others ...
 - Patterns may be identified (behavior, structure, composition, etc.)

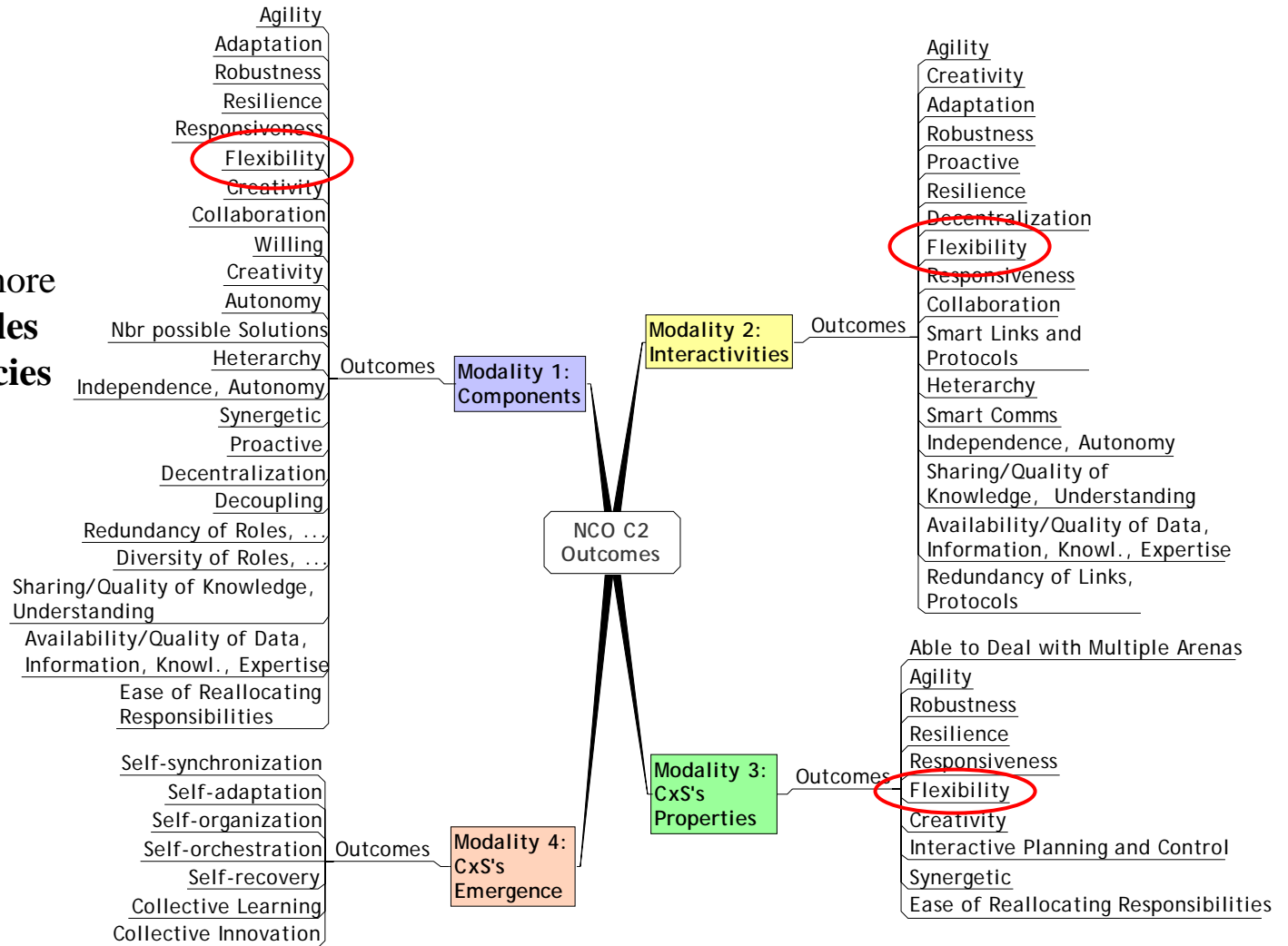


3 Application to NCO C2

Identification of Modalities' Outcomes

NATO's working groups could help (SAS-050 & 065):

→ They identified more than **350 C2 variables** and **interdependencies** between them



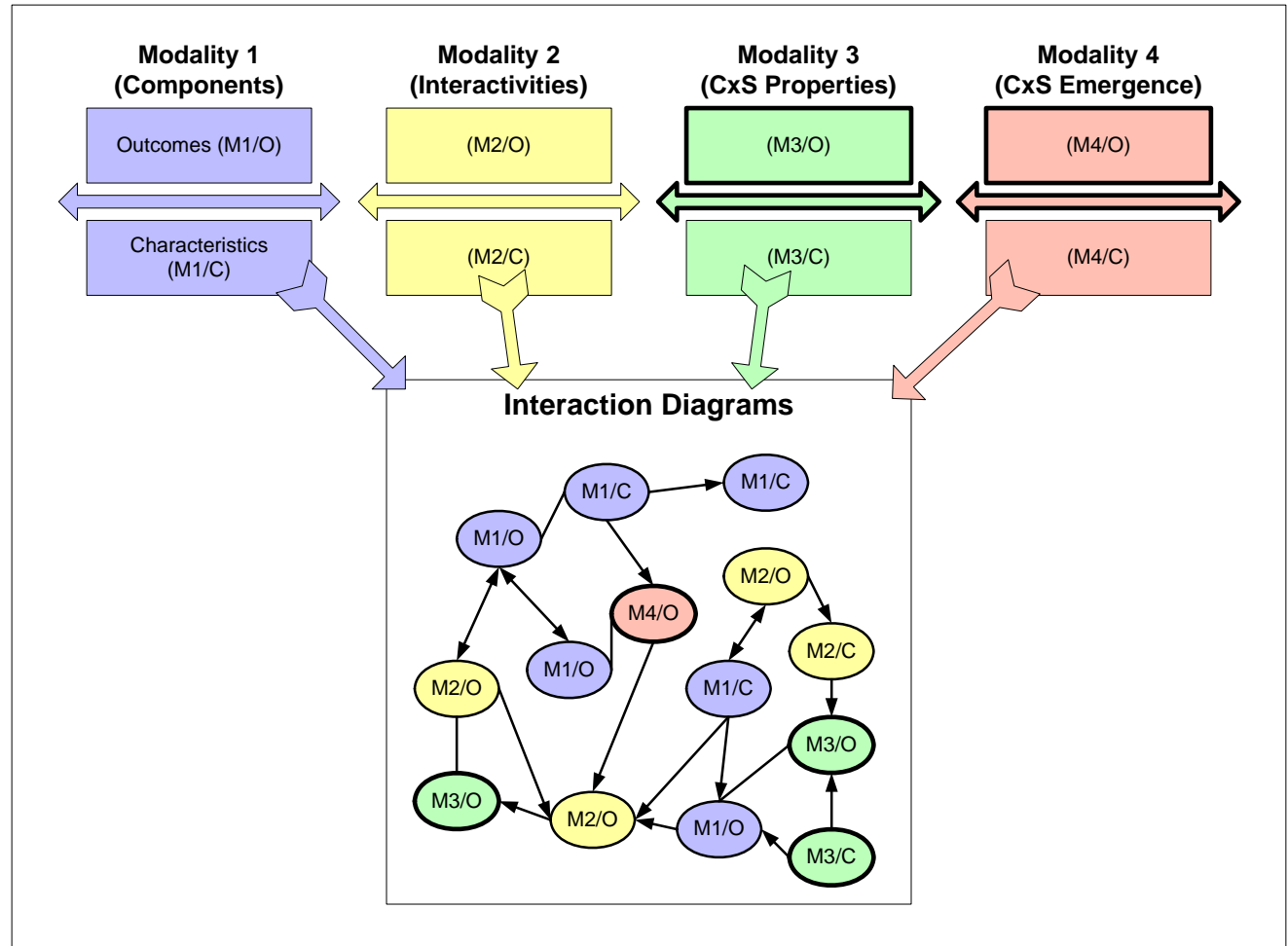


3 Application to NCO C2

The Use of Modalities and Interaction Diagrams

The Basis →
(Modalities)

Must be
supported by
specialized
tools

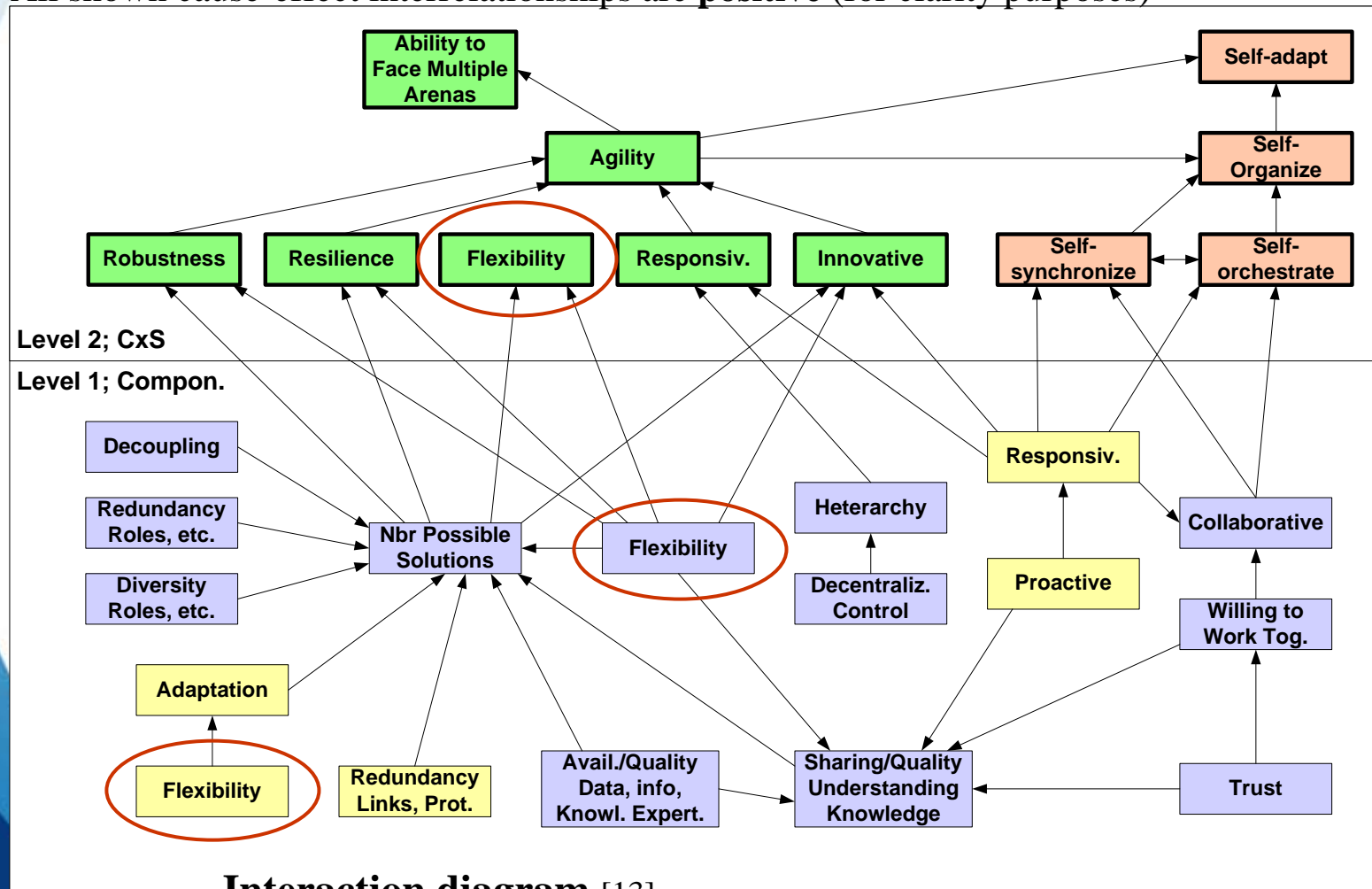




3 Application to NCO C2

Identification of Cause-effect Interrelationships Between Outcomes

All shown cause-effect interrelationships are **positive** (for clarity purposes)



Interaction diagram [13]



4 Conclusion

- **The design, study and use of CxS is challenging:**
 - Intricate interactions between systems (includes human, ...)
 - Many concurrent sources of complexity (not static)
 - Some solutions were proposed to ease this task.
 - **Interaction diagrams:**
 - Study cause-effect relationships (independently of domains)
 - The iterative and incremental building of understanding
 - A set of **four modalities:**
 - New way to structure complex studies (based on CxT)
 - Helps define used key words
 - **Holism, top-down** and **bottom-up** approaches (Anderson, 2006)
- We are currently testing these solutions with the engineering of C2-I-CxS
- ➔ Evolution of systems, maintenance of their survivability attributes



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Questions

This is an on-going work

Please, send us your comments/suggestions

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