Complexity Considerations for Systems Engineering

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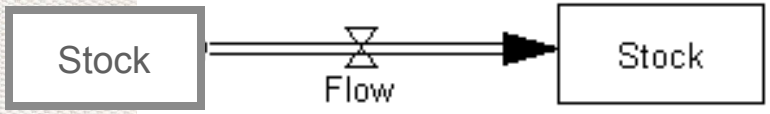
Third Millennium Systems

Questions

- What is complexity, in the context of engineering complex systems
- What are the “atomic pieces” of complex systems?
- What makes a system more or less complex?
- What flavors of complexity are there?

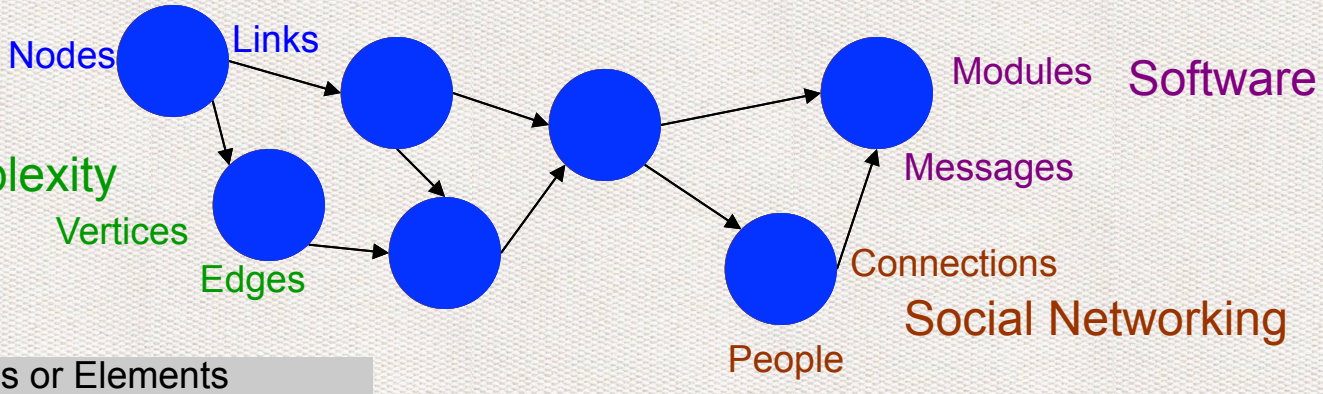
“Atomic Pieces” of Complexity Representation

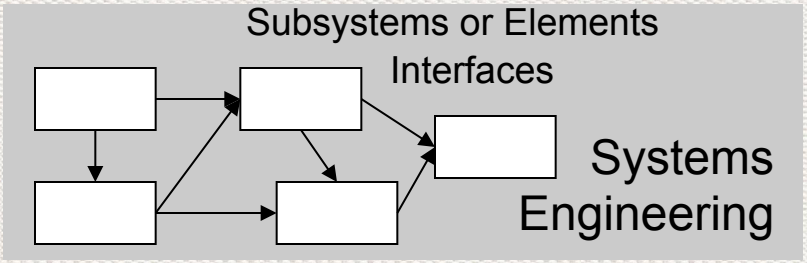
System Dynamics

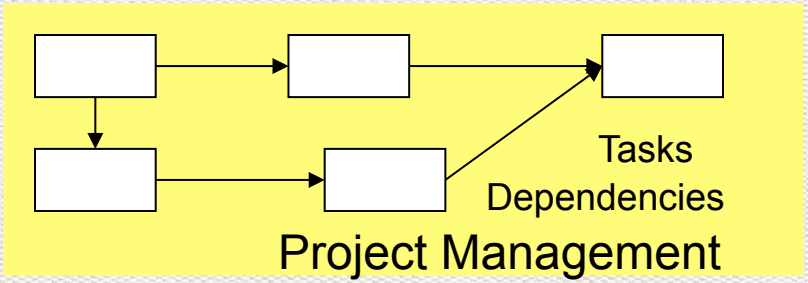


Networks

McCabe Complexity







System Analysis

Entities

Relationships

Model = Things + Relationships

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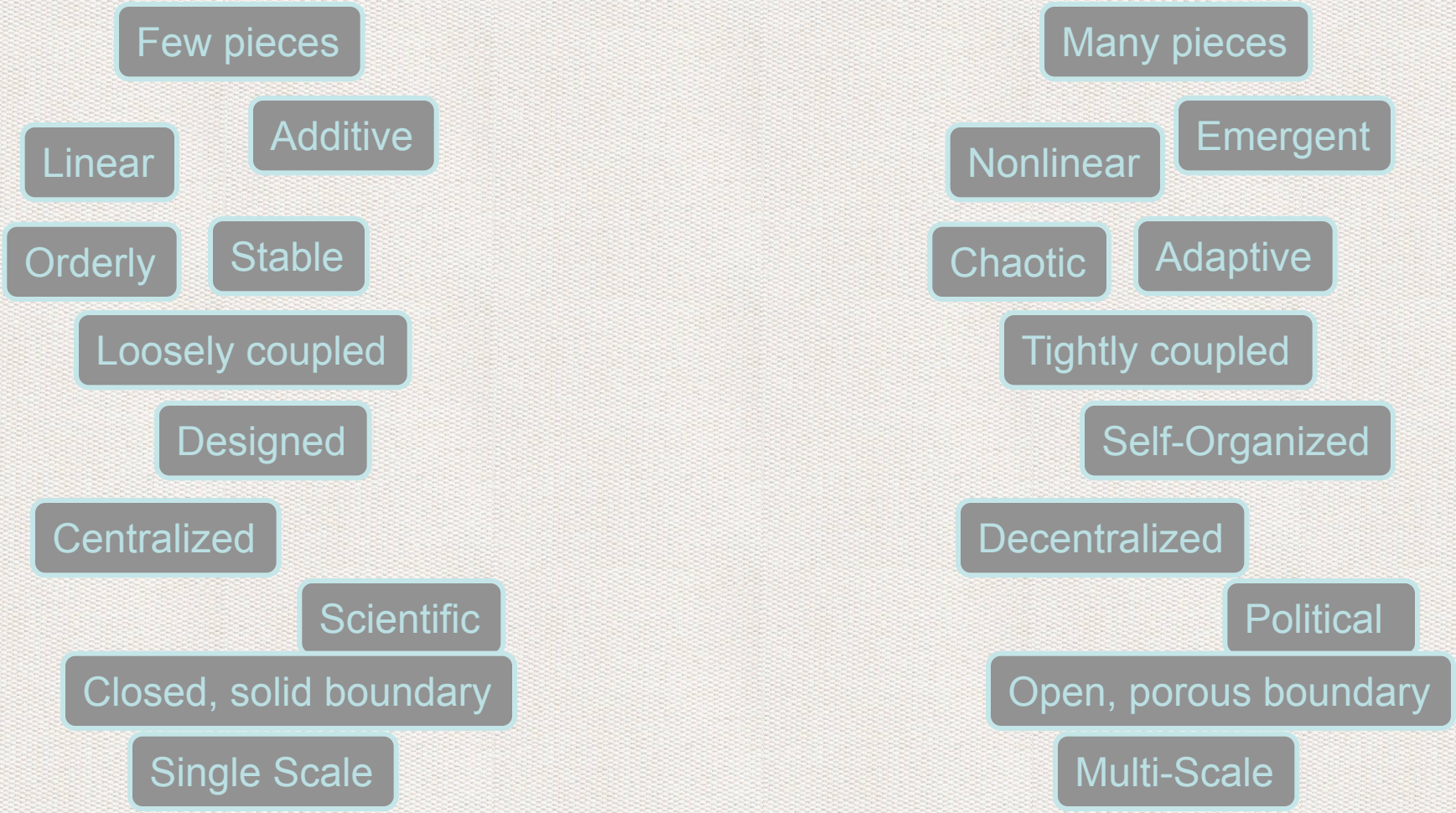
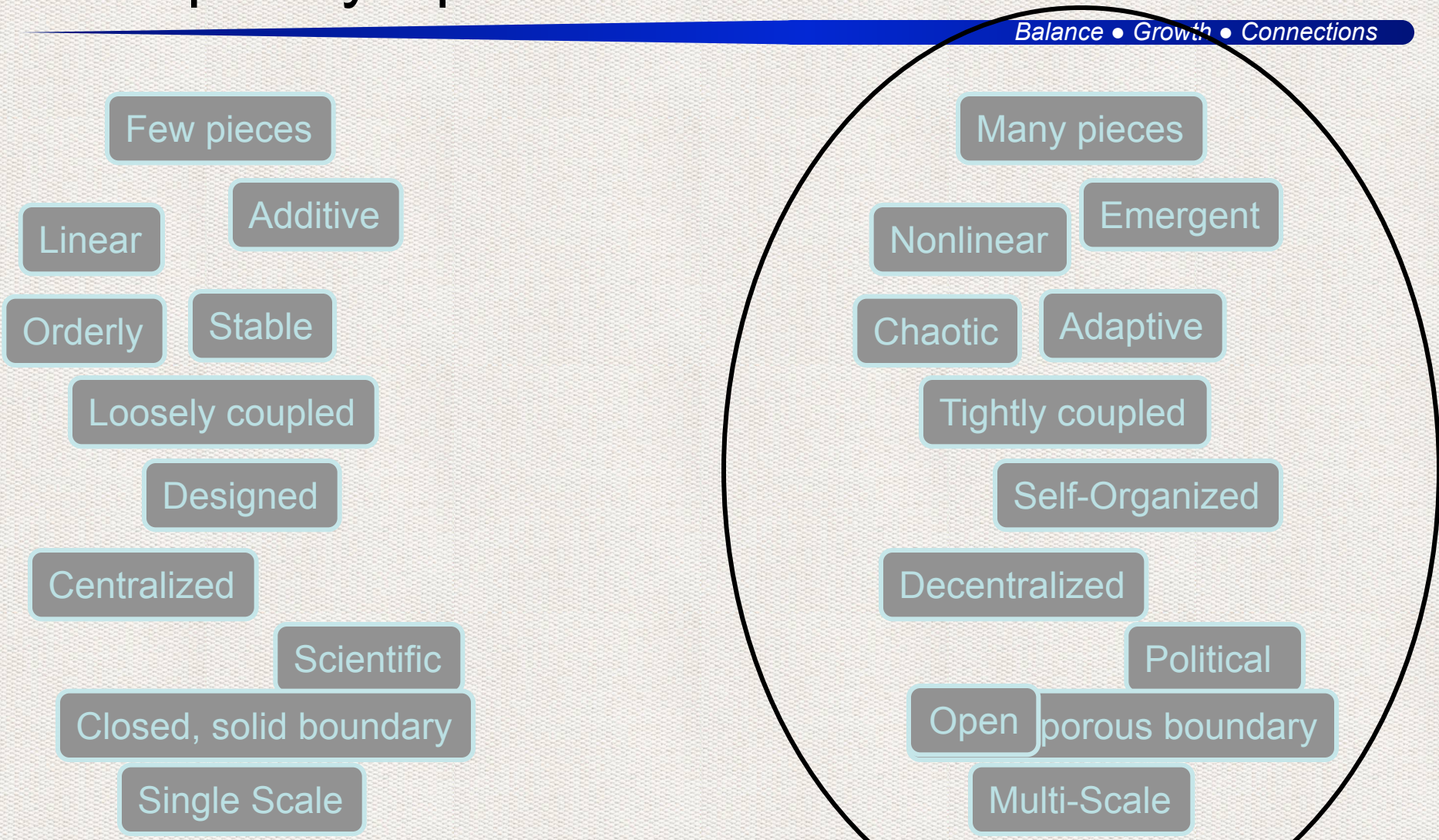
Complexity Spectra I



Complexity Spectra II



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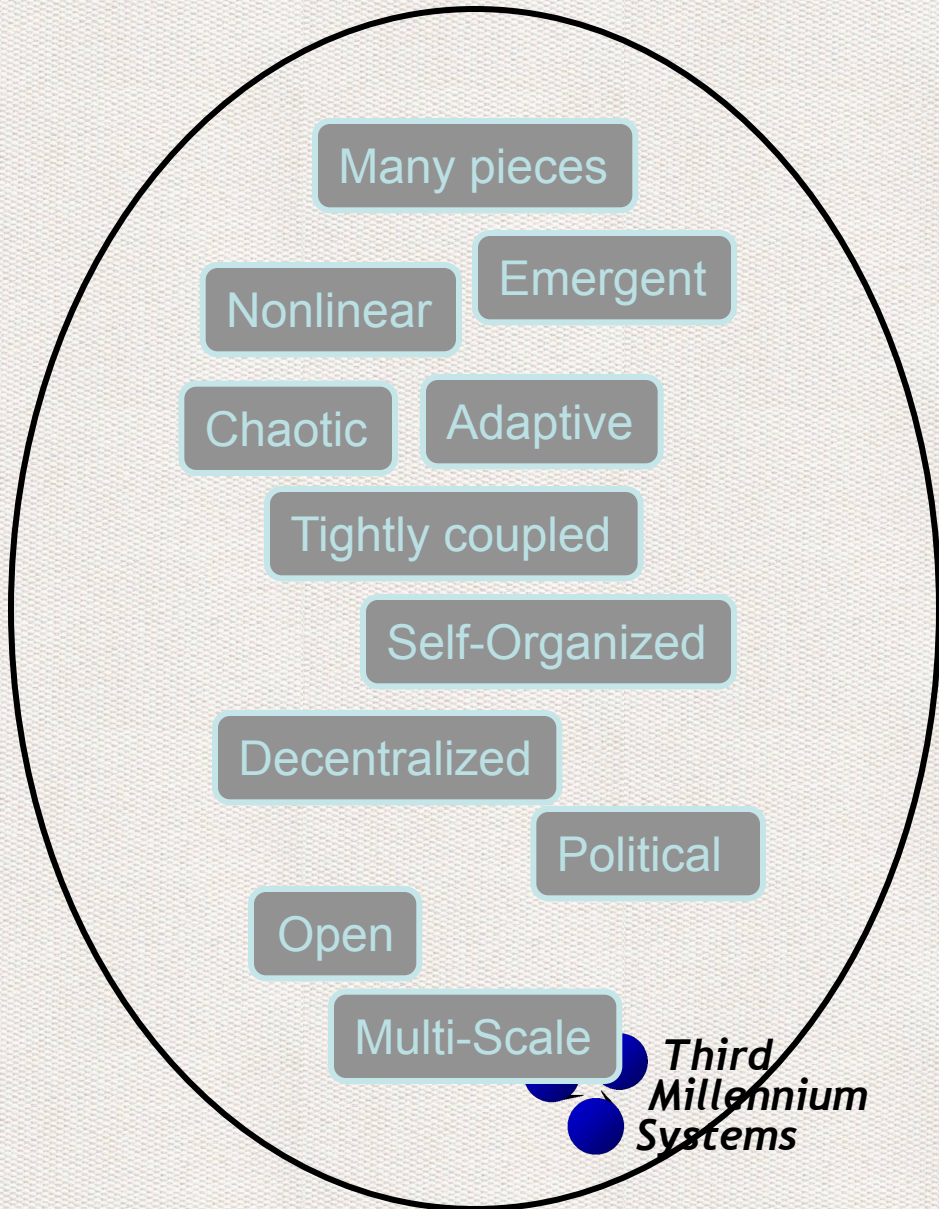
Complexity Spectra II



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Complexity Spectra III

- Uncertain
- Difficult to understand
- Unclear cause and effect
- Unpredictable
- Uncontrollable
- Unstable
- Unrepairable, unmaintainable
- Costly
- Takes too long to build

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Complexity

- Many pieces
- Nonlinear
- Emergent
- Chaotic
- Adaptive
- Tightly coupled
- Self-Organized
- Decentralized
- Open
- Political (vs. Scientific)
- Multi-Scale

- Uncertain
- Difficult to understand
- Unclear cause and effect
- Unpredictable
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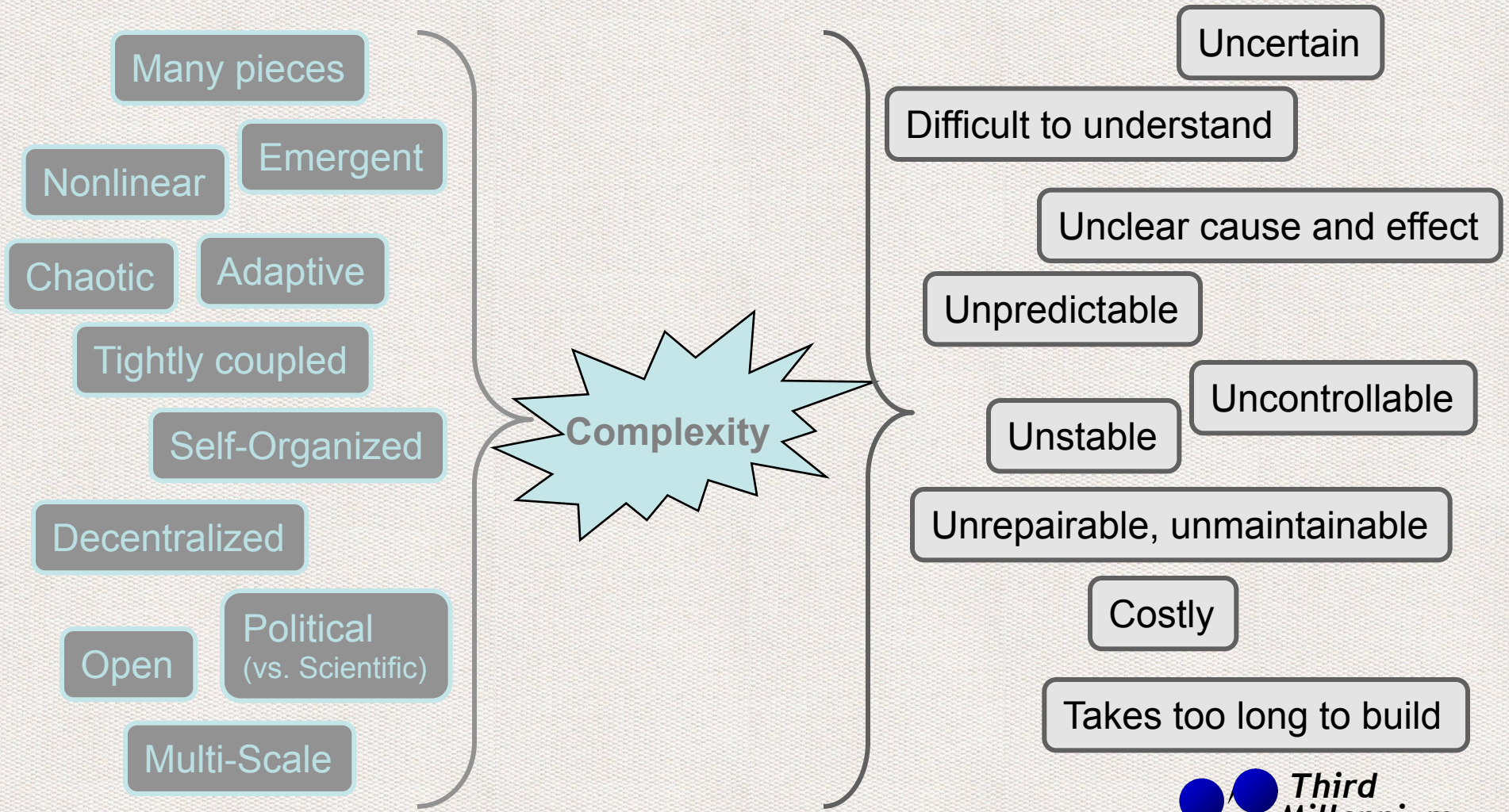
Complexity Contributors and Results



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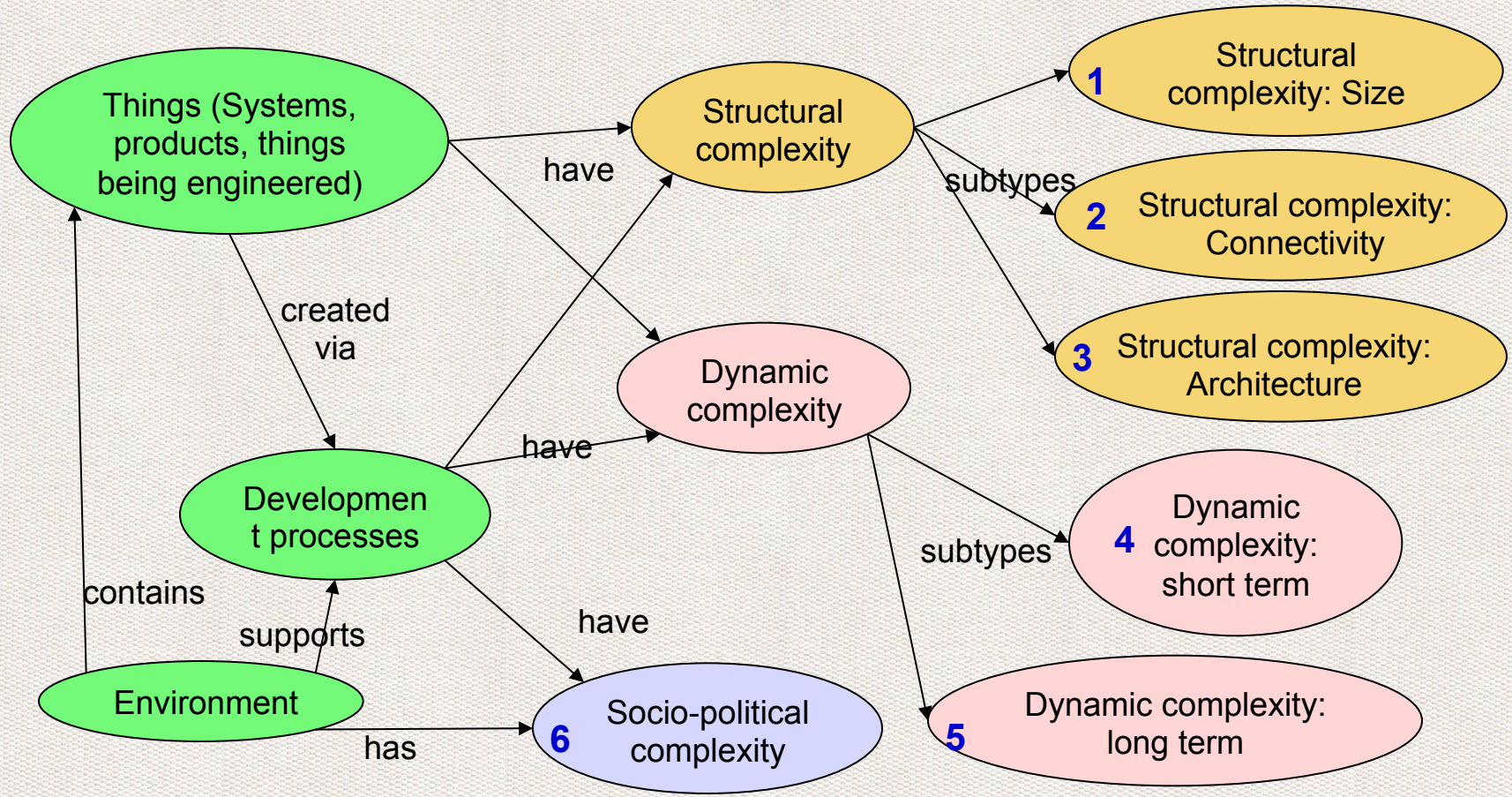
Types of complexity



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Types and Examples

1 Structural Complexity: Size	# elements, # instances, # types of elements -of development process
2 Structural complexity: Connectivity	# connections, types, strength of connections -of development process
3 Structural complexity: Architecture	Patterns, chunkiness of connections, inhomogeneity, boundaries
4 Dynamic complexity: Short Term	Nonlinearity, dynamic emergence, sudden rapid change in system behavior —butterfly effect -development system behavior
5 Dynamic complexity: Long Term	Changes in # and types of things and relationships
6 Socio-political complexity	Human cognitive limitations, multiple stakeholders, global context, environmen-tal sustainability, economics -“Coop-etition,” supplier chain depth, distributed development

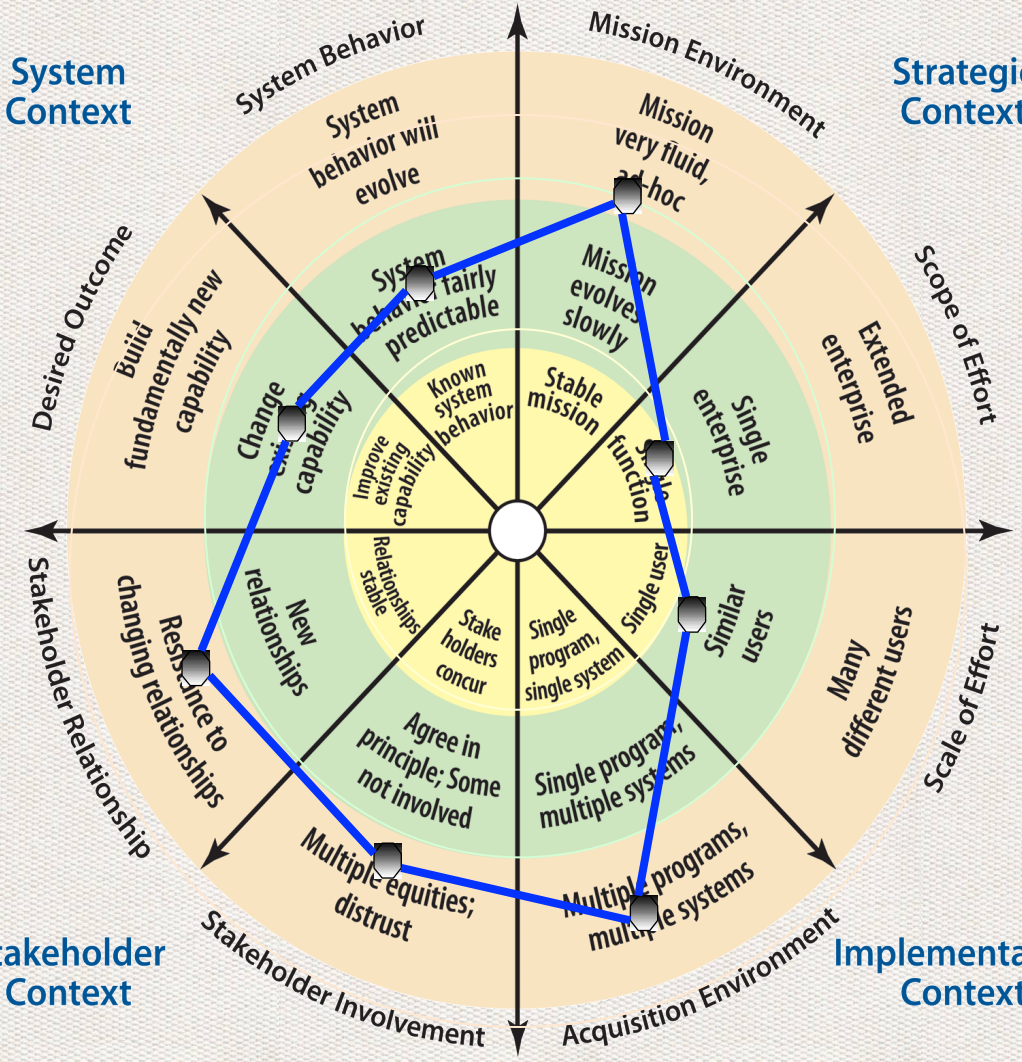
What does SE literature say?

- Does not categorize; assumes complexity = risk
  - PSM and COSYSMO: input; Architecture "relative difficulty"
  - ESE Profiler (MITRE, Renee Stevens)
  - Maier, Dimensions of Complexity
  - Case studies: AAS, other failures
  - Entropy calculations , # connections
- Extracted potentially usable measures

Maier: Factors Associated with Complexity

	Simple			Complex
Sponsors	One, w/ $	Several, w/ $	One, w/o $	Many, w/o $
Users	Same as sponsors	Aligned with sponsor	Distinct from sponsor	Unknown
Technology	Low	Medium	High	Super-high
Feasibility	Easy	Barely		No
Control	Centralized	Distributed		Virtual
Situation-Objectives	Tame	Discoverable	Ill-structured	Wicked
Quality	Measurable	Semi-measurable		One-shot and unstable
Program Scope	<$ 1 Million	$10's of Millions	$100's of Millions	>$ 1 billion
Org'l Maturity	High	Inside low, outside high		First of kind
Technical Scope	Discrete product	Product + Delivery Enterprise	Products or Product-line + Del'y Enterprise	Assemblage of products, enterprises
Operational Adaptation	Stable	User Adaptive	Competitor Adaptive	Full Scope Adaptation

Enterprise Systems Engineering Profiler™ (MITRE)



- Traditional program domain
  - ***Well-bounded problem***
  - ***Predictable behavior***
  - ***Stable environment***
- Transitional domain
  - ***Systems engineering across boundaries***
  - ***Influence vs. authority***
- Messy frontier
  - ***Political engineering (power, control…)***
  - ***High risk, potentially high reward***
  - ***Foster cooperative behavior***

Source: Renee Stevens, "Engineering Enterprise Systems: C*hallenges and Prospects,"* Presentation to DAS XIII, 2006.

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Complexity Types from SE Literature I

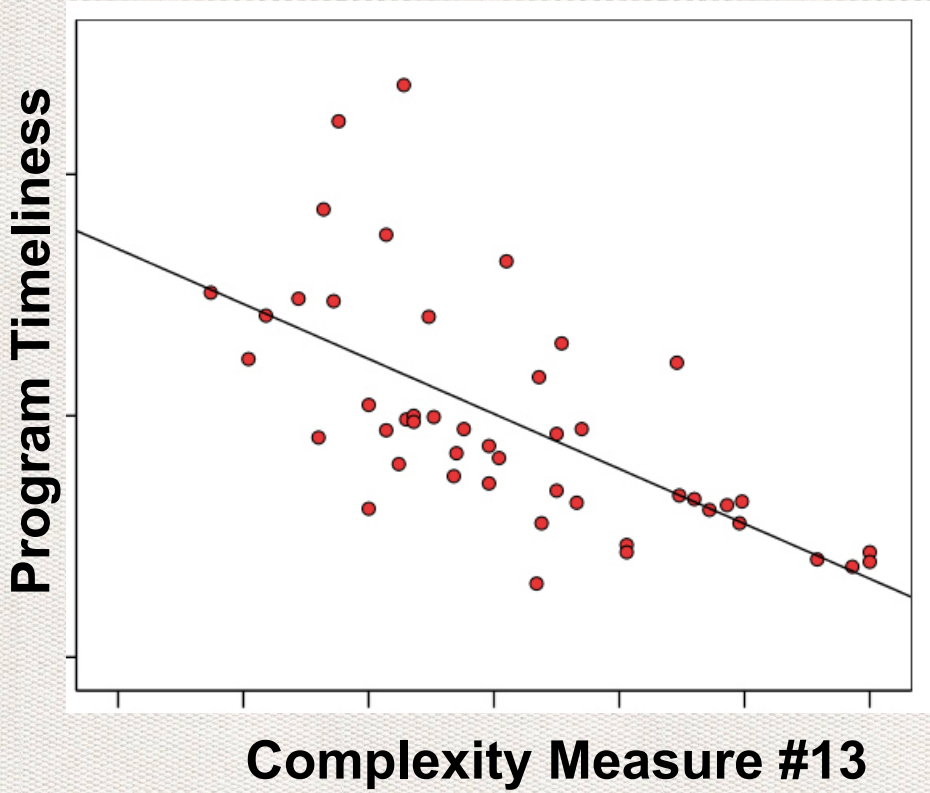
- Requirements and problem space
  - Conflict
  - How many people would you have to get into a room to understand the whole problem?
- Technical feasibility
  - Match of needs to plan
- Skills
  - Domain knowledge
  - Gap between know and need to know
  - How long to come up to speed?

Complexity Types from SE Literature II

- Technology Maturity
  - Technology and interfaces
  - TRLs
  - Computer and language
- Socio-Political subcategories
  - Organizational instability
  - Organizational structure
  - Stakeholder cohesion
  - Management task
  - Testing

Complexity Measures

- Winnowing down measures to a surveyable set
- Seek correlation
- Looking for historical programs to interview
- Need both successful and unsuccessful programs (late, very overrun, cancelled)
- Need your help!



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Survey Questions

- How complex was a program you worked on? (20-30 measures, probably bins)
- How successful was it? (cost, schedule, performance/quality)
- Your program information
- Your role and contact information

Future Work

- Identify complexity measures related to complex (acquisition-related) systems
  - Physical system
  - Institutional part of Complex, Large-scale, Interconnected, Open, Sociotechnical (CLIOS) system
- Correlate complexity to program success at completion
- Identify means of predicting program success based on these measures
- Potentially, identify methods for assessing and reducing system complexity early in program

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Acronyms and Abbreviations

- TRLs Technology Readiness Levels
- SS, SC, SA, DS, DL, SP