Managing Software and System Complexity

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Software Solutions Conference 2015

November 16–18, 2015

DM-0003038

Managing Software and System Complexity

Growth of Complexity

What is Complexity?

Example: Systems of Systems complexity

Contributing Factors

What Worsens Complexity?

Reducing Objective Complexity

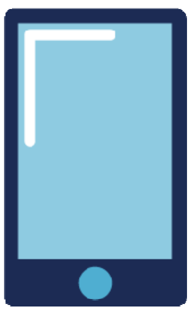
Reducing Subjective Complexity

Conclusion

Motivation

Any sufficiently advanced technology is indistinguishable from magic.

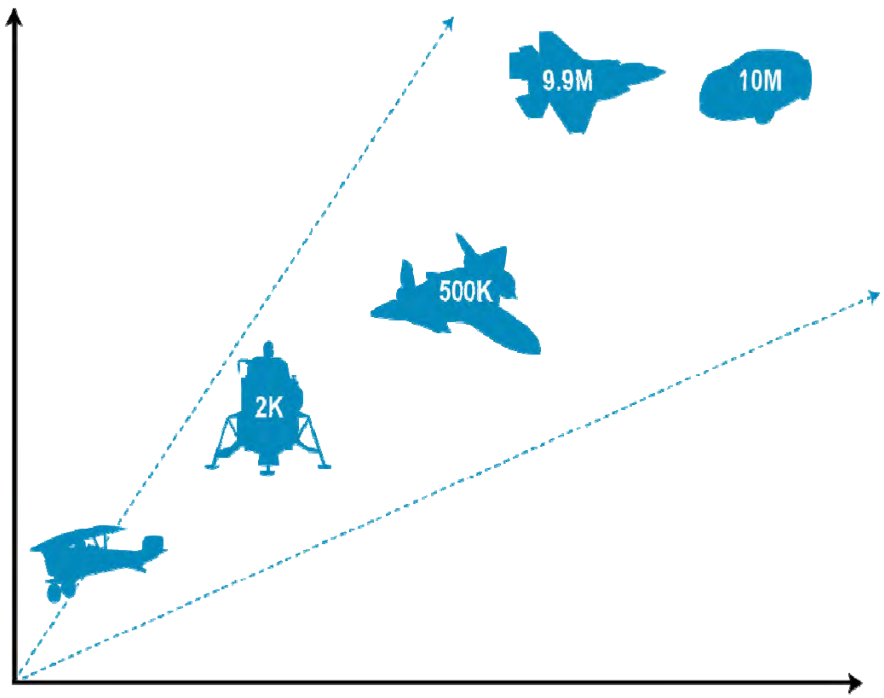
-Arthur C. Clarke



Any technology distinguishable from magic is insufficiently advanced.

- Gehm's Corollary

Growth of Complexity



Every year, systems are more complex than last year

Capability grows…our systems do more thinking

Number of systems to interoperate with grows

Systems to be redundant, resilient, adaptable, and secure to a variety of digital threats

Results in growing complexity

What Is Complexity?

Complexity is a state or quality of being composed of many intricately interconnected parts, in a manner that makes it difficult for humans, supplemented by tools, to understand, analyze, or predict behavior

Objective Complexity
Characteristics of technical system

Subjective Complexity
Characteristics of human experience with the system

Aspects of Objective Complexity

Size (number of elements, requirements, users…)

Interconnectedness (number of links)

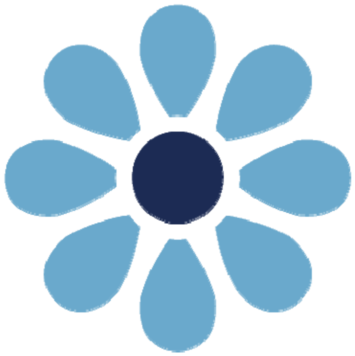
Heterogeneity (heterogeneity of elements, and of links; multi-scale important elements)

Change (short term dynamics – butterfly effect, behavior – and long term dynamics – evolution)

Sociopolitical complexity (Stakeholder conflict, stakeholder changes)

-Sheard 2012 Dissertation,
see http://seir.sei.cmu.edu/sheard/

Aspects of Subjective Complexity



Difficulty understanding

Difficulty determining cause and effect

Confusion and frustration

Unpredictability

Inability to list all the major problems

Difficulty teasing a problem apart into component sub-problems

Concepts Related to Complexity

Are These Objective or Subjective?

Lines of code	O
Unmaintainable	S
Difficult to verify	S
Nonlinear behavior	O
Strong coupling	O
Open system	O
Unclear system boundary	S
Not possible to understand	S
Can have cascading failures	O
System of systems	O
Heterogeneous elements	O
User cognitive load	S

Objective → *Causes* → Subjective

Many pieces

Tightly coupled pieces

Nonlinear behavior

SoS with many stakeholders

Causes

Uncertain

Risky

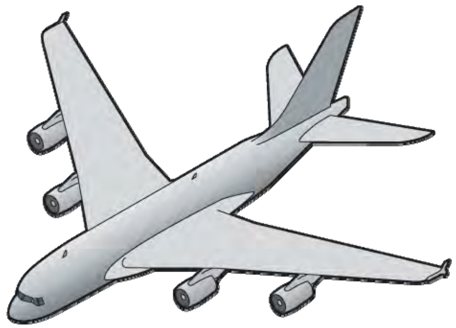
Hard to understand

Unpredictable

Frustrating

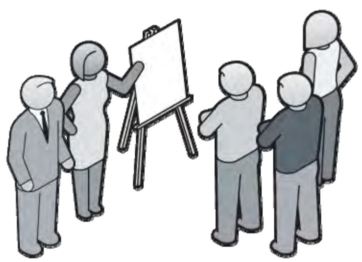
Uncontrollable

What Can Be Complex?



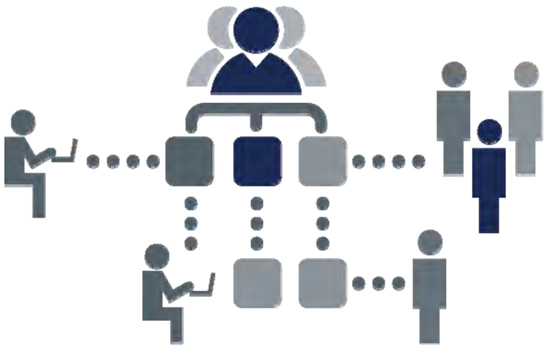
Systems

- Software, computer hardware, other hardware
- *Safety case*



Projects

- Teams, process, constraints, laws, deadlines, …



Environments

- Technical – interfacing systems
- Sociopolitical

Is Complexity Bad?

Yes

In performance, schedule, cost: a more complex system is worse than a simpler system

No

More complex systems can have more intelligent functionality

Complexity is in all cases *difficult* to deal with.

It may be *necessary*.

Splitting Complexity

Split complexity between technical system and operator

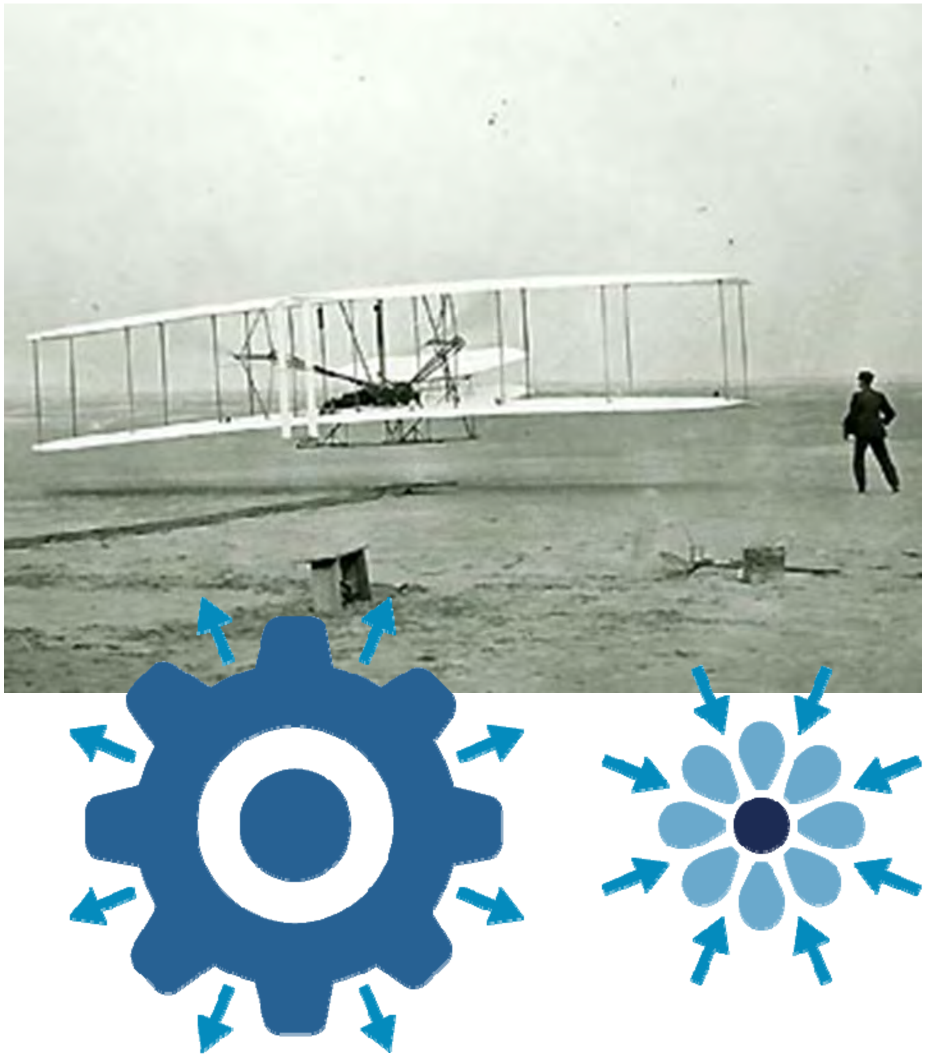
- Technical system can handle complexity that could confuse an operator (e.g. calculate position from sensor data)

Goals:

- System shouldn't be so simple it leaves all complexity to the operator

- System shouldn't be so complex it hides issues and leaves the operator completely out of the loop

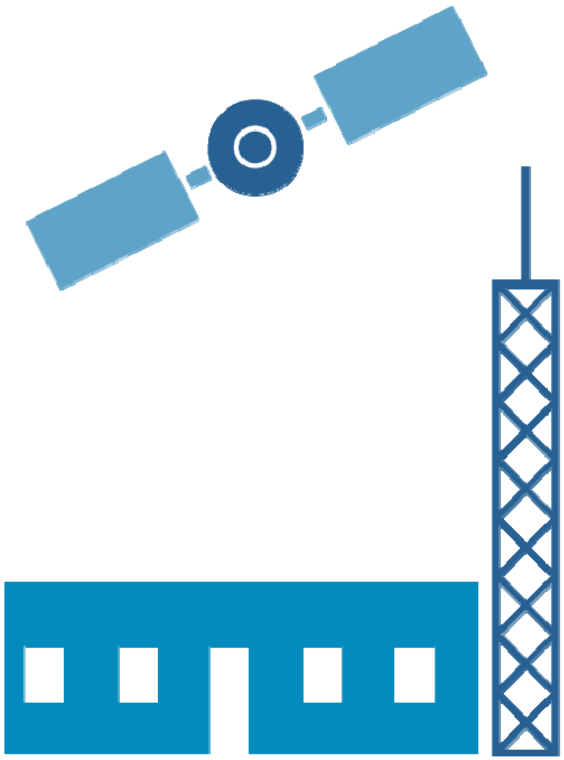
Complexity Changes with Time



Complexity, however defined *objectively*, relentlessly increases

Complexity, defined *subjectively*, relentlessly decreases (for a given system)

Example: Complexity of a System of Systems



Purpose: to create a multi-purpose, multi-user technology

Organization: One enterprise including several ACAT 1 programs

- Each program has cost, schedule, performance issues and makes adjustments per own priorities
- Each program can hold up all the others

Desire top-down control; best you can get is agreements

Example: Contributing Factors to Complexity

- This system will be launched into orbit, and we can't fix it after that
- Dealing with legacy systems
- Conflict between cheapest now and most adaptable for the future
- Stakeholders change
- New standards came out since we started designing this

- Example: Internet of Things

Reasons for Today's Complexity Increase

Environment evolves

- Distributed systems, distributed development
- Requirements
  - Interoperability
  - Safety
  - Resilience, flexibility and adaptability
- Evolving nature of security threats and countermeasures
- Tools and environments allow it, e.g., optimizing compilers, higher-order languages.

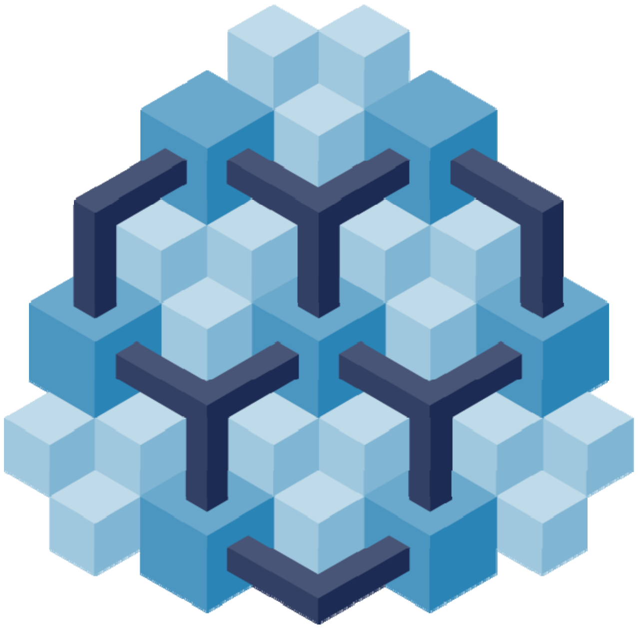
-- Sheard, Sarah and A. Mostashari, "Principles of complex systems for systems engineering." Systems Engineering 12(4), 2009: 295-311.

What Makes Complexity Worse?

- Using more components
- Patching after-the-fact
- Requirement changes approved midway through the program
- Using components about which little is known (Legacy, COTS)
- Inadequate time for engineers to think (“Just do the process”)
- Multiple stakeholders, especially when they change their minds
- Changing relationships among stakeholders
- Lack of clarity in architecture
- Lack of clarity regarding which experts are the final authority

- Experience

Dealing With Complexity



Reduce objective complexity

- Often: Architecture

Reduce subjective complexity

- Many tools and techniques from project management and systems engineering

Treat remaining complexity as risks

Dealing With Complexity: 2

Project management and **systems engineering** activities

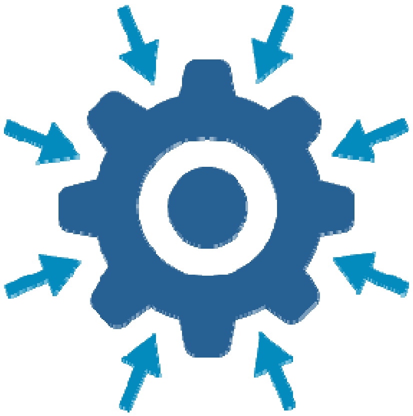
- Planning, tracking
- Identification and prioritization of requirements
- Allocation of tasks to people
- Allocation of requirements to components
- Trade studies
- Communication with customer representatives
- Risk management

Identify and address "system of systems" engineering concerns

Identify systems and software architectures that best address needed qualities

Evolve the right design by adapting proven designs

Reducing Objective Complexity



Use fewer components/pieces

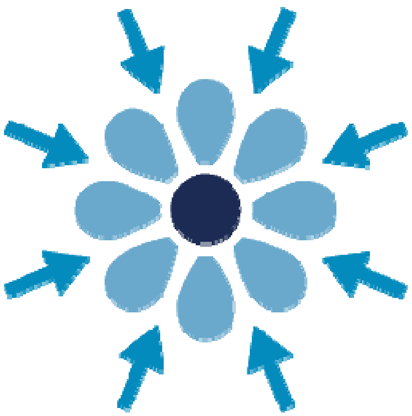
Use fewer *kinds of* components or pieces

Decouple (caution: this may reduce capability)

Reduce the frequency of change (defer to "next version")

Improve clarity of communication

Reducing Subjective Complexity



Establish capable modeling, configuration management, and design environment

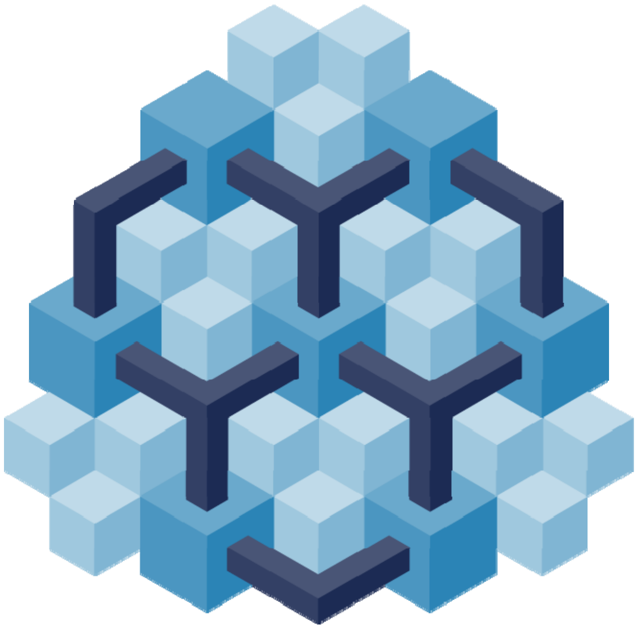
Probe, proof the new technology: Prototype

Learn from others who are using it

Improve clarity of communication

Train engineers and give them time to think

Treat Remaining Complexity as Risks



- Identification
- Analysis
  - What, how, when
  - Any cascading effects
  - How likely and how bad
  - Evaluation
- Mitigation
- Monitoring

Conclusion

Objective complexity relates to the system and can be measured

- Systems become more objectively complex over time

Subjective complexity varies with person and time

- A system becomes less subjectively complex with familiarity and tools

Reduce complexity with standard tools and techniques

- Architecture; planning, tracking, communicating

Treat remaining complexity as a risk: identify, analyze, mitigate

Contact Information

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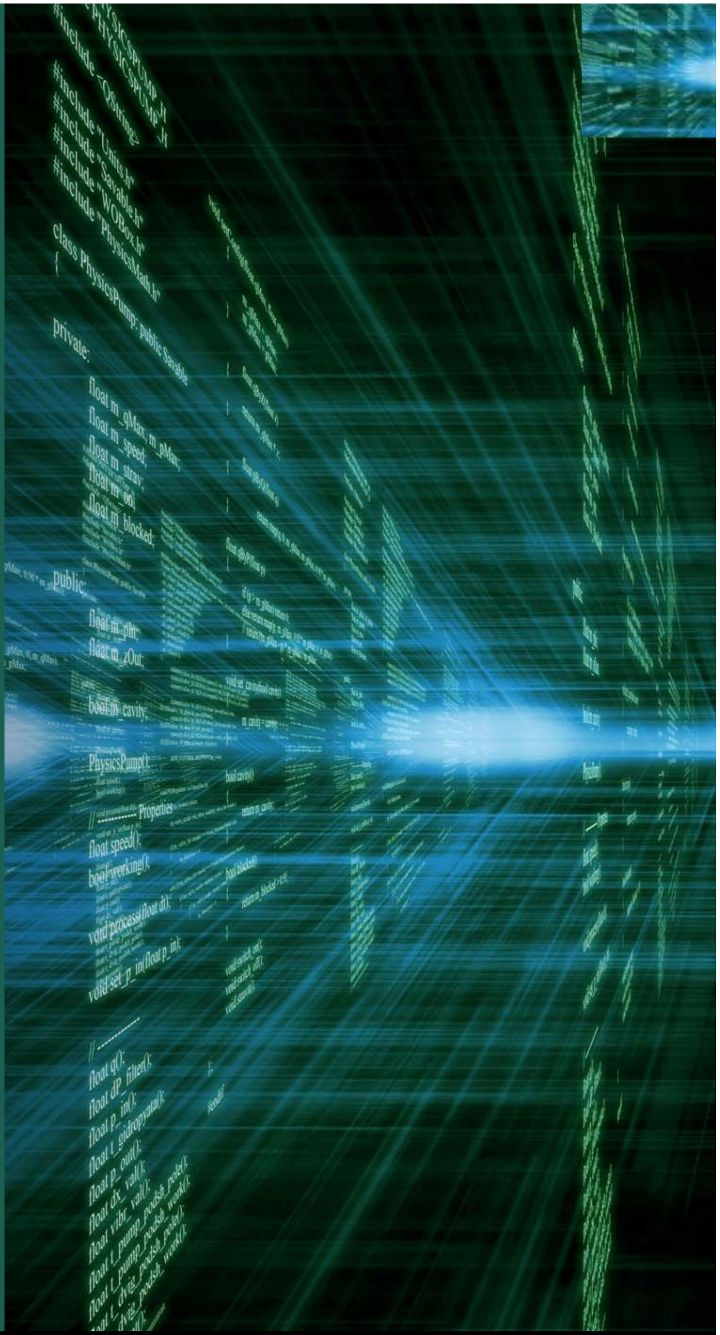

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