Emerging Complexity

Impacts on Systems & Mission Engineering

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DEFINED BUSINESS SOLUTIONS LLC

S&ME Conference, October 18, 2023

Agenda

- Complexity - Definition and Science
- Emergence as an Attribute of Operations
- Relationship to Systems and Mission Engineering
- Response
- Conclusion

What is complexity?

Chat GPT

Complexity refers to the degree of intricacy, intricateness, or sophistication of a system, problem, object, or concept. It is a multifaceted concept that can be applied to various fields and contexts, including science, mathematics, computer science, sociology, and philosophy, among others. Complexity often involves multiple interacting components or elements that give rise to a level of intricacy that makes understanding, predicting, or managing the system or problem challenging.

Bing

Complexity theory is a field of study that explores how the computational complexity of problems changes as the number of cases involved increases and how to classify the problems based on the algorithms and time required to solve them. It also examines how some systems, such as living organisms, markets, or networks, display emergent behavior that cannot be explained by their constituent parts and how to model and predict such behavior. Complexity theory is shared by mathematics and computer science and has applications to various domains.

Change Drives Complexity

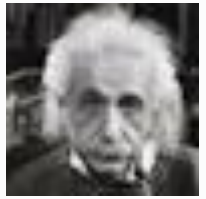
MEDICINE

Poultice

Neurosurgery

HUMAN KNOWLEDGE

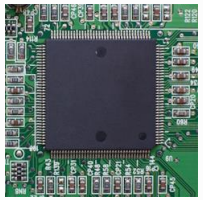
Aristotle



Einstein

TECHNOLOGY

Stone Age



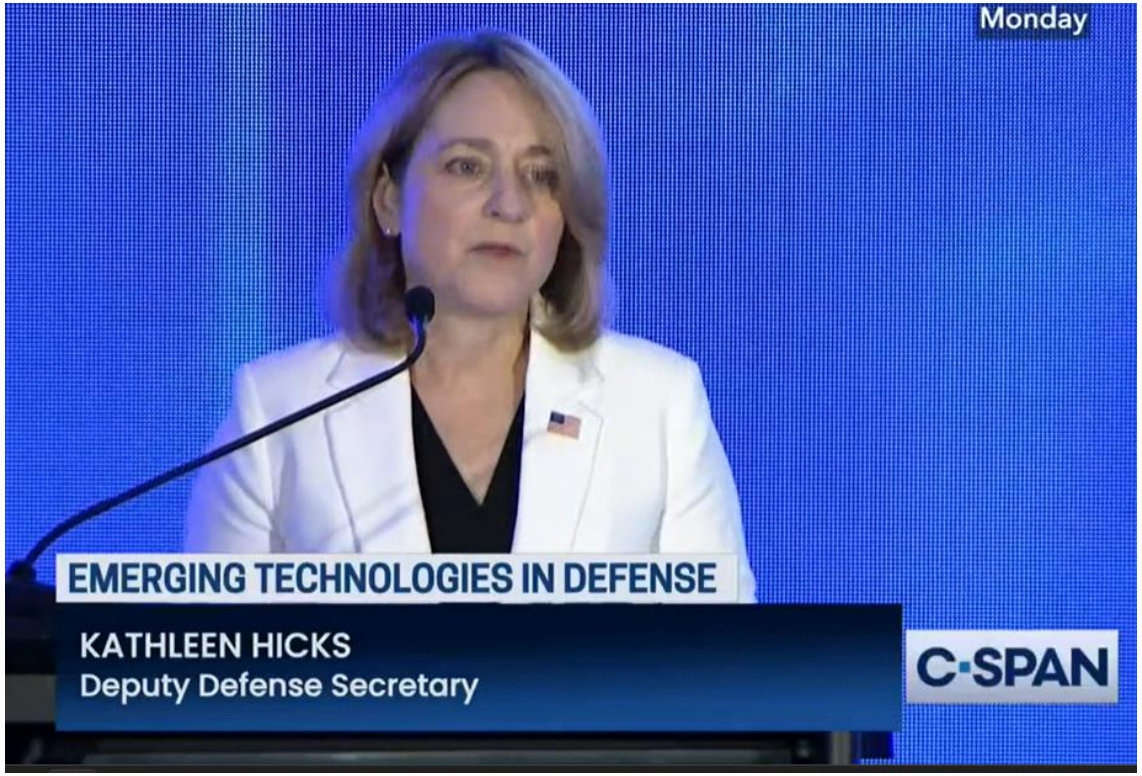
Digital Age

COMMUNICATIONS

Pigeons

Internet

Pace of Change – Speed of Relevance



NDIA Emerging Technologies for Defense Conference

Video https://www.c-span.org/video, Transcript https://www.defense.gov/News

"…our goal is to seed, spark, and stoke the flames of innovation…at DoD, we've already been investing in attritable autonomous systems…and in multiple domains: self-piloting ships, uncrewed aircraft, and more."

- Deputy Secretary Kathleen Hicks, August 28, 2023

Why Did the Robot Do That?

Jonathan Rey, Icon Archive, https://www.iconarchive.com/artist/jonathan-rey.html
(c) Lucas Film Ltd.

- Emerging Technology
  - No or little experience with the tech
  - Unknown consequences
  - Disruptive
- Increasing use of AI & autonomy
  - Software quality and security
  - Authoritative data
  - Ground truth
  - Speed
  - Independence of action
- Is it trusted?

“There are known knowns — there are things we know we know. We also know there are known unknowns — that is to say, we know there are some things we do not know. But there are also unknown unknowns, the ones we don’t know we don’t know.”

- Donald Rumsfled, Secretary of Defense, February 2002

“The absence of evidence is not evidence of absence”

Complicated Systems

- Engineered and Deterministic
- Many interacting components
- Dependencies
- Predictable, known, planned and linear behavior

THESE

must function within

Complex Systems

- Unordered and Stochastic
- Many interacting components
- Dependencies, competitions, relationships
- Exhibit nonlinearity, emergence, self-organization, adaptation

THESE





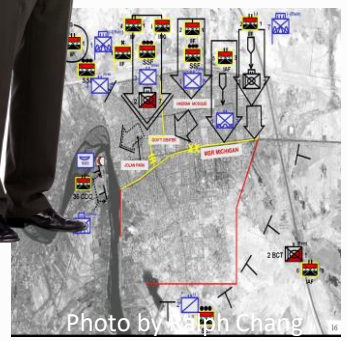
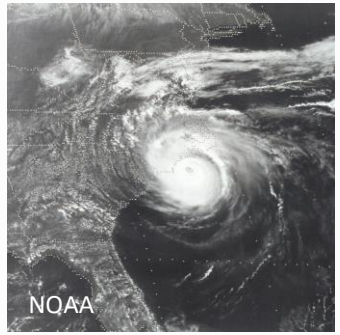
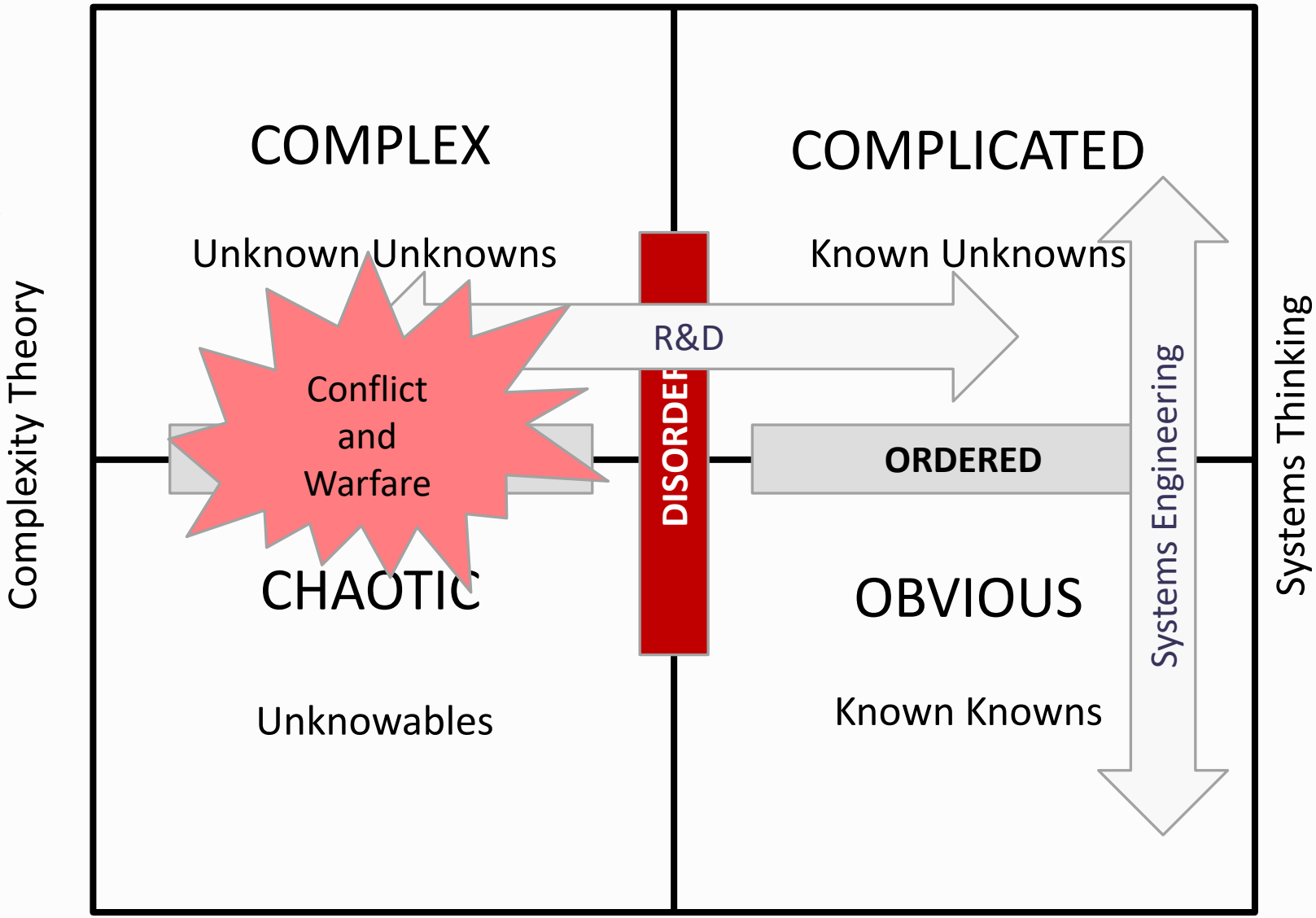


Photo by Ralph Chang

Photo by Michał Ludwiczak

NOAA

Cynefin Framework

- Sense-making for leaders
- Help to identify how they perceive situations (understand) and make sense of their own and other people's behavior
- Related to Theory of Constraints
- Each domain can be addressed with different mental model



Dave Snowden, The Cynefin Co. https://thecynefin.co/

Kurtz and Snowden, IBM, **2003**

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Navigating

Map, rules , tools, certainty

Wayfinding

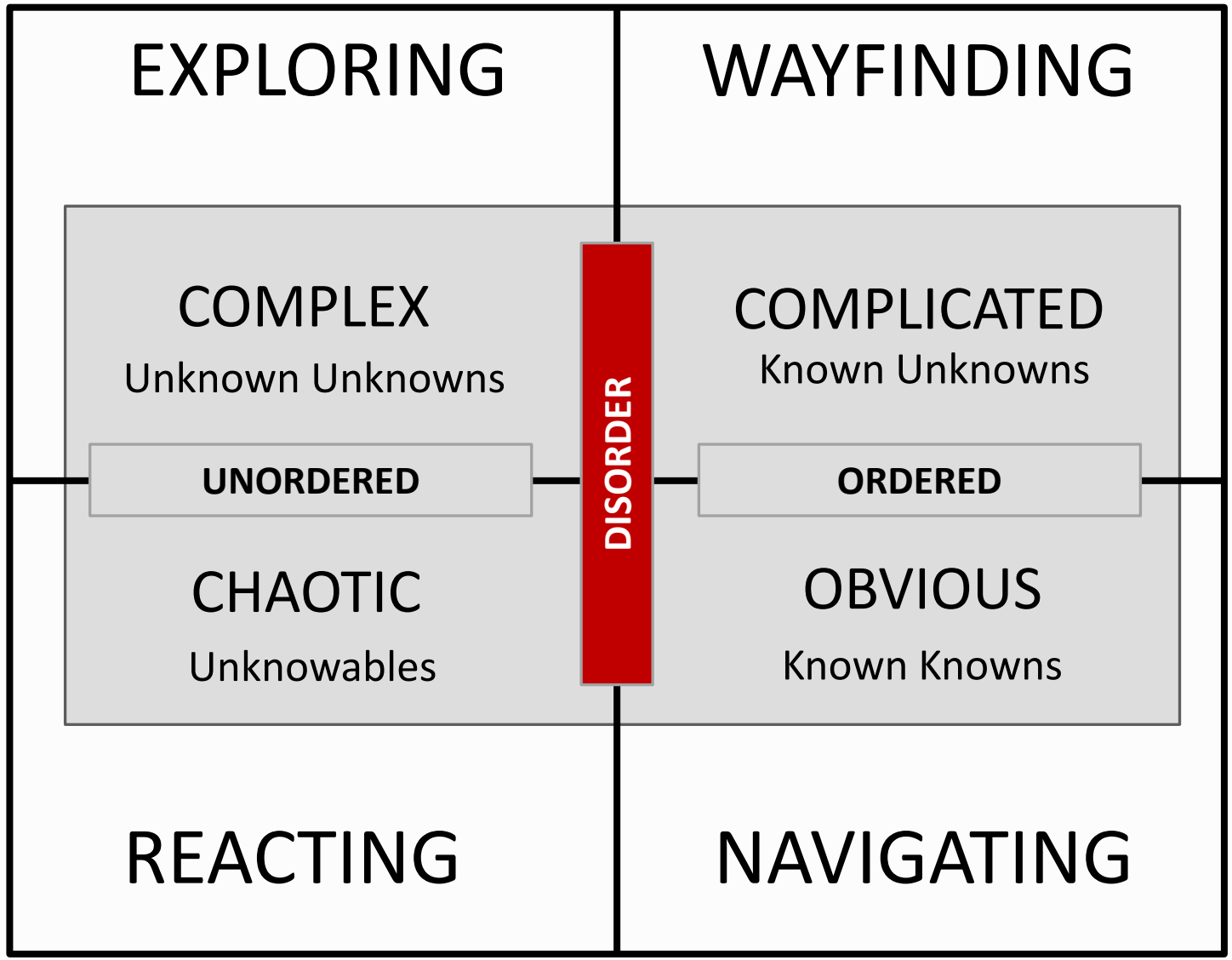
Partial map, rules , tools, some uncertainty

Exploring

Start point, some rules and tools, testing, observing

Reacting

Unplanned, unexpected, no rules, limited tools



Kurtz and Snowden, IBM, **2003**

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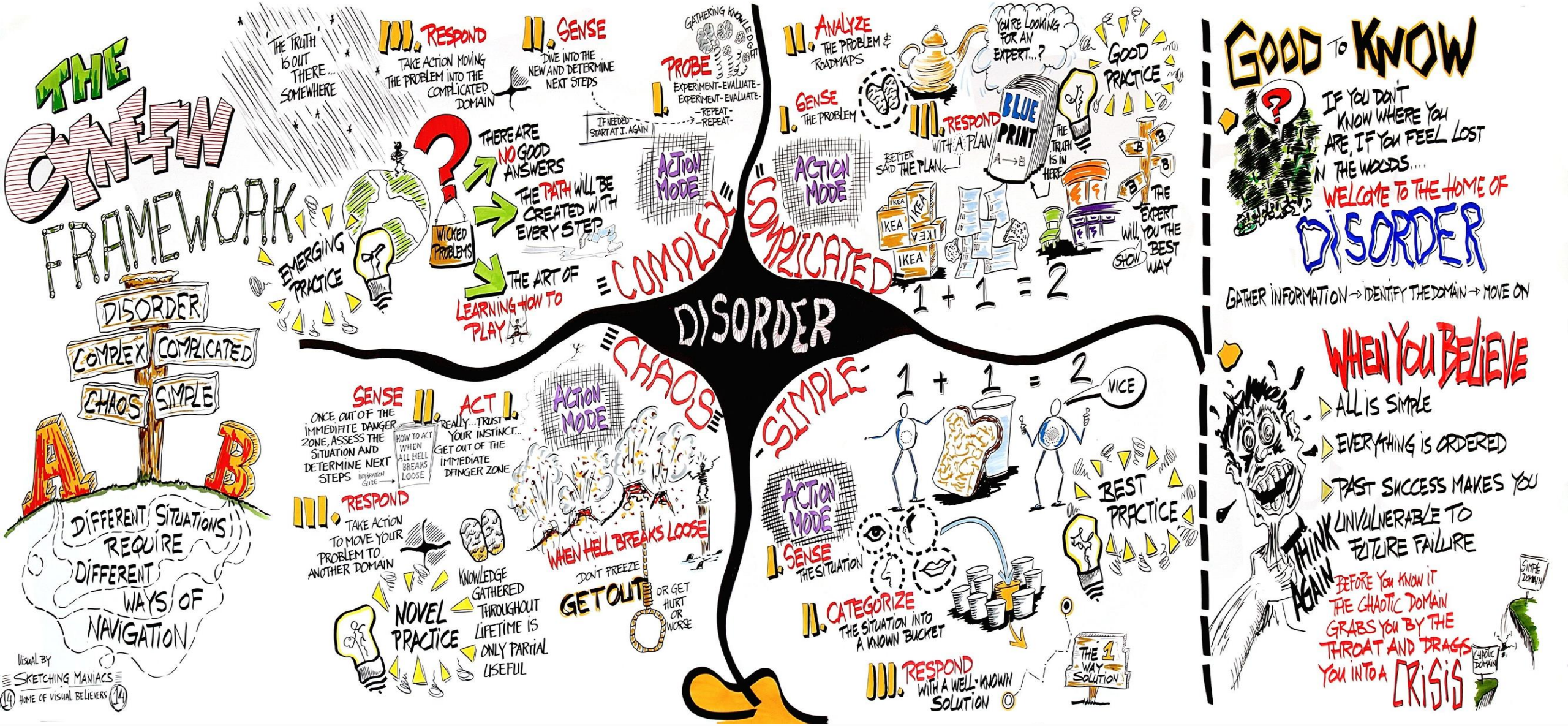


By Edwin Stoop (User:Marillion!!62) - [1], CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=53810658

How do you KNOW you have Complexity!?

- Small issues have disproportionately large impact
- Highly networked, connected, collaborative SoS*
- Lots of interdependencies, decentralized
- Emergent behaviors (desirable or undesirable)
- Difficult to predict or model
- Collaborative operations and external autonomy
  - C-JADC2, Joint Fires, Integrated deterrence
  - Budget instability

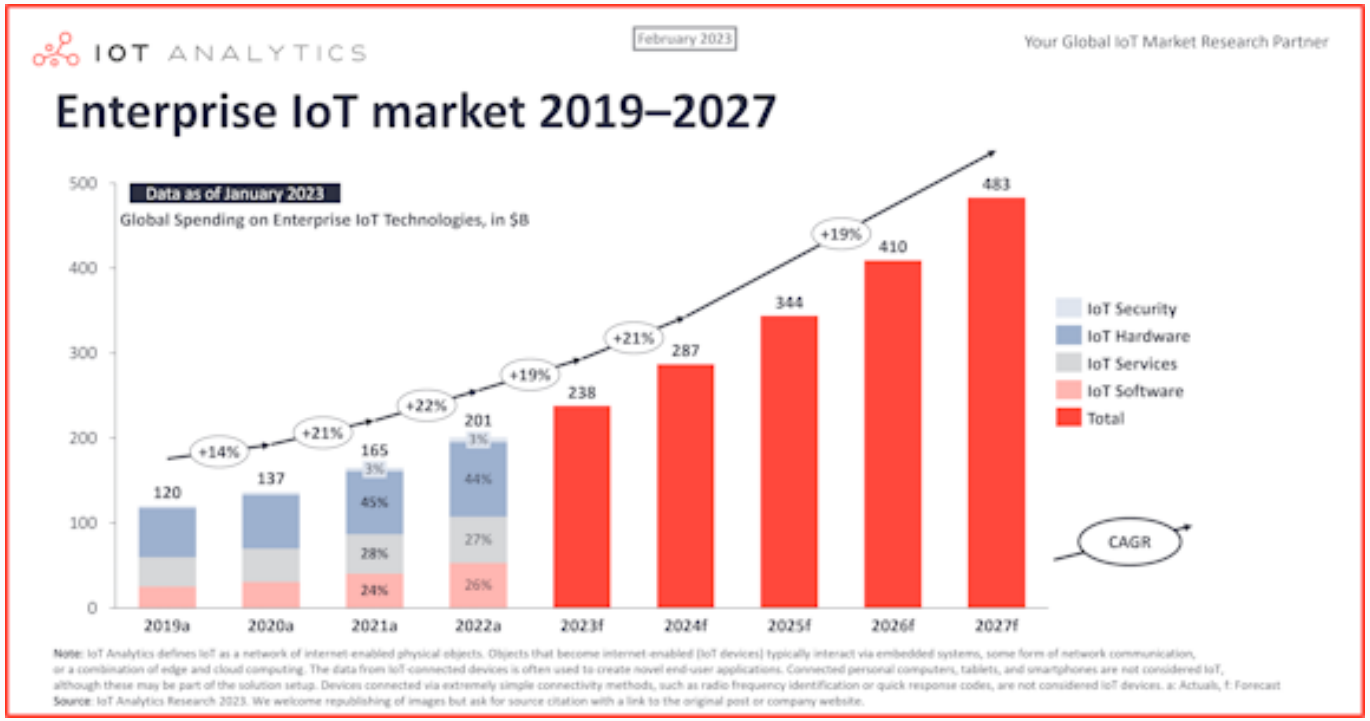
* See Emergent Behavior In Systems of Systems, Osmundson, Huynh, Langford, 2008

Contributors

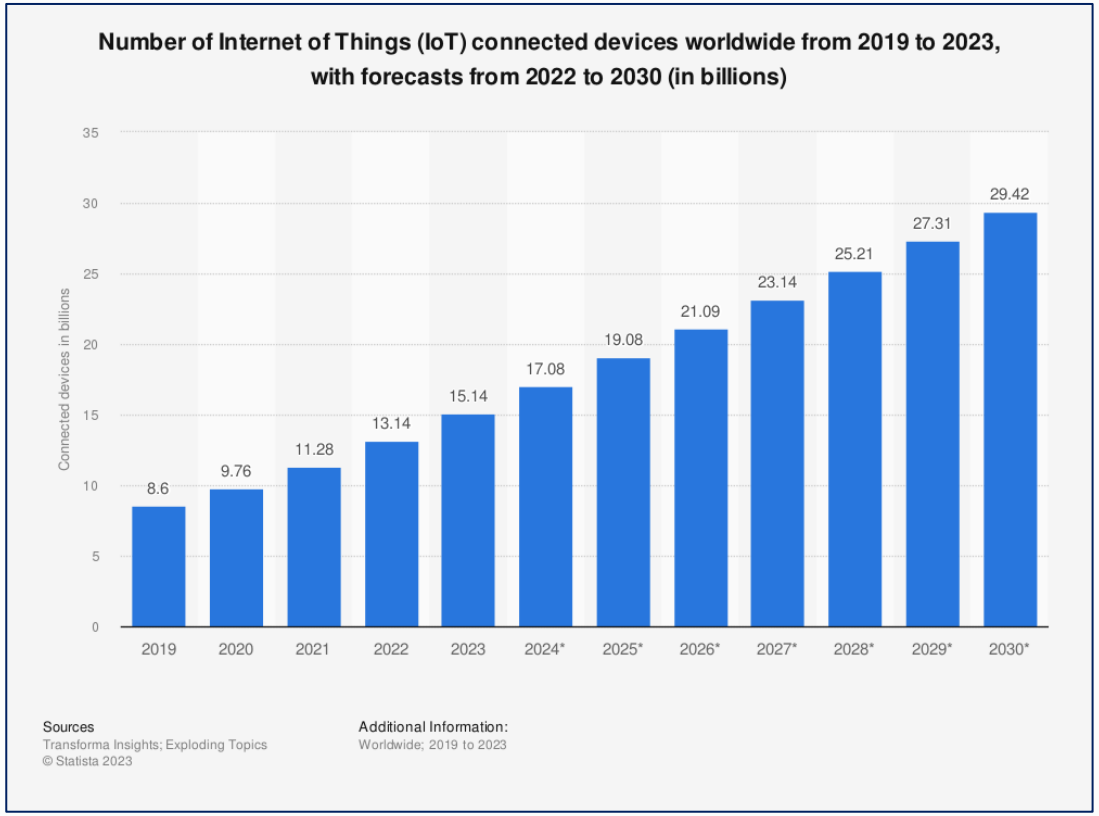
- Digital Transformation
  - DE environment (models, data)
- Operational Concepts
  - C-JADC2, Joint Fires
- External Influences
  - Budgets, regulations, NDAA, etc.
- Emerging Technology
  - AI, autonomy, EV, IoT, smart sensors,
- Innovation at Speed and Scale

Is Complexity Increasing?

Internet of Things Market Trends



Phillip Wegner, IOT Analytics, Feb 2023, https://iot-analytics.com/iot-market-size/



Lionel Sujay Vailshery, Jul 27, 2023, Statista https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/

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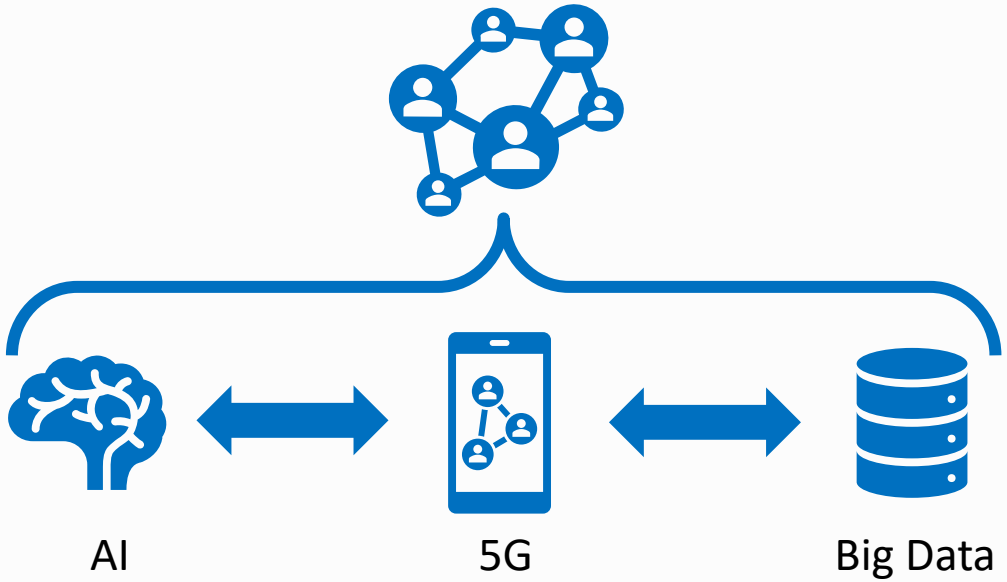
Fusion of AI and IoT



By 2025, there's projected to be 42 billion IoT-connected devices globally. (IDC)

The amount of data generated by IoT devices is expected to reach 73.1 ZB (zettabytes) by 2025. (IDC)

1 ZB = 1 billion TB = 1 trillion GB

Artificial Intelligence of Things (AIoT)

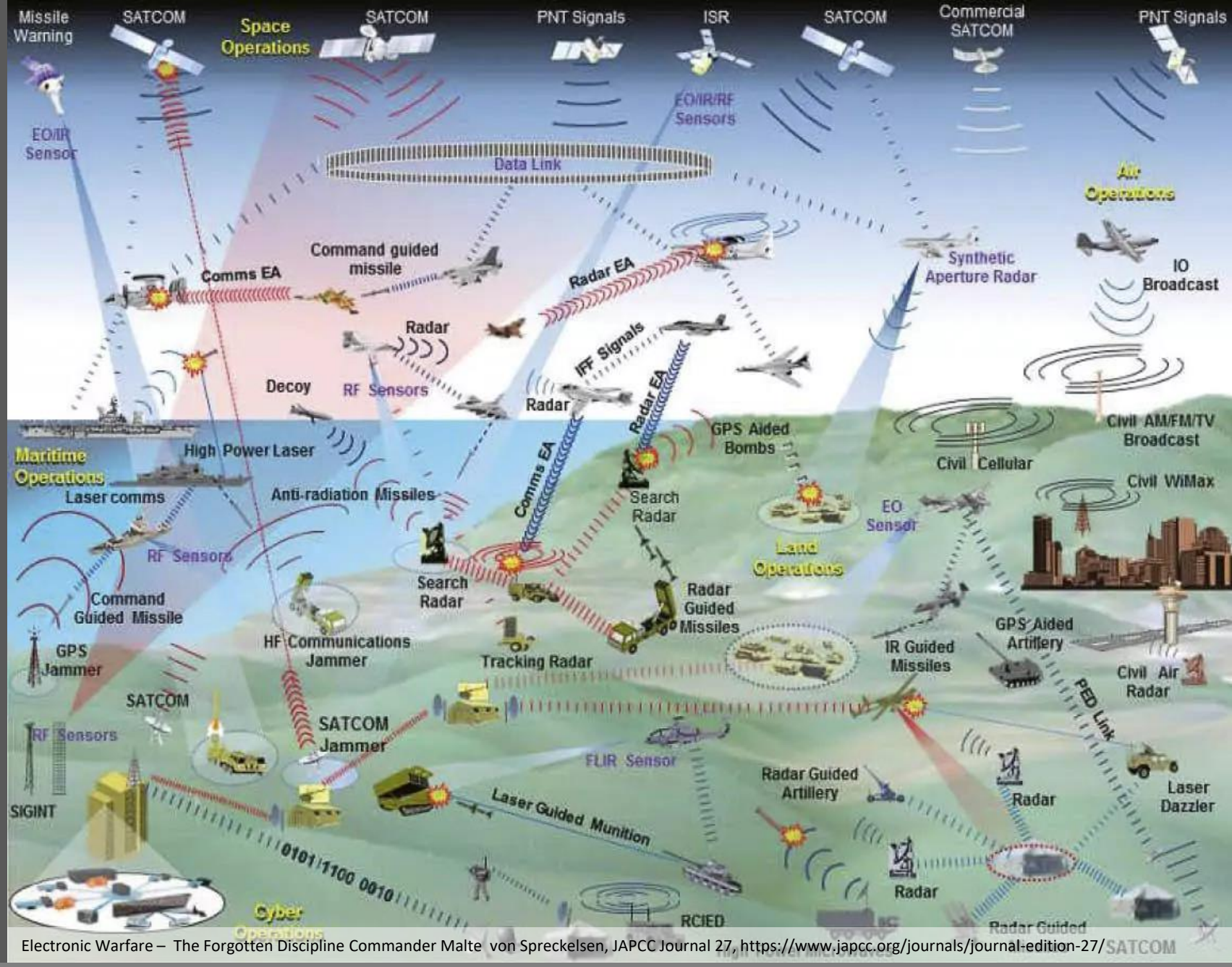
Category	Today	Tomorrow
Edge computing	Smart thermostats Smart appliances	Home robots Autonomous vehicles Sensor to Shooter
Voice AI	Smart speakers	Natural language processing ePayment voice authentication
Vision AI	Massive object detection	Video analytics on the edge Super 8K resolution

TSMC Infographic, When AI Meets IoT Technology https://www.visualcapitalist.com

Era of Multi-Domain Operations

Combined Joint All-Domain Command and Control (C-JADC2)

- Multi-Mission Flexibility
- Data Intensive
- Highly Networked
- Joint Fires
- Sensor-to-Shooter
- Replicator



Electronic Warfare – The Forgotten Discipline Commander Malte von Spreckelsen, JAPCC Journal 27, https://www.japcc.org/journals/journal-edition-27/

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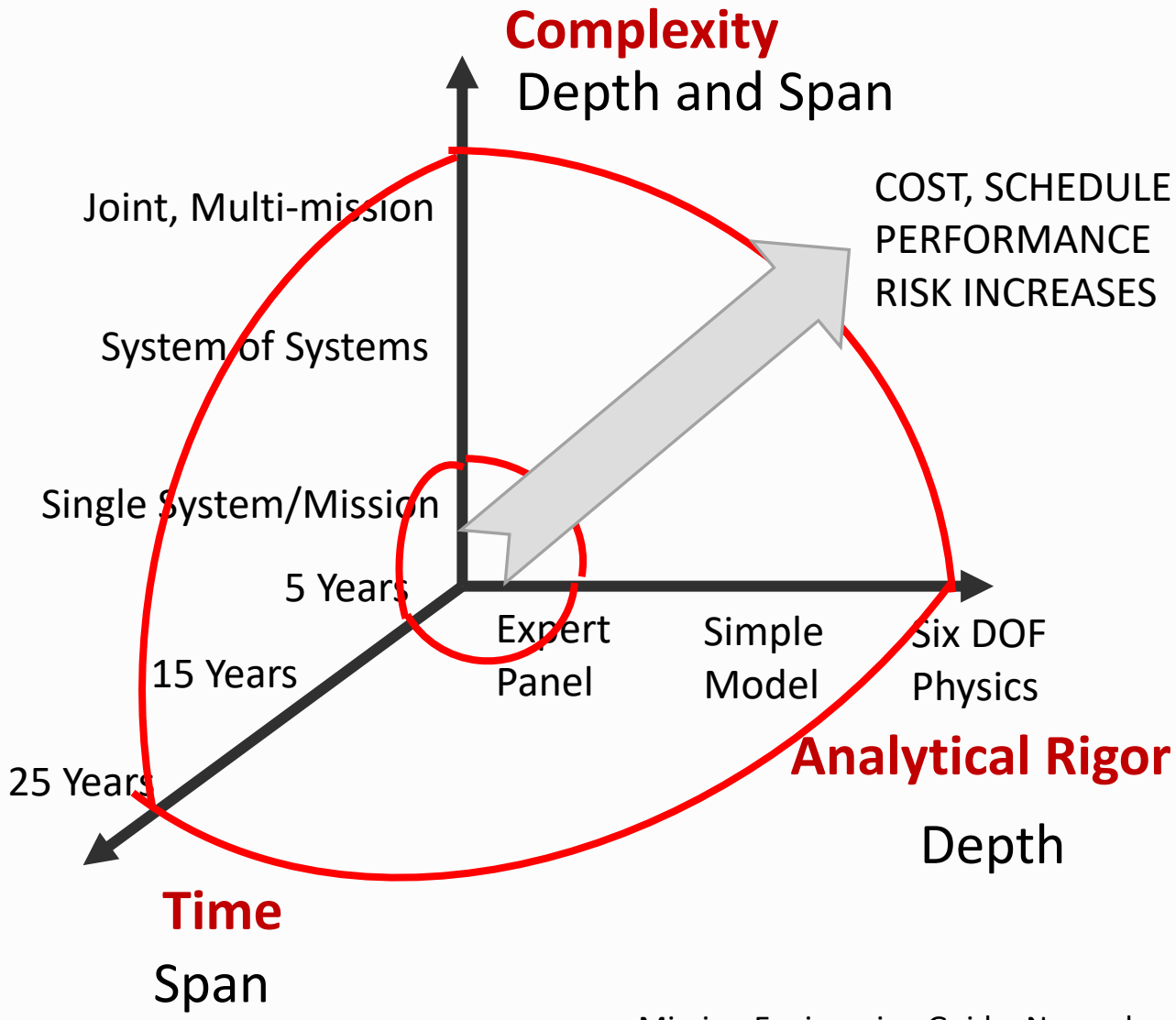
Mission Engineering Balance

Overreach on any axis will impact

- Confidence in ME products
- Validity of analysis
- Availability of data

Three Axes of Mission Engineering



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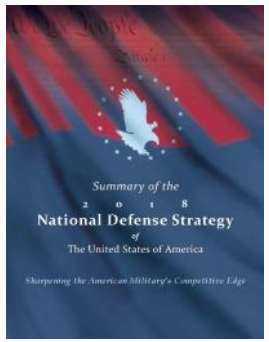
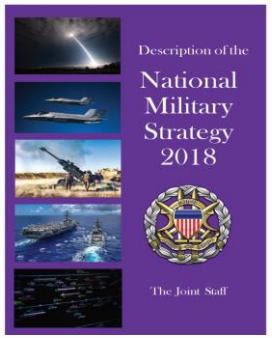
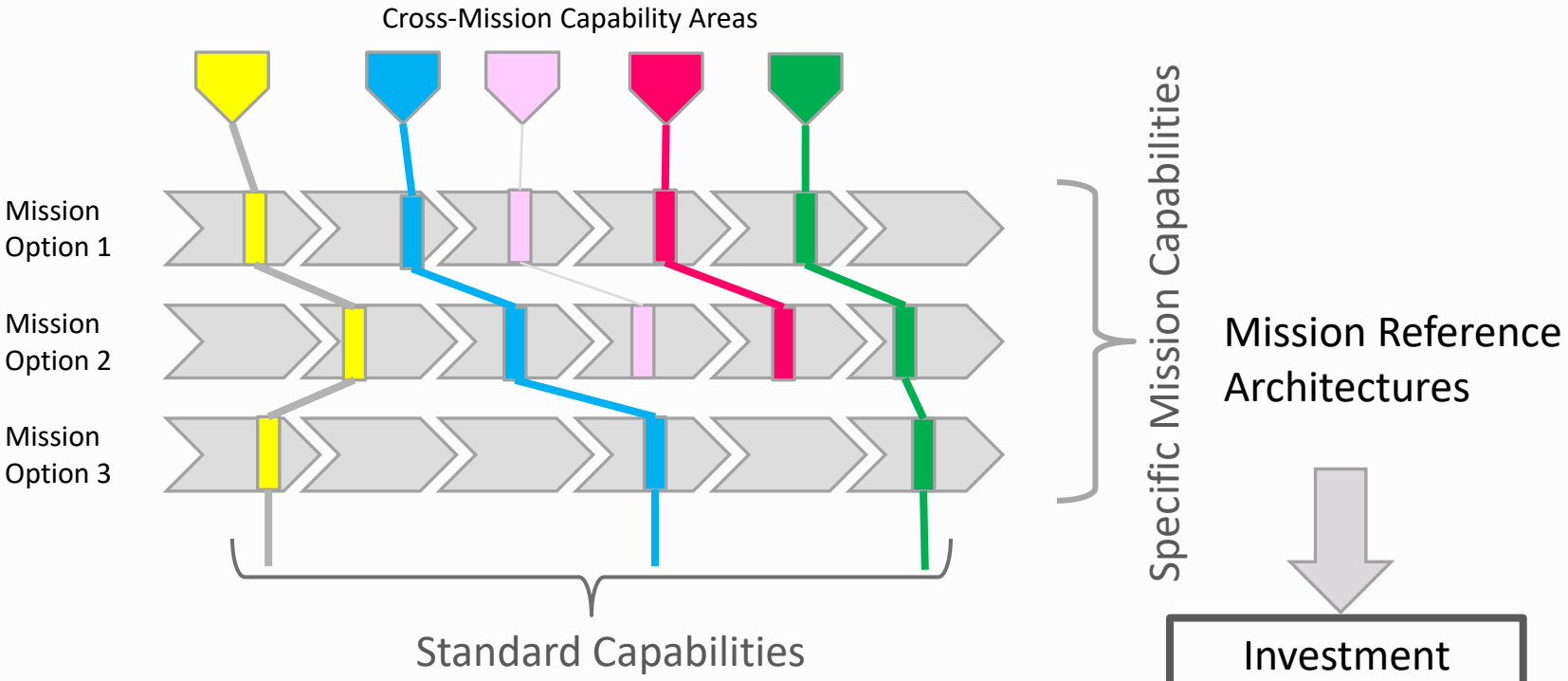
Strategy & Guidance





Mission Engineering Analysis



Trade studies between mission effectiveness and common capabilities

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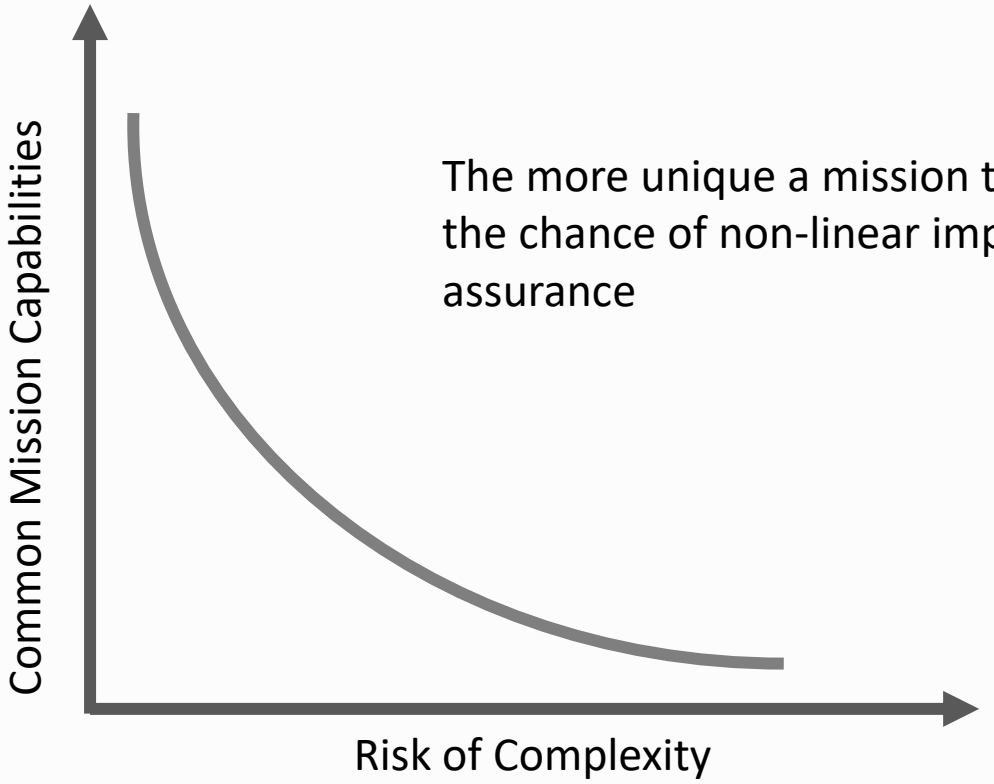
The Non-linearity Effect

For want of a nail the shoe was lost. For want of a shoe the horse was lost. For want of a horse the rider was lost. For want of a rider the battle was lost. For want of a battle the kingdom was lost.

- A Proverb

- Something minor has a disproportionate effect on outcomes
- Complexity increases the possibility of having non-linear interdependencies
- Standardization of capabilities across missions provides a measure of assurance



The more unique a mission thread is the greater the chance of non-linear impacts on mission assurance

What Do We Know?

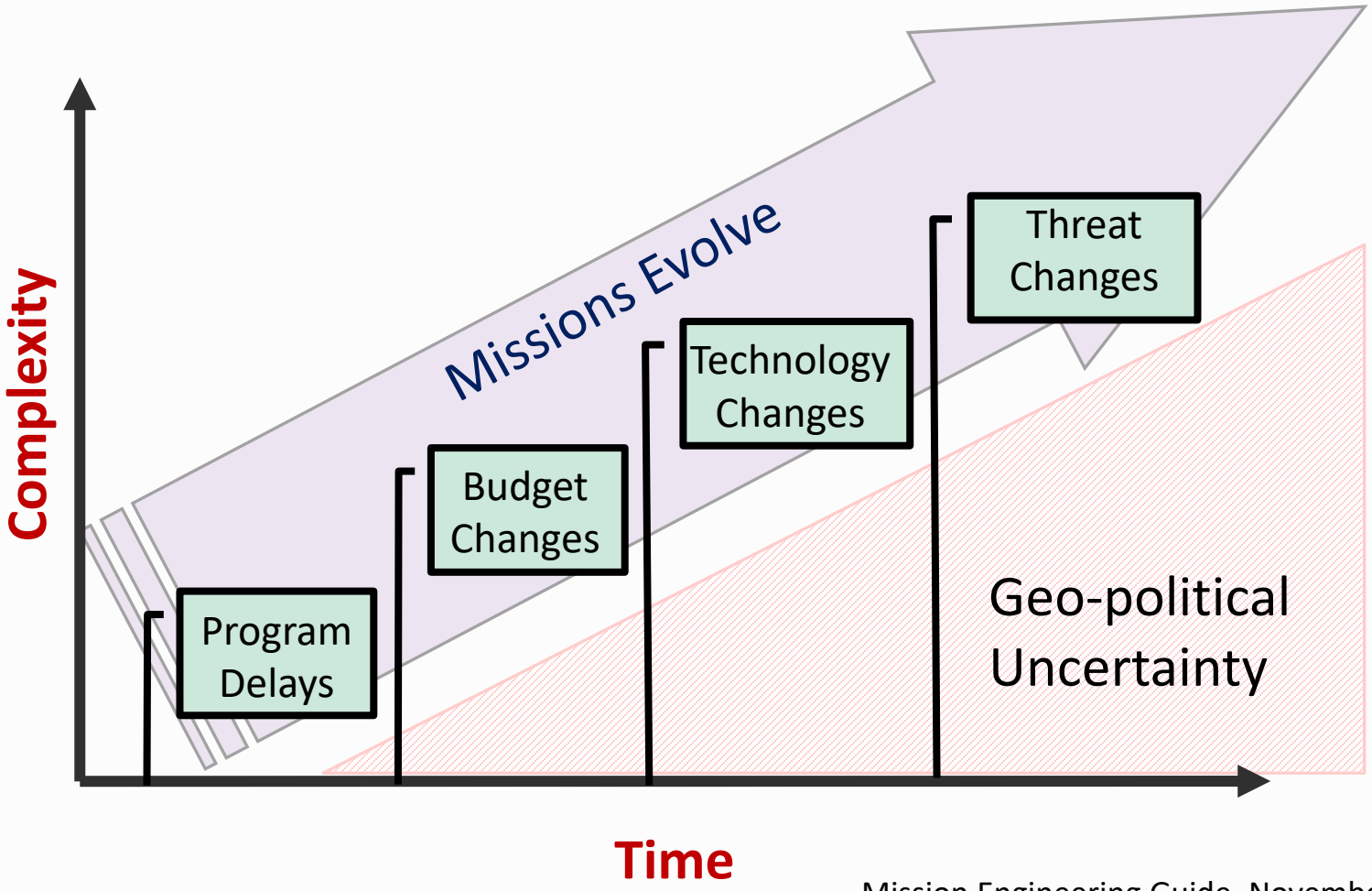
Change is constant and unpredictable

Organizations must adapt

Real-world complexity always creeps in

Present imperative is to move faster, innovate quicker

Three Axes of Mission Engineering



Mission Engineering Guide, November 2020

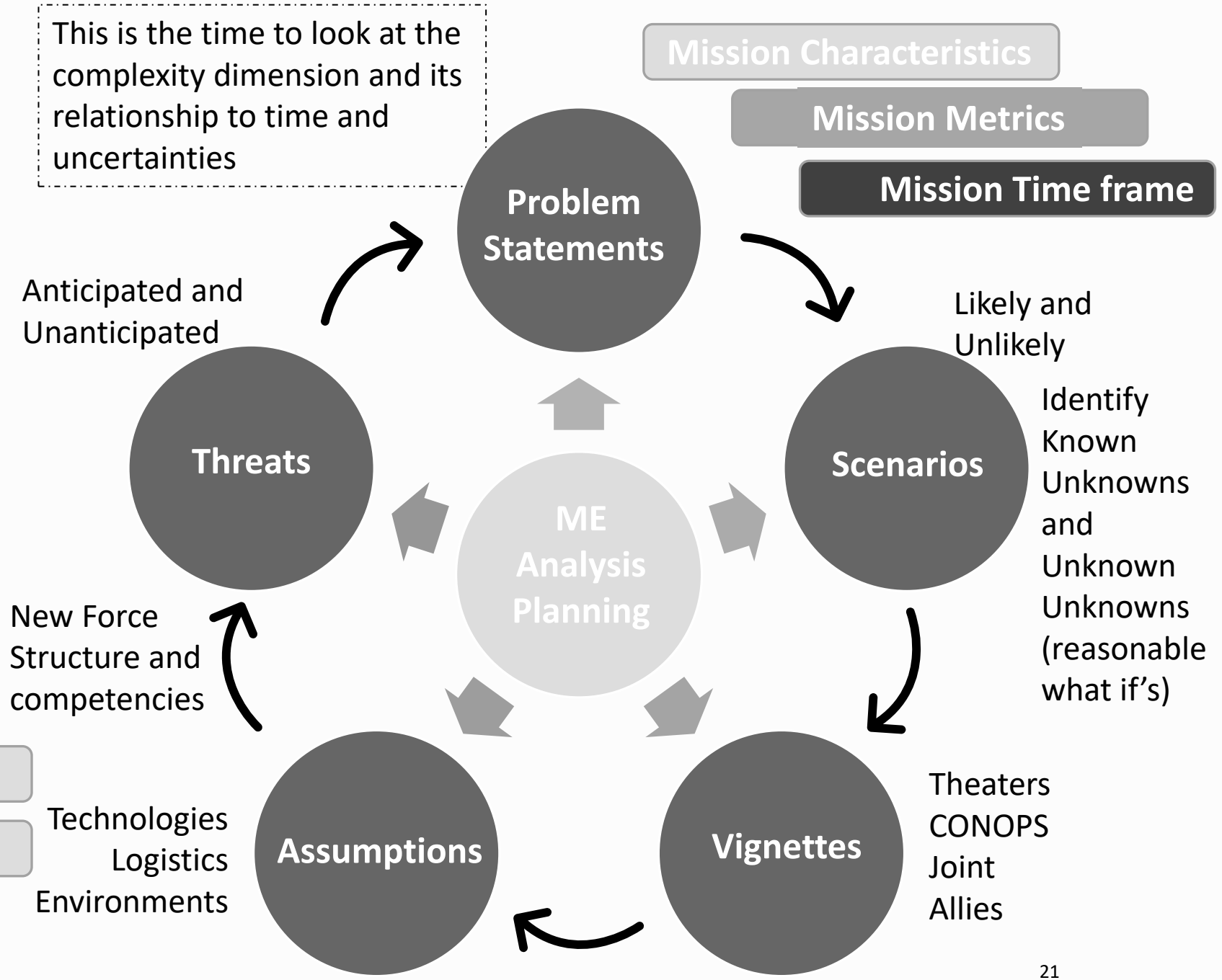
How does ME Deal with Complexity

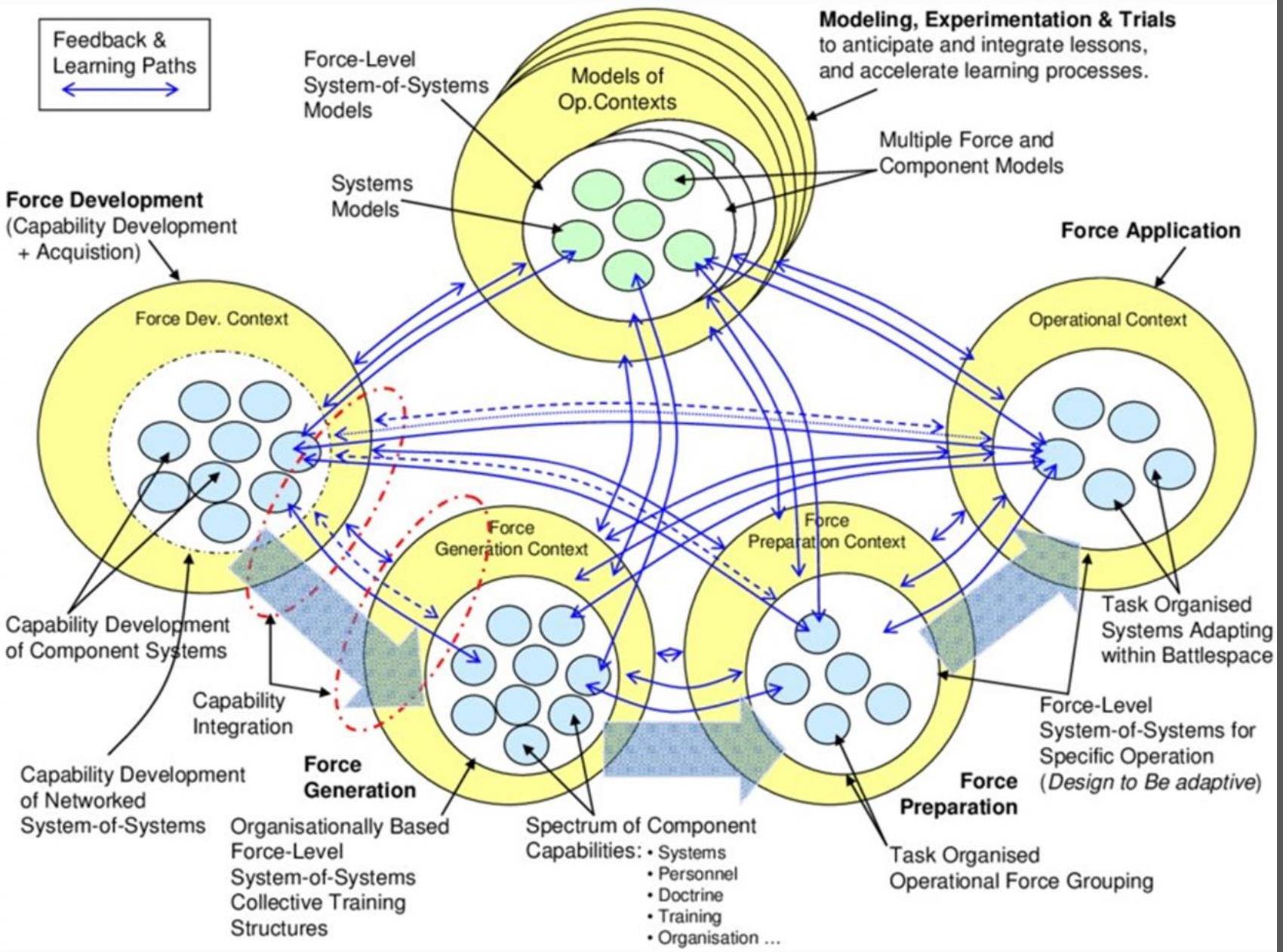
By addressing questions that impact mission architectures while planning the analysis

- What are we trying to do?
- Who should be doing it?
- What is the context?
- What is the timeframe?

Relationships

Dependencies





Engendering Flexibility in Defence Forces, 14th ICCRT, Mark Unewisse Defence and Anne-Marie Grisogono, Defence Science and Technology Organisation, Australian Department of Defence, June 2009

At Speed and Scale

Future operations must have responsiveness, agility, resilience, and flexibility

Complicated, Dynamic Interdependent, Coordinated

- Collaborative SoS
- Distributed (Allies and Partners)
- Continuous planning and modeling
- Integration of AI
- Flexible, scalable, tailorable C2
- Composable Force Structure
- Adaptive Behavior

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What Can We Do?

Prepare by Enabling Different Thinking

Personal	Organizational
Develop situational awareness	Establish rapid reaction framework
Recognize cognitive biases	Re-skill the workforce
Seek informal networks	Train for collaboration
Take responsibility for own re-skilling	Recognize constraints
Recognize limitations	Plan for the unplanned

In the Future Complexity is Inevitable

Summary

- Mission Engineering Addresses Complexity
  - Problem Statements, Scenarios, Assumptions
- Systems Engineering Provides Necessary Flexibilities
  - Modeling and simulation, MOSA, SOS Interoperability
- Train to deal with uncertainty and complexity
- Over time the ability to deal with complexity shifts from design to operations – plan on it!

Dave Chesebrough

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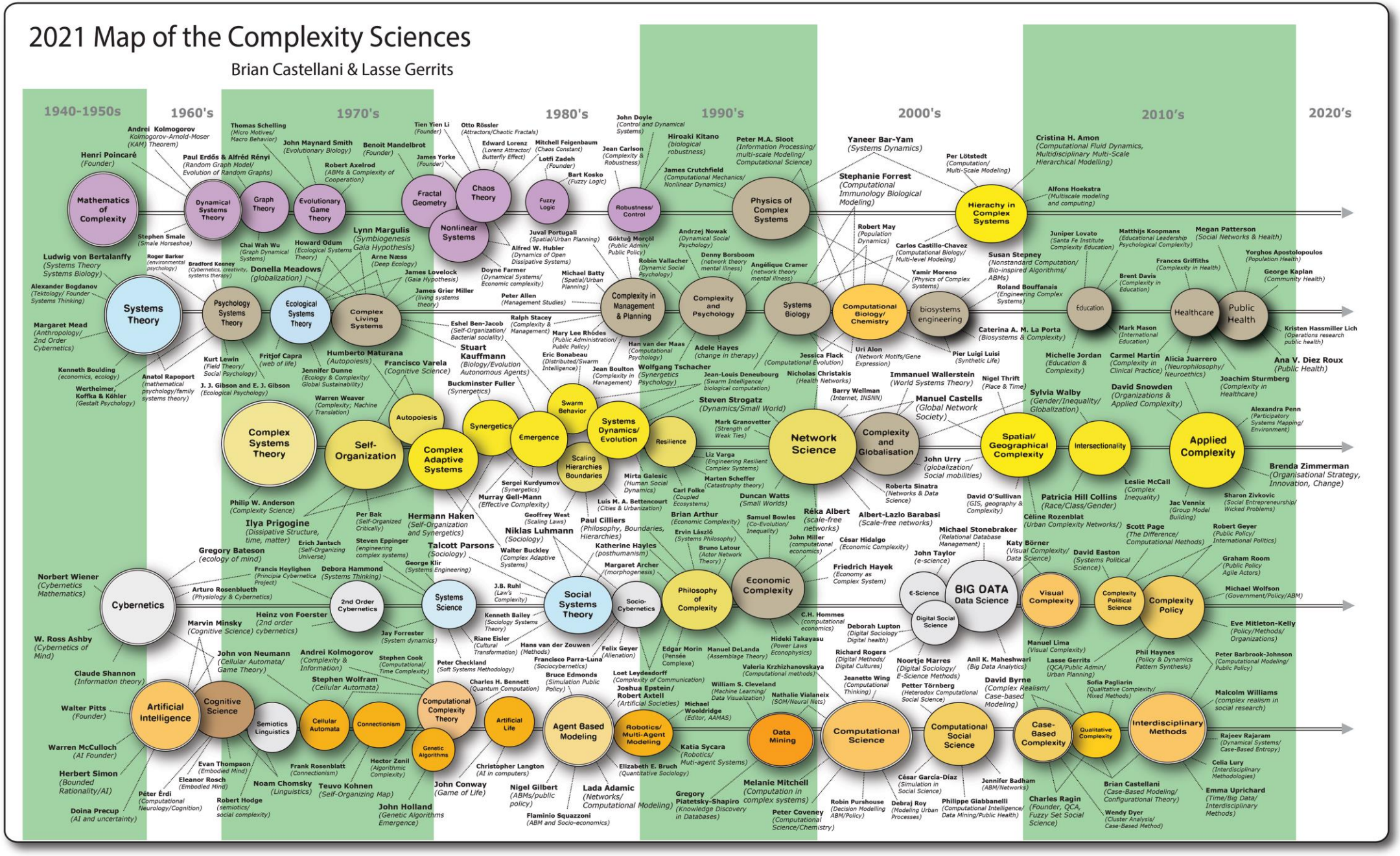
Backup Slides



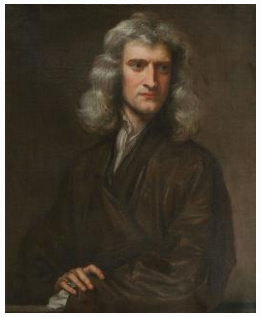
Castellani, B. (2018) Map of the Complexity Sciences. Art & Science Factory. https://www.art-sciencefactory.com/complexity-map_feb09.html

Complexity Sciences

Driven by computational science

Branched into five distinct lines of research

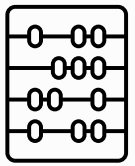
17th Century **Science of Dynamics**



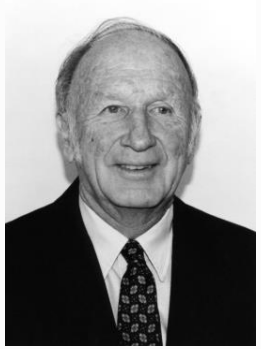
By Godfrey Kneller
Public Domain,
Wikimedia

Isaac Newton

Ability to predict motion based on Newtonian mechanics



20th Century **Chaos**



Fair use,
https://en.wikipedia

Edward Lorenz, MIT
Computer Weather Modeling

- deterministic nonlinear systems
- Butterfly effect
- deterministic nature of these systems does not make them predictable

Complexity

Theoretical Computer Science and Information Theory

- Nonlinear
- Emergent, non-predictable behavior
- Transitions between order and disorder

Chaos and Complexity both feature non-linearity

Systems Thinking

Focus on structure, relationships, interdependence

Thinking systematically about the properties of the whole being different from the parts

Define the end-state and work to fill the gaps

Complexity Theory

- the study of complex dynamic, non-linear, self-organizing, open, emergent, sometimes chaotic and adaptive systems (Larsen-Freeman, 1997)
- There are limits to what can be anticipated given current knowledge
- We don't know what we don't know
  - COVID-19 results in chip shortage
  - Office utilization plummets as work patterns change

The search for simple – if not simpleminded – solutions to complex problems is a consequence of the inability to deal with complexity

- Russell L. Ackoff, Wharton School

Complexity Theory – Current

Santa Fe Institute

- Founded 1984
- First research institute dedicated to the study of complex adaptive systems
- Focus on complex physical, biological, social, cultural, technological areas

Cynefin Framework

- Developed in 1999 by Dave Snowden, IBM Global Services
- Draws on research into systems theory, complexity theory, network theory and learning theories
- Conceptual framework to aid in decision-making

Mission

a duty assigned to an individual or unit

Mission Integration Management

the synchronization, management, and coordination of concepts, activities, technologies, requirements, programs, and budget plans to guide key decisions focused on the end-to-end mission.

MISSION ENGINEERING CONSUMERS

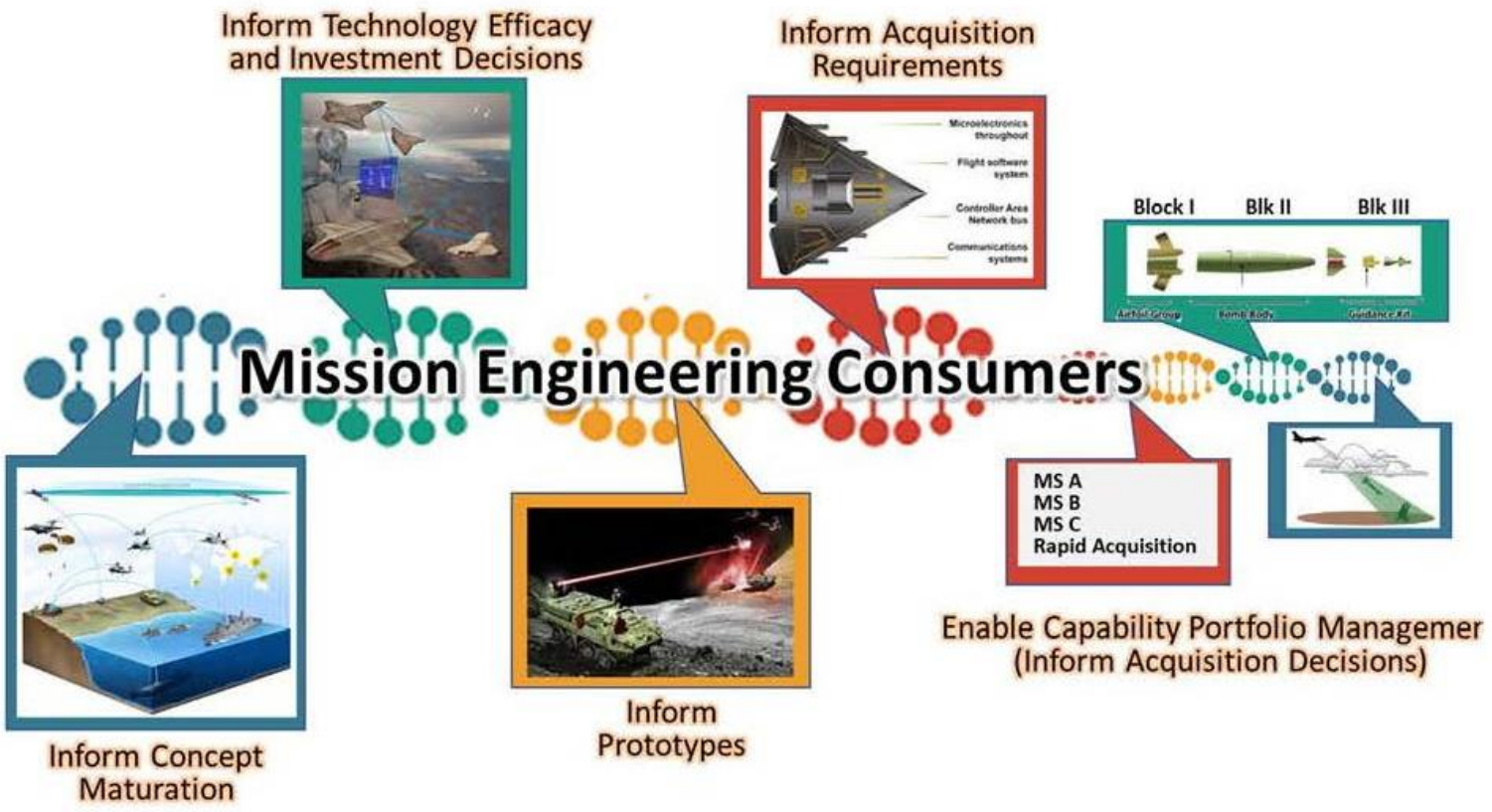


Figure 1-1. Consumers of Mission Engineering Outputs

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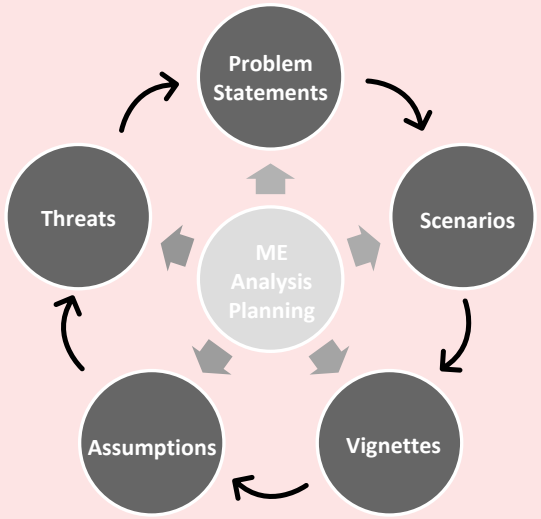
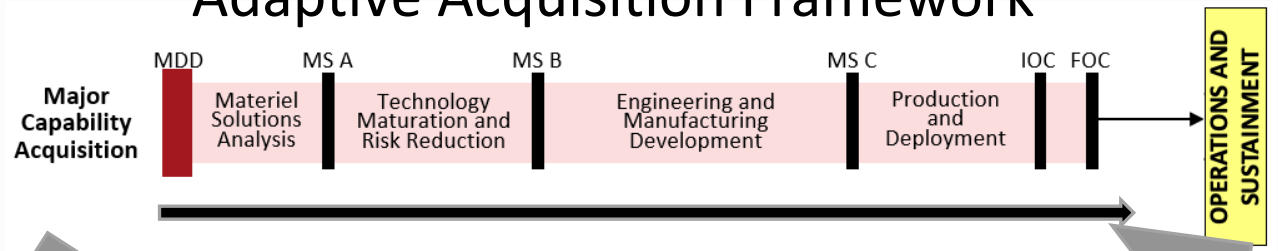


GMRA/GCRA

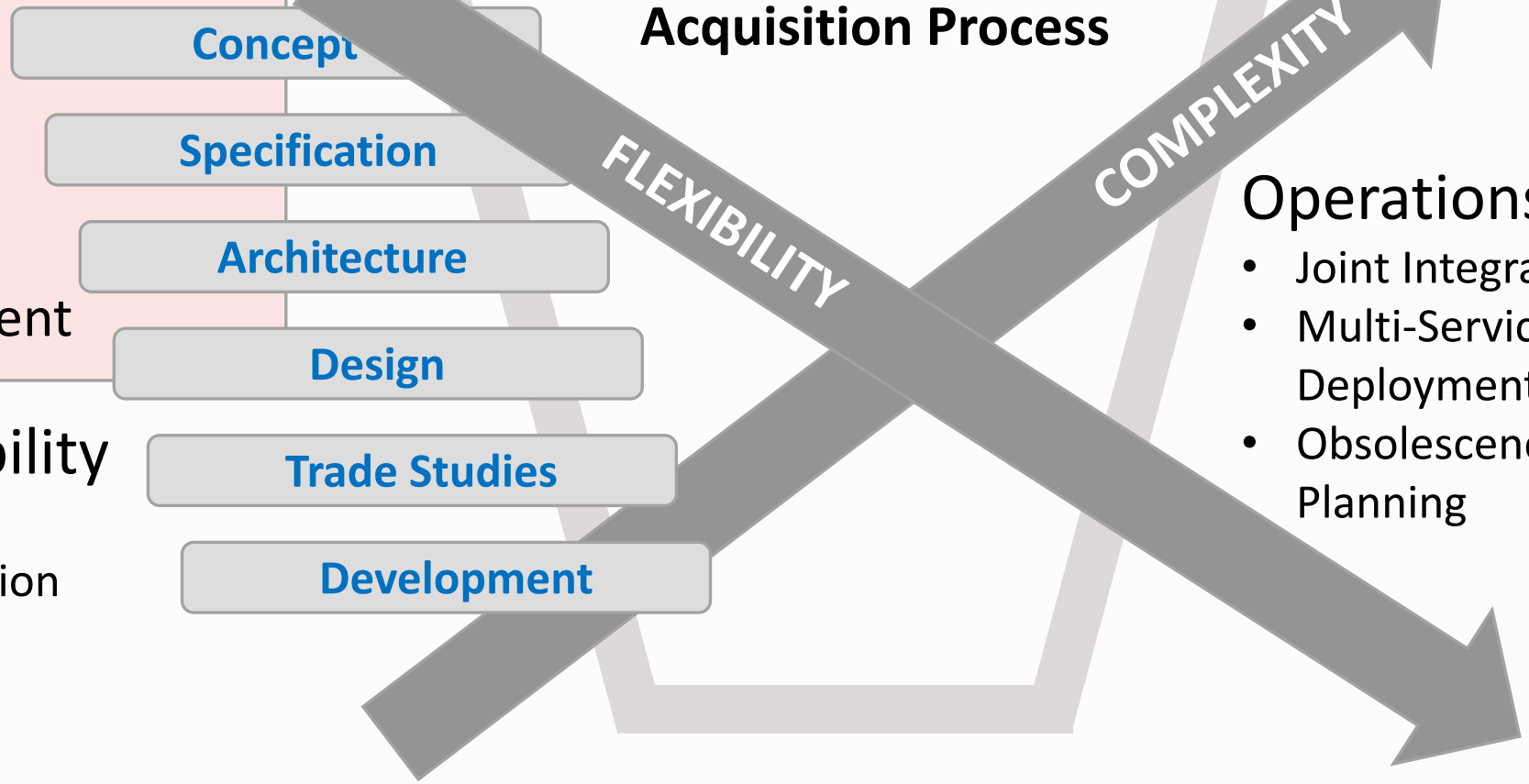
Mission Engineering

Capability Assessment

Adaptive Acquisition Framework



Acquisition Process



Design for Flexibility

- Digital Engineering
- Modeling & Simulation
- MOSA
- SOS Interoperability

Operations

- Joint Integrated Ops
- Multi-Service Force Deployment
- Obsolescence Planning