SoSECIE Webinar

Welcome to the
2020 System of Systems Engineering Collaborators
Information Exchange (SoSECIE)

NDIA National Defense Industrial Association MITRE

We will start at 11AM Eastern Time

Skype Meeting +1 (703) 983-2020, 46013573#

You can download today's presentation from the SoSECIE Website:

https://mitre.tahoe.appsembler.com/blog

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August

NDIA SE Division SoS Committee Industry Chairs:

Mr. Rick Poel, Boeing

Ms. Jennie Horne, Raytheon

OSD Liaison:

Dr. Judith Dahmann, MITRE

Simple Rules of Engagement

- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
  - I will start with questions submitted online via the CHAT window in Skype.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2020-2021 System of Systems Engineering Collaborators Information Exchange Webinars
Sponsored by MITRE and NDIA SE Division

March 10, 2020
Analysis of Interoperability to Support Mission-Oriented SoS
Dr. Ronald Giachetti

March 24, 2020
Extending the DoD Digital Engineering Strategy to Missions, Systems of Systems, and Portfolios
Philomena Zimmerman

April 21, 2020
Mission Engineering, Systems Engineering and Systems of Systems Engineering
Dr. Andreas Tolk

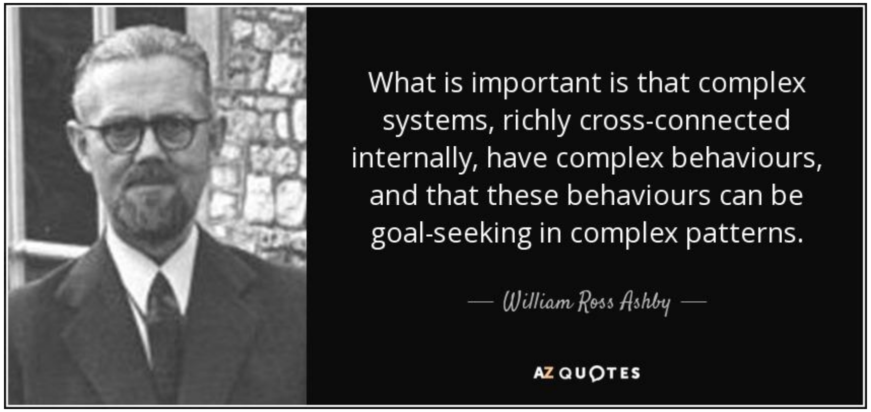
Cybernetics, Complexity, and the Challenges to the Realization of System of Systems

System of Systems Engineering Collaborators Information Exchange (SoSECIE)

Tod M. Schuck, PhD
Lockheed Martin RMS
Moorestown, NJ

Purpose

- We will view systems-of-systems (SoS) through a similar lens at the much ballyhooed Internet-of-Things (IoT)
- As more and more systems are linked together to form directed, acknowledged, collaborative, and virtual SoS, the exercise of control becomes problematic
- Emergent properties, hostile agents, evolutionary and adaptive development, and other characteristics of systems will enable complex behaviors in SoS that are not part of the constituent systems
- If information theory and cybernetics laws are not considered in the construction of complex SoS (IoT), then the behaviors that will emerge can have destabilizing and disastrous outcomes



SoS Typology

Internet of Things

Virtual. **Virtual SoS lack a central management authority and a centrally agreed upon purpose for the system-of-systems. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely upon relatively invisible mechanisms to maintain it.**

SoS Combined Operations

Collaborative. **In collaborative SoS the component systems interact more or less voluntarily to fulfill agreed upon central purposes. The Internet is a collaborative system. The Internet Engineering Task Force works out standards but has no power to enforce them. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards.**

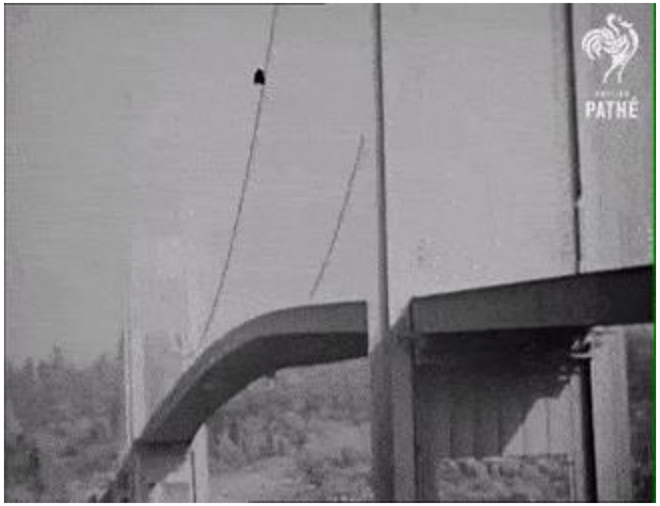
SoS Joint Operations

Acknowledged. **Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system.**

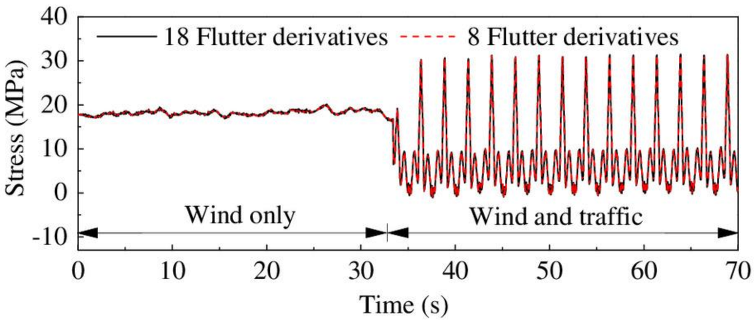
Directed. **Directed SoS are those in which the integrated system-of-systems is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.**

Galloping Gertie

- On July 1, 1940 the Tacoma Narrows Bridge located near Tacoma Washington, opened to traffic
- On November 7th of the same year it collapsed due to uncontrolled oscillatory behavior in high wind conditions
- Suspension bridge design philosophy changed to emphasize “lightness, grace, and flexibility”
- The result was that its width to center span length ratio (1:72) was much greater than either the Golden Gate (1:47) or George Washington (1:33) bridges



Galloping Gertie



- So what happened???
  - Aeroelastic flutter

"Flutter is a dynamic (second-order) aeroelastic phenomenon that involves the interactions of a structure's elastic and inertia characteristics with the aerodynamic forces produced by the airflow over the vehicle"

- Transformation normally *complicated system* into a ***complex system***
- Interaction with its environment (regular strong winds) elevated second order effects to first order
- Emergent property of single degree of freedom torsional motion (oscillation) due to the response to a complex separated airflow

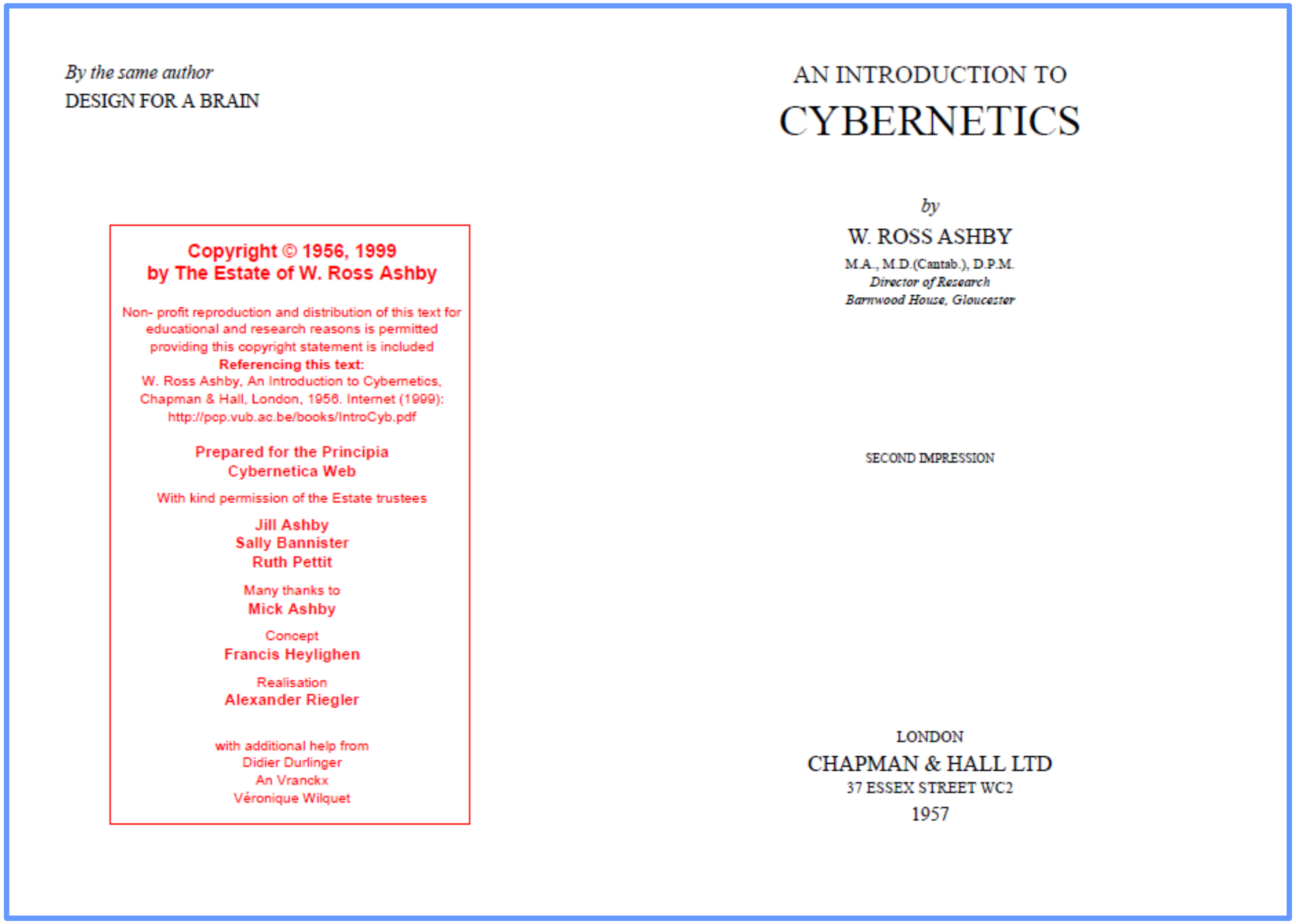
Why Are We Here?

- In this presentation, it is proposed that without a thorough and complete understanding of the information interfaces (static) and behavior (dynamic) of entities of SoS that comprise a notional IoT, then failure will occur
- This is the essence of ***cybernetics***
- Ashby developed the ***Law of Requisite Variety*** **(LoRV)** as part of the foundation of cybernetics
- To paraphrase Ashby's work, the LoRV can be stated as follows:

"*If you want to control anything; your control channels must be as wide as the thing you are controlling is complex. If you do not have such channels, you are not in control.*"

Cybernetics

"…communication and control in animal and machine"
- Norbert Wiener



By the same author
DESIGN FOR A BRAIN

AN INTRODUCTION TO
CYBERNETICS

by
W. ROSS ASHBY
M.A., M.D.(Cantab.), D.P.M.
Director of Research
Barnwood House, Gloucester

SECOND IMPRESSION

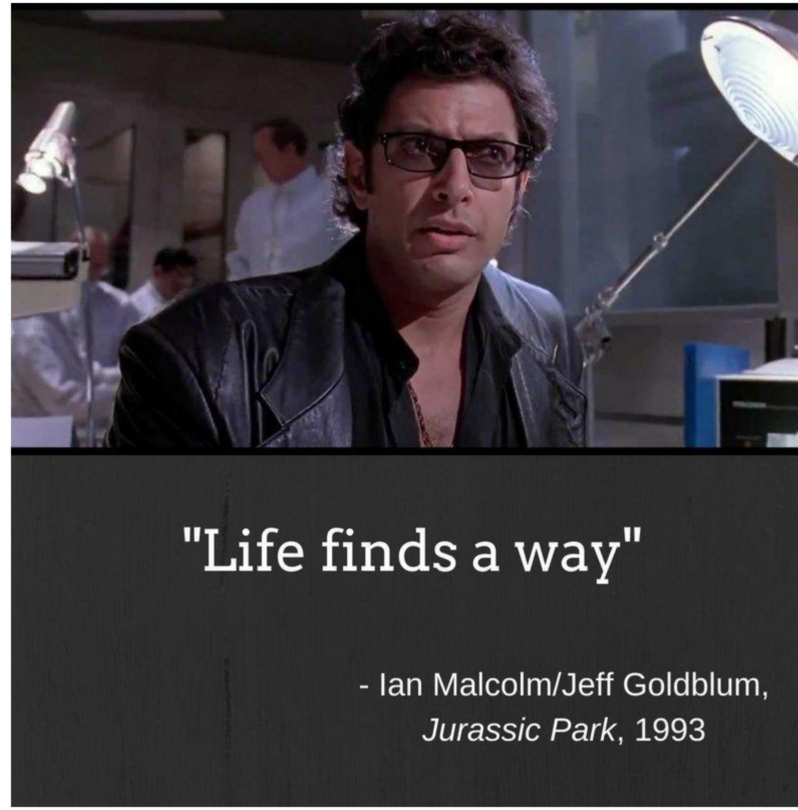
LONDON
CHAPMAN & HALL LTD
37 ESSEX STREET WC2
1957

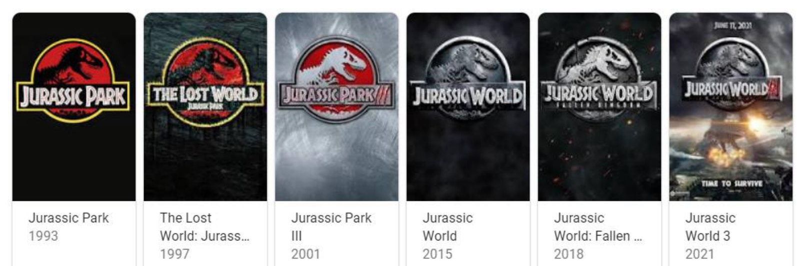
"What you don't control, controls you" – Tod

Ashby's Law of Requisite Variety (LoRV)

"Only variety absorbs variety"

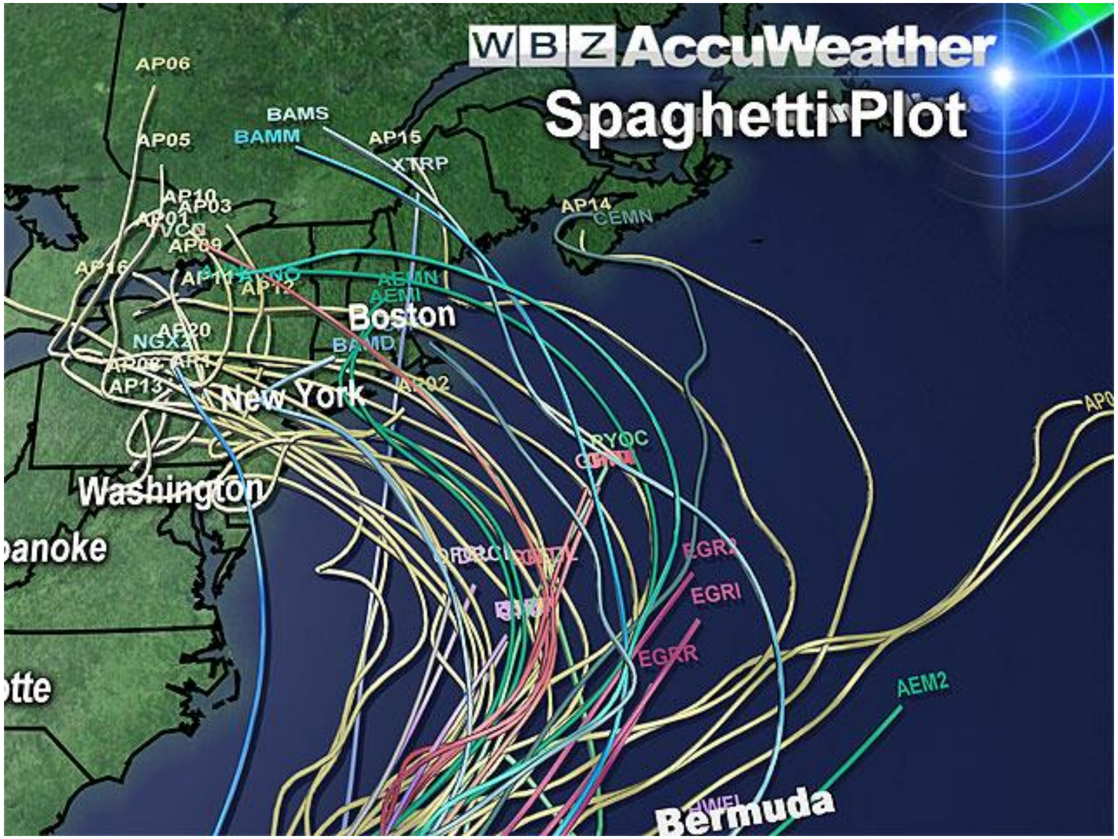
They Never Learn!!!!!





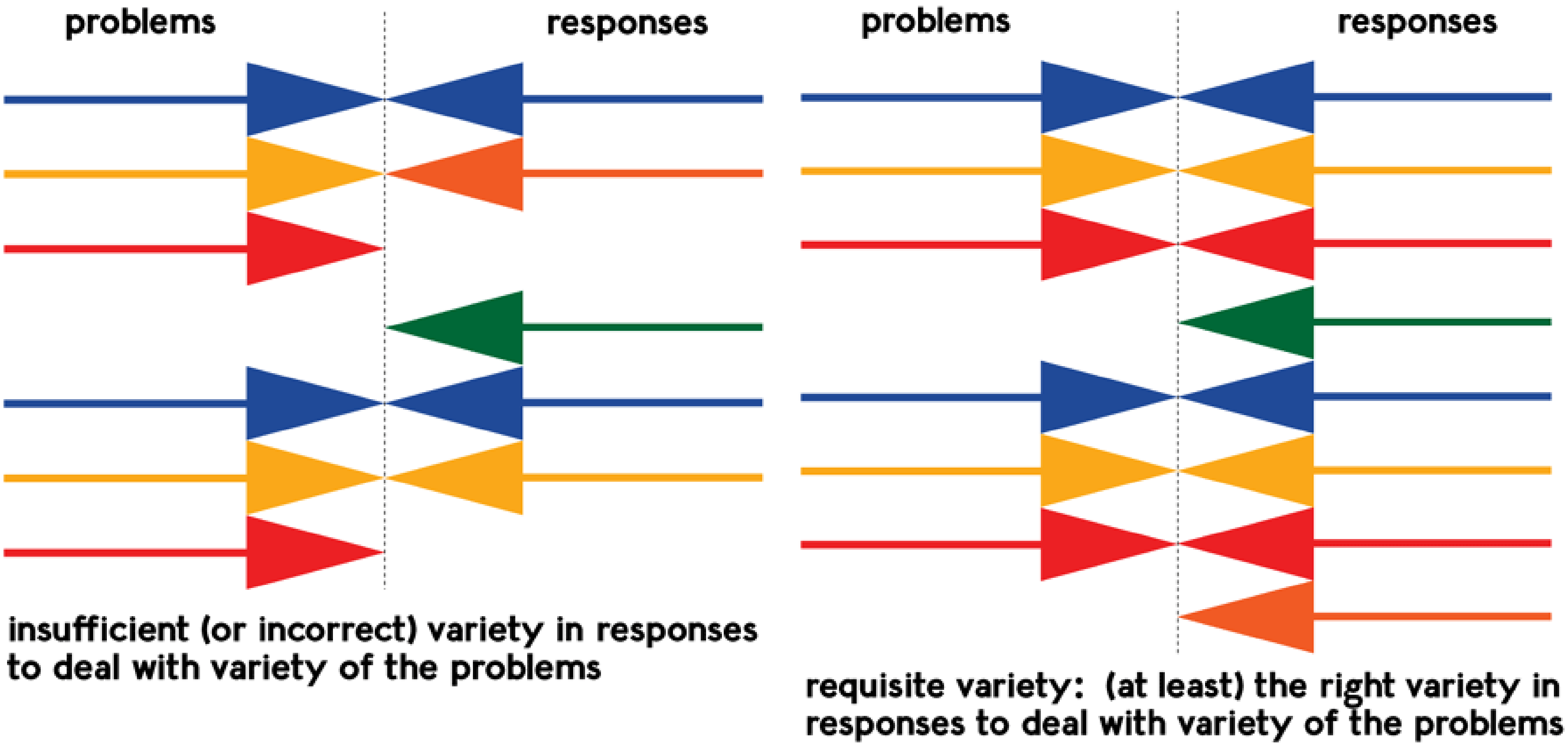
LoRV and Weather Guessing

- Superstorm Sandy "spaghetti" plot
- This illustrates that we really don't understand the variable and control space associated with complex systems like major weather events
- The same is true of economic systems, power generation and transmission systems, etc.



All models are wrong – some models are useful
- George E. P. Box (1976)

What is Requisite Variety (another look)?



A representation of the "control of influence"

What Does This Mean for Control? – Ashby's Law

Ashby's Law of Requisite Variety: ***if you want to control anything; your control channel must be as wide as the thing you are controlling is complex – If you do not have such a channel then you are not in control.***

"Goldfish Bowl" Example

- What is needed for environmental control:
  - Water pH
  - Dissolved oxygen
  - Temperature
  - Waste removal
  - Food availability
- *If any one of these is missing, you don't have control*
- closely follows Shannon information theory and Information Maneuverability (IM)

Cyber Security Possible???

ENSCO

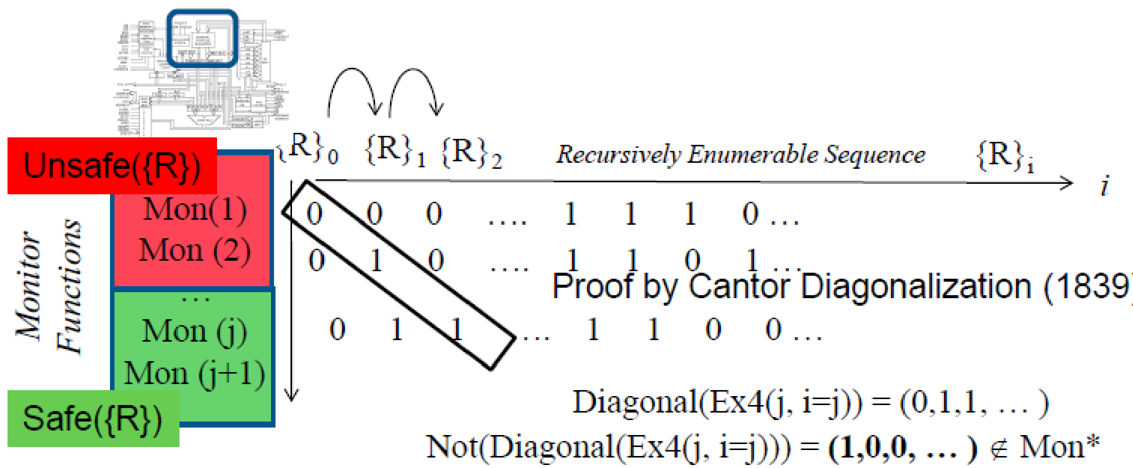
How Can We Systems Engineer Trust into Increasingly Autonomous Cyber-Physical Systems?

5 February 2020

Dr. Joseph Mitola III, Chief Technologist
Aerospace Sciences and Engineering (ASE) Division
ENSCO, Inc., Cocoa Beach, Florida

Protecting COTS CPUs is Impossible

COTS von Neumann Stored-program CPU Architecture Cannot Be Guaranteed Safe()



*Power Set of Safe($\{R\}_i$) **is not decidable** ⇒ Monitor(Rj) can **never** be complete*

Hackers [Erickson] "Bits are bits"

Not Enough Control Bandwidth…

DefenseNews Air Land Naval Space Cyber C4ISR Pentagon Congress Global TV/Video Thought Lea

Sailor error led to failed US Navy ballistic missile intercept test

By: David B. Larter July 24, 2017

4.7K + 38

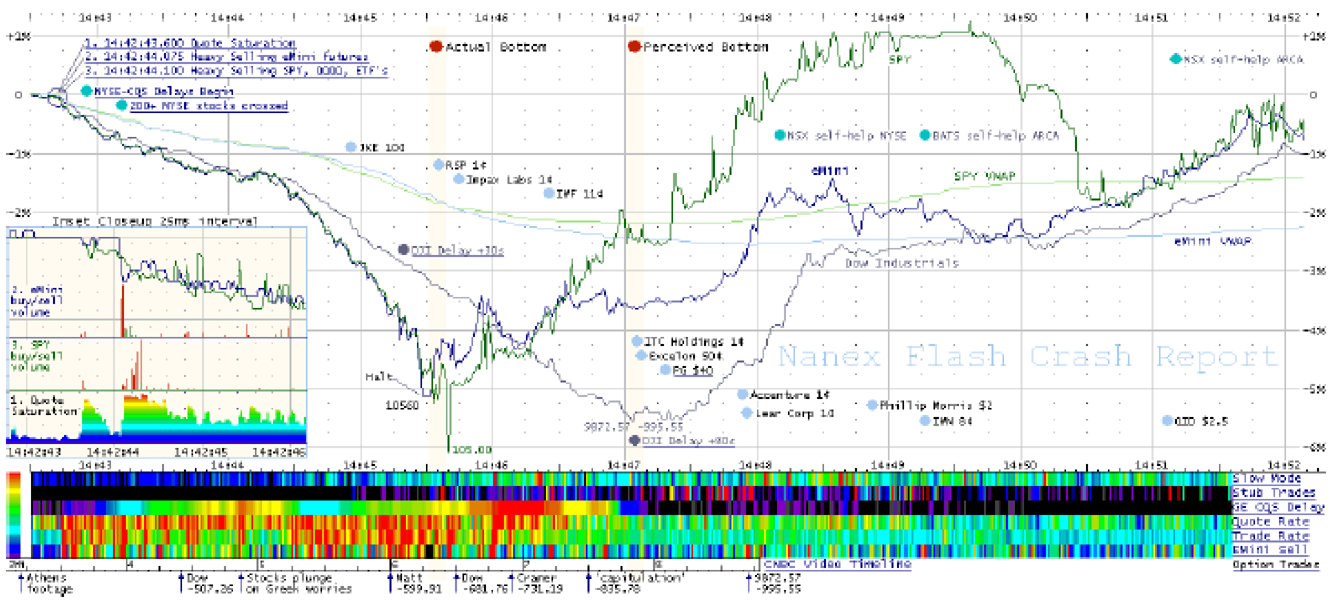
The U.S. destroyer John Paul Jones departs Joint Base Pearl-Harbor-Hickam for a scheduled underway. John Paul Jones is the U.S. Navy's ballistic missile defense test ship. (MC1 Nardel Gervacio/Navy)

WASHINGTON – A U.S. Missile Defense Agency review of a failed ballistic missile intercept test showed that a mistaken input into the combat system by a sailor on the destroyer John Paul Jones caused the missile to self-destruct before reaching the target.

Trillion Dollar Flash

CHALLENGES: What is going on with our markets?

Global financial markets: May 6, 2010 Flash Crash!!!



(a) The May 6, 2010, Flash Crash also known as The Crash of 2:45, the 2010 Flash Crash or simply the Flash Crash, was a United States trillion-dollar stock market crash, which started at 2:32 and lasted for approximately 36 minutes.

STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY

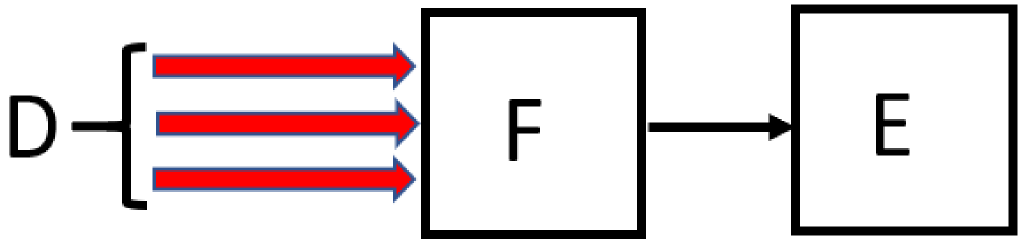
From: S. Yang, “A Multi-agent Behavior Approach to Identifying Vulnerability of a Complex System”, Stevens Institute of Technology, May 2016.

Knowledge-Control Matrix

	Know	Don't Know
Control	**1** Know that you control a system variable	**2** Don't know that you control a system variable
Don't Control	**3** Know that you don't control a system variable	**4** Don't know that you don't control a system variable (or that it is even present)

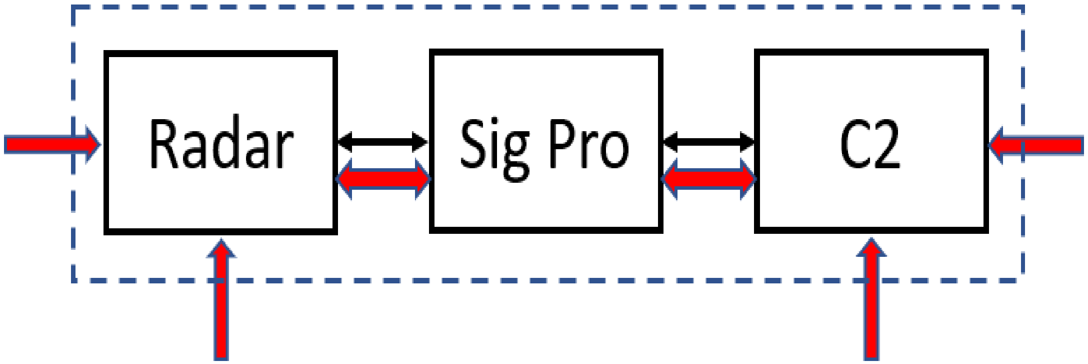
- A general systems assumption will default to quadrants 1 and 3
- More difficult to understand and quantify the "Don't Know" column (quadrants 2 and 4)
- In the case of the design of the Narrows bridge, the primary knowledge-control culprit was a quadrant 2 error - designers could control the aeroelastic flutter by reducing the width to span ratio of the bridge
- Quadrants 2 and 4 is where emergence is likely to occur

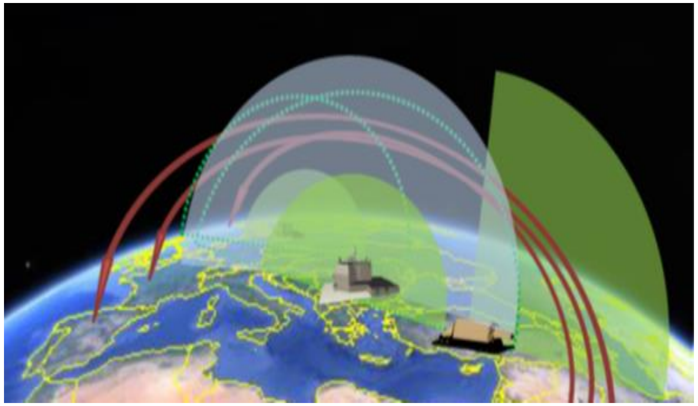
LoRV Schematic



- D is the variety of *disturbances* and other inputs to the system
- F is a system component designed to mitigate the effects of variety – *a regulator* (like a firewall)
- E is the set of *essential variables* that define the system and its performance

LoRV for Military Systems





- The internal interfaces are shown via the **black double** arrows and all outside effectors including disturbances are shown via the single **red single** arrows
- The internal **red double** arrows demonstrate the manifestation of disturbances internally in this SoS from external sources (e.g. cyber-attacks against C2) - this is true even though the Sig Pro, is isolated from outside information sources (no disturbances flowing into it directly)
- Unique issue with SoS architectures: ***a problem in the control of essential variables in one component can lead to unforeseen propagation of disturbances to more susceptible components of the SoS***

Complex Systems Governance

DOI: 10.1002/sres.2621

RESEARCH ARTICLE

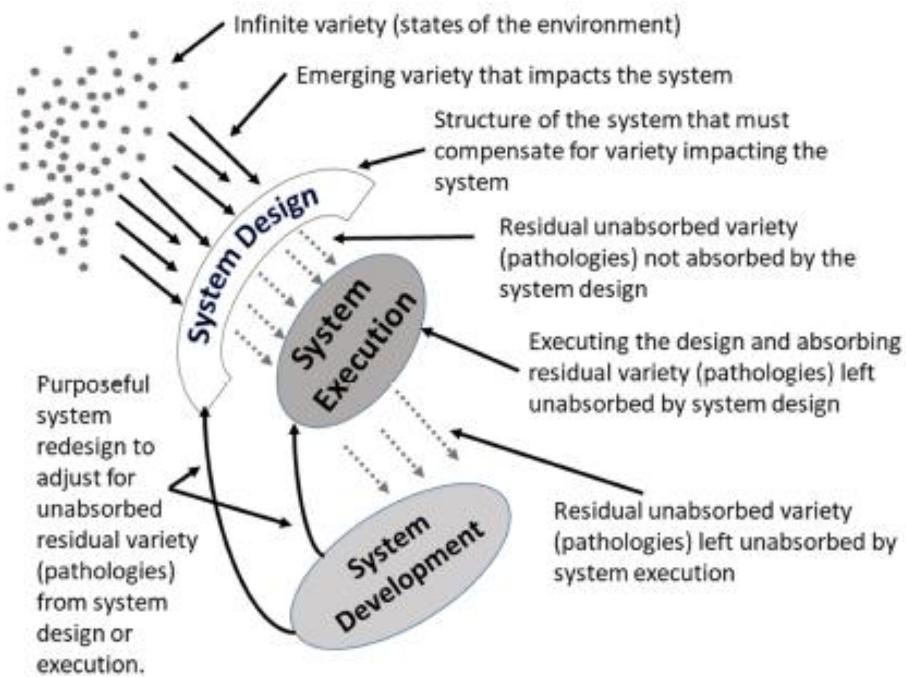
WILEY Systems Research and Behavioral Science

Complex system governance: Concept, utility, and challenges

Charles B. Keating[1] | Polinpapilinho F. Katina[2]

[1] Engineering Management and Systems Engineering, Old Dominion University, Norfolk, Virginia, USA

Abstract
Complex system governance (CSG) is an emerging field focused on design, exe-



$$T_{uv} = (SD_{uv} + SE_{uv}) - SR_v, \leq 0$$

- T_{uv} = Total unabsorbed variety for a system
- SD_{uv} = Residual unabsorbed variety from system design
- SE_{uv} = Residual unabsorbed variety from system execution
- SR_v = Variety generated from system redesign or enhanced system execution

A $T_{uv} <= 0$ perfectly balanced system (requisite variety) but most likely unattainable

Google Maps Spoof (Feb 2020)

C4ISRNET Artificial Intelligence Unmanned Battlefield Tech Information Warfare Electronic Warfa

Battlefield Tech

What electronic warfare can learn from a wagon full of smartphones

By: Kelsey D. Atherton 1 day ago

Normally creating a traffic jam takes actual traffic, like the cars seen here. With a wagon full of smartphones, a traffic jam can be created without the need for a long line of cars. (EveryPicture, via Wikimedia Commons CC-BY-SA-3.0)

https://www.c4isrnet.com/battlefield-tech/2020/02/06/what-electronic-warfare-can-learn-from-a-wagon-full-of-smart-phones/?utm_source=Sailthru&utm_medium=email&utm_campaign=C4ISRNET%20Daily%202.7&utm_content=B&utm_term=Editorial%20-%20Daily%20Brief

https://www.youtube.com/watch?v=k5eL_al_m7Q#action=share

Now Let’s Add Ethics…

Technology & Ideas

How to Build a Morally Ethical Self-Driving Car

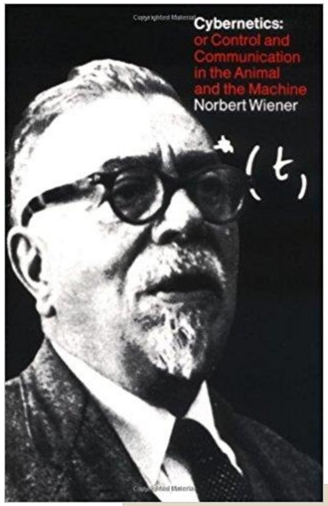
A road hazard appears in front of your autonomous taxi. Will it make a choice that saves you but kills others? Or will it decide to save others at the price of its passenger?

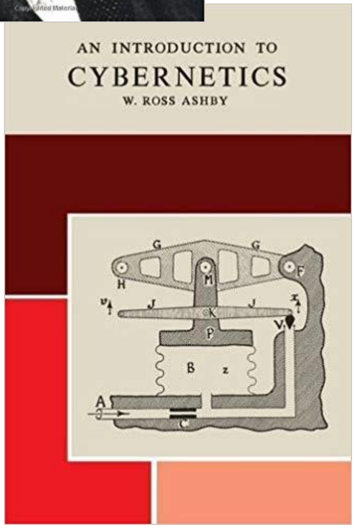
By Mark Buchanan
February 6, 2020, 9:00 AM EST

What happens when the road gets bumpier? *Photographer: Christof Stache/AFP via Getty Images*

Recap and Thoughts

- Understand a <brief> sample of the origins, history, and purpose of cybernetics
- Understand that information theory and cybernetics are intimately related are at the core of understanding all systems in the universe – including biological, physical, and virtual
- Why do systems fail? Ultimately it is because they violate the Law of Requisite Variety in some way – there are no exceptions
- Complex systems (e.g. military, economic, infrastructure) are especially prone to problems in accommodating variety – please understand this as you architect, design, test, and certify the systems that we make!





Next?

All ideas, suggestions and criticism are welcome!!!