Resilience is a Verb

How adaptive capacity is built, sustained, degraded, & lost in complex systems

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NASA failure history captures cumulative complexity circa 2000

Creating Safety Under Pressure

NASA in a changing environment under performance demands and resource pressures:

- Drive down the cost of launch
- Shorter, aggressive mission schedules
- New partners and relationships
- New roles
- Skill erosion
- Heightened public interest

"Risk, therefore, becomes the "fourth dimension" of project management—treated equally as important as cost and schedule."

NASA failure history captures creeping complexity

1999: 3 space exploration failures

Report
on
Project Management in NASA

by the
Mars Climate Orbiter
Mishap Investigation Board

March 13, 2000

increasingly brittle systems
under
faster, *better*, cheaper (FBC) pressure

2003: Run up to Columbia accident

STS-112/ET-115 Bipo

- Rationale for Flight
  - Current bipod ramp closeout has not b
  - The Orbiter has not yet experienced "S of Flight" damage from loss of foam in 112 flights (including 3 known flights with bipod ramp foam loss)
  - There have been no design / process / equipment changes over the last 60 ETs (flights)
  - All ramp closeout work (including ET-115 and ET-116) was performed by experienced practitioners (all over 20 years experience each)
  - Ramp foam application involves craftmanship in the use of validated application processess
  - No change in Inspection / Process control / Post application handling, etc
  - Probability of loss of ramp TPS is no higher/no lower than previous flights
  - ***The ET is safe to fly with no new concerns (and no added risk)***

FBC: finite resources, continuing change

Resilience Engineering

- Stance & perspective: adapting to cope with *complexity – empirical patterns*
- Multiple lines of inquiry: biological, cognitive, control, networked, human systems – *Layered Networks*
- Science-based: fundamental *laws & hard constraints*
- *Humble but different* integrated systems engineering
- *Pragmatic* engineering capabilities to outmaneuver complexity penalties

poised to adapt

The capabilities a system draws on to respond to inevitable surprises. Systems can be reliable and brittle, i.e., not robust or resilient.

Adaptive capacity is a system's *readiness* or potential to change how a system currently works – its models, plans, processes, behaviors – to continue to fit changing situations, anomalies and surprises.

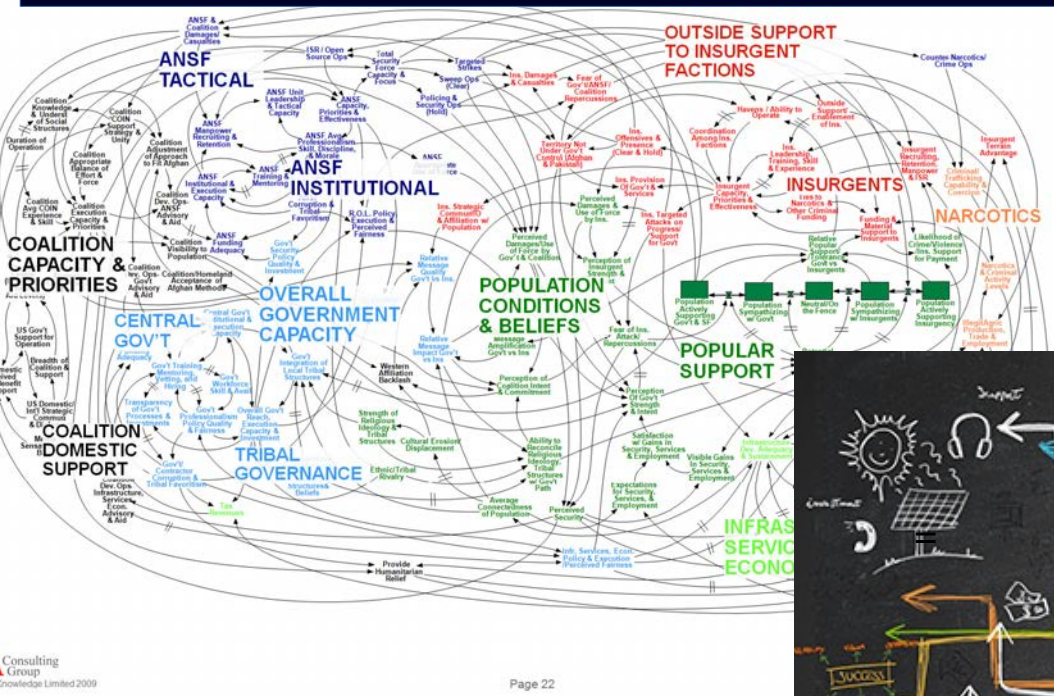
Model surprise is ubiquitous.

Responding to surprise requires preparatory investments that provide the *potential for future adaptive action*.

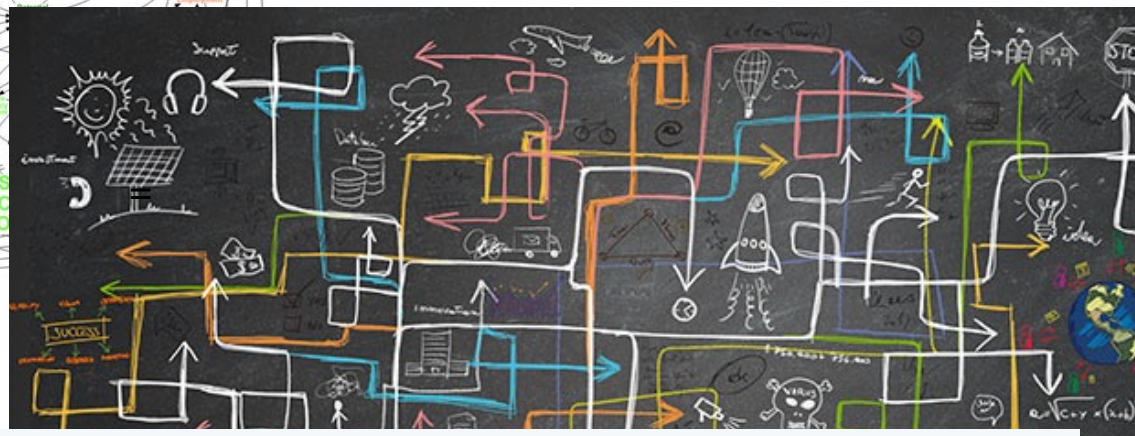
Operating in Seas of Complexity

places where surprise is tangible

Complexity: extensive and hidden interdependencies as capabilities increase



The Spaghetti Constraint



every time I work on my CI/CD software projects I am blown away by how many unseen dependency spaghetti messes are hidden in modern software infrastructure

Amy Tobey May 7, 2020

No plan survives first contact with a disaster-in-the-making

∧ ∧

“perfect” software production traffic

theregister.co.uk

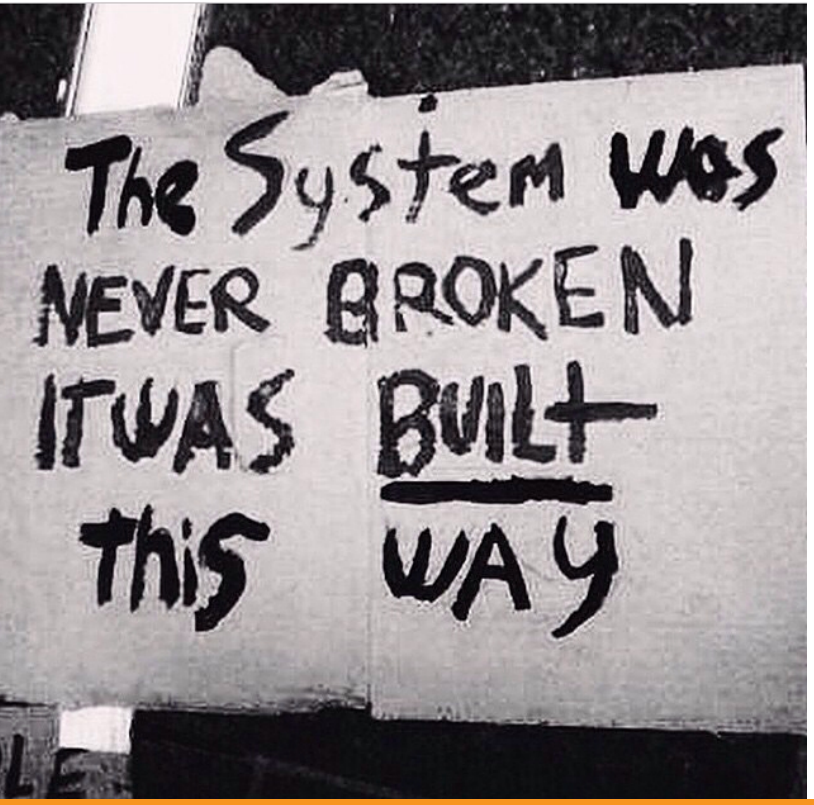
British Airways' latest Total Inability To Support Upwardness of Planes* caused by Amadeus system outage

Stuck on the ground awaiting a load sheet? Here's why (100 kB)

Area	Example
Airline systems	*"British Airways computer glitch causes big delays at multiple airports."* September 6, 2016 Mullen J (2016). CNN Business, https://money.cnn.com/2016/09/05/news/companies/british-airways-computer-system-delays/, accessed July 2, 2020.
Stock exchanges	"*NYSE shut down for nearly 4 h by technical glitch*", July 7, 2015 McCrank J (2015). Reuters, https://www.reuters.com/article/us-nyse-trading-idUSKCN0PI25A20150709, accessed July 2, 2020
Hospitals	*"Software issue fixed, UK HealthCare no longer diverting patients"* September 23, 2019 WKYT News Staff (2019). WKYT, https://www.wkyt.com/content/news/UK-HealthCare-diverting-patients-to-other-hospitals-citing-computer-issues-561140481.html, accessed July 2, 2020.
"Cloud" computing	*"Multifactor authentication issue hitting North American Azure, Office 365 users"*, October 18, 2019. Foley MJ (2019).. ZDNet, https://www.zdnet.com/article/multifactor-authentication-issue-hitting-north-american-azure-office-365-users/, accessed July 2, 2020.
Entertainment	*"Hulu's World Series Stream Crashed in the Middle of Game 4"*, October 29, 2017. Robert JJ (2017). Fortune, https://fortune.com/2017/10/29/world-series-hulu-crash-problems/accessed July 2, 2020.
Retail	*"Target says cash registers back online and customers can make purchases again after systems outage"*, June 15, 2019. Connley C, Kimball S (2019). CNBC, https://www.cnbc.com/2019/06/15/targets-in-store-payment-is-system-down-impacting-stores-nationwide.html accessed July 2, 2020

Systems are Messy
(some) People provide Resilient Performance

resilience essential for systems to succeed despite their design



Finite Resources / Change

Pressures

SNAFU is normal

Poised to Adapt

SNAFU CATCHERS

SNAFU is the natural state of systems

- **Rebound** from shock event

Linear Systems

- **Robust** adjust competence envelope to handle ***well-modeled*** disruptions

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Adaptive Systems / Non-Linear

- **Graceful Extensibility** (vs. brittleness)
the capability to stretch/extend near and beyond boundaries
how to be prepared to be surprised
- **Sustained Adaptability** ability to adapt over cycles of change, given hard tradeoffs (architecture for continuous adaptability)

Perspective and Miscalibration

Perspective and Miscalibration

Perspective and Miscalibration

Graceful extensibility (SNAFU Catching) is essential for the viability of adaptive systems in complex worlds

organizations rationalize core finding away on 3 grounds:

rarity, prevention, compliance

a. SNAFUs occur rarely given the organization's design thus investing in SNAFU Catching is a narrow issue of low priority.

b. there is a record of improvement that reduces the likelihood/ severity/difficulty of SNAFUs.

c. when SNAFUs occur, poor response is due to people who fail to work to the rules for their role within the organization's design.

these rationalizations *wrong* empirically, technically, & theoretically

Pragmatics

pathways to outmaneuver complexity

Coping with the Spaghetti limit

Techniques to discover hidden interdependencies in testing

Why reliable systems fail? Unconfounding reliability, robustness and resilience-as-extensibility

Resiliency Trade Space Study: The Interaction of Degraded C2 Link and Detect and Avoid Autonomy on Unmanned Aircraft

June 2018

DOI: 10.13140/RG.2.2.19395.86564

Safety management as **guided adaptability:** Build initiative and reciprocity across roles https://www.researchgate.net/publication/337179120_Safety_II_professionals_How_resilience_engineering_can_transform_safety_practice

New shared control architectures to reduce risk of saturation

Resilient Flight Control: An Architecture for Human Supervision of Automation

January 2020 · IEEE Transactions on Control Systems Technology PP(99):1-14 · Follow journal

DOI: 10.1109/TCST.2019.2959542

Table 1
Four senses of resilience (from Woods, 2015).

	term	Describes how a system …
1	*rebound*	"… rebounds from disrupting or traumatic events and returns to previous or normal activities"
2	*robustness*	"… is able to manage increasing complexity, stressors, and challenge"
3	*graceful extensibility*	"… extends performance, or brings extra adaptive capacity to bear, when surprise events challenge its boundaries"
4	*sustained adaptability*	… is able "to adapt to future surprises as conditions continue to evolve"

poised to adapt

Build & Sustain your systems' adaptive capacity

Resilience Engineering

- *Empirical patterns on* adapting to cope with complexity – *SNAFU Catching*
- Fundamental *laws & hard constraints on Layered Networks – Science-base*
- *Humble but different* integrated systems engineering capabilities to outmaneuver complexity penalties

Resilience is a Verb https://www.researchgate.net/publication/329035477_Resilience_is_a_Verb

Why Reliable Systems Fail? (13 mins)

https://www.youtube.com/watch?v=QSiXEZLZ1y0

Outmaneuvering Complexity (44 mins)

https://www.youtube.com/watch?v=KJJ2NCjc2Wg