



**Competence Envelope**  
plans, procedures  
automation,  
contingencies

Borderlands

“here be dragons”

**Surprise at boundaries**

Competence (Base) Envelope  
***P/R* ratio far from boundary**

***P/R* ratio near boundary**  
***Graceful Extensibility***

Trade off

Borderlands



Cascades, Friction, changing Tempos

**Surprise at boundaries**

as systems become more optimal under FBC pressure,  
new forms of complexity and fragility emerge

paradoxical result:

- highly competent when events fall within the envelope of designed-for-uncertainties
- sudden, large failures occur in the face of events that challenge or go beyond the envelope
- brittle, insufficient graceful extensibility



**Steep gradient**



**Borderlands**



**What adaptations produce  
Graceful Extensibility?**



(descriptive) **Brittleness**

**what Dragons lurking  
near, at and beyond boundary?**

**Anticipating crunches ahead  
generating/sustaining a readiness to respond**

**Graceful Extensibility**

# Borderlands



**Readiness to Respond:**  
**Deploy**  
**Mobilize**  
**Generate**

**Graceful Extensibility**

Competence (Base) Envelope  
***P/R*** ratio far from boundary

**Trade off**

***P/R*** ratio near boundary  
***Graceful Extensibility***

Borderlands



**Surprise at boundaries**

# Competence Envelope

Far from

Near to

# Borderlands



Pursuit of optimality  
under FBC pressure

Adapt to sustain  
graceful extensibility

## Net adaptive value

# Balance of two P/R ratios

# Borderlands



**Decompensation /Anticipation**

**Working at cross purposes / Synchronizing  
over units**

**Stuck in Stale / Proactive Learning**

**Graceful Extensibility**

Adaptive Units **UABs**

Adaptive Capacity

Range of Adaptive Behavior

Brittleness

Risk of Saturation / Exhausting Capacity for Maneuver

Adaptive Value / Net Adaptive Value / Fitness

## Modeling UABs

Finite Resources / Continuous Change →

Bounds / Range of Adaptive Behavior →

Surprise is normal and ongoing →

Brittleness / Risk of Saturation / Exhausting Capacity  
for Maneuver

Graceful Extensibility trades off with Robust Optimality

Net Adaptive Value

To be a UAB: Must have non-zero graceful extensibility

but Bounds apply to all UABs:

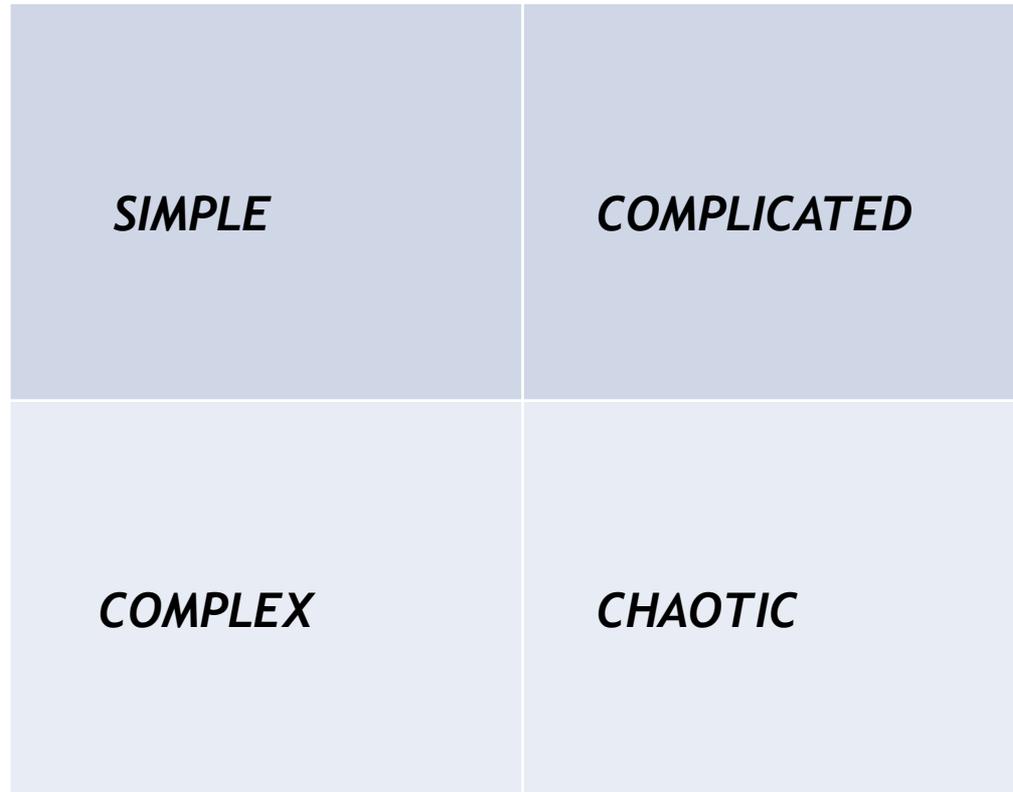
no UAB can have sufficient graceful extensibility

Graceful Extensibility has to be  $> \text{zero}$ , or

if completely brittle, non-viable in the long term

## Modeling UABs





This chart is wrong!

# Modeling UABs

# Theory of Graceful Extensibility

- Assumptions:
- A. All adaptive units have finite resources.
  - B. Change is continuous.

## Subset A: Managing Risk of Saturation

- 1: The adaptive capacity of any unit at any scale is finite, therefore, all units have bounds on their range of adaptive behavior, or capacity for maneuver.
- 2: Events will occur outside the bounds and challenge the adaptive capacity of any unit, therefore, surprise continues to occur and demands response, otherwise the unit is brittle and subject to collapse in performance.
- 3: All units risk saturation of their adaptive capacity, therefore, units require some means to modify or extend their adaptive capacity to manage the risk of saturation when demands threaten to exhaust their base range of adaptive behavior.

## Modeling UABs

# Theory of Graceful Extensibility

- Assumptions:
- A. All adaptive units have finite resources.
  - B. Change is continuous.

## Subset B: Networks of Adaptive Units

- 4: No single unit, regardless of level or scope, can have sufficient range of adaptive behavior to manage the risk of saturation alone, therefore, alignment and coordination is needed across multiple interdependent units in a network.
- 5: Neighboring units in the network can monitor and influence – constrict or extend – the capacity of other units to manage their risk of saturation, therefore, the effective range of any set of units depends on how neighbors influence others as the risk of saturation increases.
- 6: As other interdependent units pursue their goals, they modify the pressures experienced by a UAB which changes how that UAB defines good operating points in a multi-dimensional trade space and changes how that UAB searches the multi-dimensional trade space for good operating points.

## Modeling UABs



# Resilient Engineering

## how to be prepared to be surprised

Probability? Nothing is so improbable as what is true. It is the unexpected that occurs; but that is not saying enough; it is also the unlikely—one might almost say the impossible.

Ambrose Bierce, 'The Short Story'

downloaded <http://intheplayingfields.tumblr.com/tagged/ambrose-bierce>



A common expression from military decision making:  
*No plan survives contact with a disaster-in-the-making.*

... our experience [is] that every response is totally different and causes unforeseen problems or opportunities. We have never gone to an actual response and used the equipment the way we thought we would. (Murphy & Burke, 2005, p. 4)

How to be Prepared to be Surprised?

*Potential for surprise* is related to

- the next anomaly or event that practitioners will experience and
- how that next event will challenge pre-developed plans and algorithms in smaller or larger ways.

To assess potential for surprise in a setting, ask how the above generalization applies?

- *how do plans survive or fail to survive contact with events?*
- search for the kinds of situations and factors that challenge the textbook competence envelope

# *Model* Surprise

alt: surprise as frequency,  
but heavy tails, asymmetric consequences, viability

# Adaptive Capacity is about the Future

A. Adaptive capacity exists before disrupting events call upon that capacity

it is a **potential** for future adaptive action

B. One assesses (observes/models/measures) adaptive capacity through its exercise in the anticipation and reaction to past disruptions.

(A) means that the resources that support the potential, prior to visible disrupting events, may not be seen at all since they are not used; or if seen, they will be seen as excess capacity since it is not in use.

# Resilient Engineering

modeling (co-) adaptive cycles

how pressures create conflicts

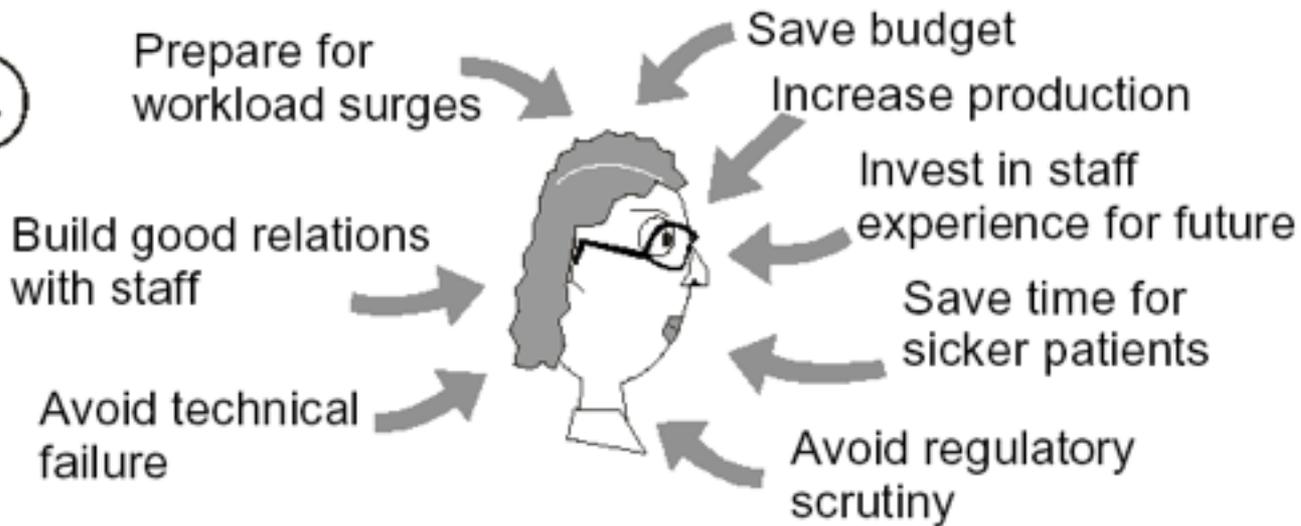
how conflicts stimulate adaptations

how shortfalls and new resources create opportunities

tracing adaptive cycles



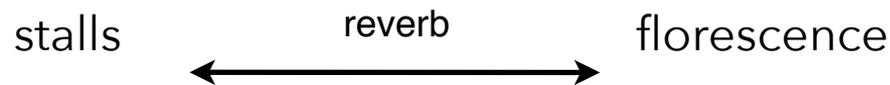
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roles balance multiple pressures

## *Adaptive Cycles*: studies of resilience in action

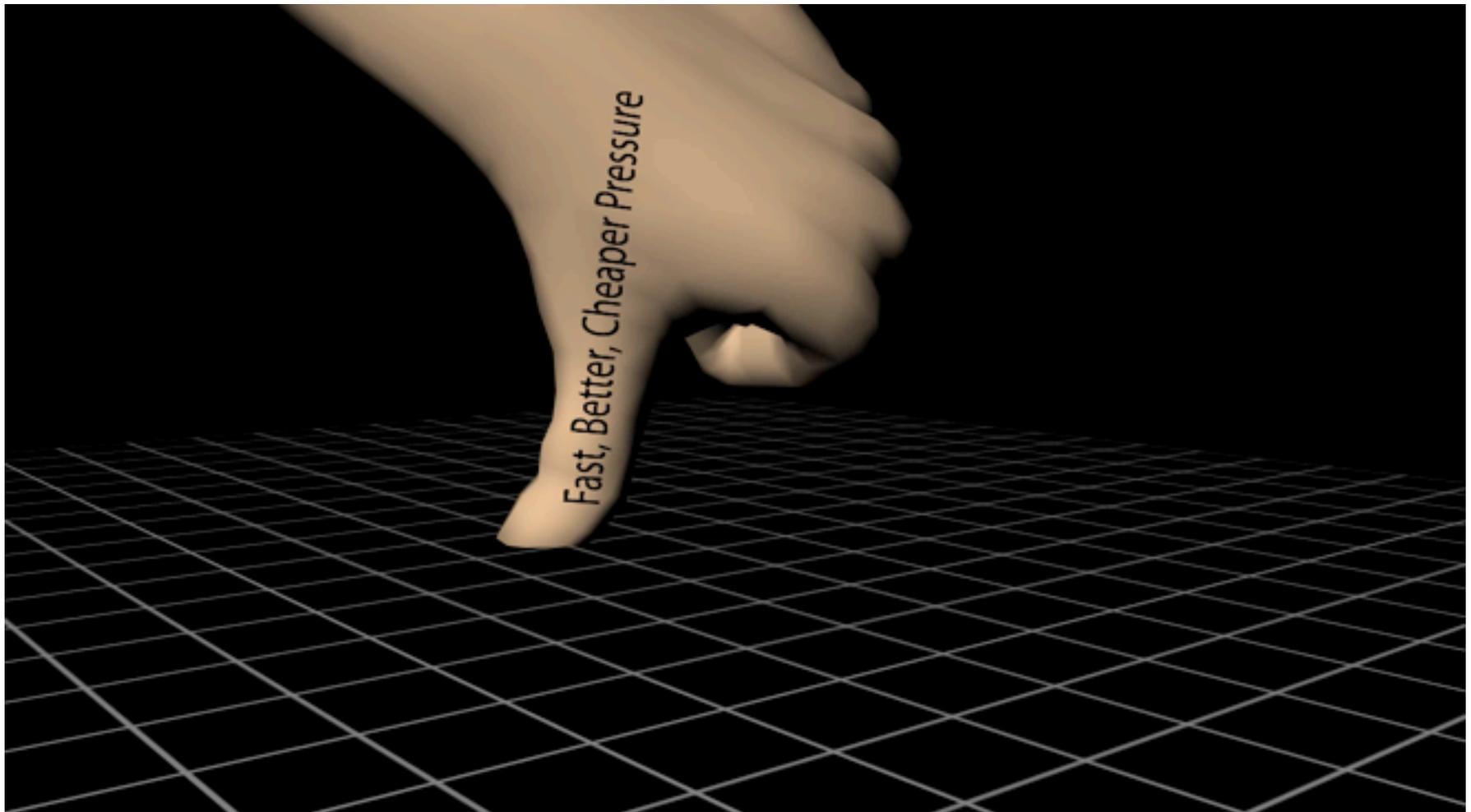
charting how changes reverberate through multi-role, multi-echelon networks  
each response to change by some unit triggers adaptive responses across other units



Reverberation across a Tangled Layered Network of interdependent units:  
the degree that *changes in one area tend to recruit or open up beneficial changes in many other aspects of the network*;  
which opens new opportunities across the network, ...

**Adaptive Cycles in multi-role, multi-echelon networks**





Acute - chronic trade-off and the sacrifice judgment

**FBC: faster, better, cheaper pressure**

# Adaptive Cycles: studies of resilience/brittleness in action

charting how changes reverberate through multi-role, multi-echelon networks  
each response to change by some unit triggers adaptive responses across other units

Adaptive cycle (clef): 



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Adaptations locally resolve conflicts

## Adaptive Cycles in multi-role, multi-echelon networks



# Adaptive Cycles

*triggering events – pressures – conflicts – adaptations*

Adaptive cycle (clef): 



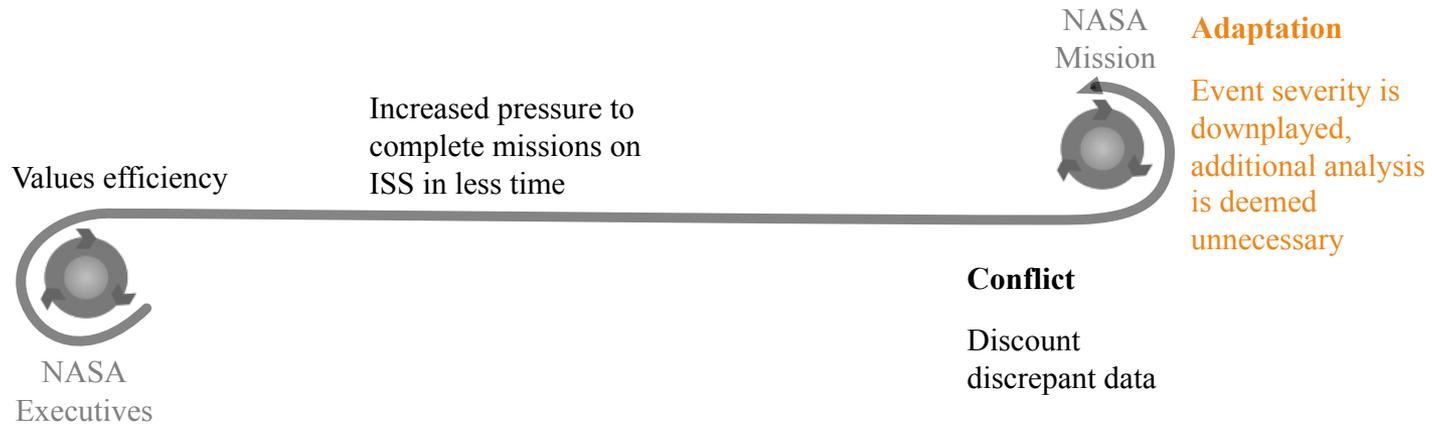
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Adaptations locally resolve conflicts

**Adaptive Cycles in multi-role, multi-echelon networks**

# Adaptive Cycles

*triggering events – pressures – conflicts – adaptations*



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Adaptive Cycles: Contributors

Looks a little different!!!

**Adaptive Cycles in multi-role, multi-echelon networks**

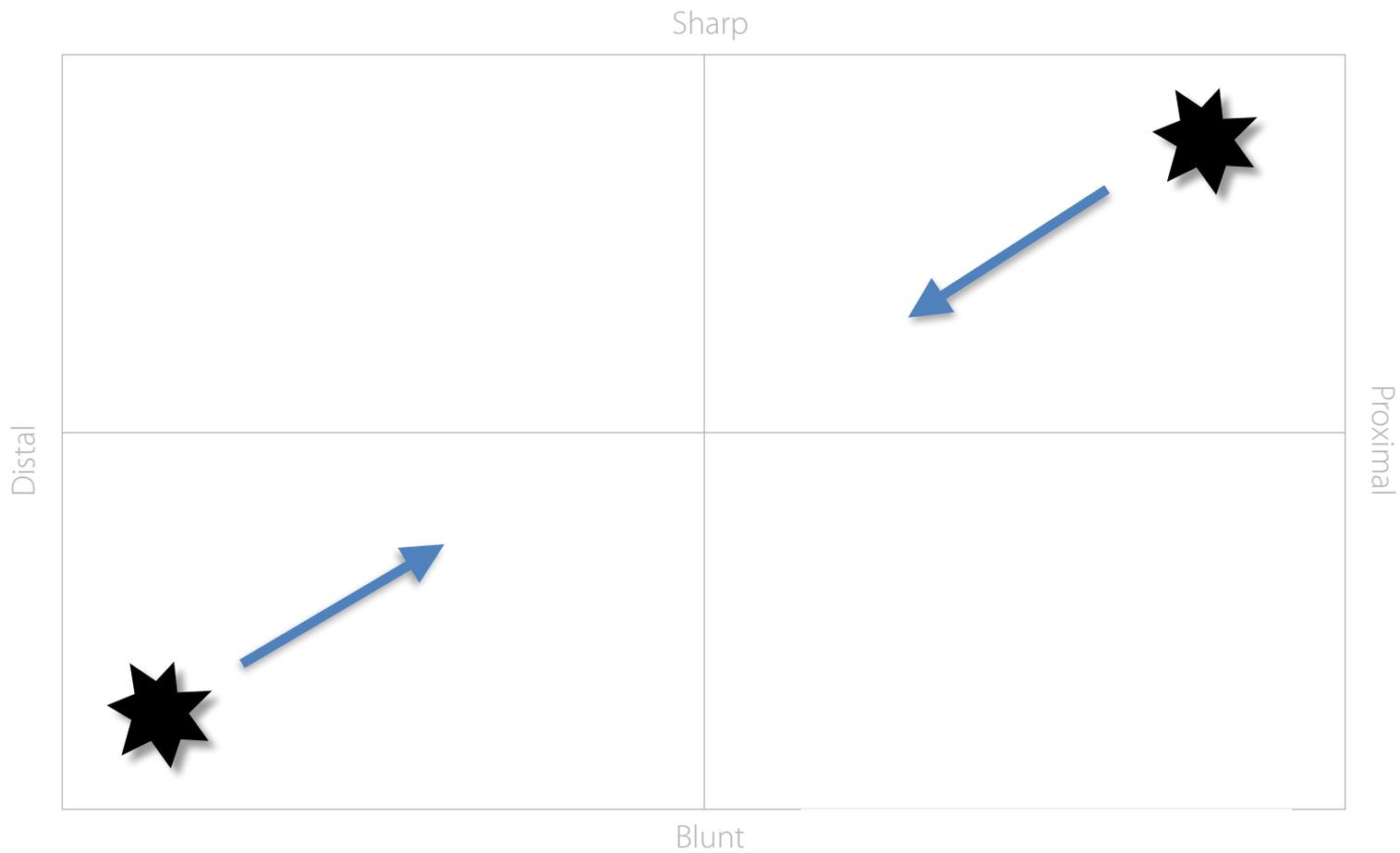


# Adaptive Cycles

*triggering events – pressures – conflicts – adaptations*



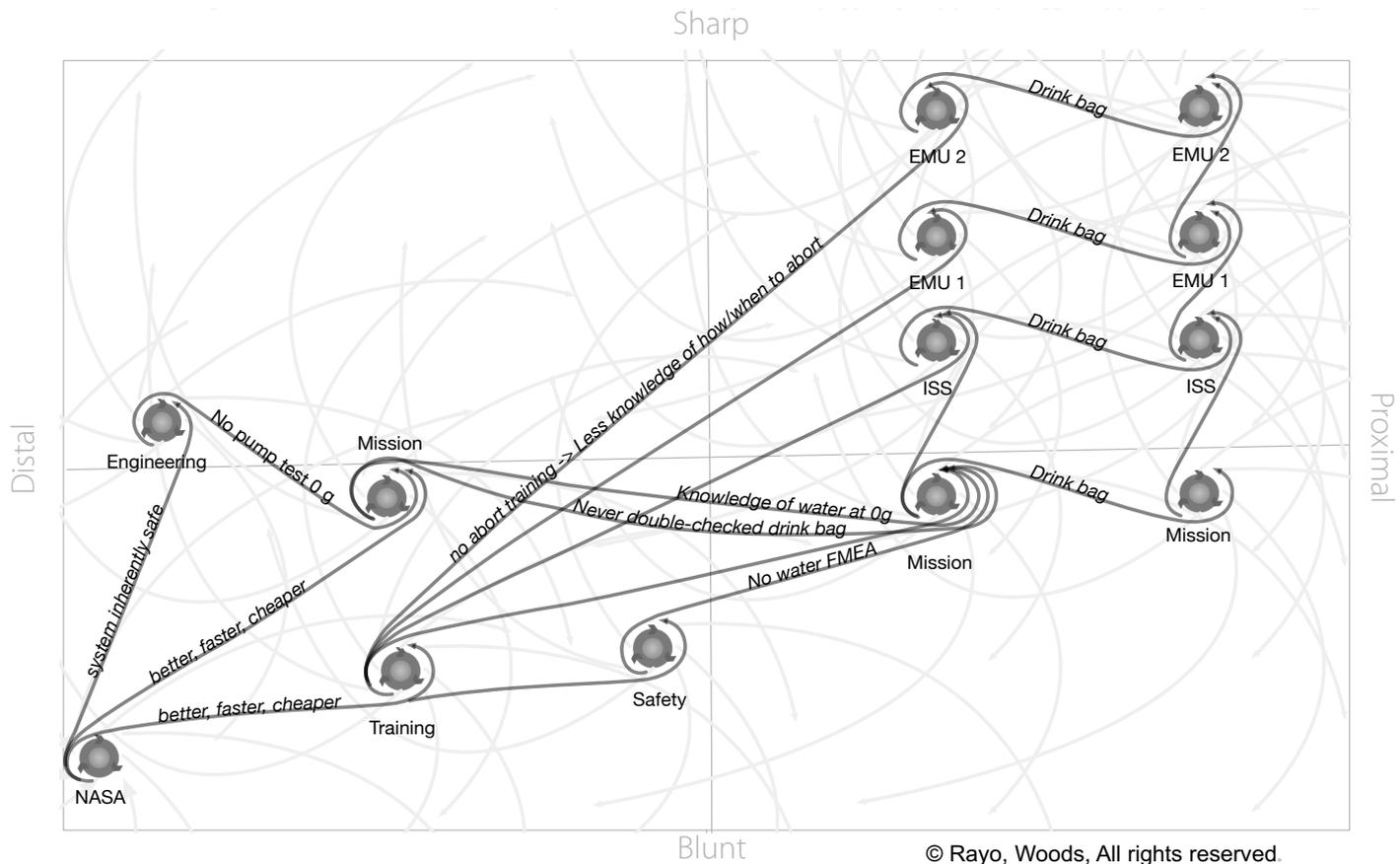
**Adaptive Cycles in multi-role, multi-echelon networks**



Roles, Levels,  
Triggers, Events,  
Pressures, Conflicts,  
Opportunities, Adaptations

# Adaptive Cycles

triggering events – pressures – conflicts – adaptations



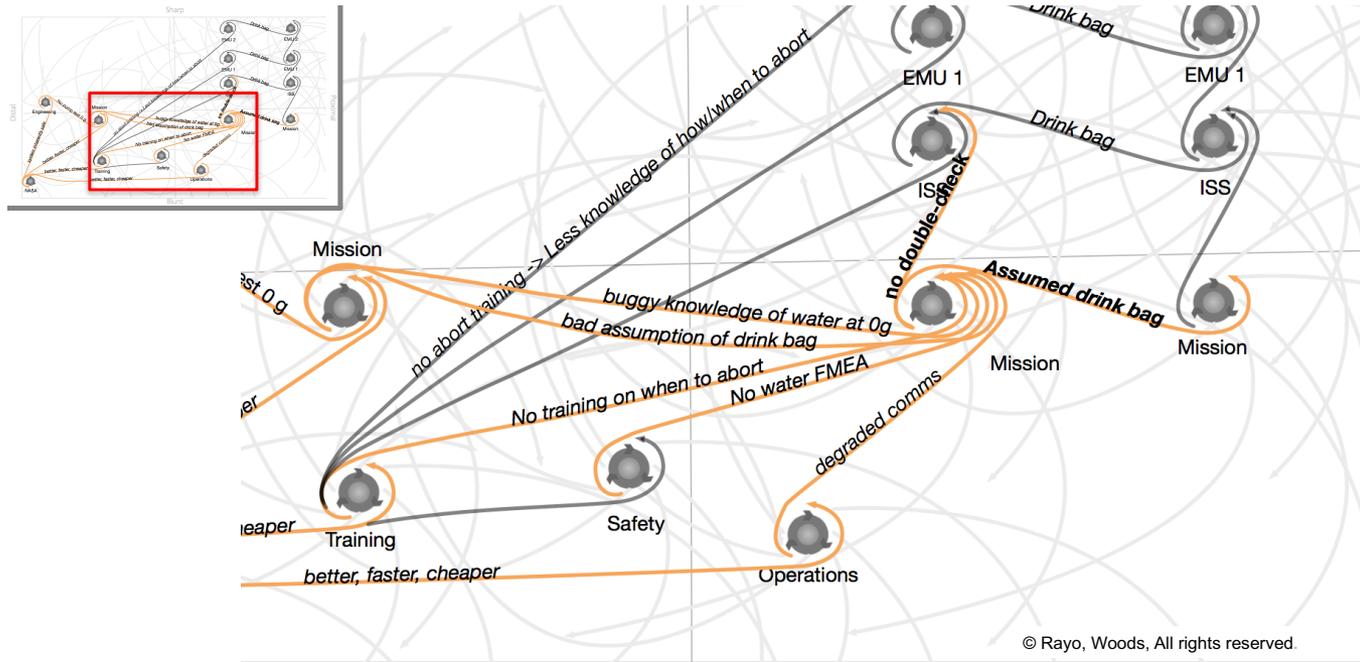
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Adaptive Cycles in multi-role, multi-echelon networks



# Adaptive Cycles

triggering events – pressures – conflicts – adaptations



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A closer look at Mission (Ground)

Their adaptive capacity is strained!

## Adaptive Cycles in multi-role, multi-echelon networks

## *Adaptive Cycles*: studies of resilience in action

charting how changes reverberate through multi-role, multi-echelon networks  
each response to change by some unit triggers adaptive responses across other units



Reverberation across a Tangled Layered Network of interdependent units:  
the degree that *changes in one area tend to recruit or open up beneficial changes in many other aspects of the network*;  
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**Adaptive Cycles in multi-role, multi-echelon networks**

