Challenges for a Theory of Complex Cognitive Work Systems

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Cognition

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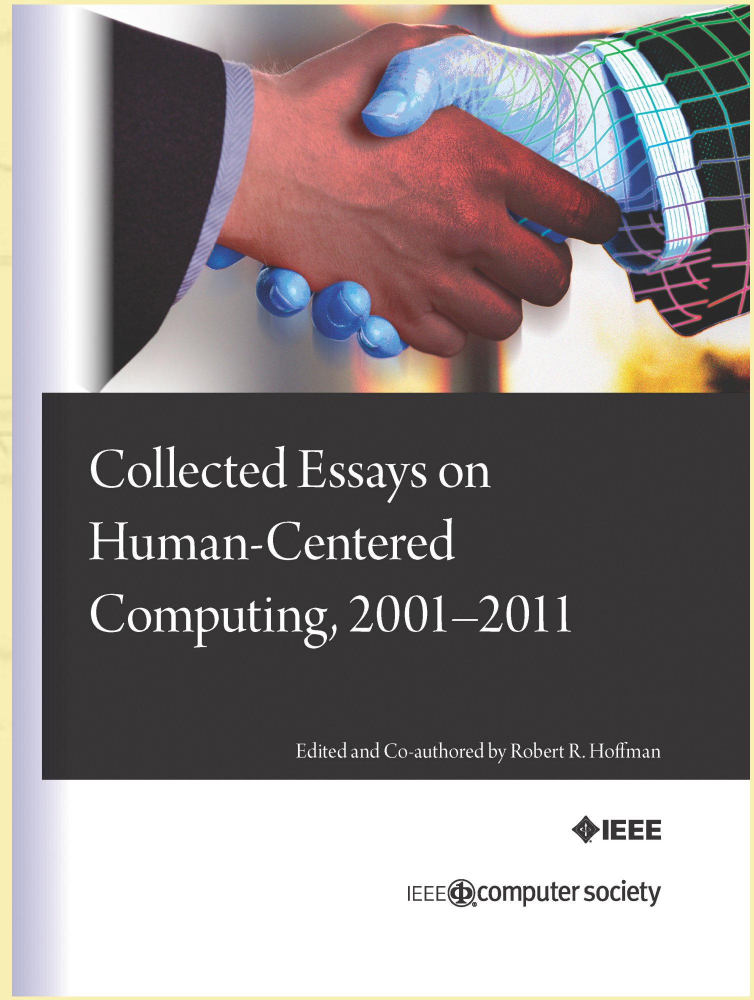
Technologies that amplify and extend human abilities

To Know
To Learn
To Perceive
To Collaborate



Artificial Intelligence

Robotics

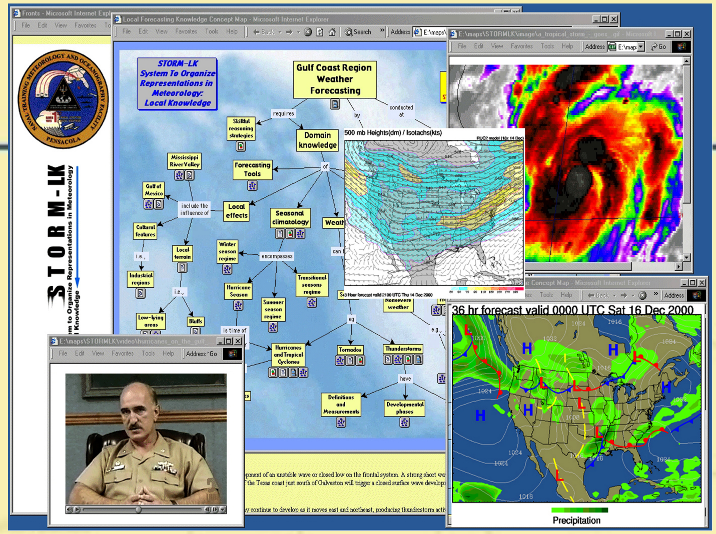
Avionic Technology

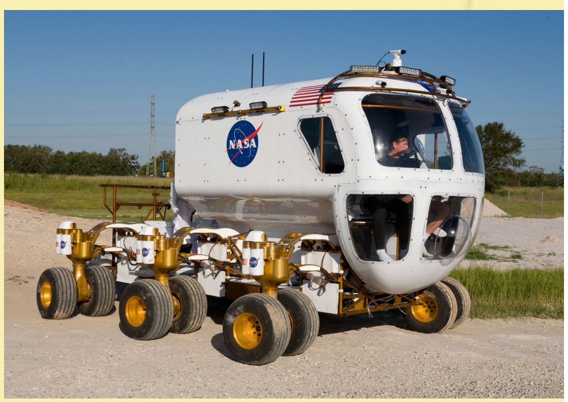
Space Systems

NLP

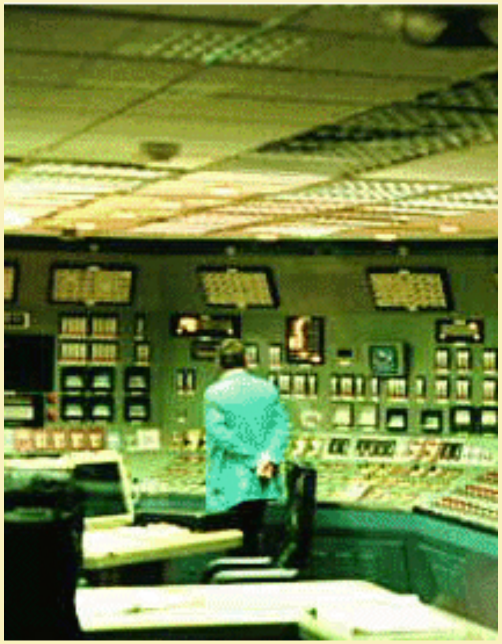
Knowledge Management

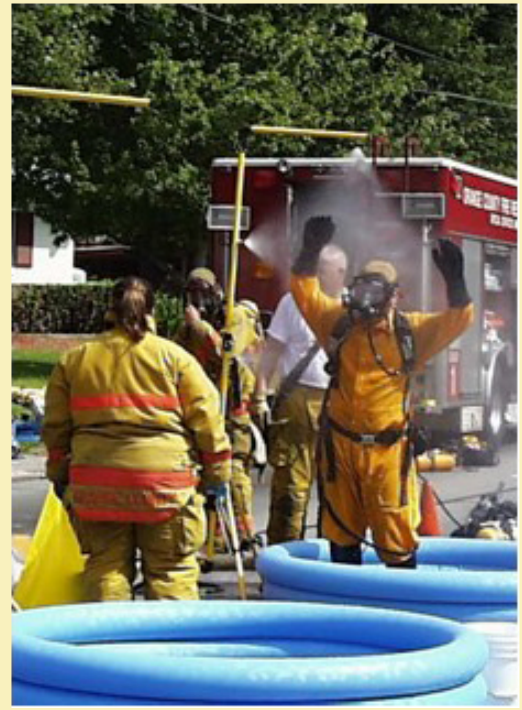
Multi-sensory Interfaces





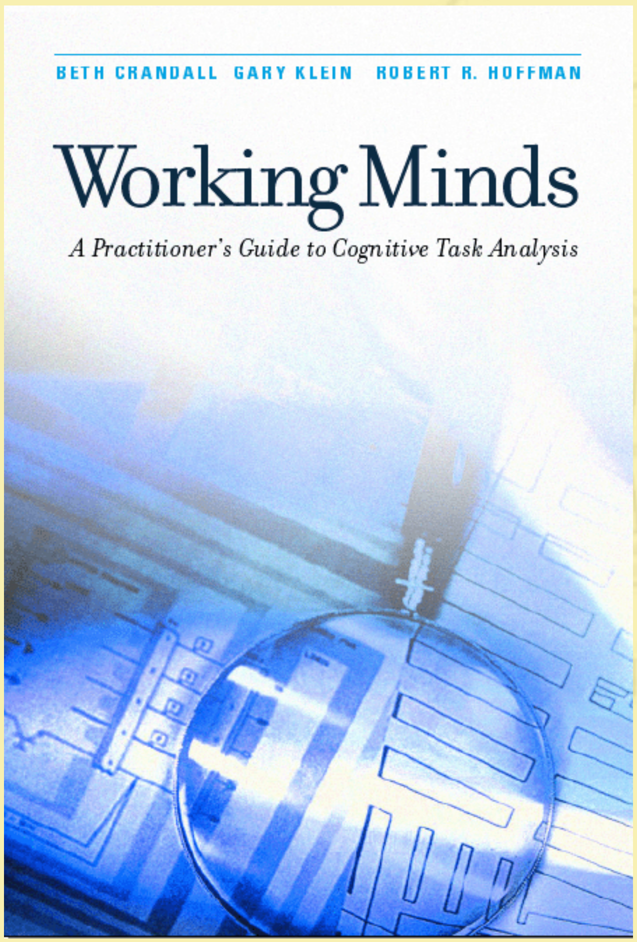
Challenges for a Theory Complex Cognitive Work Systems

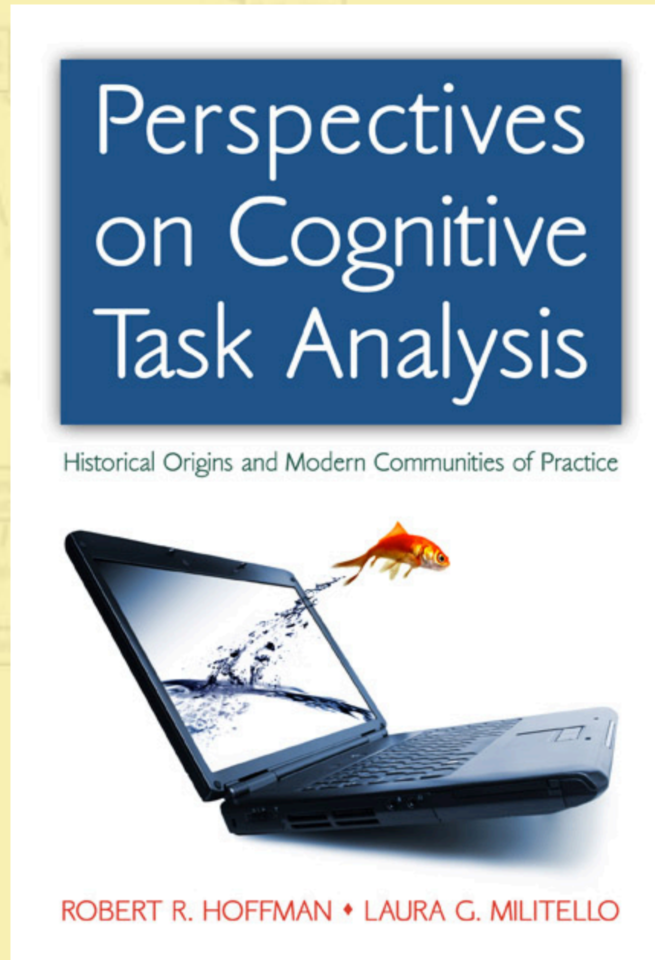




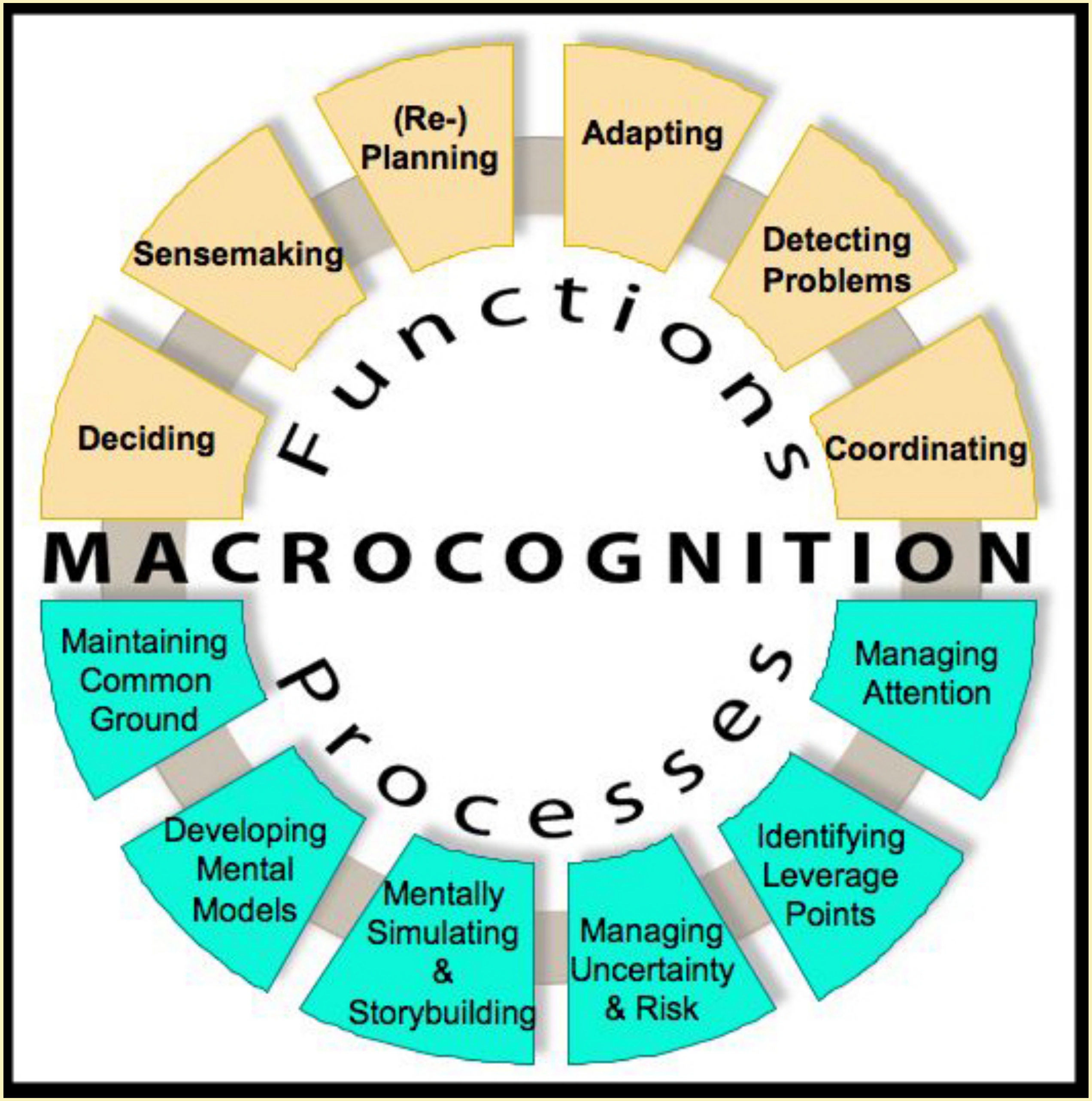

Methods Used on Cognitive Systems Engineering

- Cognitive Task Analysis and Knowledge Elicitation -





Theoretical Framework



Complexity in Macrocognitive Work

Monitoring progress toward goals only makes sense if the goals don't change.

Goals can be ill-defined.

Multiple simultaneous goals, and often in conflict.

People have to discover goals even while trying to and solve them.

But there do seem to be laws that govern these situations

Laws of Macrocognitive Work Systems

Shoshone guide for
Lewis & Clark ---
without whom the expedition
could not have succeeded

Human-Centered Computing

Law?
Challenge?

The Sacagawea ~~Principle~~

Mica Endsley, *SA Technologies*
Robert R. Hoffman, *Institute for Human and Machine Cognition*

Many software tools and systems restrict the availability of information and make information integration and exploration difficult.[1] Poorly designed tools are often brittle, because they prescribe task sequences. But in complex sociotechnical contexts, workers do not perform tasks; they engage in knowledge-driven, context-sensitive choices from among action sequence alternatives in order to achieve goals.[2] So, good tools must be flexible—they must provide the information that workers need to generate appropriate action sequences by which they can achieve the same goal in different situations. Adapted from the writings of Donald Norman is a principle we call the Sacagawea Principle:

> Human-centered computational tools need to support active organization of information, active search for information, active exploration of information, reflection on the meaning of information, and evaluation and choice among action sequence alternatives.

Context-conditional variation includes variation due to the worker—each worker has his or her own needs, entailing different requirements and constraints. This implies that individuals should be able to choose different trajec-

As with many HCC principles, we have named this one after a person to give it a concrete and meaningful label. Sacagawea served as a guide, without whose help the Lewis and Clark expedition might not have achieved the successes it did. The name is also somewhat ironic, because Sacagawea was, for part of her life, a captured slave. The theme of machines and robots as slaves is arguably the oldest in the robotics literature, and it is still often used as a metaphor to describe the tools people use to accomplish their work. In this essay, we explore an approach for fulfilling the Sacagawea Principle in system design—an approach based on empirical study of the way in which people process their environments in complex worlds.

Situation awareness: Key to designing human-centered systems

One of the most important functions that people must perform, when they are using machines for exploring and understanding the world, is to maintain a state of *situation awareness* (SA). This is especially true in domains such as aviation, firefighting, and weather forecasting. The user must form what is often referred to as a *mental model* of the ongoing situation—a situational model or SA. Domain practitioners often report an imagistic experience, manifested as a 4D simulation of events that is driven or constrained

“Good” technology supports:

- Active organization of information,
- Active search for information,
- Reflection on the meaning of information,
- Exploration of information,
- Evaluation and choice among alternative activities.

Additional Laws

"Never trust anything if you can't tell where it keeps it's brain."

Mr. Weasley's Law:

Workers always hold some mixture of: (1) justified and unjustified trust and (2) justified and unjustified mistrust in their MWS and its technology.

Trust in automation is not a single variable.
Trust in automation is not a state.

Additional Laws

<u>The Toolness Law:</u> To be adaptive, workers need to discover toolness.

- Artifacts become tools through use.

<u>The Law of the Kluge</u>

- MWSs pressure workers to adapt by creating work-around and kluges. This is an empirical inevitability, not to be swept under the rug by blaming the"users."

Completing tasks despite design flaws (Work-around)
Completing tasks despite component failures (compensation)
Using tools in ways not envisioned buy the designers (extension)
Intentionally misleading the computers (subversion)
Using temporary fixes that are awkward but that get 'er done (kluges)
Refusing to engage in functional make-work that is tedious (avoidances)
Verbally or physically attacking the machine (automation abuse)

Additional Laws

The Law of Stretched Systems

- MWSs are continually stretched to operate at their capacity. Technological interventions are exploited in an attempt to better achieve goals by pushing the CWS to its new capacity boundaries, and hence achieve a new intensity, tempo, and complexity of activity.

The Second Law of Expertise:

- As expertise grows it spills into multiple roles, which have to be coordinated.

The "You asked for it" Law.

- Abrogation of responsibility diminishes adaptability.
  Under accountability pressures, people role retreat.

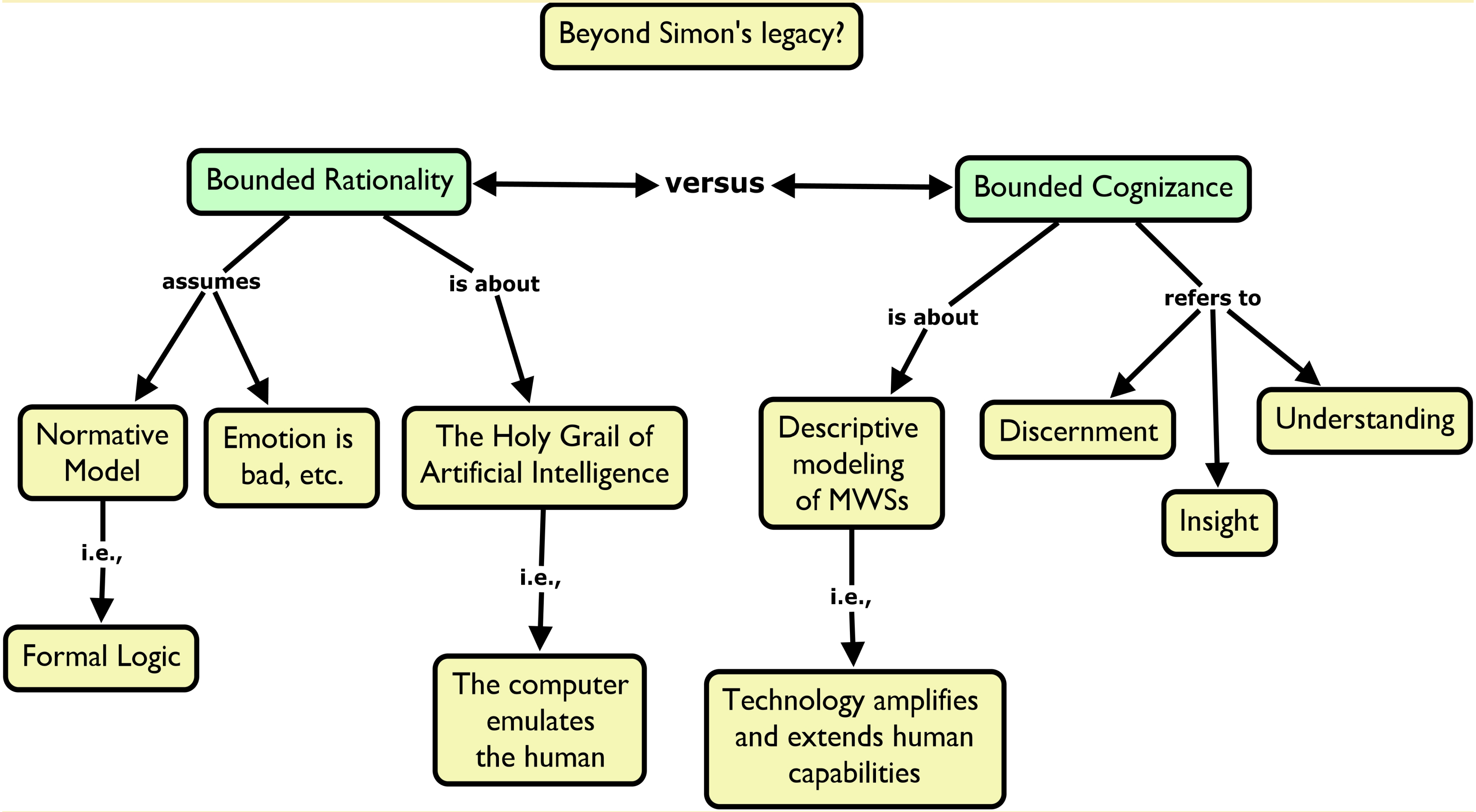
The "Ah-Ha!" Moment

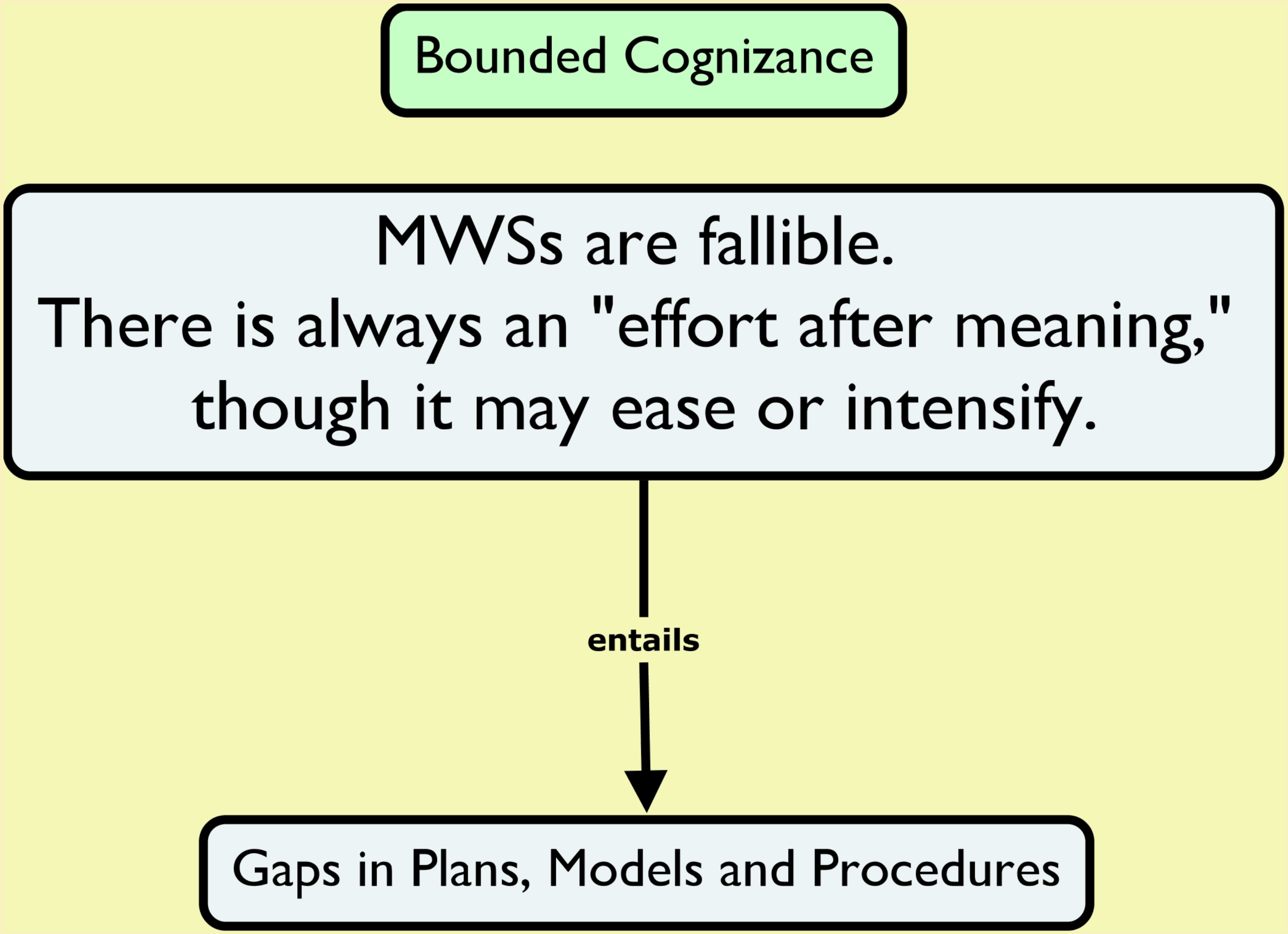
These and additional laws fall into Families

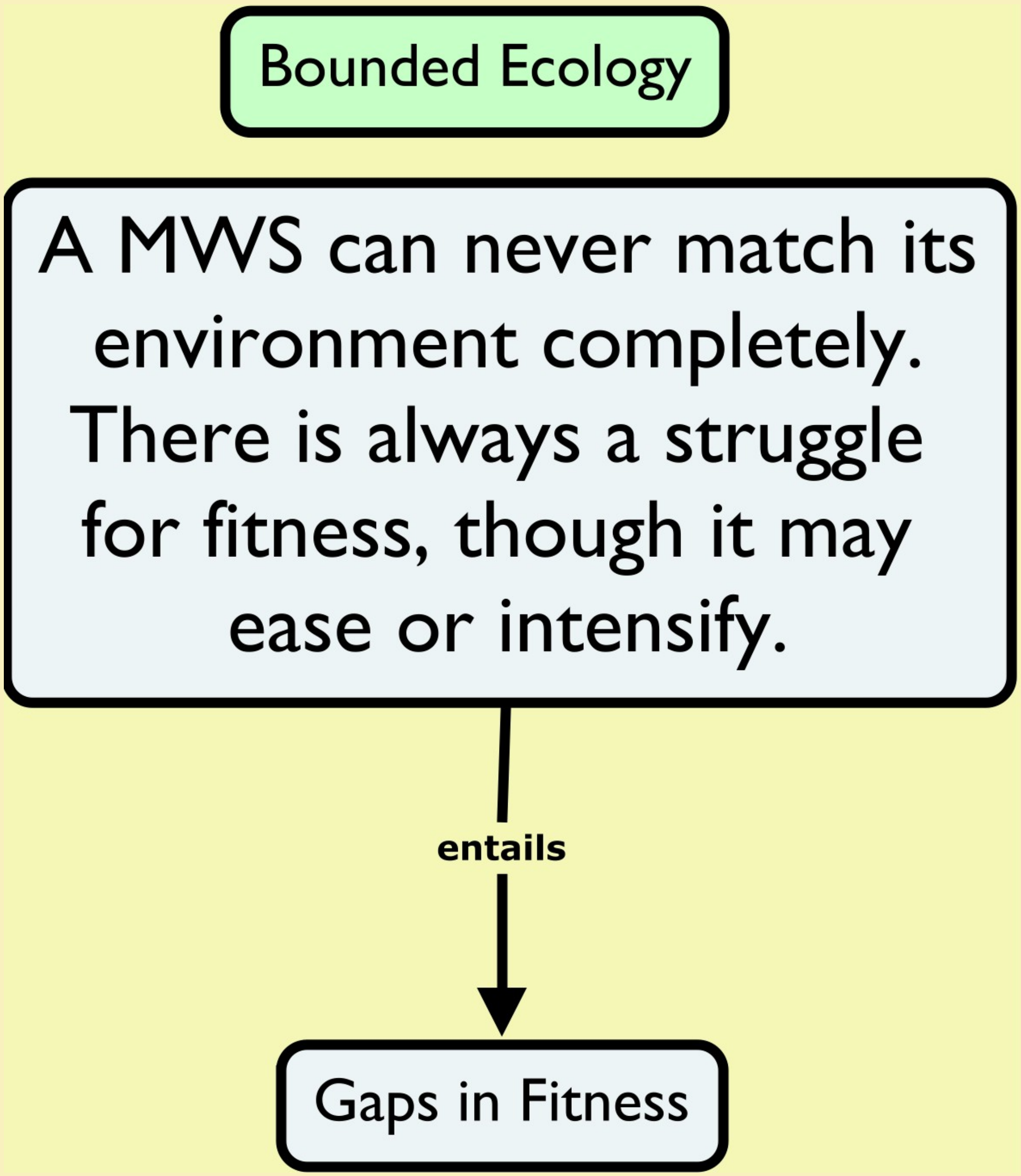
H. Simon had just one slice of the complexity!

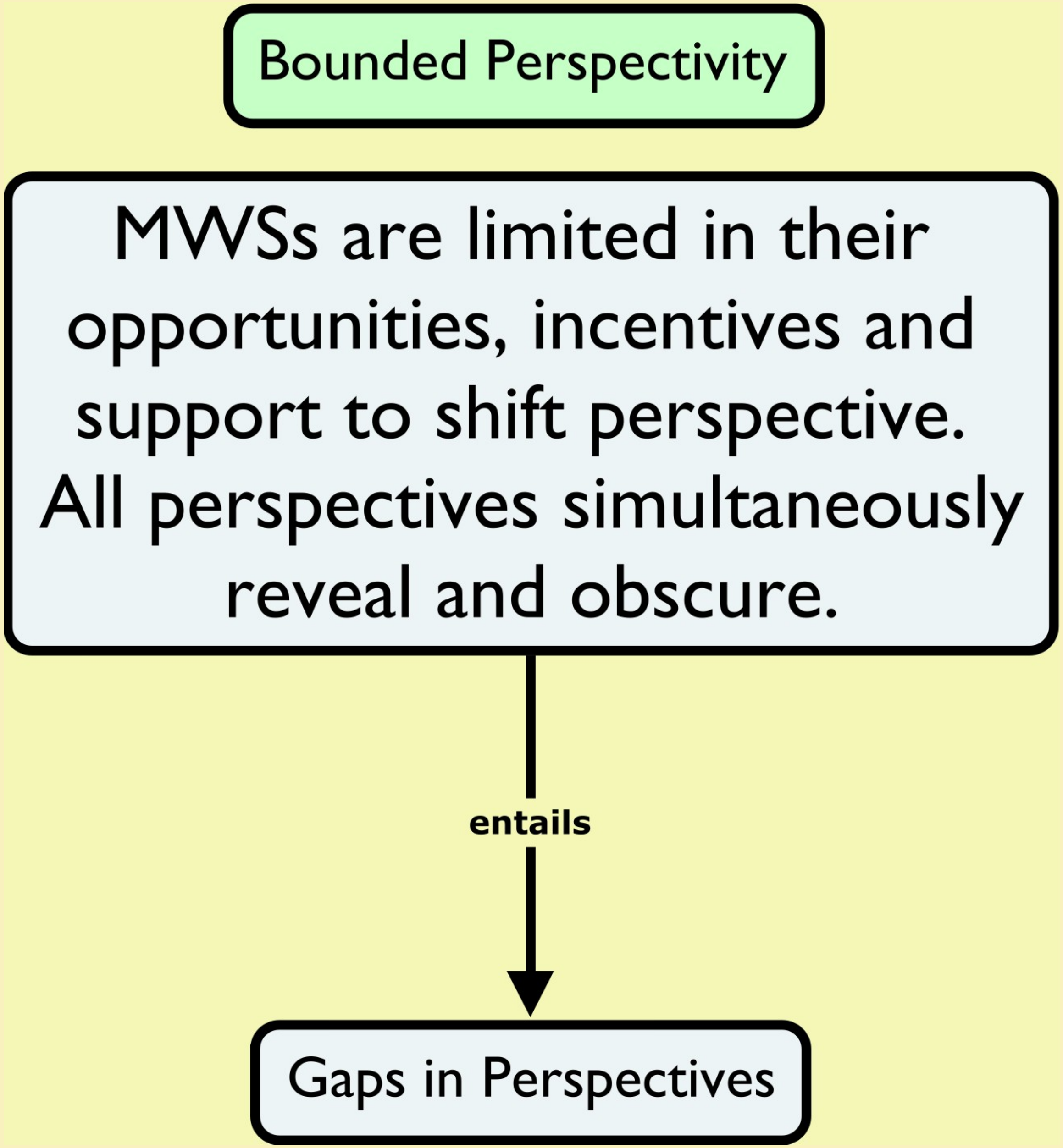
Fundamental types of "bounds"
on macrocognitive work systems

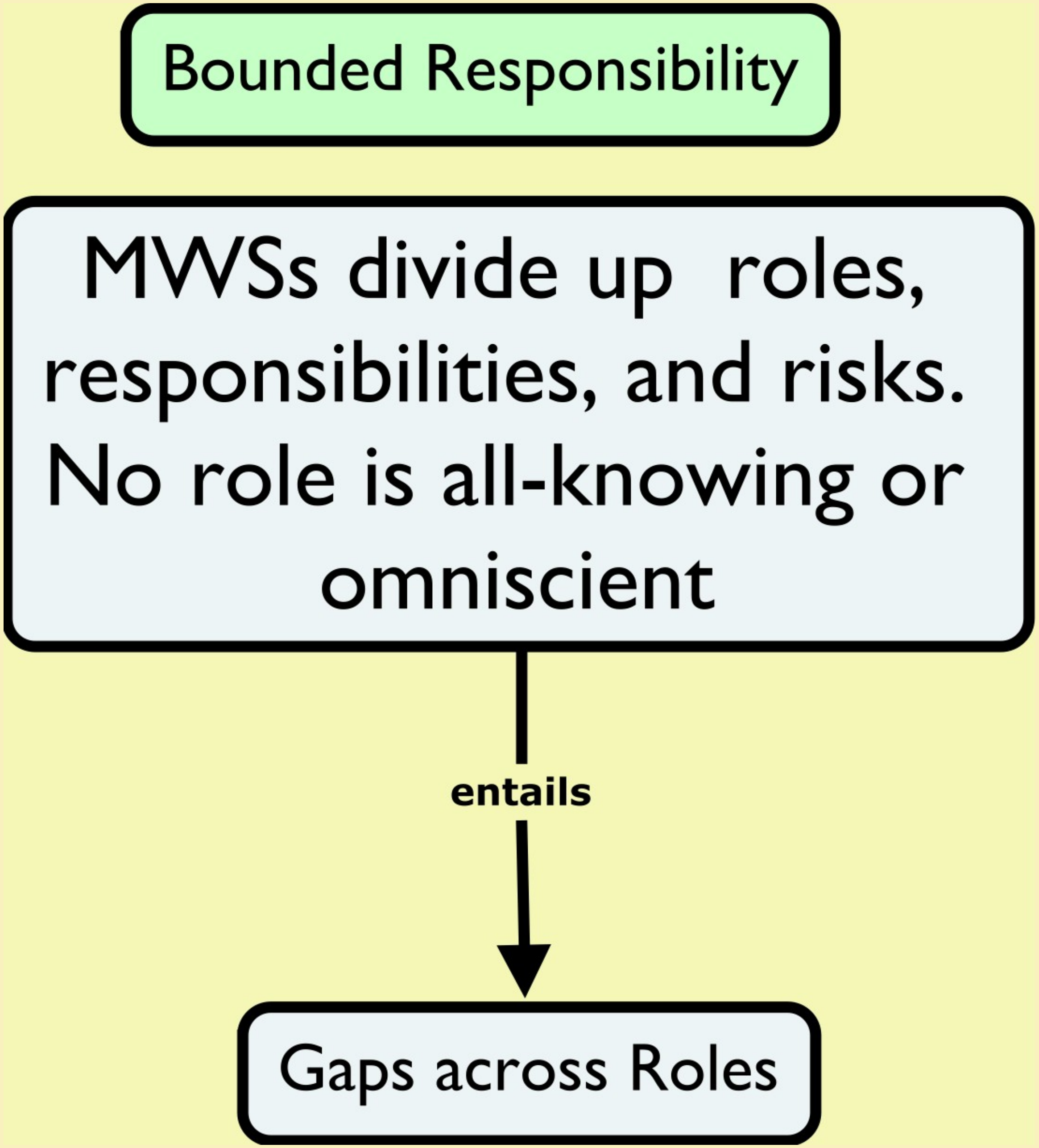
First, we refer to bounded *cognizance*, not bounded *rationality*.

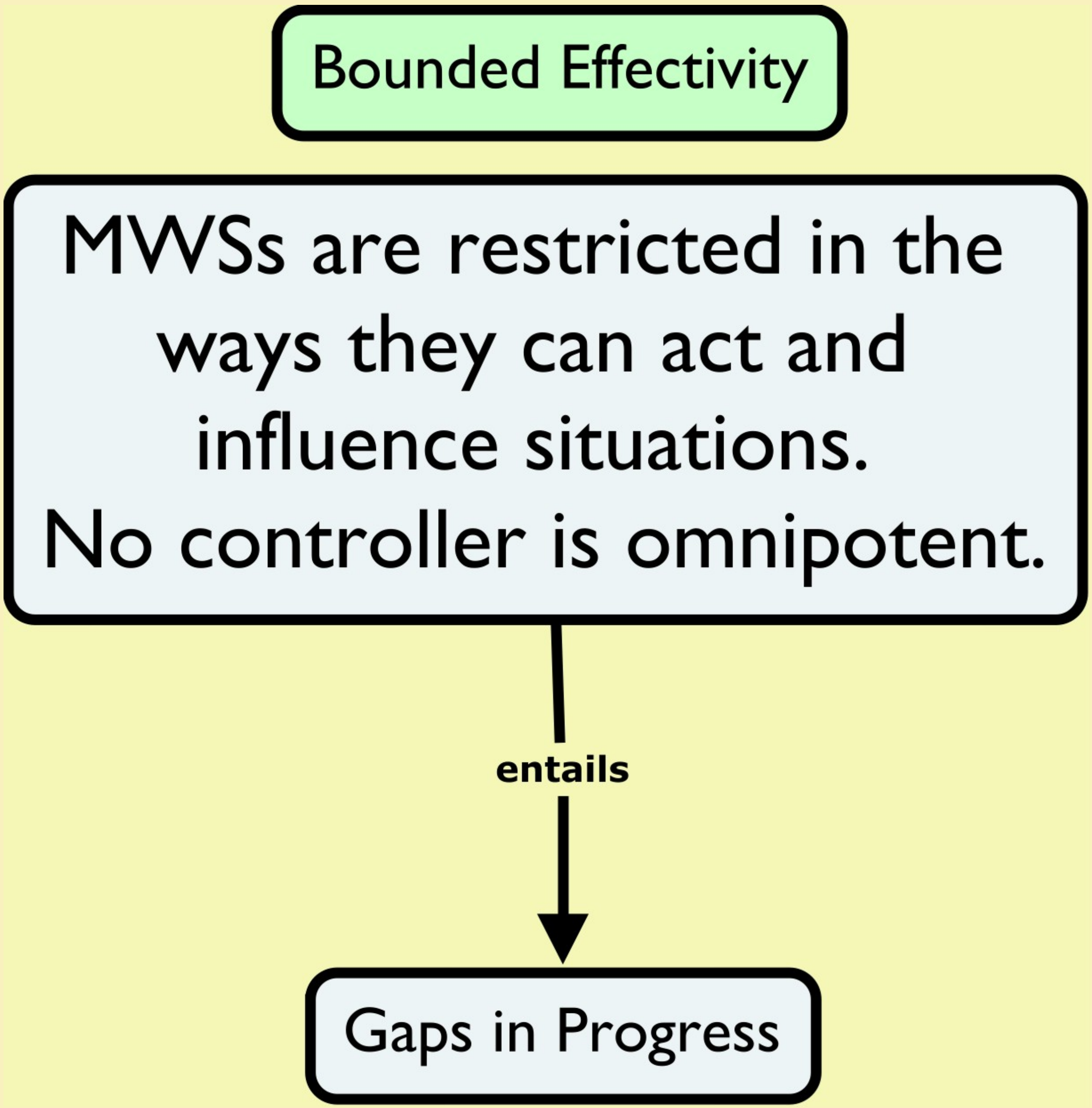



Bounded Cognizance
MWSs are fallible.
There is always an "effort after meaning,"
though it may ease or intensify.
entails
Gaps in Plans, Models and Procedures

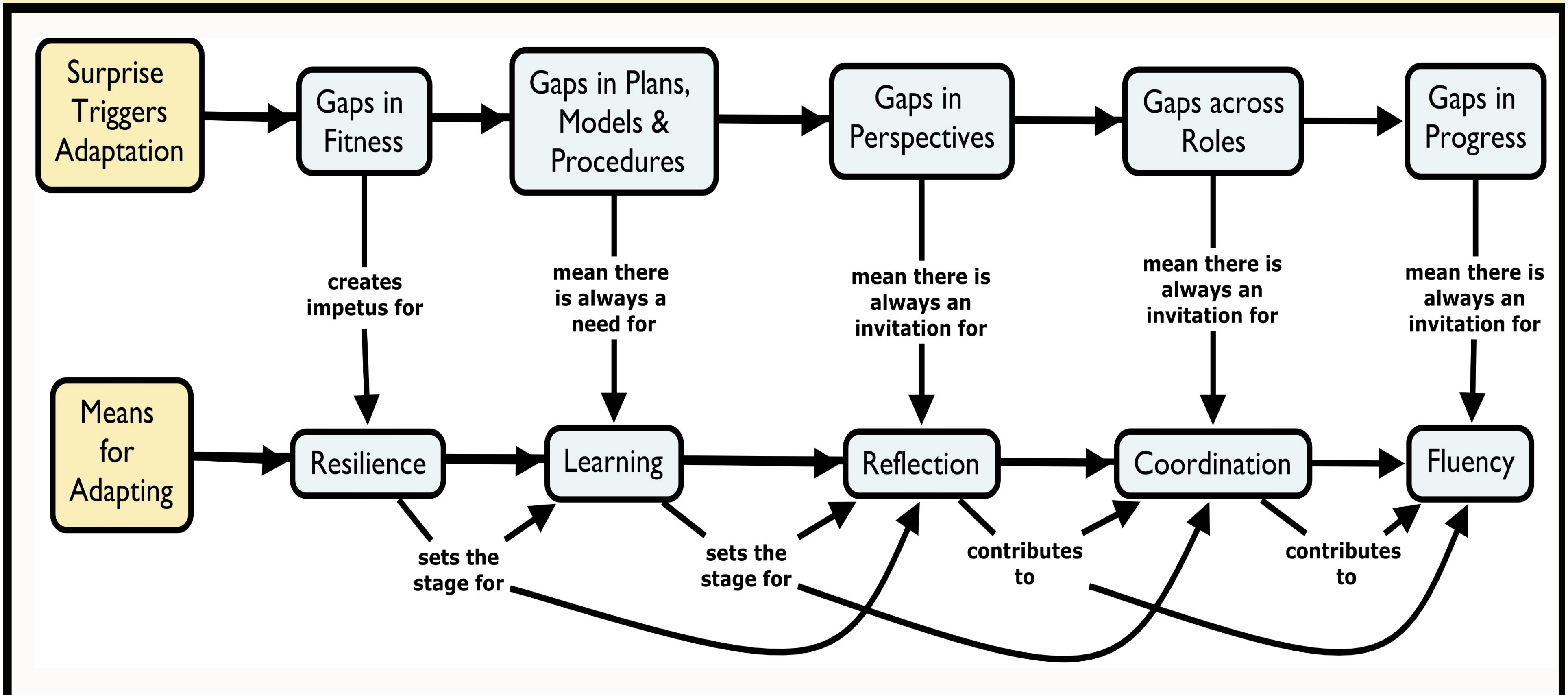

Bounded Ecology
A MWS can never match its environment completely. There is always a struggle for fitness, though it may ease or intensify.
entails
Gaps in Fitness

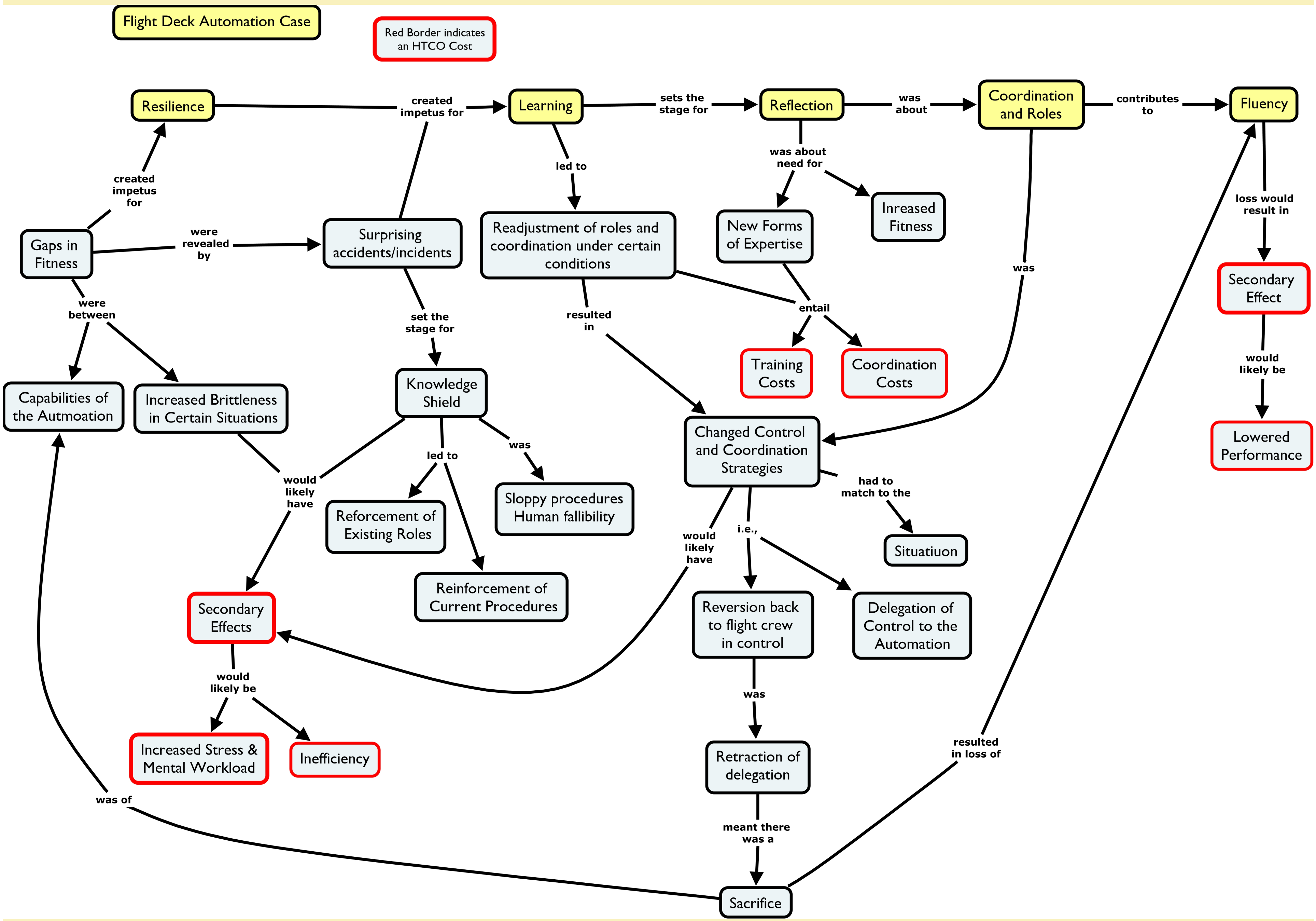

Bounded Perspectivity
MWSs are limited in their opportunities, incentives and support to shift perspective. All perspectives simultaneously reveal and obscure.
entails
Gaps in Perspectives


Bounded Responsibility
MWSs divide up roles, responsibilities, and risks. No role is all-knowing or omniscient
entails
Gaps across Roles


Bounded Effectivity
MWSs are restricted in the ways they can act and influence situations.
No controller is omnipotent.
entails
Gaps in Progress

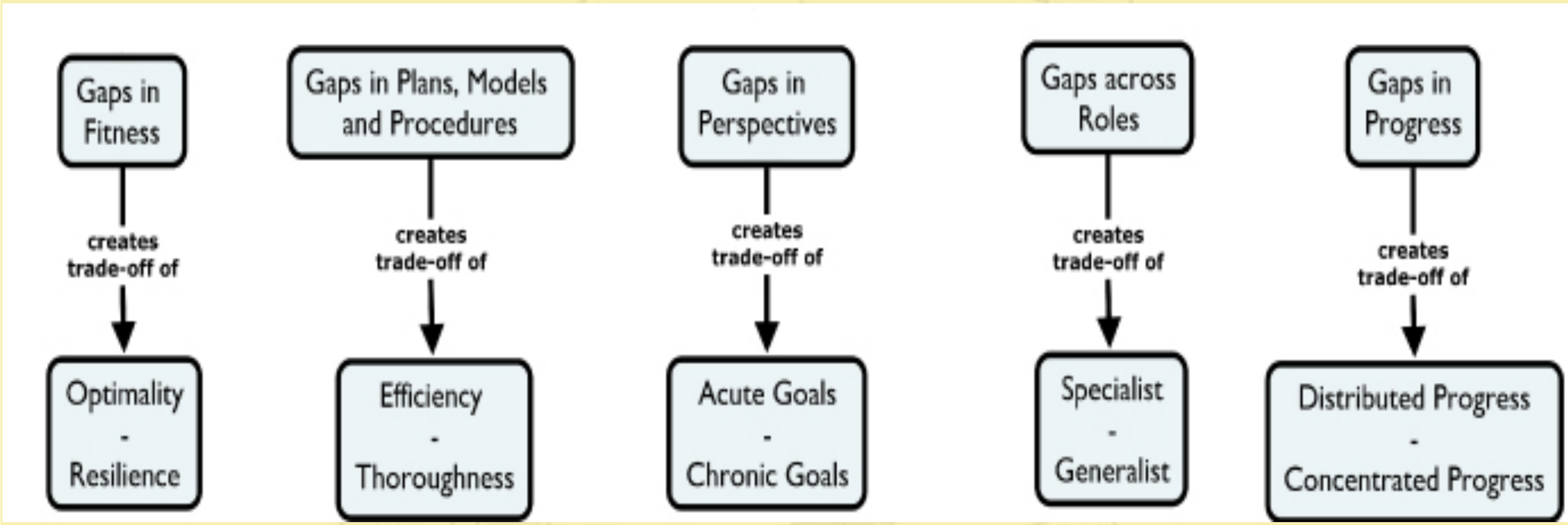
Using the Framework to Tell Stories




Flight Deck Automation Case
Red Border indicates an HTCO Cost
Resilience
created impetus for
Learning
sets the stage for
Reflection
was about
Coordination and Roles
contributes to
Fluency
created impetus for
Gaps in Fitness
were revealed by
Surprising accidents/incidents
led to
Readjustment of roles and coordination under certain conditions
was about need for
New Forms of Expertise
Inreased Fitness
was
loss would result in
Secondary Effect
would likely be
Lowered Performance
were between
Capabilities of the Autmoation
Increased Brittleness in Certain Situations
set the stage for
Knowledge Shield
resulted in
entail
Training Costs
Coordination Costs
Changed Control and Coordination Strategies
had to match to the
Situatiuon
would likely have
led to
was
Reforcement of Existing Roles
Sloppy procedures Human fallibility
Reinforcement of Current Procedures
would likely have
i.e.,
Reversion back to flight crew in control
Delegation of Control to the Automation
Secondary Effects
would likely be
Increased Stress & Mental Workload
Inefficiency
was
Retraction of delegation
meant there was a
Sacrifice
resulted in loss of
was of

- Each fundamental bound—each gap—involves a trade-off function
- A commitment to systems approach means that all substantive measures must be trade-off functions (compound measures)
- Each trade will each involve (at least) two individual measures.

Primary Tradeoff for Each Bound



A Theory of Macrocognitive Work Systems Should Conform to the Classical Norms of Theoretics

Requirements for a well-formed scientific theory

(1) A subject matter (complex systems, in general)

What is it supposed to explain?

(2) An ontology

Roster of concepts, phenomena and their definitions

(e.g., what is "emergence"?)

(3) A metatheory

What makes an assertion a law?

How can the theory be disconfirmed?

(4) A methodology

How is the theory empirically applied and evaluated?

(5) A set of laws

Nomological ("law-like") inductive generalizations

Requirements for a well-formed scientific theory

- Laws are true independent of theory (or decidable independently of theory?)
- Theory explains the laws.
- Laws explain facts (observations).
- Laws must be confirmed by all the available evidence, or at least known to be not false.
- Explanations of empirically false statements cannot be derived from the Laws.

A Theory of Macrocognitive Work Systems *Deviates* from the Classical Norms of Theoretics

As a theory of complexity, it *MUST* deviate from the classical norms of what makes for a well-formed scientific theory

This is a consequence of its very subject matter!

First of all. . . .

There really is no such thing as systems theory.

There are just scattered bags of hypotheses.

The literature of so-called systems theory is mostly mute on the subject of cognition.

So, what ***must*** a theory consist of?

Unique Characteristics

- The theory *must* manifest ontological ambiguity.
- It might include sentences that can serve as premises of explanations of contradictory statements.
- The subject matter is a teleological system—involving purpose and goals.
- The laws describe preferred states of the system; the laws can be thought of as selection processes.

Deviation #1

The Greenspan-Hollnagel Law

Complexity cannot be reduced

It transforms under translation

If you try and simplify, the complexity just pops up somewhere else in some other form.

Examples: typewriters; industrial process control

Deviation #2

Reflexive Reference Postulate

- The collectives that design MWSs are themselves a MWS
- Each Law entails a "design challenge" that can be adopted as policy for desirements.
- Such entailment relations are necessary for the postulates within a theory to "hang together."

Deviation #3

A Gödelian postulate

Choices:

- The theory says it all.
- The theory is wrong, we know.
- The theory is screwy, but it does explain some stuff.

Deviation #3

A Gödelian postulate

- The theory of MWSs is necessarily incomplete.
- The consistency of the laws is indeterminate.
- The ontology cannot be either complete or internally consistent.
- The ontology will be dynamic.

The Gödelian Postulate

TMWS can be disconfirmed by a *forced inconsistency*

- Forced inconsistency is when accordance with one law necessarily causes a violation of some other law.
- Making a MWS conform to any one of the design challenges will not in and of itself make it dis-conform with any of the other design challenges.

Measurement

Measurement within a theory of MWSs presents a number of challenges

How to measure complex things?

Some Conceptual Possibilities

- Rate of increase in the scope of the routine.
- Frequency of surprises that force adaptation to variations.
- Ratio of time, effort, resources directed to acute vs. chronic goals.
- Resources devoted to the management of responsibility across roles.
- Ratios of: (1) effort and resources devoted to the management of responsibility across roles vs. (2) effort and resources devoted to coordination across roles vs.(3) effort and resources devoted to creation of new roles.
- Effectiveness and flexibility of mechanisms balancing micromanagement vs. delegation.
- Enhanced intrinsic motivation of the workers.
- Accelerated achievement of proficiency by the workers.
- Increased facility for coping with rare or tough cases.

Flavors of the Month

<u>Adaptivity</u>

The capacity of a (work) system to achieve its goals despite the emergence of circumstances that "push" the system toward the boundaries of its competence envelope.

The work system can employ multiple ways to succeed, or develop new ways to succeed, and can move seamlessly among them.

The work system can reallocate and re-direct its resources to move away from the boundary region, and achieve its primary task goals.

Resilience

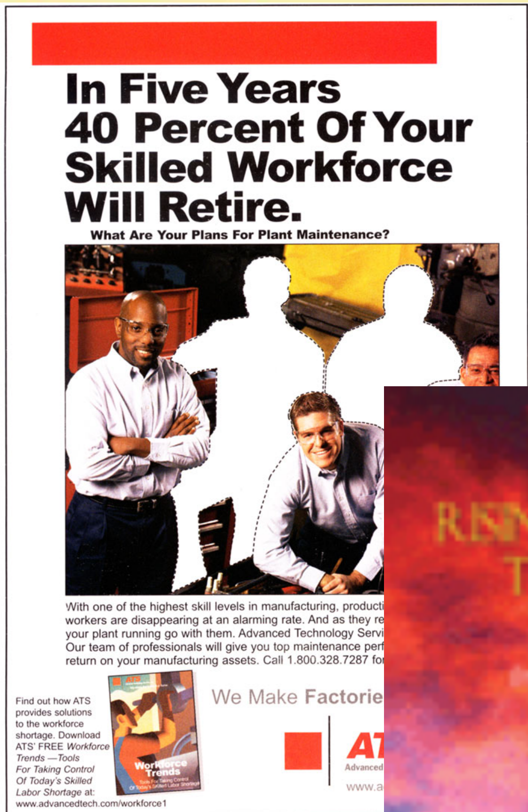
The capacity to change as a result of circumstances that push the work system *beyond* the boundaries of its competence envelope.

The system will have to change some of its procedures, resources, responsibilities, roles.

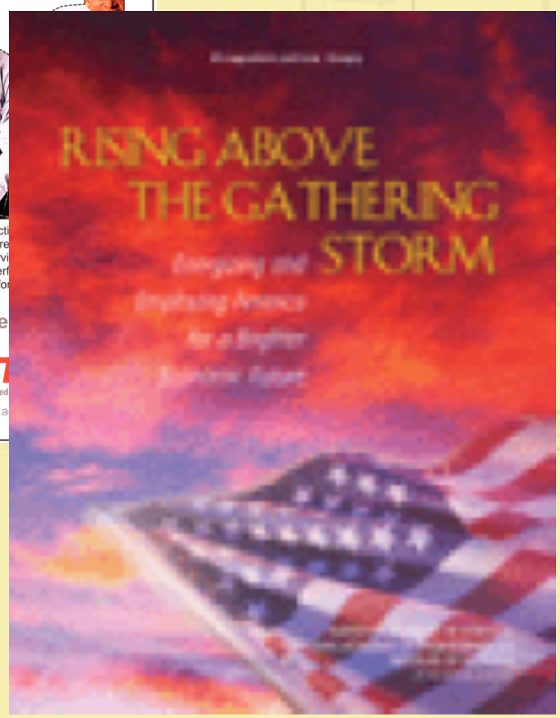
The system has to change some of its goals, perhaps including its prmary goals.

Because of those changes, the work system has a changed competence envelope.

National Policy & Workforce Issues

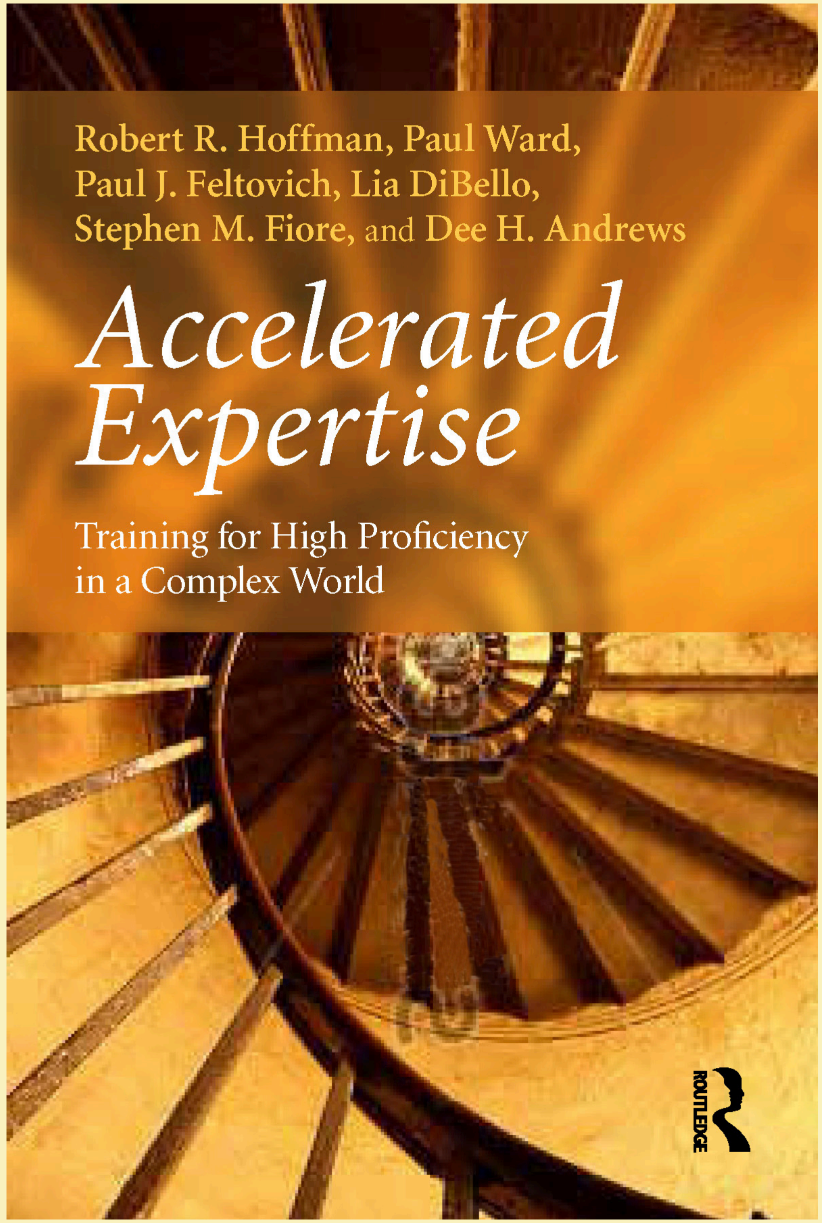


National Academy
of Science
2005



The elicitation and preservation of knowledge resources is a concern for all organizations.

"United States must compete by optimizing its knowledge-based resources"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