International Ergonomics Association

Introduction to Cognitive Engineering

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Agenda

- What is Cognitive Engineering?
- Critical issues and challenges in Cognitive Engineering
- Cognitive Engineering constructs
- Cognitive Engineering and Decision Making

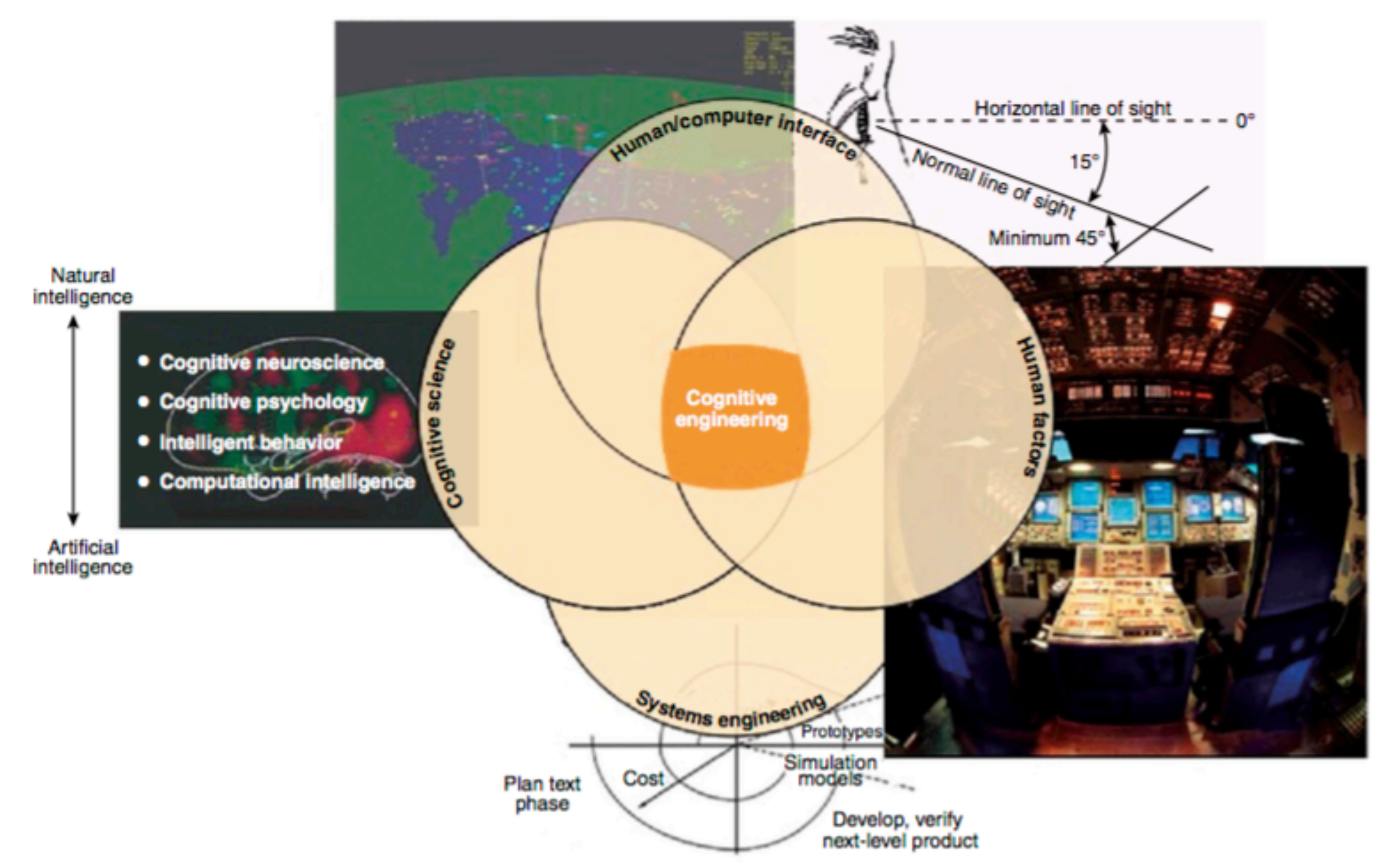
What is Cognitive Engineering?

Application of knowledge and techniques from cognitive psychology to design of human-machine systems in complex domains

- "Cognitive Systems Engineering" adds broader perspective – humans, technology and work seen as joint cognitive system

- "Human-Systems Integration" – design and develop systems that integrate human capabilities and limitations

- "Cognitive Engineering and Decision Making" incorporates focus on how people make decisions in the real world



From Gersh, McKeeley, & Remington, 2005

Cognitive Engineering Challenges

- Abundance of technology increases importance of cognitive engineering
- Design of ‘good’ work systems must consider cognitive as well as physiological factors
- Cognitive processes are hard to measure
- Cognitive processes may vary depending on expertise
- Match between system design and cognitive processing is critical to successful use
- Well-engineered systems should protect against errors/failures

Features to take into account:

1) Importance of context – real-world situations, goals, constraints
2) Importance of
    - accessibility and use of situation-relevant knowledge
    - impact of this knowledge on cognitive behavior
3) Must incorporate complex systems and problems into research paradigms for design solutions
4) Must use systems perspective in analysis and design
5) Multiple cognitive agents (human and machine)

Cognitive Engineering Constructs

- Vigilance and Monitoring Behavior
- Situation Awareness
- Cognitive Workload & Mental Effort
- Mental Models
- Collaborative Work
- Decision making and Expertise

Vigilance and Monitoring

Attention & Perception

- Cues and information must be attended to and perceived

- Not just a matter of perceptual limitations –
  - Salience
    - Location of information and displays
    - Top level vs. buried

  - Alarms and alerts
  - Clutter
  - Ease of interpretation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Vigilance and Monitoring

Complacency and Automation Bias

- Humans are not very good at long-term vigilance

- Experience with reliable automated systems fosters complacency and automation bias (Mosier & Skitka, 1996)

- As automation takes over more and more tasks, this likely will get worse


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Cognitive Engineering Constructs

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Situation Awareness

Full and accurate understanding of the situation and task - “the perception of elements in the environment…, the comprehension of their meaning and the projection of their status in the near future.”

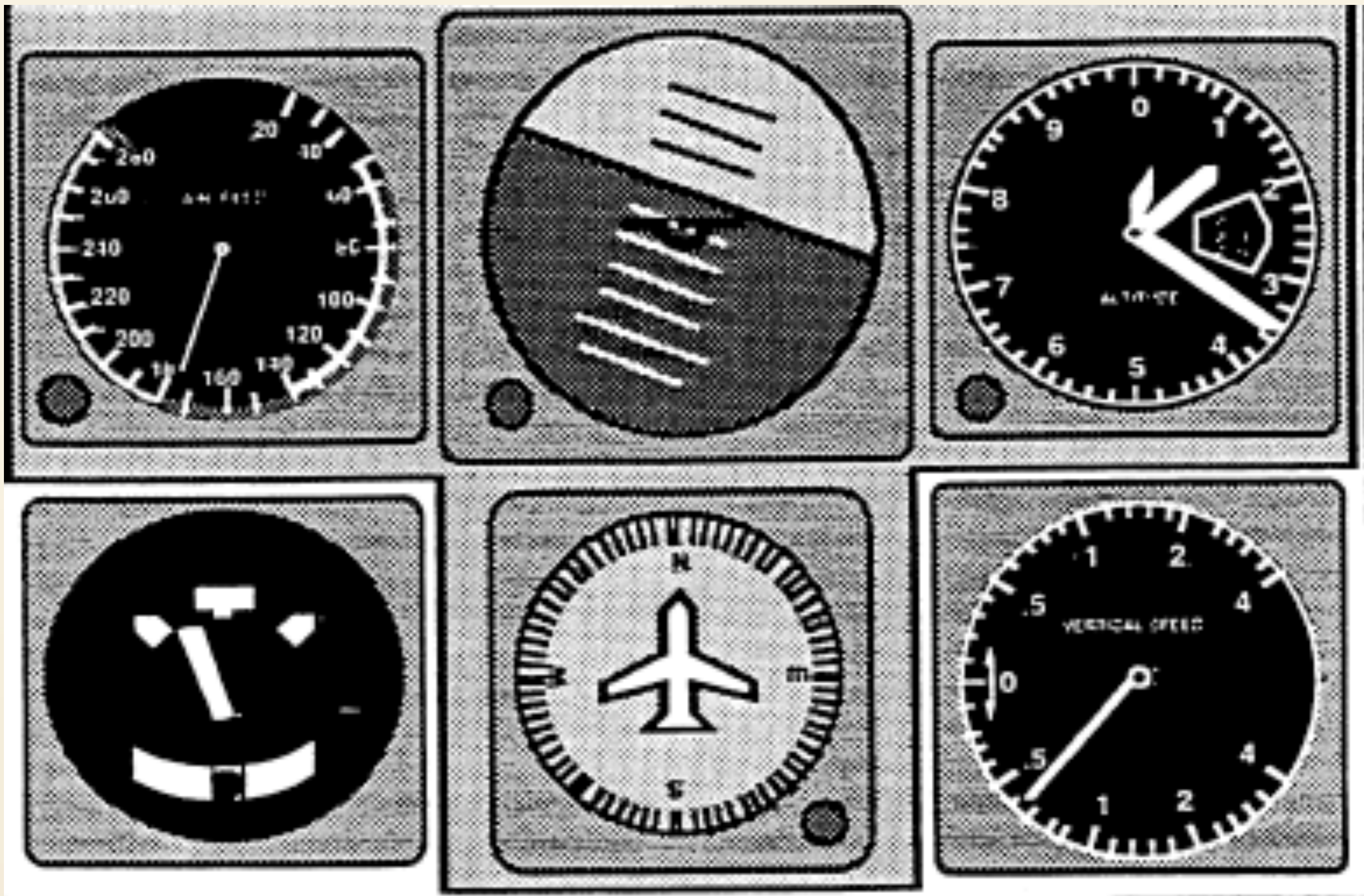
(Endsley, 1988, p. 97)

		Phase	
		Process	**Outcome**
Objective	Tactical (Short-term)	Situation assessment	Situation awareness
	Strategic (Long-term)	Sensemaking	Understanding
		Extrapolation in time	Prediction

Situation Awareness requirements

- Monitor automated systems AND external environment
- Integrate electronic and environment data sources, system information
- Stay ‘in the loop’ – ‘meaningful involvement’ of operators
- Understand automation functioning and be able to predict automation actions
- Make effective decisions through accurate situation assessment
- Maintain patterns of attention when technology changes

Primary Instrument Display



All-in-one Display

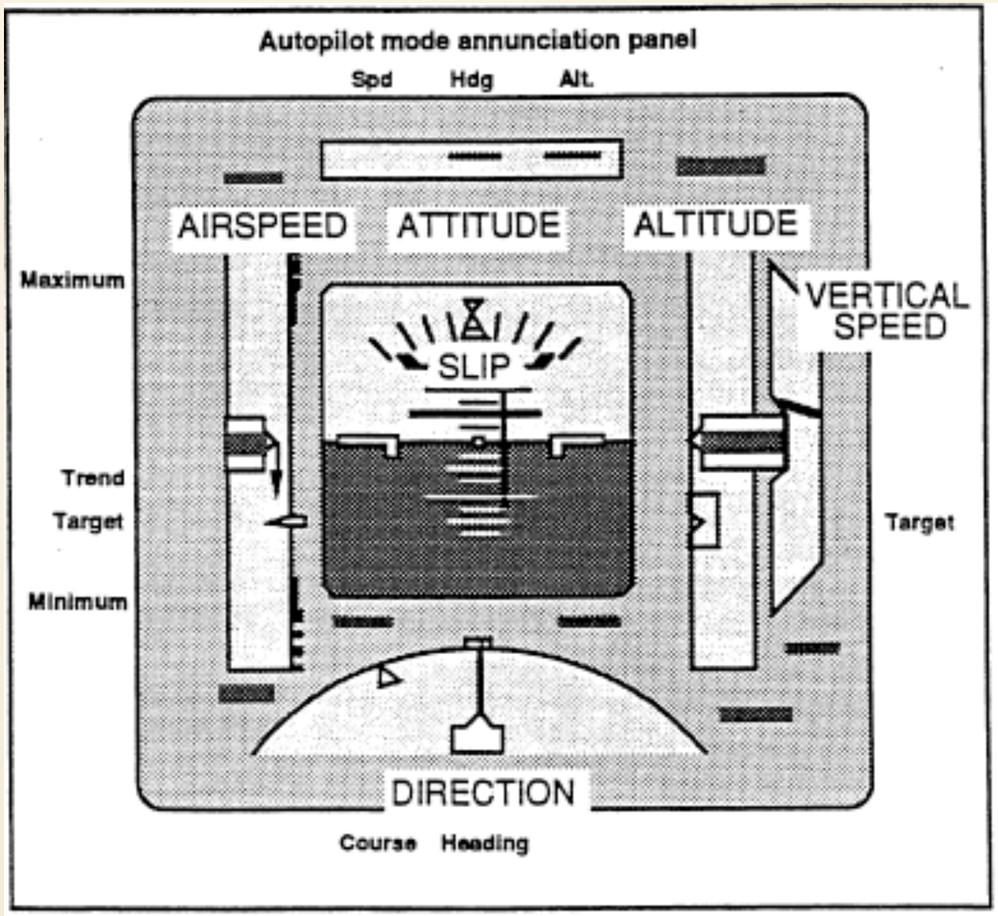
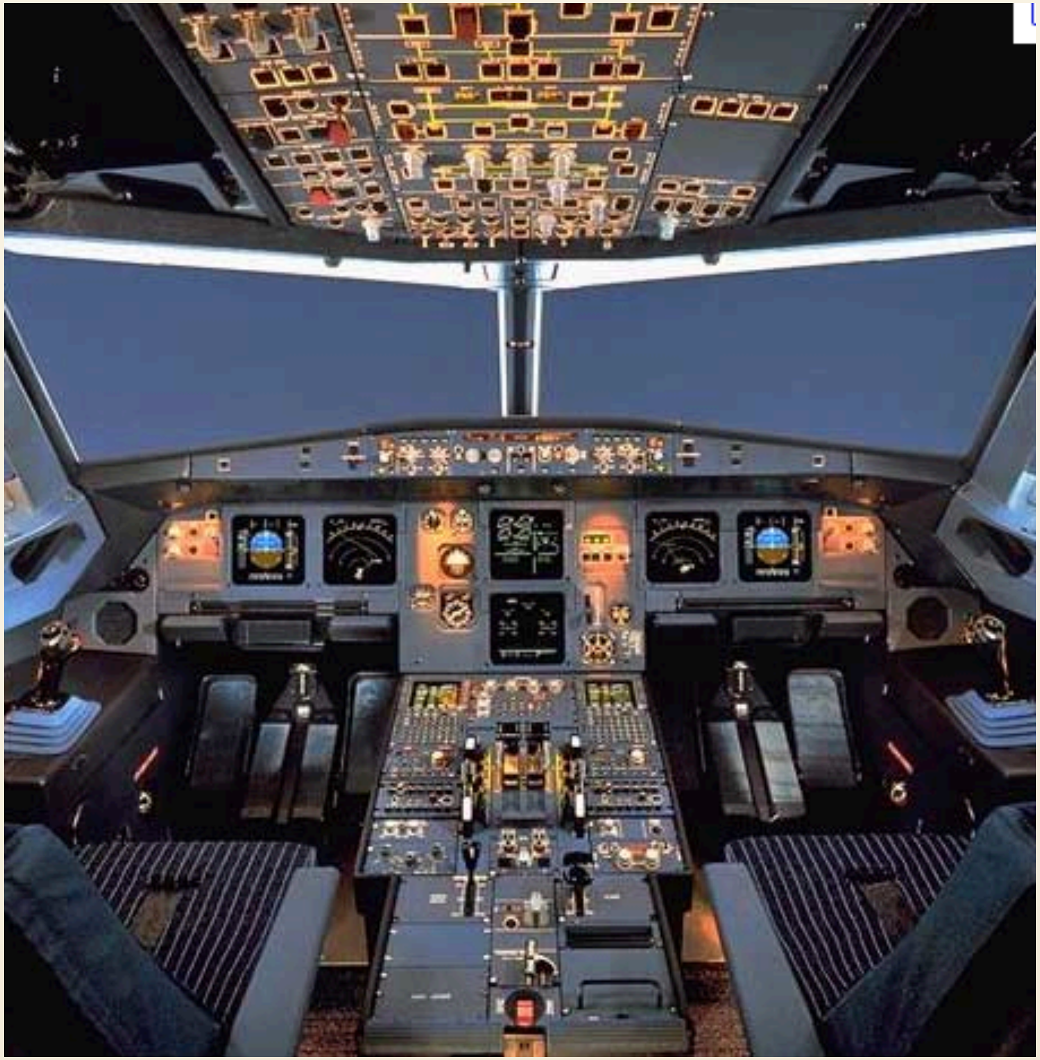


Fig. 3-15: Electronic primary flight display, generic. Note that in general, the "T" arrangement of most essential information has been preserved in this electronic display.



Cognitive Engineering Constructs and Challenges

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Cognitive Engineering Constructs

Cognitive Workload & Mental Effort

- Cognitive engineering domains often involve dynamic operational environments, time pressure, high risk, multiple-task demands – already high in cognitive load
- Paradoxically, automation may increase cognitive workload
- Technology makes abundant information available→ TMI (too much information!)
- Need integration of information – across systems and contexts
- Adaptive and adaptable automation – tailored to context and human state

Cognitive Engineering Constructs

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Cognitive Engineering Constructs

Mental Models

- Automation and displays must facilitate shared accurate mental models of system, situation and task among all team members

  - Integration of information
  - Shared or mirrored displays
  - Alerts for system status or other control changes, or prioritization of tasks and goals
  - Clear signals for transition of tasks/authority between humans and also between humans and automation


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Cognitive Engineering Constructs

New Models of Collaborative Work –

- Human/Human Teams
- Human/Automation Teams
- Remote Multi-Agent Teams


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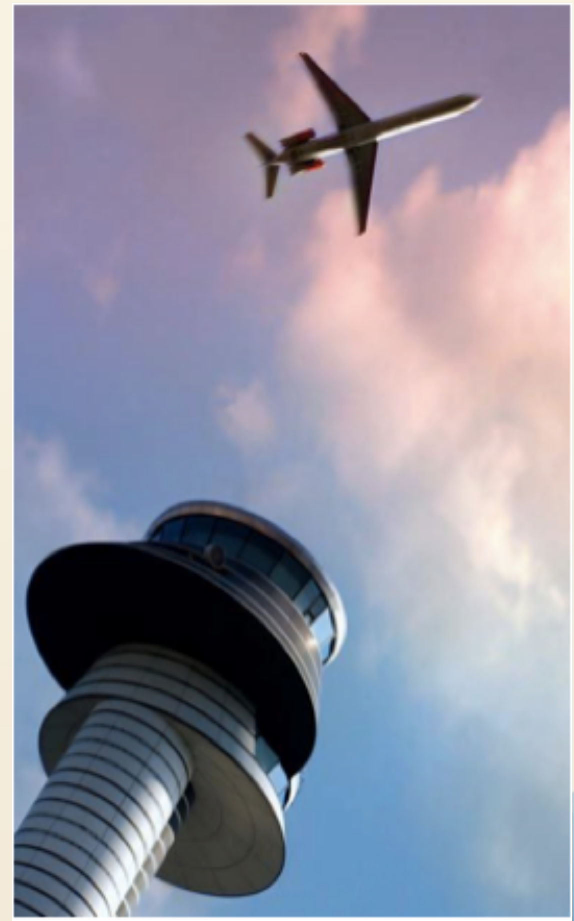
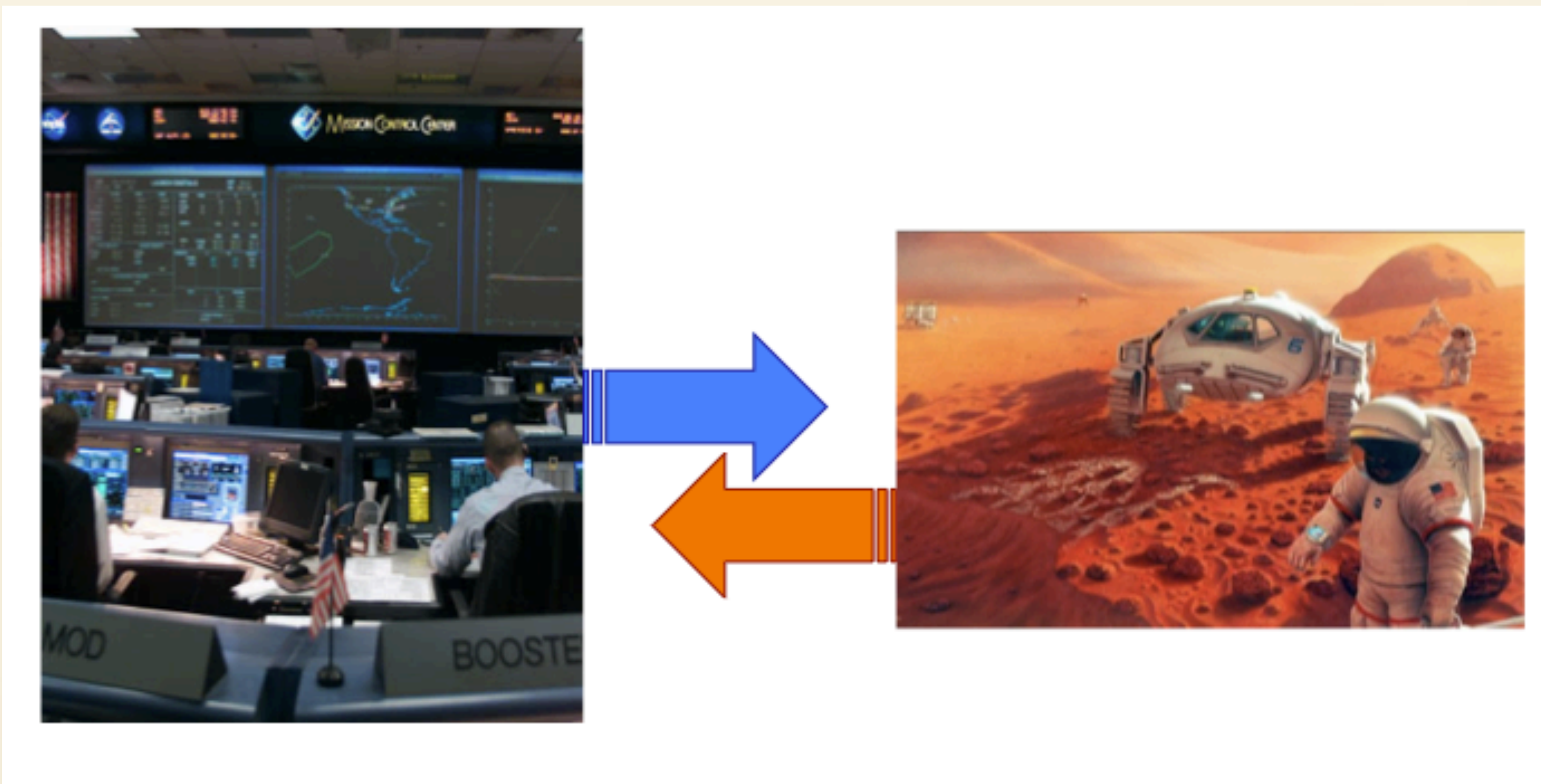
Remote, Multi-Agent Team Collaboration



Remote, Multi-Agent Team Collaboration



Cognitive Engineering Constructs

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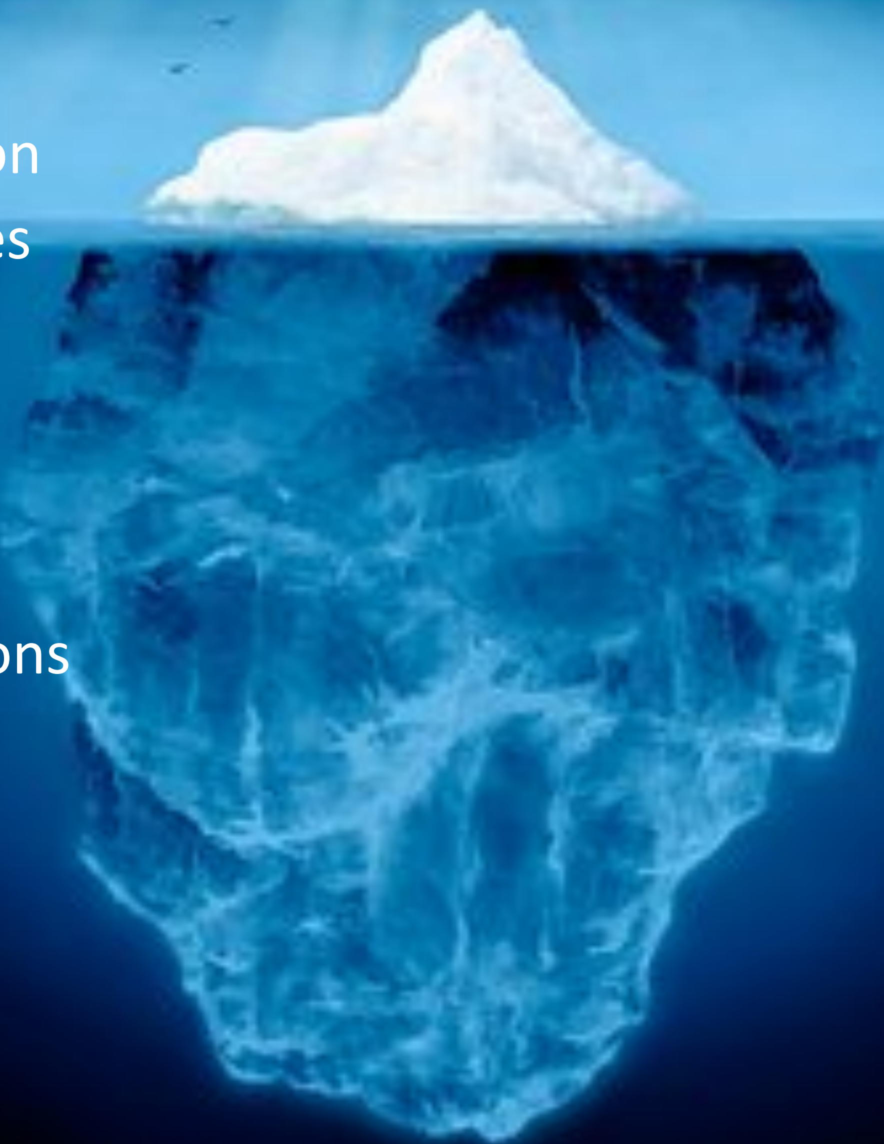
Cognitive Engineering and Decision Making

- End users of human-automation systems are often domain experts – medical personnel, pilots, engineers, fire fighters
- **Naturalistic Decision Making** – experienced decision makers in their domain of expertise
- Experts make decisions differently than non-experts
  - Identification and use of critical cues
  - Repertoire of situations in memory
  - Recognitional, pattern-matching processes
  - Identification of usable path/decision
  - Can't always articulate how they come to a decision

Six Types of Knowledge

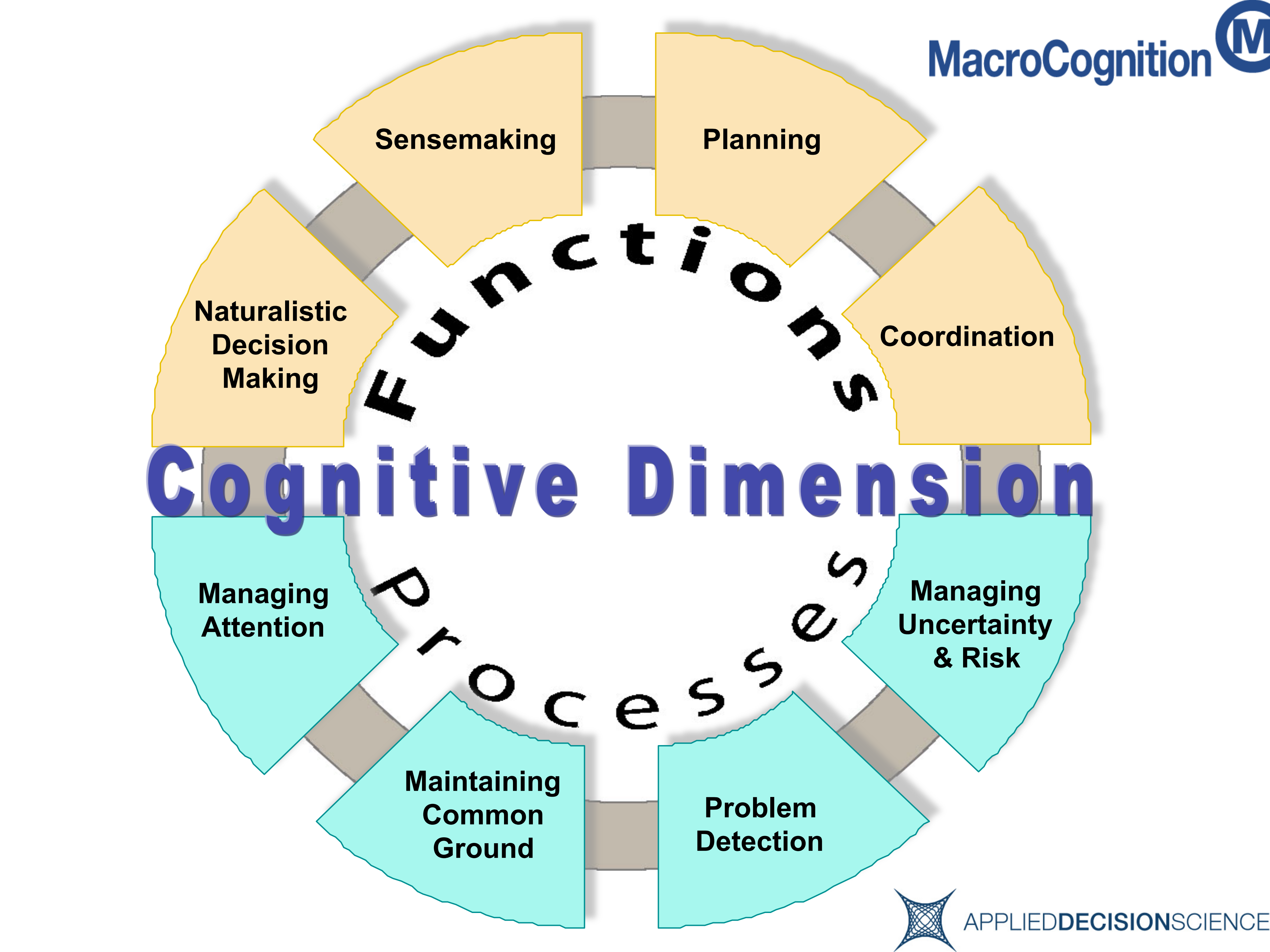


Explicit Knowledge:

1. Declarative information
2. Routines & procedures

Tacit Knowledge:

3. Pattern recognition
4. Perceptual discriminations
5. Mental models
6. Judging typicality


MacroCognition
Sensemaking
Planning
Naturalistic Decision Making
Coordination
Functions
Cognitive Dimension
Processes
Managing Attention
Managing Uncertainty & Risk
Maintaining Common Ground
Problem Detection
APPLIEDDECISIONSCIENCE

Cognition in Context

Get inside the heads of experts and look at the world through their eyes.

Cognitive Task Analysis

CTA is the description of the skills and strategies needed to perform a task proficiently

Knowledge Elicitation

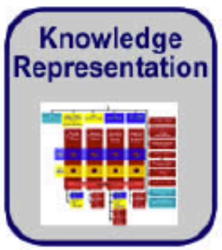
Incident-Based Methods

Interview is grounded in real, lived incident

- Increases accuracy of recall
- Facilitates discussion of context
- Encourages first-person perspective
- Evokes detailed memories

- Critical Decision Method
    - Hoffman, Crandall, Shadbolt, 1998

Components of CTA and Cognitive Engineering



Knowledge Elicitation: Obtaining CTA data via interviews, observations

Data Analysis: Data handling; identify findings; extracting meaning

Knowledge Representation: Data display; presenting findings

Design: Create training, technology, organization

Evaluation: Assessing the impact

Militello, Applied Decision Science

Work-Focused Design

- Accounts for cognitive requirements
- Engages workers effectively
- Maximizes system effectiveness
- Anticipates challenges and risks
- Is resilient to potential errors/failures

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Gracias!

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- Rieger, C.G.; Gertman, D.I.; McQueen, M.A. (May 2009), *Resilient Control Systems: Next Generation Design Research*, Catania, Italy: 2nd IEEE Conference on Human System Interaction
- Sarter & Amamberti, 2000, *Cognitive Engineering in the Aviation Domain*
- Woods & Hollnagel, 2006, *Joint Cognitive systems: Patterns in Cognitive Systems.*

- *Many thanks to Laura Militello, Applied Decision Science, LLC. Cognitive Task Analysis expert*

Resilient Systems

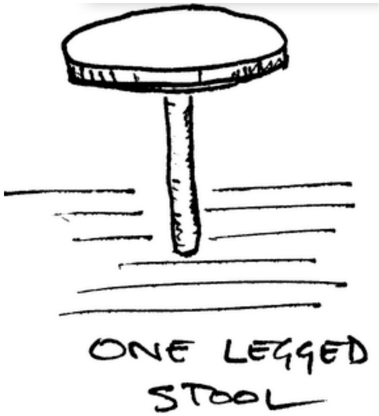
A resilient control system is one that maintains state awareness and an accepted level of operational normalcy in response to disturbances, including threats of an unexpected and malicious nature

Rieger et al, 2009

A system should only be called 'resilient' when it is tuned in such a way that it can utilize its potential abilities, whether engineered features or acquired adaptive abilities, to the utmost extent and in a controlled manner, both in expected and unexpected situations.

Yushi Fujita, IEA President

The Vigilance Problem



The Vigilance Problem

The CDM "Sweeps" Overview

1. Incident identification and selection
2. Timeline verification and decision point identification
3. Deepening; the story behind the story
4. "What if" queries, expert-novice differences, decision errors, etc.