Modeling Cognition in the DoD Architecture Framework for Early Concept Development

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Disclaimer and Acknowledgement

I think I am supposed to put this statement on everything…

The views expressed in this presentation are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States Government.

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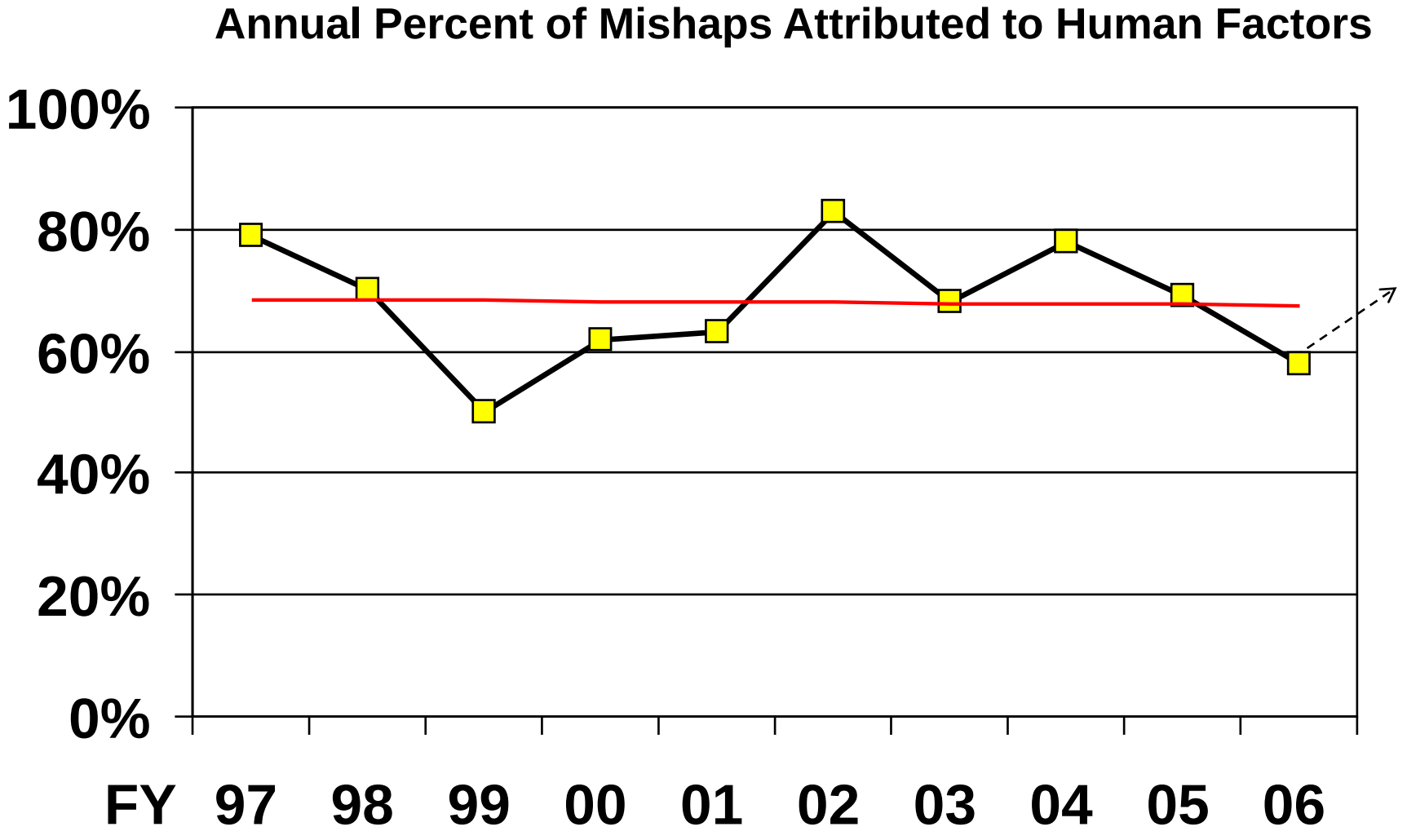
Overview

- **Purpose**: To provide an (interesting) informational brief and facilitate discussion on integrating cognitive task modeling into DoDAF and JCIDS

- **Trends**
- **Problem**
- **Background**
- **Methodology - Integrate Cognition into Early SE**
  - **Why Cognition?**
  - **What Cogition?**
  - **How?**
- **Conclusions**

Historical Baseline: Human factor



Reference: Air Force Safety Center

Human Error in the News

MSNBC.com

Human error causes most Predator crashes

Air Force researcher finds that biggest problem is operator mistakes

The Associated Press

updated 9:09 p.m. ET, Mon., Aug. 25, 2008

MARCH AIR RESERVE BASE, Calif. - As the U.S. military scrambles to get more robotic warplanes like the Predator drone aloft, it is confronting an unexpected adversary: human error.

The drones are prized by the Pentagon for their ability to provide reconnaissance imagery and close-air support to ground commanders in Iraq and Afghanistan.

But an Air Force researcher has found that operator mistakes are responsible for a growing number of Predator mishaps in recent years, a period in which the drones have been flown by increasingly inexperienced crews.

"The Air Force has increased the sheer volume of pilots put through the training pipeline and shipped them off to war with the bare minimum training required," researcher Lt. Col. Robert P. Herz said in an e-mail.

Herz investigated the Predator's record earlier this year in a doctoral dissertation that has circulated among military planners and safety experts. He provided a copy of the research to The Associated Press.

The military can continuously operate 29 of the Predator and Reaper surveillance planes, which are flown by remote control from the United States. Each crew consists of a pilot, who is an officer, and a sensor operator, who is an enlisted airman responsible for running the plane's cameras and weapons.

Seven Predators have been destroyed this year, all in combat zones. The causes are still under investigation.

In the last few years, the number of "Class A mishaps" — those resulting in $1 million or more in damage — has generally been between four and six.

The planes cost about $4 million each.

Predator operators in high demand

Early in the Predator program, most crashes were blamed on equipment breakdowns, many of which have now been resolved. Herz found that 71 percent of Predator mishaps from 2003 to 2006 could be attributed to "human error factors."

Operator error periodically causes the drones to go down behind enemy lines, where fighters must then bomb them so prized technology does not fall into the wrong hands. Other times, the planes slam onto runways, damaging optics and landing gear. On rare occasions, pilots bank the aircraft so steeply that the drones briefly lose contact with the satellite feeding them commands.

Herz's findings come at a time when the military relies more than ever on remote-controlled warplanes.

Federal funding for unmanned aerial vehicles has increased from $3 billion in the 1990s to more than $12 billion through 2009, according to Herz, who completed the dissertation earlier this year at Northcentral University in Prescott Valley, Ariz., where he studied for a doctorate in business administration with a concentration aerospace operations.

Damian Dovarganes / AP

Research shows that most Predator mishaps are the result of inadequate skills, lack of teamwork and lack of situational awareness.

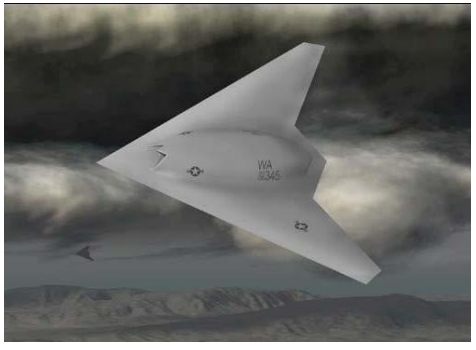
Could this have been reduced by better SE?

Operational Trends

- **Increased demands on operators**
  - New missions, CONOPS, tactics
  - Increased volume/rate of information
  - Manpower Reductions
- **Changing human roles**
  - Increased vehicle autonomy
  - Control of multiple platforms
  - Multi-mission tasking

Multi-mission tasking

Re-configurable work stations



Single operator control of multiple vehicles

Mission management of manned and unmanned systems

Highly automated processes

Supervisory control

Reference: Air Force HSI Office

Human Systems Integration (HSI) in Systems Engineering

- Air Force Human Systems Integration (HSI) Office
- Increased HSI emphasis in SE Societies
  - INCOSE 2009 theme is *The Human Dimension to Systems Engineering*
    INSIGHT Jan 2008 Themed Issue, Active INCOSE HSI Working Group
  - NDIA: Systems Safety-ESOH & HSI track this year at this conference
- National Research Council of the National Academies – *Human System Integration in the Systems Development Process*, 2007
  - Better "shared representations"
  - Better Methods and Tools
  - Full integration of Human Systems with SE

Problem Statement

Complex, socio-technical systems do not effectively consider human capabilities and needs early and throughout the system design and development process

How to better address Humans in System Design?

Where can it also be best integrated into DoD capability and acquisition processes?

Human Systems Integration

-- Interdisciplinary technical and management processes for integrating human considerations within and across all system elements

Systems Engineering

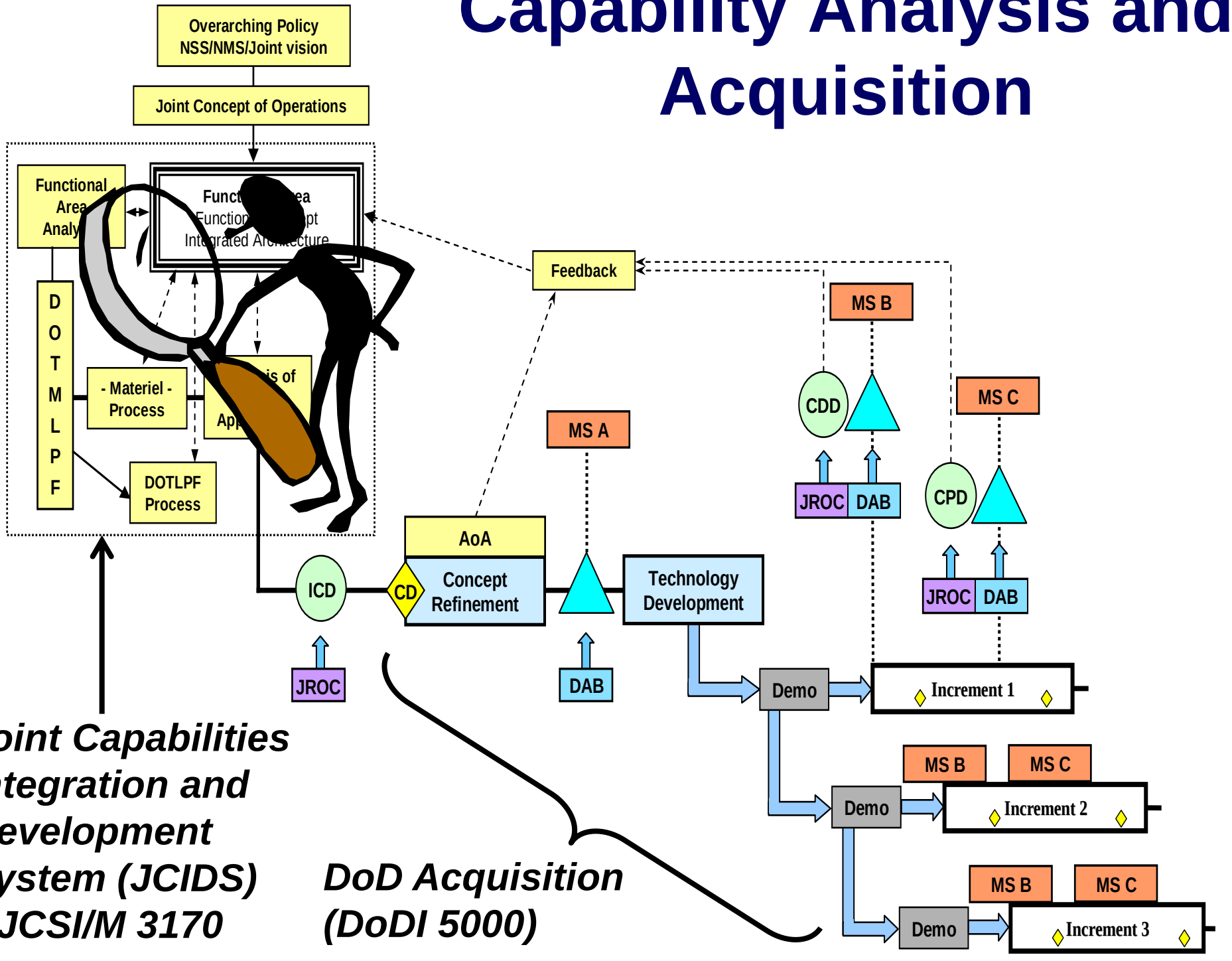
-Technical Processes

-Technical Management Processes

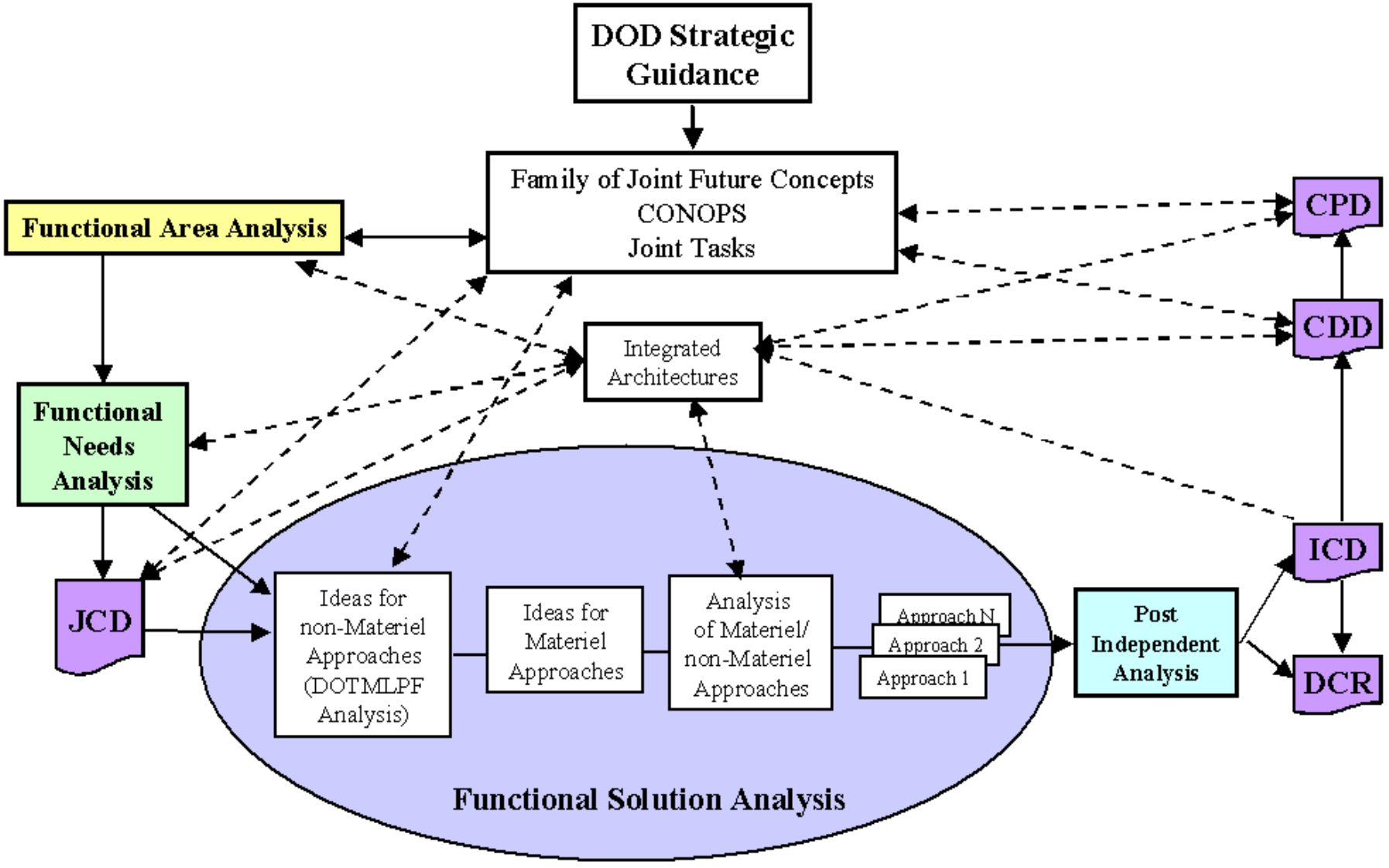
- Domain knowledge

…an essential enabler to systems engineering

Capability Analysis and Acquisition

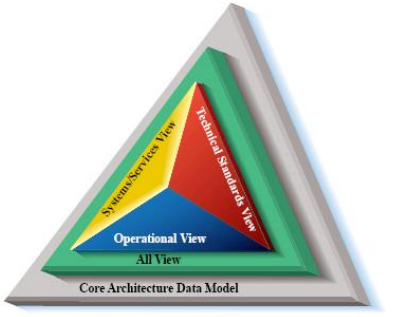


JCIDS Analysis and Documents



DoD Architecture Framework (DoDAF) Version 1.5

- DoDAF - No mention of Human Systems Integration, Human Factors or Cognition



- Sparse placeholders
  - OV-2 Operational nodes *can* be Human Roles
  - OV-4 primarily Organizations, but *can* be Human Roles
  - OV-5 *can* represent human tasks and activities
  - OV-6a *can* define business rules/ conditions for human tasks
  - OV-6b humans *could* cause operational state transitions
  - SV-1 *can* show Human systems and Human-Computer I/F
  - SV-4 *can* show Human functions

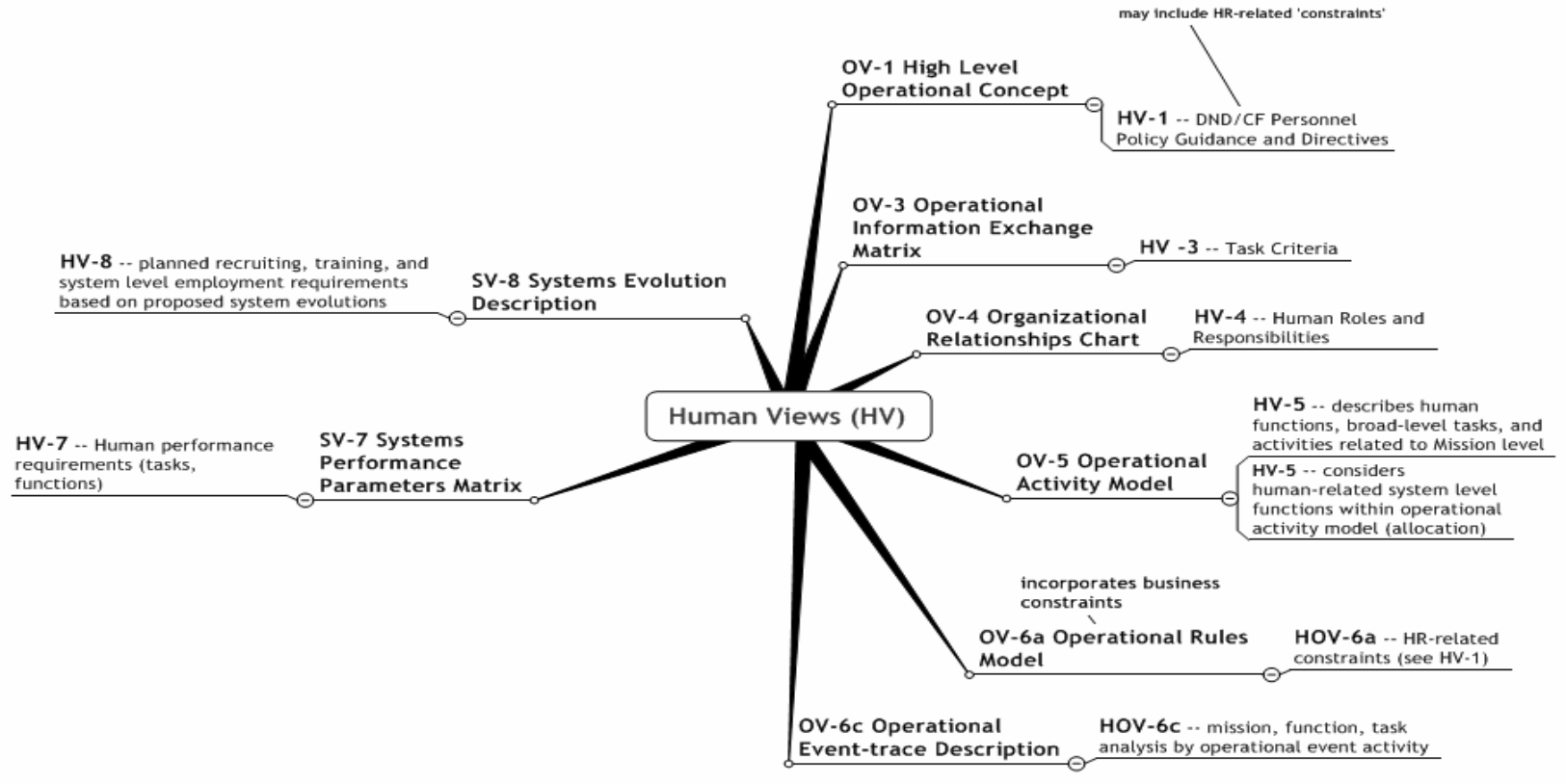
Greenley & Associates

- DoDAF does not adequately address the human aspect of capability engineering
  - Cannot provide HR organizations the ability to identify the impact of new projects to specific personnel issues
  - Cannot identify whether the new project under development will require new skills, knowledge or competencies
  - Cannot model areas where fiscal constraints may impact the ability to provide adequate personnel to fill new positions
  - Does not permit human characteristics and performance information to be integrated into the system definition, design, development or evaluation.
- As a result, the human-machine interface is not optimized for task and capability performance

Baker, Kevin and others. “Human Views: Addressing the Human Element of Capability-Based Decisions.” Excerpt from unpublished article. http://www.dsto.defence.gov.au. 30 January 2008.

Propose new Human Views

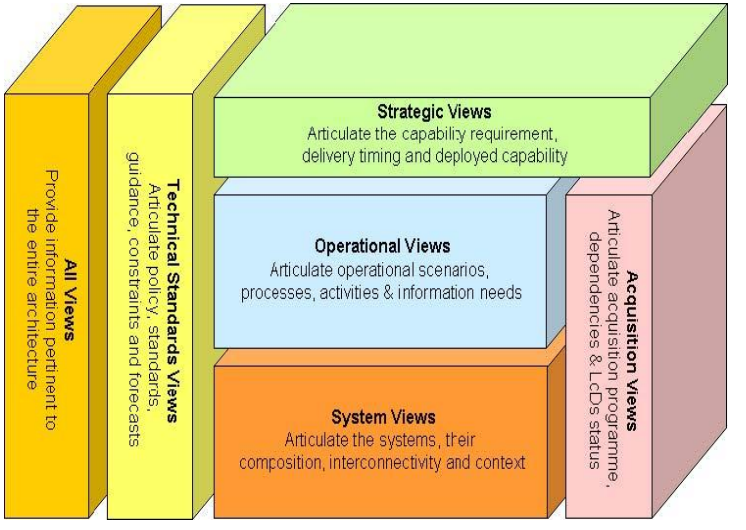
- Approach – New HV products need to demonstrate the human role within the system, and identify the impacts on human performance



Baker, Kevin and others. "Human Views: Addressing the Human Element of Capability-Based Decisions." Excerpt from unpublished article. http://www.dsto.defence.gov.au. 30 January 2008.

Ministry of Defense Architecture Framework (MoDAF) Ver 1.1

- MoDAF developed from DoDAF Version 1.0
- Version 1.1 added human factors to the SVs
  - SV-1 explicitly shows organizations, posts and roles
  - SV-4 is simply the Functionality Description
    - Functions in the SV-4 can be conducted by Roles (human), Systems (machines), or combinations
  - SV-9 renamed the Technology and *Skills* Forecast
    - The skills forecast describes current and future skills
    - Can be used to provide human resource trend analysis and personnel recruitment planning
    - Gain insight into MPT decisions



Propose new Human Views

- Dr. Bruseberg, human factors consultant to the MoD
- Existing MODAF Views are inadequate in capturing critical human factors concerns
- Recommends 7 new Human Views to MODAF
  - HV-A: Personnel Availability
  - HV-B: Quality Objectives and Metrics
  - HV-C: Human Interaction Structure
  - HV-D: Organization
  - HV-E: Human Functions and Tasks
  - HV-F: Roles and Competencies
  - HV-G: Dynamic Drivers of Human Behavior

Bruseberg, Anne. "Applying the Human Views for MODAF to the conception of energy-saving work solutions," *INCOSE 2008: Systems Engineering for the Planet. 2008.*
Bruseberg, Ann and Lintern, G. "Human factors integration for MODAF: Needs and solution approaches," *INCOSE 2007: System Engineering, Key to Intelligent Enterprises. 2007.*

Method

- Examine DoDAF in the JCIDS context
- Functional Area Analysis
  - Early concept formulation
  - Forecast operator tasks, needs and requirements
  - Functional/ task analysis with measures
- Functional Needs Analysis
  - Quantifiable capability gaps (DOTLPF)
- Functional Solutions Analysis
  - Better understand automation / human function allocation
  - Specific Manpower, Personnel and Training implications

Human Factors

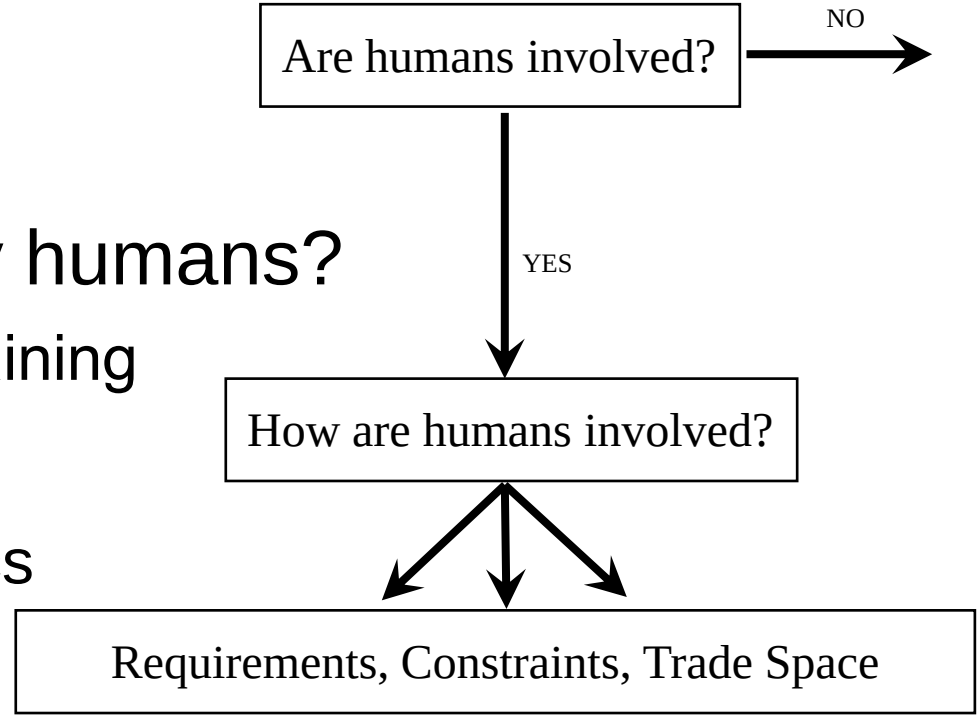
- Human Factors - One of the 9 elements of HSI
  - Highly related to Manpower, Personnel and Training (MPT)
- Focuses on the unique characteristics and system design limitations that humans share
- Three primary areas
  - **Cognitive**
  - Physical
  - Sensory

Cognition

- Webster's: *the act of knowing; knowledge, perception*
- Much research in cognition place emphasizes on "how" and "why" internal to the human brain
- Systems Engineering needs a "Black Box" approach
  - Creates focus on information that crosses boundaries
    - Inputs, Triggers (controls) and Outputs
    - Internal mechanics of the activity remain hidden
  - More applicable to DoDAF
    - Provides concrete method for modeling
    - Permits direct traceability to design decisions

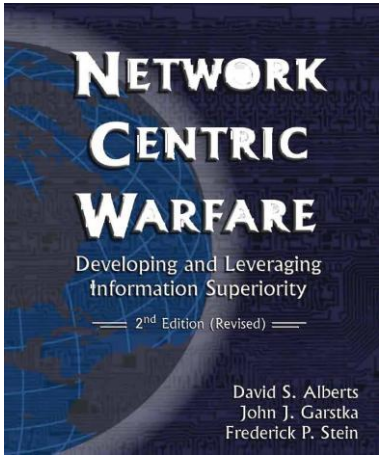
Why Cognition?

- Provides base rationale for human involvement in the system design
- Will humans be a part of this system as External Actors, Detached Participants, Direct Participants?
- Why humans?
  - Cognition
- What type and how many humans?
  - Manpower, Personnel… training
- Where Humans?
  - Human Factors/ Ergonomics
  - Environment



Why Cognitive?

One Domain in Net-Centric Operations



Physical Domain
where strike, protect, and maneuver take place across different environments

Information Domain
where information is created, manipulated and shared

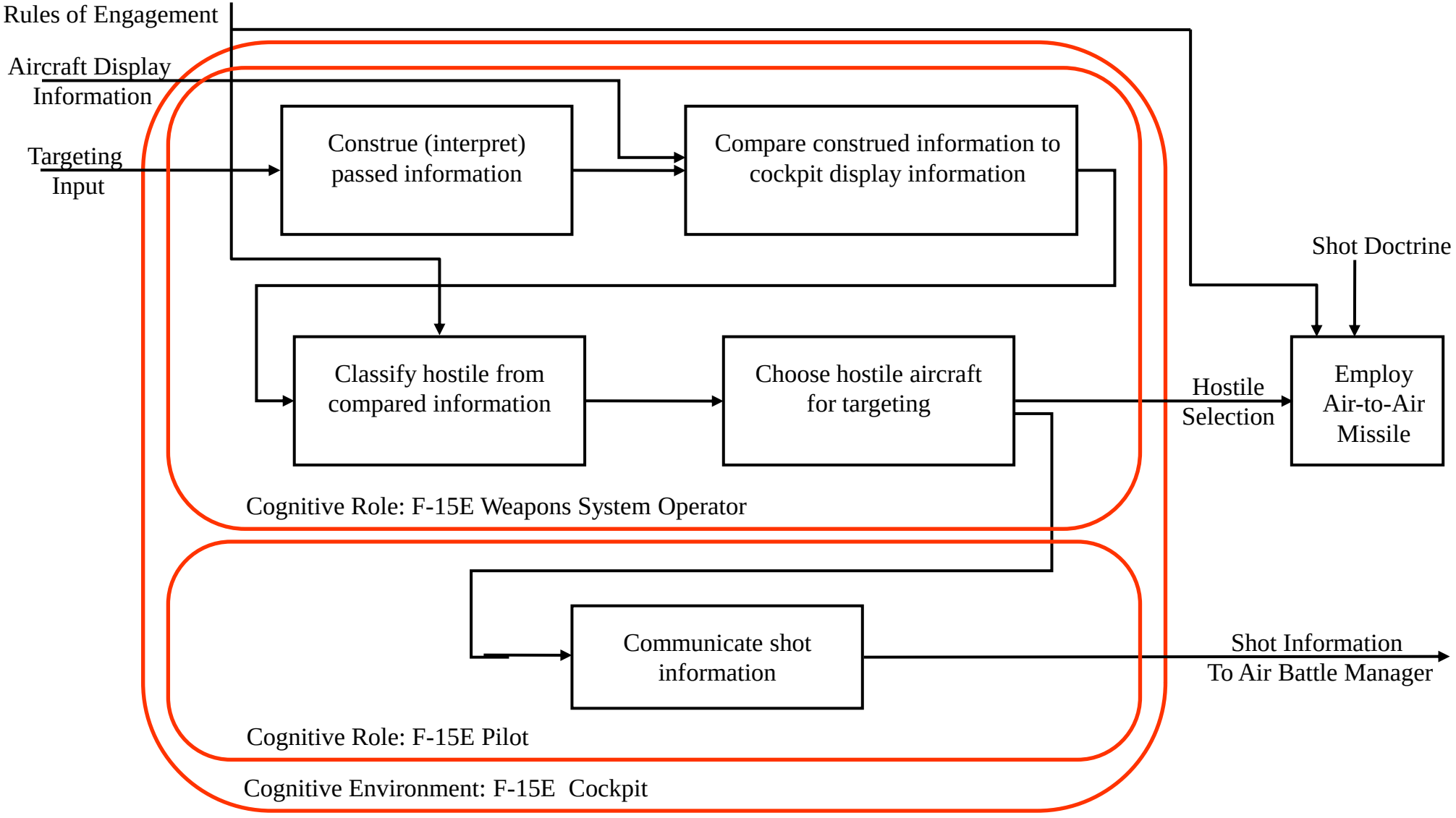
Cognitive Domain
where perceptions, awareness, beliefs, and values reside and where, as a result of sensemaking, decisions are made

Social Domain
where force entities interact

Cognitive SE Model

1. **Cognitive Activities / Tasks**
   - Functions that are accomplished through human cognition
   - HSI “Manpower, Personnel”
2. **Cognitive Input**
   - Input into a activity / task / function resulting from a cognitive action
   - HSI “Human Factors”
3. **Cognitive Output**
   - Specific output resulting from cognitive action
   - HSI “Human Factors”
4. **Cognitive Roles**
   - Human roles that accomplish cognitive activities within a joint cognitive system
   - HSI “Manpower, Personnel”
5. **Cognitive Environment**
   - Where we expect the human(s) to accomplish the activities
   - HSI “Environment”

Integrating the Model Artifacts Example: F-15E Targeting



Starting Point – List of Cognitive Tasks

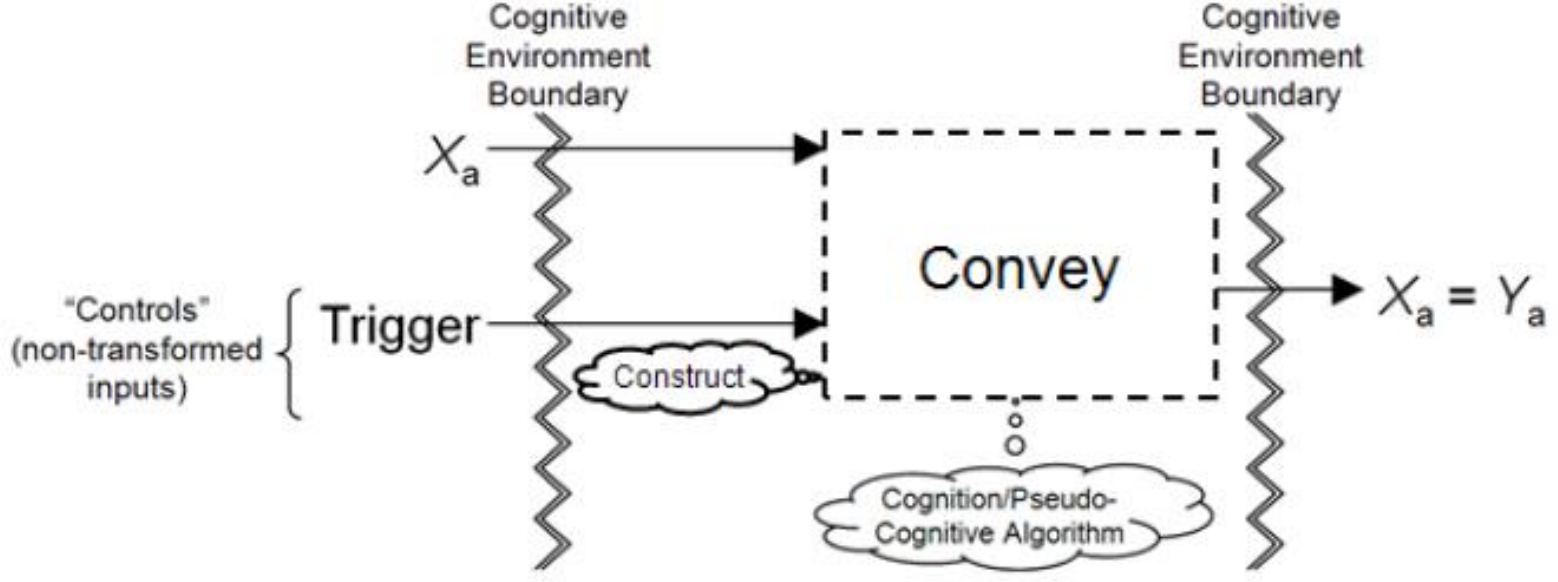
- Abduce
- Acquire
- Aggregate
- Anticipate
- Assign
- Choose
- Classify
- Communicate
- Compare
- Conceive
- Decide
- Deduce
- Derive
- Describe
- Detect
- Discriminate
- Estimate
- Evaluate
- Generate
- Induce
- Integrate
- Identify
- Interpret
- Judge
- Match
- Monitor
- Perceive
- Plan
- Prioritize
- Reason
- Recognize
- Remember
- Verify
- Adapt
- Analyze
- Categorize
- Characterize
- Construe
- Control
- Convey
- Recall
- Create
- Edit
- Filter
- Infer
- Locate
- Purge
- Read
- Test
- **Etc, etc, etc**

Cognitive Task Types

- Need to define the domain for “Type”
- Building Blocks(“Eigenfunctions”)
  - Eight fundamental Cognitive/Pseudo Cognitive (CPC) tasks
  - All other CPC tasks can be built from combinations of the fundamental tasks
  - Two categories
    - Translation (1)
    - Transformation (7)
  - Provides a definition of “Cognitive/Pseudo-Cognitive”
    - Inputs are sets of information
    - Controls include cognitive construct, cognitive triggers, and attribute/relationship tensors
    - Outputs are sets of information, attributes and/or relationship tensors

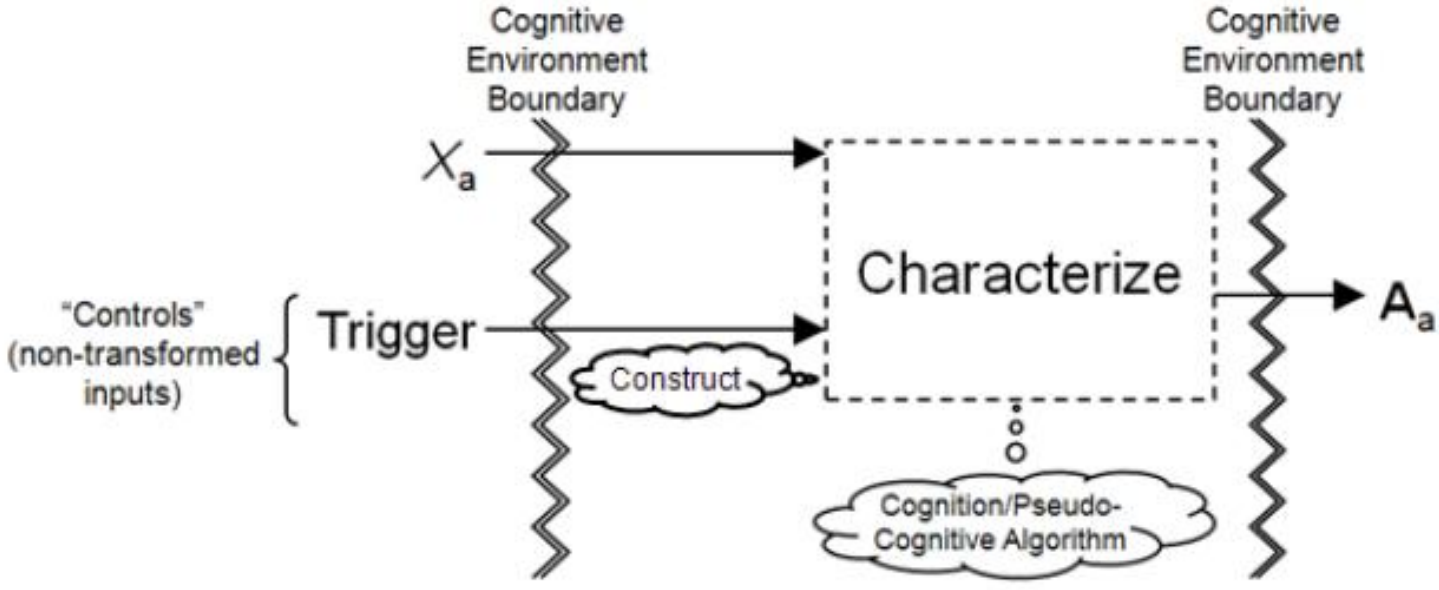
Activity Type Domain

- 8 Cognitive Tasks
  - Translations: Convey (Call/Recall)
  - Transformations: Classify, Characterize, Choose, Combine, Compare, Create, Construe
- Example: Convey



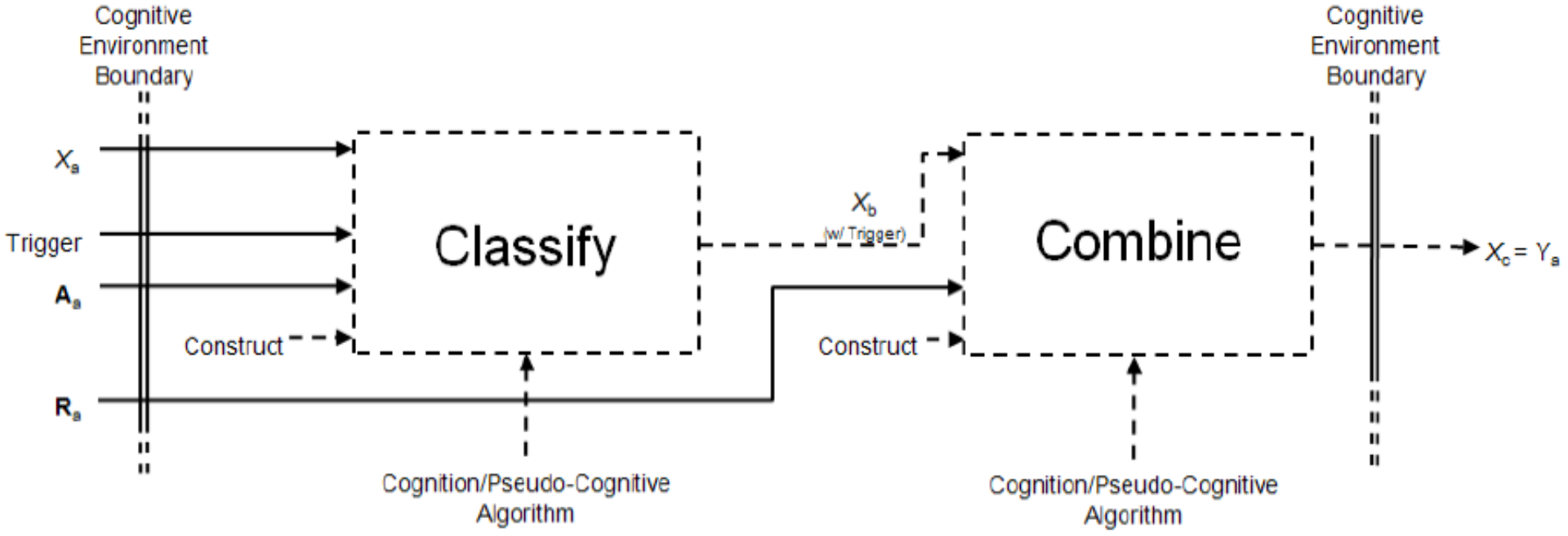
Activity Type Domain

- Example: Characterize



Activity Type Domain

Example: Prioritize (compound) = Classify + Combine

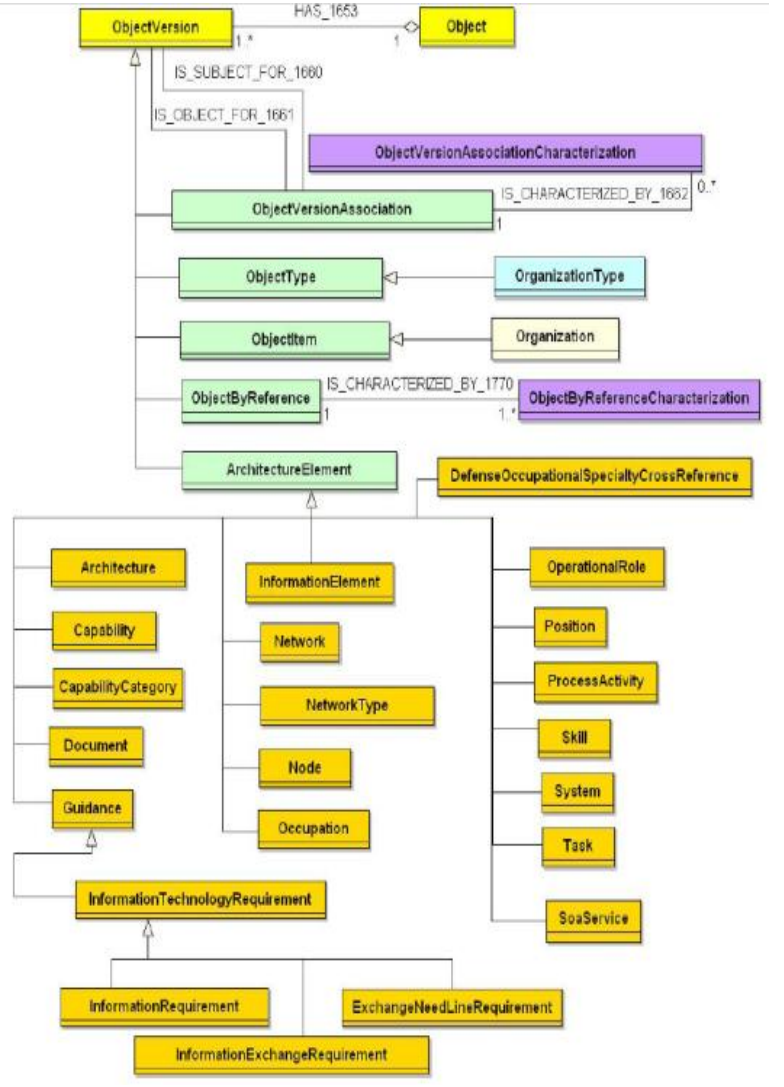


8 Elemental Cognitive Tasks

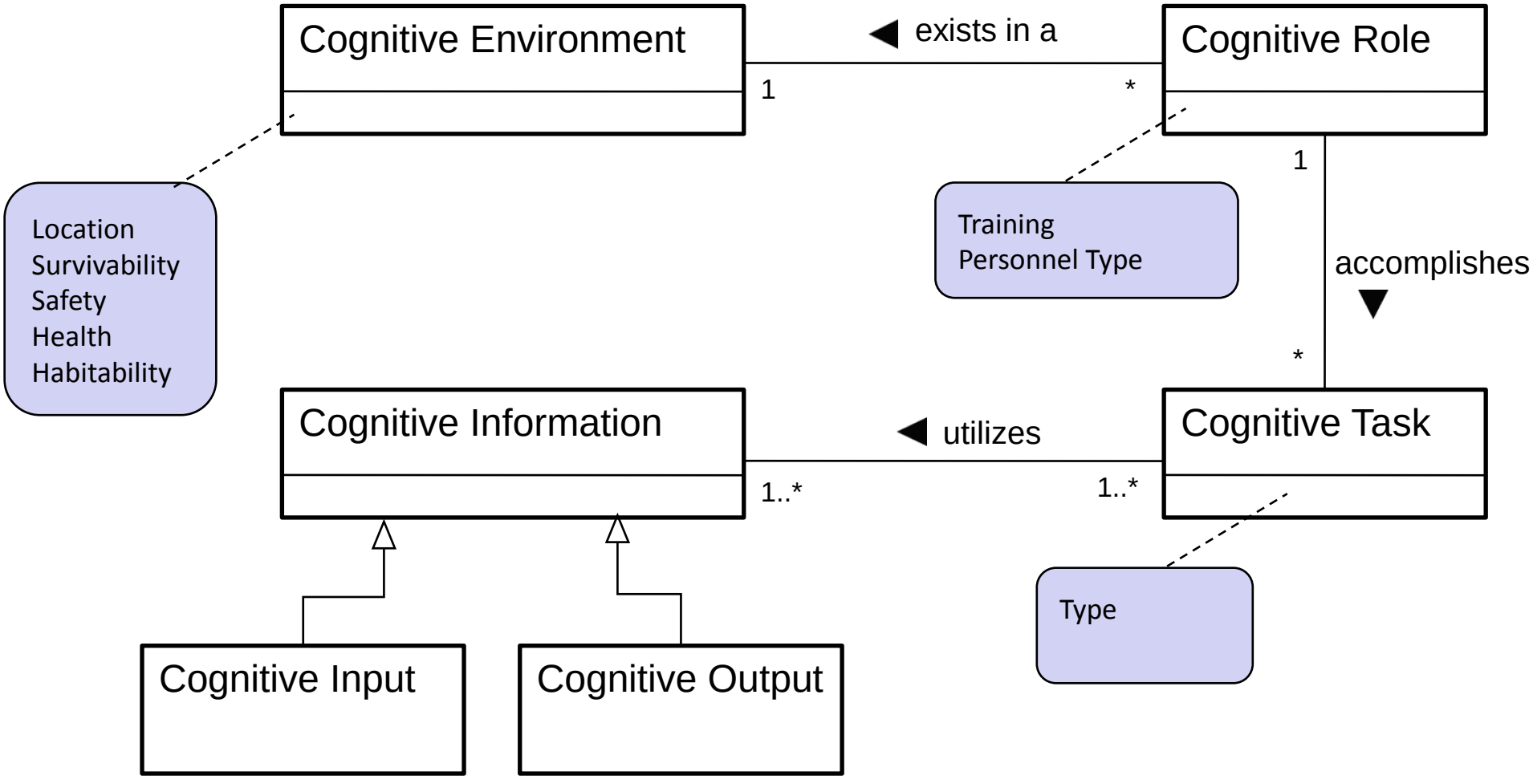
Cognitive Task Type Label		Description	Definition		
			Inputs		Outputs
			Primary	"Controls" (includes "*Construct*" & "*Trigger*")	
Trans - lation	Convey (ReCall)	to translate a set of information through space-time from one spatial and/or temporal location to another without transforming the information	X_a	Ø, $\mathbf{A}_a$, or $\mathbf{R}_a$	X_a
Transformations	Classify	to group objects within a given set of information according to a given set of attributes with values/ranges	X_a	$\mathbf{A}_a$	$G_i(\mathbf{A}_i) = X_b$ (where $X_b \subseteq X_a$)
	Characterize	to determine a set of attributes with values/ranges from a given set of attributes with values/ranges, or of a given set of information	Ø or X_a	Ø or $\mathbf{A}_a$	$\mathbf{A}_a$
	Choose	to select a subset of a set of information based on a given set of relationships between the objects within the given set of information	X_a	Ø or $\mathbf{R}_a$	X_b (where $X_b \subseteq X_a$)
	Combine (Calculate)	to transform a given set of information based on a given set of relationships between the objects within the given set of information or between the given and transformed sets of information	X_a	$\mathbf{R}_a$	X_b
	Compare	to determine a set of relationships between the objects/subsets of a given set of information	X_a		$\mathbf{R}_a$
	Create	to generate a set of information from nothing, or from a given set of attributes with values/ranges and/or a template set of information	Ø or X_a	Ø or $\mathbf{A}$--$_a$	X_b, $\mathbf{A}_b$, or $\mathbf{R}_b$
	Construe (Interpret)	to generate a set of information which is the interpretation or meaning of a given set of information	X_a	Ø or $\mathbf{R}_a$	$M_i(X_a) = X_b$

Core Architecture Data Model

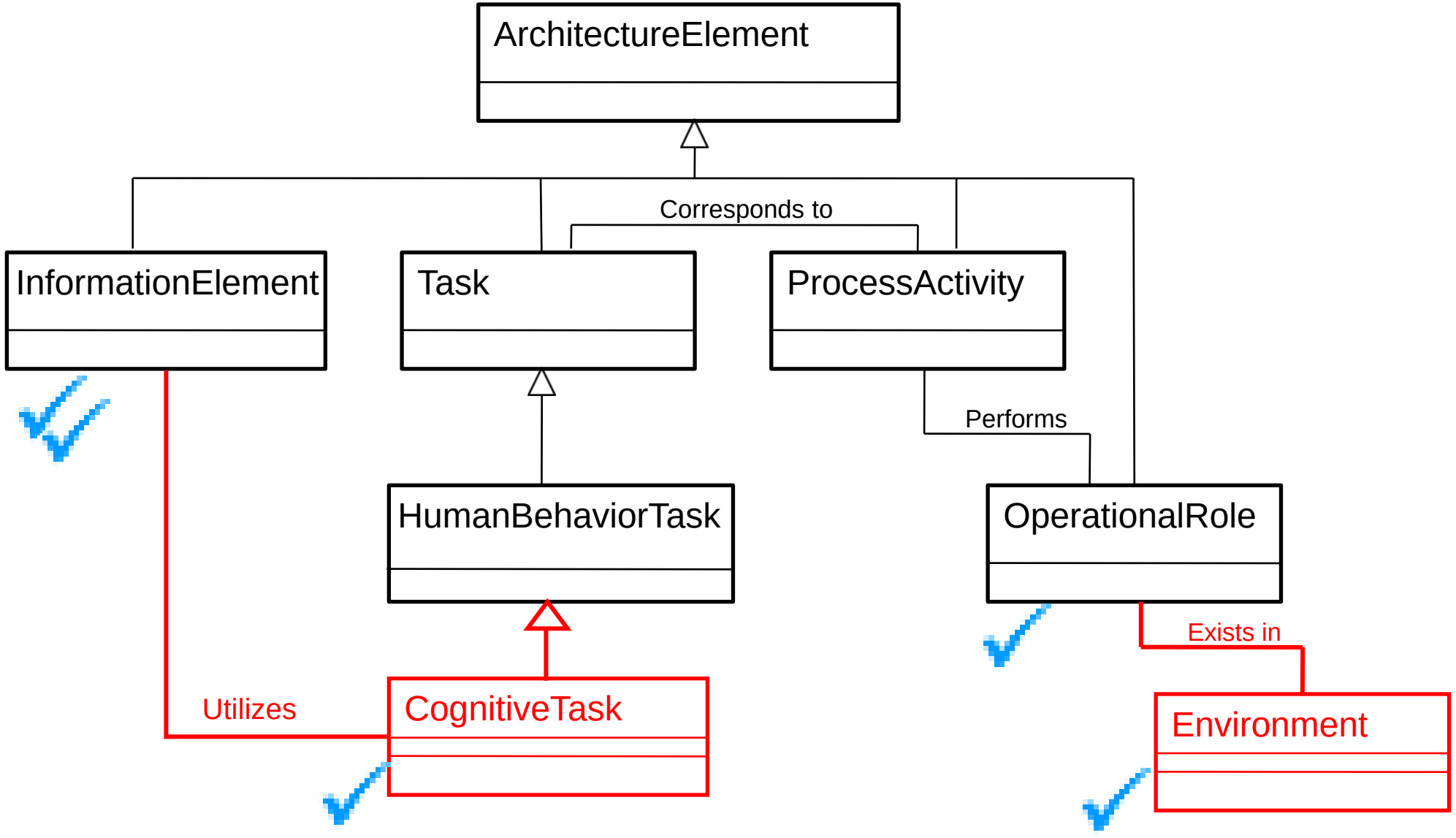
- Foundation of DoDAF!
  - Ver1.5 focus is “data-centric”
- Created with specific data elements, attributes and relationships
  - Task,
  - Node, Information,
  - Performance,
  - Function, Interface, System, …



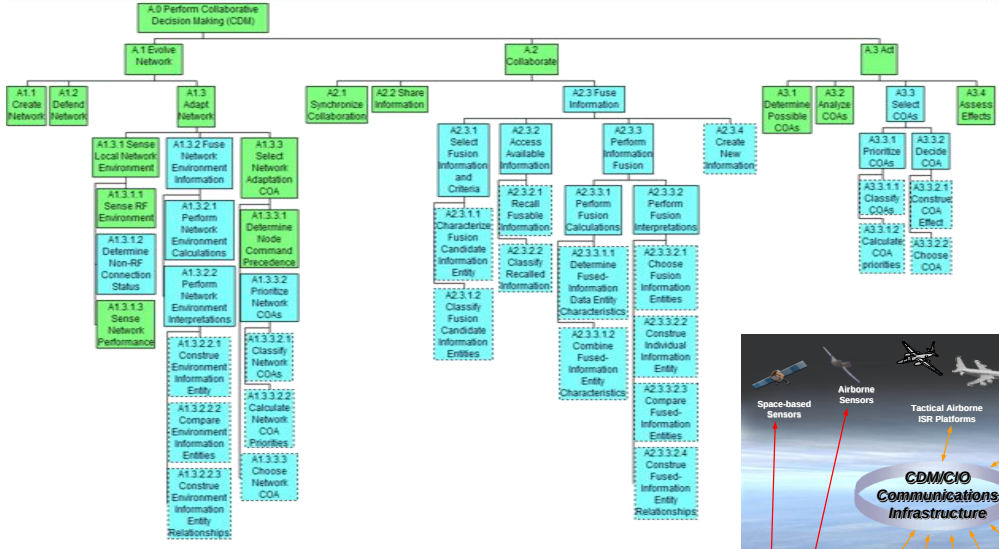
Cognitive Model - Class Diagram

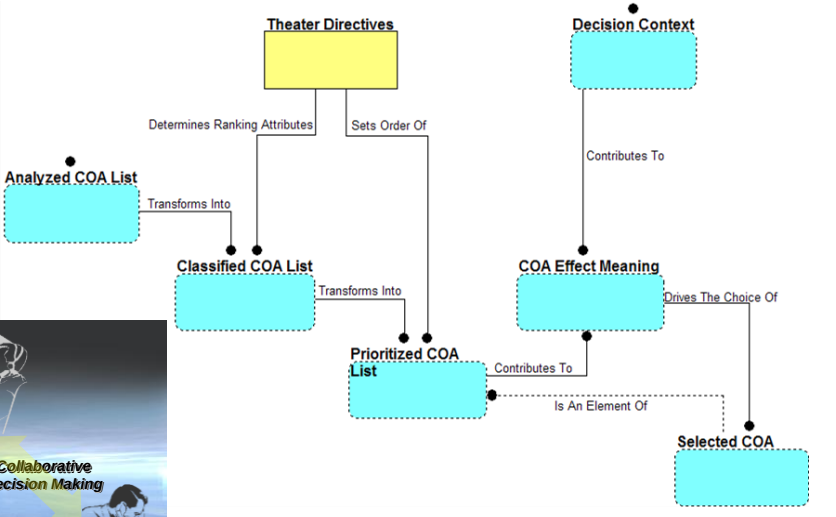


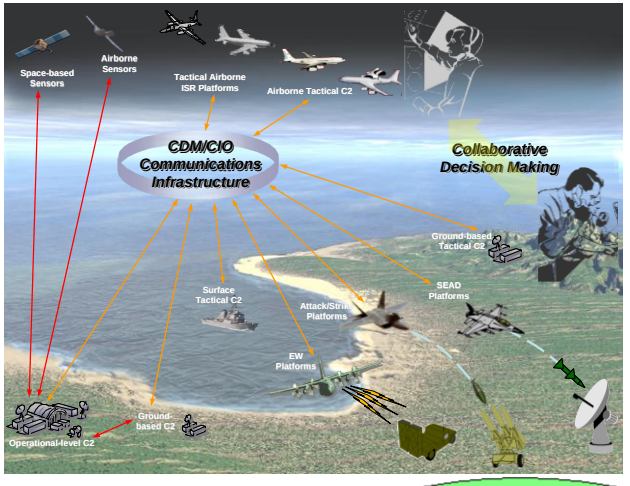
CADM 1.5 Extended

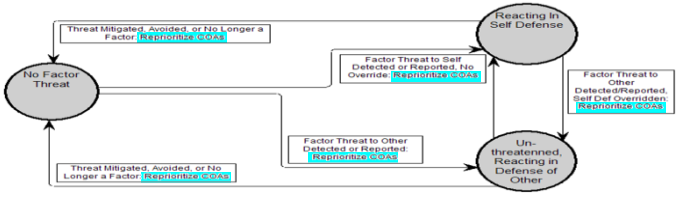


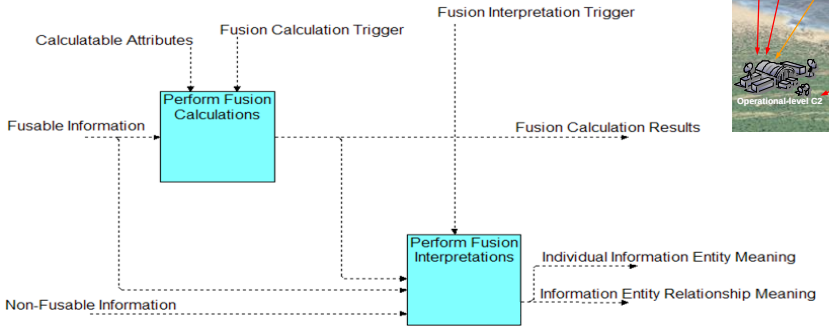
Examine a Distributed, Collaborative Decision Aiding System

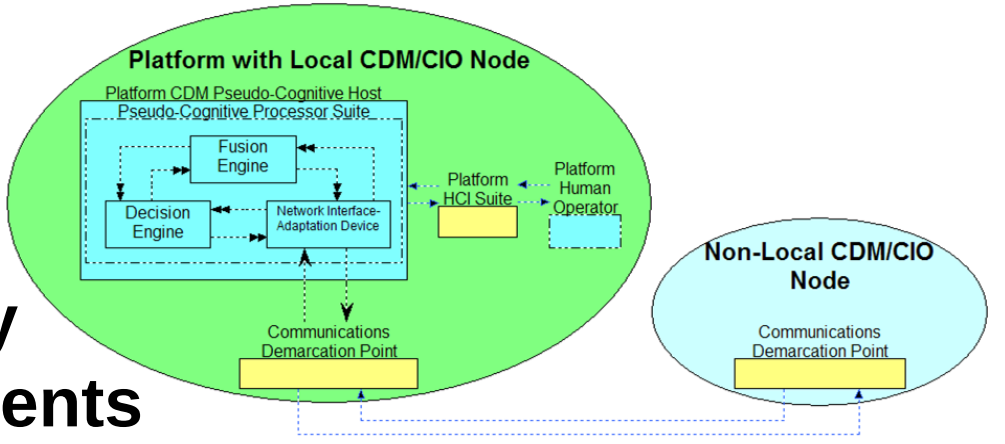










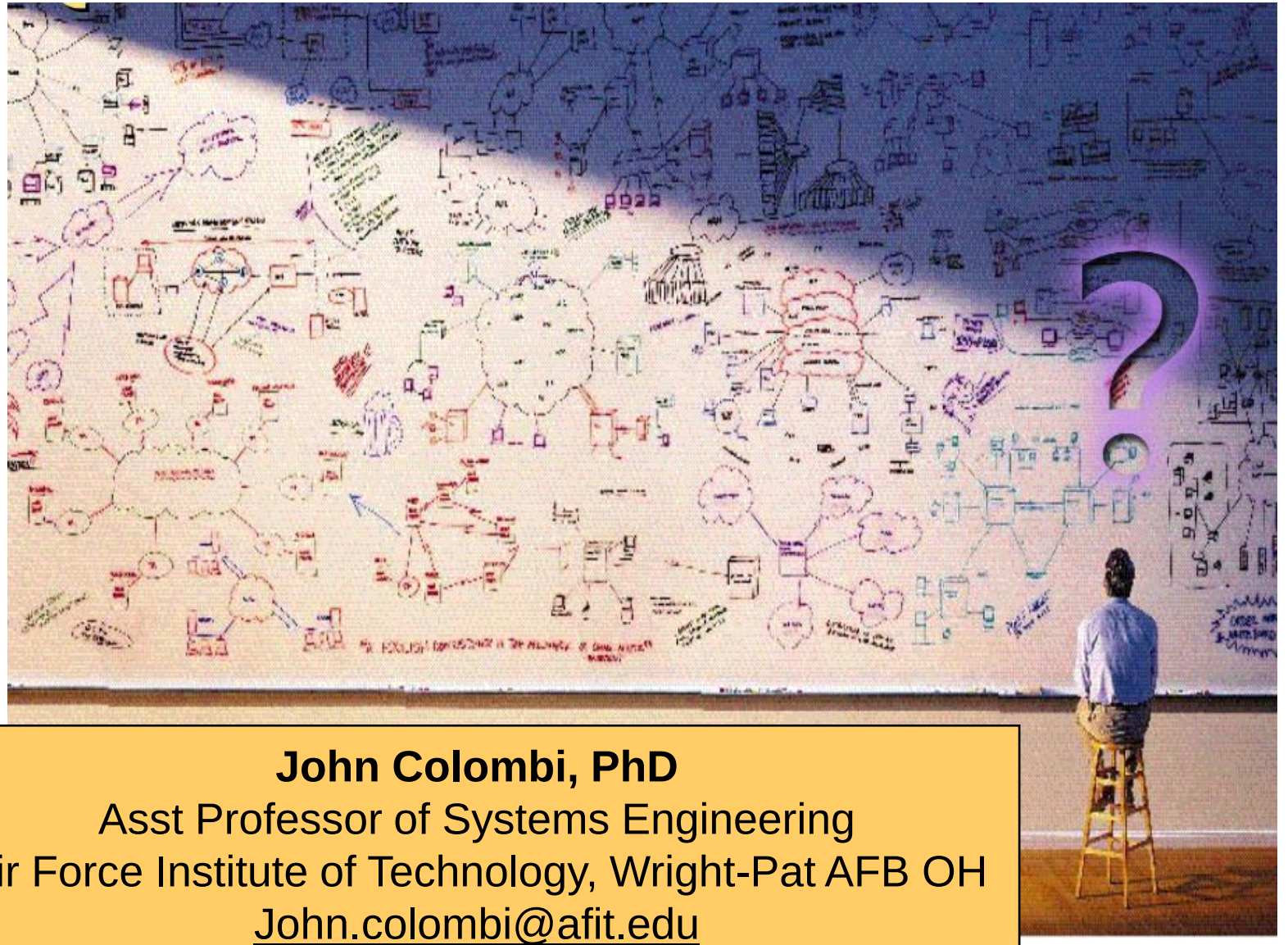


Would also need to visually modify /flag cognitive elements

Conclusion

- DoDAF Version 1.5 is not far from being able to support a cognitive construct / model
- The five cognitive elements can answer “how” the human will complement the concept/ solution in JCIDS analysis
- All cognitive tasks can be defined by, decomposed into, eight fundamental CPC tasks
- The greatest impact occurs during early concept development and solutions analysis
  - Improved design with more accurate system constraints
  - Early Manpower, Personnel (Training) traceability
  - Reduced HSI risks

Any Questions, Thoughts, Comments or Criticisms?



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