A Work-Centred Approach to Seeding the Development of Design Concepts to Support Shipboard Command and Control

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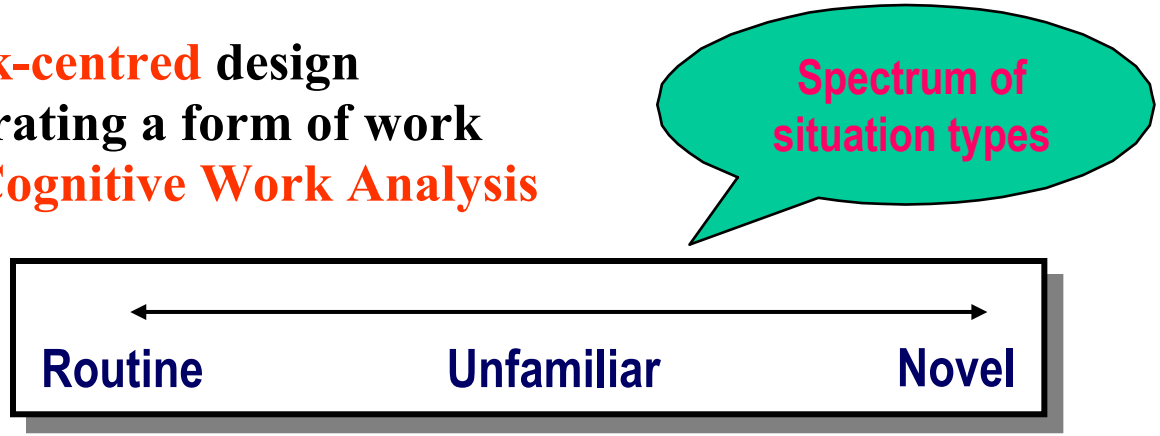
Outline

- How do we design to support C2 work?
- HALIFAX Class frigate application areas
- Exploratory design framework
- Cognitive Work Analysis (CWA) framework
- Knowledge elicitation
- Work modeling
- Developing design seeds
- Summary and conclusions

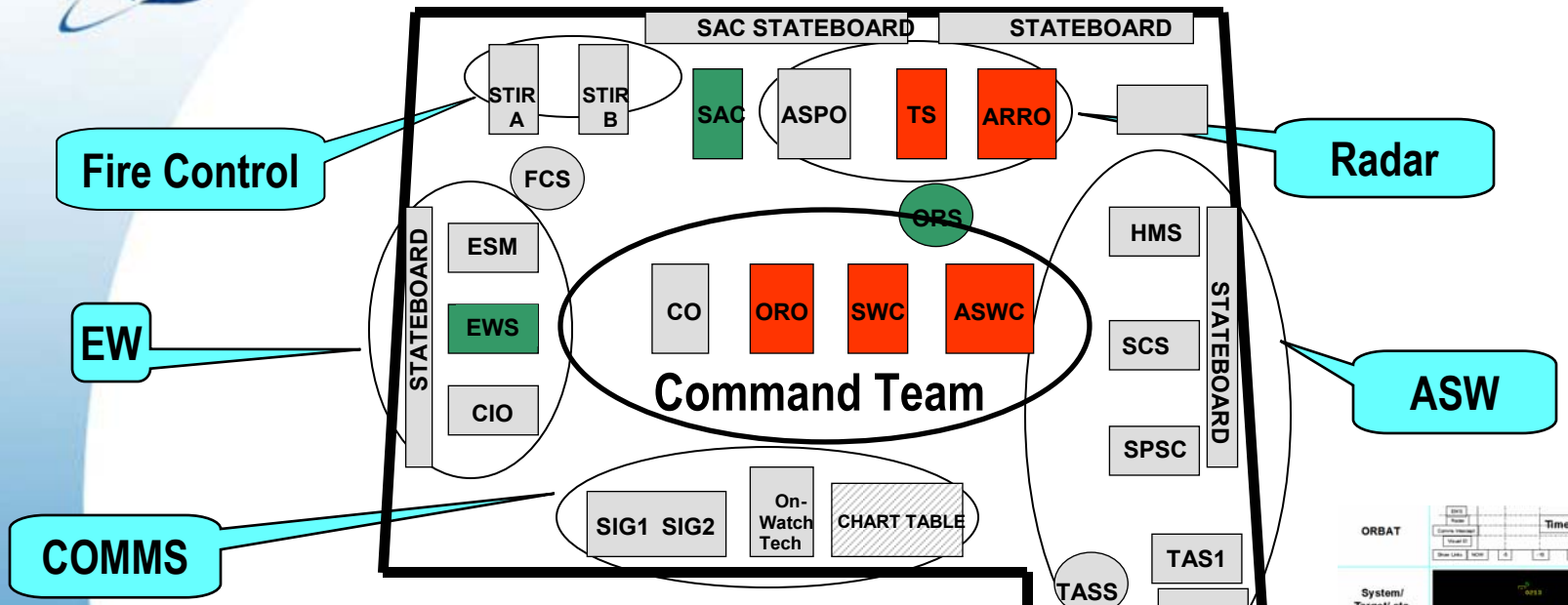
HALIFAX Class Frigate

How do we Design to Support C2 Work?

- Cognitive activity distributed across multiple, interacting actors
- Evolving **interconnected flow of activities**, varying phases and tempos
- **New missions, new operational contexts** are leading to evolving cognitive and collaborative demands and increasing complexities
- **Growing pressures for agile and adaptive responses**
- **Human expertise and capacity for adaptation play an increasingly vital role in this environment**
- **Few design frameworks aimed at developing tools to support operator adaptation**
- **Investigating a work-centred design framework incorporating a form of work analysis known as Cognitive Work Analysis**

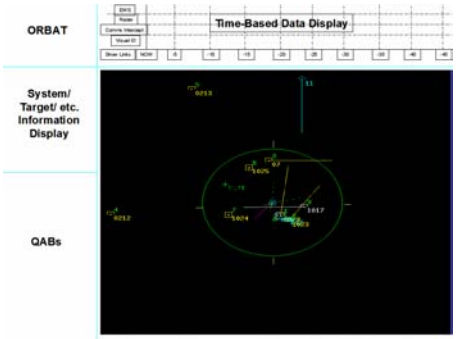


HALIFAX Class Frigate Operations Room



Application areas

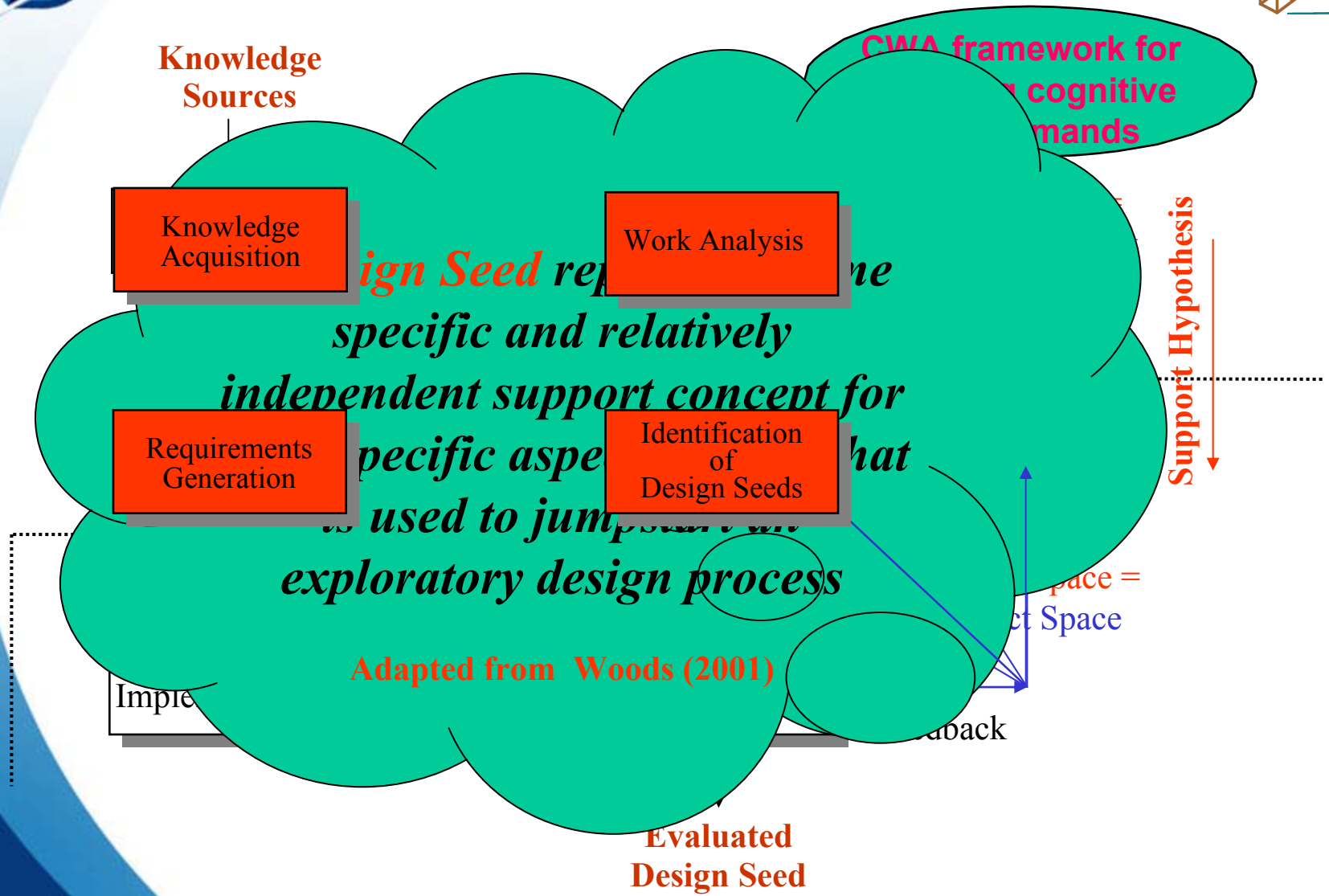
- Maritime Tactical Picture Compilation
- Tactical Planning and Response Management



Application focus

- Support existing work processes with computer-based solutions (evolutionary changes)
- High-level consideration of a ‘blue sky’ design solution (revolutionary changes)

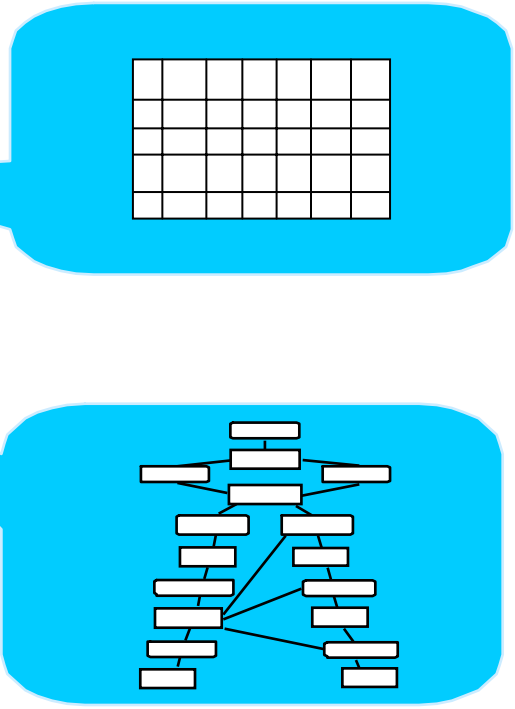
Exploratory Design Framework



Cognitive Work Analysis (CWA) Framework

Increasing Constraint

Phases of CWA	Kinds of Information	Modeling Tools
Work Domain Analysis	**Purpose and structure of work domain**	**Abstraction-decomposition space (ADS)**
Control Task / Activity Analysis	**Goals to be satisfied, decisions/cognitive processing req'd**	**Decision ladder (DL) template**
Strategies Analysis	Ways that processing can be executed	Information Flow Map
Social Organisation and Cooperation Analysis	Who carries out work and how it is shared	Annotations on all the above
Competencies Analysis	Kinds of mental processing supported	Skills, Rules and Knowledge model

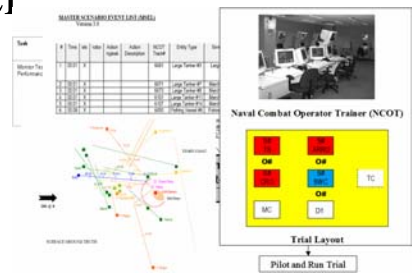


- CWA concentrates on modeling intrinsic behaviour-shaping constraints on work
- Formative focus promotes concepts to support, flexible, adaptive operator behaviour:

  higher-level control (situation independent) vs lower-level control (situation dependent)

Knowledge Elicitation

- Earlier work has used various approaches: Subject Matter Experts (SMEs) walk-through with pre-scripted scenarios; SMEs work through pre-scripted scenarios in Navy trainer
- Work reported here based on semi-structured, but open-ended, interviews with teams of SMEs
- CIT vs. CDM
  - Originally looked at Flanagan's Critical Incident Technique (CIT)
    - CIT not specifically designed for retrospective interviews
    - CIT looks at a large corpus of critical incidents – hundreds (or thousands)
  - Critical Decision Method (CDM) designed for retrospective interviews, focuses on fewer decision points and cognition bases of judgement and decision making
- Chose Critical Decision Method (CDM; Klein, Calderwood and MacGregor, 1989).
- 3 intact operator teams involved over 2 days



CDM Interview Steps

- Step 1 – Identify an incident
- Step 2 – Unstructured incident approach
- Step 3 – Sequence of events construction
- Step 4 – Planning (Decision) point identification
- Step 5 – Decision point probing: triggers/cues, information, goals, options, situation awareness, etc.

Data Reduction

- Collate notes from data collection sessions
- Integrate notes from different analysts
- Supplement with audio data where necessary
- Enter into Excel spreadsheet
- Finalize chronological description of the scenarios described by the SMEs
  - expanded sequence of events based on responses to decision point probes
  - structured according to high-level tasks, lower level activities or observations
  - derived directly from SME statements

"Escort vessel through Strait of Hormuz" (Planning incident)

…

"Consider risks in escort" (Event/high-level task)

…

"Determine the trade-off between defending High-Value Unit and putting Own-Ship at undue risk" (Lower-level activity/observation)

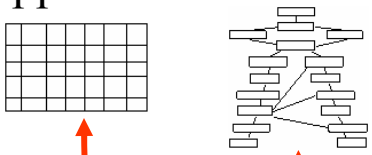
…

…

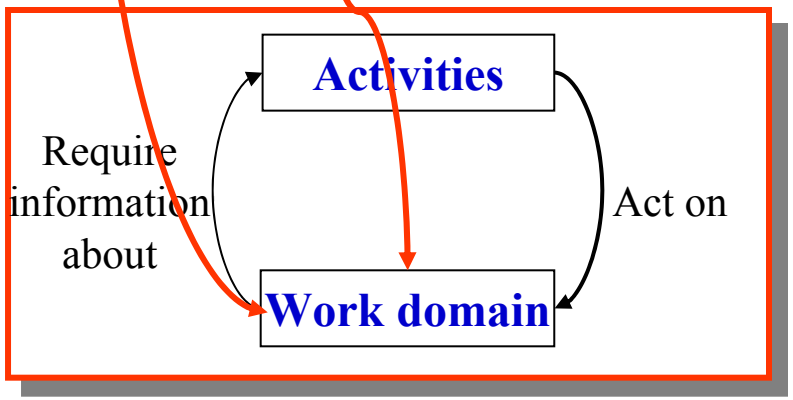
Work Modeling

General Modeling Procedure Followed

- 4 analysts independently mapped each SME statement onto the CWA model templates:

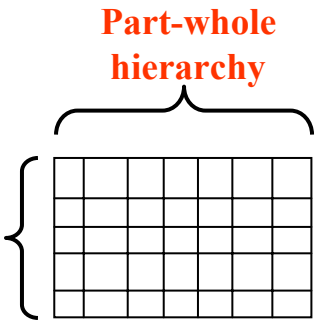


- Need for mechanisms to ensure mapping reliability: exemplars, guidelines
- Analysts met at end to reconcile mapping differences and agree on a final mapping



Work Modeling: Work Domain Analysis (WDA)

- A WDA models the work domain in the form of an Abstraction-Decomposition Space
- ADS built, including a set of exemplars for each ADS cell
- Analysts' mapping of SME statements, using exemplars as a check of internal consistency



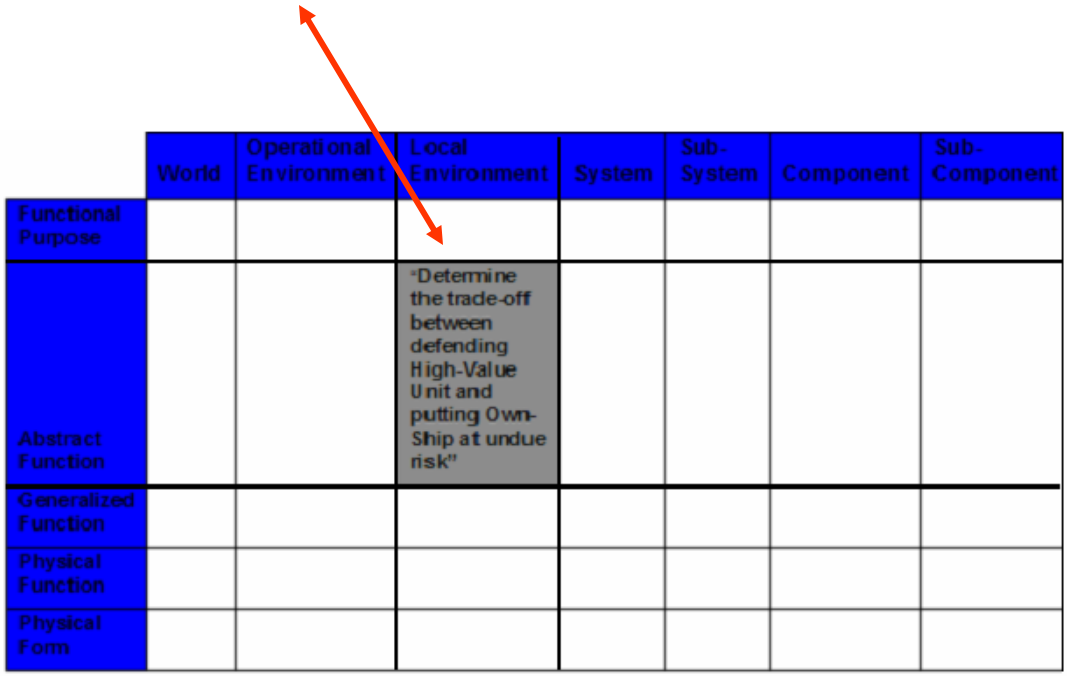
Abstraction Hierarchy Level	Generic Questions
Functional Purpose	What was the work domain designed to do?
Abstract Function	What are its underlying laws or principles?
Generalized Function	What are the processes that are involved?
Physical Function	What entities are involved and what are their capabilities?
Physical Form	What is the physical appearance and location of an entity?

World	Operational Environment	Local Environment	System	Sub-system	Component	Sub-Component
Geopolitical, weather, geophysical, etc.	Physical (including air, surface and subsurface contacts - both hostile and friendly (Task Group)) and non-physical (air/ship lanes, weather) elements	Logical groupings within operational environment (e.g., Task Group, Air Contacts, Environment)	Self-contained units within the operational environment (e.g., Own-Ship)	Logical groupings within self-contained units (e.g., personnel, vehicles, ship systems)	Entities within logical groupings of self-contained unit (e.g., information system, communication system, bridge personnel, helicopter, weapons systems)	Component elements of entities (e.g., a weapon, an element of database, information, rudder)

WDA (cont'd)

An example:

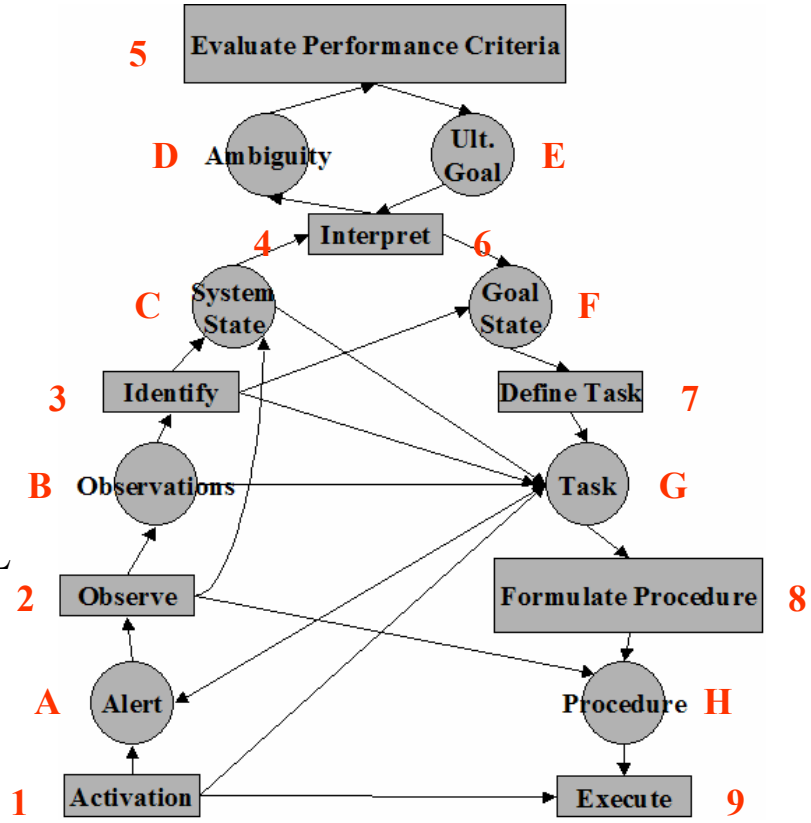
"Determine the trade-off between defending High-Value Unit and putting Own-Ship at undue risk"



	World	Operational Environment	Local Environment	System	Sub-System	Component	Sub-Component
Functional Purpose							
Abstract Function			"Determine the trade-off between defending High-Value Unit and putting Own-Ship at undue risk"				
Generalized Function							
Physical Function							
Physical Form							

Work Modeling: Control Task Analysis (CTA)

- A CTA maps out control tasks in terms of data-processing activities and states of knowledge using a decision ladder (DL) template
- Coding scheme developed and guidance provided to analysts for mapping onto the DL
- Analysts' mapping of SME statements



CTA (cont'd)

An example:

"Consider risks in escort" (Event/high-level task of ship's tactical coordinator)

– "Determine the trade-off between defending High-Value Unit and putting Own-Ship at undue risk"

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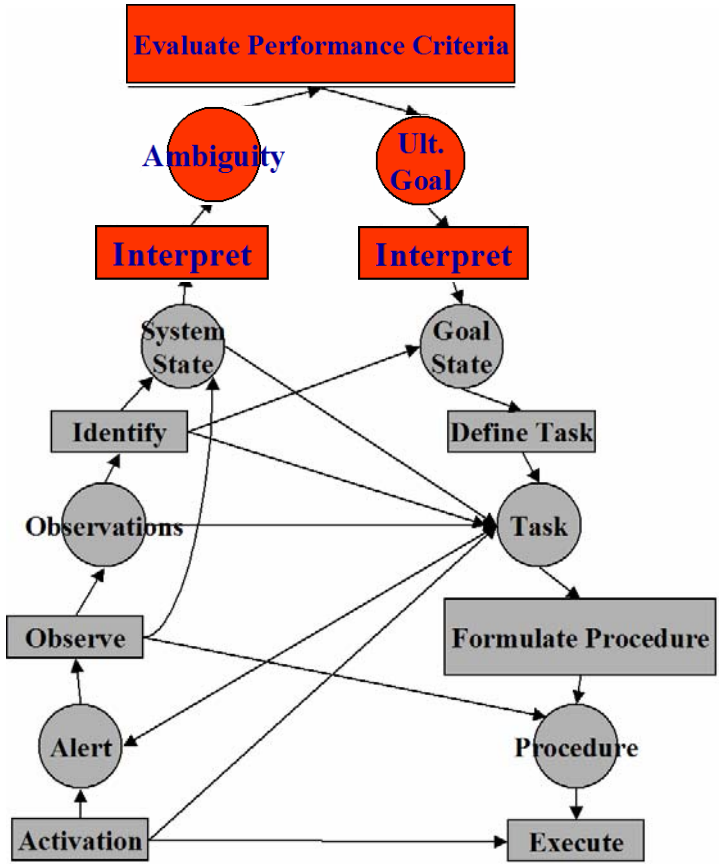
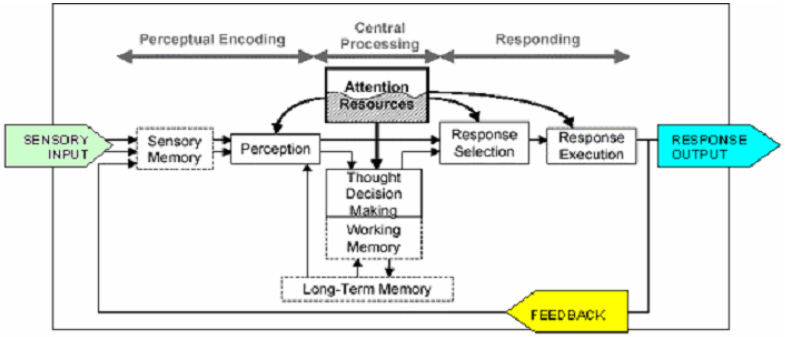
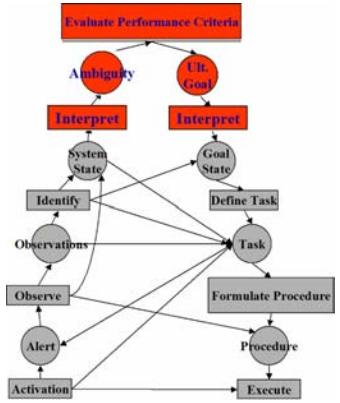


Developing Design Seeds

- A design seed is some specific and relatively independent support concept for some specific aspect of the work; could be realized in a number of forms; jumpstarts exploratory design process
- Will be accompanied by a specific hypothesis about the nature of its support
- Focusing on design seeds as an intermediate step allows designer to consider them both individually and collectively to see how they complement a proposed overall integrated support concept
- 4 stage process followed, based on analysis of each SME statement
  - Identify potential operator difficulties
  - Map cognitive basis of difficulties
  - Analyze WDA modeling results (Abstraction-Decomposition Space)
  - Analyze CTA modeling results





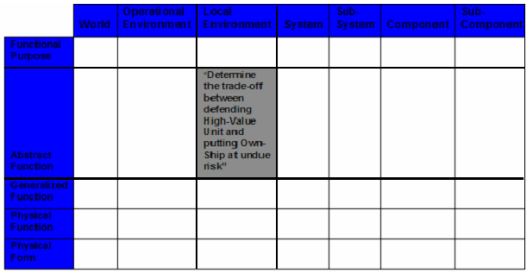
General design themes and support hypotheses

Specific design information: specific support reqmts, nature of support, etc.)

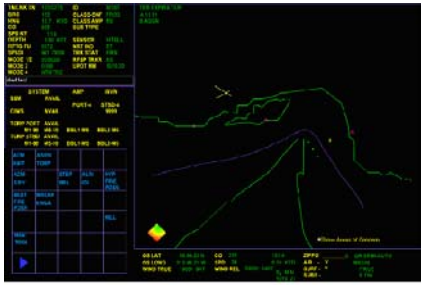
	World	Operational Environment	Local Environment	System	Sub-System	Component	Sub-Component
Functional Purpose							
Abstract Function			"Determine the trade-off between defending High-Value Unit and putting Own-Ship at undue risk"				
Generalized Function							
Physical Function							
Physical Form							

Developing Design Seeds: A WDA Example

Abstraction Hierarchy	Cognition	High-level Design Seeds
Functional Purpose	Significant paradigm shift	Monitor to determine when functional purpose must change
Abstract Function	Novel problem solving	Display/monitoring of work constraints but permitting flexible ways of working
Generalized Function	Mental models, schemas, scripts, etc, feeding decision making and situation awareness	Automated support functions
Physical Function	Situation awareness	Display of entities, their capabilities and their behaviour
Physical Form	Perception	Appearance, location, layout



- Support for novel problem solving and decision making
- Make constraints apparent (e.g., display of dynamic relationships between risk considerations) (Abstraction Hierarchy)
- Since operator must consider local environment (i.e., not just Own-Ship), extend considerations to HVU relationships (e.g., databases, adaptive selection and re-calibration of relationships)
- Led to the development of a risk management assistant support concept for tactical planning



Summary and Conclusions

- Knowledge elicitation based on open data collection allowed SMEs to identify and frame the problem space themselves
- Data structuring was achieved within 3 days of data collection by a team of 4 analysts; WDA and CTA analyses and production of design seeds took analyst team 12 days
- Analysis and modeling was hindered by the variability in the data:
  - further phase(s) of knowledge elicitation
  - development of a formal and precise grammar for representing the data
- Identification of design seeds and specific support hypotheses was arguably the most successful part of the process: a design seed was generated for each SME statement
- Resource and time constraints in this project meant that the utility of a CWA-based approach was severely tested, yet not found to be as onerous as the literature suggests
- Although CWA was developed primarily for revolutionary design, it was found to be also effective from an evolutionary design perspective
- To date only a limited evaluation of design concepts has been undertaken
  - feedback from Command Team members to a crude mock-up of a risk management assistant during a Canadian Navy Task Combat Readiness Operation
- A number of firsts in this work (as far as we know)
  - use of CDM to do a CWA
  - use of CWA's Abstraction Decomposition Space and Decision Ladders to model SME statements for a shipboard Operations Room
  - has led to a convincing demonstration of a traceable design thread from actual SME data, to work analysis and work modeling, to identification of design seeds and support hypotheses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