Cognitive Models of Operators

16.459 Humans & Automation Seminar

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Road Map

- Laughery, & Corker, (1997) “Computer Modeling and Simulation”
  - Introduction and Overview of General Human Performance Modeling
  - Micro Saint Task Network Model
    - *Model Overview*
    - *Case Study : Modeling Crew Workload for the LHX Helicopter*
  - MIDAS
    - *Model Overview*
    - *Case Study : Exploring an Optimum Time Range for Issuing a CTAS Descent Clearance*
- Zachary, Ryder, & Hicinbothom, (1998) “Cognitive Task Analysis and Modeling of Decision Making in Complex Environment”
  - COGNET
    - *Model Overview*
    - *Cognitive Task Analysis Using COGNET Framework*
    - *Case Study : Analyze and model decision making process of the Anti-Air Warfare Commander (AAWC)*
- Comparison of the 3 Models
- Discussion

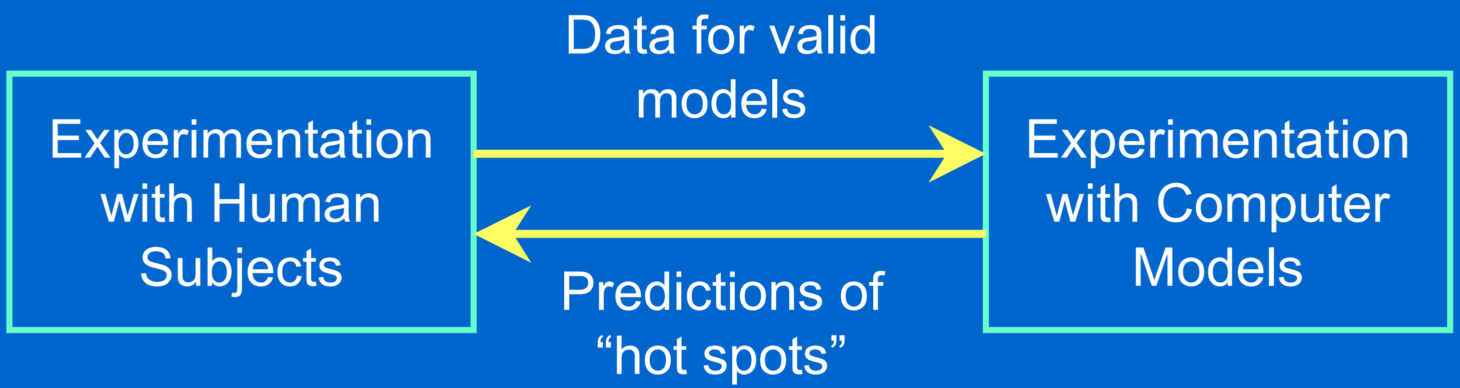
Motivations of Operator Modeling

- Providing substantive and well-supported input regarding human-system performance prediction and design tradeoffs to the system development process from the earliest design stage.
- Tools to support early analysis and design:
  - Design guidance (handbook or computer program)
    - *Does not provide system-level performance prediction.*
  - User-computer interface prototype
    - *Is often costly to perform human-subject experimentation.*
  - Computer model and simulation
    - *Utilizes general human-factors and ergonomics knowledge to predict system-level performance as a function of human-factors system design alternatives.*
    - *Should be used mutually supportive manner with prototyping method.*

Laughery & Corker, 1997

Synergy between Modeling and Experimentation

- Computer modeling of human behavior increases the effectiveness of limited prototype experiment with human subjects.
- The human-subject experiment results are used to enhance and refine the computer model.



Laughery & Corker, 1997

HF Questions Addressed by Models

- As a function of system design, task allocation, and individual capabilities, etc., how do following factors change?
  - Task completion time
  - Expected error rates
  - Workload demands
  - Effect of environment
  - Number of operators required
  - Effect of environmental stressors (heat, cold, drugs, etc.)
  - … And so on

Laughery & Corker, 1997

What's Important to System Behavior?

- Which elements of human-system performance should be represented in the model?
  - Human performance representation
  - Equipment representation
  - Interface requirements
  - Control requirements
  - Logical and physical constraints
  - Simulation driver
- Including too many factors may make the system too complex and untenable.
- It is better to begin with too few factors, then add to it later.

Laughery & Corker, 1997

Measure of System Effectiveness

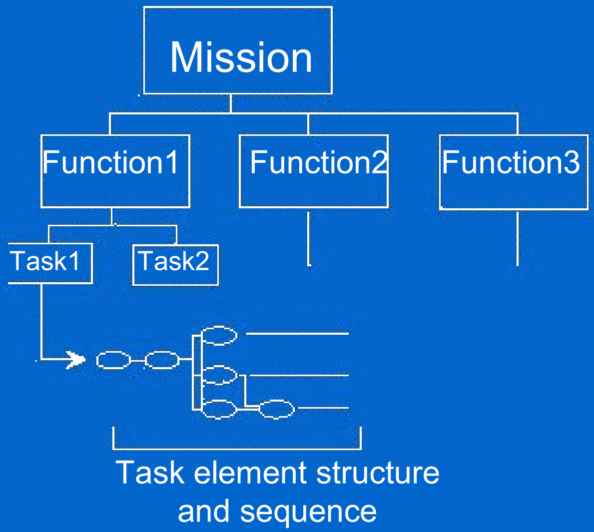
- Goal of the modeling is to predict human performance that will clearly impact the system performance.

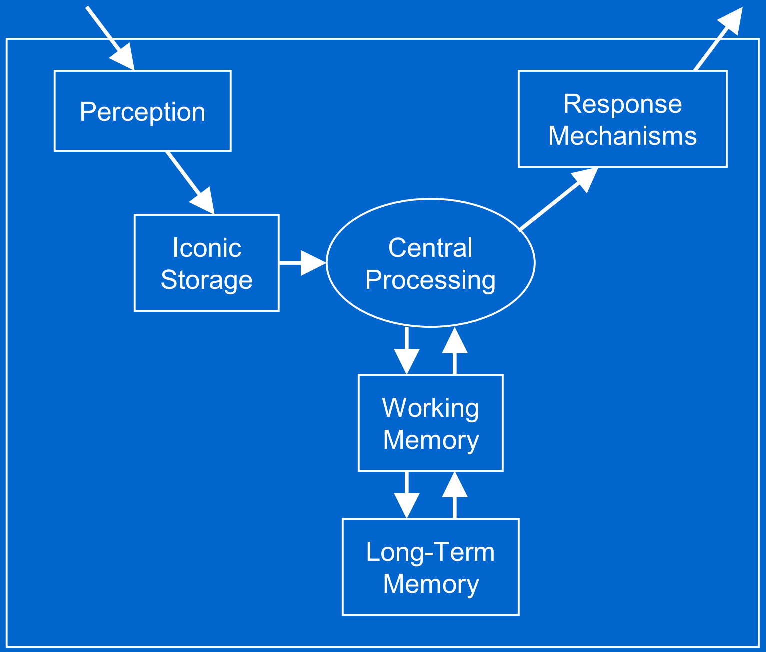
- What aspect of the human performance and system performance measures are important?
  - What operational success measures are important to the system? (Success Criteria)
  - How important is it to establish a range of performance for each experimental condition as a function of the stochastic behavior of the system? (Range of Performance to be Studied)

Laughery & Corker, 1997

Classes of Models

- Reductionist Models
  - Primary organizing structure is task sequence.
  - Larger aspects of human system behavior is decomposed into smaller task elements.



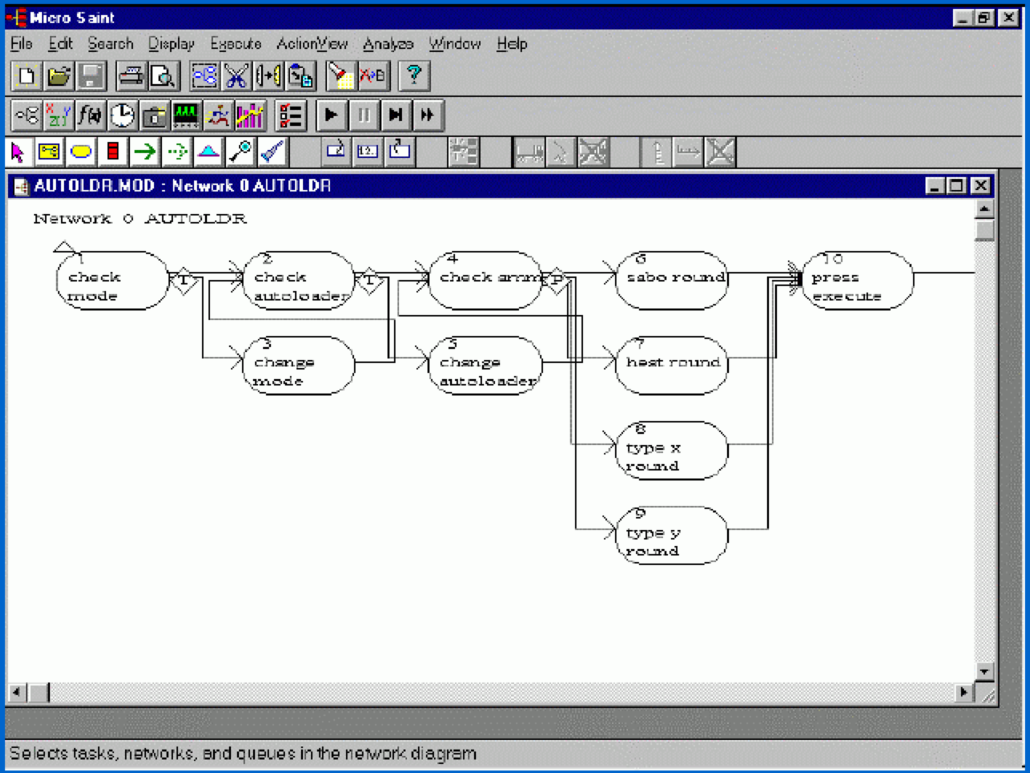


- First-Principle Models
  - The organizing framework includes embedded structures each of which represents elemental aspect of human.
  - The modeled human process interacts with the system and environment.

Laughery & Corker, 1997

Micro Saint Task Network Model

- This is an example of Reductionist model.
- Model concept is relatively simple.
- First, task analysis is conducted.
- Then, task network (sequence of tasks) is constructed, where each node represents a task.
- Nodes are interrelated by shared variables.



Micro Saint Main Window for Task Network Construction and Viewing

Laughery & Corker, 1997

Micro Saint (Cont'd)

- Each task is defined with detailed characteristics including;
  - Task completion time
    - *Monte Carlo simulation is conducted with designer-defined probability distribution.*
  - Release condition
    - *The task will not start until these conditions are met.*
  - Beginning / launch / ending effects
    - *These effects change the shared variables.*
- Three types of decision logic for the case more than one path out of a task are available:
  - Probabilistic (random drawing, e.g. human error)
  - Tactical (e.g., rule-based decision making)
  - Multiple

Laughery & Corker, 1997

Micro Saint Case Study

- Modeling Crew Workload for the LHX Helicopter
  - Question : "Is one-person cockpit feasible?"
  - The model attempts to predict operator workload without human-subject experimentation.
  - Assumption : high workload is caused by situations where multiple tasks must be performed simultaneously.
  - In order to represent workload demand in the task network, multiple resource theory of information processing was incorporated.
  - Each operator activity is characterized by the workload demand required in each of 4 channels:
    - *Auditory channel*
    - *Visual channel*
    - *Cognitive channel*
    - *Psychomotor output channel*

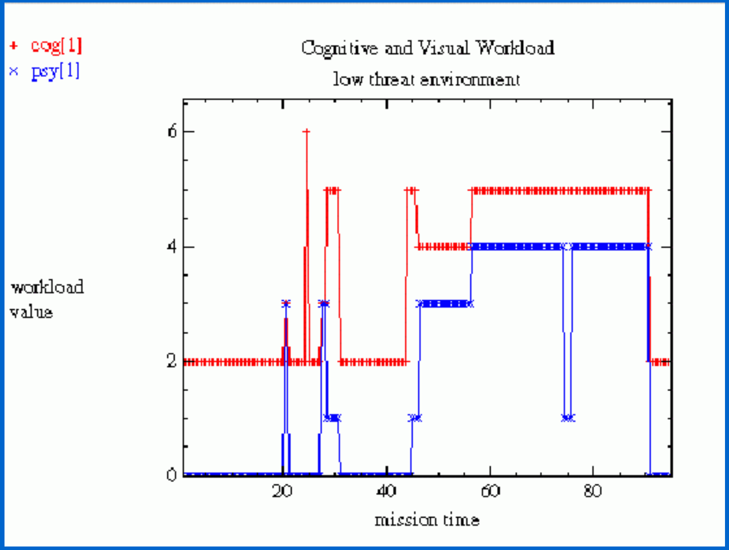
Laughery & Corker, 1997

Micro Saint Case Study (Cont'd)

- Modeling Crew Workload for the LHX Helicopter (Cont'd)
  - Activities in each channel are scaled according to the attentional demand.
  - The total attentional demands are calculated as a sum of attentional demands across all tasks being performed simultaneously.
  - Pilot's task performances are simulated under different scenarios.
  - Workload value over 7 was considered cause of concern, and further reviews are conducted.
  - Conclusion: one-person cockpit will be quite difficult to achieve.

Scales for Visual Attentional Demands

Value:	Activity:
1	Monitor, scan, survey
2	Detect movement, change in size, brightness
3	Trace, follow, track
4	Align, aim, orient
5	Discriminate symbols, numbers, words
6	Discriminate based on multiple aspects
7	Read, decipher text, decode



Predicted Workload Profile

Laughery & Corker, 1997

MIDAS Man-machine Integration Design and Analysis System

- First-principle model, which
  - Framework provides models of human behavior based on elementary models of perception, attention, working memory, and decision making.
  - Can provide full behavior of large-scale interactive human-machine system.
- Developed to enable crew-system designers to work with computational representations of the crew station and human operators from early stage of design process.
- Also can be used to test theoretical perceptual and cognitive models by comparing simulation data of the elemental aspects of human behavior with empirical data.

Laughery & Corker, 1997

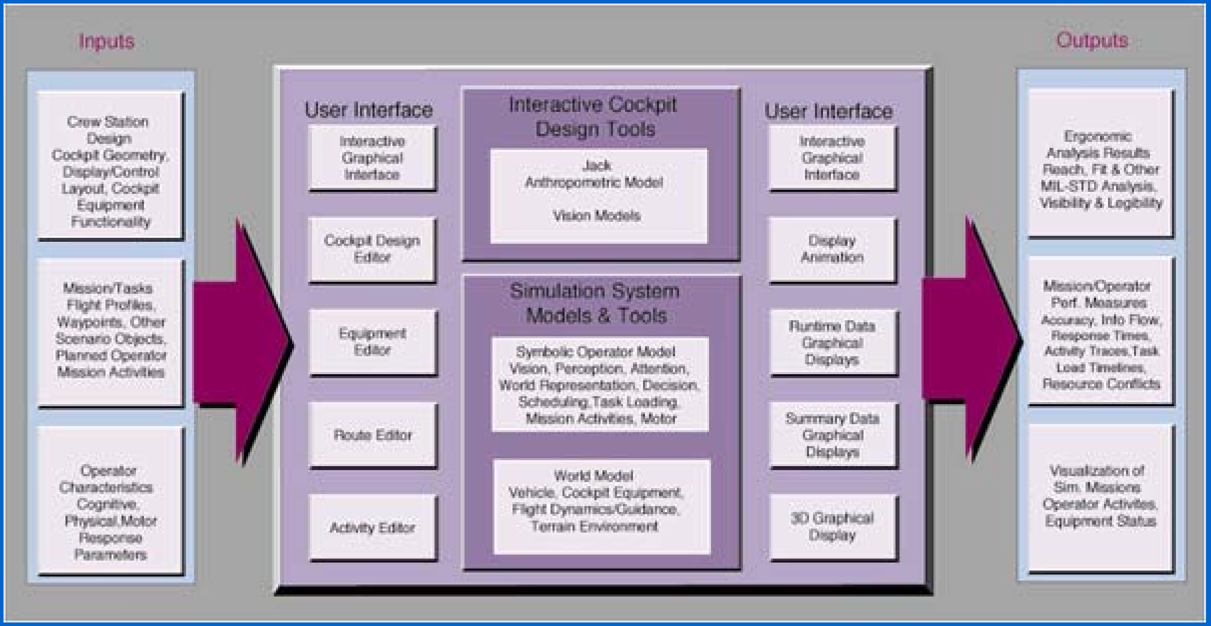
Characteristics of MIDAS

- Modifiability & manipulability
  - The model must be capable to handle systematic changes so that the model can explore the impact of changes to the baseline design.
- Transparency
  - The model must provide designers with explicit and transparent reference to the rules, decision making strategies, heuristics, and assumptions being used, as well as predicted performance.
- Dynamic analysis capability
  - The model must produce a stream of behavior in the form of dynamic timelines containing states, structure, sequences of action, and contingent responses of the human-system behavior.

Laughery & Corker, 1997

MIDAS Functional Architecture

- Specification mode … specifies operator, mission, and crew-station characteristics
- Interactive mode … designs cockpit displays and controls independent from scenarios
- Simulation mode … runs all of the system in dynamic simulation



Laughery & Corker, 1997

MIDAS Structural Architecture

- MIDAS is built around object-oriented software structures.
- Objects in MIDAS interact with each other by exchanging messages.
- The interaction among all of the objects is provided through an agent architecture.
- All agents in MIDAS have common structure containing;
  - Other agents to and from which messages can be passed.
  - Function, method, or procedure after receiving the message or at a specified time.
  - Resource management associated with its own action.
  - Biographer to track all of the messages received, operations performed, and messages sent.

Laughery & Corker, 1997

MIDAS Structural Architecture (Cont'd)

- Physical Component Agents
  - Equipment
    - *Graphical and physical aspects of projected equipment*
    - *Standard operating procedures and functional activities of each component*
  - Physical World Agents
    - *Terrain or the area where the operation takes place*
    - *Aeronautical equipment*
    - *Simulated operator's reasoning about the physical properties (the system)*

Laughery & Corker, 1997

MIDAS Structural Architecture (Cont'd)

- Human Operator Agents
  - Physical Representation
    - *Anthropometric model of human (Jack™) with animated graphical representation*
  - Perception and Attention
    - *Mainly model of visual perception*
    - *Tagging objects whether it is in or out of*
      - peripheral view or foveal fields of view
      - the attention field of view (depending on the task)
      - focus (relative to the fixation plane)
    - *Objects in the peripheral view can be perceived in salient changes.*
    - *To be fully perceived, the information must be in focus, attnded, and within the foveal field of view.*
    - *Commanded eye movements (scanning, searching, fixating, tracking) can be also simulated.*

Laughery & Corker, 1997

MIDAS Structural Architecture (Cont'd)

- Human Operator Agents (Cont'd)
  - Updatable World Representation (UWR)
    - *Individual operator's personalized information about the operational world*
    - *The data in the UWR are constantly updated by the perceptual mechanism.*
    - *The data in the UWR are operated on by daemons and rules, and are the sole basis for a given operator's activity.*
    - *The UWR may be deviated from the "ground truth" of the simulated world!*
    - *The perceptual data and knowledge about the world are organized by a structure called semantic net*
      - Each node represents a concept (e.g., "altimeter")
      - Nodes are connected by links (e.g., "part-of," such as "altimeter" is "part-of" "primary flight instrument")
    - *The information in the UWR is subject to decay by forgetting function.*

Laughery & Corker, 1997

MIDAS Structural Architecture (Cont'd)

- Human Operator Agents (Cont'd)
  - UWR (Cont'd)
    - *Activity Representation*
      - Activities can be performed by any dynamic agents in the simulation
      - Representations of all available activities are contained in the operator's UWR
    - *Rule-Based and Decision Activities*
      - Performed by human operator or any intelligent agents in the simulation
      - Daemons … Monitor any information change in the UWR through perceptual processes, and notify other objects of these changes.
      - Rules … Responds to changes by spawning activities based on the If-Then rules.
      - Decisions … Are made when anomalous situations triggered by deviations from the expected state.
        - » *MIDAS utilizes prescriptive decision making algorithms depending on the amount of time available ("the decision horizon")*

Laughery & Corker, 1997

MIDAS Structural Architecture (Cont'd)

- Human Operator Agents (Cont'd)
  - Task Loading Model
    - *Task loading is computed based on the multiple resource model of capacity in the dimensions of visual, audition, physical, cognitive components.*
  - Scheduler
    - *Activities computed by the Task Loading Model are executed in priority order by the Scheduler based on the operator's strategies, such as "workload balancing," "task time minimization," etc..*
    - *Scheduler supports parallel activity execution, interruption of on-going activities by those of higher priority, and the resumption of interrupted activities.*

Laughery & Corker, 1997

MIDAS Case Study

- Exploring an Optimum Time Range for Issuing a CTAS Descent Clearance
  - Background
    - *Center Tracon Automation System (CTAS) is a decision aid that provides a descent profile that is optimized for multiple aircraft descending into a terminal area.*
    - *However, the current CTAS implementation does not include exact wind and weight information from the aircraft.*
    - *Therefore, the flight path proposed by the CTAS may be different from the flight path generated by the aircraft's flight management system.*
    - *Flight crews sometimes must interpret and incorporate this difference via the aircraft flight controls.*
  - Objective of This Study
    - *Define the ideal range of time for the issuance of a CTAS descent clearance so that the air crew would be likely to accept the clearance and enact it using flight deck automation rather than manual control.*

Laughery & Corker, 1997

MIDAS Case Study (Cont'd)

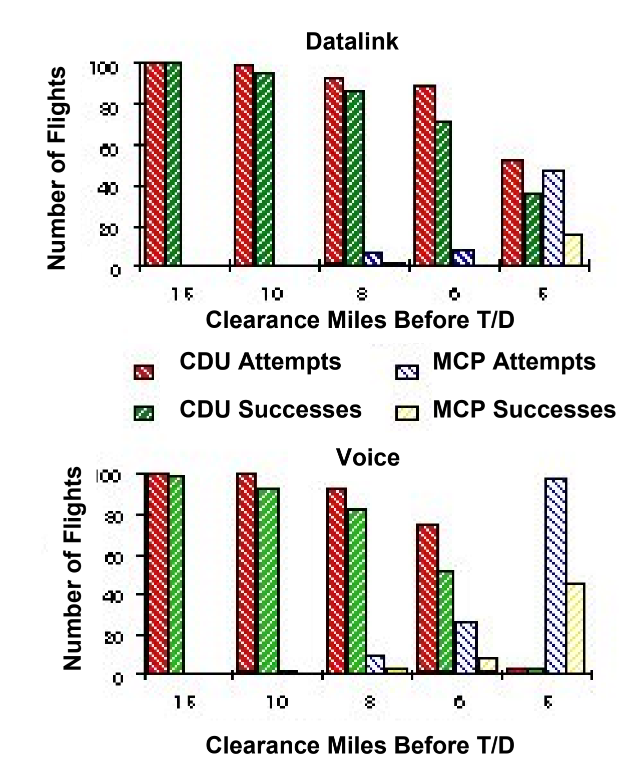
- Development of the Nominal Activity Set
  - *Interruptions of current activity (e.g., responding to traffic calls) also may be simulated.*
- Development of the Decision Rules
  - *The rule set was developed from an expert opinion survey focused on standard procedures.*
- Development of the Flight Crew's UWR
- Factors manipulated in the MIDAS experiment
  - *Automation mode: (Autoload, CDU, or MCP)*
  - *Communication mode: (datalink or voice)*
  - *Time provided to implement the clearance*

Laughery & Corker, 1997

MIDAS Case Study (Cont'd)

– Analysis

- *As the T/D point is approached the crew model tends to select a flight mode that involves less automation (MCP).*
- *Voice communication provides a more pronounced use of nonautomated modes as the T/D approaches.*
- *The interaction between the communication medium and the flight mode was also replicated in the human performance data.*
- *Within 5 to 8 miles from T/D, the number of successes in any clearance compliance is reduced significantly.*



MIDAS Simulation Results

Laughery & Corker, 1997

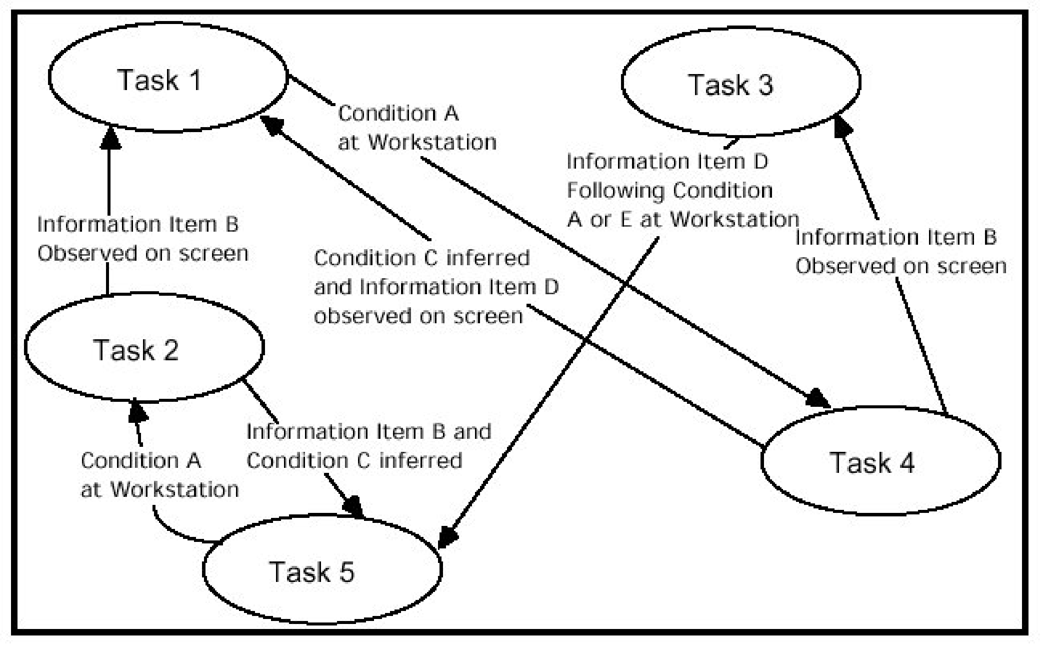
COGNET <u>Cog</u>nition as a <u>Net</u>work of <u>T</u>asks

- Original purpose of COGNET development was to model human problem-solving performance in real-time, multi-task domain, where the human operator must share attention among competing task demands.
- The basic concept of COGNET is based on the "Pandemonium" metaphor of cognitive processes composed of "shrieking demons." (Slefridge, 1959)
  - Each demon is able to perfomr some aspect of cognition and shrieked for attention as an opportunity arises for that process to occur.
  - As the situation bcomes closer to the ideal conditions for the demon, it shrieked louder and louder.
  - Attention is simply the process of placating the shrieking demons by allowing the loudest one to act.

Zachary, Ryder, Ross, & Weiland, 1992

COGNET (Cont'd)

- RTMT decision making situation is represented as a network of cognitive tasks.
  - Each node represents a partial or local strategy for performing some task
  - Flow of the operator's attention from one task to another is triggered by momentary changes in the problem environment.



Concept of Attention Flow

Zachary, Ryder, Ross, & Weiland, 1992

COGNET (Cont'd)

- COGNET framework contains 4 types of knowledge representations:
  - Declarative Knowledge
  - Procedural Knowledge
  - Action Knowledge
  - Perceptual Knowledge

Zachary, Ryder, & Hicinbothom, 1998

COGNET (Cont'd)

- Declarative Knowledge
  - Internal representation of the current problem
  - All declarative information related to the solution strategy for the current problem & all long-term knowledge about the environment.
  - COGNET framework uses blackboard notation for the declarative knowledge.
    - *Each "panel" of blackboard consists of a hierarchy of knowledge element, called "levels."*
    - *Each level may represent different degree of abstraction, or simple partitioning of the conceptual space into different aspects.*
  - Information on the blackboard provides the "context" for the cognitive processes at that time.
  - The structure of the blackboard represents the operator's "mental model" of the domain.

Zachary, Ryder, & Hicinbothom, 1998

COGNET (Cont'd)

- Procedural Knowledge (Cognitive Task)
  - Information processing activity occurs through the activation and execution of chunks of procedural knowledge.
  - Each chunk is integration of multiple lower-level information processing operations and a domain-specific high-level goal.
  - Each goal is defined with a triggering context and relative priority in that context (Priority expression).
- Other 3 COGNET operators groups
  - Action Operators … operates interaction with workstation, communication, comprises Action Knowledge.
  - Cognitive Operators … posts, unposts, or transforms the blackboard info.
  - Metacognitive Operators … triggers or suspends the execution of procedures.

Zachary, Ryder, & Hicinbothom, 1998

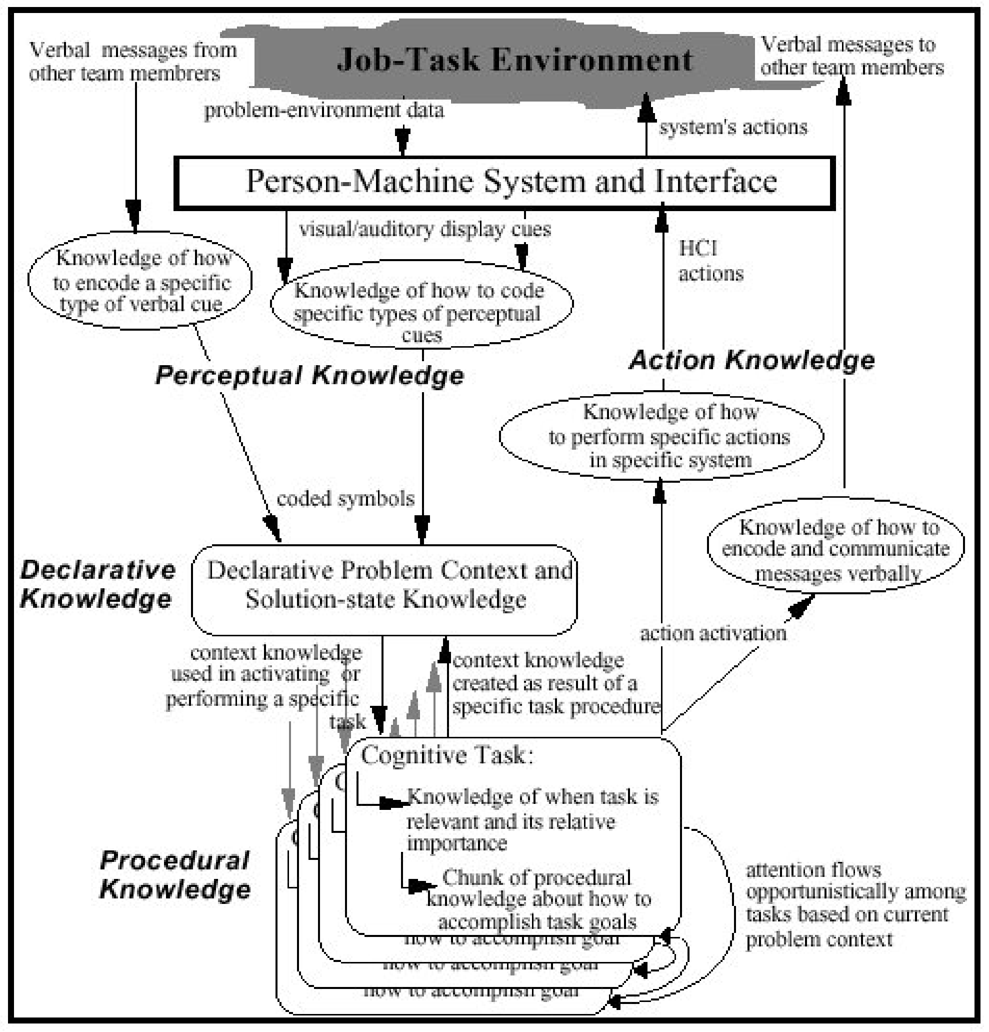
COGNET (Cont'd)

- Perceptual Knowledge
  - Perceptual system passes the perceived information to the cognitive subsystem by being entered directly onto the problem representation blackboard.
  - The rules used in posting (or unposting, transforming) the blackboard information is called Perceptual Demon.
  - The demon is spontaneously activated and executed whenever the corresponding sensory event is sensed.

Zachary, Ryder, & Hicinbothom, 1998

Framework Modification to Accommodate Team-based Decision Making

- The concept of perceptual knowledge was broadened to include not only simple workstation-based cues but also verbal communication with other team members.
- The operator's mental model was expanded from representing just the problem to representing the problem and the team.



Zachary, Ryder, & Hicinbothom, 1998

Cognitive Task Analysis Using COGNET

- COGNET framework is designed to facilitate the cognitive task analysis.
- Data collection
  - In each scenario, decision-making activities of each subject expert are observed and recorded.
  - Verbal introspective data are also collected using knowledge elicitation methods (e.g., thinking-aloud protocols, question-answering protocols immediately after the experiment)
  - System documentation, job descriptions, and information environment audits drawn from the recorded data and interviews.

Zachary, Ryder, & Hicinbothom, 1998

CTA Using COGNET (Cont'd)

- Data Analyses
  - Identify available motor actions and required perceptual demons from system documentation, etc.
  - By reviewing the sequence of problem-solving behavior, decompose the decision processes into a set of cognitive tasks in order to organize the procedural knowledge and initial blackboard structure.
  - Identify the primary principles for structuring the domain knowledge to be posted on the blackboard in order to support the decision making.
  - Observe the attention shifting among competing tasks incorporating the context of the current problem situation posted on the blackboard.
  - The blackboard structure is defined iteratively because its elements are needed to specify the trigger condition, priority expression, and GOAL conditions in the various cognitive tasks.
  - Then, determine necessary cognitive operators to post, unpost, and transform the blackboard information, and insert them into the tasks and perceptual demons.
  - Review, validate, and revise the model.

Zachary, Ryder, & Hicinbothom, 1998

CTA Case Study

- Analyze and model the decision making process of the Anti-Air Warfare Commander (AAWC)
  - CTA is conducted to support Tactical Decision Making Under Stress (TADMUS) project for developing decision-making systems and decision-training tools.
  - Data were collected from following sources:
    - *Observations and recordings of AAWC actions during parts of 4 3-week team-training classes at a high-fidelity team-training simulator.*
    - *Debriefing by participants in observed team training sessions.*
    - *Verbal protocols collected in the context of replays of the recordings of observed AAWC behavior.*
    - *Review and walkthroughts of the evolving analysis by a variety of experts in AAW, Navy tactical experts, members of several ships' crews, and AAW trainers.*

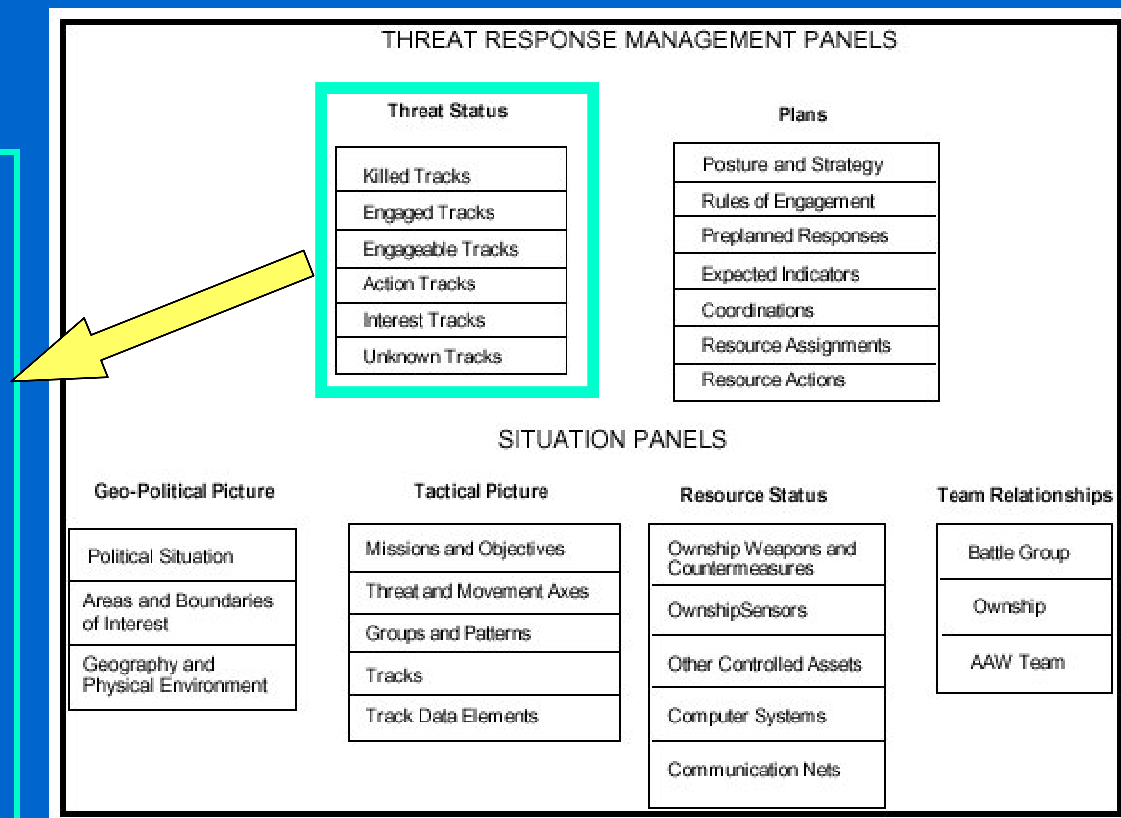
Zachary, Ryder, & Hicinbothom, 1998

CTA Case Study (Cont'd)

- Analysis Results
  - Blackboard composes 6 panels
  - For instance, the "Threat Status" panel consists of 6 levels corresponding to the threat level.

6 Levels of "Threat Status" panel

Killed Tracks
Tracks that have been destroyed
Engaged Tracks
Tracks that have been engaged
Engageable Tracks
Tracks that have met the Rules of Engagement (ROE)
Action Tracks
Tracks requiring some action to be taken (e.g., warnings, reports)
Interest Tracks
Tracks that must be monitored because they are potential threats or are friendly tracks that the AAWC must be aware of for coordination in an engagement
Unknown Tracks
Unevaluated tracks



6 Panels of COGNET Blackboard

Zachary, Ryder, & Hicinbothom, 1998

CTA Case Study (Cont'd)

- Analysis Results (Cont'd)
  - 10 cognitive tasks and 19 perceptual demons are resulted.

10 Cognitive Tasks

1. Manage battle space
2. Evaluate track
3. Plan specific threat response
4. Plan posture for expected threat
5. Neutralize/control potential threat
6. Cover track
7. Take (engage) track
8. Position AAW asset to maintain desired posture
9. Manage CAP status
10. Manage resources

19 Perceptual Demons

1. Radar acquires new track
2. New track acquired through datalink
3. CAP reports of track behavior
4. State reports
5. Link reports
6. Identification reports
7. Missile system supervisor reports
8. Tactical action officer orders
9. Course change report
10. Change in weapon/warning status
11. Radar loses track
12. Datalinked track lost by reporting unit
13. AAW readiness reports
14. Doctrine setup
15. Electronic warfare reports
16. Reports from air intercept controller, air control supervisor
17. Battle group AAW commander orders
18. Commercial air track coming out of commercial air corridor
19. Query about track, track group, or engagement

Zachary, Ryder, & Hicinbothom, 1998

CTA Case Study (Cont'd)

- Simple example of how the model works:
  - Perceptual demon posts "a new unknown track on the radar."
  - Cognitive Task, "Evaluate Track," is triggered if its priority is high enough.
  - The task uses messages from other panels and levels and decides that this track is interesting; "Interest Tracks" is posted on the blackboard.
  - Task determines to take some action, and posts a new level, "Action Tracks," on the blackboard, and CAP investigation plan message to the "Resource Assignments" level on the "Plan" panel.
  - Task releases the AAWC's attention, waiting for the plan to be fleshed out and implemented.
  - Once visual identification from the CAP is received and perceived, the "Evaluate Track" task is triggered again.
  - In fact, the track is a commercial airliner; the message is removed from the "Threat Status" panel, and the "Tracks" level of the "Tactical Picture" panel is updated as the track no longer has to be monitored.

Zachary, Ryder, & Hicinbothom, 1998

Comparison of 3 Models

	Micro Saint	MIDAS	COGNET
Perception	Detection/ Identification Prob, Time, Accuracy	Perceptual Agent	Perceptual Demon
Working Memory	N / A	N / A	Multi-panel Blackboard
Long-Term Memory	N / A	Semantic net, UWR	Multi-panel Blackboard
Motor	Time, Accuracy	Jack-animated mannequin	User-defined
Declarative Knowledge	Global Variables	Objects	Blackboard, Semantic net
Procedural Knowledge	Task networks	Functions, Demons, Rules, Decisions	Goal hierarchies, Task description

Pew & Mavor, 1998

Comparison of 3 Models (Cont'd)

	Micro Saint	MIDAS	COGNET
Multi Task Serial / Parallel	Parallel with switching to serial resources limited	Resource limited parallel	Serial with switching & interruptions
Multi Task Resource Representation	Visual, Auditory, Cognitive, Psychomotor WL	Visual, Auditory, Cognitive, Motor resources	Limited focus on attention, parallel motor/perceptual process
Task Management	Simple dynamic prioritization	Z scheduler, time&resource constraint	Priority based on task context
Multi-Operator	Yes	Limited	Through multiple COGNET models

Pew & Mavor, 1998

Discussion

- Based on the operator model, what kind of decision-aiding system will you design? Should the decision-aiding system necessarily think like the human operator?
- Can you model cognitive activity of any kind of human performance? What kind of activity may cause difficulty in modeling?
- How would you model the difference between expert and novice operators' decision-making strategies? Would putting more information in the internal knowledge components be enough? Doesn't the expertise-level difference result in different model structure?

References

- Main papers:
  - Laughery, K. R., Jr., & Corker, K., (1997) "Computer Modeling and Simulation," *Handbook of Human Factors and Ergonomics*, Gavriel Salvendy (Ed.), pp. 1375-1408.

    (Some figures used in the slides were taken from
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