Identifying Cognitive Limitations in Complex and Safety-Critical Systems

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Objectives of Research

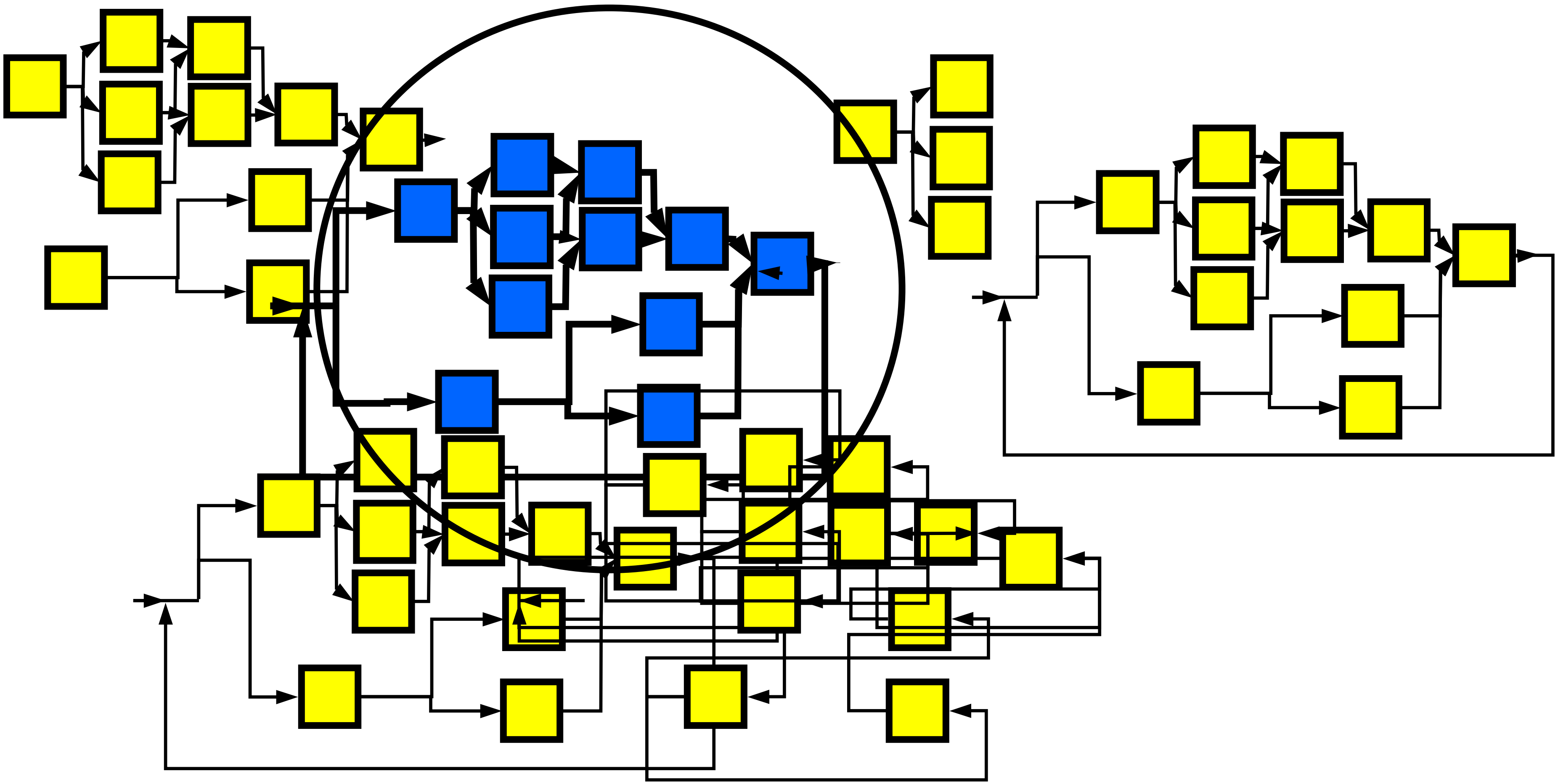
- Develop a better understanding of the cognitive limitations imposed on the human by a complex, safety-critical task
- Identify how mental patterns of organization are created to address the inherent cognitive limitations
- Identify the characteristics of these patterns of organization that aid in effectively managing the complexity of the task
- Specifically identify cognitive limitations and patterns of organization of the air traffic controller and make recommendations on future information system requirements and training

Method

- Identify the cognitive limitations of the air traffic controller
  - Past ATC studies and proposed cognitive model
  - Observations of trainees and the patterns of organization used by experts
- Elicit patterns of organization used to overcome initial cognitive limitations
  - Analysis of ATC training materials, training controller interviews & observations of trainees
  - Identify implicit patterns of organization through observations of trainees
- Perform experiments to evaluate whether teaching novices patterns of organization improves their performance
- Provide recommendations for future information support systems and training

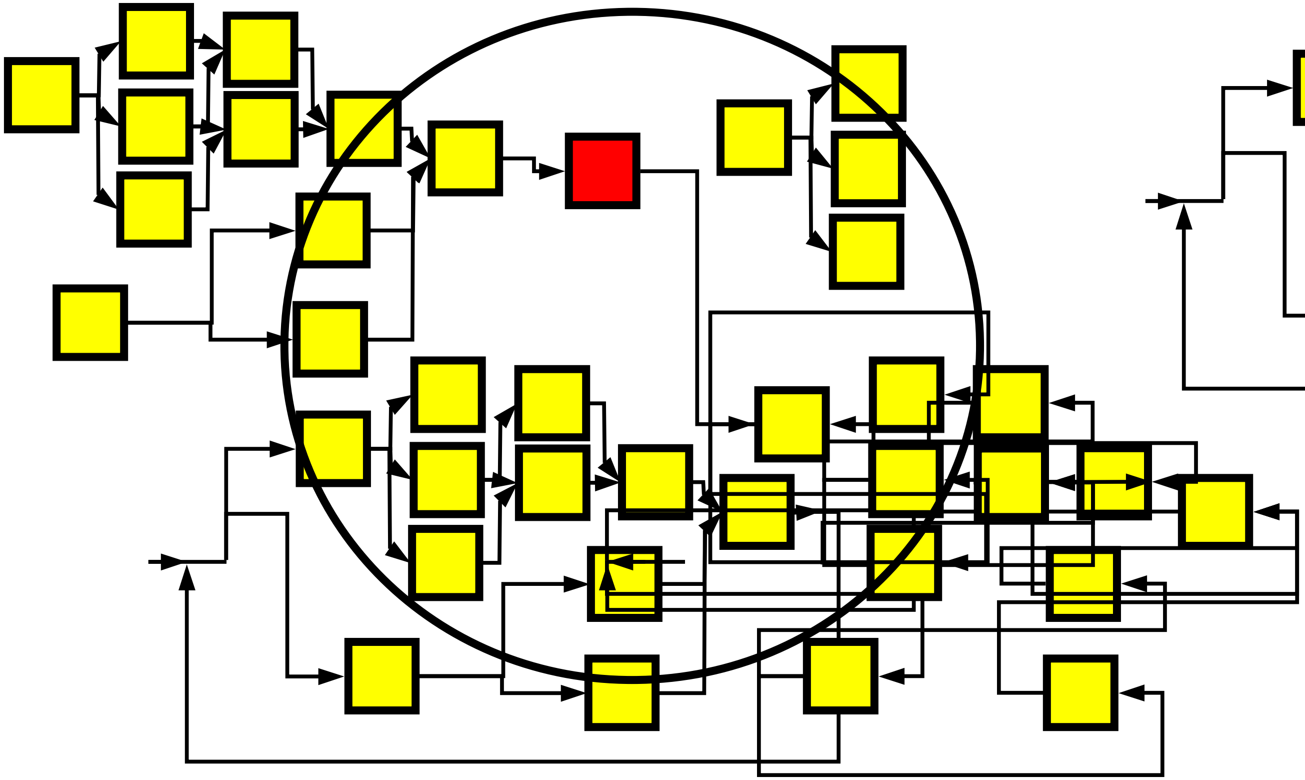
Mental Model

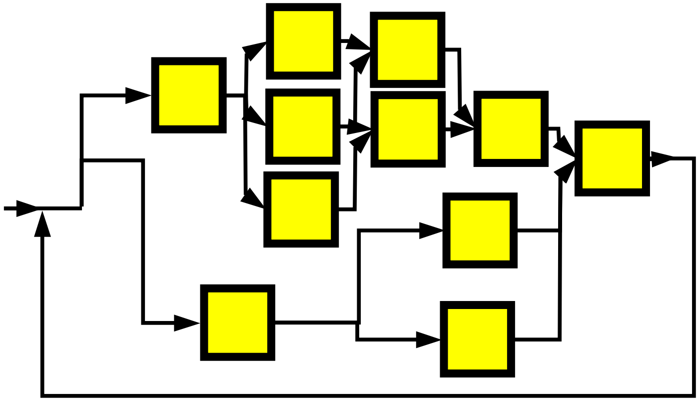
- Operator's conceptual representation of a physical system that is used to predict future states of the system; There may be multiple mental models, and they are innately fuzzy and incomplete. (Moray, 1998; Norman, 1983; Doyle & Ford, 1987)



Abstraction

- "Act or process of leaving out of consideration one or more properties of a complex object so as to attend to others" (Webster's Dictionary); however, Rasmussen (1986) states, "the change in the system properties represented is not merely removal of details of information on physical or material properties…information is added on higher level principles governing the cofunction of the various functions or elements at the lower levels."

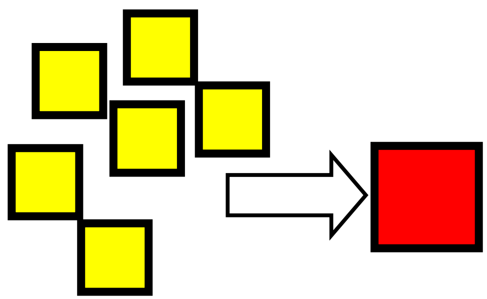




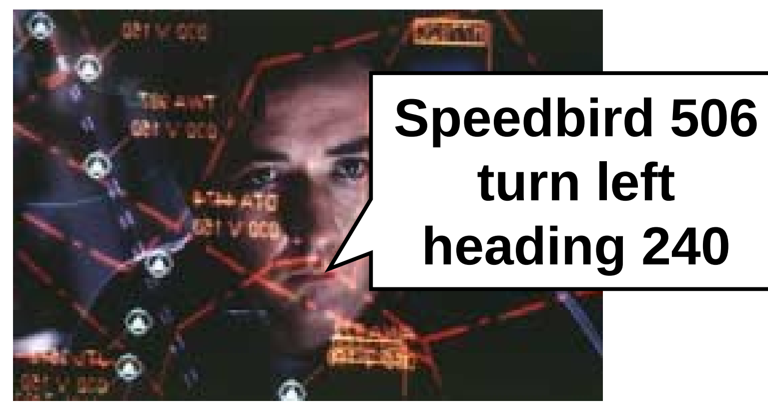
Strategies

- Learned cognitive processes used to perceive, organize information, and act efficiently, according to the level of abstraction of the particular mental model in use.

Visual Scan

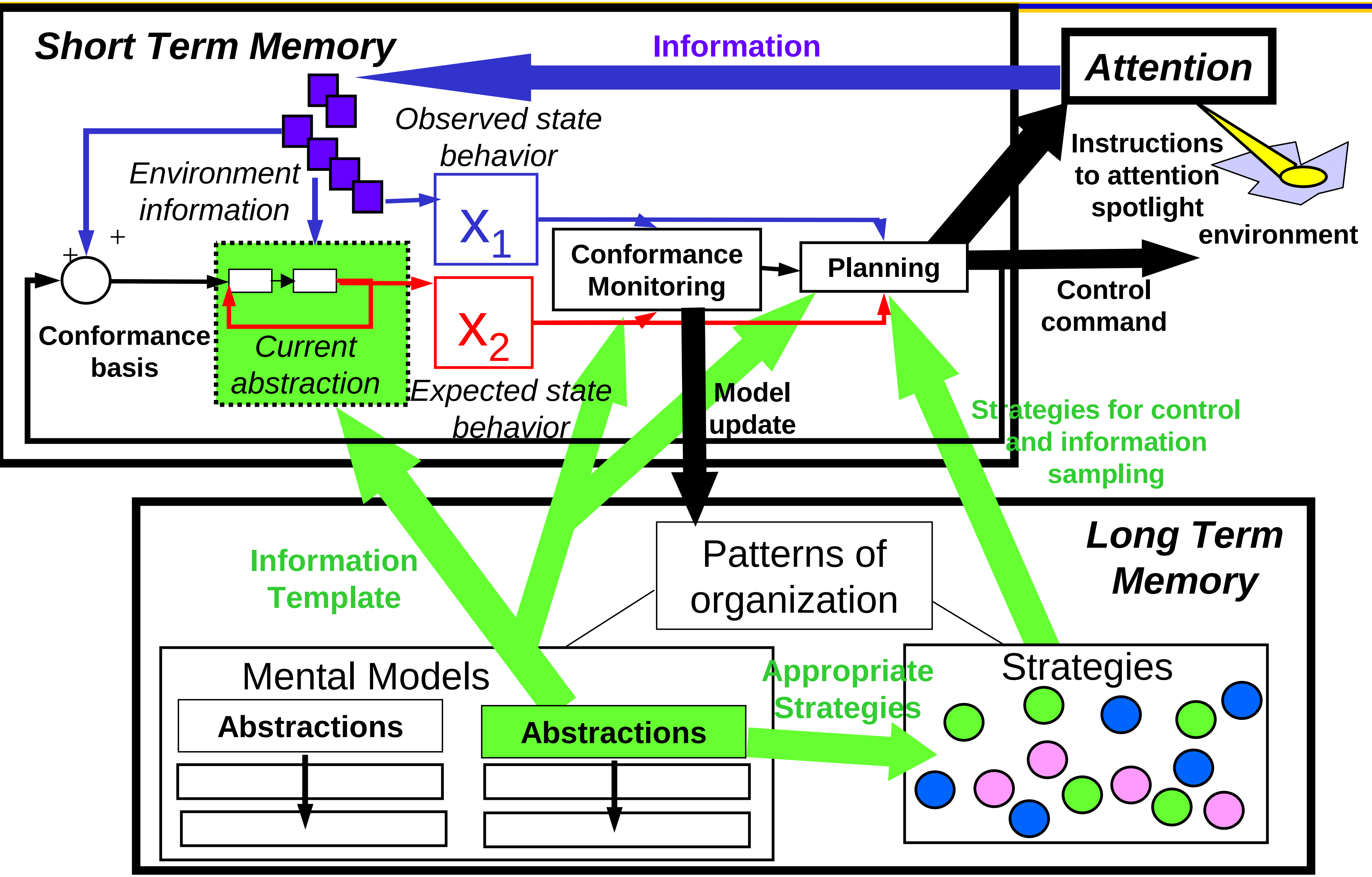


Chunking



Verbally controlling aircraft

Proposed Cognitive Model



Possible Cognitive Limitations

- Short Term Memory limitation (7 +/- 2)
- Attention limitations
- Processing limitations
  - Decision-making based on information from different levels of abstraction
  - Inability to connect complex mental models
  - Absence of an adequate mental model
  - Incorrect mental model
- Other limitations
  - Speed of speech
  - Speed of data entry/Typing

Future Directions

- Investigate further what standard abstractions and strategies are taught during training and further hypothesize on possible cognitive limitations experienced through:
  - Analysis of training materials
  - Interviews with ATC trainers
  - Observations of trainees
- Collaborate with Tom Reynolds & Jonathan Histon to identify key implicit abstractions that the controllers are hypothesized to have
- Perform experiments to test whether teaching these abstractions to novices improves their performance
- Provide recommendations on how to utilize standard abstractions in future information systems and training

Models from ATC training

- Input into Mental Models
  - Learned through classroom (static inputs) & OJT (dynamic models) and altered with daily experiences
  - Static input from the physical system trained in the classroom (from Boston TRACON materials)
    - Radar area map
    - Low & high altitude charts
    - Exit fixes
    - Adjacent control facilities & LOA's
    - Class B airspace
    - Airport layout
    - BOS arrival & departure flows based on runway config.
    - Local obstructions

Strategies from ATC training

- Dynamic models of the system are often taught in OJT
  - Aircraft characteristics
  - Wake Turbulence restrictions

❑ Strategies

- Cognitive strategies are taught in an apprentice-type fashion in OJT
- Types of strategies taught in OJT:
  - Scan patterns
  - Planning
  - Timing of actions (when & how to vector aircraft)
- Strategies adapted through experience
  - What to expect out of different types of pilots (experienced, inexperienced, non-native English-speakers, etc.)

Why understand abstractions?

- **Communicate between pilot and controller using same abstraction**
- Train novice controllers to use standard expert abstractions
- Design information systems to support known system abstractions