Human and Team Modeling

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VAMS TIM #2

Outline

Goals and requirements

Approach to human performance modeling

Milestones accomplished in FY'02

Outyear milestones

Questions and comments

Goals

Provide models of human performance that can be used in fast-time simulation evaluations of airspace concepts

Provide software agents for use in real-time simulations

Develop a computational architecture that supports rapid configurability, promoting the reuse of software modules across scenarios

What Modeling & Simulation Needs to Address

Existing ATM Framework

- Aircraft
- ATC
- System Command Center
- Airline Operations Center
- System operations
  - **Capacity, delays**
  - **Sector & route structures**
  - **Planning**
  - **Equipage**
  - **Constraints**

Innovations

- CNS Technology
- Broader access to information
- Distributed management
- Flexibility
- Automation

Impacts

- Safety
- Security
- Environment

Requirements for Human and Team Modeling

Model operationally relevant agents and functions

- Aircrews
- Air traffic controllers
- Dispatchers

Make operationally useful predictions

- System throughput (capacity)
- Error consequences and recovery
- Sensitivity to deviations from nominal human performance

Simulate performance in external simulation environments

- HLA compatible modeling toolkit
- Software agents for real-time

Model team performance characteristics

- Distributed decision making
- Communications
- Characteristics of supervisory control involving other humans or highly automated systems

Concepts

System Level Concepts

- All Weather Maximum Capacity Concept
- Massive Point-to-Point (PTP) & On-Demand Air Transportation System Investigation
- Air Transportation System Capacity-Increasing Concepts Research Proposal
- Concepts for System-wide Optimization

Domain Specific Concepts

- Capacity Improvements Through Automated Surface Traffic Control (Surface)
- Surface Operation Automated Research (Surface)
- Centralized Terminal Operation Control (Terminal)
- Terminal Area Capacity Enhancement Concept (Terminal)
- Advanced Airspace Concept (Enroute)

Approach

Complex dynamic environments

Time Pressure: **Users must make timely inputs**

Multitasking: **Users juggle multiple tasks**

Predictability: **Similar patterns occur over time**

Unpredictability: **Interruptions occur**

Mixed-initiative: **Decision authority distributed, includes other users and automated systems**

Resource Allocation

A multi-tasking agent must allocate resources proactively and reactively

- Mechanisms for task suspension and recovery
- Mechanisms for parallel task execution subject to *resource constraints* and *logical dependencies*

These mechanisms are also important for HCI predictions that arise from the interleaving of primitive *cognitive*, *perceptual*, & *motor* acts

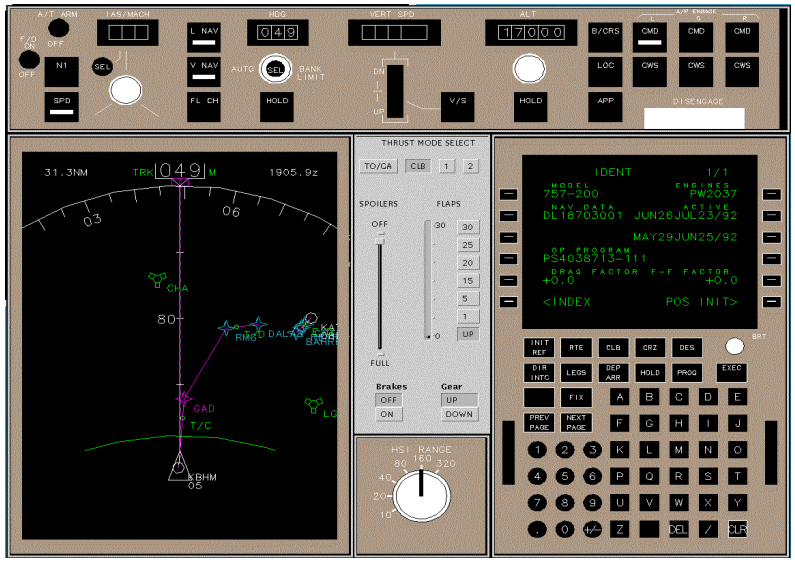
Motivations

Construct a modeling system that can make useful predictions about skilled operator behavior in complex dynamic environments

Make cognitive modeling more accessible to non-specialists, especially in the design phase

- Reduce model development time
- Simplified cognitive architecture
- Reusable packets of psychological theory that can attach to a standard task analysis (templates)
- Focus on routine, well-learned behavior

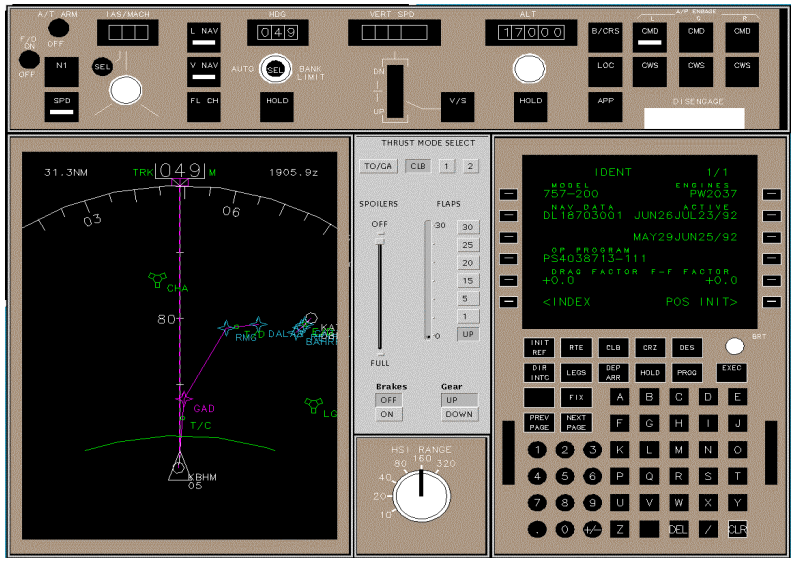
Usability Analysis



Route planning, entry, and modification using Flight Management System (FMS)

- Situation Awareness
- Knowledge of how to use
- Anticipating FMS behavior
- Routine Use

Usability Analysis



Skilled operator

Knows what she wants to do

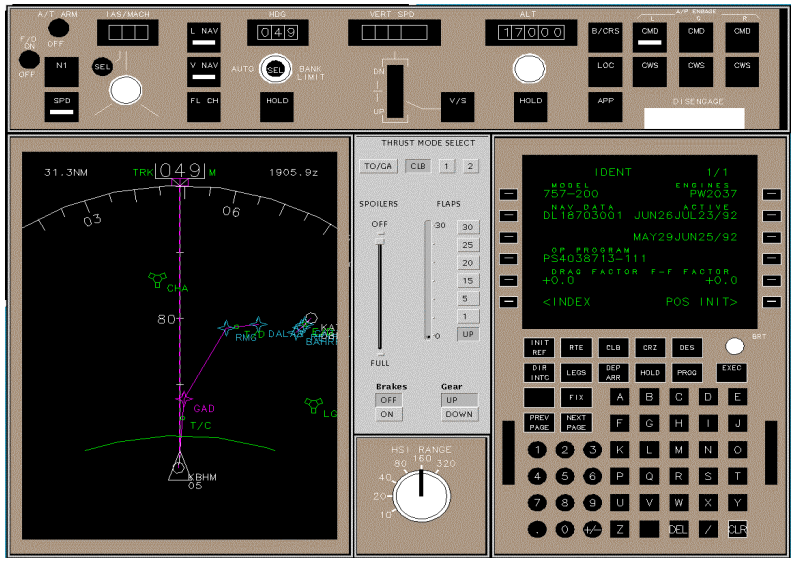
Knows how to do it

Is not confused about FMS state or behavior

How easy is the system to use?

- Time
- Effect on concurrent tasks

Usability Analysis



Modeling a skilled user in routine interaction

- Casual Observation
- Expert Consultants
- Human Factors Guidelines & Handbooks
- Informal Usability Testing
- Part-Task Experiments
- Full-Mission Simulation

Apex and CPM-GOMS

Apex

- Computational Architecture for Human Performance Modeling
  - Task Representation Language
  - Human Resources
  - Resource Scheduler
- Software System Implemented in Lisp
- No built-in theory of Human Resource Interaction

CPM-GOMS

- Methodology for Human Performance Modeling
  - Task Analysis Method (Goals, Operators, Methods, Selection)
- No Software Implementation
- No automatic resource scheduling
- Theory of Human Resources (Cognitive, Perceptual, Motor)

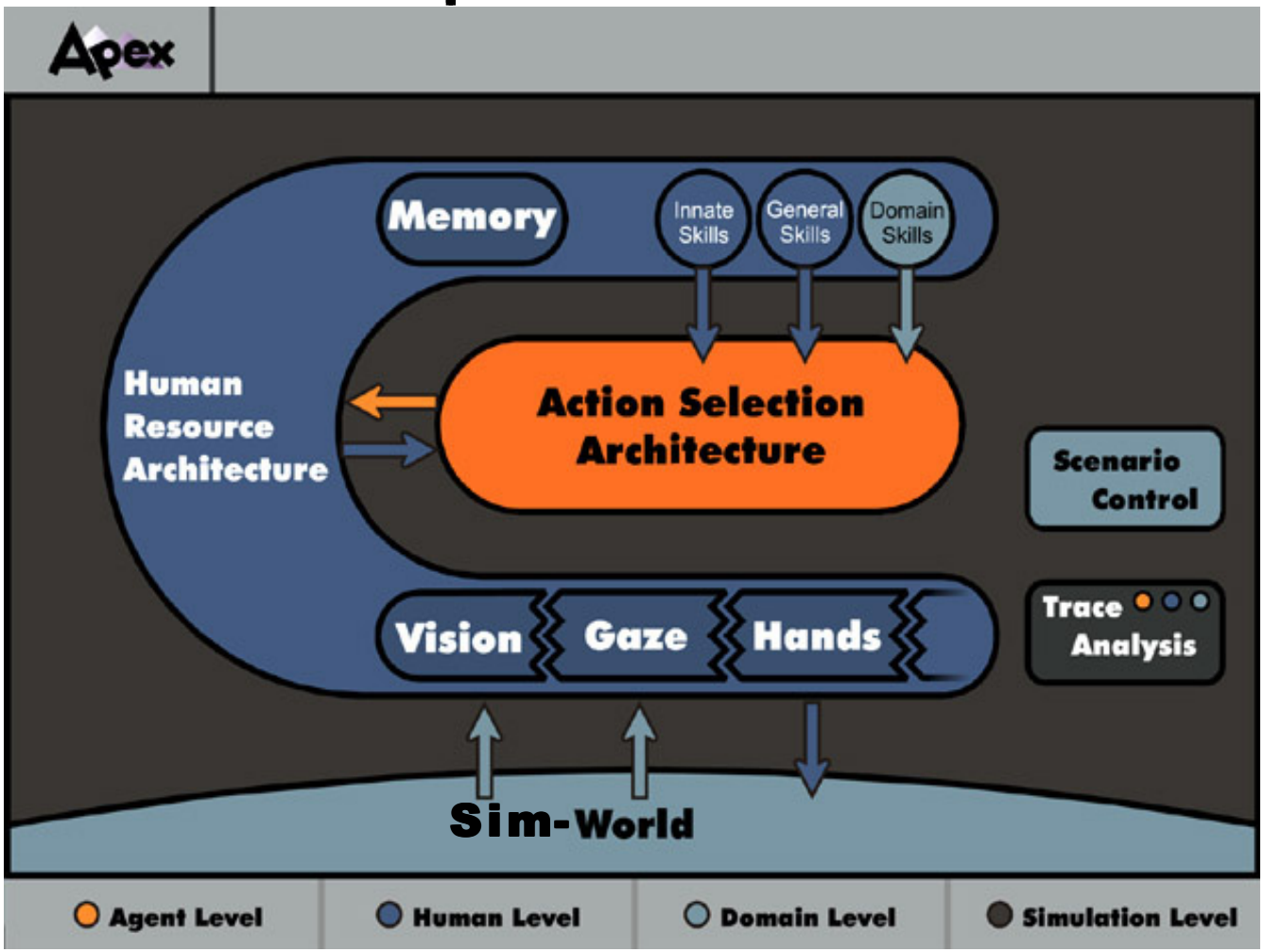
Apex approach

Apex simulates an agent planning and scheduling its limited resources to accomplish multiple task goals

Knowledge is represented as procedures

It's intended to be a flexible architecture that allows the modeler to implement a theory that specifies the constraints on parallel execution of procedures

The Apex Architecture



Task (Goal) Decomposition

Action Selection Architecture

Reactive planner

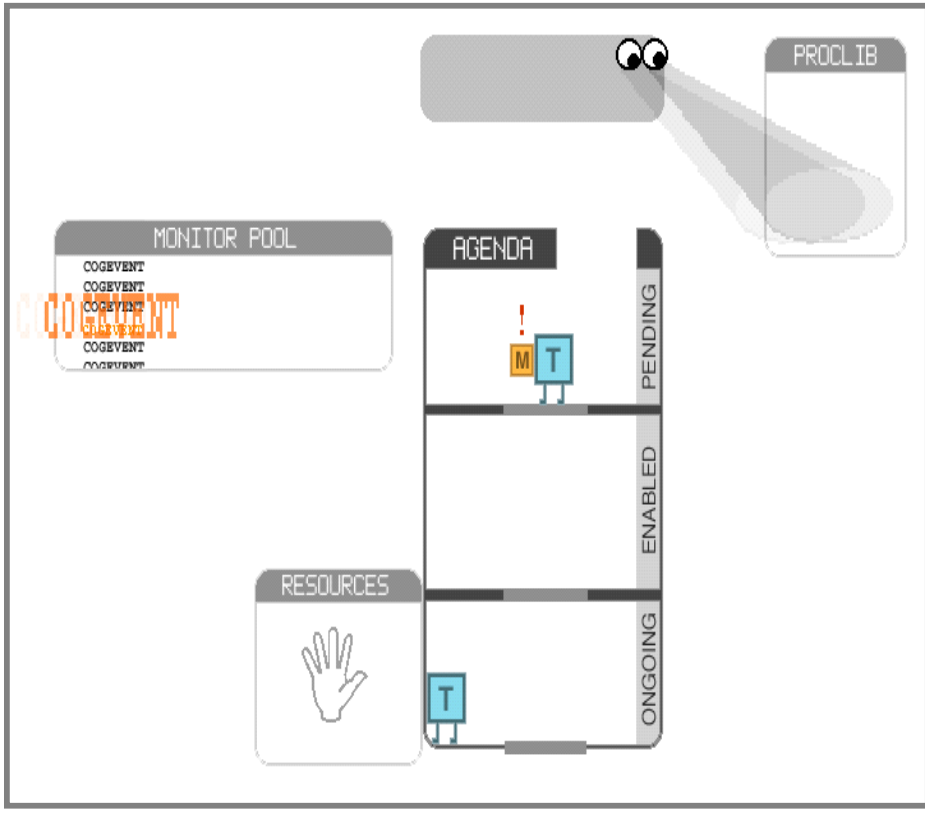
- Sketchy plans
- Hierarchical task decomposition
- Multitasking (Interruption)

Maximizes parallel processing

- Resource constraints
- Data dependencies

A Language for representing domain and human models

- Procedure Definition Language (PDL)



GOMS

GOALS	OPERATORS	METHODS	ELECTION

GOMS Components

Task Analysis

- **Goals**: Tasks decompose into nested hierarchy of goals and subgoals
- **Operators**: Hierarchy terminates in operators, whose actions cause transitions between states
- **Methods**: Sequences of operators executed to accomplish a set of subgoals
- **Selection Rules**: Rules that determine which method to use

Performance Computation

- Operator execution takes time
- Sequence of operators determines sequence of overt behaviors and task time

Varieties of GOMS

Keystroke-Level-Model (KLM)

- Flat task structure
- Mentally prepare coupled with primitive

Card-Moran-Newell GOMS (CMN-GOMS)

- Hierarchical goal decomposition
- Primitive operators in task domain (e.g. move mouse)

Cognitive-Perceptual-Motor (CPM-GOMS)

- Combines hierarchical goal decomposition with primitive CPM resources based on Model Human Processor

Goal of CPM-GOMS

Model the time for highly skilled people to accomplish tasks by using methods made up of elementary Cognitive, Perceptual, and Motor operators

Create cognitively-plausible, reusable "templates" that capture the parallelism and constraints in these methods

Integrate templates into a model that allows predictions to flow from a CMN-GOMS task hierarchy

- Shield the analyst from the complexity of templates
- Keep the analyst in the task domain

"Highly Skilled"

KLM and CMN-GOMS predict human behavior well

- When the user knows the procedures of a domain well and is presented with a new task
- When operators can be assumed to work sequentially

CPM-GOMS is needed

- When task becomes so routine that users perform activities in parallel to achieve faster execution time
- Examples in the lab:
  - **Card, Moran & Newell, 1983, Chapter 8, Section 4.-- Text editing**
  - **Baskin & John, 1998 -- CAD**
  - **John, et. al., 2002 -- ATM**
- Example in the field
  - **Gray, et. al., 1993 -- Project Ernestine: telephone operator**

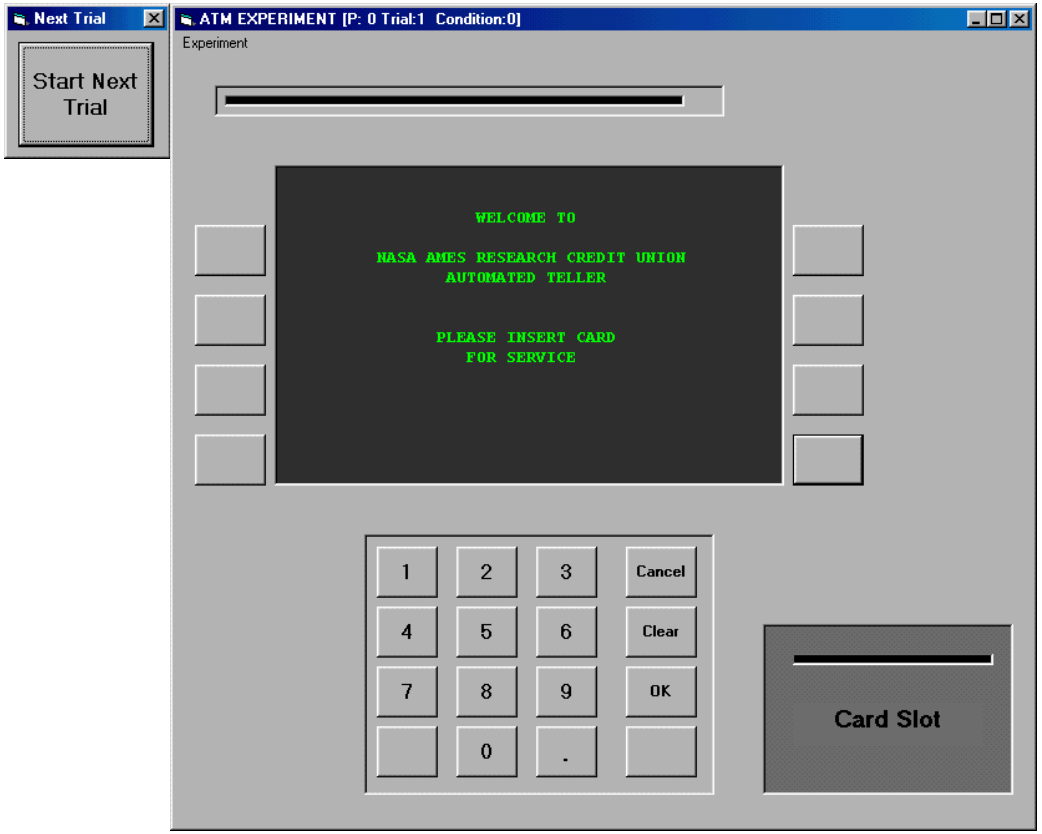
Project Ernestine

Gray, John, & Atwood (1993)

CPM-GOMS: Perhaps the most successful HCI technique.

Project Ernestine: application of CPM-GOMS saved Bell Atlantic millions of dollars per year

ATM Study

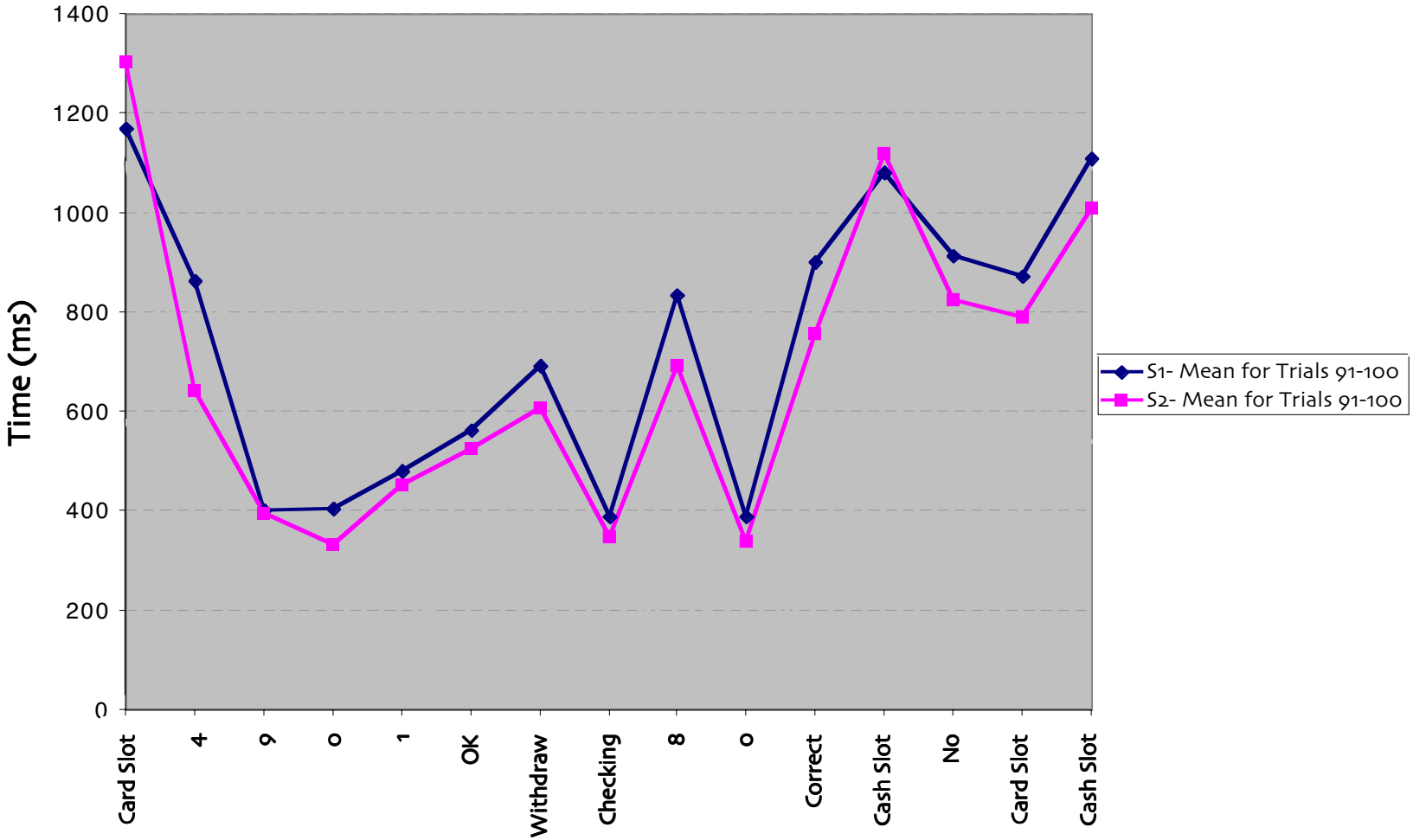


- 2 subjects
- 200 trials each

Steps:

Insert card (click card slot)
Enter PIN (4901)
Press OK
Select transaction type (withdraw)
Select account (checking)
Enter amount (80)
Press if correct/not correct? (correct)
Take cash (click cash slot)
Other Transaction (no)
Take card (click card slot)
Take receipt (click cash slot)

Subject Move-and-Click Times



Modeling with Templates

Templates are models of small units of behavior at the level of Cognitive, Perceptual, and Motor resources

- Button pressing
- Mouse move-and-click
- Typing

Allow long sequences of behavior to be constructed from small unit tasks

Allow generality across task domains

Templates for Moving and Clicking Mice

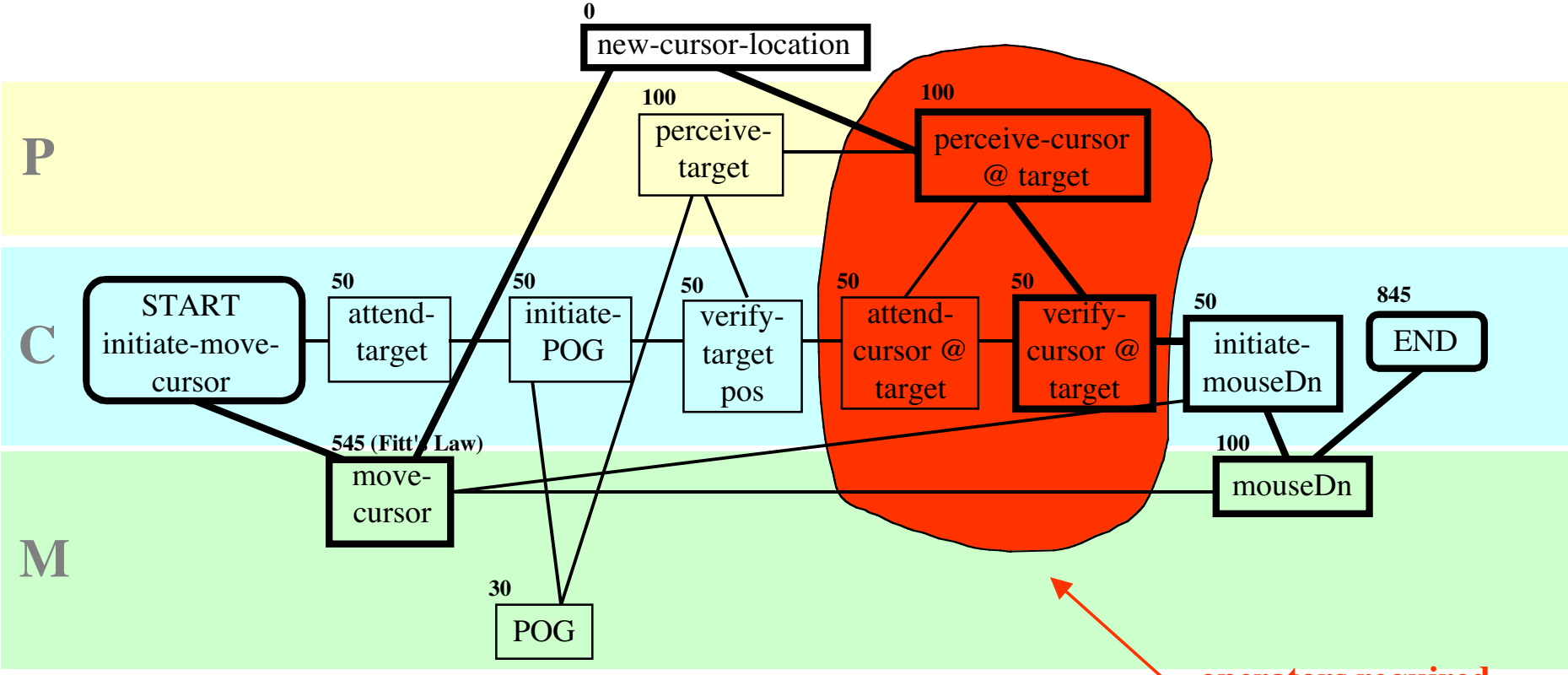
Gray & Boehm-Davis (2001)

Identified distinct micro-strategies that arise with practice in repetitive perceptual-motor tasks

Developed templates that model mouse move-and-click micro-strategies

- Slow mouse-move-and-click
- Fast mouse-move-and-click

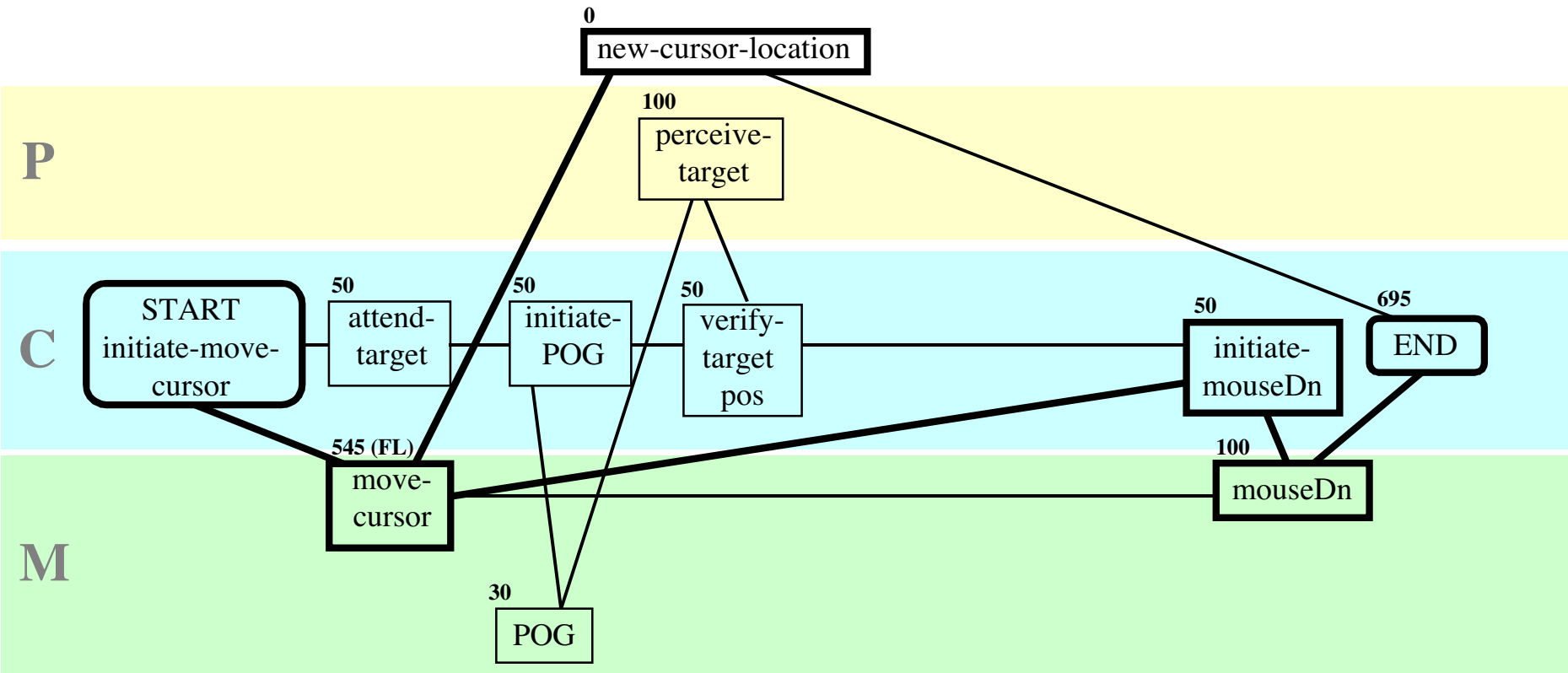
SLOW MOVE-CLICK



operators required to verify that cursor is in button

- from *Gray and Boehm-Davis (2001)*

FAST MOVE-CLICK



- from *Gray and Boehm-Davis (2001)*

Constructing sequences of behavior from templates

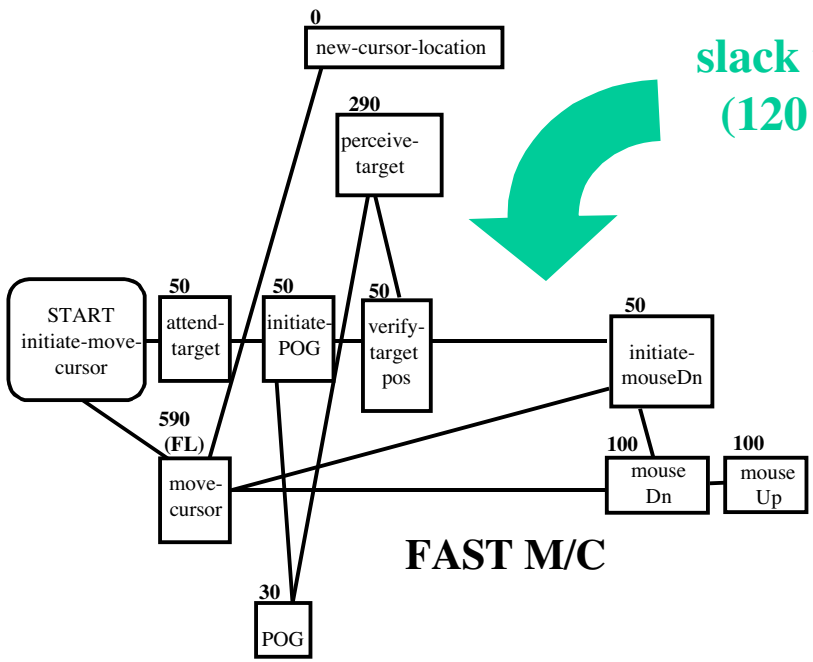
Can't just stick templates end-to-end

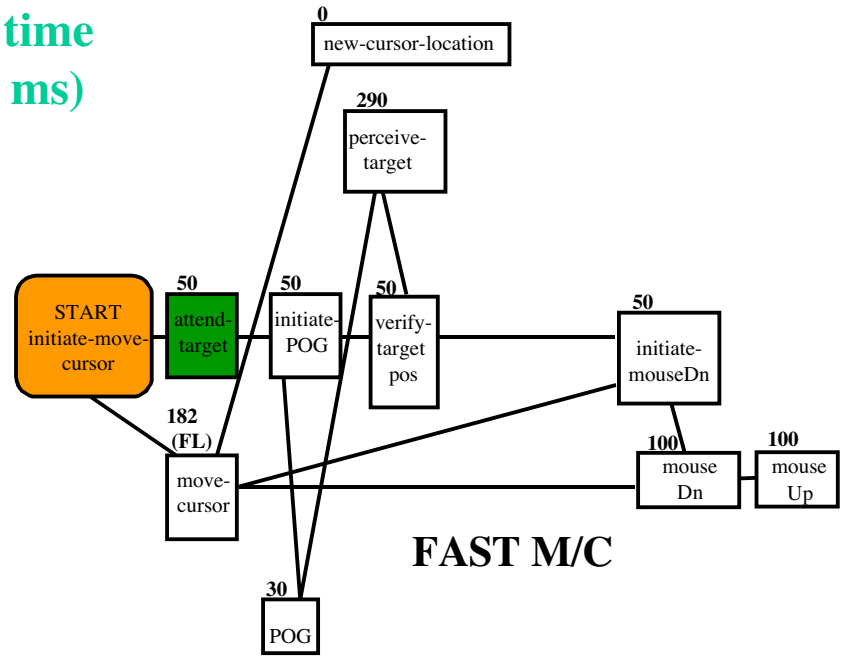
- Overestimates the time
- Fails to capture parallelism in human behavior

Interleave templates

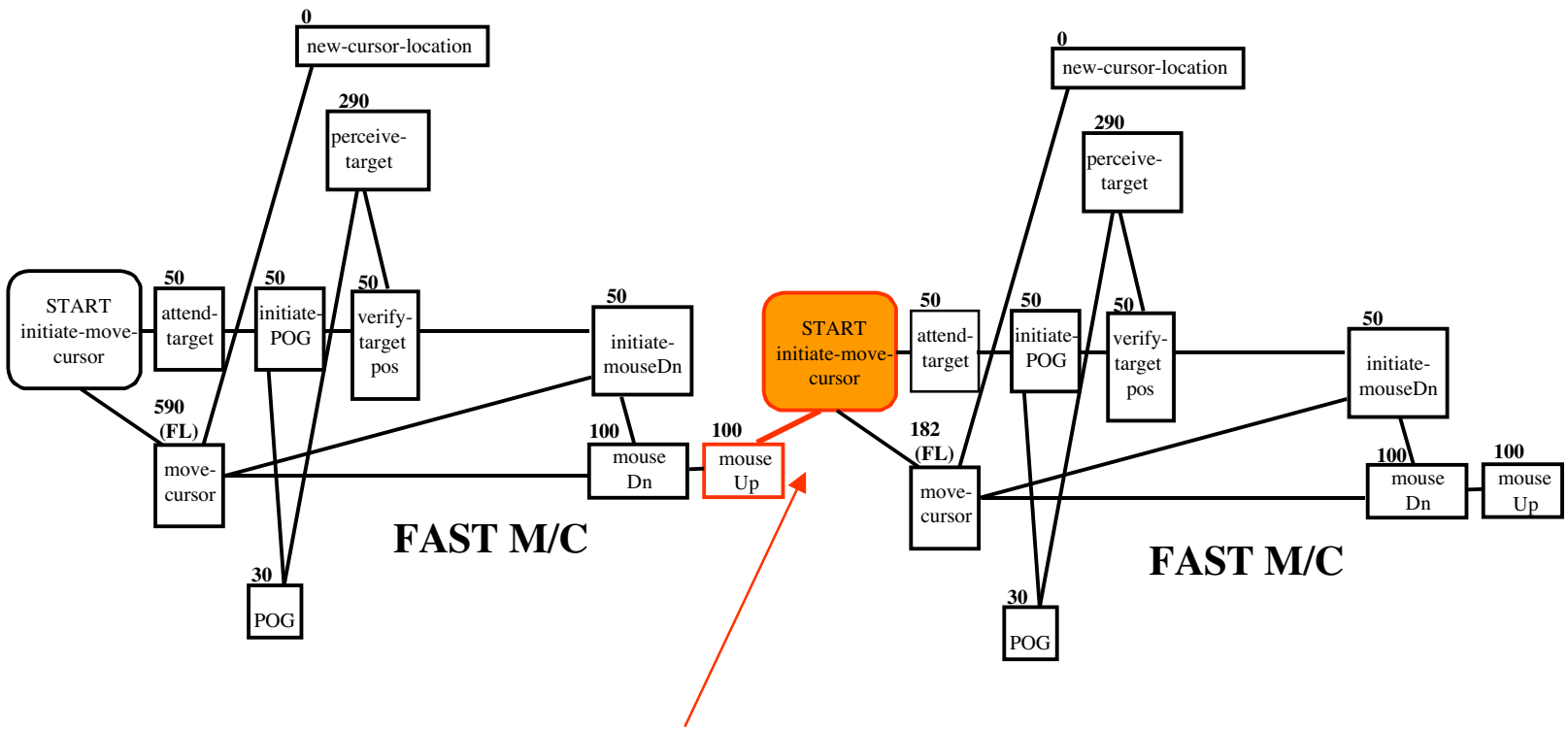
- Execute **Cognitive** operators from a later template in the slack time in an active template
- Must consider logical and resource dependencies
- Interleaving embodies a theory of human parallel processing

Interleaving Templates



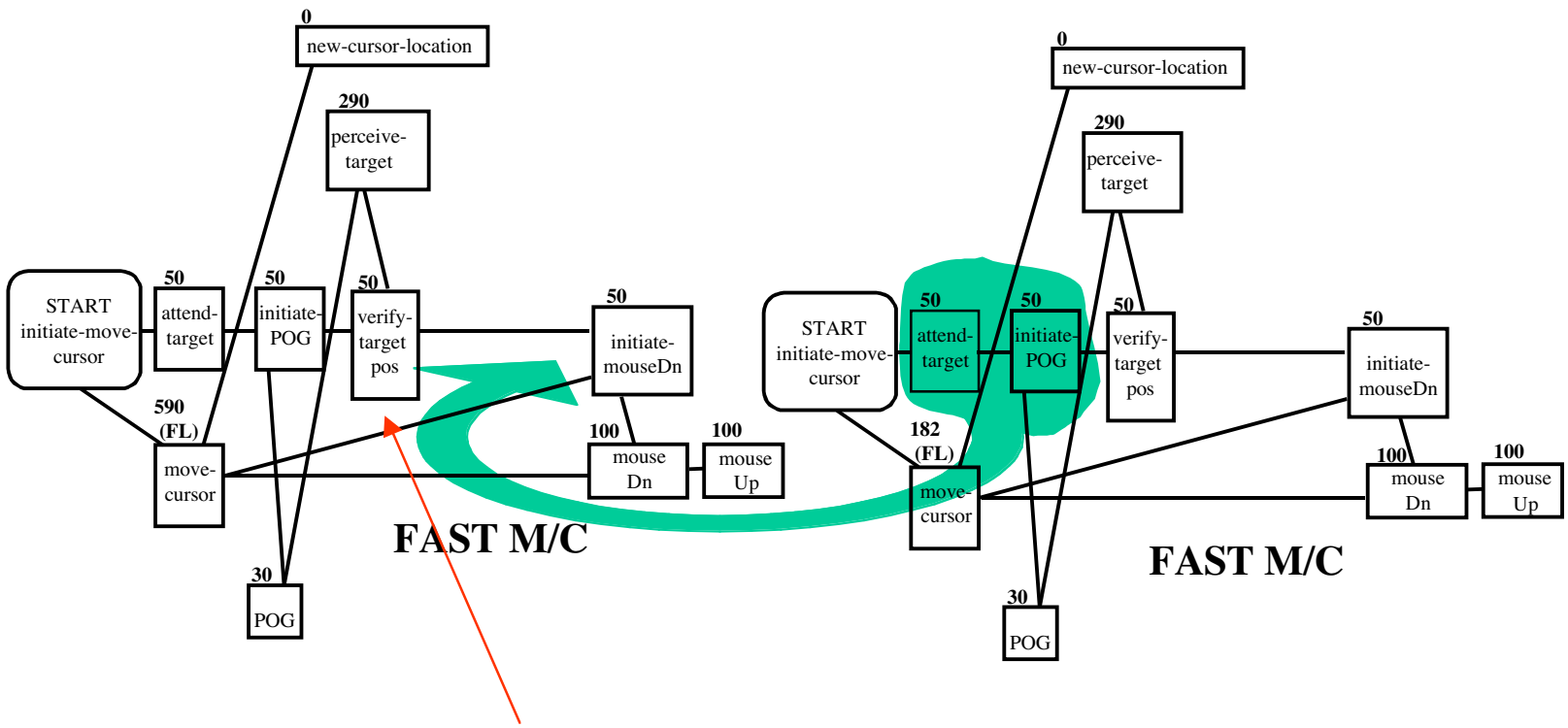


Interleaving Templates



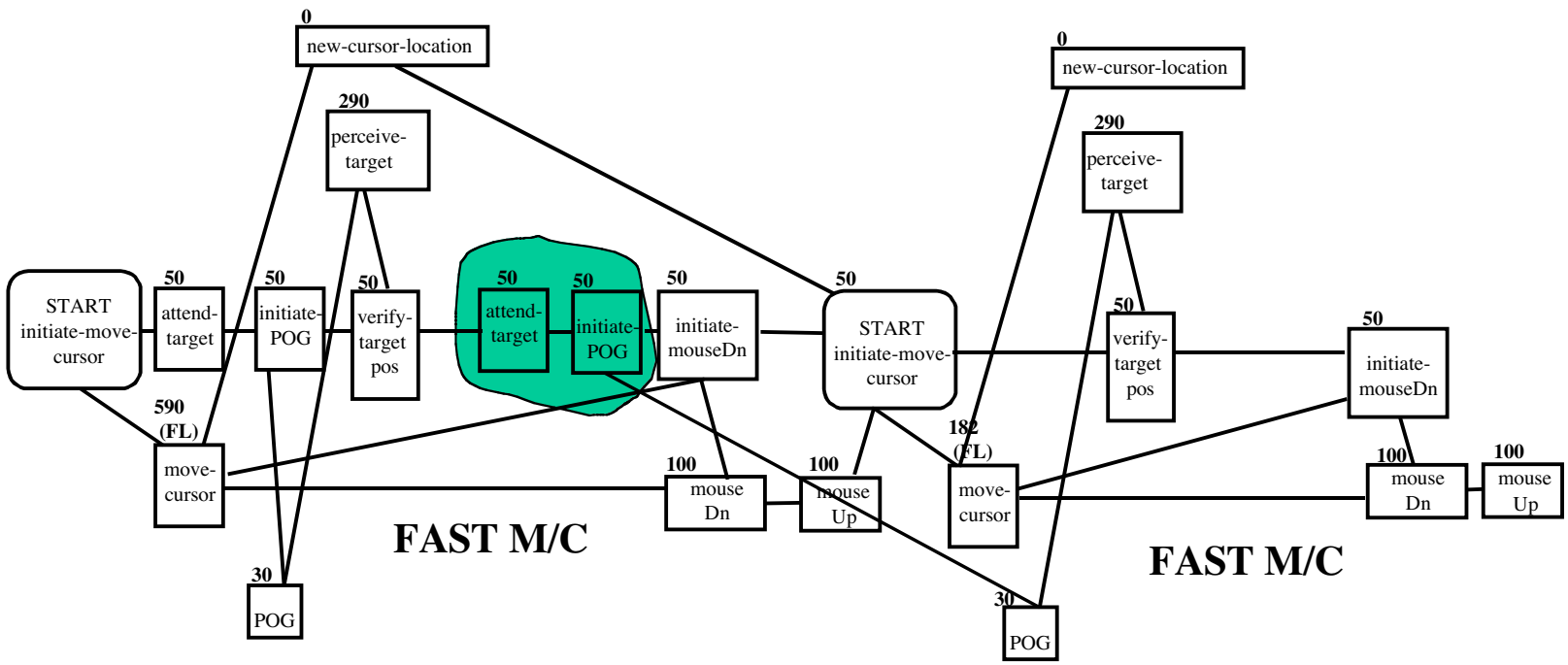
initiate move cursor cannot precede the last motor action with the same hand in the previous operator

Interleaving Templates



last vision action in the previous operator

Interleaving Templates



A CPM-GOMS Model of a Portion of the ATM Task

insert card (slow M/C)

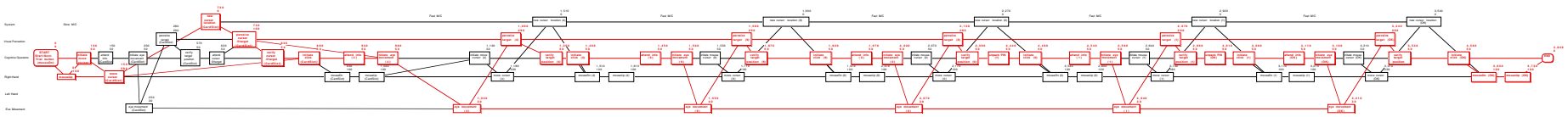
4 key (fast M/C)

9 key (fast M/C)

0 key (fast M/C)

1 key (fast M/C)

OK (fast M/C)



This part of the model describes ~ 5 sec of behavior, and it took over 6 hours

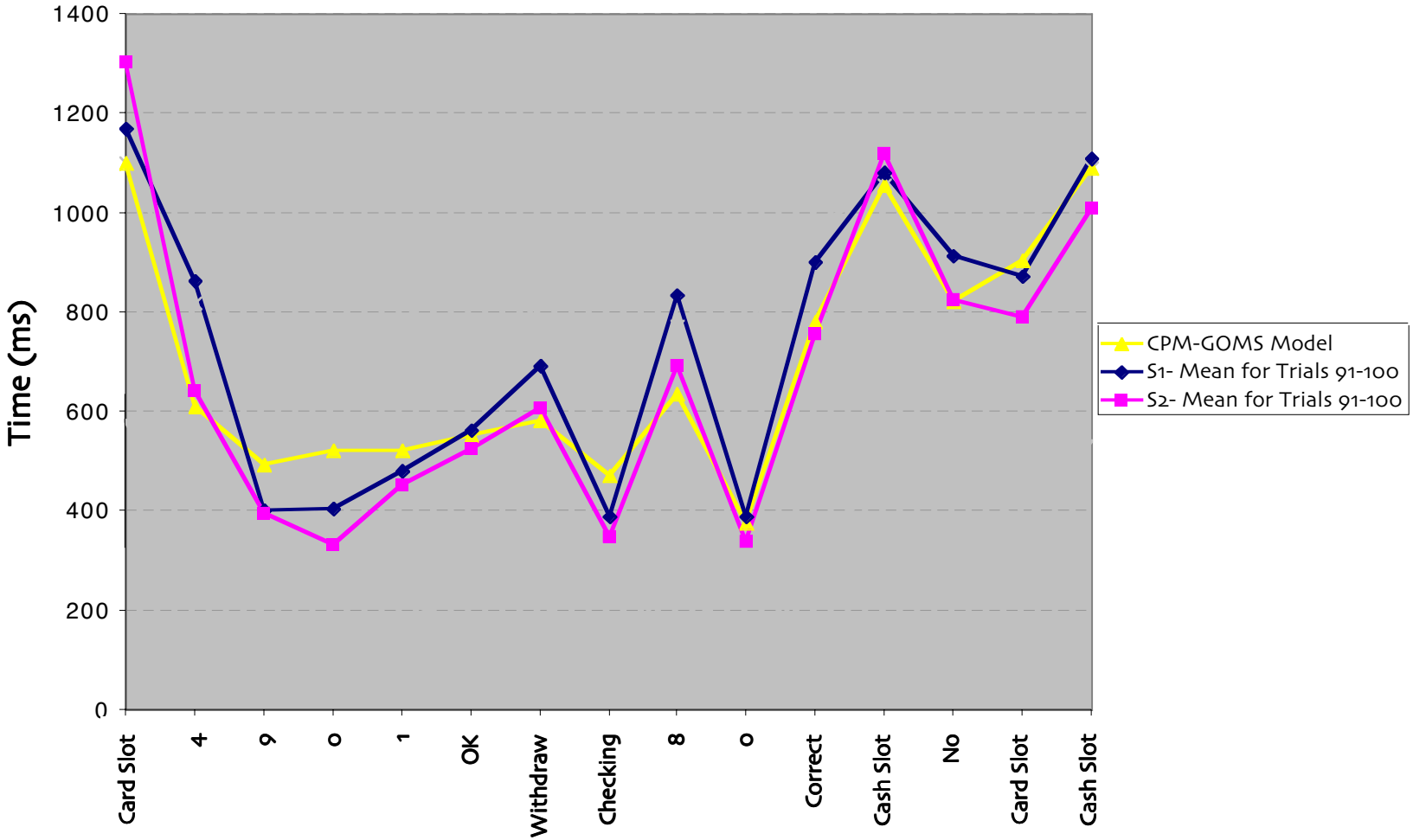
Expert Rules for Interleaving

In-depth interviews and discussions with two CPM-GOMS experts (Alonso Vera and Bonnie John)

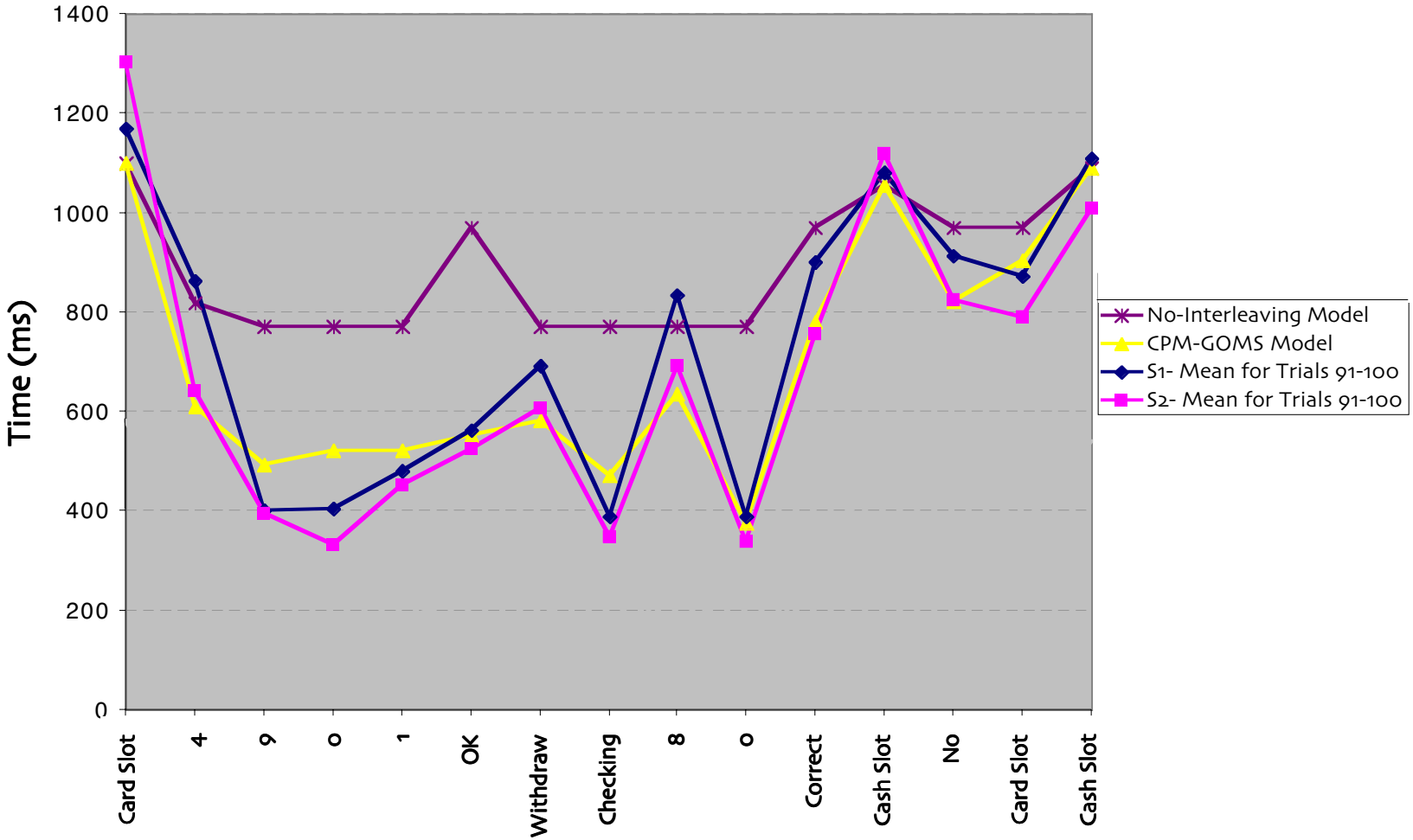
At each boundary between templates, for each operator, ask…

1. Is the candidate operator a cognitive initiate action for resource X? If yes,
2. Is there enough slack time at the end of the first template to allow interleaving? If so,
3. Are there any logical dependencies preventing the candidate cognitive operator from interleaving? If not,
4. Have all operators of the same type in the previous template that use X completed? If yes,
5. Interleave the candidate operator and GOTO 1.

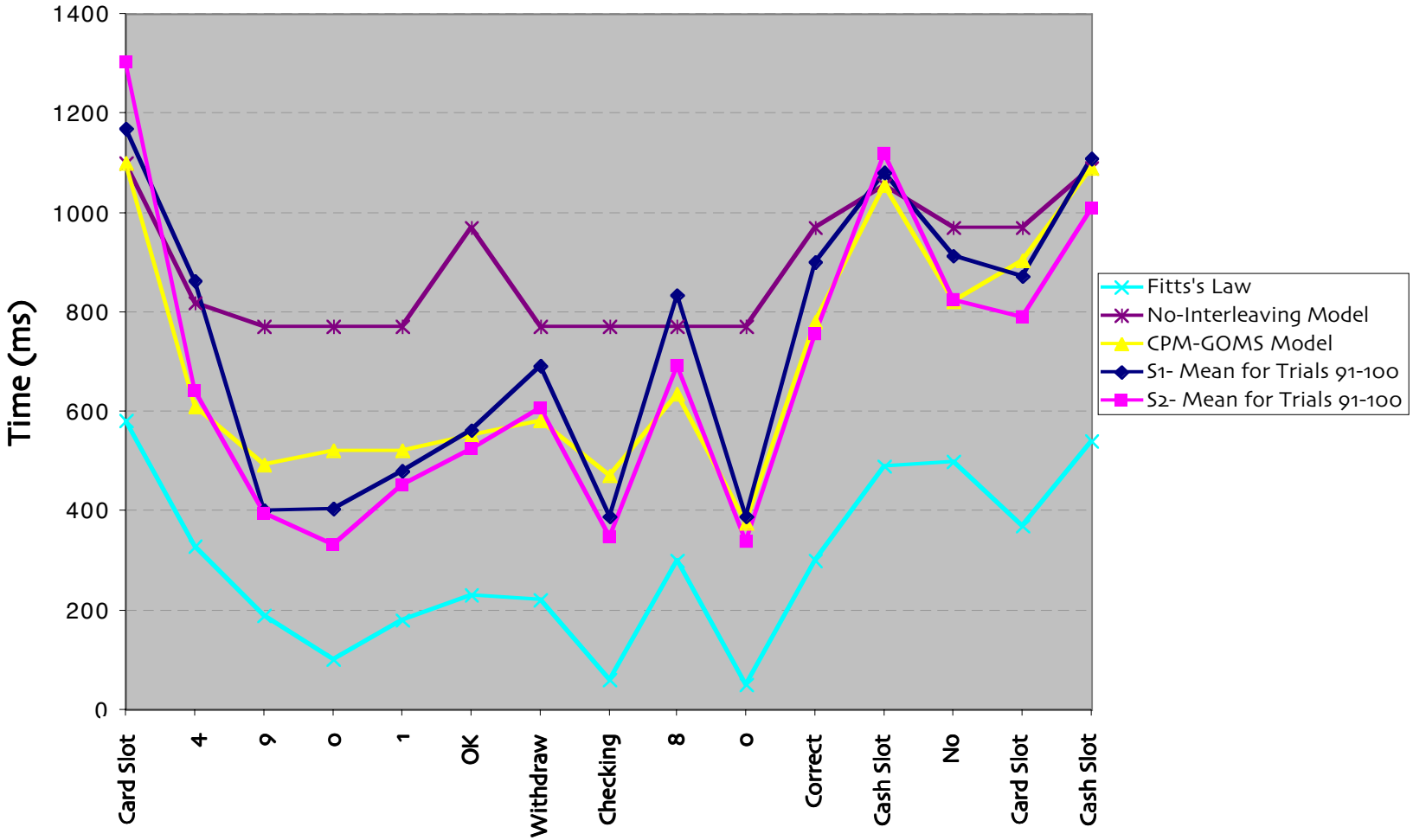
Human/Model Comparisons: CPM-GOMS model built with Apex



Human/Model Comparisons: No Interweaving



Human/Model Comparisons: Fitts's Law only



Significance

Ability to model large-scale, dynamic environments

- Automated resource scheduling (template interleaving) makes it feasible to tackle complex environments
- Templates provide a pre-packaged theory module
- Templates constitute a library of reusable software modules

Capability to realize the latent potential of CPM-GOMS for providing generic level of modeling human-system interaction

Capability of going from theories of information processing to macroscopic world of flight deck or air traffic control

Website

ftp://eos.arc.nasa.gov/outgoing/apex/apex

- Latest versions of Apex (Apex 2.2b4)
- Macintosh and PC
- Some of the worlds
- Documentation
- Instructions on downloading and running
- Patches
- We are trying to update it regularly to keep it current

FY'02 Milestones

Develop requirements for a cognitive modeling architecture that supports rapid reconfiguration of human performance models

- Vera, A., Remington, R., Matessa, M., John, B.E., Freed, M.A. (2002). Automating human-performance modeling at the millisecond level. *Journal of Human-Computer Interaction* (submitted)
- John, B., Vera, A., Matessa, M., Freed, M., & Remington, R.W. (2002). Automating CPM-GOMS. Annual meeting of ACM SigCHI, April 22-25, Minneapolis, MN.
- Freed, M. & **Remington, R.W.** (2000). Making human-machine system simulation a practical engineering tool: An Apex overview. In *Proceedings of the 2000 International Conference on Cognitive Modeling* Groningen, Holland.

Develop a computational architecture that can interact with the external simulation environments specified for VAMS system builds

Outyear milestones

- Demonstrate interoperability with external software or simulation environment (12/02)
- Provide preliminary models of controller and aircrew for Build 1 that model delays introduced by human operators (5/03)
- Investigate and model human multitasking characteristics relevant to aircrew, controller, and dispatch operations (9/03)
- Provide models of controller, aircrew, and dispatch that extend preliminary models by including multitasking applied to specific concepts (9/04)
- Investigate human factors issues associated with supervisory control in teams for concepts involving other decision agents, including humans and automation (e.g., super-sector) (9/04)
- Incorporate aircrew, controller, and dispatcher models into modeling toolbox (9/05)