Automating Hierarchical Goal Decomposition in Apex

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HEM Workshop
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Human Performance Modeling

"When viewed from these perspectives, human error can be discovered in thoughtful, detailed models of robust, successful human performance!"

– Dick Pew (via Steve Deutsch), HEM Workshop

Modeling Expert Performance

- A powerful way to understand expert performance is to:
  - represent procedural knowledge, skills, and interaction with the context in which behavior occurs as **g**oals, **m**ethods and **s**election rules
  - achieved with the execution of low-level **o**perators (i.e., the actual sequence of behaviors observed during task performance)

Applied HCI
Cognitive Modeling Tools

- Make computational cognitive modeling more accessible to non-specialists
- Re-use and automation of modeling components

Overview

- GOMS and CPM-GOMS
- Reusable HCI behavior templates
- Automating CPM-GOMS with Apex
- Example Model

GOMS

The Psychology of Human Computer Interaction
Card, Moran & Newell, 1983

- GOMS
- MHP

- **G**oals, **O**perators, **M**ethods, and **S**election Rules
- Methodology for task analysis and prediction/ modeling of human behavior based on hierarchical goal decomposition
- **CMN-GOMS**

GOMS

The Psychology of
Human Computer Interaction
Card, Moran & Newell, 1983

- GOMS
- MHP

- **Model Human Processor**
- separate parallel processors for perception, cognition, motor
- each with associated cycle times

e.g.,	cognitive operator	50 ms
	eye movement	30 ms
	basic motor action	100 ms

GOMS

The Psychology of
Human Computer Interaction
Card, Moran & Newell, 1983

- GOMS
- MHP
- NGOMSL - Natural Language GOMS

GOMS

The Psychology of
Human Computer Interaction
Card, Moran & Newell, 1983

- GOMS
- MHP
- CPM-GOMS

GOMS

The Psychology of Human Computer Interaction
Card, Moran & Newell, 1983

- GOMS
- MHP
- CPM-GOMS

- **Cognitive, Perceptual, Motor**
- parallel resource activities, assigned empirically derived times
- John (1996) - TYPIST
- Project Ernestine (Gray, John, & Atwood (1993)
- Templates for HCI behavior

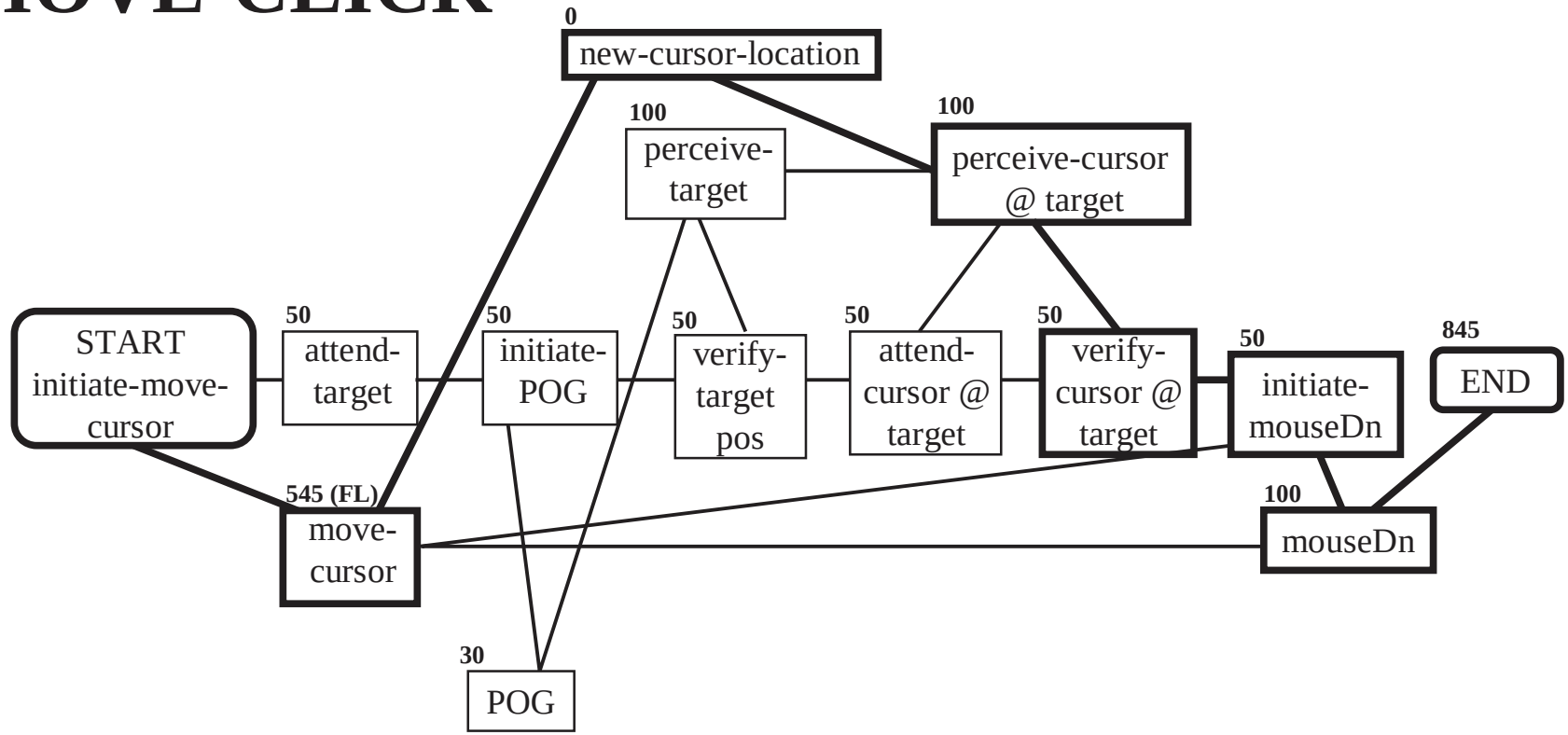
Reusable Templates

- Package the abundance of data on human perceptual, cognitive, and motor phenomena into a set of HCI behavioral primitives, or templates, (e.g., mousing to a target) that can be directly incorporated into models
- Templates reduce the amount of psychology and modeling methodology required to build models
  - Compile the human performance data into templates
  - Focus the modeler on task analysis

Reusable Templates

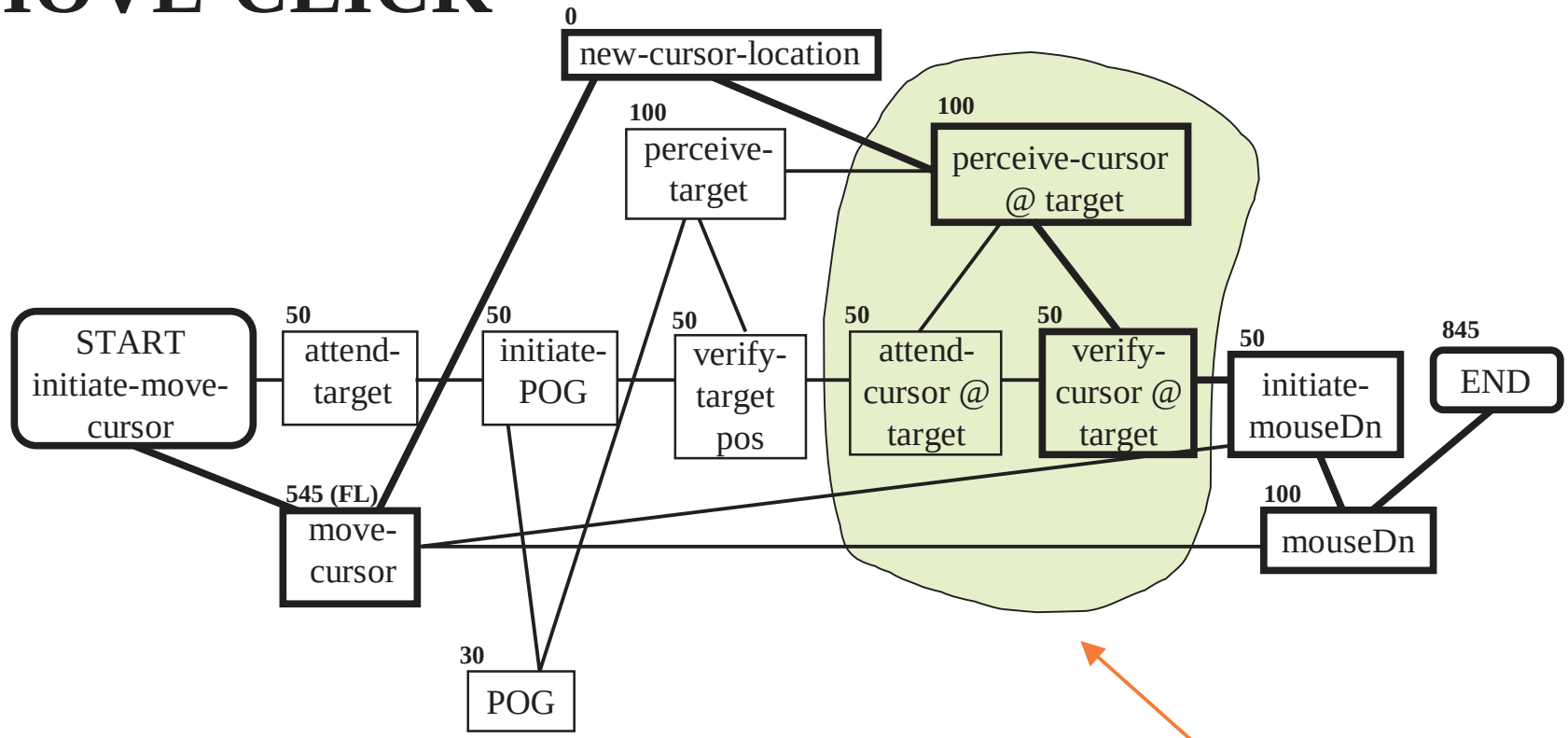
- Cognitive modeling has made wide use of general performance characteristics
  - Fitts's Law
  - Vision/perception
  - Working memory capacity & latency
  - Speaking and reading rates
- Some have been incorporated into larger modules
  - Keystroke templates (John & Gray, 1992; Gray, John, & Atwood, 1993)
  - Auditory & verbal templates (John & Gray, 1992; Gray, et al., 1993)
  - Conversation (John & Gray, 1992; Gray, et al., 1993)
  - Transcript typing (John,1996)
  - Mouse move-and-click routines (Gray & Boehm-Davis, 2000)

SLOW MOVE-CLICK



- from *Gray and Boehm-Davis (2000)*

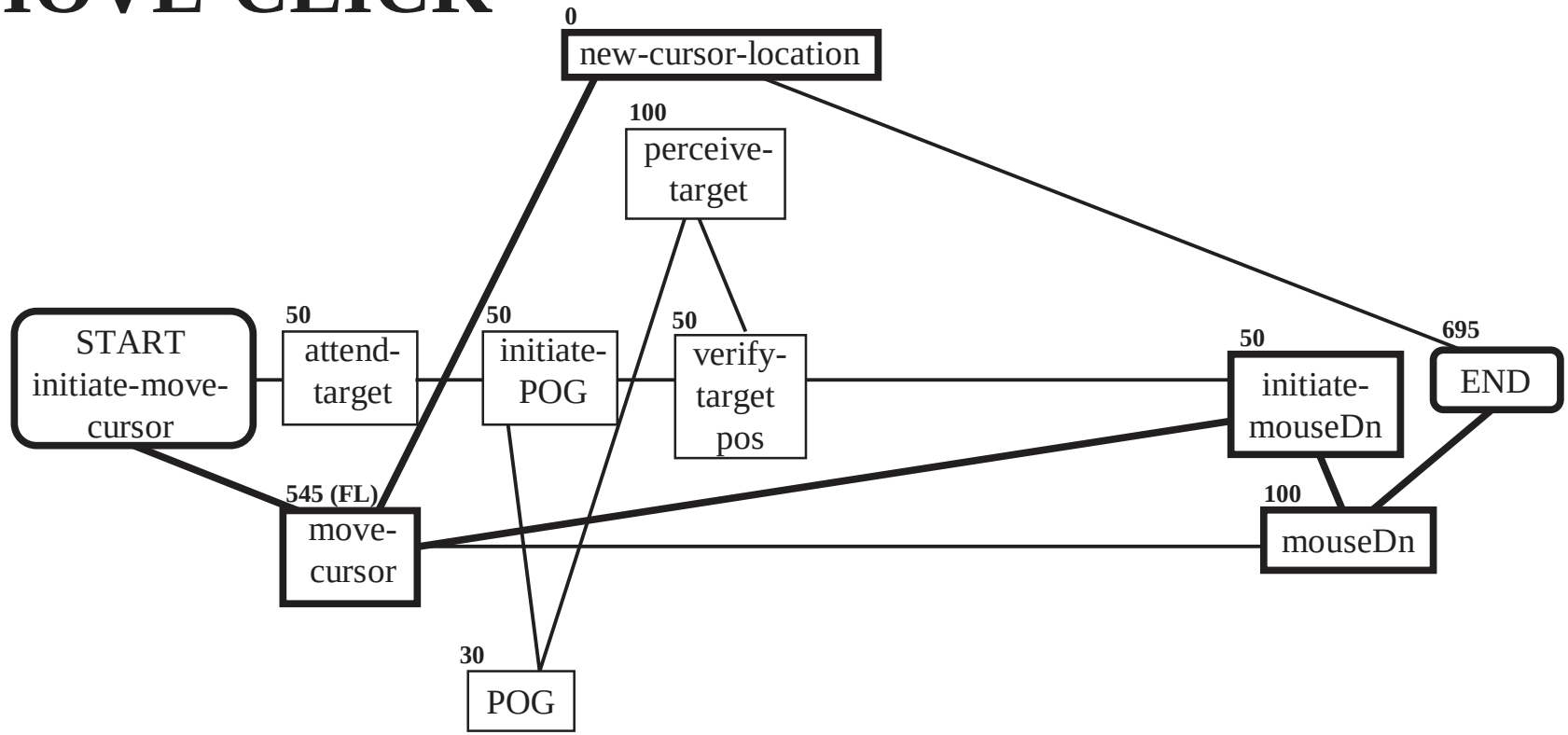
SLOW MOVE-CLICK



operators required to verify that cursor is in button

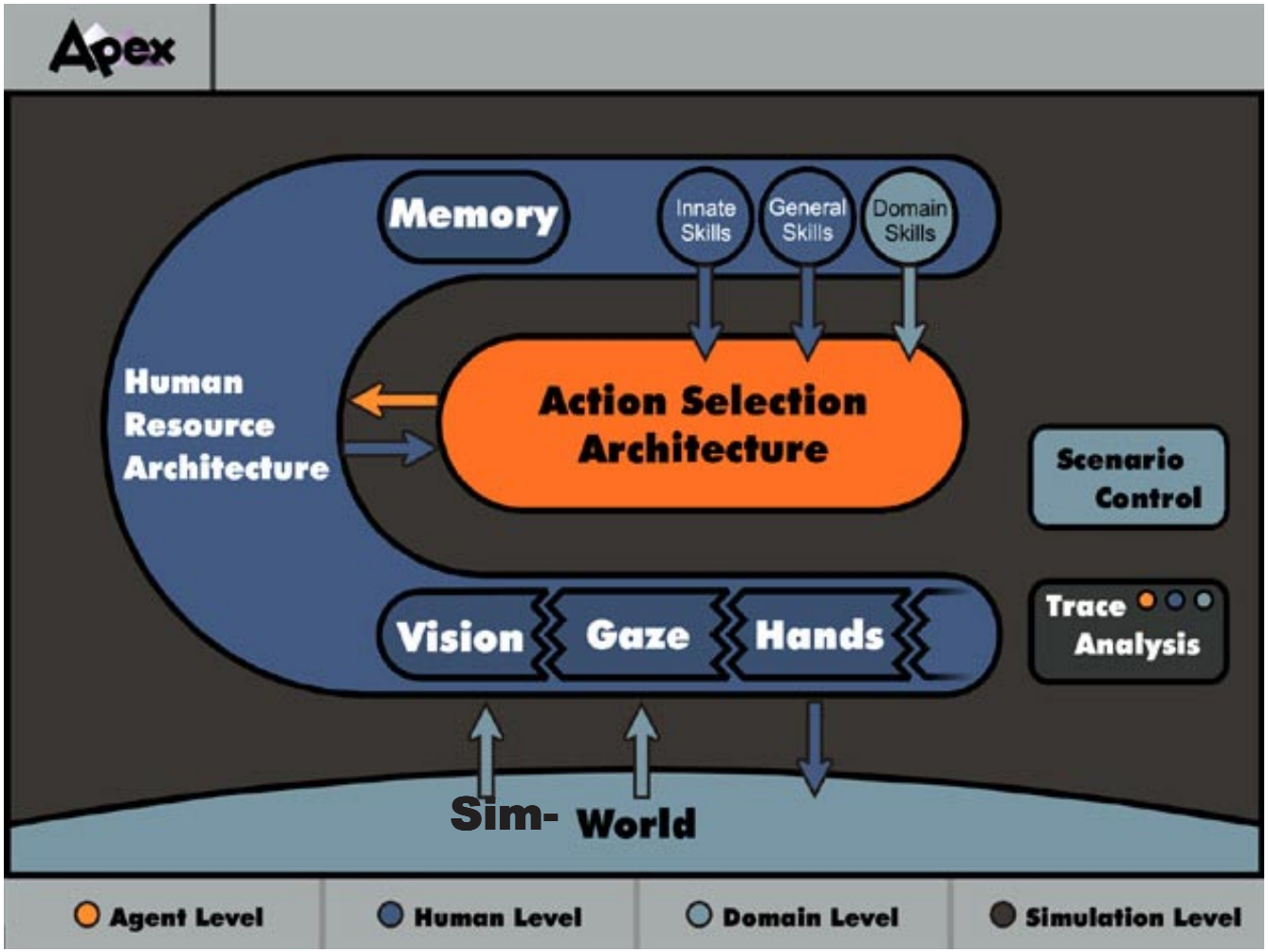
- from *Gray and Boehm-Davis (2000)*

FAST MOVE-CLICK



- from *Gray and Boehm-Davis (2000)*

The Apex Architecture



The Human Resource Architecture

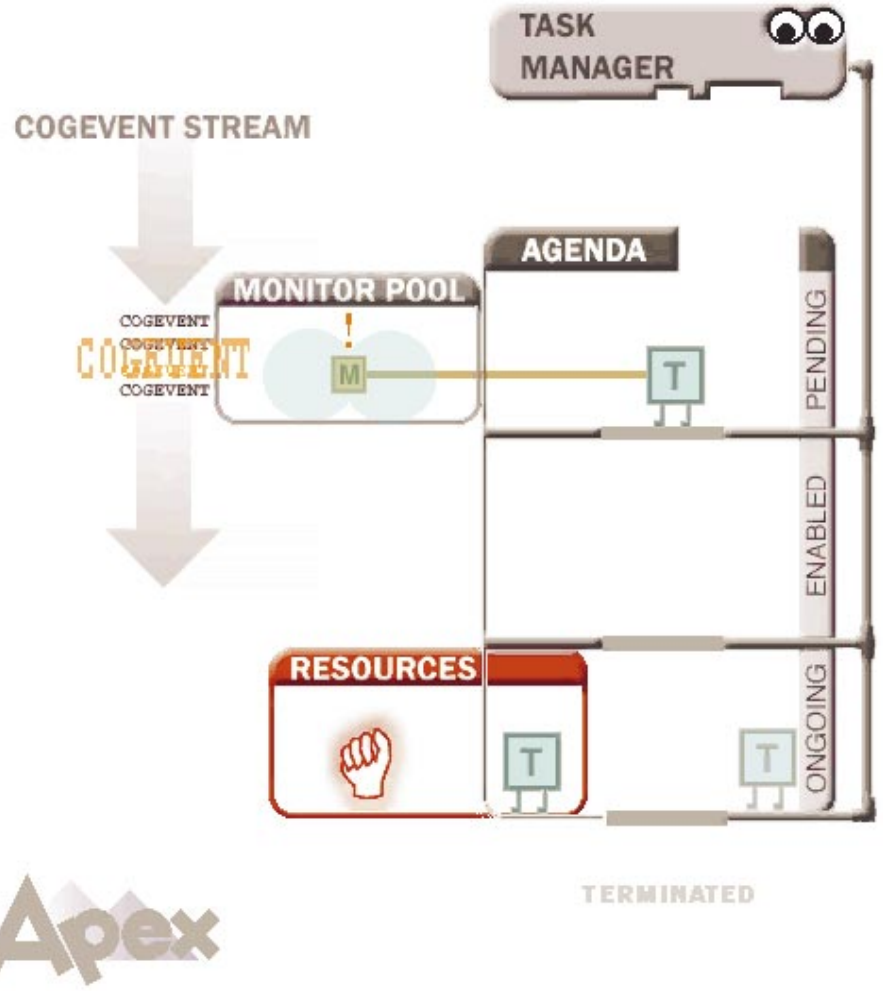
- Simulates the activities of perceptual, cognitive, and motor processing
- Captures processing times and resource constraints

Three main types of resources:

- **cognition**
- **vision/perception**
- **motor**

The Action Selection Architecture

- Implements a reactive planner that supports
  - Sketchy plans
  - Hierarchical task decomposition



A CMN-GOMS Model

- get money from an ATM
- start with a goal-based hierarchical decomposition

A CMN-GOMS Model of ATM

- **do banking**
  - **initiate session**
    - **insert card**
    - **enter password**
      - **enter 4**
      - **enter 9**
      - **enter 0**
      - **enter 1**
      - **enter OK**
  - **do transaction**
    - **choose withdraw**
    - **choose account**
    - **enter amount**
      - **enter 8**
      - **enter 0**
      - **enter correct**
    - **retrieve money**
  - **end session**
    - **enter no** [more transactions]
    - **retrieve card**
    - **retrieve receipt**

Hierarchical Task Decomposition in PDL

```
(procedure
  (index (do banking))
  (step s1 (initiate session))
  (step s2 (do transaction) (waitfor ?s1))
  (step s3 (end session) (waitfor ?s2))
  (step s4 (terminate) (waitfor ?s3)))

(procedure
  (index (initiate session))
  (step s1 (insert card))
  (step s2 (enter password) (waitfor ?s1))
  (step s3 (terminate) (waitfor ?s2)))
```

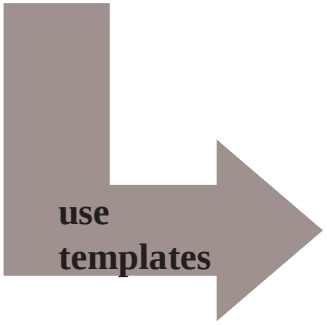
CMN-GOMS (incomplete)

- **do banking**
  - **initiate session**
    - **insert card**
    - **enter password**
  - **do transaction**
  - **end session**

Procedure Description Language: the Apex formalism for writing models

CPM-GOMS PDL

```
(procedure
 (index (choose withdraw))
 (step s2 (terminate) (waitfor ?s1)))
```



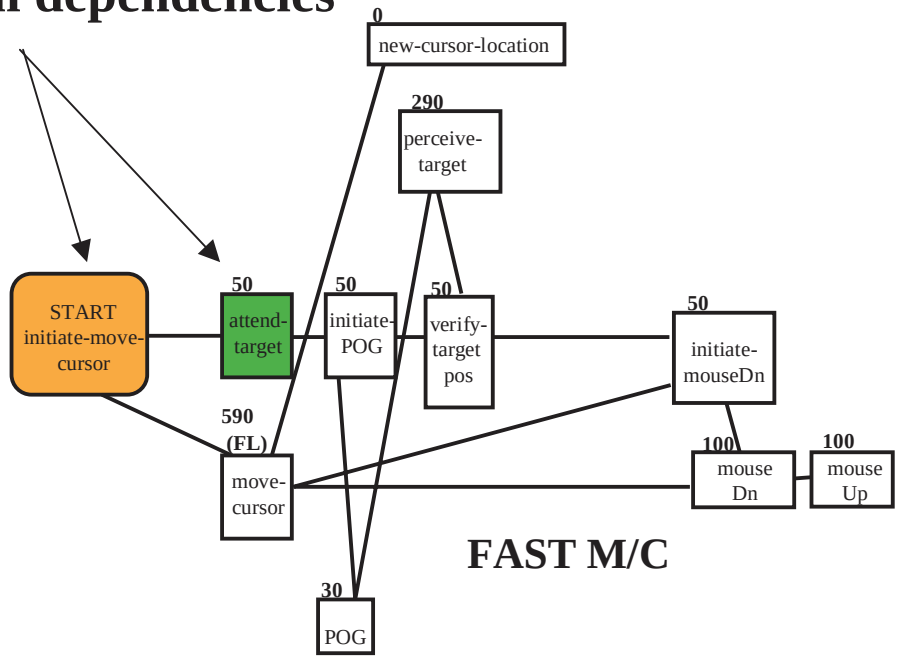

```
(procedure
 (index (choose withdraw))
 (step s1 (fast-move-click withdraw-key))
 (step s2 (terminate) (waitfor ?s1)))
```

CPM-GOMS & Templates

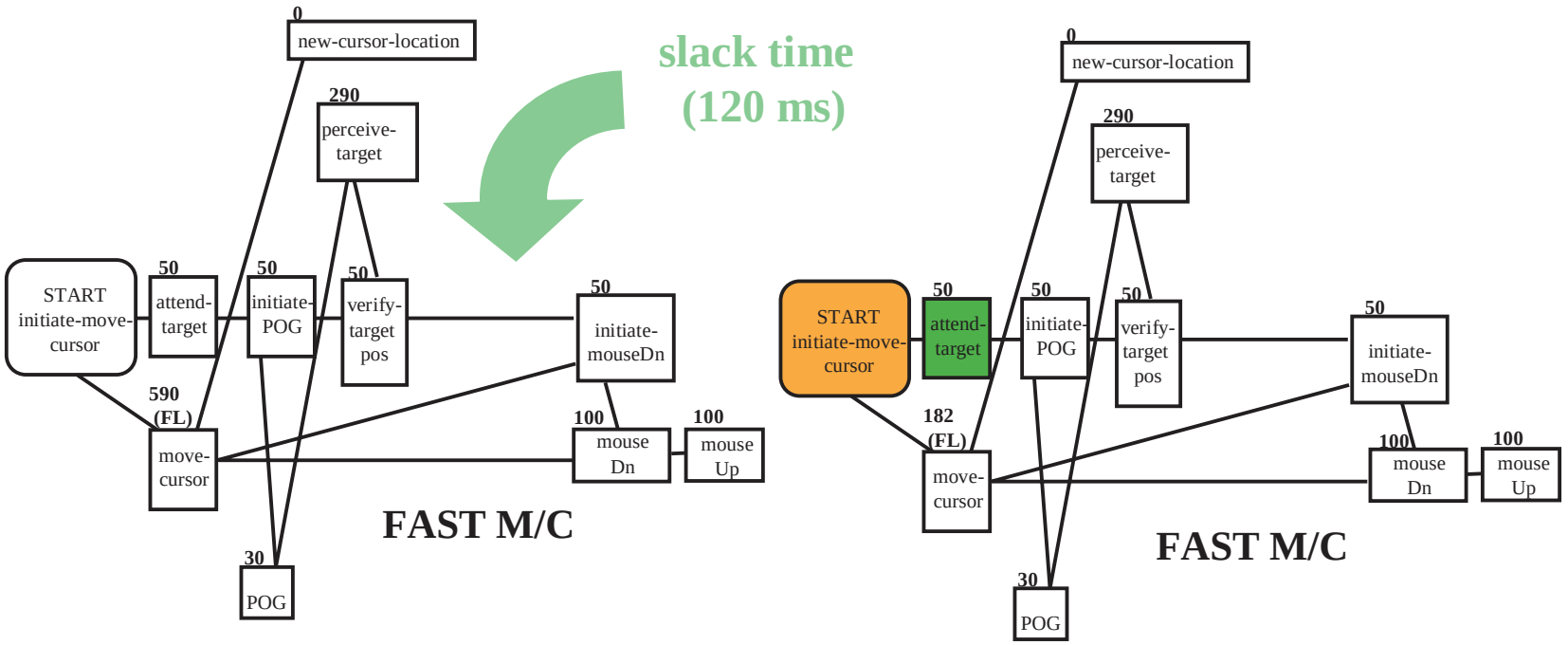
- CPM-GOMS joins CMN-GOMS with MHP-level timing predictions utilizing resource parallelism for steps at the lowest levels in the hierarchy
- To create a model of a task like withdrawing money from an ATM, one needs to string together the appropriate templates

Interleaving Templates

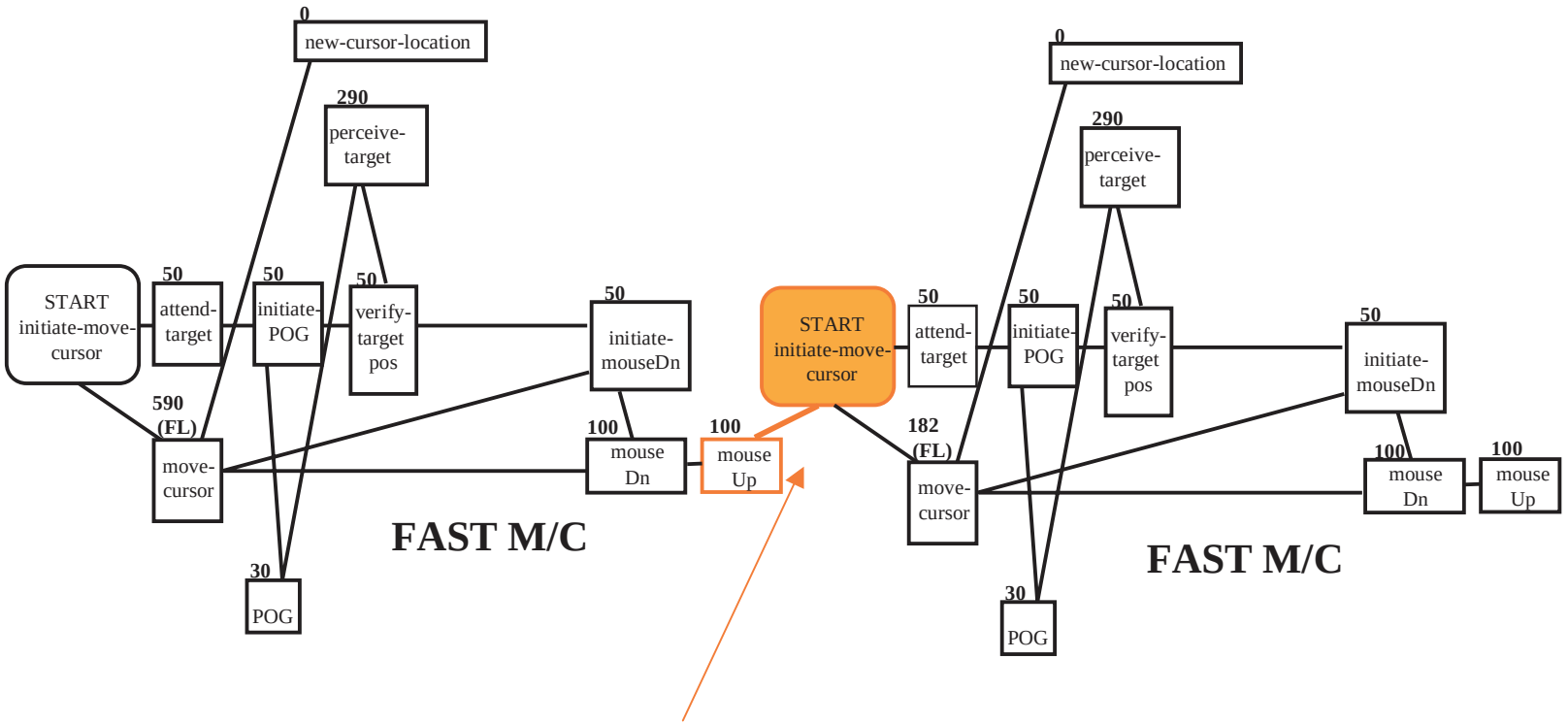
within a template these do not have logical dependencies



Interleaving Templates

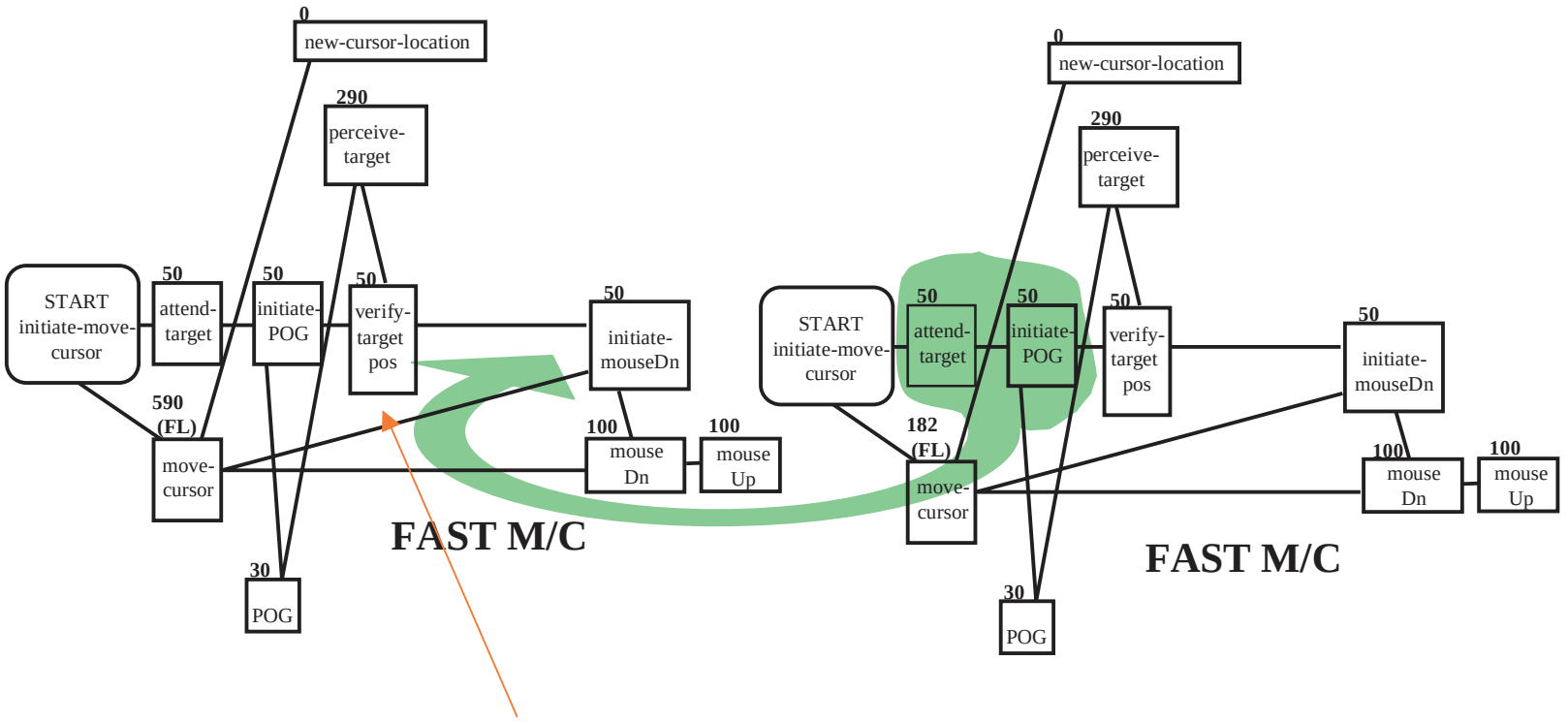


Interleaving Templates



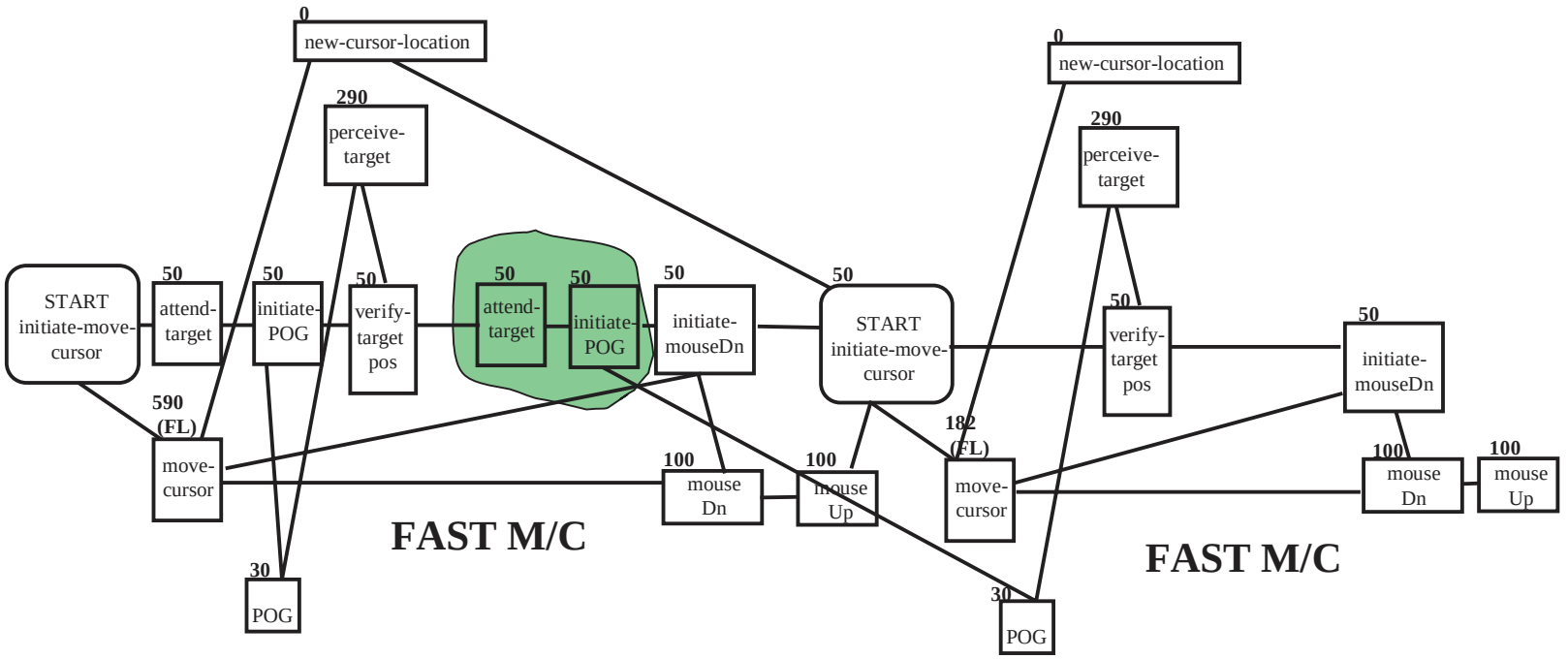
initiate move cursor cannot precede the last motor action with the same hand in the previous operator

Interleaving Templates



last vision action in the previous operator

Interleaving Templates



Summary of Interleaving Procedure

At each boundary between templates, ask…

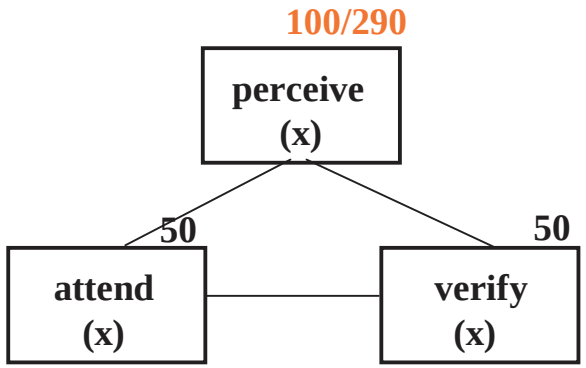
1. Is there enough slack time at the end of the first template to allow any of the cognitive operators at the beginning of the next template to interleave? If so,
2. Are there any logical dependencies preventing a candidate cognitive operator from interleaving? If not,
3. Interleave the candidate operator and GOTO 1.

How to Make a CPM-GOMS Model in 5 Hours or More

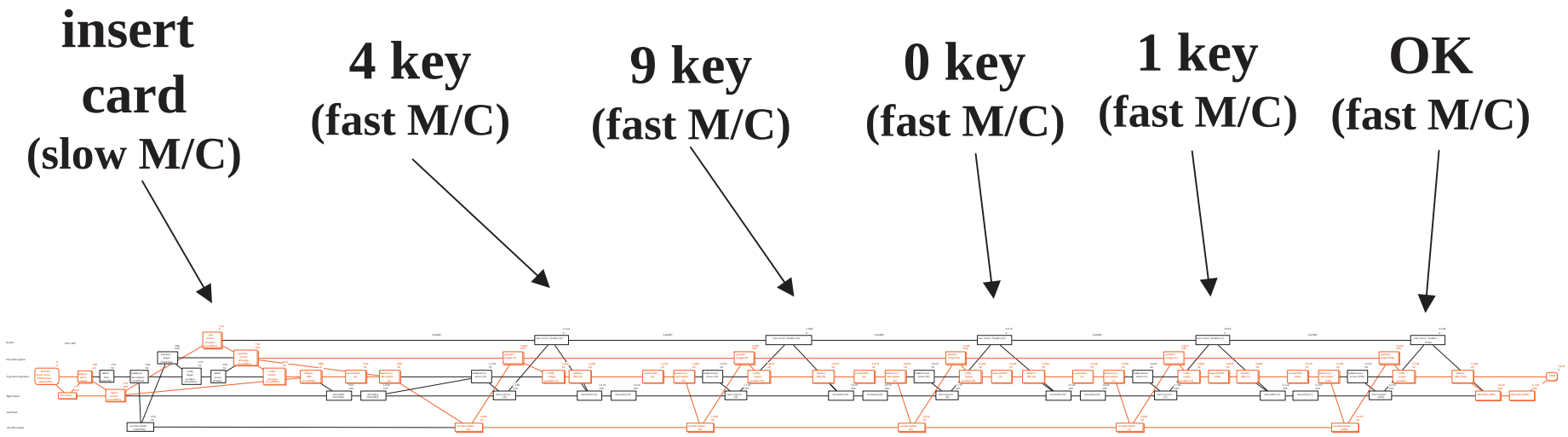
- Create serial CMN-GOMS model with templates at bottom of hierarchy
- By hand, Copy&Paste the appropriate sequence of pre-created templates into MacProject®
  - ATM task needs 15 templates, about 15 screensful, 10 pages printed out
- Think hard about interleaving at each boundary of the templates

How to Make a CPM-GOMS Model in 5 Hours or More

- By hand:
  - change duration parameters
  - fill in names of operator targets (x)



A CPM-GOMS Model of the ATM Task



-constructing CPM-GOMS models by hand is labor-intensive and error prone (this part of the model took over 6 hours with MacProject®)

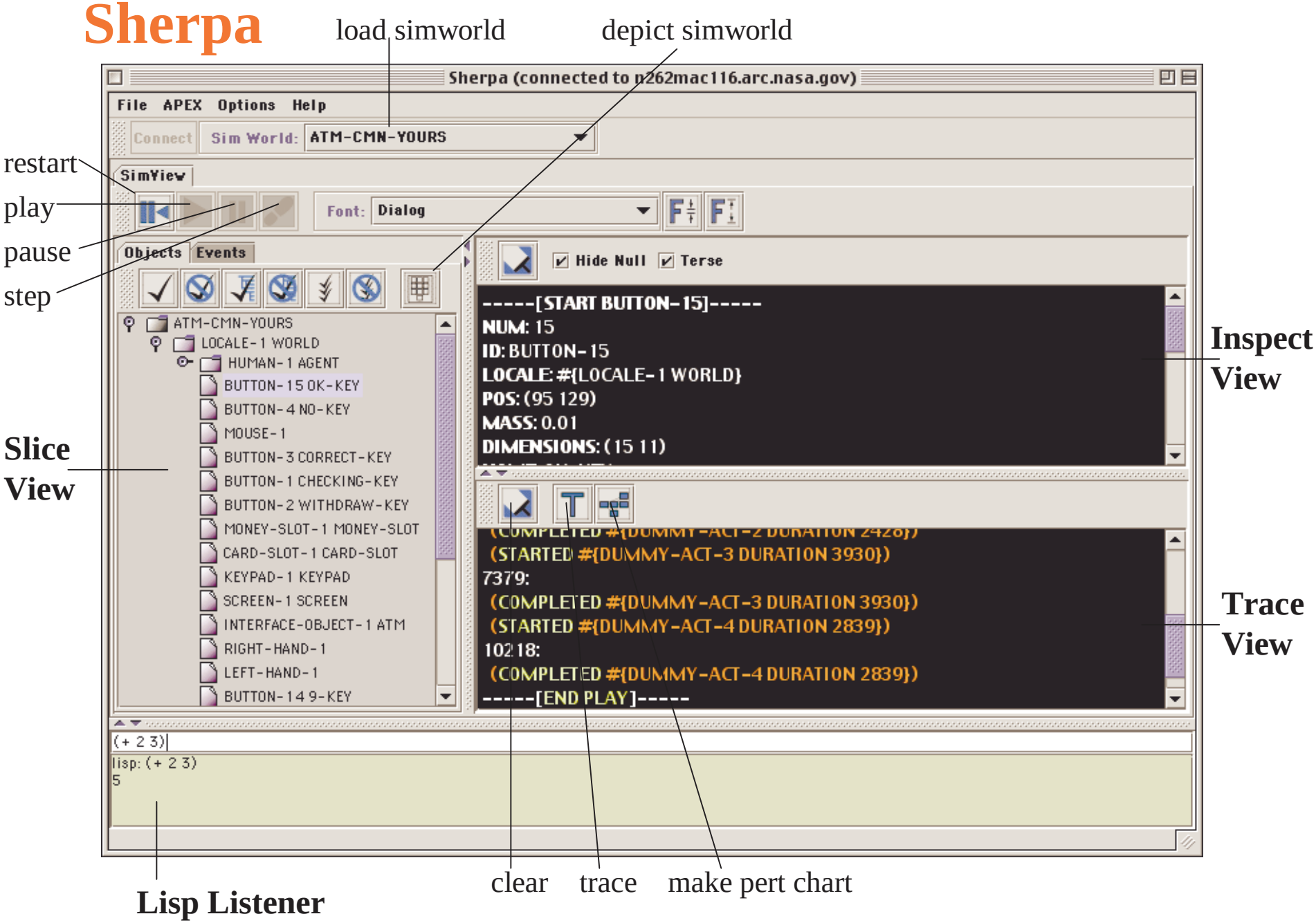
How Apex does it in 5 Minutes or Less

- Create serial CMN-GOMS model with templates at bottom of hierarchy
- Implement the CMN in PDL, simply calling procedures that contain pre-created templates at the bottom
- Run the PDL program
- Press the PERT-chart button

Sherpa

- Graphical interface with multiple view and interactive capabilities:
- Views:
  - runtime
  - PDL
  - scenario
  - objects
- Facilitates process of model construction and analysis of output

Sherpa


load simworld
depict simworld
restart
play
pause
step
Sherpa (connected to n262mac116.arc.nasa.gov)
File APEX Options Help
Connect
Sim World: ATM-CMN-YOURS
SimView
Font: Dialog
Objects
Events
Hide Null
Terse
ATM-CMN-YOURS
LOCALE-1 WORLD
HUMAN-1 AGENT
BUTTON-15 OK-KEY
BUTTON-4 NO-KEY
MOUSE-1
BUTTON-3 CORRECT-KEY
BUTTON-1 CHECKING-KEY
BUTTON-2 WITHDRAW-KEY
MONEY-SLOT-1 MONEY-SLOT
CARD-SLOT-1 CARD-SLOT
KEYPAD-1 KEYPAD
SCREEN-1 SCREEN
INTERFACE-OBJECT-1 ATM
RIGHT-HAND-1
LEFT-HAND-1
BUTTON-14 9-KEY
-----[START BUTTON-15]-----
NUM: 15
ID: BUTTON-15
LOCALE: #{LOCALE-1 WORLD}
POS: (95 129)
MASS: 0.01
DIMENSIONS: (15 11)
(STARTED #{DUMMY-ACT-3 DURATION 3930})
7379:
(COMPLETED #{DUMMY-ACT-3 DURATION 3930})
(STARTED #{DUMMY-ACT-4 DURATION 2839})
10218:
(COMPLETED #{DUMMY-ACT-4 DURATION 2839})
-----[END PLAY]-----
(+ 2 3)
lisp: (+ 2 3)
5
Inspect View
Slice View
Trace View
Lisp Listener
clear
trace
make pert chart

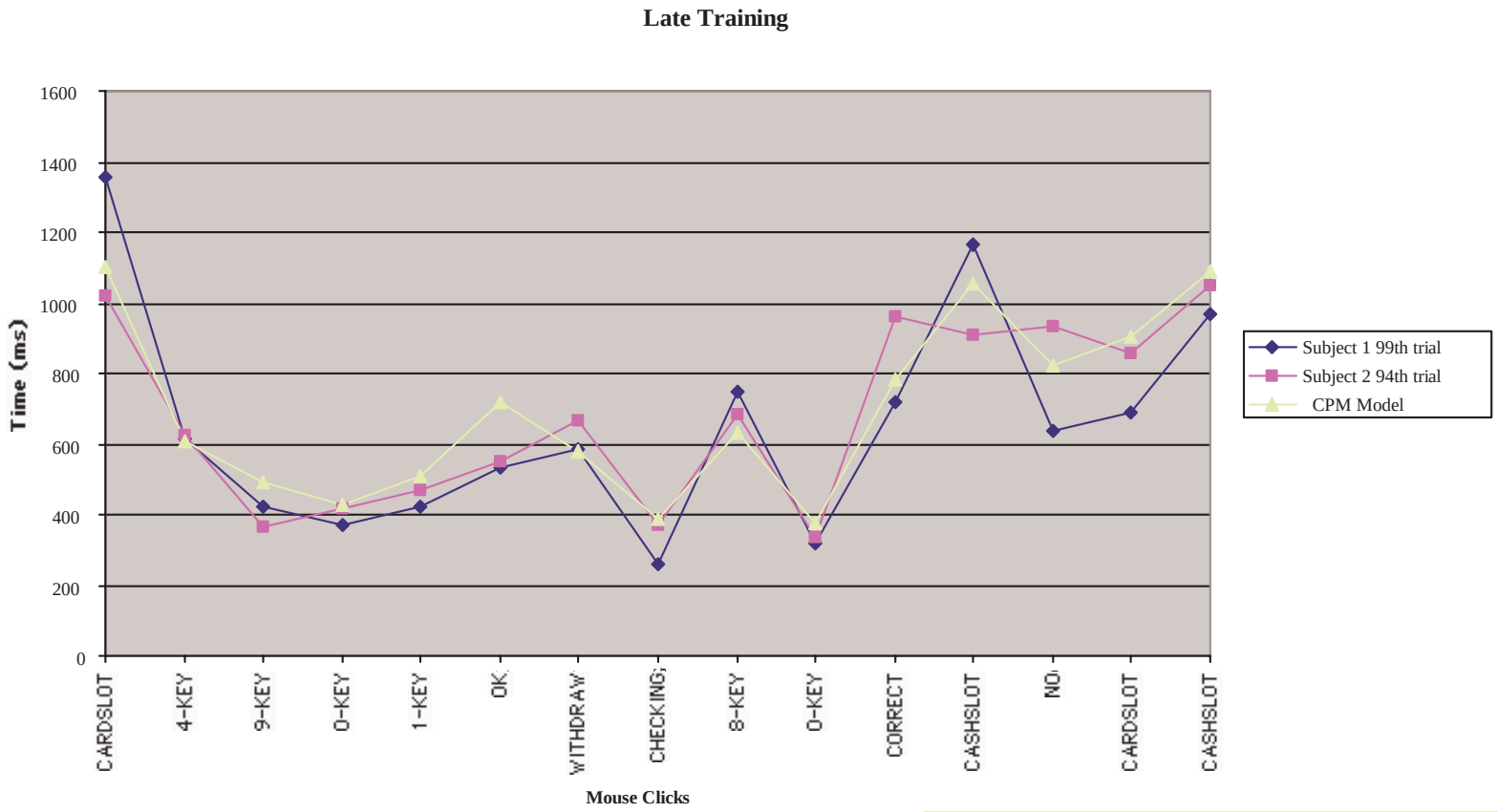
ATM Data

- 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)

Well-Practiced Subjects vs. CPM-GOMS



-model uses Gray & Boehm-Davis' (2000) templates

GOMS in Apex

- Reactive resource allocation in Apex handles low-level resource competition
  - allows behavior to emerge from a sequence of pre-defined templates
  - automatically interleaves templates
  - supports hierarchical task decomposition that simplifies CPM-GOMS modeling

Use and Usability Issues with Computational Cognitive Models

- Problem
  - Poor at predicting human behavior in complex tasks
  - Human performance data not in a form that can be directly applied
  - Model building time-consuming, complex, error prone (even for experts)
- Approach
  - Implement a useful human performance modeling methodology to describe expert knowledge and skills
  - Reusable templates that incorporate human performance characteristics
  - Software tools that integrate templates into large-scale models

Summary

- A fast, automatic, consistent integration of model elements that yields improved prediction
  - used predefined CPM-GOMS templates to predict performance
- A modeling environment with tools to:
  - inspect models and output
  - trace model activity
  - analyze and represent model output (pert charts)

Sherpa

Next Steps

- ATC/flight deck applications
- MHP, CMN/CPM exploration
- More HCI templates
- Sim-world creation facilities
- Desktops and class-rooms

Basic PDL Concepts

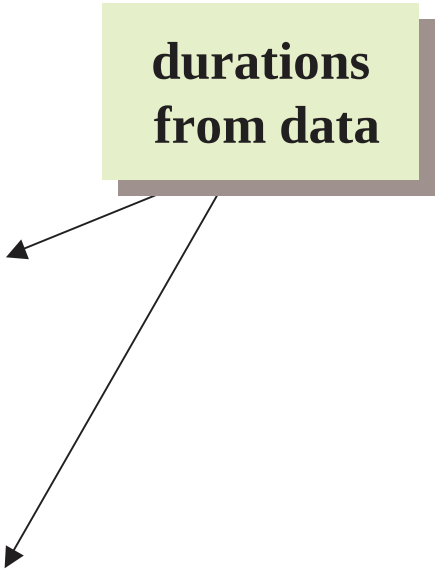
- **procedure**: instructions, like a recipe, for accomplishing a given goal
- **step:** a separable and distinct “thing to do” as a part of larger procedure.
- **waitfor:** represents sequencing information in the instructions or recipe. What needs to have happened already, for the next step to be enabled.

```
(procedure
  (index (initiate session))
  (step s1 (insert card))
  (step s2 (enter password) (waitfor ?s1))
  (step s3 (terminate) (waitfor ?s2)))
```

PDL decomposition of initiate session

```
(procedure
  (index (insert card))
  (profile memory)
  (step s1 (start-activity memory memory-act :duration 1021 => ?a))
  (step s2 (terminate) (waitfor (completed ?a))))

(procedure
  (index (enter password))
  (profile memory)
  (step s1 (start-activity memory memory-act :duration 2428 => ?a))
  (step s2 (terminate) (waitfor (completed ?a))))
```



Fitts's Law in PDL

```
(procedure
 (index (move-cursor ?target))
 (profile right-hand)
 (step s1 (mouse-time ?target => ?time))
 (step s2 (start-activity right-hand mouse-move-act :object ?target
                  :duration ?time => ?a) (waitfor ?s1))
 (step s3 (terminate) (waitfor (completed ?a))))

(procedure :special
 (index (mouse-time ?object))
 (fitts-time (pointer *mouse*) ?object))

(setf *fitts-a* 100)
(setf *fitts-b* 0.5)

(defun fitts-time (pointer obj)
  (let* ((obj (lookup-unique-name obj *agent*))
         (d (distance (pos pointer) (pos obj)))
         (s (min (first (dimensions obj))
                 (second (dimensions obj)))))
    (if obj
      (floor (* *fitts-a* (log (+ (/ d s) *fitts-b*) 2)))
      (format t "Error: no object found~&"))))
```

HCI and GOMS Modeling

- Interleaving of resources is also critical for GOMS models that make useful HCI predictions
- The modeling process is:
  - labor intensive
  - error prone
  - requires specialized knowledge of human cognition and modeling methodologies
  - takes engineers out of their domain of expertise
- Modeling will not become a common tool for engineering development until these obstacles are overcome

Changes from KLM

- priorities for soft-sequencing of low-level operators
- templates
- using resources in parallel
  - vision for perception
  - memory for cognition
  - right-hand for mousing
  - gaze for eye movement
  - virtual resources: holding and releasing