Cognitive Modeling

Fundamentals of Human-Centered Computing

Cognitive Modeling

Another classical theory of Human-Computer Interaction

A formal specification of how the brain works

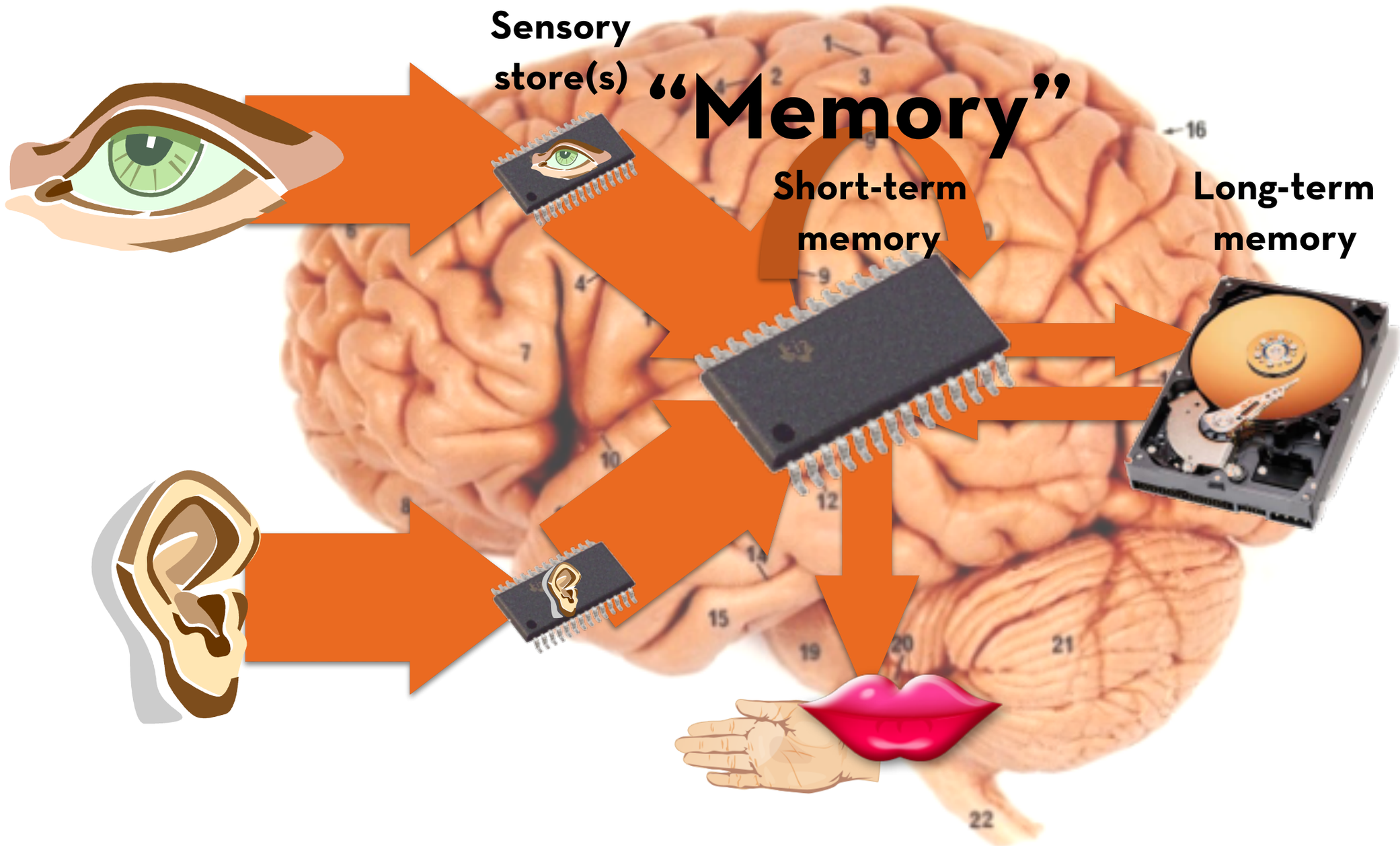
Today I will cover:

- A model of the brain (The Model-Human Processor)
- A cognitive architecture (ACT-R)
- Cognitive modeling (GOMS and CogTool)
- Cognitive walkthrough

In the brain

The Model-Human Processor

In the brain



Sensory stores

Very short memory

About 150ms

Can easily be erased by new info

Merging, masking

Holds about 9-12 items

Depends on how you measure!

Short-term store

Typically 30 seconds

Unless rehearsed

Room for about 7 items

Chunking to retain more

With interference: down to 3

Visual information: 4 objects

Long-term store

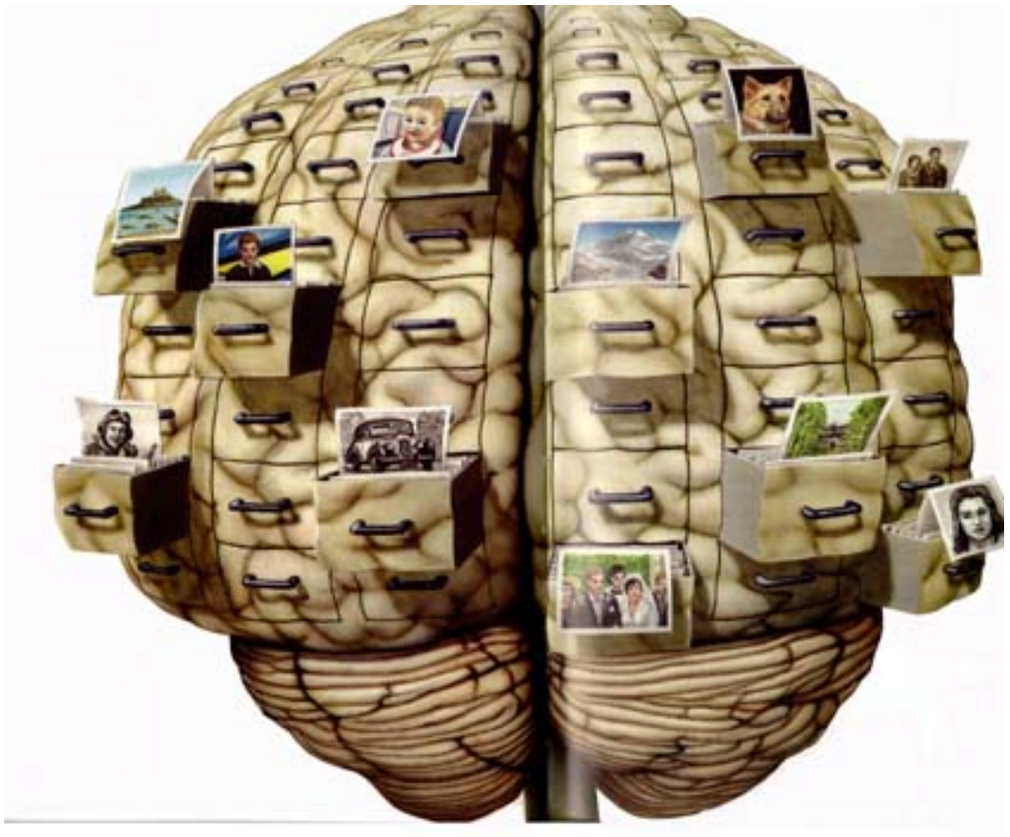
Retain over very long periods

Limits unknown

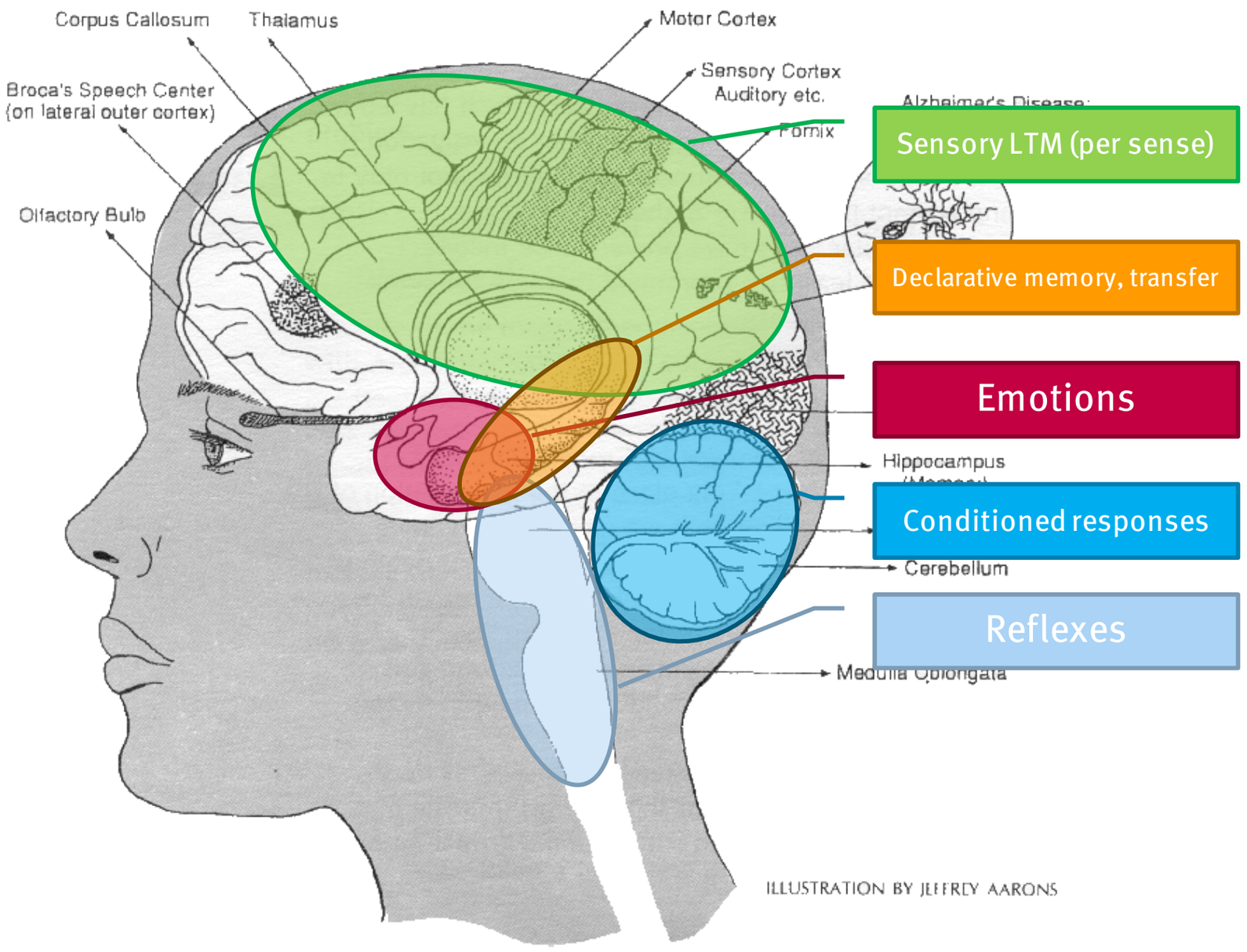
- Capacity, retention

Differences in type of info

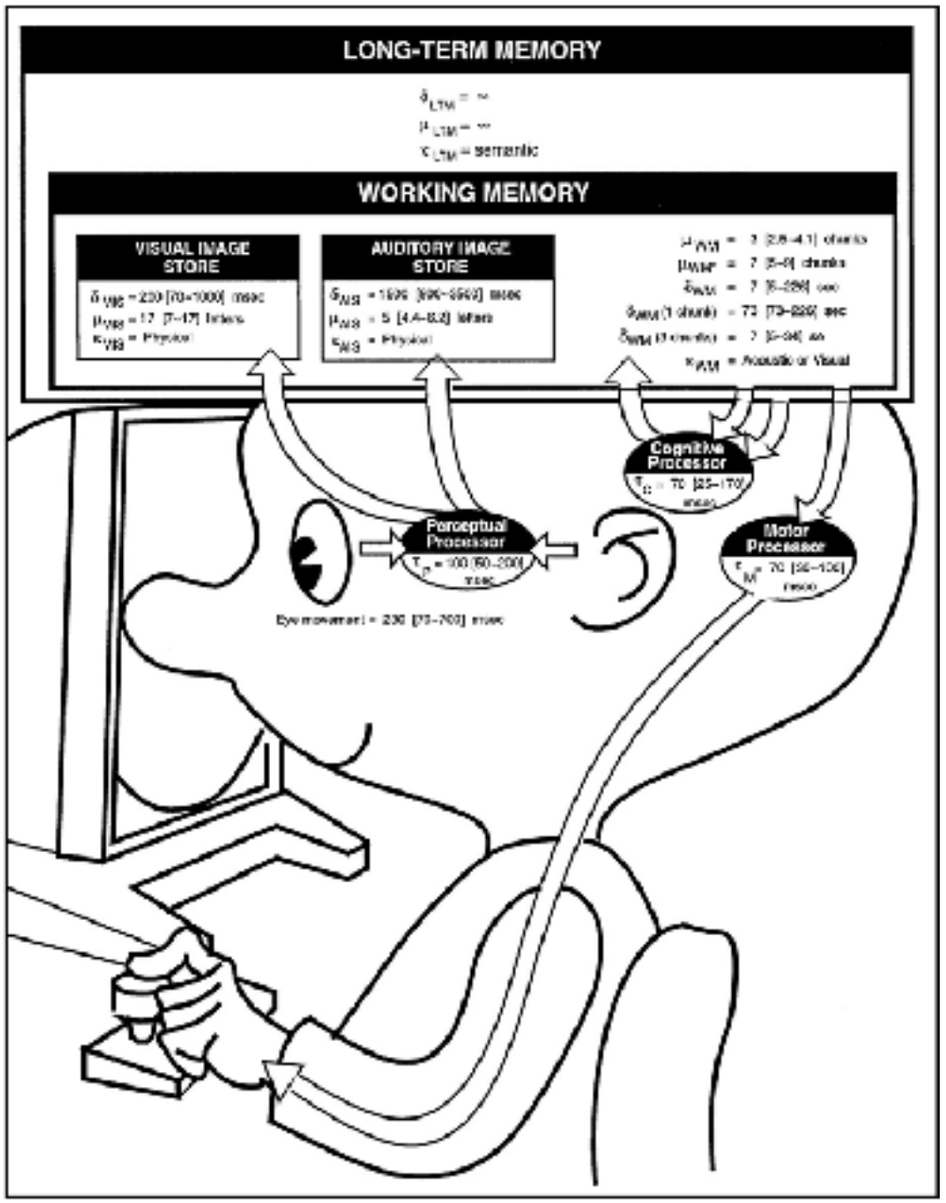
- Recognition vs. recall
- Facts vs. skills



In the brain


Corpus Callosum
Thalamus
Motor Cortex
Sensory Cortex
Auditory etc.
Broca's Speech Center
(on lateral outer cortex)
Fornix
Olfactory Bulb
Hippocampus
Cerebellum
Medulla Oblongata
ILLUSTRATION BY JEFFREY AARONS
Sensory LTM (per sense)
Declarative memory, transfer
Emotions
Conditioned responses
Reflexes

MHP



Adds performance boundaries to our model

Can be used to calculate performance

Discussion

Is the Model-Human-Processor really how the brain works?

Does it matter?

Is the MHP sufficiently precise?

What can it model? What not?

What is missing?

What else do we need for the MHP to inform HCI?

Cognitive architecture

ACT-R

Cognitive architecture

A cognitive architecture
is a specification of the structure of the brain
at a level of abstraction that explains how it
achieves the function of the mind.

MHP?

MHP describes the mind, but largely ignores the brain

Problem: This is like a specification of a building's architecture that ignores what the building is made out of

Some modeling parameters are impossible!

e.g. some cognitive models are intractable

Connectionism?

Connectionism models the function of the brain by merely specifying its structure

> "Just make a deep learning neural network"

This approach is too clinical

> It requires an outside force to set it up and interpret the result in a meaningful way

Rational Analysis?

Rational analysis models the function of the brain by describing and its forcing function

- "Just make a bayesian model"

This approach is limited to cognitive sub-functions

- It does not model end-to-end behavior

ACT-R

Visual: see the problem

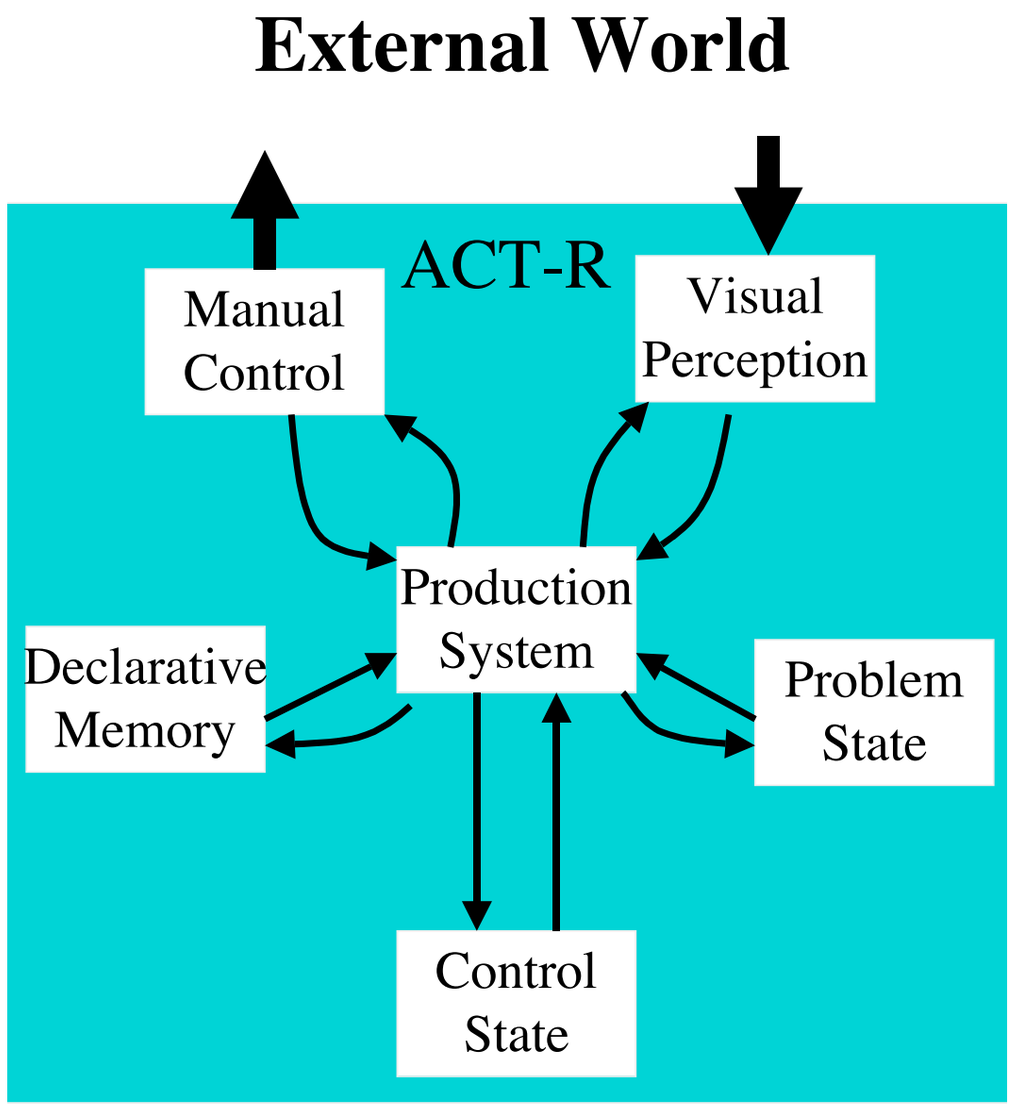
Problem state: STM-ish

Control state: objective

Declarative: LTM

Manual: create output

Production system: move things between modules



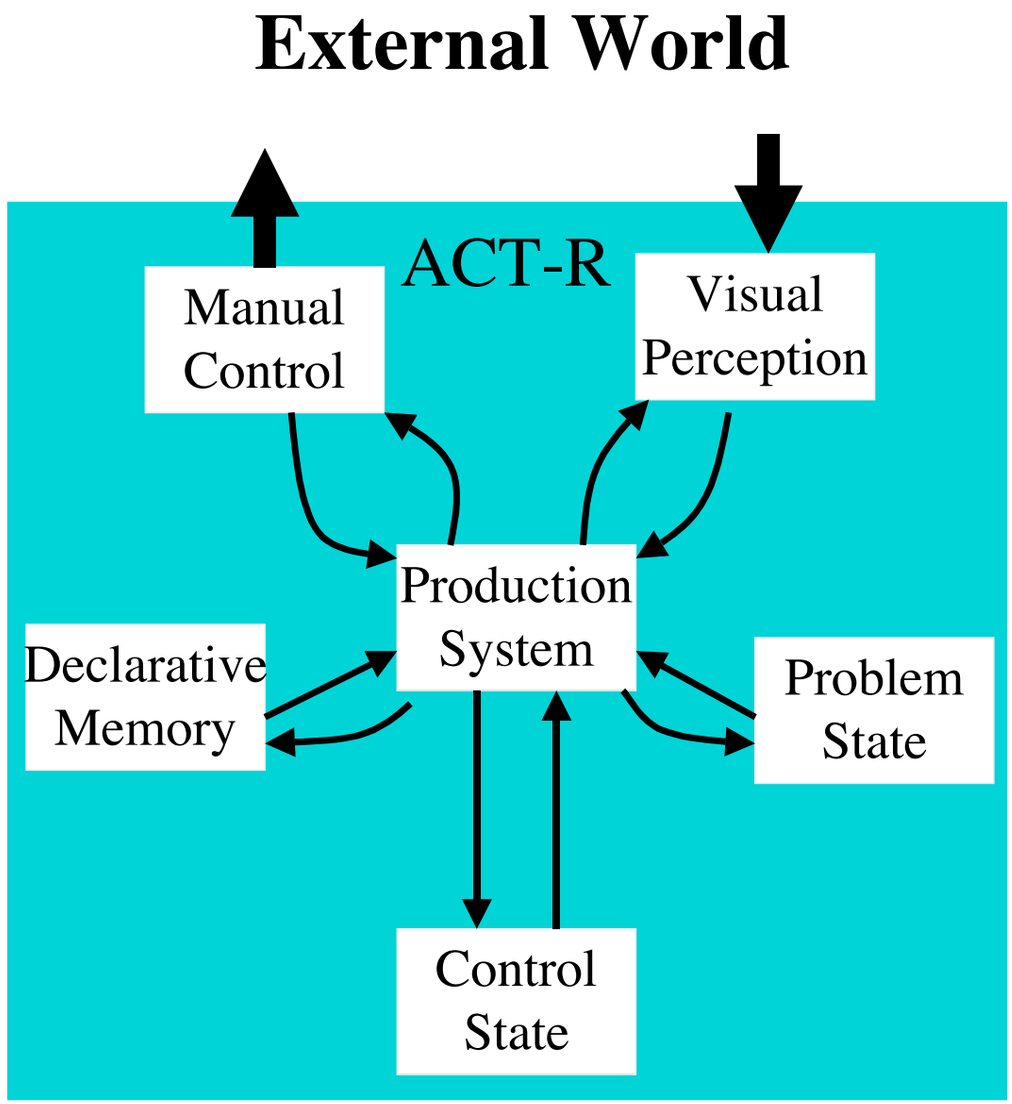
ACT-R

Within module: parallel and fast

Between modules: serial, slow, low bandwidth

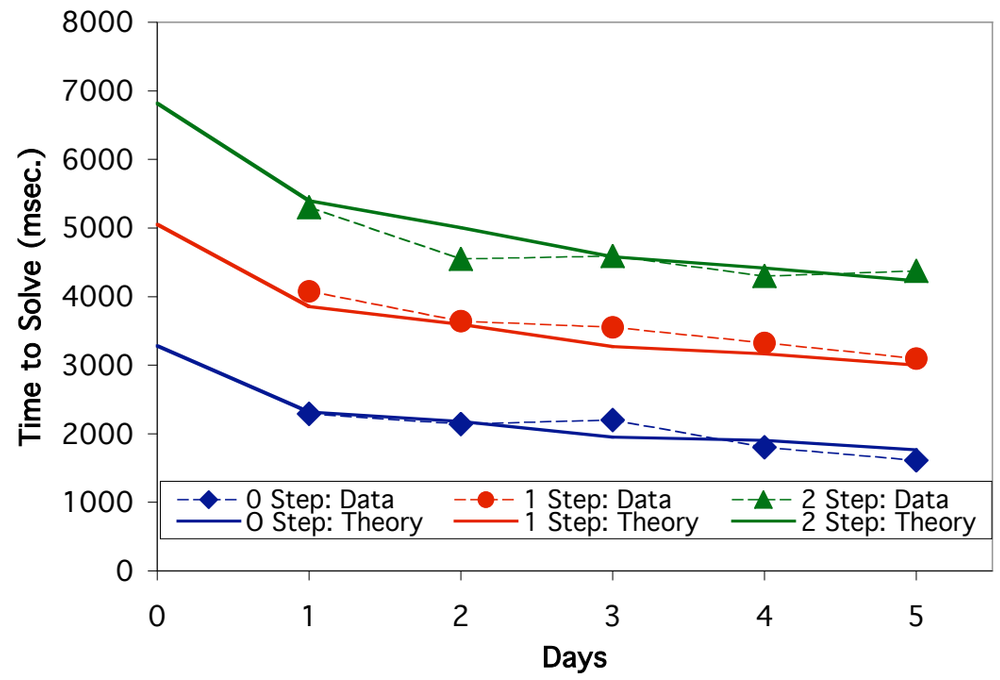
> Everything flows through the production system

Production system can "learn" new rules



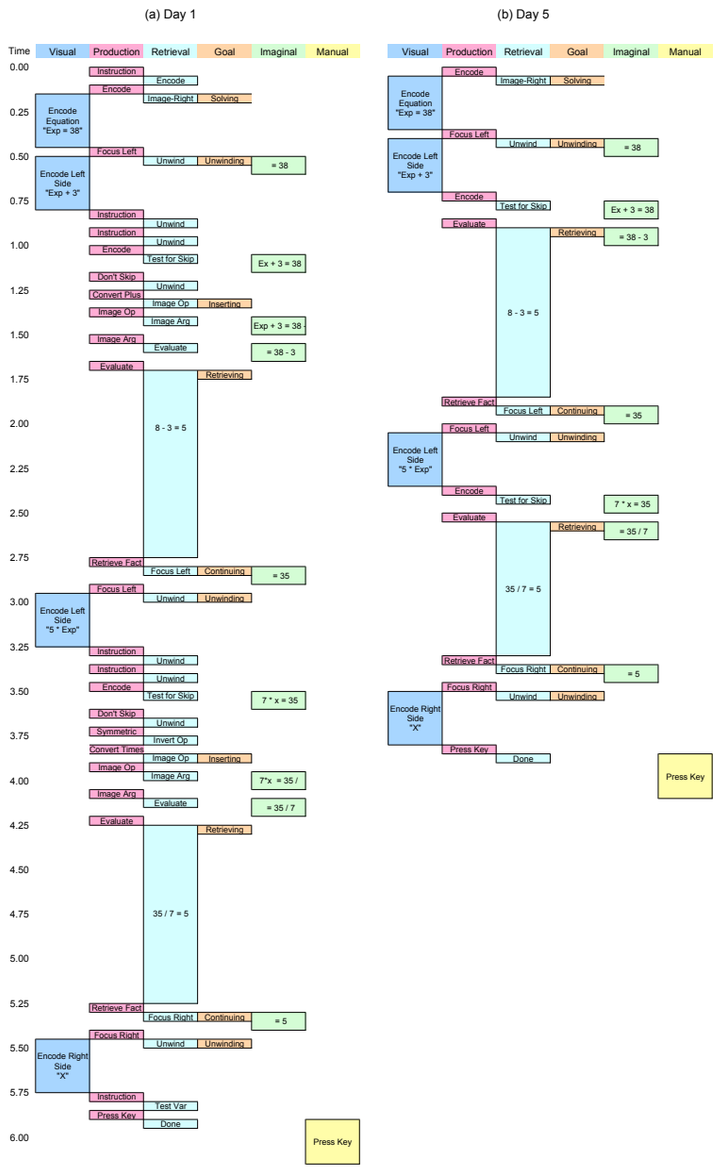
ACT-R

It models task performance pretty well



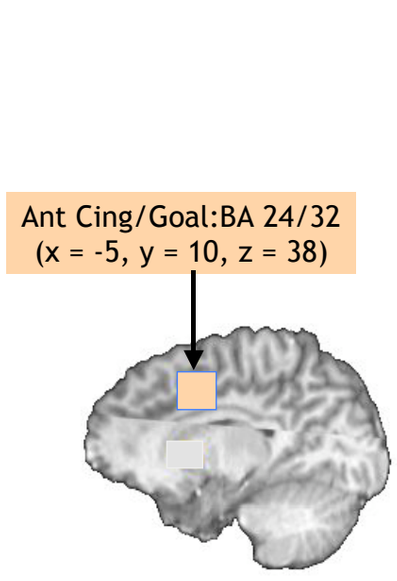
ACT-R

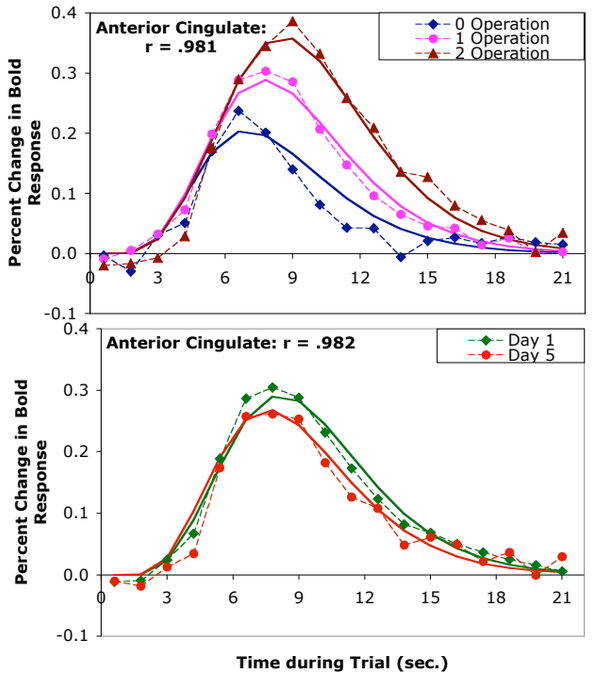
It's inspectable



ACT-R

It matches brain activity





ACT-R

Based on brain functioning

Explicit assignment of functionality to modules

Subsymbolic system that provides numeric bounds

End-to-end integration

Discussion

Where are Norman's visceral, behavioral, and reflective functions in this architecture?

What parts of the brain are serial? What parts are parallel?

What are potential applications of ACT-R in HCI?

Cognitive modeling

GOMS and CogTool

Cognitive modeling

GOMS models: goals, operations, methods, and selection rules

- Quantitative prediction of **expert users'** interaction performance
- Cognitive science component: based on measurement of human cognitive capabilities (see model-human-processor)

Advantages

- No users needed
- Very accurate results

Keystroke modeling

Keystroke-Level models: Simplest GOMS-family member

No representation of goals, methods or selection-rules, just a sequence of operators that constitute a task

Input

A suite of benchmark tasks

A system design

Output

The time it would take a skilled user to perform the tasks

Keystroke modeling

Card, Moran and Newell studied people using interfaces

- Break down behavior into simple steps
- Determine performance for each type of step
- Aggregate steps = prediction of total time

Construction

List the overt actions necessary to do the task

Keystrokes and button actions (K), mouse movements (P), hand movements from keyboard to mouse (H)

Also system response time (if user has to wait)

Insert mental operators (M)

Assign execution times from previous research

K, M, H are straightforward; P requires Fitts's Law

Add up the execution times

Email login

Move mouse to input field	P	1.10
Click	K	0.20
Move hand to keyboard	H	0.40
Type username	8K	1.60
Move hand to mouse	H	0.40
Move mouse to input field	P	0.30
Click	K	0.20
Move hand to keyboard	H	0.40
Type password	12K	2.40
Move hand to mouse	H	0.40
Prepare for Log On	M	1.35
Move mouse to Log On	P	1.10
Click	K	0.20
Total		**10.05**

Keyboard shortcuts

Move mouse to input field	P	1.10
Click	K	0.20
Move hand to keyboard	H	0.40
Type username	8K	1.60
Press Tab	K	0.20
Type password	12K	2.40
Press Enter	K	0.20
Total		**6.10**

Pre-filled username

Move mouse to input field	P	1.10
Click	K	0.20
Move hand to keyboard	H	0.40
Type password	12K	2.40
Press Enter	K	0.20
Total		**4.30**

Downsides

Hard to construct the modes

- Forget H operators
- Rules for placing mental operators (M)

Fitts's Law is tedious and error-prone

Limited scope

- Only for modeling fully trained experts
- No analysis of possible mistakes
- Does not analyze whether the system is "logical"

Solution: CogTool

Simulate the user using ACT-R

Benefit: more granular performance predictions

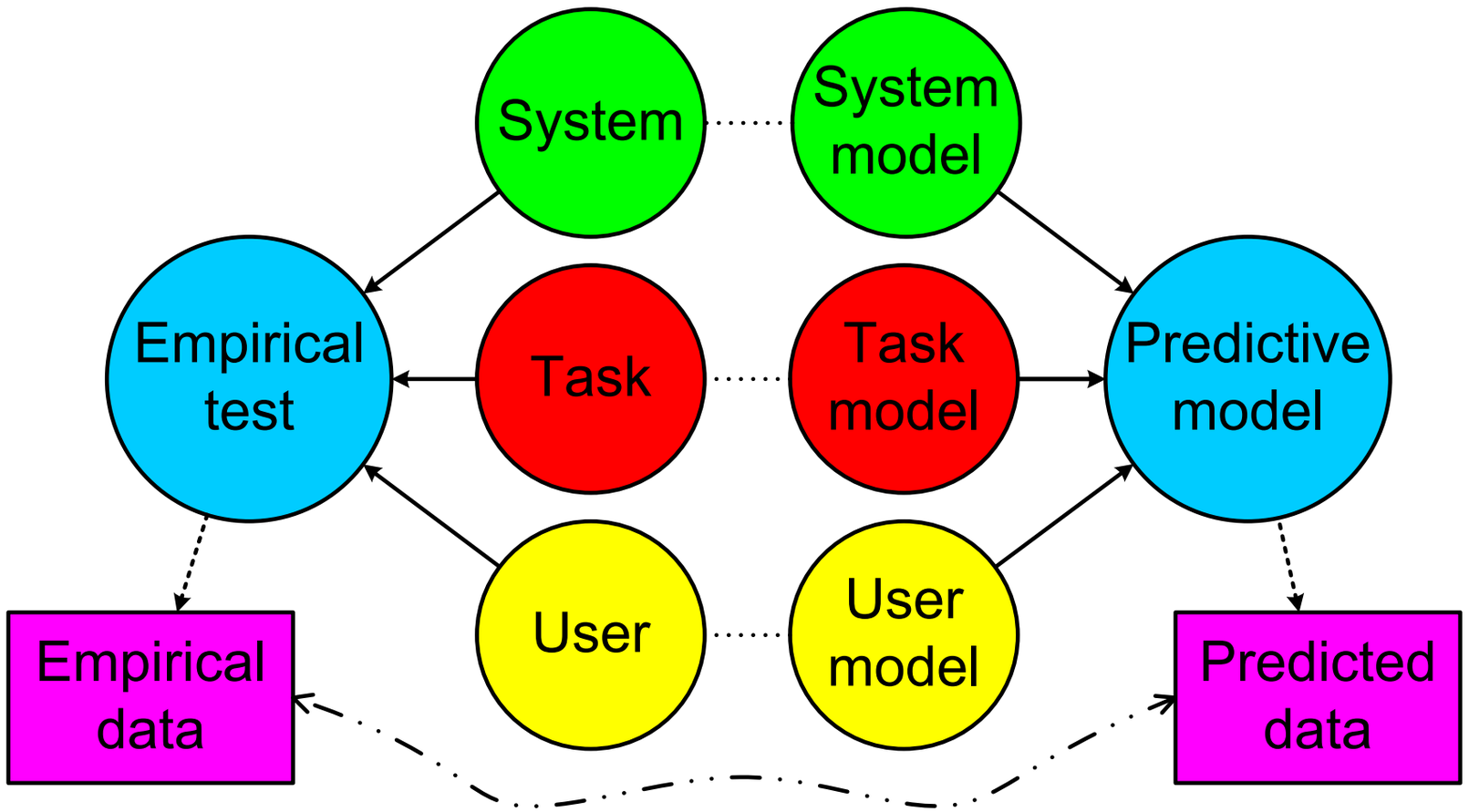
Simulate the interface

A mockup that ACT-R can "use"

Simulate the task

Construct a keystroke specification by example

Simulated test



Benefits

Let ACT-R do the specified task(s) on the provided interface(s)

- Outcome: Performance prediction
- Same characteristics as empirical user test
  - Added bonus: A breakdown for each step!
- Results reflect empirical test results (within 3%)
  - It takes about 5-10 minutes to build a model
  - Easy to tweak the interface and get immediate results

Discussion

When is this useful? When not?

How does KLM reason about the use image?

Cognitive walkthrough

...and how to automate it

Cognitive walkthrough

Cognitive Walkthrough: Walk through a scenario, and reason if a user would be able to perform each step

Find out how **novice users** work with an interface

Cognitive science component: novice users apply pre-existing schema's and scripts through analogical reasoning

Advantages

No users needed

Fairly in-depth analysis

Cognitive walkthrough

Four principles of fulfilling tasks:

Q1. Will the user try to achieve the right effect?

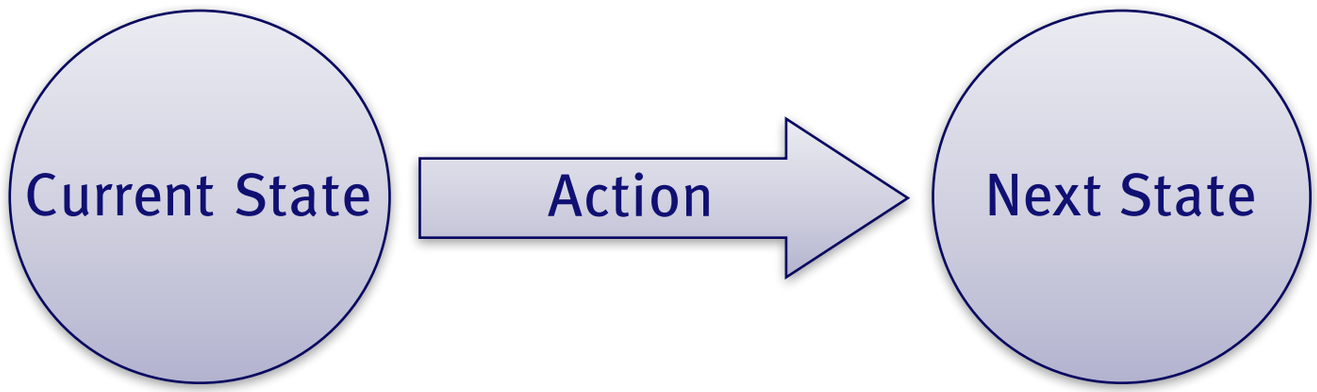
Q2. Will the user notice that the action is available?

Q3. Will the user associate the action with the effect?

Q4. Will the user see progression?

State diagram

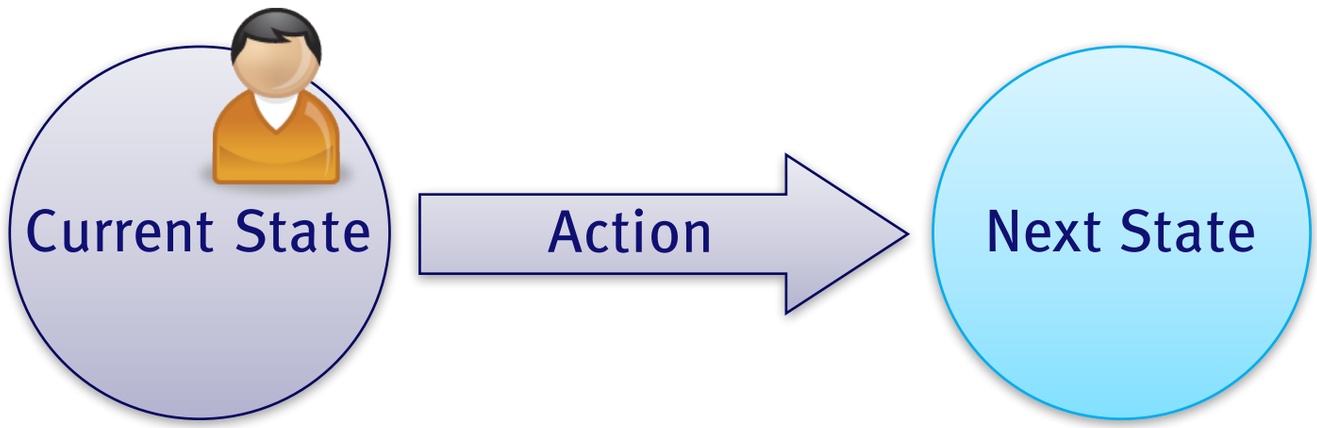
Given that the user is in the Current State, the questions can be about the Action, or the Next State



State diagram

Will the user try to achieve the right effect?

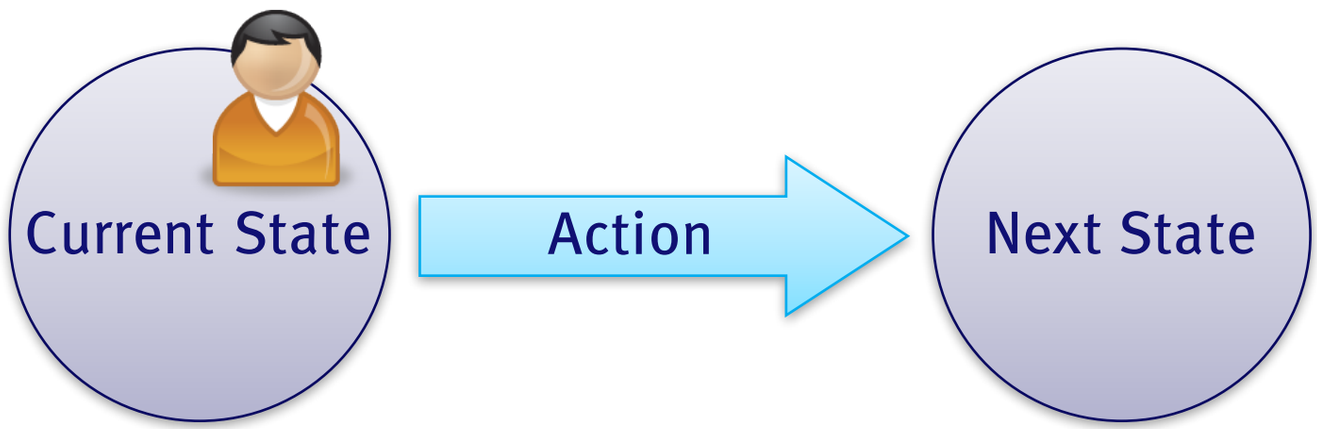
When in the Current State, will the user know that she wants the system to be at the Next State?



State diagram

Will the user notice that the action is available?

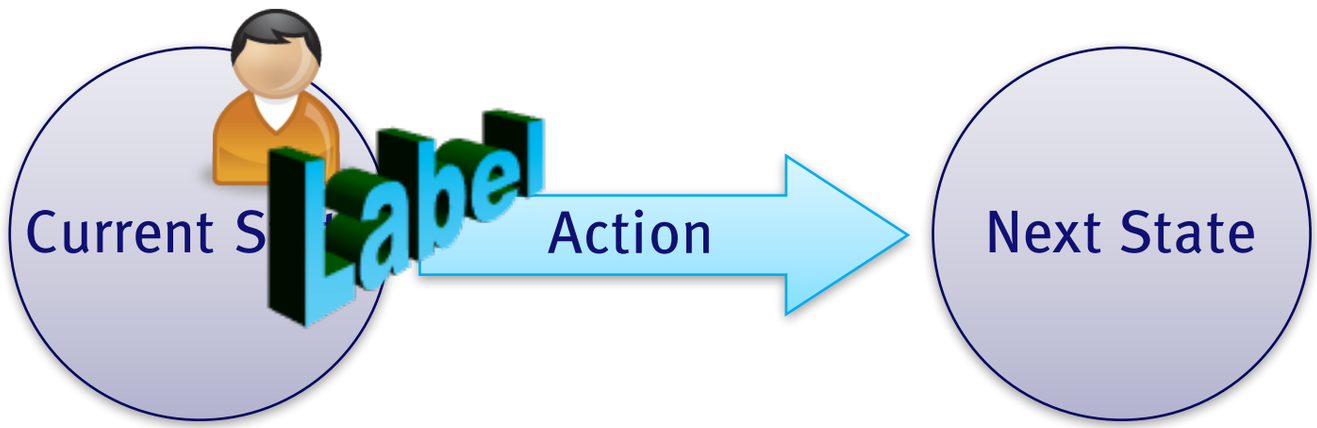
When in the Current State, will the user perceive the control for the action that would get her to the Next State?



State diagram

Will the user associate the action with the effect?

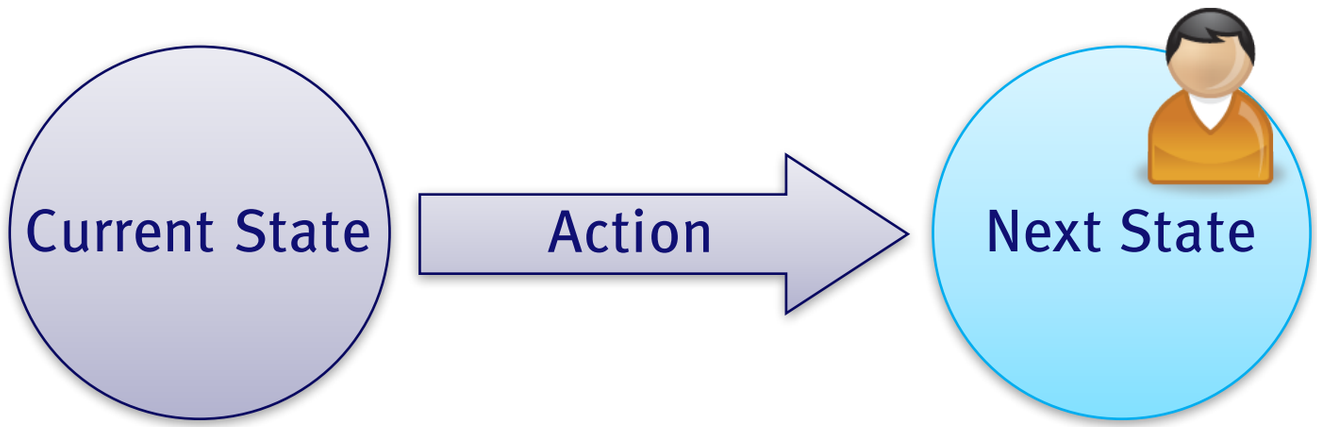
When in the Current State, will the user link the control for the action to the Next State, usually through a meaningful label?



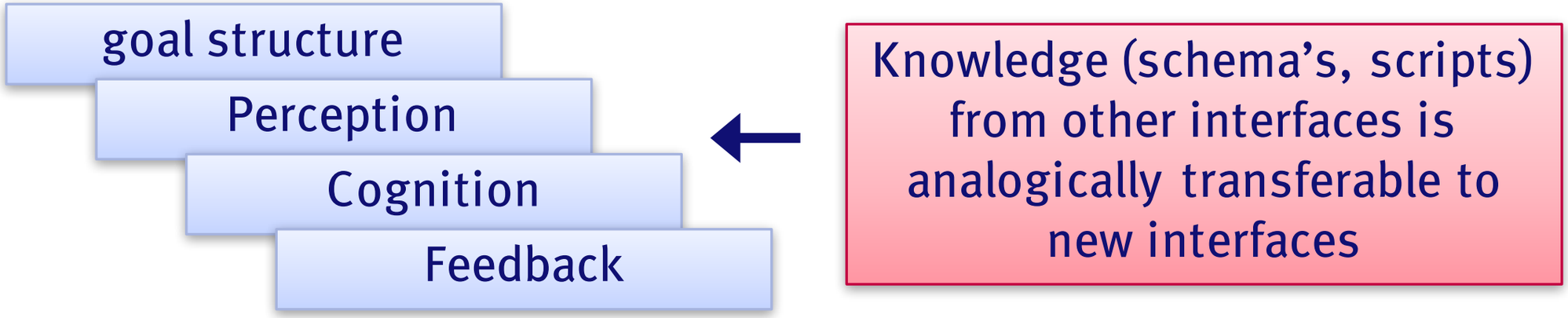
State diagram

Will the user see progression?

When in the Next State, will the user perceive and comprehend information about whether progress towards the goal state has been made?



Cognitive walkthrough



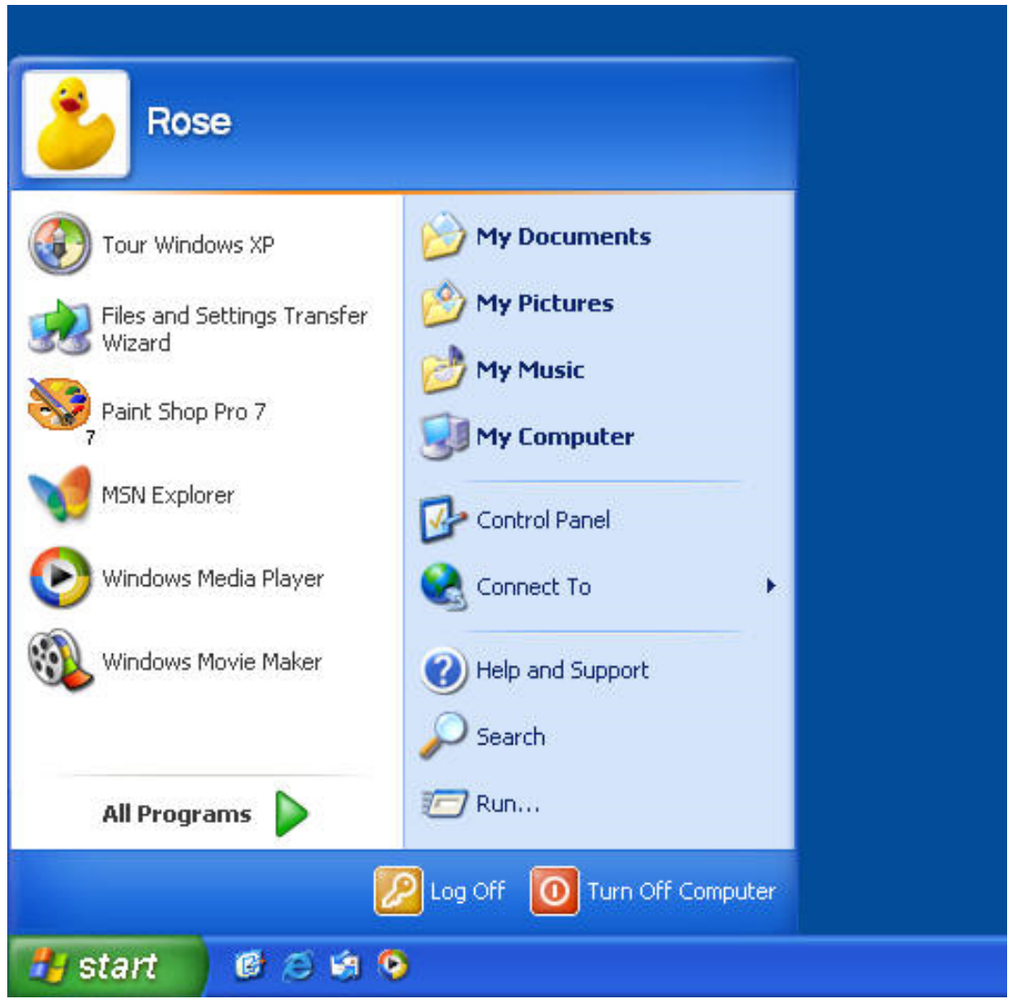
Example

Will the user try to achieve the right effect?

Yes, the user wants to see a “Turn off” or “Shut down” button

Will the user notice that the action is available?

Yes, the action is “start”, and it is noticeable



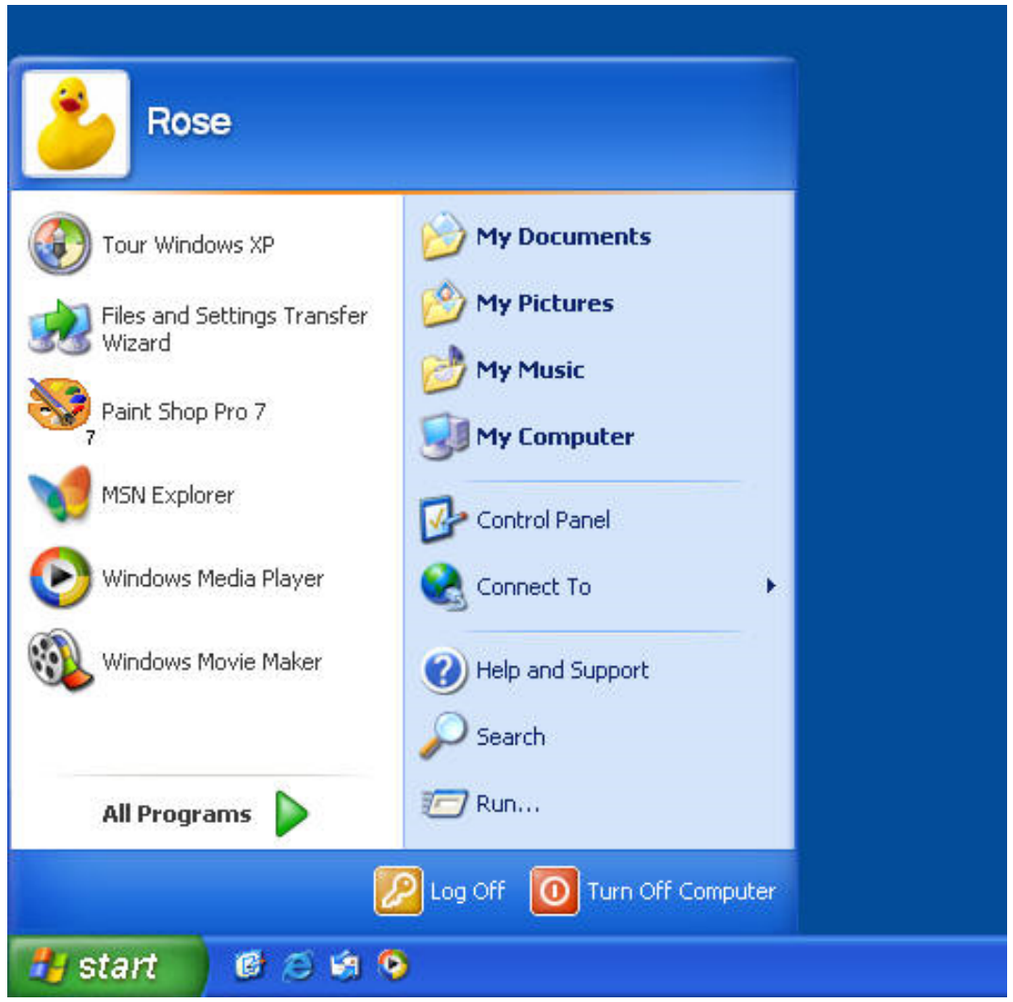
Example

Will the user associate the action with the effect?

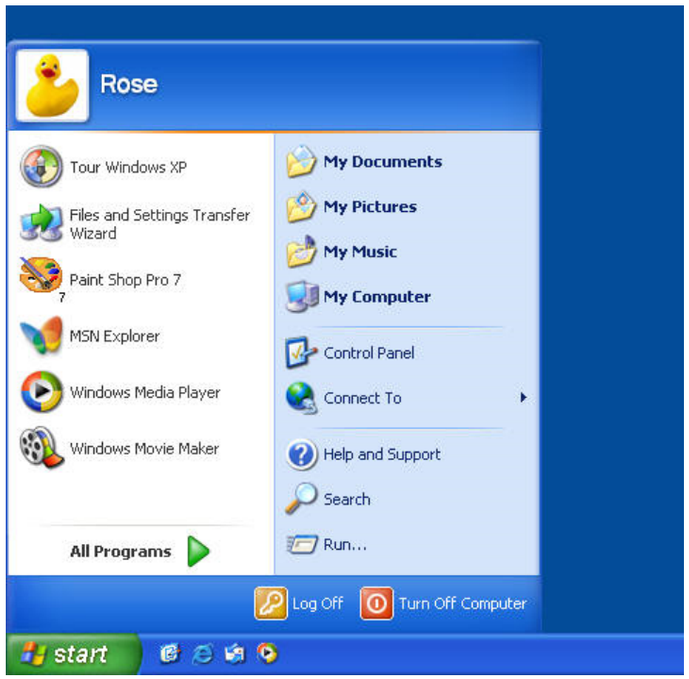
No, the user will not associate “start” with “shutting down”

Will the user see progression?

Yes, if the user presses start he/she will see the “Turn off” button



Example



If the user already knew how to use a Mac:

Will the user associate the action with the effect?

Yes, the user knows that the corner-button with the logo has to be clicked to see the main menu

Downsides

No “real” data

- But grounding is a bit better

Low coverage

- Typically you can only evaluate a small number of scenarios
- Only novices are considered

Solution: ACW

Can we automate it with ACT-R?

Make an ACT-R model of a user

Let it ask the CW questions

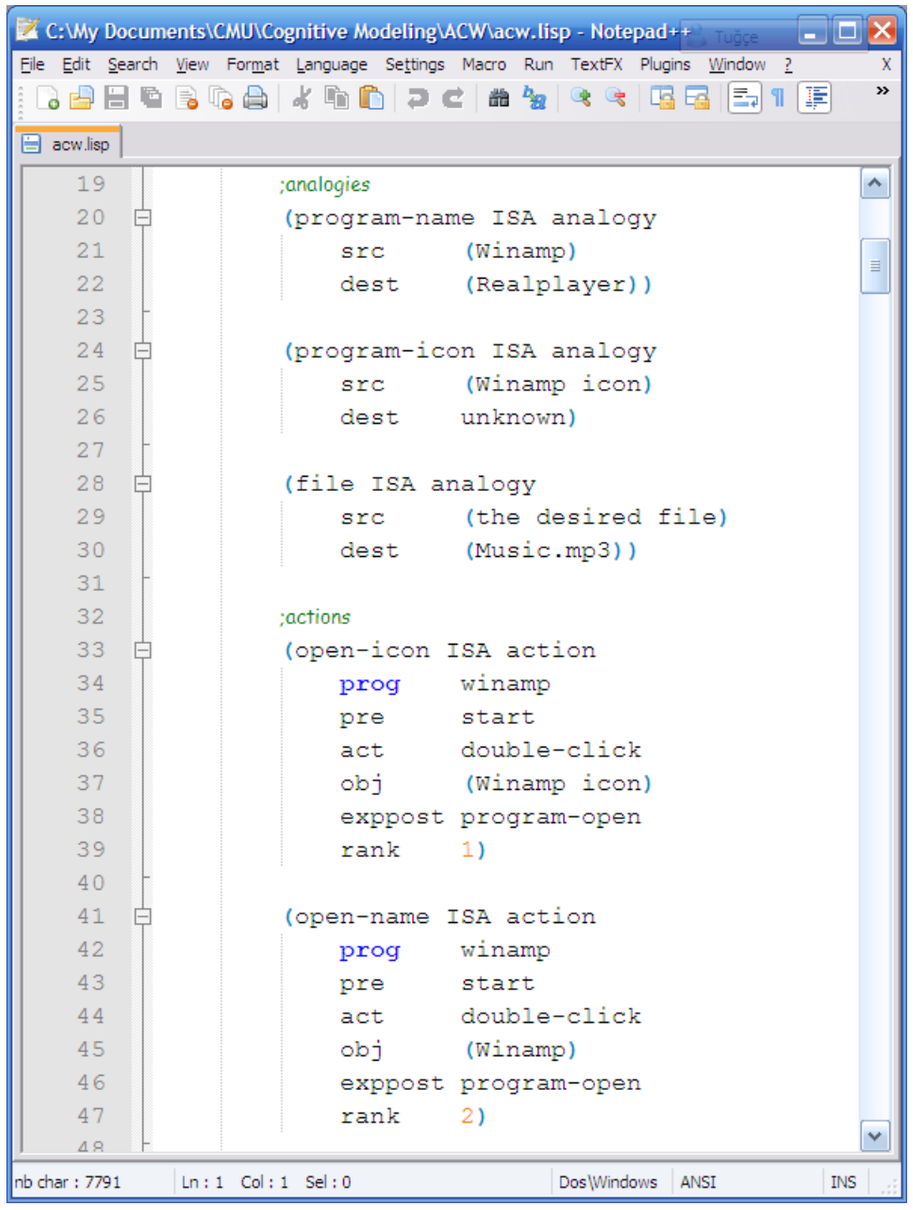
Learn from the breakdowns

Making a model

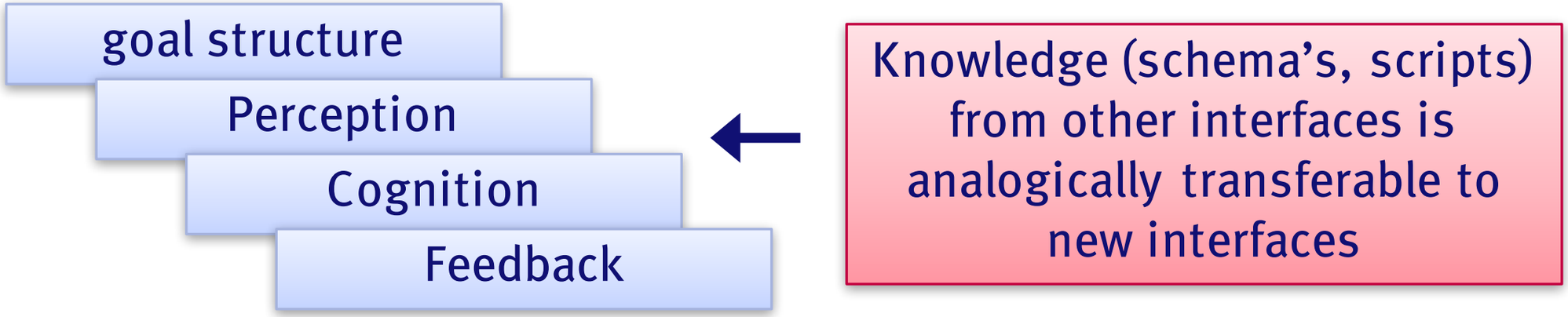
Give the ACT-R model a goal

Provide it with common sense interface knowledge and some domain knowledge

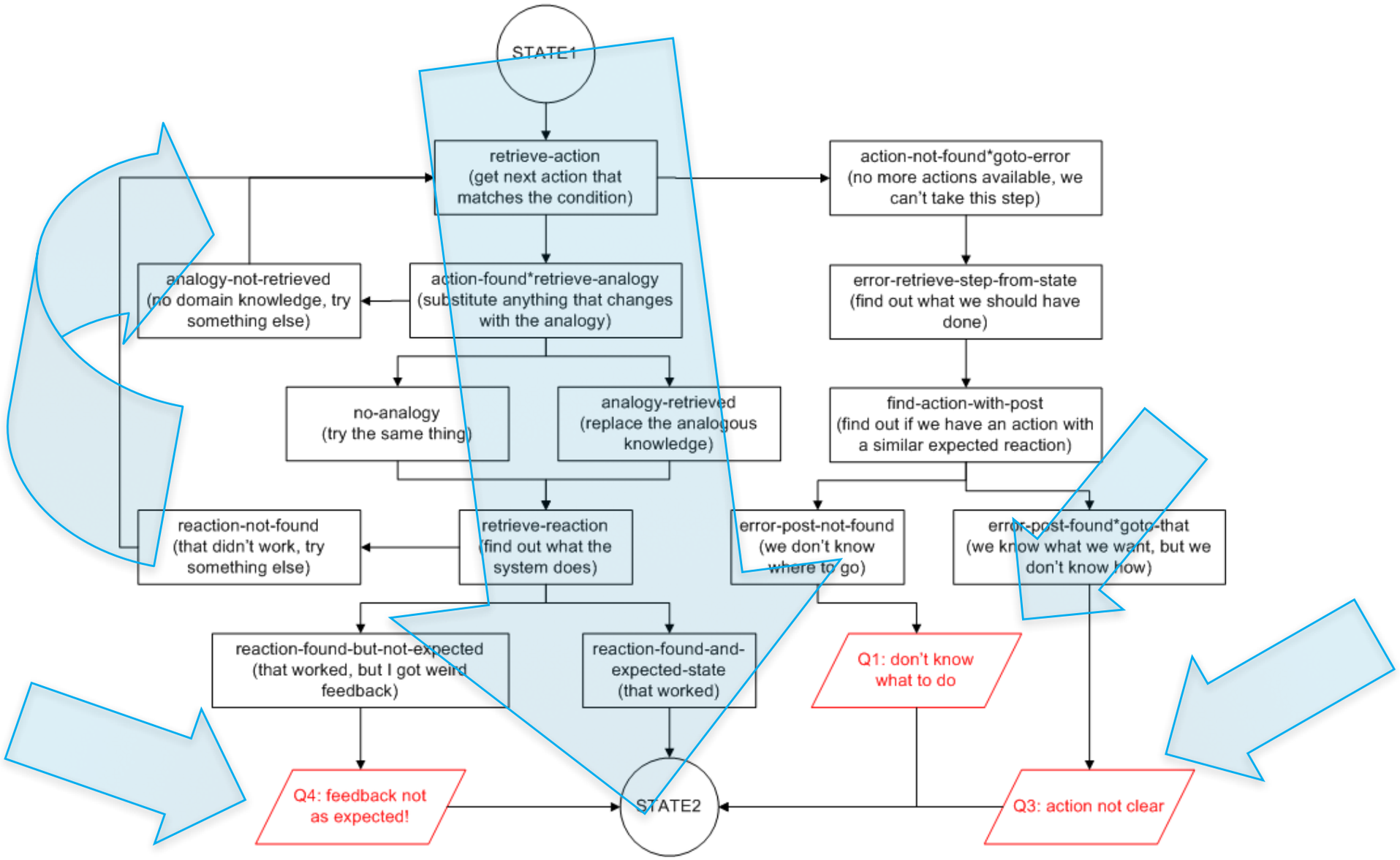
Can it reason by analogy how to do the task?

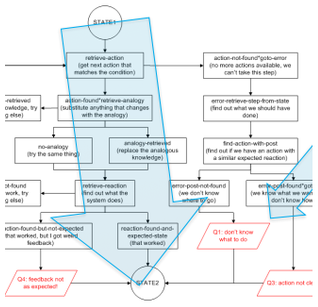


Asking questions



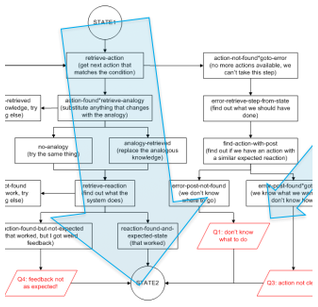
Asking questions





Inspect the model

```
     5.600   GOAL                    SET-BUFFER-CHUNK GOAL STEP0
     5.650   PROCEDURAL              PRODUCTION-FIRED RETRIEVE-ACTION
     6.650   DECLARATIVE             SET-BUFFER-CHUNK RETRIEVAL LOAD-BUTTON
     6.700   PROCEDURAL              PRODUCTION-FIRED ACTION-FOUND*RETRIEVE-ANALOGY
IN WINAMP I CLICK (EJECT BUTTON) - WHAT SHOULD I DO IN REALPLAYER?
     6.900   IMAGINAL                SET-BUFFER-CHUNK IMAGINAL ACTION3
     7.700   DECLARATIVE             RETRIEVAL-FAILURE
     7.750   PROCEDURAL              PRODUCTION-FIRED NO-ANALOGY
I 'LL TRY THE SAME THING
     7.800   PROCEDURAL              PRODUCTION-FIRED RETRIEVE-REACTION
     8.800   DECLARATIVE             RETRIEVAL-FAILURE
     8.850   PROCEDURAL              PRODUCTION-FIRED REACTION-NOT-FOUND*NEXT-ACTION
THAT DIDN 'T WORK
     8.900   PROCEDURAL              PRODUCTION-FIRED NEXT-ACTION
LET 'S TRY SOMETHING ELSE
     9.900   DECLARATIVE             SET-BUFFER-CHUNK RETRIEVAL OPEN-FILE-MENU
     9.950   PROCEDURAL              PRODUCTION-FIRED ACTION-FOUND*RETRIEVE-ANALOGY
IN WINAMP I CLICK (FILE MENU) - WHAT SHOULD I DO IN REALPLAYER?
    10.150   IMAGINAL                SET-BUFFER-CHUNK IMAGINAL ACTION4
    10.950   DECLARATIVE             RETRIEVAL-FAILURE
    11.000   PROCEDURAL              PRODUCTION-FIRED NO-ANALOGY
I 'LL TRY THE SAME THING
    11.050   PROCEDURAL              PRODUCTION-FIRED RETRIEVE-REACTION
    12.050   DECLARATIVE             SET-BUFFER-CHUNK RETRIEVAL OPENED-FILE-MENU
    12.100   PROCEDURAL              PRODUCTION-FIRED REACTION-FOUND-BUT-NOT-EXPECTED
Q4 - I 'M UNFAMILIAR WITH THE FILE-MENU-THAT-LOOKS-DIFFERENT
```



Inspect the model

```
    16.400   DECLARATIVE              SET-BUFFER-CHUNK RETRIEVAL LOAD-FILE
    16.450   PROCEDURAL               PRODUCTION-FIRED ACTION-FOUND*RETRIEVE-ANALOGY
IN WINAMP I CLICK (PLAY FILE...) - WHAT SHOULD I DO IN REALPLAYER?
    16.650   IMAGINAL                 SET-BUFFER-CHUNK IMAGINAL ACTION6
    17.450   DECLARATIVE              RETRIEVAL-FAILURE
    17.500   PROCEDURAL               PRODUCTION-FIRED NO-ANALOGY
I 'LL TRY THE SAME THING
    17.550   PROCEDURAL               PRODUCTION-FIRED RETRIEVE-REACTION
    18.550   DECLARATIVE              RETRIEVAL-FAILURE
    18.600   PROCEDURAL               PRODUCTION-FIRED REACTION-NOT-FOUND*NEXT-ACTION
THAT DIDN 'T WORK
    18.650   PROCEDURAL               PRODUCTION-FIRED NEXT-ACTION
LET 'S TRY SOMETHING ELSE
    19.650   DECLARATIVE              RETRIEVAL-FAILURE
    19.700   PROCEDURAL               PRODUCTION-FIRED ACTION-NOT-FOUND-BUT-TRIED…
    19.750   PROCEDURAL               PRODUCTION-FIRED ERROR-RETRIEVE-STEP-FROM-FOUNDST…
    20.750   DECLARATIVE              SET-BUFFER-CHUNK RETRIEVAL OPENED-FILE
    20.800   PROCEDURAL               PRODUCTION-FIRED ERROR-STEP-FOUND…
    21.000   IMAGINAL                 SET-BUFFER-CHUNK IMAGINAL REACTION0
    21.800   DECLARATIVE              SET-BUFFER-CHUNK RETRIEVAL LOAD-BUTTON
    21.850   PROCEDURAL               PRODUCTION-FIRED ERROR-POST-FOUND*GOTO-THAT
Q3 - I DON 'T KNOW HOW TO GET TO FILE-PICKER
```

Benefits

Let ACT-R do the specified task(s) on the provided interface(s)

- Outcome: Feasibility prediction

Same characteristics as empirical user test

- Added bonus: A breakdown for each step!

Could be tested with different levels of novice users

- Different amounts of knowledge that can be applied analogously

Discussion

When is this useful? When not?

How does CW reason about the use image?