Cognitive Supermodels

or: We Can't Play 20 Models with Nature and Win, Either
or: Dr. Strangebrain, or, How I Learned to Stop Worrying and Turn On All the Learning Mechanisms

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A Tale of Two Modeling Efforts

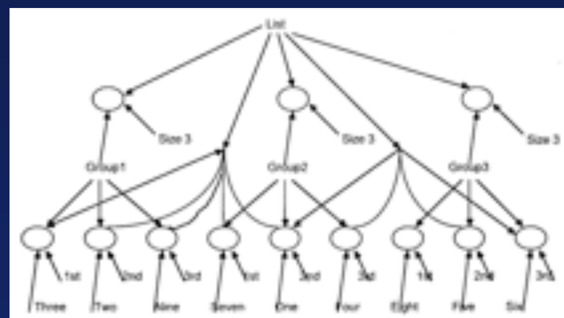
- We can very roughly characterize the past decade of cognitive modeling work in 2 ways
- (1) Modeling “software” for a specific domain
  - sometimes a focused experimental domain
    - e.g., task switching, dual-choice/PRP
  - sometimes an applied domain
    - e.g., driving
    - e.g., air-traffic control
  - good in their accounts of the details of a task
  - not as good for generalizing to (even very similar) tasks
    - e.g., could driver model be used for walking? biking?

A Tale of Two Modeling Efforts

- (2) Modeling “hardware” aimed at a specific, cross-domain aspect of cognition
  - several recent examples
    - production compilation
    - utility learning
    - threaded cognition
  - good for their generalization of component cognitive skills across domains
  - good for continuing to flesh out the architecture
  - but agnostic (at best) / useless (at worst) without actual domain-specific “software”
    - or at least declarative instructions that result in “software”

A Tale of Two Modeling Efforts

- What we don’t have very much of:
  Cross-domain software models
  - a single model that accounts for behavior across many diverse task domains
- There have been instances of this, such as...
  - list memory:
    representations & rules
    - e.g., used for dialing #s
  - analogy



- Can we build on recent successes toward a larger-scale effort for cross-domain models?

Cognitive Supermodels

- Idea: Consider a single cognitive model with...
  - a single (initial) set of declarative chunks
  - a single (initial) set of production rules
  - with a single (initial) set of parameter settings
  - on a fixed cognitive architecture
- ... and try to account for behavior across a range of diverse domains...
  - list memory, algebra, dual-choice/PRP, etc.
  - driving, air-traffic control, etc.
- This is what I'll call a Cognitive Supermodel

Cognitive Supermodels

- Another way to think about this:
  - A person comes into your experiment.
  - This person has a lifetime of experiences that has shaped his/her chunks, rules, parameters.
  - Can we represent this canonical person as a single canonical model — a cognitive supermodel?
  - Ideally, this model should represent the distribution of all possible participants in the experiment (i.e., of the target group: age, skill sets, etc.)
    - but for now, a canonical supermodel is hard enough

Development Environment

- We need a development environment that allows for testing of one or more models across many domains
  1. real-time simulation for visualization, fast simulation for fast estimates
  2. single-domain simulation for testing, cross-domain simulation for model fitting
  3. implementation of complex task environments
- LISP ACT-R can do all this (though #3 is harder)
- But I wanted something a bit more integrated

Java ACT-R

- Java ACT-R is a completely re-implemented version of ACT-R
  - includes all the basic functionality
  - currently uses the tutorial sample models for testing
- This is not jACT-R (by Tony Harrison)
  - jACT-R is intended to be plug & play for different architectural modules
    - can specify model in XML or LISP(ish) (except for params)
  - this new system is intended to be more monolithic and streamlined, centered on batch model testing
- Demo...

Java ACT-R

- What Java ACT-R does have
  - all the core learning mechanisms
  - all the core perceptual/motor mechanisms
  - simple evals (arithmetic + user-defined)
  - p*-style slot variables
  - threading, EMMA
- What Java ACT-R does not have
  - no chunk types!
    - can set any slot name to a slot value
    - “isa” like any other slot (except for fan & partial matching)
    - chunk types don’t seem to be necessary

Java ACT-R

- Many workshops ago (1995), I presented a new implementation of ACT-R in C
  - back then, LISP speed was an issue; now, it's not
  - the challenge then & now: maintaining the code
    - the LISP implementation = the theory
- This new system
  - the goal is *not* to maintain correspondence with the LISP version
  - in fact, the goals are
    - (1) to explore different variations on ACT-R
    - (2) to use this as the foundation for a monolithic cognitive supermodel that accounts for a set of domains

A First Cognitive Supermodel

- For our first attempt at a cognitive supermodel, we need…
  - basic declarative knowledge
    - number facts, etc.
  - basic procedural skills
    - e.g., clicking an interface icon, typing a key
    - instruction-following skills
      - listening to and encoding instructions
      - following them to generate actions
    - extending previous work by Taatgen, Fu, Anderson, etc.

Instruction Following

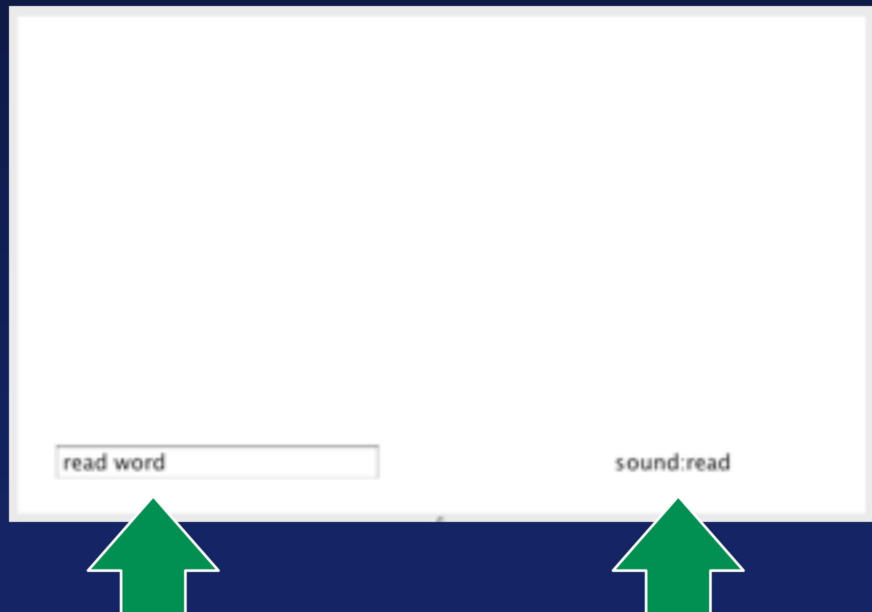
- Listening / encoding instructions
  - encode instructions aurally, word-by-word
  - memorize each instruction (phrase) by rehearsal
  - go until “start <task>” is heard
- Following instructions
  - recall instruction one at a time
  - perform action or initiate associated subgoal
    - some instructions are a single rule
      - e.g., type a letter
    - some instructions initiate complex subgoals
      - e.g., the simple instruction “drive”
  - compiled with production compilation

#1: Paired Associates

- Instructions

to respond:

wait-for visual-change
read word
recall number for word
if success type number
wait-for visual-change
read number
memorize state
repeat



current instruction (invisible to model)

current word (presented as audio)

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specifies the task/goal being defined

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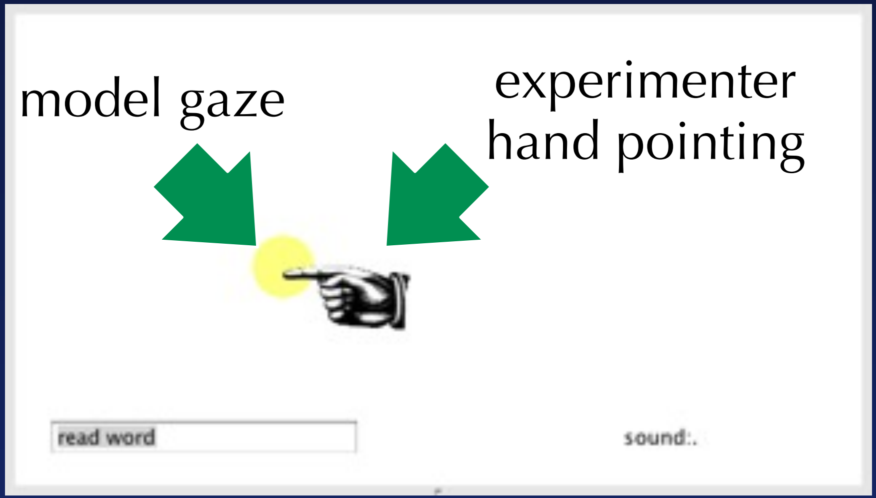

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```
(p read*done
    =goal>
        isa read
        object word
        ...
    =visual>
        isa text
        value =value
    =imaginal>
==>
    =imaginal>
        word =value
    =goal>
        ...
)
```

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    wait-for visual-change
    read word
    recall number for word
    if success type number
    wait-for visual-change
    read number
    memorize state
    repeat

"word" in instruction defines the slot name for recall

memorized *imaginal* state contains both word and number; it is this state that is recalled

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all task information accumulated in the imaginal buffer ("problem state"); can be memorized via repeated rehearsals

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start respond

#1: Paired Associates

- Instructions

to respond:

wait-for visual-change
read word
recall number for word
if success type number
wait-for visual-change
read number
memorize state
repeat

many aspects of the instructions make use of well-practiced skill knowledge

#2: Fan Effect

- Challenges
  - tutorial model accounts only for the testing stage
    - chunks are already in memory, activated strongly
  - a supermodel needs to account for the studying stage
    - chunks must be learned, and activated sufficiently
    - how do we activate them all evenly?
      — any discrepancy can alter the data pattern drastically
    - randomize study sequence, 10x/sentence
    - randomize test sequence

```
Human Data:

1.11, 1.17, 1.22
1.17, 1.20, 1.22
1.15, 1.23, 1.36

1.20, 1.22, 1.26
1.25, 1.36, 1.29
1.26, 1.47, 1.47
```

#2: Fan Effect

- Instructions

to study-sentences:
    wait-for visual-change
    read person
    read location
    memorize state
    repeat

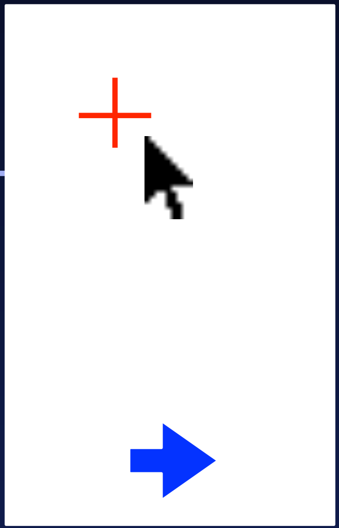
to recall-sentences:
    wait-for visual-change
    read person
    read location
    recall location for person as recalled-location
    compare location to recalled-location
    if success type k
    if failure type d
    repeat

start study-sentences

(...and then later...)

start recall-sentences

#3: Tracking & Choice



- Task
  - tracking: follow arrow with the mouse
  - choice: identify left/right arrows
- Challenges
  - multitasking: tracking & choice learned separately, must be interleaved
    - answer: threaded cognition
  - eye movements: effects arise from distance of arrow from target area
    - answer: EMMA eye-movement model

#3: Tracking & Choice

- Instructions

to track-target:
    move-mouse-to target
    repeat

to respond-to-arrow:
    read arrow
    if failure repeat
    compare arrow literal ‘<‘
    if success punch left-pinkie
    if failure punch left-middle
    repeat

start **track-target** and **respond-to-arrow**

Challenges

- Base-level learning
  - should be on -- it's a core learning mechanism
  - affects instruction following
    - need to rehearse instructions, or they're gone later
  - affects Paired Associate model
    - need to memorize state chunks enough to retrieve later
  - affects Fan Effect model
    - tutorial model uses (set-base-levels ...)
    - rehearsing each chunk to achieve the same base level is difficult in practice -- study has to be done just right

Challenges

- Production compilation
  - should be on -- it's a core learning mechanism
  - affects the Paired Associate model
    - forms specific rules for specific pairs
  - affects the Tracking model
    - reduces tracking loop from 7 to ~3 rule firings (good!)
    - how does compilation interact with threads?
  - affects the Fan Effect model
    - eliminates retrievals --> no more fan effect (bad!)
    - this is a general issue of keeping some retrievals
      - e.g., rehearsal productions shouldn't be compiled

Challenges

- Other parameters
  - activation noise (:ans)
    - Paired: 0.5
    - Fan: none
  - expected gain noise (:egs)
    - Paired: 0.1
    - Fan: none
  - retrieval threshold (:rt)
    - Paired: –1.7
    - Fan: 0.0

Results

- Currently... not great

Task	Check	Score
Paired	true	~.96
Tracking	true	~.70
Fan	true	bad!

- Paired model is robust
- Tracking model is somewhat robust
- Fan model is very sensitive

Reflections

- Some of this retraces previous work
  - like Fu et al.'s "over-the-shoulder" instructions
- Some new things
  - the "experimenter finger"
  - no chunk types (not a new idea though)
    - variable slots & instruction following
  - new integrated testing environment
- The big challenge
  - Bonnie John has said, 'Why can't we just turn on all the learning mechanisms at once?'
  - this is a test of this question — there's no easy answer

Reflections

- The big benefit: model testing & fidelity
  - let's say we propose a new theory of...
    - sequential actions, like Memory for Goals
      - every goal must be rehearsed, then retrieved
    - basal ganglia, a la Andrea Stocco's work
      - especially: no two variables on the LHS
    - etc. etc.
  - when integrated into a cognitive supermodel,
    we immediately test its effects across many domains

Moving Forward

- After a lot of work, we have...
  a single model of 3 tasks, sort of
- But now we have the infrastructure to start rigorously pursuing a cognitive supermodel

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For this each domain uses a different model

Can we do this with the same model?

```
Task                    Check        Score
------------------------------------------
Unit1-Count             true         ----
Unit1-Addition          true         ----
Unit1-Semantic          true         ----
Unit1-Tutor             true         ----
Unit2-Demo              true         ----
Unit3-Sperling          true         ----
Unit4-Paired            true         0.98
Unit5-Siegler           true         0.96
Unit5-Grouped           true         ----
Unit5-Fan               true         0.86
Unit6-BST               true         0.73
Unit7-Paired            true         0.99
```

Moving Forward

- After a lot of work, we have...
  a single model of 3 tasks, sort of
- But now we have the infrastructure to start rigorously pursuing a cognitive supermodel

Here's what we have now

Task	Check	Score
Paired	true	~.96
Tracking	true	~.70
Fan	true	bad!

Moving Forward

- After a lot of work, we have...
  a single model of 3 tasks, sort of
- But now we have the infrastructure to start rigorously pursuing a cognitive supermodel

Here's what
we want...

Task	Check	Score
Fan Effect	true	0.86
Paired Assoc.	true	0.94
PRP	true	0.98
Driving Exp 1	true	0.87
Driving Exp 2	true	0.82
Driving Exp 3	true	0.84
ATC Exp 1	true	0.90
Document Editing	true	0.78
Web Browsing	true	0.91
Choosing Coffee	true	0.99

etc. etc. etc.