Modeling and Neuroscience (or ACT-R and fMRI)

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Overview

- Motivation
- Task Specifics
- Modeling Specifics
- Experiment Results
- Implications

“Neuroscience” issues

- Where does x take place?
- What does circuit x do?
- How is x computed?

“Modeling” issues

- How is x computed?
- Where does x take place?
- What circuit participates in x?

Modeling & fMRI Issues

- Computational cognitive modeling provides rich predictions of behavior over time. Can we use the richness of a cognitive model to drive fMRI data analysis and if so how do we do it?

- How can we use fMRI results to guide development of specific cognitive models and ACT-R theory in general

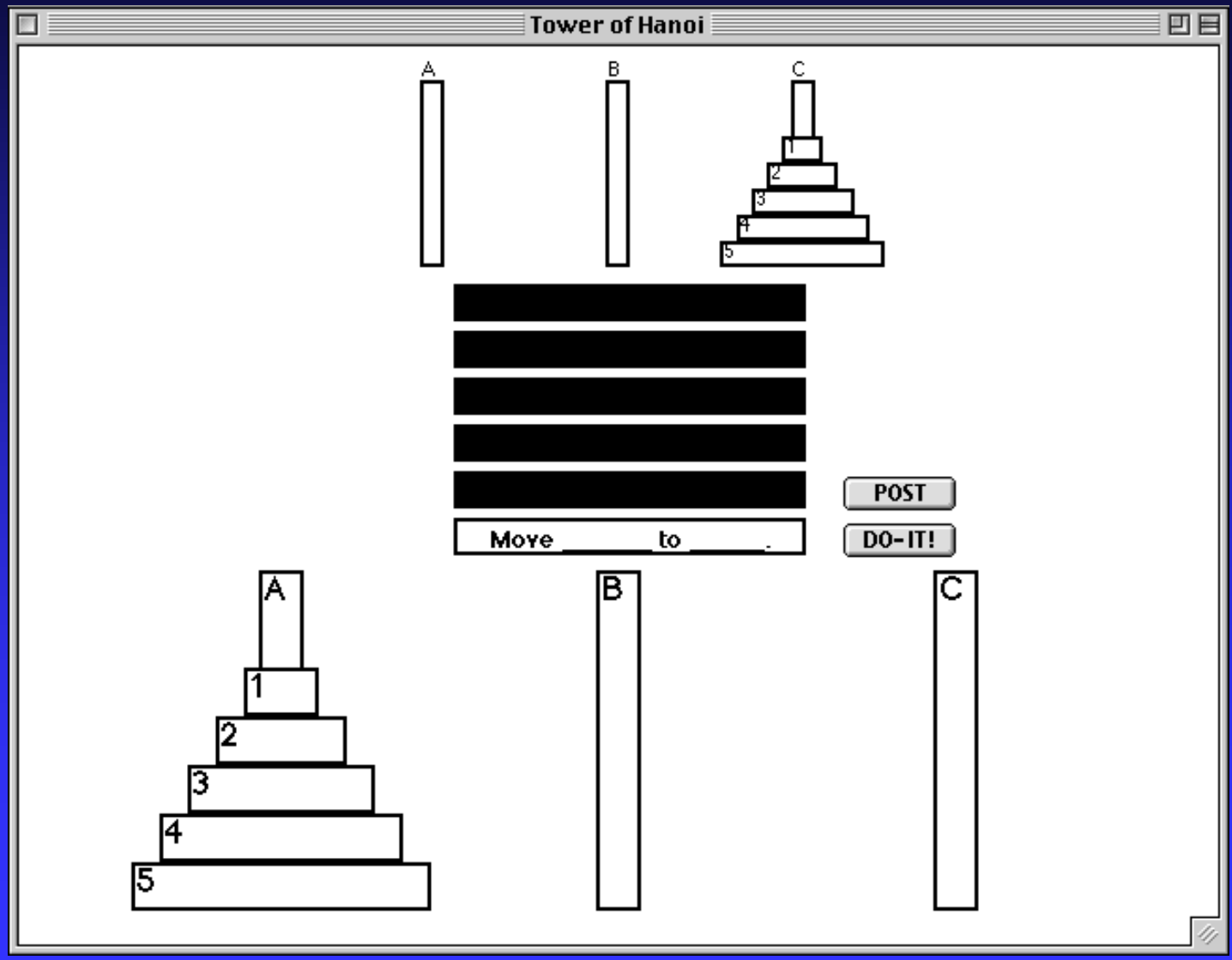
The Task: Tower of Hanoi (of course)

- The 5-disk Tower of Hanoi (TOH) task is behaviorally rich planning task
- The subgoaling strategy involves *varying numbers of planning steps* at each move while progressing toward the goal state
- ACT-R cognitive model nicely captures behavioral data

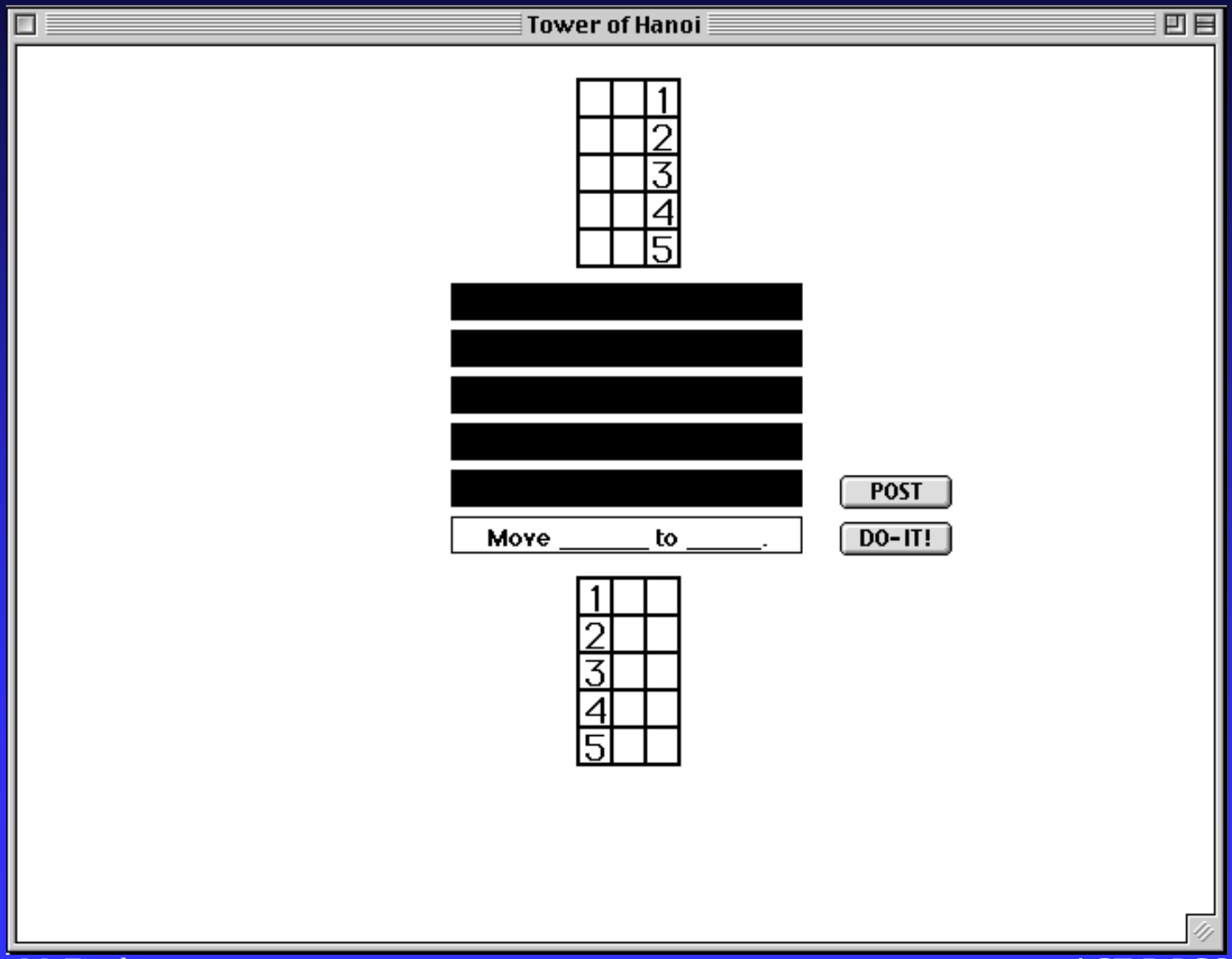
Task Summary: Pre-scan practice

- 21 pseudo-random problems, ***classic interface***, explicit subgoal posting, mousing
- 21 pseudo-random problems, ***grid interface***, explicit subgoal posting, mousing
- 7 problems, grid interface, secondary task, no subgoal posting, 3 button response
- Memorize single goal state, 10 simple practice problems

TOH Classic Interface



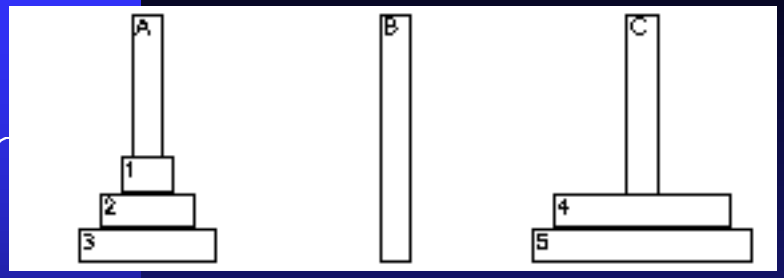
TOH Grid Interface



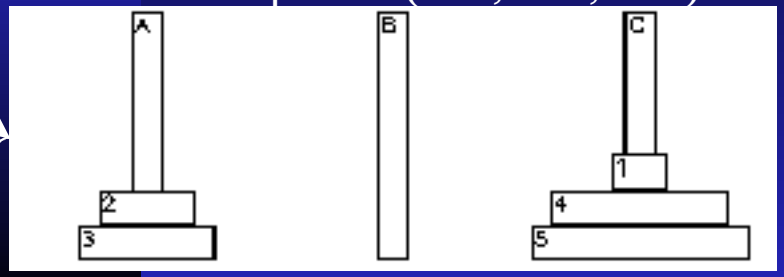
The Subgoaling Strategy

- 1. Select largest out of place disk in current context and destination peg.
- 2. If direct move, do it and goto step 1. Otherwise, set subgoal to make move
- 3. If next largest disk blocks destination, select it and other peg & go to step 2.
- 4. If next largest disk blocks source, select it and other peg & go to step 2.

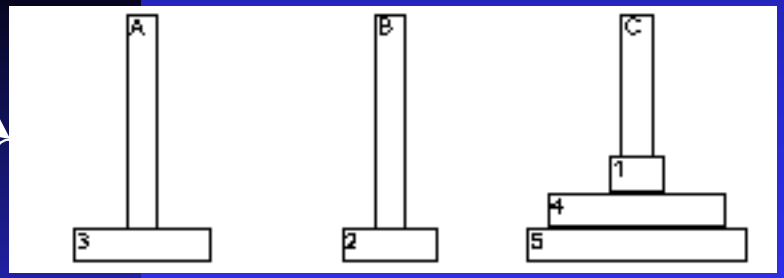
TOH 3-tower example move sequence



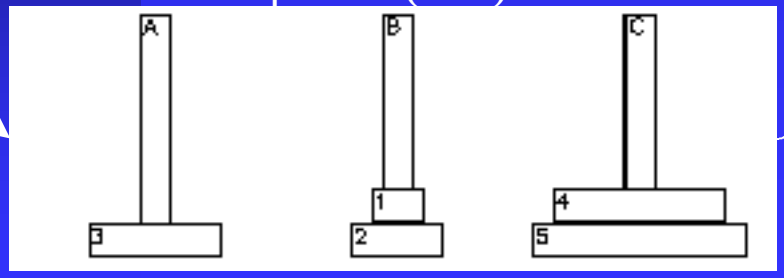
Plan 3 move sequence (3-C, 2-B, 1-C)



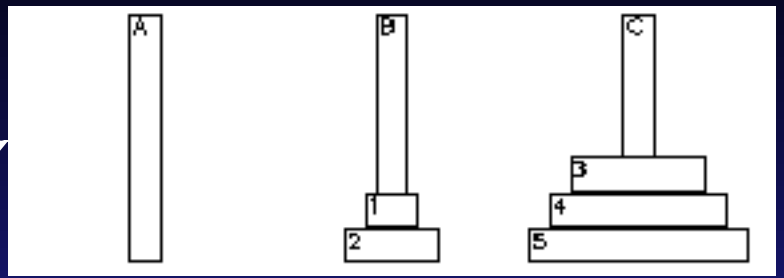
Plan 1 move sequence (2-B)



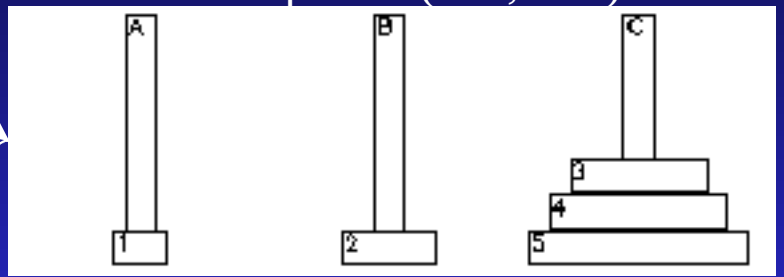
Plan 1 move sequence (1-B)



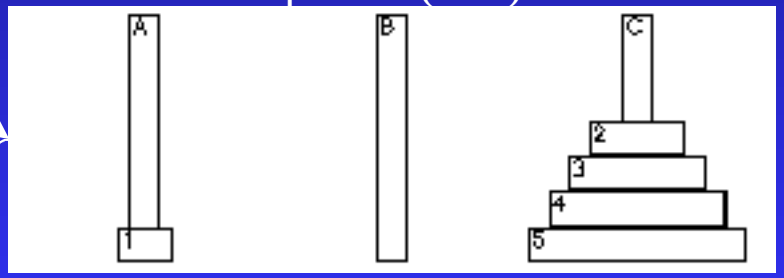
Plan 1 move sequence (3-C)



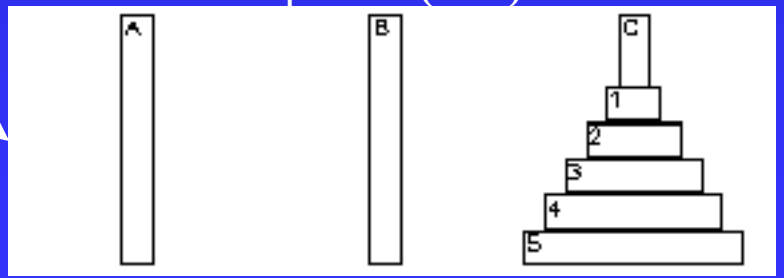
Plan 2 move sequence (2-C, 1-A)



Plan 1 move sequence (2-C)



Plan 1 move sequence (1-C)

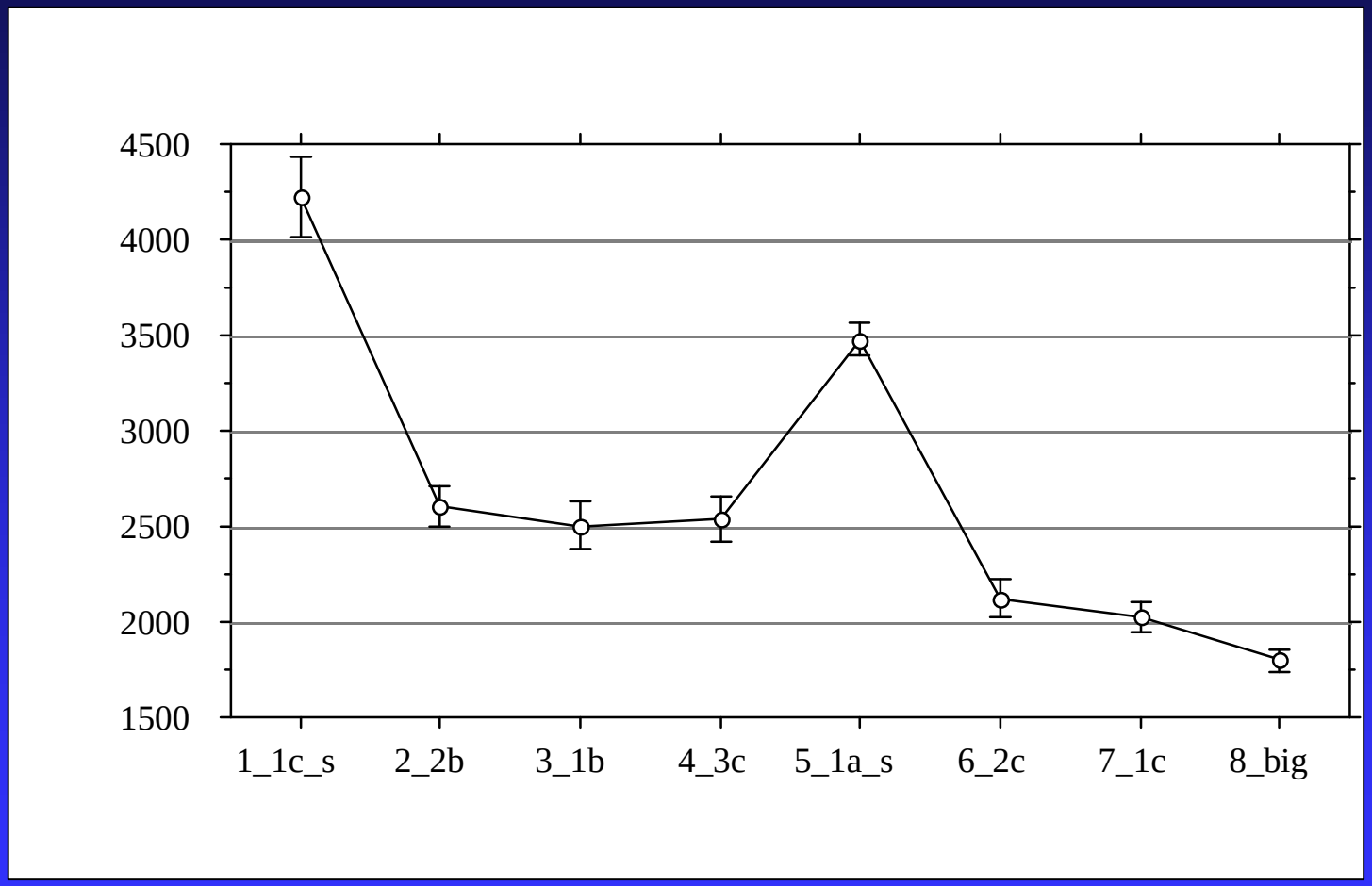


Goal State

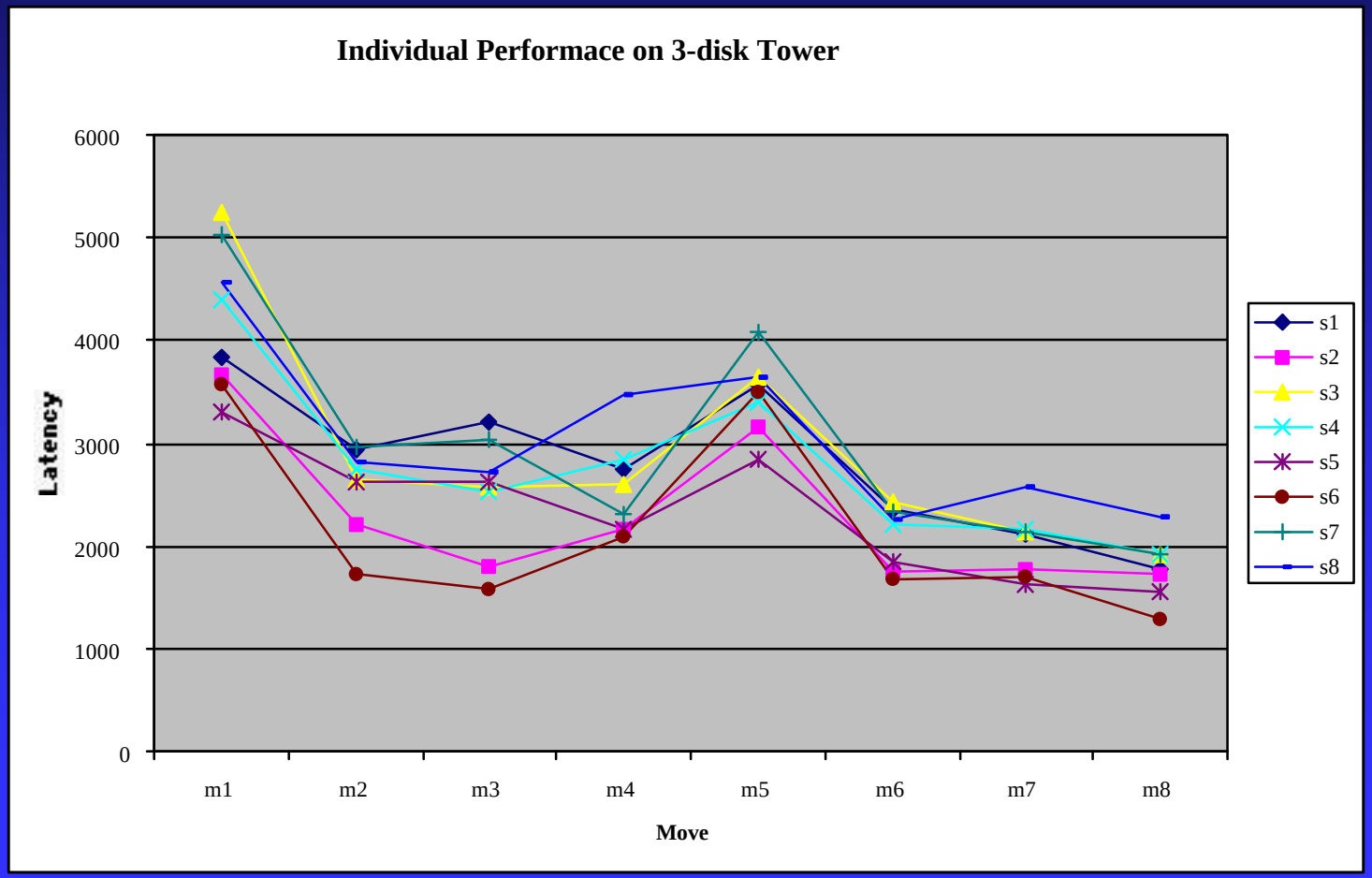
The Task: TOH in the magnet

- One full volume (25 slices) every 4 seconds
- 16 seconds per move = 4 scans per move
- 12 20-23 move problems, about 6 minutes each

Behavioral Results



Behavioral Results



What do we want to see?

- How does the brain handle goal processing?
- Which brain areas are differentially responsive to goal setting operations?
- Are there identifiable circuits that collectively implement manipulation of goals?

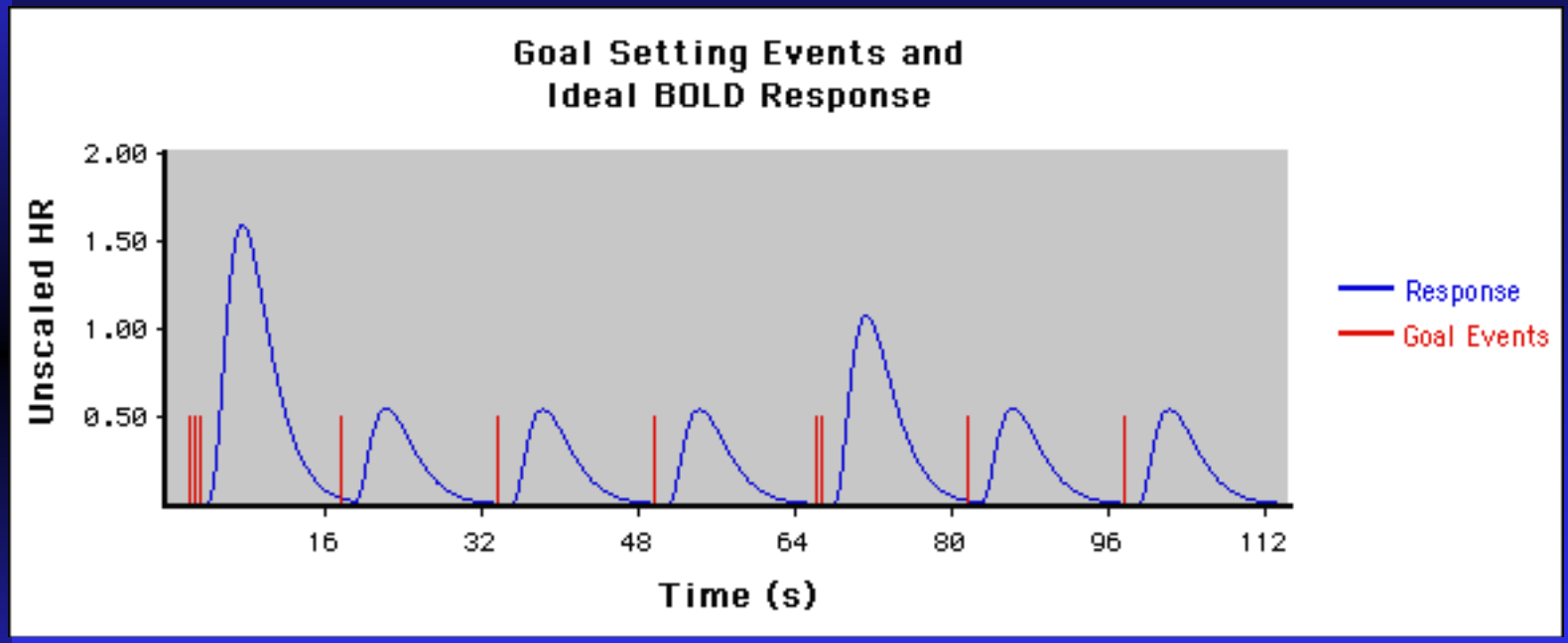
Terminology

- BOLD - Blood Oxygenation Level Dependent response (aka hemodynamic response)
- MR - magnetic resonance, signal measured in the magnet
- Voxel - approximately cube “point” within the brain

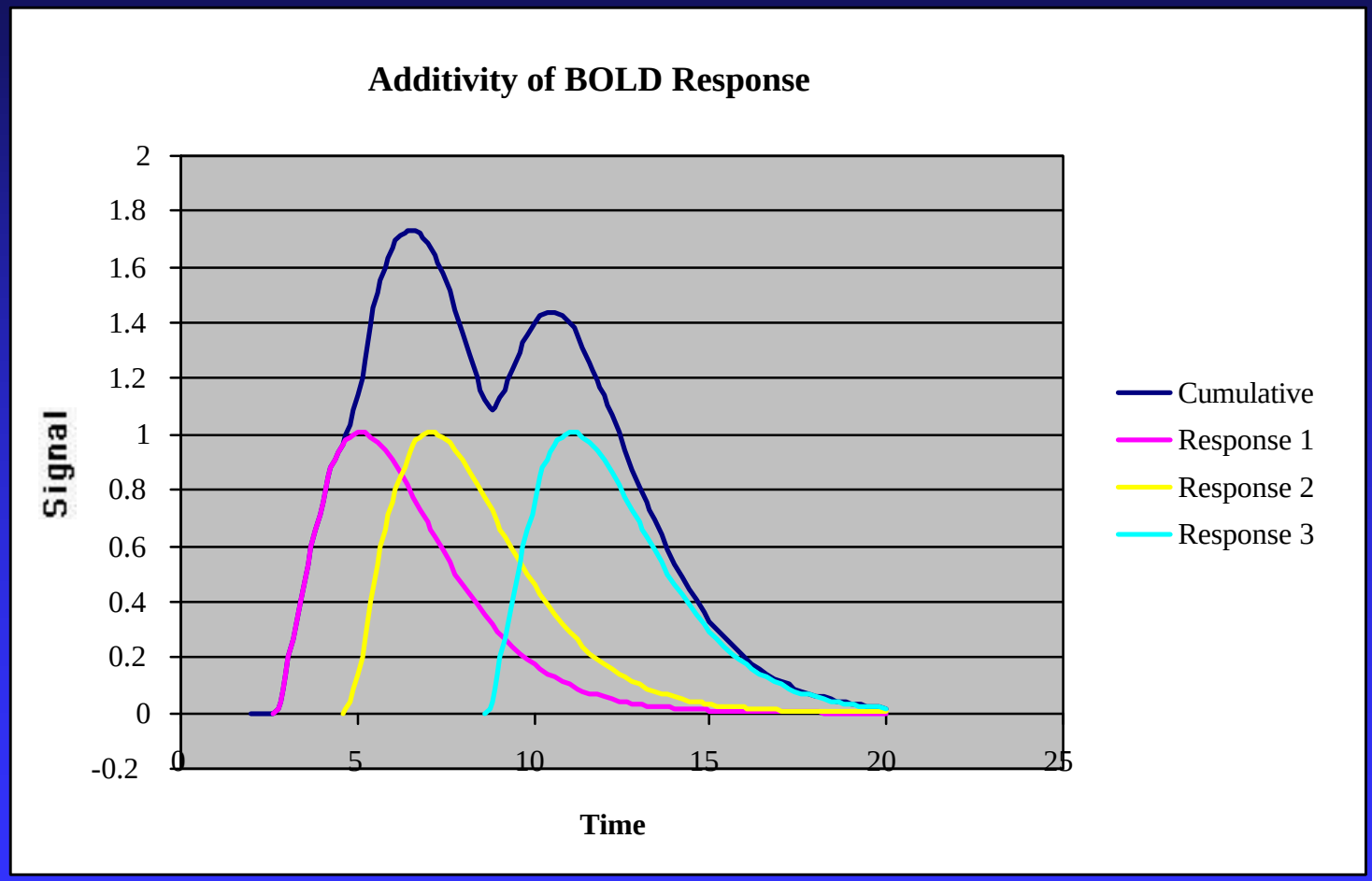
Where do we begin?

- Run model over problem set, collecting goal setting event timestamps
- Use goal setting timestamps to generate an ideal BOLD-like timeseries

ACTR(t) Events and Time Series



BOLD Response Characteristics



Identifying a responsive voxel

- Model MR signal as a function of the ACT-R generated time series
  - $MR(t) = B_0 + B_1 * trial(t) + B_2 * ACTR(t) + \varepsilon(t)$
  - Ignore error trials and immediate successors
  - Run regression for every one of the 25x64x64 voxels
  - Result is a beta map for each regressor

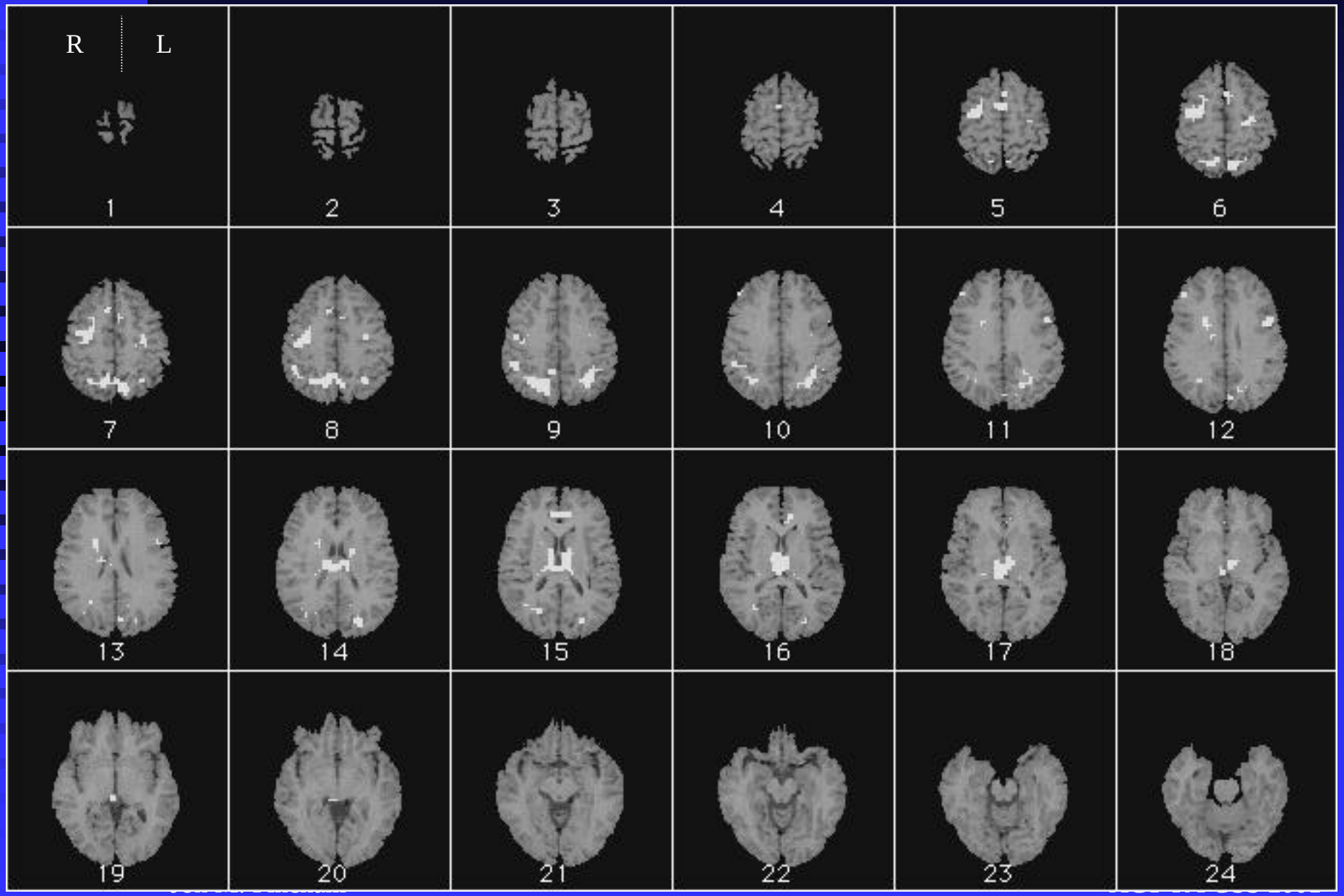
Group Analysis

- Morph each brain into a reference brain
- Voxel-wise 2-tailed t-test of H_0: $B_2 = 0$ across subjects

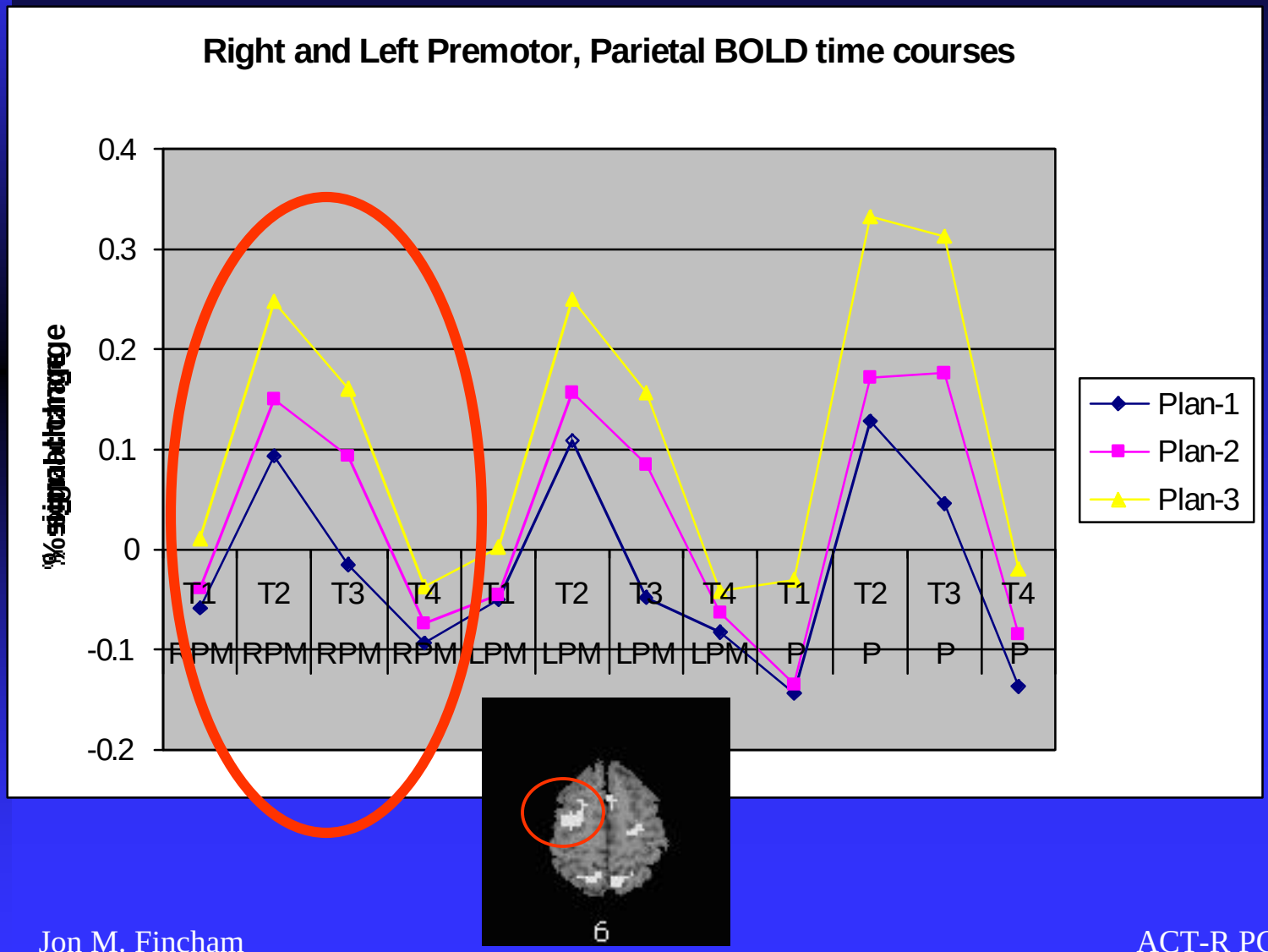
Analysis Summary

- Within subject voxel-wise regression of MR signal against ACT-R generated time series
  - $MR(t) = B_0 + B_1 * trial(t) + B_2 * ACTR(t) + \varepsilon(t)$
  - Ignore error trials and immediate successors
- Voxel-wise 2-tailed t-test of H_0: $B_2 = 0$ across subjects
- Threshold at $p<0.0005$ and contiguity of 8 voxels

TOH Activation Map ($p < 0.0005$, contiguity = 8)



Premotor & Parietal activity increase parametrically with number of planning steps



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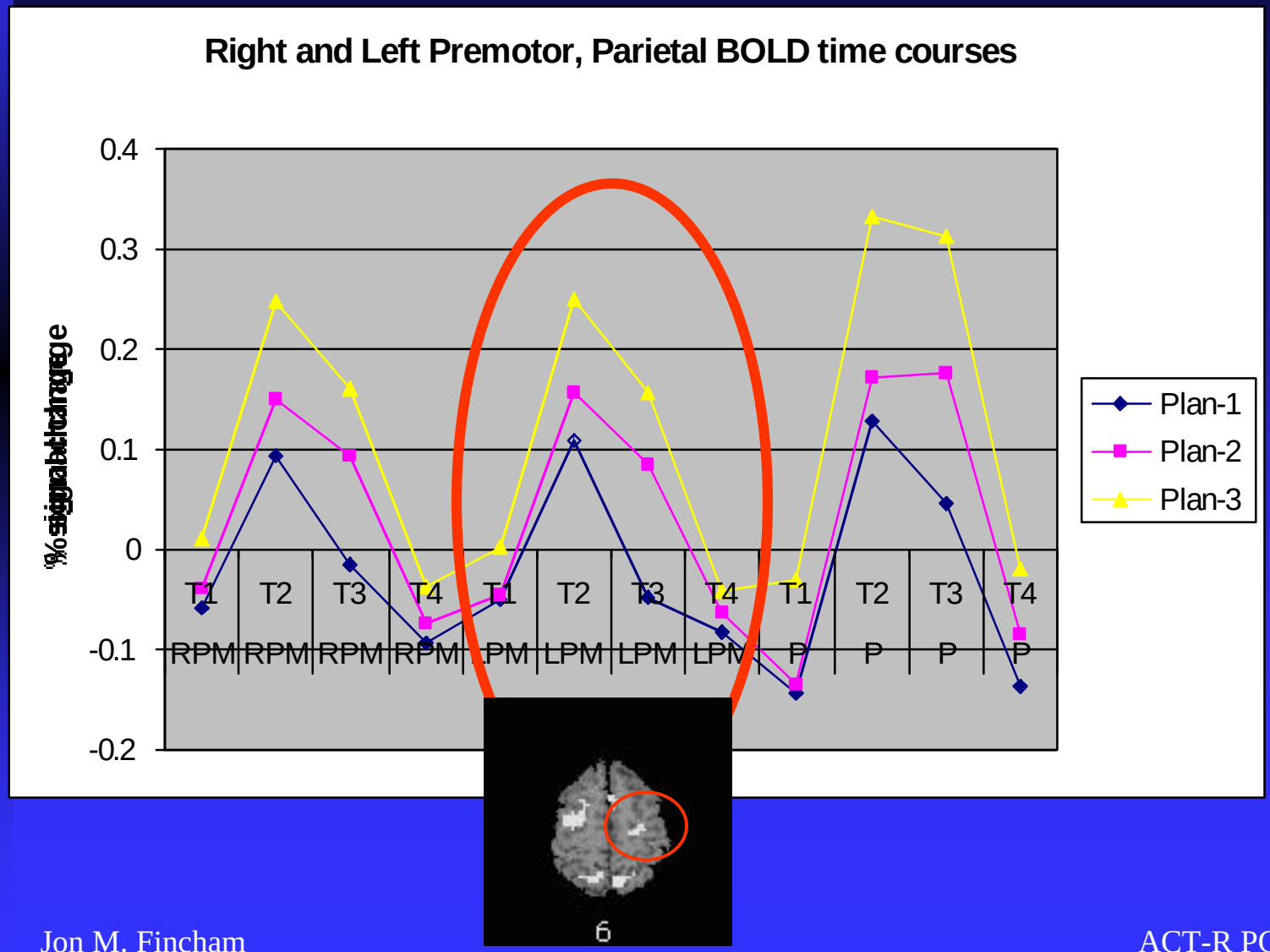

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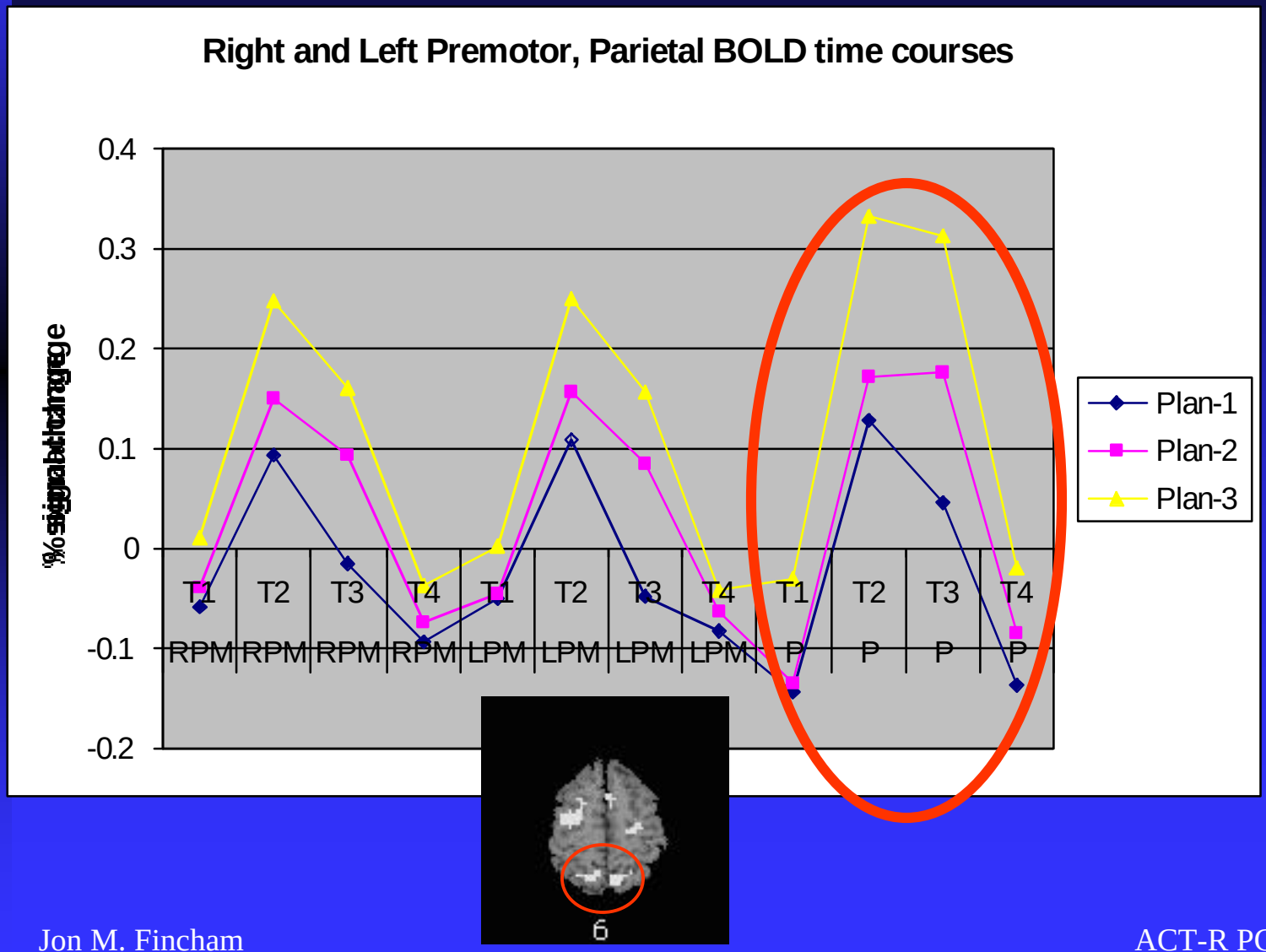
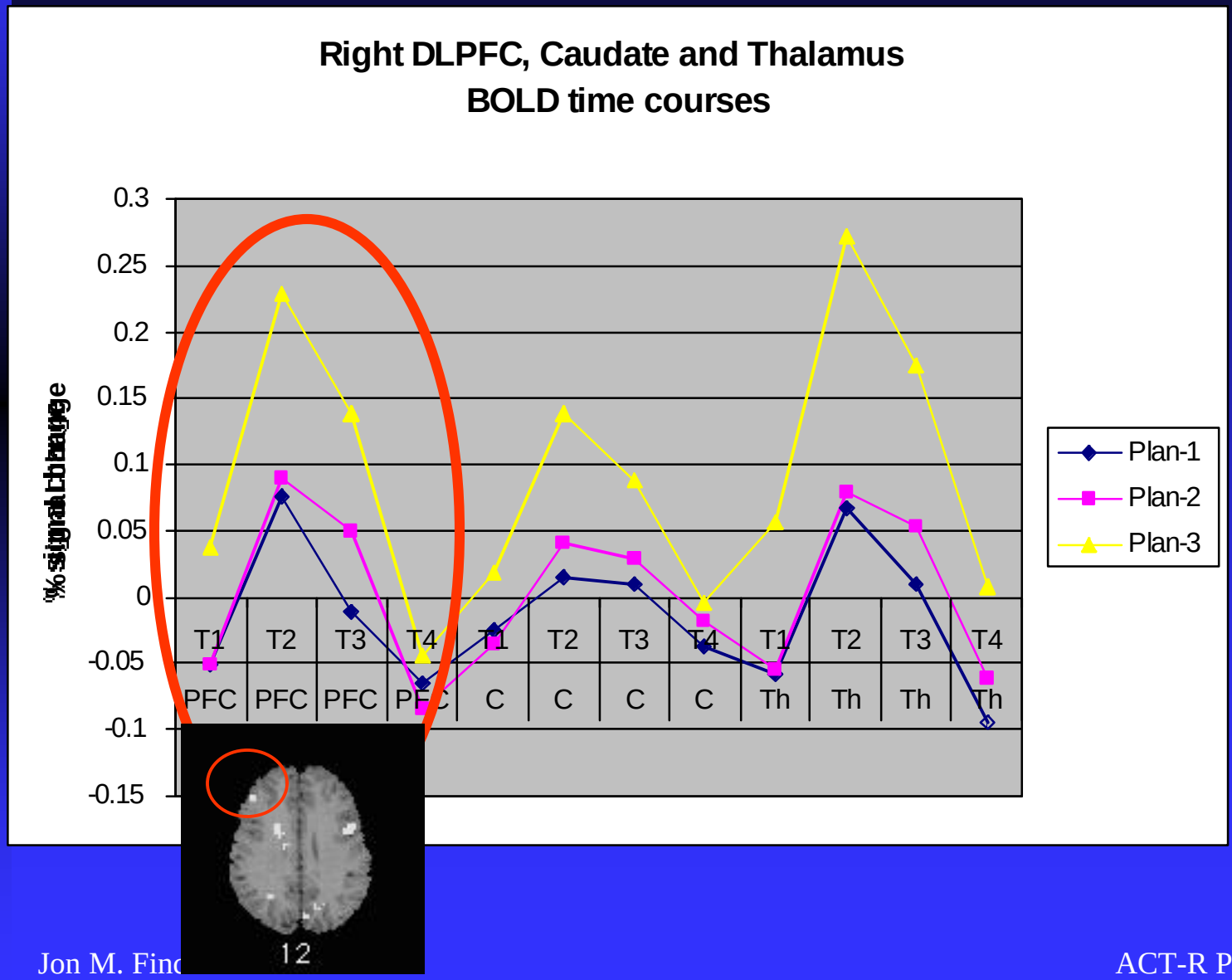


Prefrontal - Basal Ganglia - Thalamic Circuit



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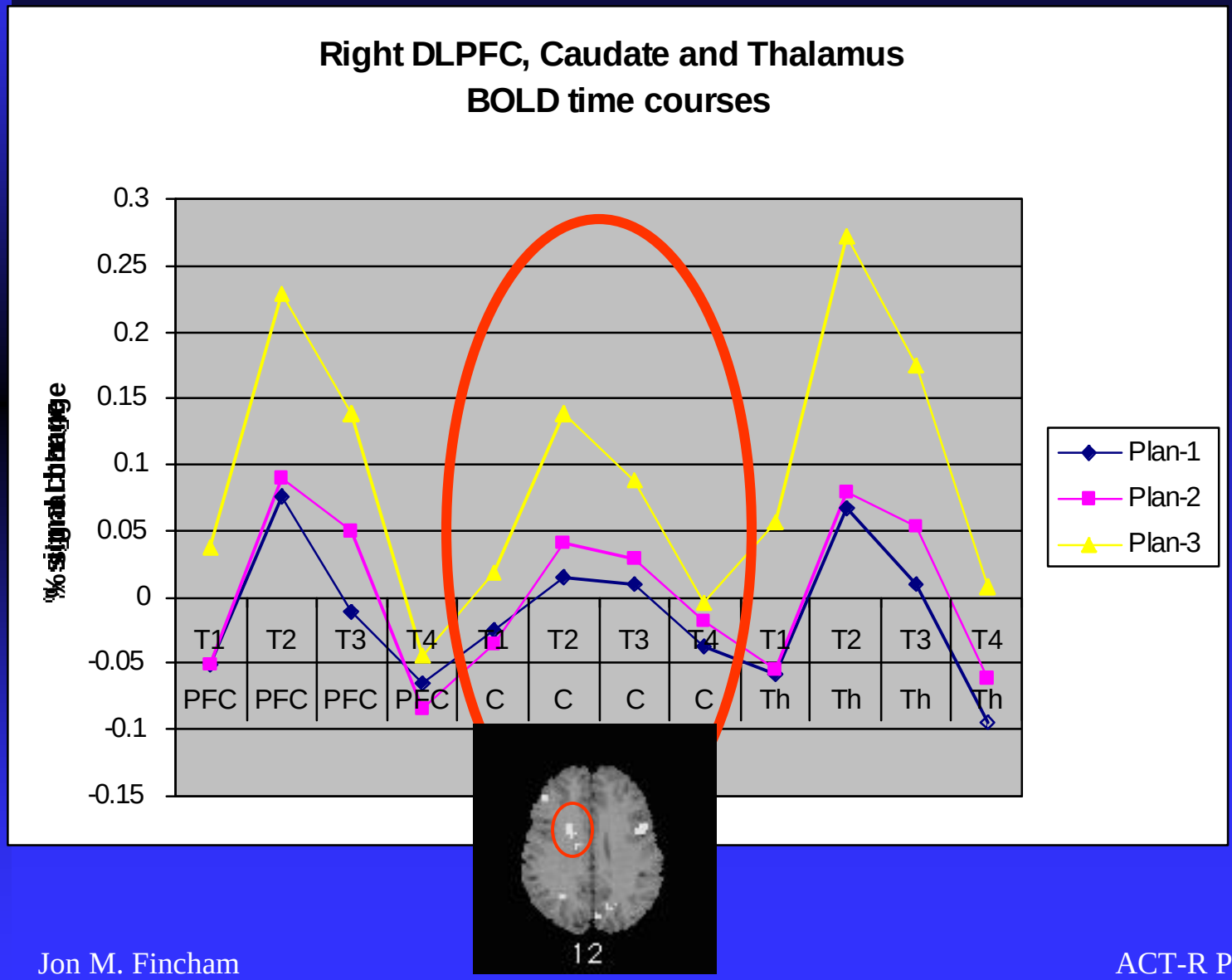

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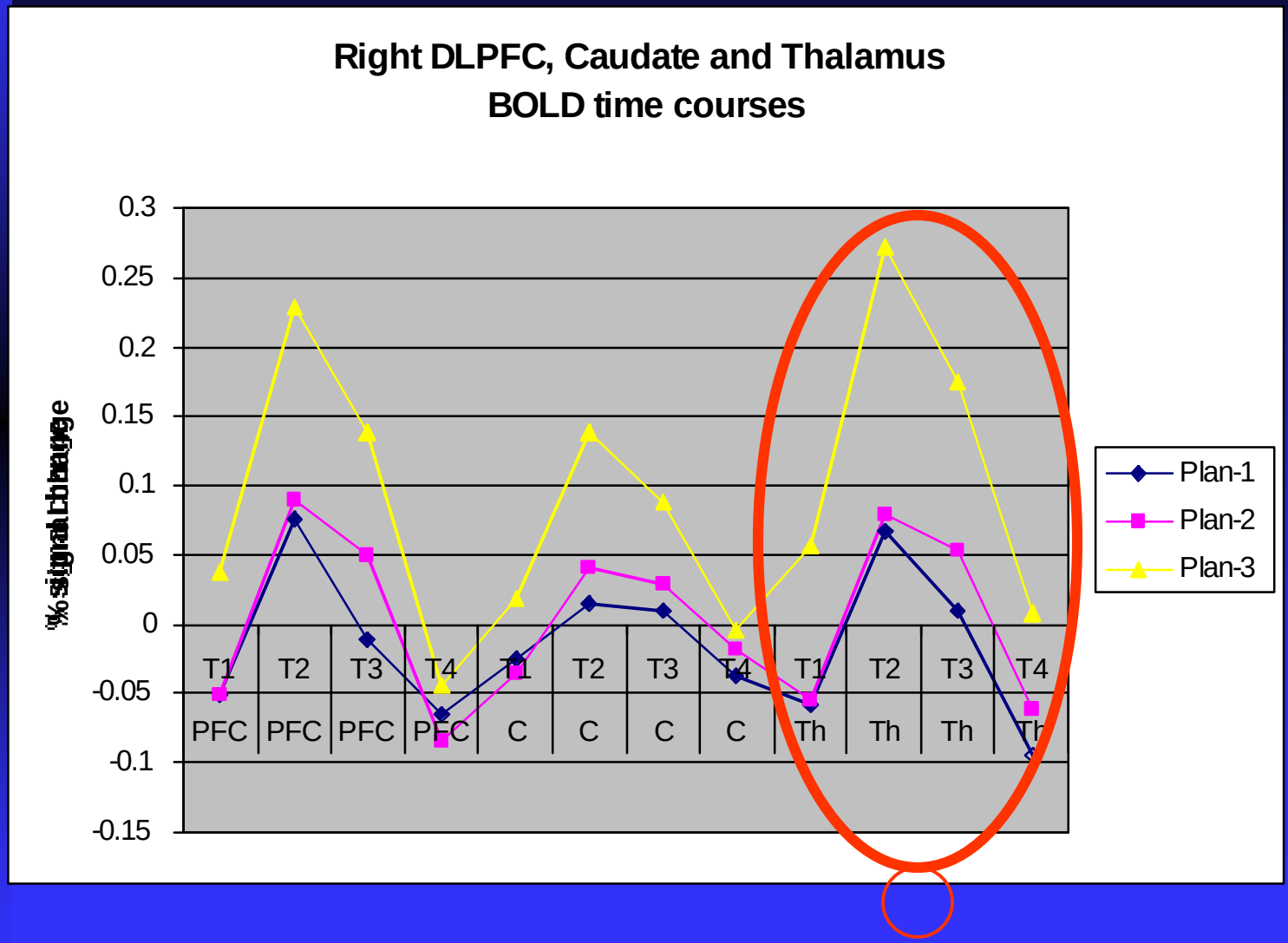

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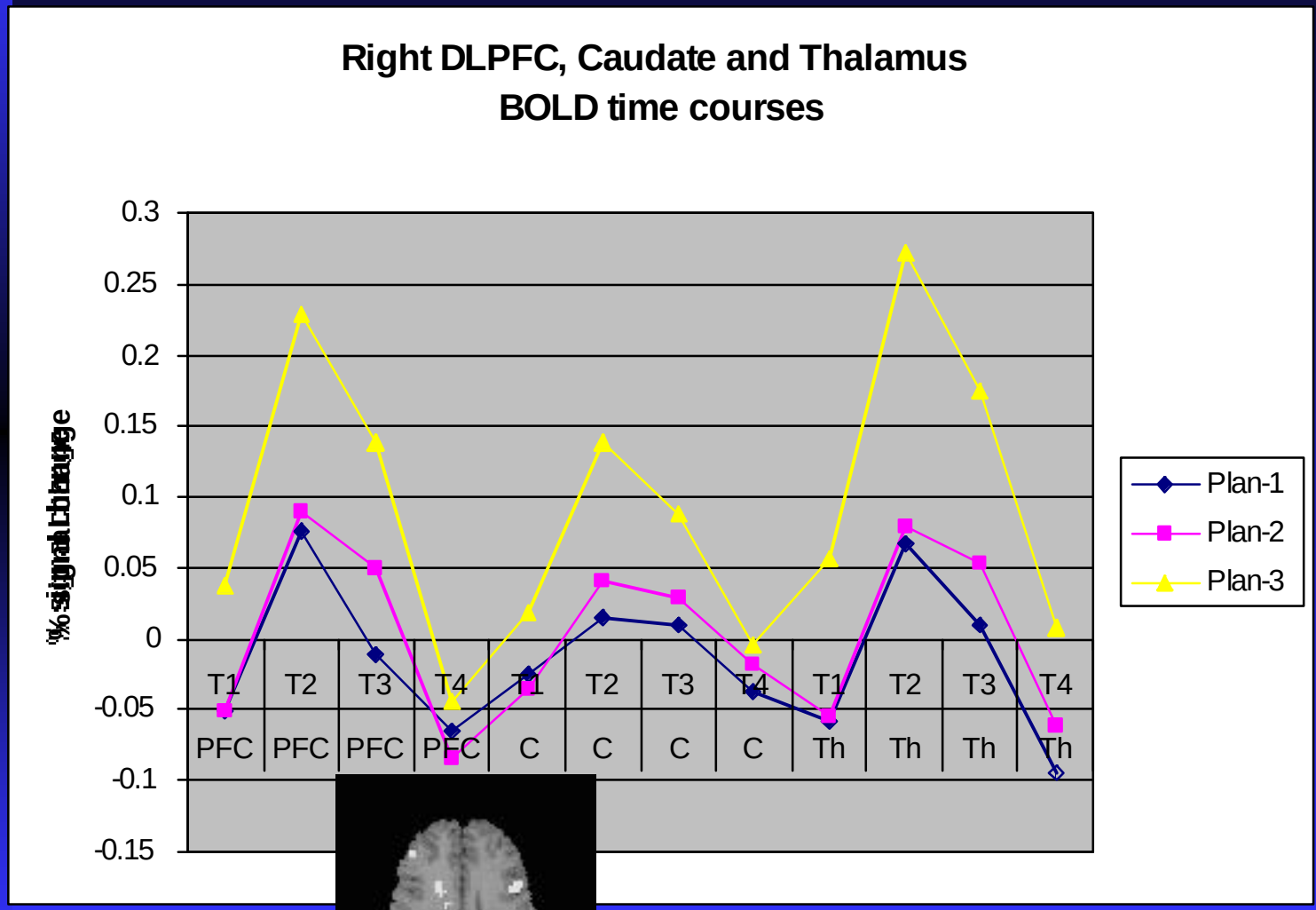
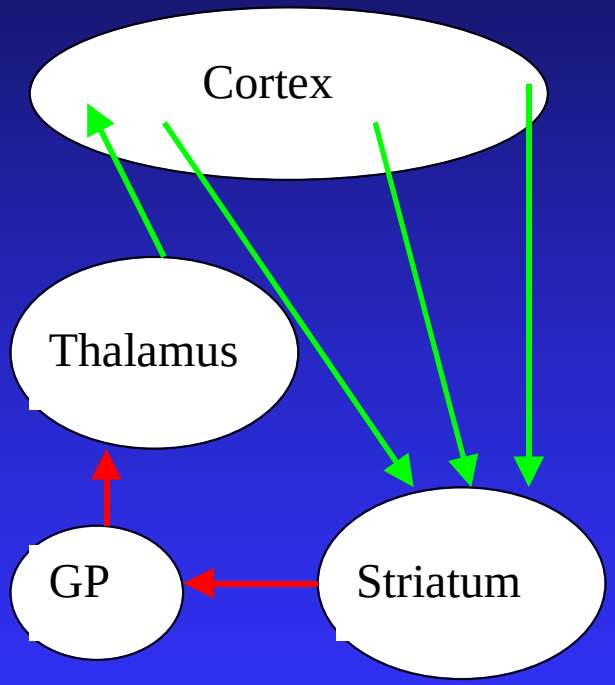


PFC -Basal Ganglia -Thalamus



- Striatum = Pattern Matching & conflict resolution?
- Result gates thalamus to update buffers?

Summary of findings so far...

- Move planning activity in parietal and premotor areas varies parametrically with number of planning steps
- PFC-Basal Ganglia-Thalamic circuit does not vary parametrically with number of planning steps but shows significant BOLD response during high planning moves only
- Suggests PFC becomes engaged when sequencing of multiple moves is required

What can we conclude about the model?

- Subjects are bypassing subgoaling procedure for 2-tower subproblems
- Setting a goal “move disk 1 to opposite of where disk 2 goes”
- Now we can use GLM model comparison techniques to confirm best fitting models...

What can we conclude about ACT-R?

- Nothing…….yet.
- Goal manipulation does seem to predict brain activity in the “right” places, but
- Need to run other studies in different domains (and different models) to gain confidence in our label of “goal processing” circuitry

What have we learned so far?

- Applying cognitive modeling to the neuroimaging domain is feasible: models can inform analysis
- fMRI data can inform models
- fMRI data can inform architecture
- Symbiotic relationship exists between modeling and fMRI
- What else?

What else can we examine?

- +goal>, +retrieval>, +visual>, +aural>, +manual>,
- Number of elements in goal
- Number of full buffers

Thank you!