How to give ACT-R a brain?

Jelmer Borst

Post-Graduate Summer School
July 19, 2011
ACT-R simulates cognition and implements cognition.
ACT-R simulates cognition and implements cognition.
The Present
State-of-the-Art

**Confirmatory:**
ROI Analysis

**Exploratory:**
Model-Based Analysis
Regions-of-Interest

Goal
Manual
Visual
Problem State
Declarative Memory
Procedural Memory

Motor Cortex
Posterior Parietal
Anterior Cingulate
Fusiform
Prefrontal
Basal Ganglia

courtesy of Andrea Stocco
Regions-of-Interest

Model Predictions

Data

Manual Module
Left Motor Cortex

Location

x = -42
y = -23
z = 54
State-of-the-Art

Confirmatory: ROI Analysis

Exploratory: Model-Based Analysis
Model-Based fMRI Analysis

BOLD response

Model Predictions

linear model per voxel

which voxels correspond to the model predictions?
Model Predictions

![Model Predictions Diagram]

- **Problem State**: Easy-Easy, Hard-Easy, Easy-Hard, Hard-Hard
- **Vision**: Stimulus function
- **Memory**: Manual time (s)
- **Condition A**
- **Condition B**
- **Condition C**
- **Condition D**

![HRF Graph]
Model-Based fMRI Analysis

Model Predictions

Problem State
- Easy-Easy
- Hard-Easy
- Easy-Hard
- Hard-Hard

Vision
- 0
- 50
- 100
- 150
- 200
- 250
- 300

stimulus function

Memory
- Manual
time (s)

stimulus function
hemodynamic response function

linear model per voxel

which voxels correspond to the model predictions?
Problem State/Imaginal

Declarative Memory

(Borst et al., 2011, *NeuroImage*)
State-of-the-Art

Confirmatory: ROI Analysis

Exploratory: Model-Based Analysis

Brain regions:
- Prefrontal
- Anterior Cingulate
- Motor Cortex
- Posterior Parietal
- Fusiform
- Basal Ganglia

Graphs and tables show data across different conditions (Easy-Easy, Hard-Easy, Easy-Hard, Hard-Hard) with annotated values on the x-axis and corresponding data points.
The Past
What did neuroscience give ACT-R?

Model validation:

Model Predictions

Data

Manual Module
Left Motor Cortex
Location

x = .42
y = -23
z = 54
What did neuroscience give ACT-R?

Model validation:

![Model Predictions and Data](chart.png)

**Problem State Module**
*Left Intraparietal Sulcus*

Location

\[ x = -24 \]
\[ y = -67 \]
\[ z = 44 \]
What did neuroscience give ACT-R?

- Model validation
- New constraints:
  - Separate Problem State/Imaginal Module
    (Anderson et al., 2004, Cogn. Neurosci.; Qin et al., 2003)
  - Andrea Stocco’s Basal Ganglia model:
    Limit on number of variable bindings in procedural module
Andrea’s Model

Stocco, Lebiere, & Anderson, 2010, Psych. Review
Andrea’s Model

“It’s a small-scale version.”

“It is actually rather complex.”

Stocco, Lebiere, & Anderson, 2010, Psych. Review
As far as I understand the basal ganglia, they cannot support the full range of computations of ACT-R.

The limits of the circuit should not be counted in productions, but in variables.

For example, if the limit is two variables, then you can execute two one-variable productions, or one two-variable production.

What did neuroscience give ACT-R?

• Model validation

• New constraints:
  – Separate Problem State/Imaginal Module
    (Anderson et al., 2004, Cogn. Neurosci.; Qin et al., 2003)
  – Andrea Stocco’s Basal Ganglia model:
    Limit on number of variable bindings in procedural module
What did ACT-R give neuroscience?

“If the mind happens in space at all, it happens somewhere north of the neck.”

(Fodor, 1999)

• Functional interpretation of fMRI data (model-based)
• Explaining complex fMRI data (ROI)
The Future
How to improve neuroscience for ACT-R?

• Model-based multi-voxel pattern analysis, ‘mind-reading’
Multi-Voxel Pattern Analysis

Visual | Declarative Memory | Imaginal
---|---|---
Participant P1
Mean over participants

Pars opercularis (z=24 mm) | Postcentral gyrus (z=30 mm) | Superior temporal sulcus (posterior) (z=12 mm)

Mitchell, et al., 2008, Science
How to improve neuroscience for ACT-R?

- Model-based multi-voxel pattern analysis, ‘mind-reading’
- Dynamic Causal Modeling (DCM)
Dynamic Causal Modeling

Stephan et al. 2008, *Neuroimage*
How to improve neuroscience for ACT-R?

• Model-based multi-voxel pattern analysis, ‘mind-reading’

• Dynamic Causal Modeling (DCM)

• EEG/MEG?

• Other techniques?
How to improve ACT-R for neuroscience?
Van Maanen et al., in press, Cogn Sci

Stocco et al., 2010, Psych Rev

Jilk et al., 2008, J Exp Theor AI
Conclusions

More powerful neuroscience methods

Multi-level ACT-R modules
Thanks!