ACT-R models of training

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Our Goals in the MURI Project

- Create computational models that will be used as predictive tools for the different effects resulting from the application of empirically-based training principles
- The predictive training models will help:
  - manipulate a set of training, task and ACT-R parameters
  - determine speed and accuracy as a result of the parameter settings and the training principles
  - Easily generate predictions of training effects for new manipulations
Agenda

• Prolonged work and the speed-accuracy tradeoff
  o The data entry task
  o ACT-R models of fatigue effects
• Repetition priming effect
  o Initial ACT-R models of repetition priming
  o Predictions to be verified in current data collection
• Training difficulty principle
  o The radar task
  o ACT-R models of consistent and varied mapping effects
Data entry is ubiquitous in human life
Opposing processes affect performance

• From Healy et al., 2004: Prolonged work results in distinctive opposite effects (facilitative and inhibitory)
• Proportion of errors increases while response time decreases.
The 2x2 levels of ACT-R

http://act.psy.cmu.edu
(Anderson & Lebiere, 1998)

<table>
<thead>
<tr>
<th>Symbolic</th>
<th>Declarative Memory</th>
<th>Procedural Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chunks: declarative facts</td>
<td>Productions: If (cond) Then (action)</td>
<td></td>
</tr>
<tr>
<td>Activation of chunks (likelihood of retrieval)</td>
<td>Conflict Resolution (likelihood of use)</td>
<td></td>
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</tbody>
</table>
**ACT-R equations**

http://act.psy.cmu.edu

(Anderson & Lebiere, 1998)

### Activation

\[ A_i = B_i + \sum_j W_j \cdot S_{ji} + \sigma_A \]

### Learning

\[ B_i = \ln \sum_j t_j^{-d} \]

### Latency

\[ T_i = F \cdot e^{-A_i} \]

### Utility

\[ U_i = P_i \cdot G - C_i + \sigma_U \]

### Learning

\[ P_i = \frac{\text{Succ}_i}{\text{Succ}_i + \text{Fail}_i} \]

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**IF the goal is to categorize new stimulus and visual holds stimulus info S, F, T**

**THEN start retrieval of chunk S, F, T**

**and start manual mouse movement**
Chunk Activation

Activation makes chunks available to the degree that past experiences indicate that they will be useful at the particular moment.

Base-level: general past usefulness
Associative Activation: relevance to the general context
Matching Penalty: relevance to the specific match required
Noise: stochastic is useful to avoid getting stuck in local minima

Higher activation = fewer errors and faster retrievals

\[
A_i = B_i + \sum_j W_j \cdot S_{ji} + \sum_k MP_k \cdot Sim_{kl} + N(0, s)
\]
Production compilation

• Basic idea:
  o Productions are combined to form a macro production → faster execution
  o Rule learning:
    • Retrievals may be eliminated in the process
    • Practically: declarative → procedural transition
  o Production learning produces power-law speedup
    • The power-law function does not appear in the compilation mechanism, rather the power-law emerges from the mechanism
ACT-R Models of Fatigue Effects in Data Entry

• **ACT-R Model 1:** Prolonged work and the speed-accuracy tradeoff (Experiment 1 from Healy, Kole, Buck-Gengler and Bourne, 2004)

• **ACT-R Model 2:** Speed-accuracy trade-off changes for motoric and cognitive components (Experiment 2 from Healy, Kole, Buck-Gengler and Bourne, 2004)

• **ACT-R Model 3:** How do cognitive and motoric stressors affect different response time components: articulatory suppression and weight (Experiment 1 from Kole, Healy ad Bourne, 2006)
ACT-R model of the data entry task

- Encode next number
- Retrieve key location
- Type next number
- Hit Enter

Initiation time:
- All numbers encoded

Execution time:
- All numbers typed

Conclusion time:
ACT-R Model 1

Error Proportion

Total RT

R² = .89

R² = .89
**ACT-R model 1**

- **Speedup**: Production compilation:
  - From Visual → Retrieval (key loc) → Motor
  - To Visual → Motor
  - Faster access to key loc

- **Accuracy ↓**: Degradation of source activation (W):
  \[
  A_i = B_i + \sum_j W_j \cdot S_{ji} + \sum_k MP_k \cdot Sim_{ki} + N(0, s)
  \]
ACT-R Models of Fatigue Effects in Data Entry

- **ACT-R Model 1**: Prolonged work and the speed-accuracy tradeoff (Experiment 1 from Healy, Kole, Buck-Gengler and Bourne, 2004)

- **ACT-R Model 2**: Speed-accuracy trade-off changes for motoric and cognitive components (Experiment 2 from Healy, Kole, Buck-Gengler and Bourne, 2004)

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**ACT-R Model Accuracy**

![Graph showing the proportion of correct responses over blocks, with Observed and Predicted lines. The R² value is 0.68.](image)

R² = 0.68
ACT-R Model 2

Initiation Time

Conclusion Time

R² = .81

R² = .85

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ACT-R model 2

- **Speedup**: Production compilation
  - From Visual $\rightarrow$ Retrieval (key loc) $\rightarrow$ Motor
  - To Visual $\rightarrow$ Motor
  - Faster access to key loc
  - Gradual decrease in goal value ($G$)
    \[
    U_i = P_i \cdot G - C_i + \sigma_U
    \]
- **Accuracy ↓**: A gradual decrease in source activation ($W$)
  \[
  A_i = B_i + \sum_j W_j \cdot S_{\beta} + \sum_k MP_k \cdot Sim_{ik} + N(0,s)
  \]
ACT-R Models of Fatigue Effects in Data Entry

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**ACT-R Model 3**

Total response time

**Human data**

**ACT-R Prediction**
ACT-R Model 3

Proportion correct

Human data

ACT-R Prediction
ACT-R model 3

- Same as Model 2:
- With articulatory suppression
- Not a 'fit' but a prediction
Summary of Act-R models of Fatigue

• The model provides detailed predictions of the speed and accuracy tradeoff effect with prolonged work in the data entry task:
  o Decreased RT by production compilation
  o Increase Errors by gradual decrease in source activation
• Fatigue may affect cognitive and motor components differently:
  o strong effects of fatigue by gradual decrease in goal value
  o no effects on motor components
• The ACT-R model suggest that cognitive fatigue may arise from a cognitive control and motivational processes (Jongman, 1998)
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Empirical test of model’s predictions
(Gonzalez, Fu, Healy, Kole, and Bourne, 2006)

- Effects of number of repetitions and delay on repetition priming
  - How performance deteriorates with different delays after training?
  - How re-training may help retention of skills?
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The Radar Task
(From Gonzalez and Thomas, under review; Gonzalez, Thomas, and Madhavan, under review)
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(From Gonzalez and Thomas, under review; Gonzalez, Thomas, and Madhavan, under review)
Current data fits to human data: effects of mapping and load

RADAR: Model Latency at Training

- **Human**
- **Model**

Condition:
- CM 1 - 1
- CM 4 - 4
- VM 1 - 1
- VM 4 - 4

Response Time (ms)
- 0
- 200
- 400
- 600
- 800
- 1000
- 1200
- 1400
ACT-R Model of automaticity

Rehearse Memory Set → Focus on Next Frame

Attend to Next Target

- No More Targets
- Target Different Type as MS
- VM: Target Same Type Try Retrieving
- CM: Target Same Type Target Found

- Not Target (Retrieval Failure)
- Target (Retrieval Success)

Respond: Target Not Found

Respond: Target Found
Consistent Mapping Conditions

Rehearse Memory Set

Focus on Next Frame

Attend to Next Target

No More Targets

Target Different Type as MS

CM: Target Same Type Target Found

Respond: Target Not Found

Respond: Target Found
Varied Mapping Conditions

- Rehearse Memory Set
- Focus on Next Frame
- Attend to Next Target
  - No More Targets
  - Target Different Type as MS
    - VM: Target Same Type Try Retrieving
      - Not Target (Retrieval Failure)
      - Target (Retrieval Success)
        - Respond: Target Found
        - Respond: Target Not Found
Current model issues

- The model depends on knowing when to retrieve
  - If the target is the same type as the memory set, in CM that means it’s the target, but in VM it may be a distracter
  - When are participants aware of the condition they’re in?
- False alarm rates should indicate when participants think they’re in CM, but actually are in VM
  - Adaptation should happen over time in VM false alarm rates
  - Latency may increase in VM due to fewer skipped retrievals (participants may initially think they’re in VM and actually get the target without doing a retrieval)
Summary of this year’s accomplishments

• Generation of new ACT-R models to demonstrate the Training Difficulty hypothesis in the radar task
  o effects of consistent and varied mapping with extended task practice
  o Initial tuning of the model with experimental data collected
• Enhancement of ACT-R models and creation of new models that reproduce the speed-accuracy tradeoff effect for the data entry task
• Enhancement of current ACT-R models of repetition priming and depth of processing for the data entry task
• Initial development of a general model of ACT-R fatigue that can be applied to any existing model
Plans for next year

• On the data entry task:
  o Report on the cognitive functions and mechanisms corresponding the speed-accuracy trade off in prolonged work, based on ACT-R/empirical results
  o Enhance and create the models corresponding to the repetition priming and depth of processing effects

• Generate a predictive training tool for the data entry task in which training, task, and ACT-R parameters can be manipulated to produce speed and accuracy results

• On the Radar task:
  o Reproduce the effects of the difficulty of training hypothesis
  o Produce new predictions on the effects of stimulus-response mappings
    • Add learning to condition determination