Re-use of a Serial List Model for Procedure Learning
(A Progress Report)

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Goal

Use ACT-R To Make Quantitative Training Time and Performance Predictions for Operating Procedures

E.g. Programming Flight Management Systems in Modern Commercial Aircraft (Boeing 777 or Airbus 320)
Outline

• Our approach: re-use of serial list model
• The task: learning aircraft procedures
• Similar task: Ebbinghaus (1888)
• Model strengths/weaknesses
• Possible next steps
• Conclusions
Previous Attempts to Predict Training Time (Kieras and Polson)

- **Cognitive Complexity Theory**
  - Engineering approximation to ACT-*
  - One mental operation or physical action per rule plus working memory book keeping, e.g., updating goal structure
  - Grain size of rules very similar to ACT-R 4.0, Not like Cognitive Tutors
  - See Kieras (1997) for details

- **Training Time Linear in The Number of New Rules**
  - Take into account transfer (Singley and Anderson, 1989)
  - Training time per rule ranged from 20 to 30 sec
Our Approach

Focus on Mastery and Use of Declarative Representations of Procedures

Re-use Serial List Learning Model (Anderson et al., 1998)

– Procedures are represented as serial list of actions
– List is memorized
– Procedure is executed by retrieving each item and performing action described by item
Foundations

Three Stages of Skill Acquisition (Fitts, 1954; Van Lehn, 1996)

– Cognitive Stage: Learning basic system terminology and operations

– Associative Stage: Memorizing serial list that describes procedure

– Autonomous Stage: Large improvements in both speed and accuracy of performance; Transformation to Procedural Representation
Performing Tasks On Boeing 777 Flight Management System (FMS)

- Outline of Flight Plan Modification Procedures
  - Access Page(s) For Task
  - Enter or Edit Task Parameters
  - Press EXECUTE Key
Novices Learning Aircraft Automation Procedures

- For Pilots New to Automation, Very Painful for Both Trainee and Instructor
  - 15 to 60 hours just focused on mastering steps for all procedures
  - Skills are brittle, rapidly forgotten, and must be retrained after 1 or 2 day retention intervals

- Problems Remembering Infrequently Performed Procedures

- Anecdotal but Very Consistent Observations: Pilots View Mastering FMS as Memorizing Serial Lists of Actions That Perform Each Procedure
List Describing Direct-To A Waypoint Procedure

- **Current Practices Lead Novices To Treat Procedure Training As List Learning**

- **Pilots Must Master Approximately 30 Lists Ranging From 8 To 24 Items**

- **Resulting Lists Are Difficult To Memorize And Rapidly Forgotten**

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<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>FMS has Direct To Function</td>
</tr>
<tr>
<td>2.</td>
<td>Press Legs Page Key</td>
</tr>
<tr>
<td>3.</td>
<td>Get Waypoint Identifier</td>
</tr>
<tr>
<td>a.</td>
<td>In Clearance OR</td>
</tr>
<tr>
<td>b.</td>
<td>Retrieve From LTM OR</td>
</tr>
<tr>
<td>c.</td>
<td>*Scan Leg Page(s) OR</td>
</tr>
<tr>
<td>d.</td>
<td>Ask ATC OR</td>
</tr>
<tr>
<td>e.</td>
<td>Look up on Chart</td>
</tr>
<tr>
<td>4.</td>
<td>Enter INTO Scratch Pad</td>
</tr>
<tr>
<td>5.</td>
<td>Press LSK 1L</td>
</tr>
<tr>
<td>6.</td>
<td>Press? ABEAM PTS&gt; LSK</td>
</tr>
<tr>
<td>7.</td>
<td>Verify Change on ND</td>
</tr>
<tr>
<td>a.</td>
<td>Modify range if necessary</td>
</tr>
<tr>
<td>b.</td>
<td>Formulate what you expect to see on ND</td>
</tr>
<tr>
<td>8.</td>
<td>Press EXECUTE</td>
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</table>
Serial List Model Is Result of Trainee’s Poor Training Design Decisions

- Describe Learning FMS Procedure as Mastery of Minimal Amount of Information, e.g., the Actions
  - Lists of actions used to describe procedures in Fight Manuals
  - Spend evening in hotel room memorizing lists

- “Ignore” Cues From CDU and Rest of Environment That Would Cue Retrieval and Provide Feedback

- Treat Each Procedure as An Independent Task Interfering With Transfer of Training

- Above Result of NO Guidance On How To Learn Procedures In Training and Reference Materials
Computing Training Time Predictions

• First Approximation
  – ACT-R Model of Serial List Learning
  – Materials (numbers, words, nonsense syllables), fast presentation rate, immediate recall
  – **Learning and forgetting parameters assumed to be independent of task and materials**

• Simulated Training Regimen
  – During each session, train to criterion of one perfect recitation of list
  – After 24 delay, retrain
  – Stop when simulation can recall list correctly on 1st trail after 24 hour delay
  – Translate number of repetitions per day into training times
  – Ebbinghaus (1888/1913) Chapter 8
List Model Representation (From Anderson, et al., 1998)

FIG. 2. A network representation of the chunk structure encoding the 9-element list “329 714 856”.
Ebbinghaus (1888, Chpt. 8) Trails to Learn/Relearn 12–item List

12-item list savings

Trials

Day

Matessa & Polson
But Serious Problems With Longer and Shorter Lists

• Model Can’t Account for Ebbinghaus List Length Data for Longer Lists

• 3 to 7 Item Lists
  – One trial to criterion on any day
  – No long term retention

• Model can’t perfectly recall list after 24 hour delay even after many days of training

• Longer Lists…
  – Ebbinghaus (1888, Chpt. 8) data for 24 and 36 item lists
Ebbinghaus (1888, Chapter 5)

Ebbinghaus List Length Data

Trials to One Perfect Recitation

List Length

Matessa & Polson
Ebbinghaus (1888, Chpt. 8) Data From Longer Lists

Trials to Criterion

Days

Ebh. L-12
Ebh. L-24
Ebh. L-36
ACT L-12
ACT L-24
More On Ebbinghaus (1888, Chapter 8)

Overview of Savings Data

<table>
<thead>
<tr>
<th>Days</th>
<th>Trials to One Perfect Recitation</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
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<td>3</td>
<td>50</td>
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<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
</tr>
</tbody>
</table>

- Ebh. L-24
- Ebh. L-12
- Model L-24
- Model L-16
- Model L-12
- Model L-8
Where To Next…

• Unfilled Long Retention Intervals
  – Lists learned way to fast

• Retrieval threshold
  – was -.35 in 1998 Serial List model but was -3.75 in Lifetime Arithmetic model

• Spacing Effects
  – Important in simulating actual training environment and long lists

• Cues From System Interface
  – how to model environmental cues with current issues (initial wme-number, spurious associations, ...)

• Retrieval Structures and Encoding Strategies

Ebbinghaus (1888, Chpt. 8) Data From Longer Lists

Trials to Criterion

Days

Ebh. L-12
Ebh. L-24
Model L-12
Model L-24
Ebbinghaus (1888, Chpt. 8) Data From Longer Lists

Trials to Criterion

Days

Ebh. L-12
Ebh. L-24
Model L-12
Model L-24

Life Time Learning Retrieval Threshold …
Conclusions…

- Use ACT-R As Tool To Apply Classical Listing Learning Results to Initial Stages of Skill
  - Training environments do not correspond to any one list learning paradigm
  - Mixture of serial and paired-associates learning
  - Serial list models *Worst Case* description of skill acquisition process
  - Effective training programs provide trainees with encoding (shorter lists) and retrieval strategies
- Starting Point
  - Successful ACT-R model of Ebbinghaus results
  - We are not there yet
  - Suggestions…..
If we have time....

- Back to Cognitive Complexity Theory
- Training Time Per Rule Results
- Training Time Per Syllable
Did Ebbinghaus (1888) Anticipate Kieras and Polson Training Time Results?

- Transform Ebbinghaus (1888, Chpt. 5) Data on Trials To Master Lists as Function of Length
- Presentation Rate, .4 sec per item
- No inter trial interval.
Ebbinghaus Data Transformed
To Times

\[ y = 28x - 230.08 \]

\[ R^2 = 0.9912 \]
Translated Into Training Time

- Assume Procedure Has 12 Steps
- Use Model to Compute Number of Repetitions
- Time Parameters for Training
  - Inter trial interval = 120 sec
  - Item time = 3 sec
- Total Training Time = 2 hours