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

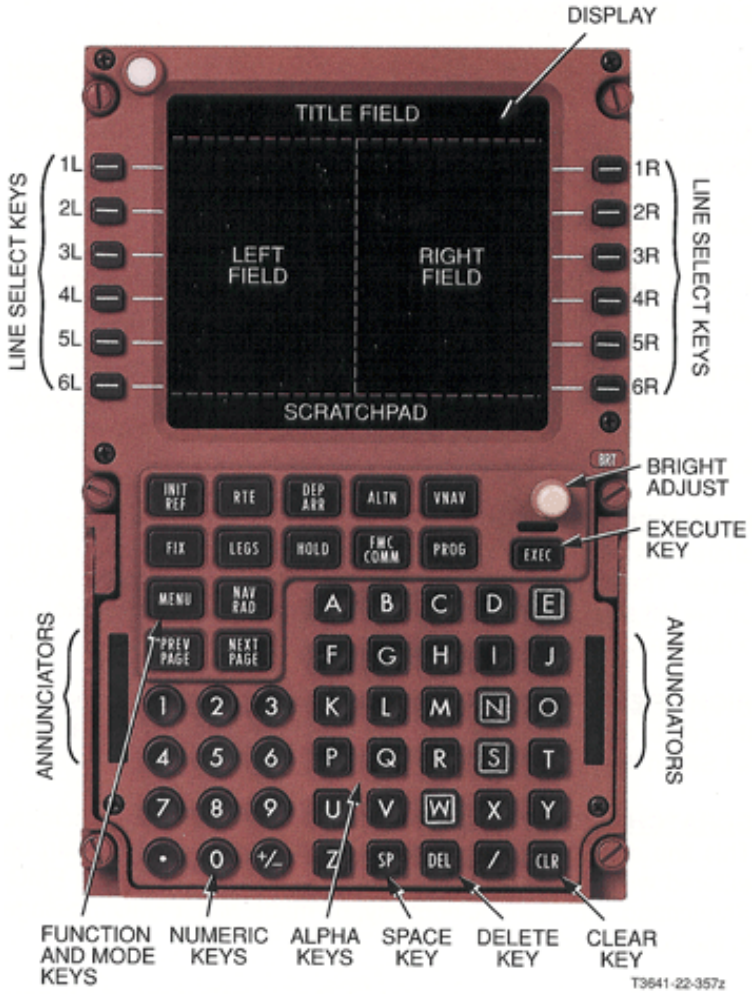


Figure 2-8
Control Display Unit

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**

1. FMS has Direct To Function
2. Press Legs Page Key
3. Get Waypoint Identifier
   a. In Clearance OR
   b. Retrieve From LTM OR
   c. *Scan Leg Page(s) OR
   d. Ask ATC OR
   e. Look up on Chart
4. Enter INTO Scratch Pad
5. Press LSK 1L
6. Press? ABEAM PTS> LSK
7. Verify Change on ND
   a. Modify range if necessary
   b. Formulate what you expect to see on ND
8. Press EXECUTE

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
    Anderson, J. R., Bothell, D., Lebiere, C. & Matessa, M. (1998). An integrated theory of list memory. *Journal of Memory and Language*, 38, 341-380.
  - 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)

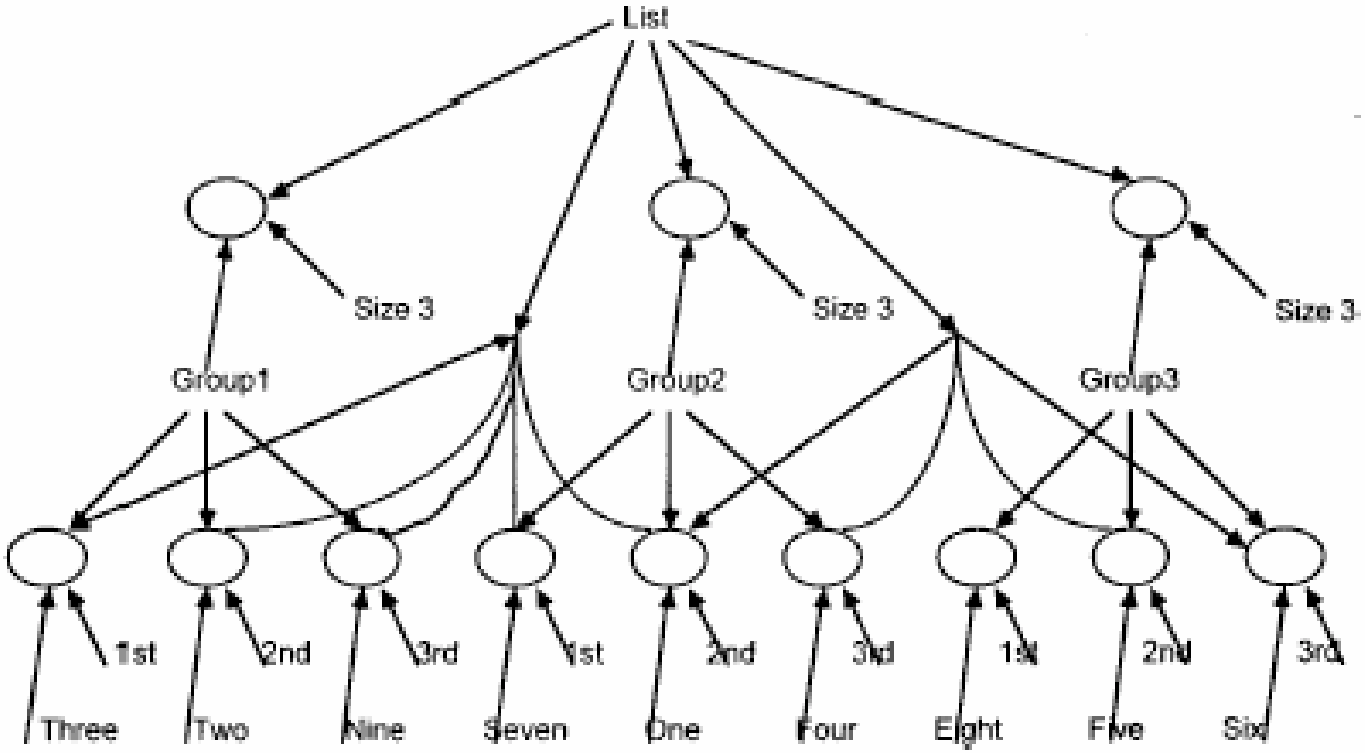
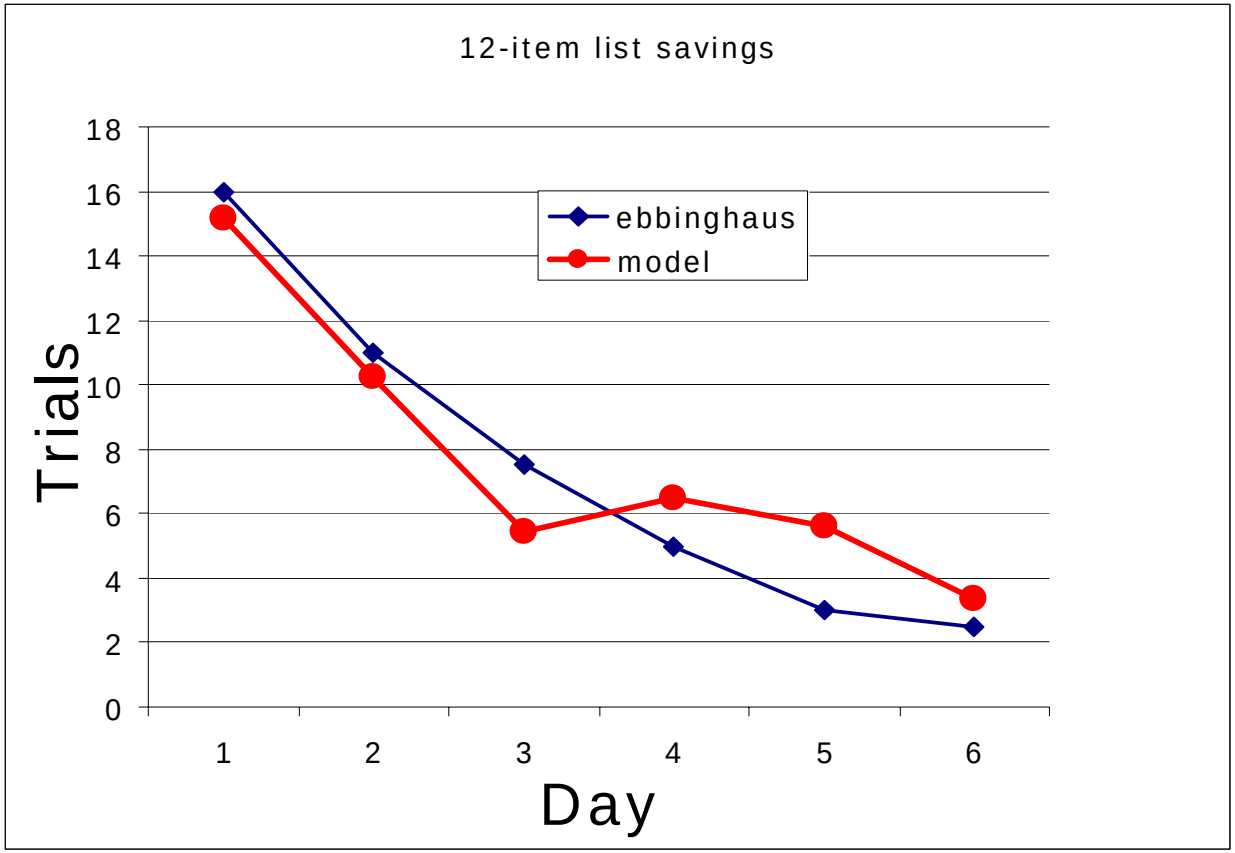


FIG. 2. A network representation of the chunk structure encoding the 9-element list "329 714 856".

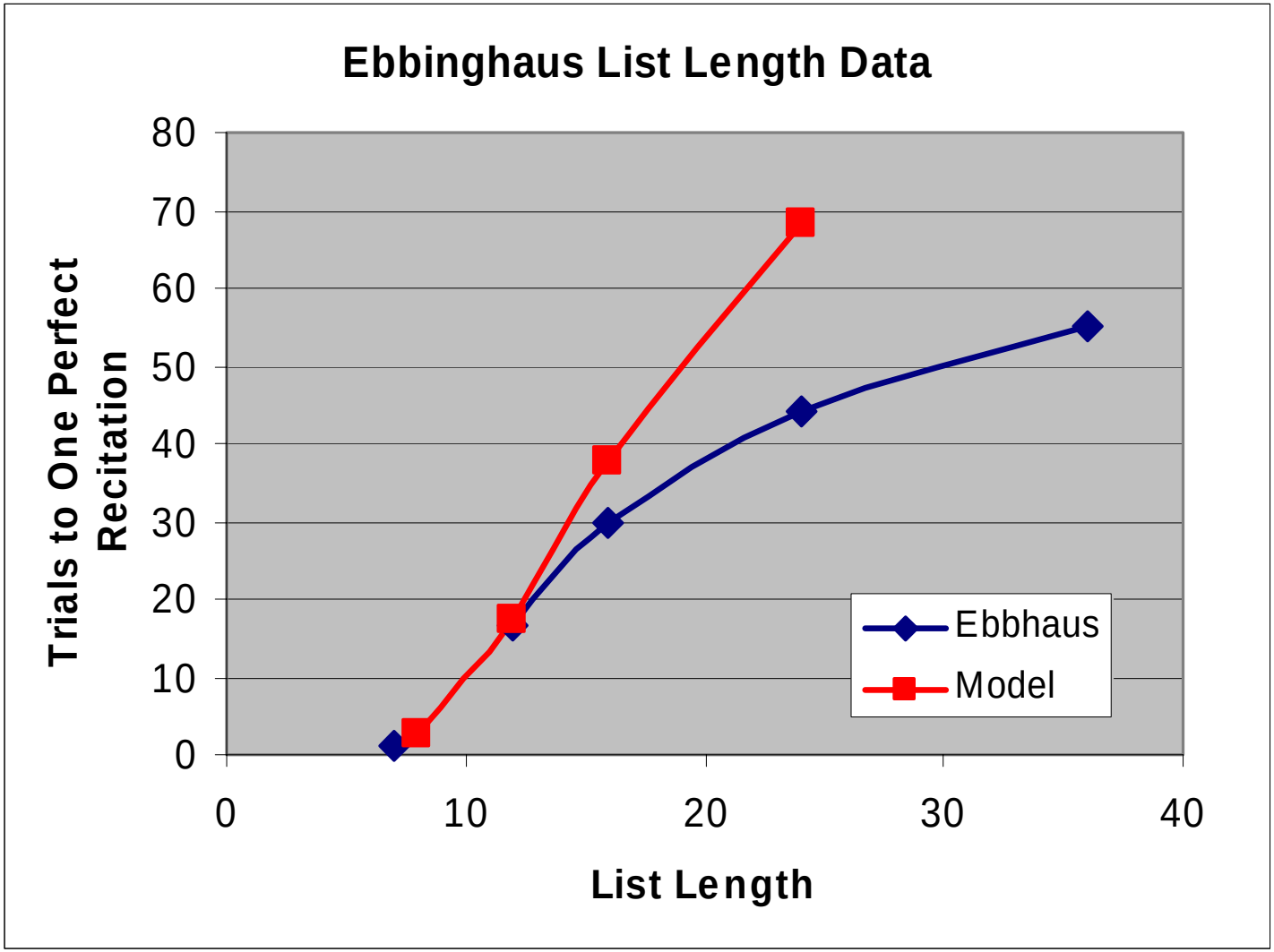
Ebbinghaus (1888,Chpt. 8) Trails to Learn/Relearn 12–item List



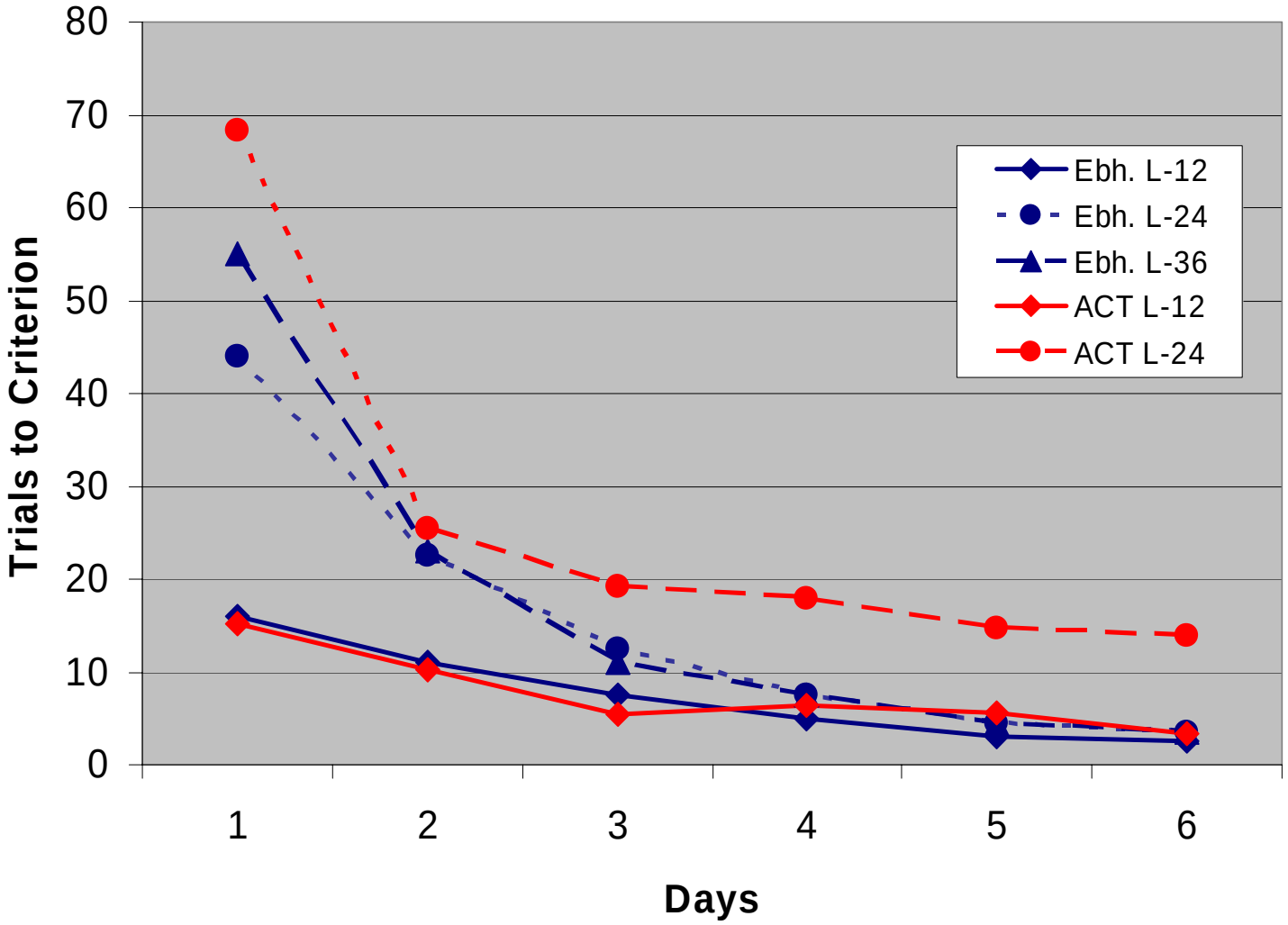
But Serious Problems With Longer and Shorter Lists

- 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

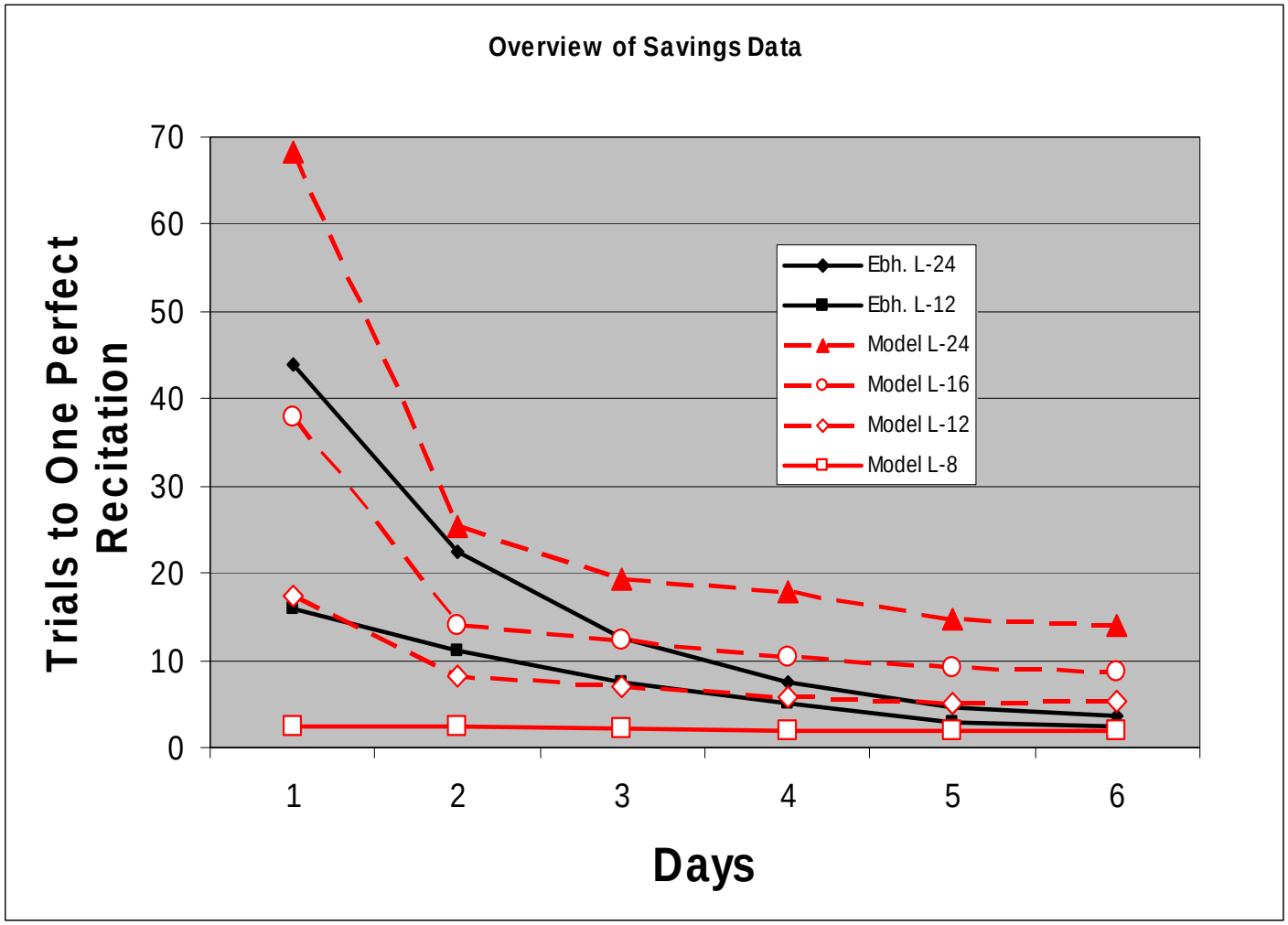
Ebbinghaus (1888, Chapter 5)



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



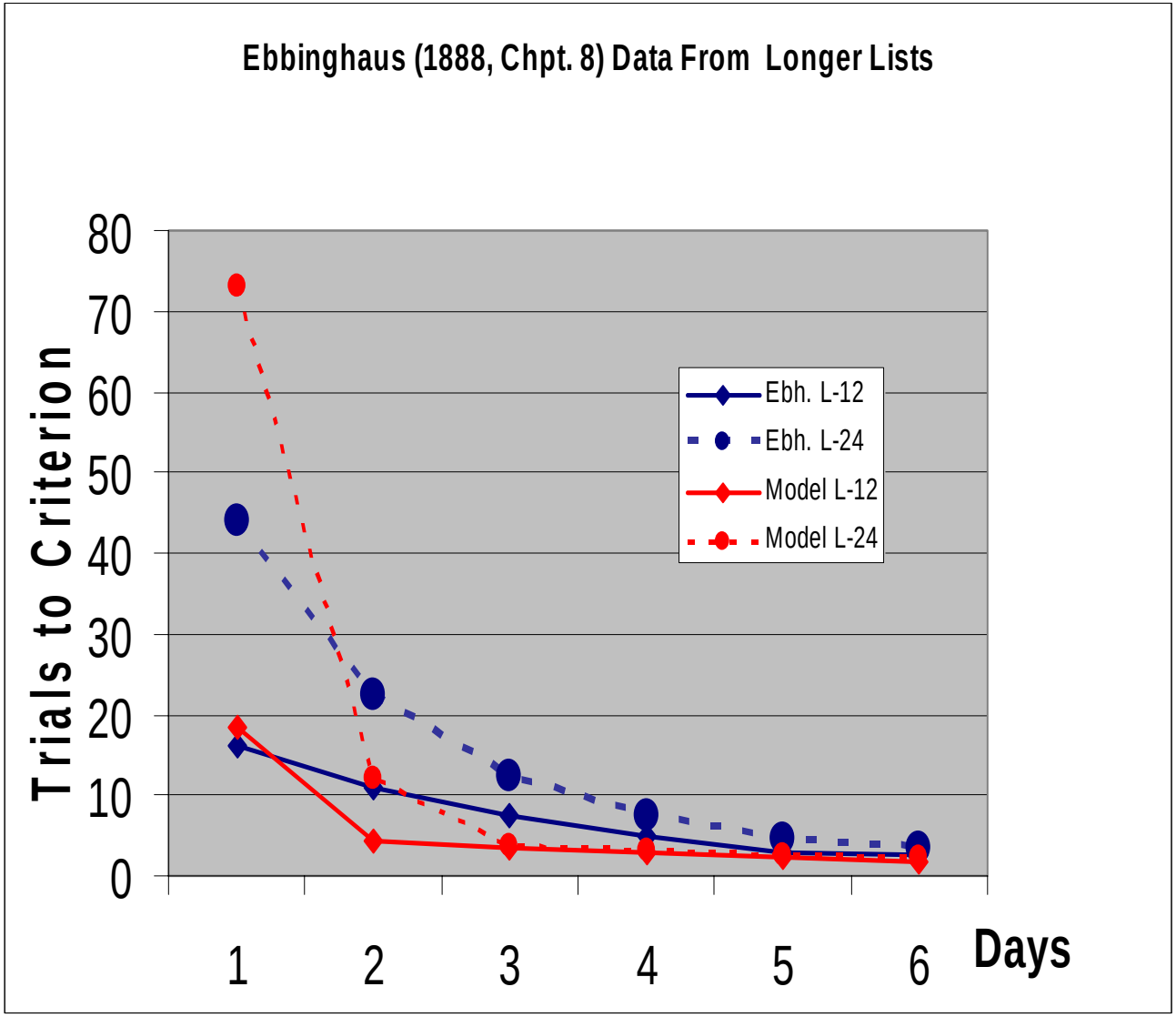
More On Ebbinghaus (1888, Chapter 8)



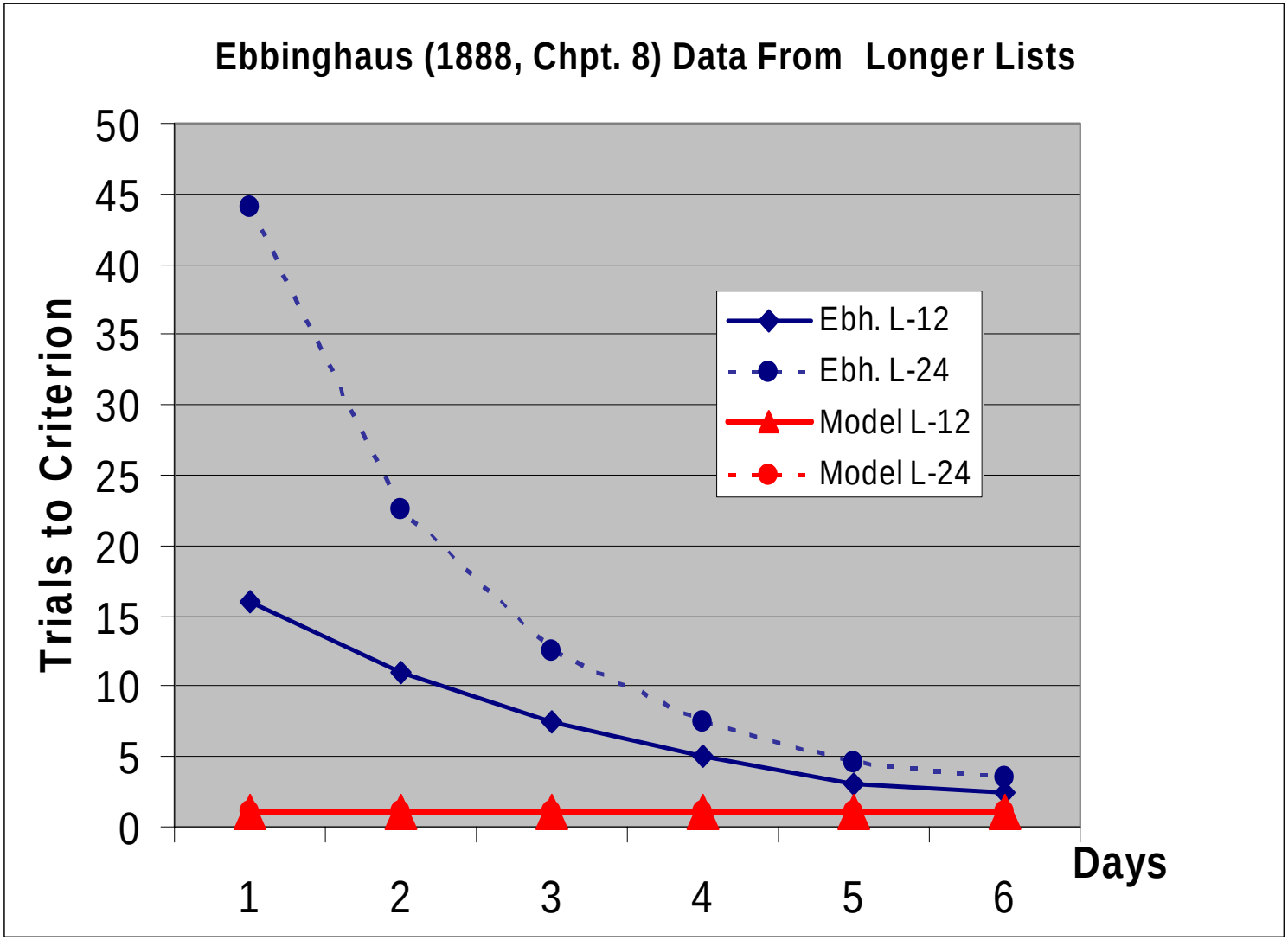
Where To Next…

- Unfilled Long Retention Intervals
  - Anderson, J. R., Fincham, J. M. & Douglass, S. (1999). Practice and retention: A unifying analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 25, 1120-1136
  - Lists learned way to fast
- Retrieval threshold
  - was -.35 in 1998 Serial List model but was -3.75 in Lifetime Arithmetic model
- Spacing Effects
  - Pavlik, P. I. and Anderson, J. R. (submitted). Practice and Forgetting Effects on Vocabulary Memory: An Activation Based Model of the Spacing Effect
  - 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

Anderson et al (1999) Assumptions About Unfilled Retention Intervals



Life Time Learning Retrieval Threshold …



Conclusions…

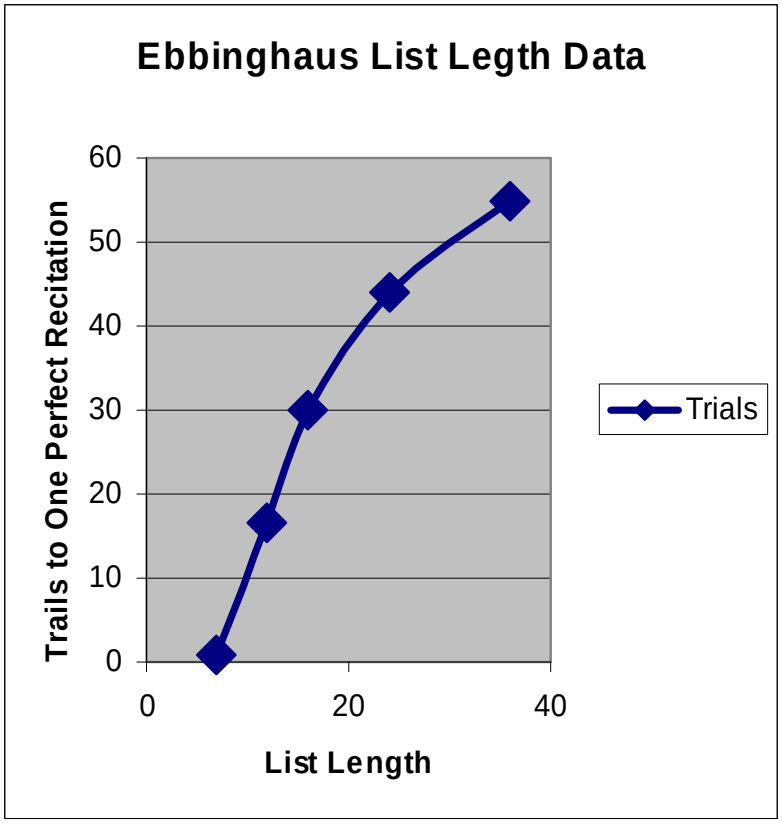
- Use ACT-R As Tool To Apply Classical Listing Learning Results to Initial Stages of Skill
  - Training environments do not correspond to any one list learning paradigm
  - Mixture of serial and paired-associates learning
  - Serial list models *Worst Case* description of skill acquisition process
  - 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…..

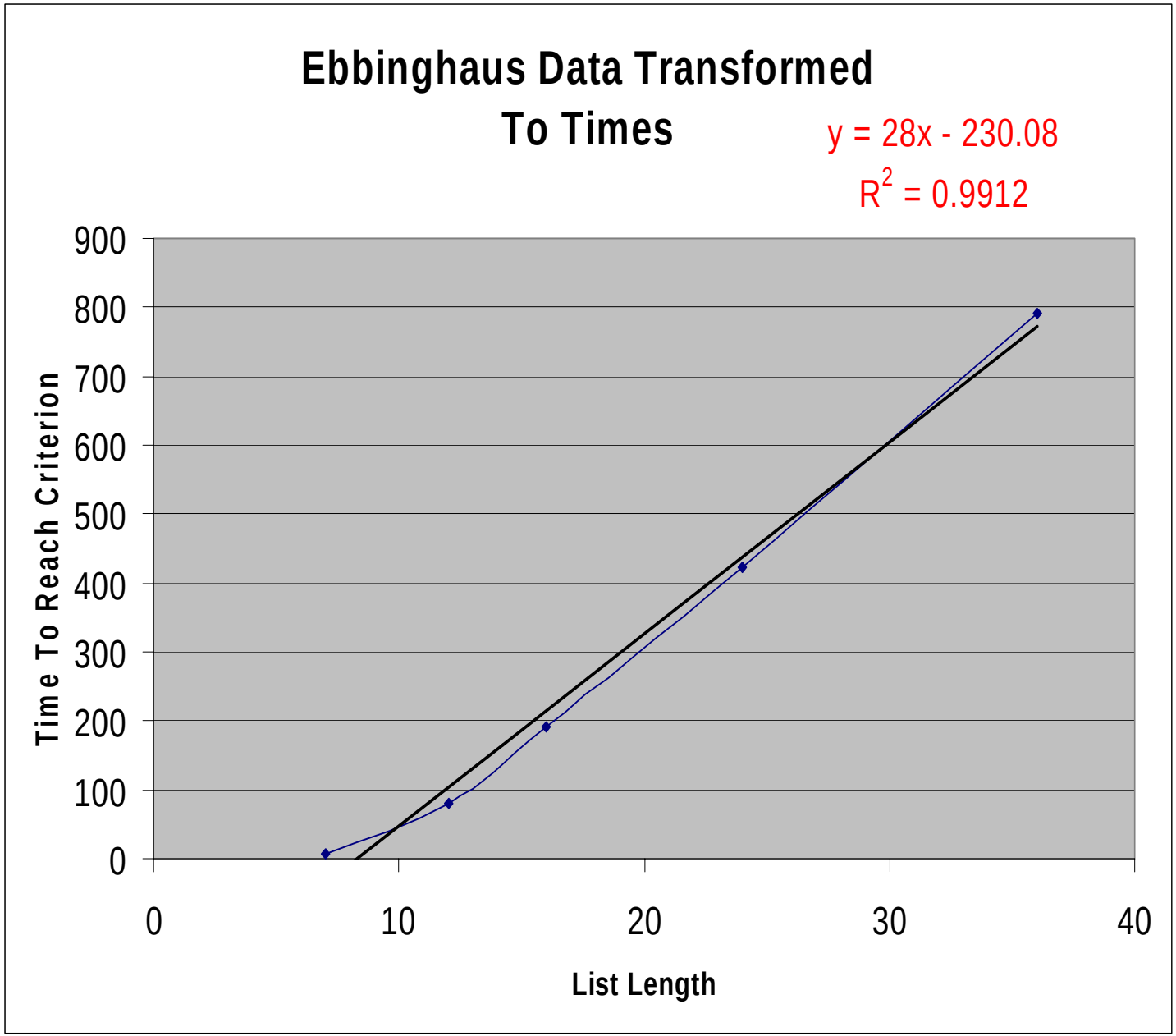
If we have time….

- 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
R2 = 0.9912
Time To Reach Criterion
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
List Length

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