Variability of behavior in complex skill acquisition

Niels Taatgen
University of Groningen
Carnegie Mellon University

Overview

- Sources of variability
- How to model variability in skill acquisition: ACT-RX
- Example: dual-task experiment by Schumacher et al.

Illustration: CMU-ASP data

Sources of variability

- Performance parameters
- General problem-solving skills
- Prerequisite skills
- Ambiguity of the task
- Noise

How to model variability in complex skill acquisition

- The current systems for declarative task representation are linear: the order in which to do things is fixed
- Variability is mainly due to parameter change or noise (e.g. model of the KA-ATC models individual differences due to WMC, speed of proceduralization and psychomotor speed)
- Need a representation that allows multiple orderings of instructions -> APEX (Freed)

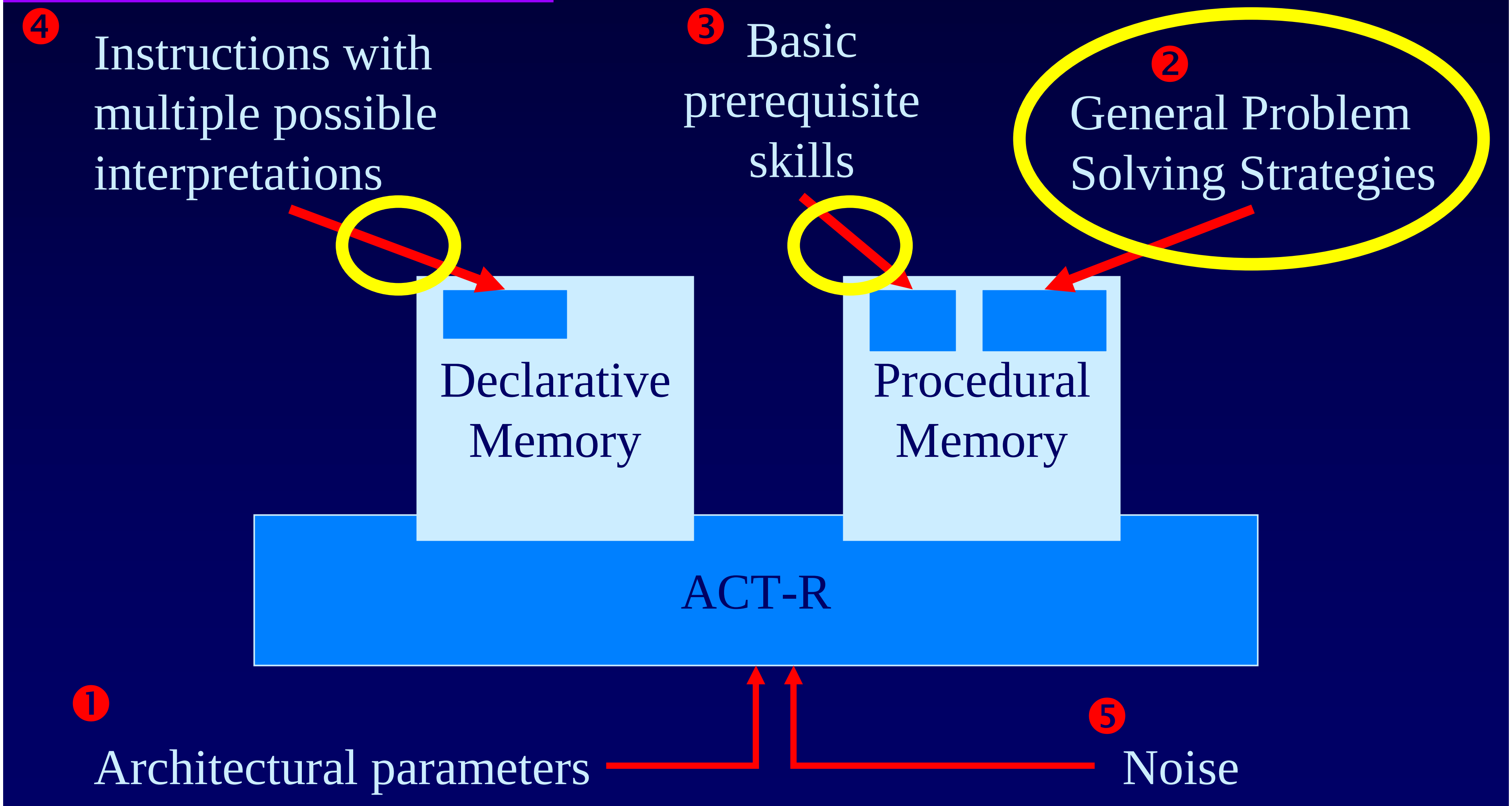
ACT-RX Goals

- Extension to ACT-R
- Make it easy to model skill acquisition of complex (or simple) tasks
- Make it easy so explore variability in task behavior
- Allow to reuse code between models

ACT-RX

- Hierarchical representation of "procedures"
- A procedure contains several steps that can be carried out in any order, unless an order constraint is added
- Each step is a procedure in itself, or a primitive action

Variability and the components of ACT-RX



ACT-RX

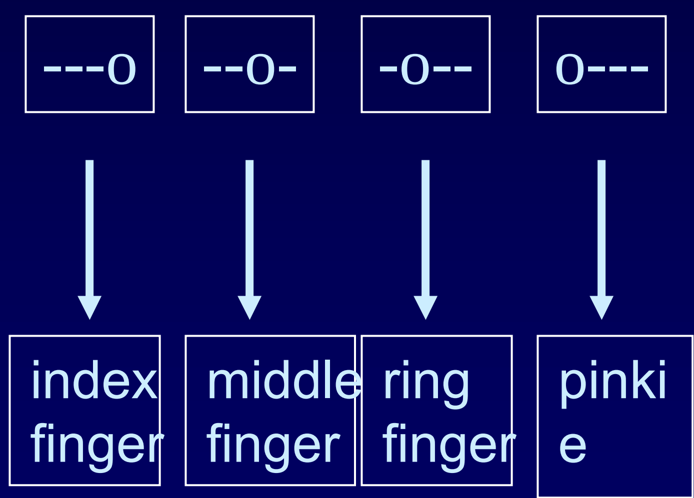
- ACT-RX has been used to model complex tasks:
  - Kanfer-Ackerman Air Traffic Controller task
  - CMU-ASP task
- But I will demonstrate it on the basis of a simple task: a dual-task experiment by Schumacher et al. (2001)

Schumacher task

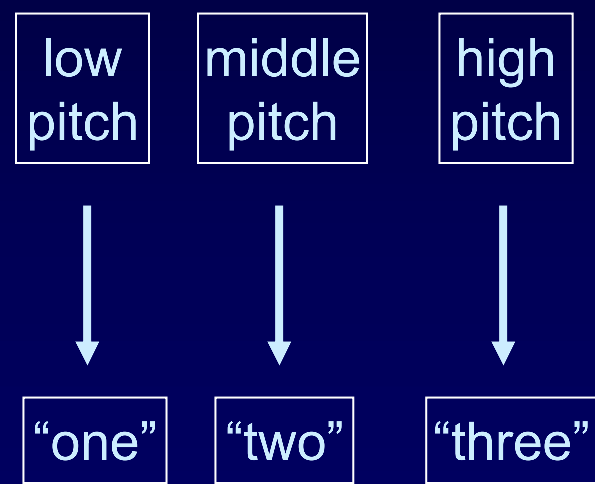
- Dual task paradigm, in which the participant may respond in any order (contrary to PRP experiments)
- Task 1: Visual-manual
- Task 2: Aural-vocal

Schumacher task

Task 1: Visual Motor

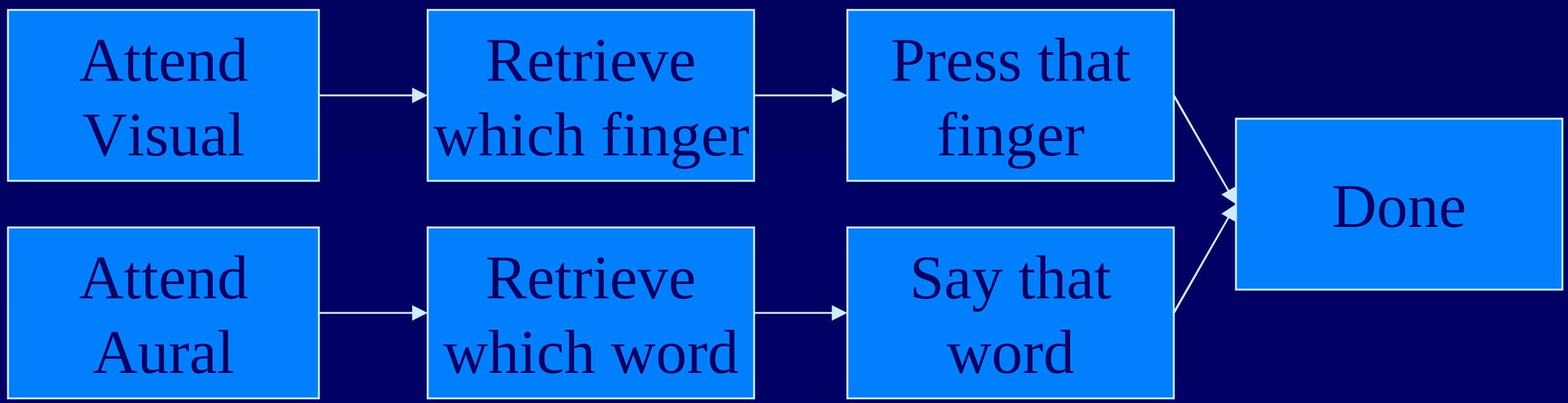


Task 2:Aural Vocal



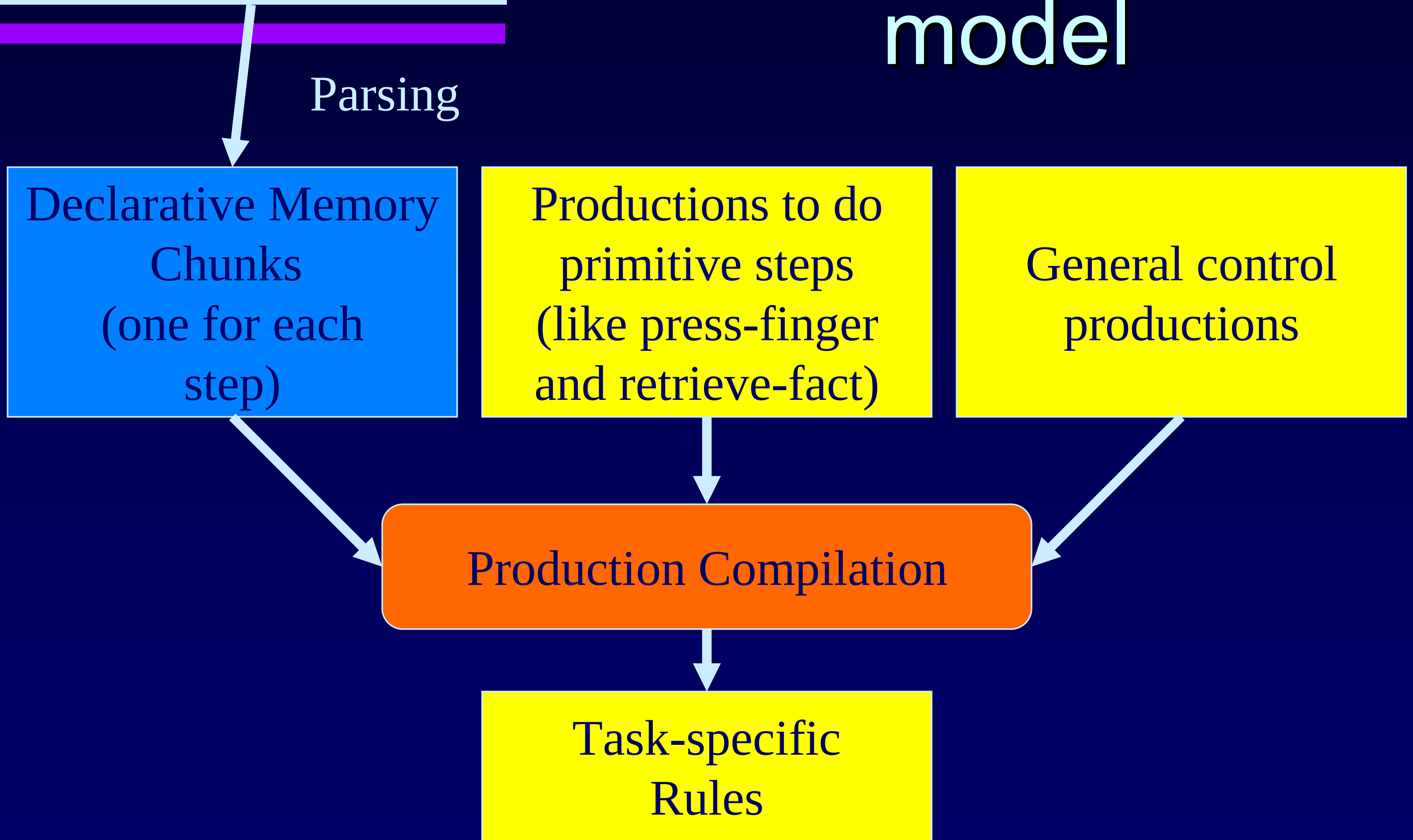
Representation in ACT-RX

```
(procedure main
  (step A attend-visual ())
  (step B retrieve-fact (?visual finger) (precondition A))
  (step C press-finger (?finger) (precondition B))
  (step D attend-aural ())
  (step E retrieve-fact (?aural word) (precondition D))
  (step F say (?word) (precondition E))
  (step G done () (precondition C F)))
```

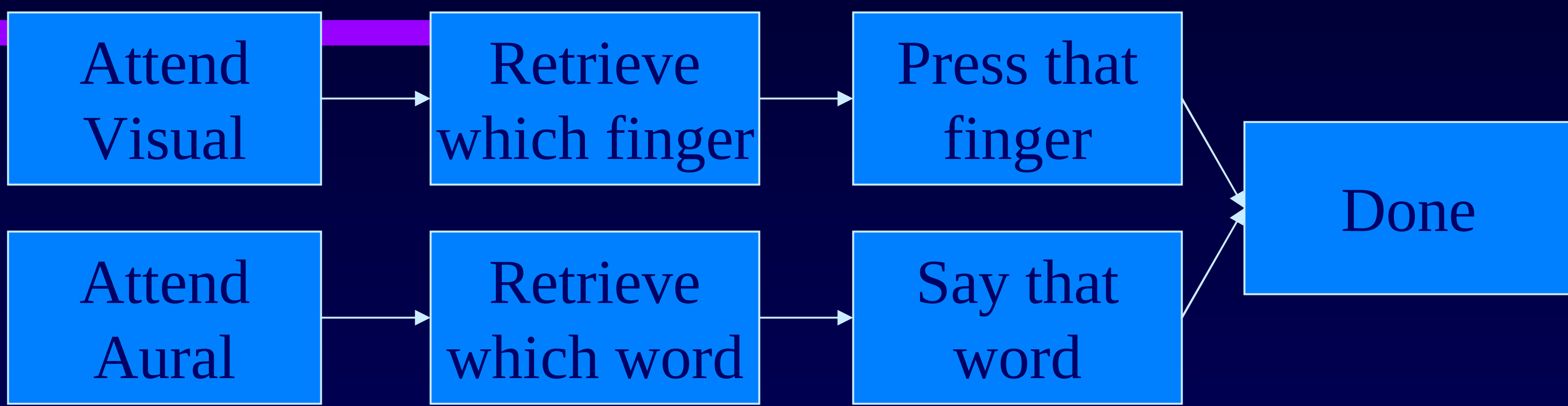


Operation of the model

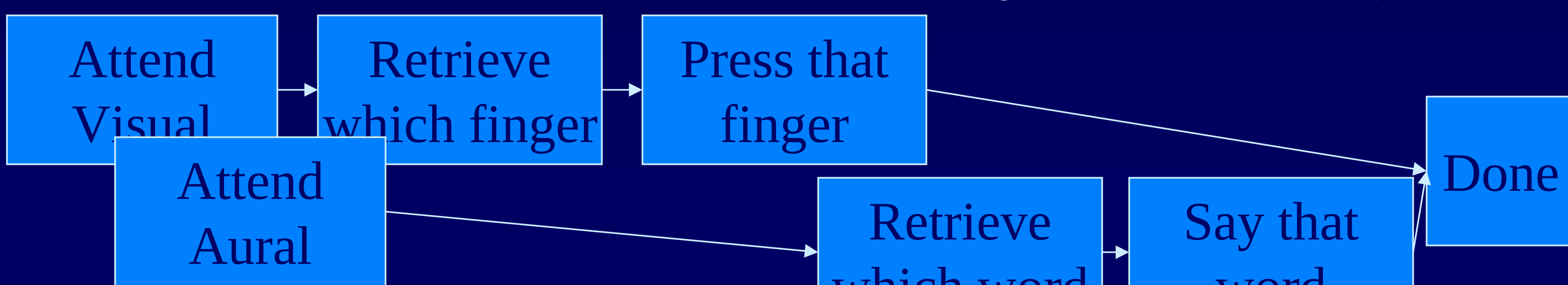
```
(procedure main
  (step A attend-visual ())
  (step B retrieve-fact (?visual finger)(precondition A))
  (step C press-finger (?finger)(precondition B))
  (step D attend-aural ())
  (step E retrieve-fact (?aural word)(precondition D))
  (step F say (?word) (precondition E))
  (step G done () (precondition C F)))
```



Optimal order of steps

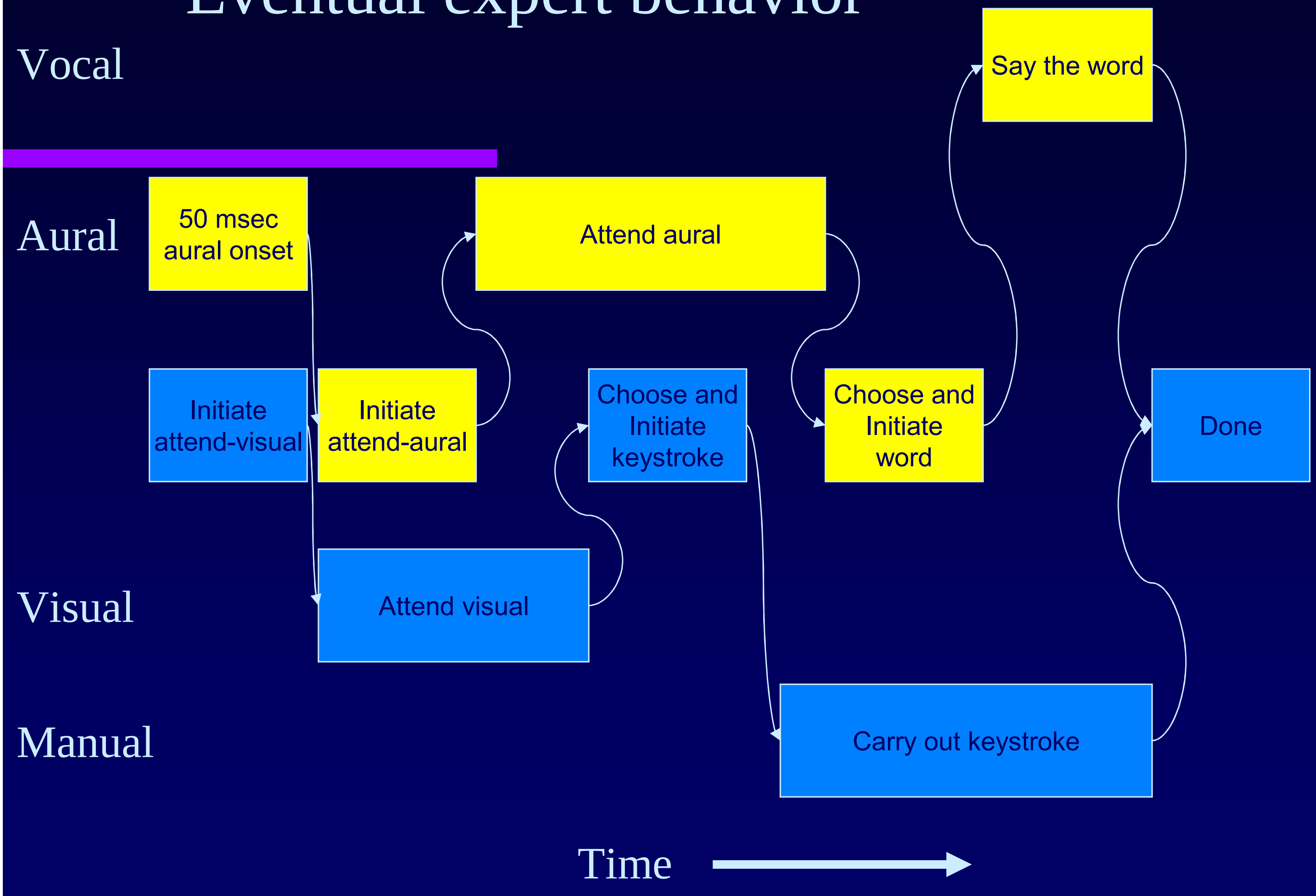


Can be ordered in 45 different ways, but the only one that avoids all dual-task costs is: (see also Byrne & Anderson)



But..... does everyone discover this optimal order?

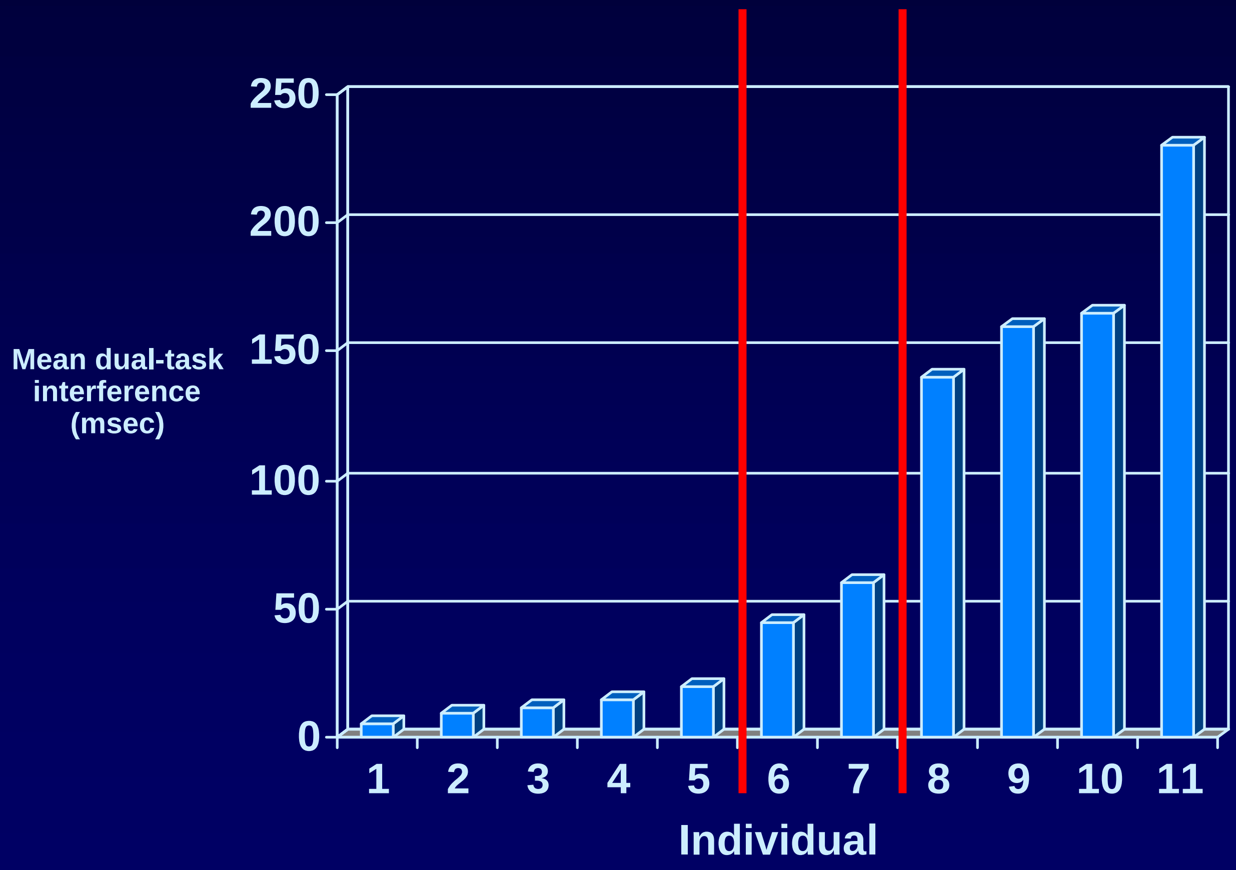
Eventual expert behavior



Data from Schumacher

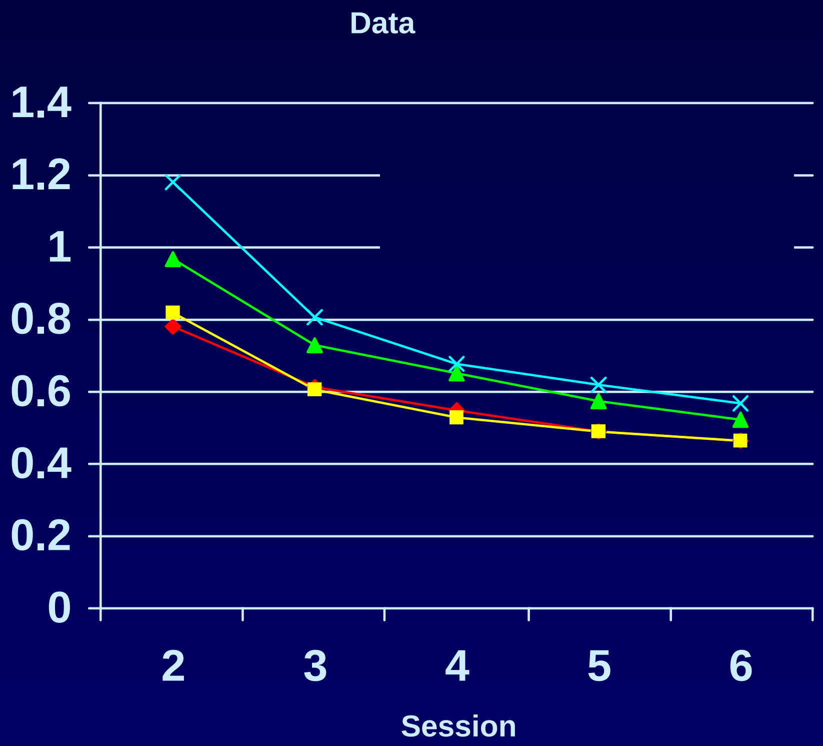
Property of optimal order: no dual-task costs

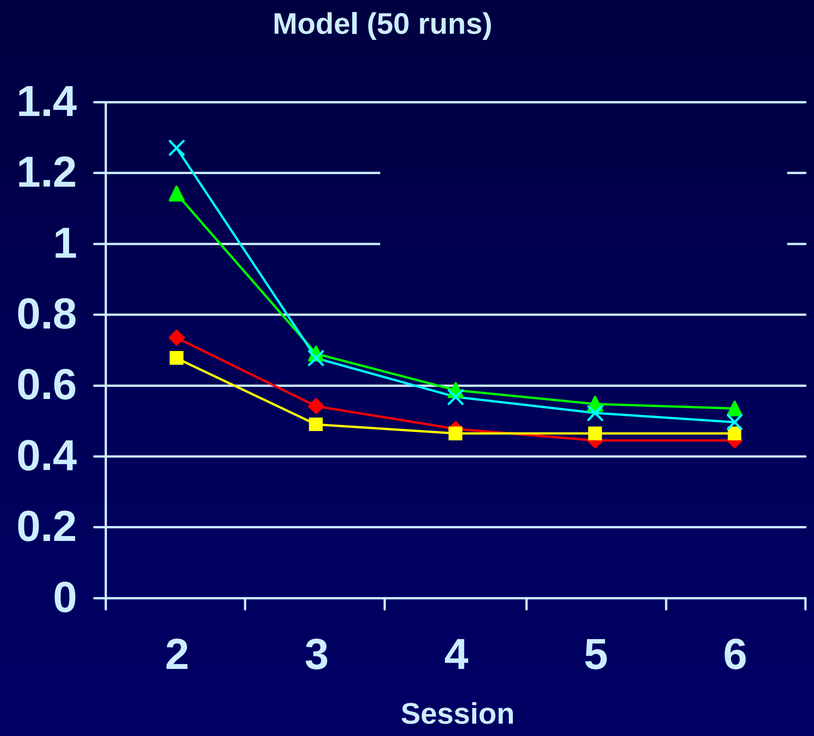
But look at individuals



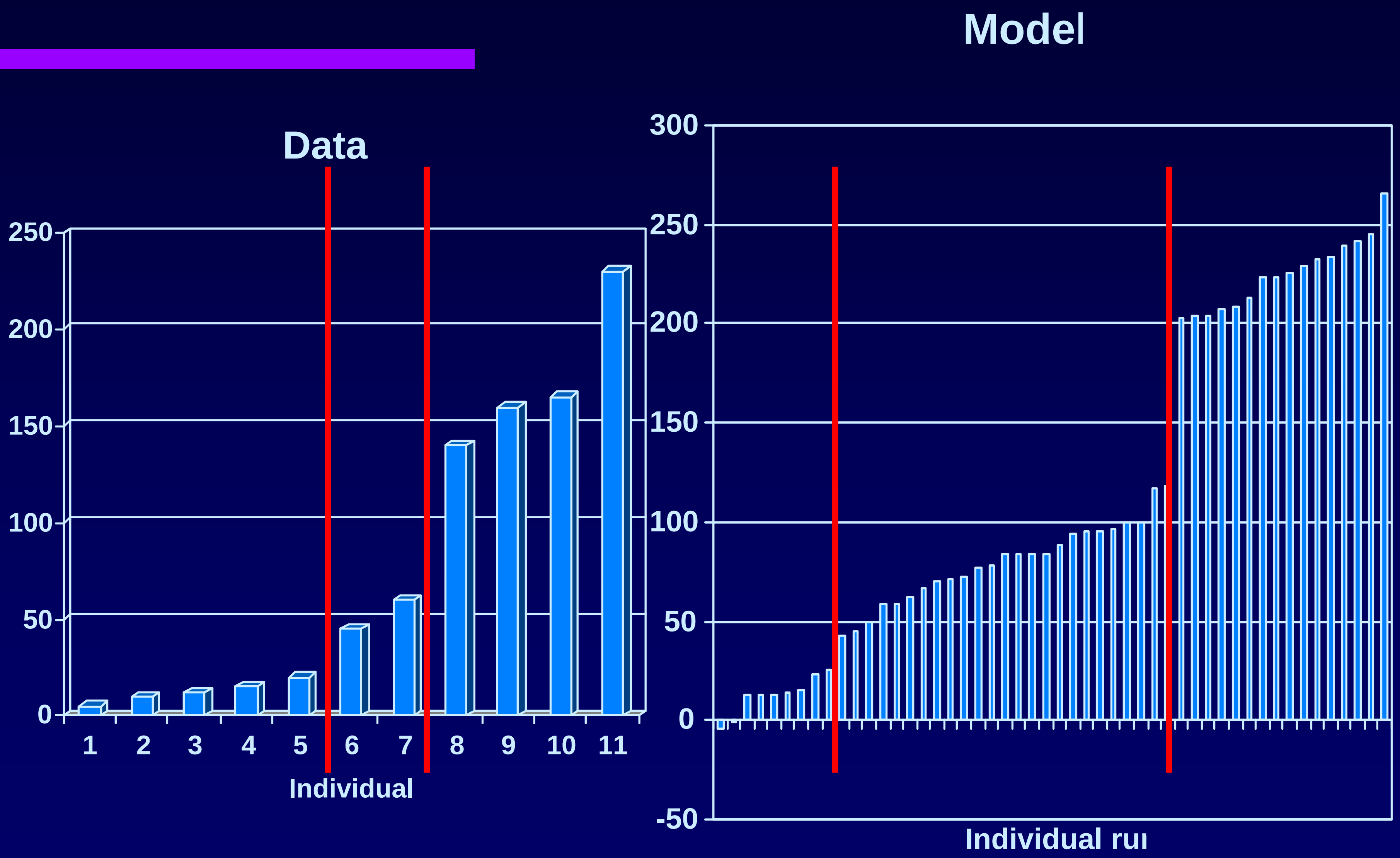
Conclusion:
Some (5 out of 11) individuals hardly have any dual task interference
but some others have huge dual costs, even after 5 (long!) sessions

Model results





Individual differences



Evaluation

- Model exhibits similar patterns of individual differences as participants
- Pure probability: 1 out of 45 with no dual-task costs (2%)
- ACT-R model: 9 out of 50 (18%)
- Participants: 5 out of 11 (45%)
- Utility learning produces the optimal order sometimes, but not always
- Solution: add dual-tasking strategies

Sources of variability

	Data	Model
Performance Parameters	Speed of proceduralization, ACT-R/PM latencies	X
Problem-solving Strategies	Multi-tasking strategies that utilize slack time	X
Prerequisite skills	Play no role in this experiment	
Task ambiguity	Multiple orders in which steps can be carried out	√
Noise	Noise determines which order of instructions is tried first	√

Conclusions

- ACT-R can learn dual-tasking
- Same representation can be used for both complex tasks (ATC, CMU-ASP), and basic psychological tasks (dual-tasking)
- Offers a more constrained theory than basic ACT-R

Future work

Make ACT-RX into a system for general use, not just to model variability of behavior, but also to make modeling complex tasks easier and more constrained

Performance parameters

- Individuals differ with respect to certain parameters, producing differences in behavior
- In ACT-R: manipulate architectural parameters
- Example: Working Memory Capacity (W)

General task-independent problem-solving strategies

- Verbal vs visual rehearsal strategies
- Strategies to multi-task
- In ACT-R: production rules that are independent of the task, and that may be present or absent
- Example: productions that exploit slack-time

Prerequisite skills

- Individuals may differ in mastery of sub-skills assumed in the task
- Example: mousing and other computer skills
- In ACT-R: manipulate whether part of the task representation is declarative or procedural

Task Ambiguity

- Operations in a task can often be done in several different orders, leading to different performance profiles
- In ACT-R: declarative instructions can be carried out in several different orders
- Example: In the CMU-ASP task, you can either do an EWS first to identify a track, or you can start by looking at the altitude and speed information

Noise

- Noise can influence the order in which people do things, whether or not they have forgotten something, etc.
- In ACT-R: noise on activation and on utility