Learning by Imitation, Reinforcement and Verbal Rules in Problem-Solving Tasks

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Problem Solving

- Solving a problem is transforming a given situation into a desired situation or goal (Hayes 1989).
- Information-processing theory
- Well-defined problems
  - Clearly defined states, operators and constraints
- Involves
  - Reasoning
  - Use of prior relevant knowledge
  - Learning
- Focus on the *learning* aspect.

Learning in Problem Solving Tasks

- Feedback (Reinforcement) learning
  - Trial-and-error
  - Limited information - binary signal: success or failure
- Explicit learning
  - Instructions for solving problems (typically *if… then…*)
  - Need an expert capable of writing concise, complete and coherent rules
- Imitation learning
  - Problem solving demonstration
  - Virtually no cost for the demonstrator
  - Very general and omnipresent
- Combinations – Mentoring, teaching

Problem Solving Tradition

- Favorite techniques to help reasoning:
  - Heuristics (Polya, 1957)
  - Hints (Katona, 1940)
  - Reasoning by analogy (Holyoak & Thagard, 1989)
- Learning by demonstration (imitation)
  - Considered as rote memorizing
  - Trivial and uninteresting
  - Our work aims at challenging this view

Imitation learning

- Behaviors or skills are acquired by watching others perform certain tasks.
- General consensus that *imitation learning* should exclude other mechanisms based on some kind of priming (actions, locations, etc.)
- Program Level Imitation (Byrne & Russon, 1998)
  - Overall arrangement of actions, particularly the planning of and sequencing of actions
  - Implies that the imitator understands the intentions of the demonstrator (goals and subgoals).
  - More complex than rote memorizing

Experimental Design (1)

- Goal: To study learning in problem-solving tasks
- Two independent variables
  - Experimental group - Between-subject factor
    - Imitation learning - 5 successful demonstrations (for different ball/weight combinations)
    - Explicit learning – Instructions for solving the problem (same amount of information as the demos)
    - Feedback learning – Told if their answers were correct or not
  - Trial quartiles – Within-subject factor
    - *Trial* – A single problem instance (each with different target ball and weight) from its initial presentation until the answer is given
    - Trials are clustered in *Quartiles* (4)
    - Study dynamic effects - how dependent variables evolve over trials

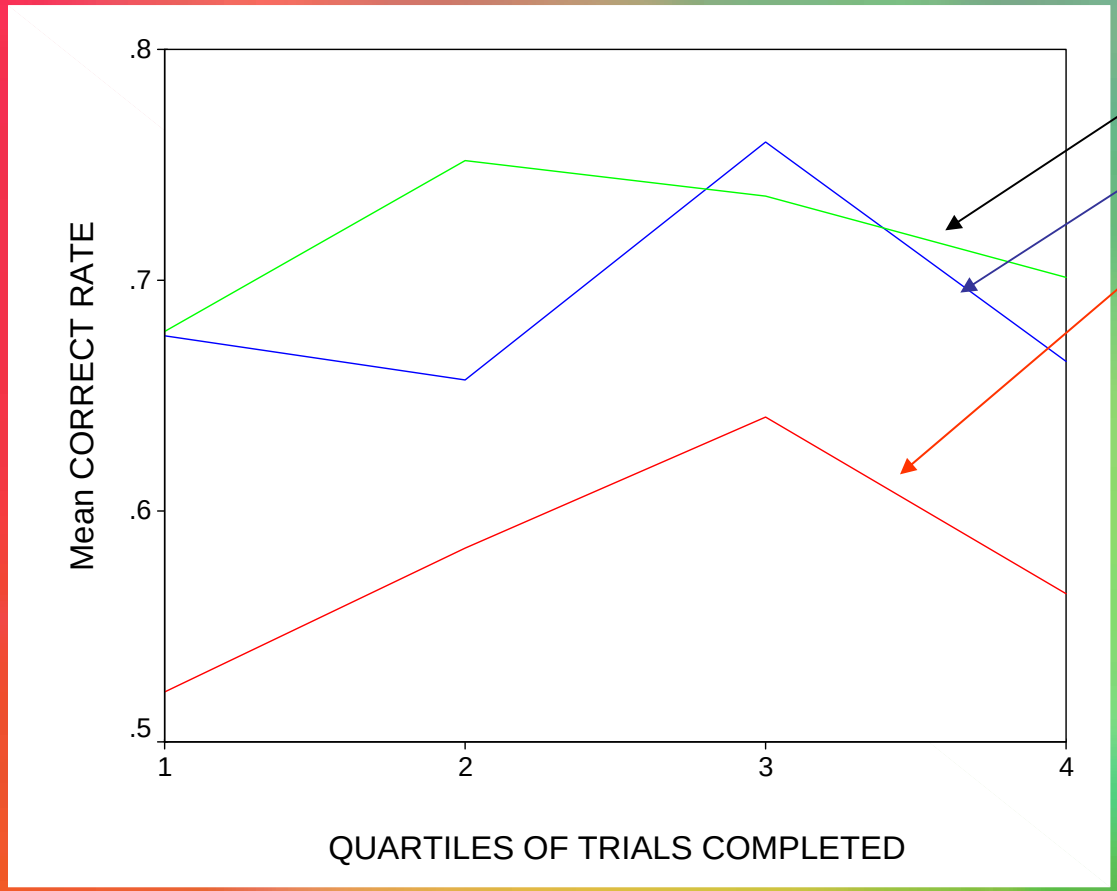
Experimental Design (2)

- Two dependent variables
  - Elapsed time
  - Whether the answer was correct or not
  - Measured on each trial and averaged over quartiles
- Hypotheses
  - Imitation learning and explicit learning groups should outperform the feedback learning group.
    - More accurate (higher correct answer rate)
    - Faster (shorter elapsed time per trial)
  - Learning effect - Subjects should get faster and more accurate with practice, especially in the feedback learning group

Results and Analysis – Correct Answer Rate

- Correct answer rates (average) per trial:
  - Feedback Learning: 0.59 (std dev: 0.49)
  - Imitation Learning: 0.76 (std dev: 0.42)
  - Explicit Learning: 0.71 (std dev: 0.45)
- Kruskal-Wallis non-parametric tests
  - Data not normally distributed
  - Significant differences in answer correct rate across Group (Chi-square=7.054, df=2, p=0.029)
    - Pair wise results
      - Feedback and Imitation Learning groups: Chi-square=5.368, df=1, p=0.021
      - Feedback and Explicit Learning groups: Chi-square=4.793, df=1, p=0.029
      - Imitation and Explicit Learning groups: Chi-square=0.430, df=1, p=0.512
  - No significant difference across Quartile (Chi-square=3.443, df=3, p=0.328)

Correct Answer Rate vs. Quartile



Imitation Learning Group

Explicit Learning Group

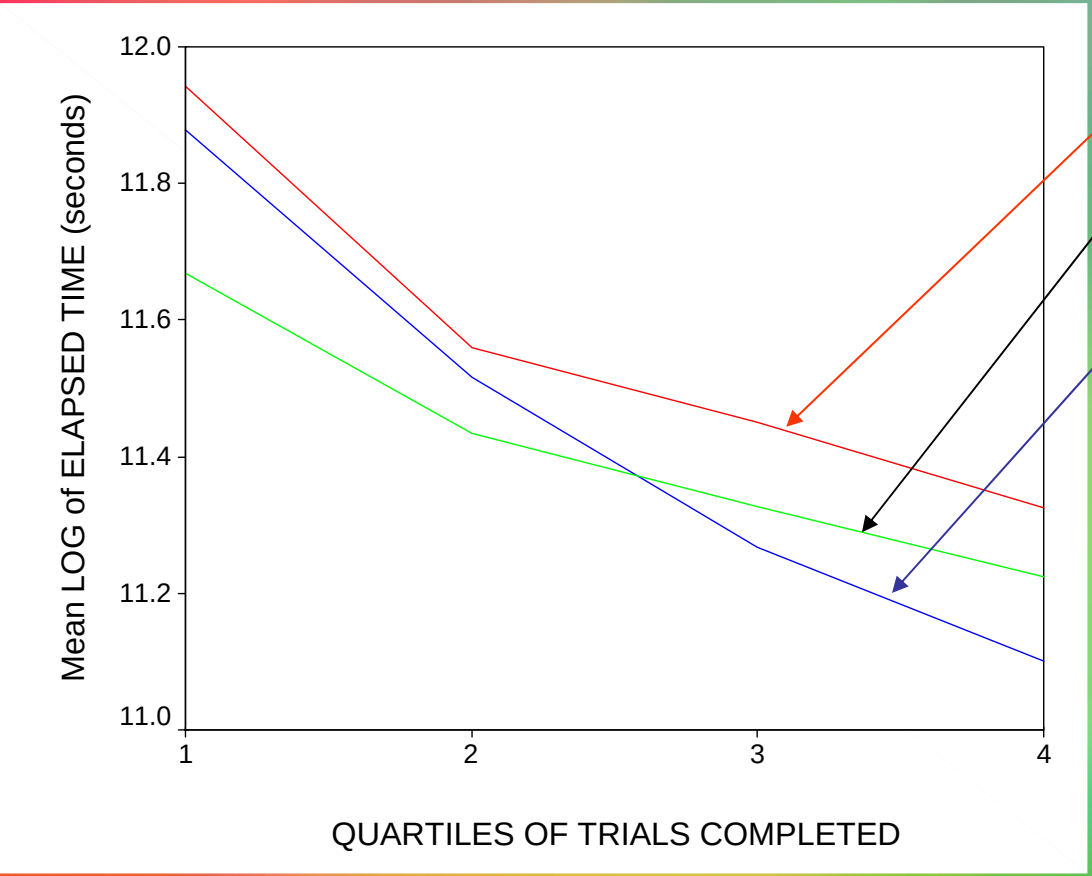
Feedback Learning Group

- *Imitation Learning* and *Explicit Learning* groups don't significantly differ
- *Feedback Learning* group significantly underperforms
- No significant difference across Quartile: no learning effect

Analysis and Discussion – Elapsed time

- Elapsed time (average) per trial:
  - Feedback Learning: 104 237 ms (std dev: 79020)
  - Imitation Learning: 87 990 ms (std dev: 51068)
  - Explicit Learning: 94 545 ms (std dev: 61180)
- Log transformation was applied (better normality)
- ANOVA procedure
- Non Significant results
  - Main effect of Group: $F_{2,60}= 1.42$, $p= 0.25$
- Significant results
  - Main effect of Quartile : $F_{3,180}= 85.7$, $p<0.001$
    - Suggests a learning effect across all groups
  - Interaction of Group and Quartile: $F_{6,180}= 2.63$, $p= 0.018$
    - Groups differ on their decrease in elapsed time across Quartile.

Elapsed Time vs. Quartile



Feedback Learning Group

Imitation Learning Group

Explicit Learning Group

- No significant main effect of Group
- Significant effect of Quartile (participants get faster)
- Significant interaction effect – Explicit learning group has the largest speedup

Conclusions

- Group (type of learning)
  - Imitation and Explicit Learning groups both outperformed the Feedback Learning group in terms of accuracy (correct answers)
  - No significant difference in speed
- Quartile (Learning effects)
  - No significant learning effect on accuracy
  - Significant effect on speed
    - Not significantly larger for the feedback learning group, but for the explicit learning group
    - Suggests that it takes practice to know how to use effectively those rules

Conclusions

- First step towards showing the importance of learning by imitation in problem solving
- Next steps
  - Determine the underlying mechanism
  - Devise a Computational model
- Rote memorizing?
  - Spontaneous use of problem solving variants never seen in demonstration

Follow-up

- Possible mechanisms
  - Memorization
  - Priming of certain states or operations
  - Program-level imitation
- Experimental approaches
  - Think aloud protocols
  - Present a simpler version of the target task to test generalization

Questions

- Demo available

Verbal Instructions

Symbolic/Verbal Instructions

Rules for Solving the 12 Balls / 3 Weighing Problem

There are two important sub-goals to keep in mind while solving each problem.
It will be necessary to alternate between selecting which balls to weigh and deciding which color markings to use.

Selecting Balls

IF this is the first weighing, THEN use 1/3 of the balls on each side of the scale.

IF the scale does not move in the first weighing,
THEN use 3 unknown vs. 3 normal
for the second weighing.

IF the scale does not move in second weighing,
THEN use 1 unknown ball from the ball bank vs.
1 normal ball for the third weighing.

IF the scale moves in the second weighing,
THEN use 1 potentially light ball vs. 1 potentially light ball,
OR 1 potentially heavy ball vs. 1 potentially heavy ball
from the scale for the third weighing.

IF the scale moves in the first weighing,
THEN use 1 potentially heavy ball + 2 potentially light balls vs.
1 normal ball + 1 potentially heavy ball + 1 potentially light ball
for the second weighing.

IF the scale does not move in the second weighing,
THEN use 1 potentially heavy ball from the ball bank vs.
1 potentially heavy ball from the ball bank for the third weighing.

IF the scale moves in the second weighing,
THEN use 1 normal ball vs. 1 potentially heavy ball from the scale
OR use 1 normal ball vs. 1 potentially light ball from the scale
OR use 1 potentially light ball from the scale vs.
1 potentially light ball from the scale
for the third weighing.

Marking Balls

1. IF the scale does not move, THEN all balls on it are of normal weight.
2. IF the scale moves, THEN all balls left in the bank are of normal weight.
3. IF there are balls of unknown weight located on the side of the scale that moves up, THEN they are of "light or normal weight"
4. IF there are balls of unknown weight located on the side of the scale that moves down, THEN they are of "heavy or normal weight".
5. IF there are balls of "light or normal weight" located on the side of the scale that moves down, THEN they are of normal weight.
6. IF there are balls of "heavy or normal weight" located on the side of the scale that moves up, THEN they are of normal weight.

Done

Imitation Learning in Neural Networks