Intelligent Agents

Human Problem Solving and Planning

Ute Schmid

Cognitive Systems, Applied Computer Science, Bamberg University

last change: June 15, 2010

Cognitive Perspective in Problem Solving

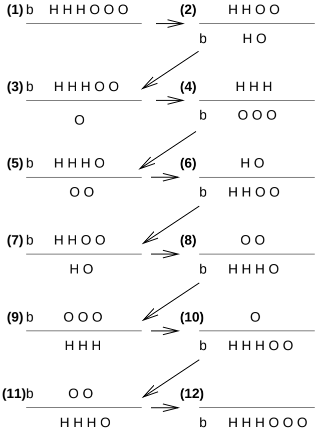
- Behaviorism: reinforcement of solutions found by trial and error
- Cognitivism: trial-and-error cannot explain the systematicity and productivity of thinking (finding new solutions)
- Most influential researchers: Newell and Simon (Human Problem Solving, 1972)
- Assumption: search in problem space
- Weak strategies (uninformed but complete)
  Strong strategies (informed but incomplete)
- Research question: What types of strong strategies are used by human problem solvers?

Greedy Strategies

- Humans often use greedy strategies for solving problems ("bounded rationality", Herbert Simon)
- The means-end (MEA) strategy which is the search algorithm used in the GPS (General problem solver) is such a greedy strategy
- Like the original STRIPS planner, MEA uses a linear strategy and therefore is not complete! (Sussman Anomaly)
- Empirical evidence: Greeno (1974) for the Hobbits-and-Orcs problem, a simulation with a production system by Schmalhofer & Polson (1986)

Hobbits and Orcs

Subjects have problems with the transformation from state (6) to (7). Here 2 and not only 1 passenger must be transported back to the left river bank. That is, there must be created a situation which is further removed from the goal state than the situation before.



Means-End-Analysis

Transform: Compare current state with goal state

IF the current state fulfills the goal
THEN stop and announce success
ELSE **Reduce** the difference between the current state and the goal.

Reduce: Find operator which reduces the difference between current state and goal

IF there is no such operator
THEN stop and announce failure
ELSE **Apply** the operator to the current state.

Apply: Apply an operator to the current state

IF the operator is applicable to the current state
THEN apply it and **transform** the resulting state into the goal.
ELSE **Reduce** the difference between the current state and the application conditions of the operator

MEA Example: Tower of Hanoi

Transform: initial state (discs 1, 2, 3 on peg A)
to goal state (discs 1, 2, 3 on peg C)

- Reduce: 3 is not on C
- Apply: Move 3 to C
  - Reduce: 3 is not free, because of 2
  - Apply: Remove 2
    - Reduce: 2 is not free,because of 1
    - Apply: Remove 1;
    - 1 can be moved to C
    - 2 is free
  - 2 can be moved to B
  - 3 is free
- Reduce: 3 cannot be moved to C,
  because of 1
- Apply: Remove 1;
- 1 can be moved to B
- 3 can be moved to C

MEA Example cont.

Transform: State (1 and 2 on B, 3 on C) to goal state
- Reduce: 2 is not on C
- Apply: Move 2 to C
  - Reduce: 2 is not free because of 1
  - Apply: Remove 1;
  - 1 can be moved to A
  - 2 is free
- 2 can be moved to C

Transform: State (1 is on A, 2 and 3 on C) to goal
- Reduce: 1 is not on C
- Apply: Move 1 to C;
- 1 can be moved to C
- 1 is on 3

Transform: State (1, 2 and 3 on C) to goal

success

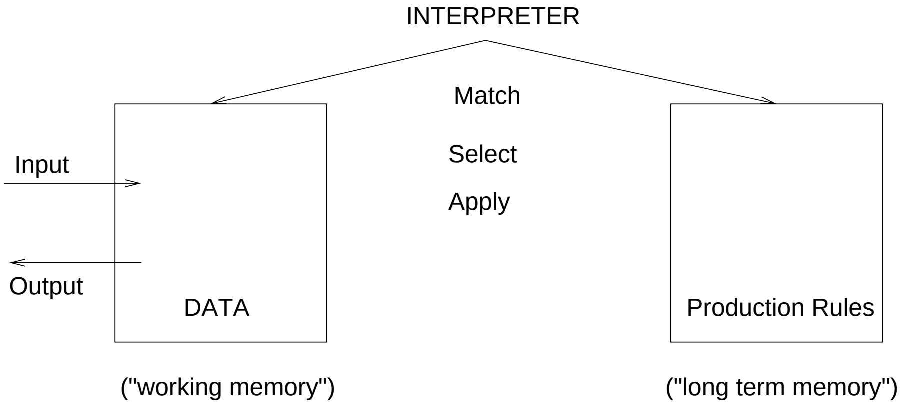
Cognitive Architectures

- Cognitive Architecture: "unified theory of cognition"
  - Explicit definition of basic mechanisms of information processing
  - Assumption that these mechanisms are constant over all domains (problem solving, language understanding, pattern recognition etc.)
  - Basic mechanisms: control of interaction with environment, representation of information in memory, strategy to select rules
  - Advantage: different models realized in the same architecture get comparable
- Alternative: special purpose cognitive models (such as SME for analogical reasoning, see below)

Cognitive Architectures cont.

- Prominent Architectures: The ACT-family (J.R. Anderson et al.), Soar (based on GPS)
- ACT and Soar are production systems
- ACT: long-term memory is divided in a declarative memory ("know what", activation net) and a procedural memory ("know how")
- Example strategies for selecting rules: most specific first, most recently used, priority values (updated in dependence of success)

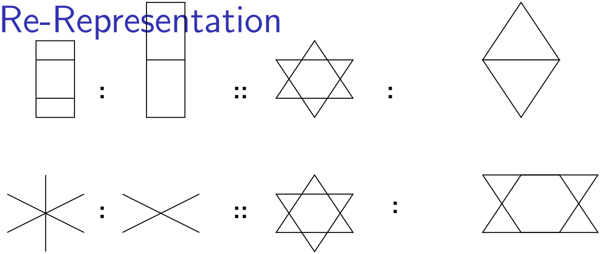
Production System

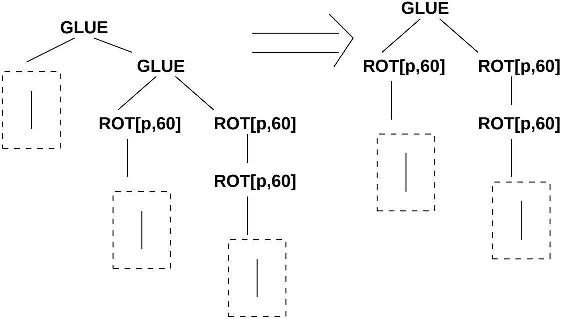


Finding a good representation

- In human problem solving, there is an interaction between constructing a suitable representation and solving the problem.
- In AI systems, typically the representation needs to be fixed before problem solving (see Kaplan & Simon, 1990). Exceptions: approaches to solving proportional analogies using re-representation (Copycat, Hofstadter et al. 1995, PAN, O'Hara 1992, Indurkhya 1992)
- Empirical studies: Pltzner & van Lehn, 1997
- Examples: Mutilated checkerboard, nine-dots problem

Re-Representation





Context Effects

- Since human problem solving is typically guided by knowledge, search for a solution might be misled by preconceptions
- Gestalt-Theory: functional fixation (Duncker 1945)
  Examples: Candle, matches, and box with pushpins; pendulum problem
- A related phenomenon: set-effect (Luchins & Luchins, 1950)
  Water jug problems

Analogical Problem Solving

- A problem solving strategy alternative to heuristic search is using analogical reasoning.
  - Retrieve a suitable source problem.
  - Map the entities of the source with the entities of the target problem in a structure preserving way.
  - "Carry-over" known parts of the source to target (possibly perform necessary adaptations)
- Gentner (1983)
- Cognitive Models: SME (Falkenhainer et al. 1989), LISA (Hummel & Holyoak, 1998)
- Empirical investigation of analogical transfer (Schmid et al., 1999)

Learning by Doing

- A problem solving system has no memory. Therefore, it might recalculate solutions which it already had achieved in another problem solving episode.
- The power law of learning (Anzai & Simon, 1979): learning curve, speed-up effect
- Humans acquire skills (procedural knowledge) when solving problem
- Cognitive Models, based on production systems: ACT (Anderson et al.), SOAR (Newell et al.): Declarative knowledge is "compiled" into rules
- But: these models do not cover strategy learning/control rule learning (see Schmid et al. 2000)

Hierachical Planning

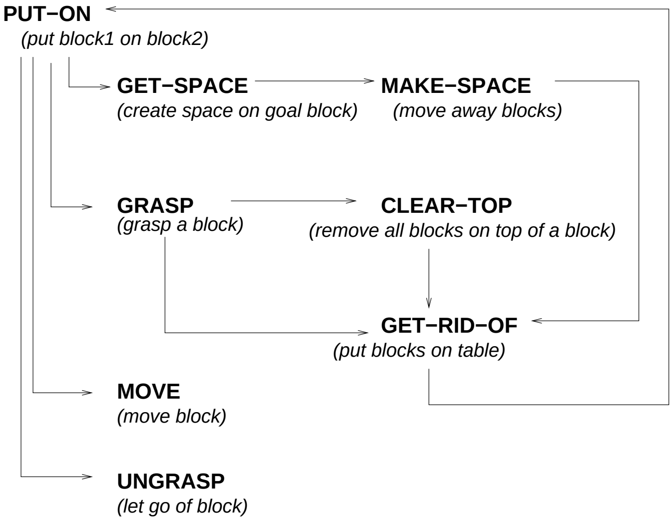
- Humans typically exploit knowledge about a domain when solving a problem
- Often, it is known which sub-goals must be fulfilled to reach a given goal
- This idea is realized in goal-driven production systems (such as ACT-R)
- This idea is also realised in hierarchical planning
- Hierachical planning is a special case of domain-dependent planning

Problem Decomposition

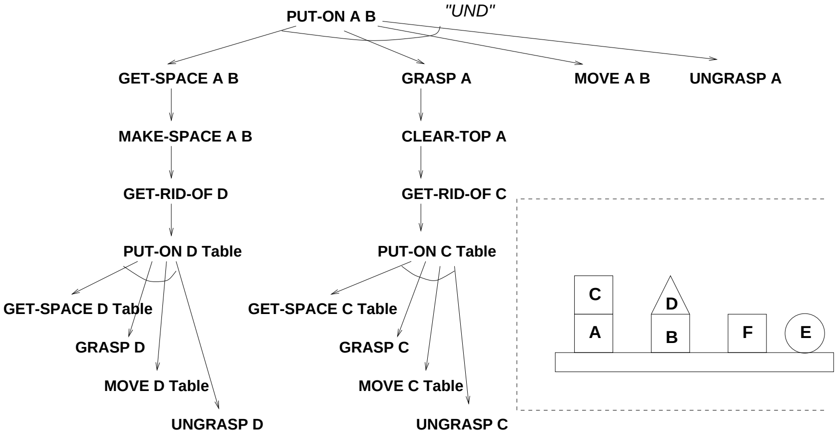
- Besides using heuristics, problem solving can be guided by knowledge about the problem structure.
- Problem decomposition: Dividing a problem in sub-problems
  $\hookrightarrow$ More complex production rules, goal-directed systems
- Advantage: dealing with smaller sub-problems and generating the solution by composition ("divide and conquer")
- Representation: AND-OR Trees
  standard tree: each arc which exits a node represents an alternative ("or"); extension: specially mark edges which lead to sub-trees which must be all fulfilled for the current node to be fulfilled ("and")
- Special heuristic search algorithm for AND-OR trees: A*

Example: MOVER

(Winston, 1992)



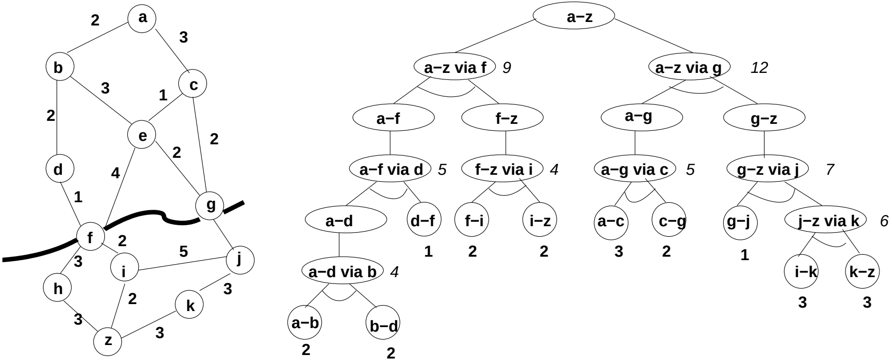
AND-OR Tree for MOVER



Example: Route Finding Problems

- "OR"-node: X - F (go from X to F), X - F is primitive, if F can be reached from X in one step (there exists an applicable operation) primitive sub-problems are leafs in the tree
- "AND"-node: X - Z via Y (go from X to Z via Y) "constraint"
- Problem solving: extracting an (optimal) AND-Tree
- Using costs: Each leaf is associated with its cost, the costs are propagated upwards in the tree, the AND-tree with the lowest costs is returned
- Algorithm: AO* (Nilsson)
- In planning: hierarchical planning

Example cont.



Two of many possible decompositions.

The Running Gag of CogSysI

Question: How many AI people does it take to change a lightbulb?

Answer: At least 67.

2nd part of the solution: **The Problem Space Group (5)**

- One to define the goal state
- One to define the operators
- One to describe the universal problem solver
- One to hack the production system
- One to indicate about how it is a model of human lightbulb-changing behavior

("Artificial Intelligence", Rich & Knight)