Lecture 9
Problem Solving

1. Problem solving in research
   - different types of problems
   - different ways of solving problems
   - historical steps of research in the area
   - creativity

2. Newell & Simon's approach
   - General theory of problem solving
   - General Problem Solver

Problem Solving: Definitions

- **Problem:**
  A question or situation that presents uncertainty, perplexity, or difficulty
  A question put forward for consideration, discussion, or solution
  [The American Heritage Dictionary]
  If there is a goal to reach that cannot be reached directly.

- **Task:**
  A piece of work assigned by a superior or done as part of one's duties.

Problem Solving ...

- ... means reducing the problem to a task and then performing the task.
- ... is the identification and selection of suitable solutions to the problem.

What kinds of problems?

- **Everyday problems**
  - How do I find my dream partner?
  - How do I tie my shoes?
  - How will I become happy?
  - How can I obtain my dream profession?
  - How do I get to the seminar room in GW2?

- **Scientifically observed problems**
  - manageable: the aim is to capture all relevant factors
  - bounded: the aim is to reduce all distracting contextual factors
  - generalizable: the aim is to study cognitive processes
  - (often) chosen in order to support or falsify a certain existing theory about problem solving processes

Hobbits and Orcs

- 3 hobbits and 3 orcs wish to cross the river
  - the boat only carries two at a time
  - there should never be more orcs than hobbits at any side of the river

- How do all get across?

Some literature

How do we solve problems?

- How to find out?
  - Observation of behavior
    - with animals: simplified problems – easier to understand and sometimes generalizable
  - Formulation of theories or models that can explain the behavior
    - possibly with computational realization
    - definition of falsifiability
  - Ask experimental participants
  - Ellicit verbal reports / protocols
    - concurrent verbalization
    - retrospective verbalization

Historical development:
Some major steps in the theory and methodology of problem solving research

Behaviorism

- trial and error
- Thorndike (1911) “Animal Intelligence”
  - Experiments with cats
    - conditioning
    - reward and punishment
    - no need for thought processes or problem solving

Gestalt theory

- Wolfgang Köhler
  - 1887-1967
  - one of the founders of gestalt theory
  - perception concerns “wholes” rather than small details
  - the same applies to problem solving: consideration of the problem in its overall “gestalt”

- Reproductive problem solving
  - earlier problem solving experience is taken into account

- Productive problem solving
  - insight into the nature of a problem
  - productive restructuring of the problem

Köhler (1927):
apes solving problems

- Insightful behavior
- Use of tools

Maier’s (1931)
“two-string” problem

- 2 strings hanging from the ceiling
  - need to be combined with each other
  - impossible to grasp both at once

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- 2 strings hanging from the ceiling
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- Restructuring of the problem
  - can be triggered by "accidental" movement of one rope by the experimenter
Duncker’s (1926) candle problem

- A candle is to be fixed to the wall so that no wax drips onto the table
- Given: candle, box of thumbtacks or nails, book of matches, table

- Functional fixedness

Scheerer’s (1963) Nine-points-problem

- Combine all points with each other by 4 continuous straight lines (without interruption!)

Creativity

- How is creativity related to problem solving?

- Creativity is a novel and relevant process

- Are creative solutions arrived at by different processes than non-creative solutions?

Traditional View on Creativity

- Wallas (1926):
  - Preparation: People must have some experience with problem to enable creative solution
  - Incubation: People need to take some time away from the problem
  - Illumination: During or after incubation, a solution shall become clear to the person
  - Verification: Although the person has a solution, that solution must be verified as correct
Open Issues with Traditional View

- Problem solving stages cannot be verified
- Can creativity be separated into discrete stages?
- Memories about problem solving process frequently are distorted
  - e.g., a subject reports the solution illuminated him during a dream
  - other evidence suggests that the solution had been sketched out previously
- Phenomenological description of events rather than a theory about the process that produces creativity

Alternatives to the Traditional View (I)

- Incubation as Release from Memory Interference
  - Memory interference has been found to sometimes hamper task performance
  - Perhaps memory interference sometimes causes poor problem solving performance
  - Incubation, or spending time away from the problem, may then allow the person to be released from that interference

Alternatives to the Traditional View (II)

- Incremental Process
  - Some have suggested that creativity is really an incremental, continuous process, rather than a discrete, insightful process
  - A person works with or plays around with the situation until a solution is found, and the solution may be a creative one

Alternatives to the Traditional View (III)

- Problem solving involves an element of problem finding / problem identification
  - Creative solutions occur when the person has found – or identified – a new problem, rather than perceiving the same old problem everyone else has been perceiving

Problem solving strategies

- Aim: to make a vague or ill-defined problem precise or well-defined
- In what ways can this be achieved?
  - Search
  - Research: how have others solved this problem?
  - Problem analysis
  - Divide and conquer
  - Analysis
  - Hypothesis testing
  - Means-end analysis
  - Work backwards from the intended goal
  - Abstraction / generalization
  - Specialization: Find a practical example
  - Visualization

Changing water into wine

- Given: a glass of water and a glass with an equal amount of wine.
  You transfer a spoon full of water from the first glass to the second; then you transfer a spoon full of mix from the second to the first glass
- Problem:
  - is the wine:water ratio in the first glass greater, equal, or smaller than the water:wine ratio in the second glass after these transactions?

Measuring water

- You are given some jugs of water and are asked to produce a certain measure.

<table>
<thead>
<tr>
<th>Jug A</th>
<th>Jug B</th>
<th>Jug C</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>127</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>18</td>
<td>43</td>
<td>10</td>
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</tr>
<tr>
<td>23</td>
<td>49</td>
<td>3</td>
<td>20</td>
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</tbody>
</table>

Set effects

- After solving some of these problems,
  - people become unaware of simpler solutions
  - some solutions actually become hard to find

- Problem can be overcome by warning people
  - telling people "Don't be blind" caused more than 50% to find the simpler solution on the remaining problems


Insight

- Archimedes had the problem of how to determine the volume of a crown so as to determine if it was pure gold or a gold/silver alloy.
- He knew how to determine the volume of simple geometric objects, but a handcrafted crown posed a problem
- Archimedes knew that gold had a different specific weight than an alloy
Archimedes in the Bath Tub

- When Archimedes stepped into his bath tub he noticed that the water level rose.
- This led to his insight into how to determine the crown’s volume.
- **Insight** that volume of irregularly shaped body corresponds to volume of displaced fluid which can be measured easily.
- **Analogy** between crown and human body.

Non-Insight Problems vs. Insight Problems

- **Gradual progress** (“getting warmer” – getting closer to the solution) for non-insight problems.
- Problems require series of steps whose difficulty can be assessed ability to predict solvability of problem.
- **Breakthrough** (“Heureka”) for insight problems.
- Problems require crucial breakthrough that gives a new perspective on the problem.
- Solvability can hardly be predicted.

An insight problem for you (Riddle)

What is greater than God
More evil than the Devil
The poor have it
The rich want it
And if you eat it you'll die.

Theory of information processing (Newell & Simon, 1972)

- **Allen Newell**
  * 18 March 1927 † 19 July 1992
  One of the founders of Artificial Intelligence

- **Herbert Simon**
  * 15 June 1916 † 9 February 2001
  one of the most influential social scientists of the 20th century
  1978: Nobel prize in economics
  for the topic of decision making in business organizations

- **Hypothesis:** Problems can be broken down into parts.

Basic assumptions (Newell & Simon, 1972:788)

- 1. Humans are representable as information processing systems while solving problems.
- 2. The problem representation can be described in detail.
- 3. Substantial subject related differences concern the program structure, the methods, and the content.
- 4. Substantial task related differences concern the structure and the content.
- 5. The task environment determines to a great extent the behavior of the problem solver.

Central questions (Newell & Simon, 1972:788)

- Given the substantial differences among individuals and among tasks, does a single theory of problem solving exist, or only a congeries of separate theories?
- What is invariant over task and over problem solver that could constitute the basic theory?
- Further, what determines the aspects that are not invariant?
- What can the theory of human problem solving be, when the shaping influence of the task environment seems to make the specifics of the problem solver’s internal structure almost irrelevant?
Some invariant features of information processing systems

- Features related to memory:
  - memory capacity
  - reading and writing speed with respect to information
  - type of activation
- Features related to task:
  - experience with the same or a similar task or with an analogical task procedure
- "Weak" methods:
  - general strategies or procedures stored in long term memory

Heuristics

- A concept mostly associated with decision making rather than problem solving but problem solving involves deciding about a way to solve the problem
- "Satisficing": Go for the first approach that appears to be satisfying for the most important aspects.
- "Bounded rationality" (Herb Simon):
  Humans only have limited cognitive abilities, they are only rational to a limited extent. In order to get to useful results they use cognitive shortcuts – also called gut feelings (Gerd Gigerenzer).
  => heuristics used for problem solving are cognitive shortcuts

Heuristics of route planning in familiar environments

- Path planning in advance:
  - orient towards main streets
- Walking directly to the goal:
  - walk in the rough direction of the goal

Theory of problem solving (Newell & Simon, 1972)

- The problem occurs, is perceived and understood
- Search in the problem space via the selection and application of operators (unprogrammed action)
- Plan oriented action (programmed procedures)
- Combination of known and novel information and insights
- Identification of suitable solution steps
- The problem space often determines which methods are adequate

Means-end analysis

- What is the difference between the current state and the goal state?
- Which intermediate state would decrease this difference?
- Which (mental) operator would be suitable for reaching this intermediate state?
  - possibly several steps needed to reach such an intermediate state
- Suitable strategy IFF suitable intermediate states can be defined at all

The Tower of Hanoi

- The disks need to be transferred to a different stick
- Only smaller disks are allowed to be placed on larger disks
- Only to be moved individually
- Disks may only be placed on sticks (not stored outside)
General Problem Solver (GPS)

- Implementation of basic insights by Newell & Simon
- GPS assumed serial processing
- STM
- LTM
- heuristics as central elements

GPS

- GPS analyzes a problem to create a goal stack
  - final goal at bottom of stack
  - series of sub-goals on top of it
- GPS uses means-end-analysis
  - a continuous examination of the difference between current state and goal
    state, so as to choose best action to decrease that difference
- GPS was quite successful at solving a wide range of problems

Difference Between GPS and People

- People are resistant to make moves that take themselves away from the goal, even if that is the only legal move available
- People are reluctant to backtrack, even though backtracking is sometimes necessary to achieve the final goal – GPS backtracks without a hitch
- GPS sometimes gets caught trying to solve sub-goals that are no longer appropriate
- GPS needs well-defined goals and problem spaces before it can do anything

Next week

- Mental Representation