PROBLEM SOLVING AND DECISION MAKING

Some slides in this presentation were developed by Rowan professor Mark Hale. Professor Hale is a Cognitive Psychologist and Human Factors Specialist and very gratefully contributed his material to this course in HCI.

Other content is abstracted from Behavioral Research Methods in Human-Computer Interaction - Thomas K. Landauer , as published I n Handbook of Human-Computer Interaction 1997

Problem Solving and Heuristics

Problem Solving & Creativity

- Problem-Solving Strategies
  - Once you have represented the problem, you can use many different strategies to attack it.
  - An algorithm is a method that will always produce a solution to the problem, although the process can sometimes be inefficient and unsophisticated.
  - One example of an algorithm is a method called an exhaustive search, in which you try out all possible answers systematically.
  - Alternatively, other strategies reduce the amount of possible choices.

- Suppose that you need to solve the following anagram: LSSTNEUIAMYOUL
  - If you use an exhaustive search algorithm you would randomly o systematically place each letter into each slot until you found a solution.
  - Instead, you might use a strategy that attempts to identify the first 2 letters of the word by picking only pronounceable combinations that frequently appear at the beginning of a word.
    - You might reject combinations such as LS, LT, and LY, but you consider LE, LU, and—ideally—SI.
    - This strategy would lead you to a solution much faster than an exhaustive search of all the 87 billion possible arrangements of the 14 letters in SIMULTANEOUSLY.

Heuristics

- The strategy of looking only for pronounceable letter combinations is an example of a heuristic.
  - Heuristics include using a rule of thumb, an educated guess, an intuitive judgment, or common sense.
  - Rule of thumb – an easily learned and easily applied procedure with broad application that is not intended to be strictly accurate or reliable for all situations.
  - In problem solving, a heuristic is a strategy in which you ignore some alternatives and explore only those alternatives that seem especially likely to produce a solution.

- We noted that algorithms such as an exhaustive search will always produce a solution, although you may grow a few years older in the process.
  - The solution will always be correct if the algorithm is applied correctly!
  - Heuristics, in contrast, do not guarantee a correct solution.

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Heuristics

- Suppose you were given the anagram IPMHYLOD and you use the same strategy as in the previous example.
- If you reject words beginning with LY, you would fail to find the correct solution, LYMPHOID.
- When solving a problem, you'll need to weigh the benefits of a heuristic's speed against the costs of possibly missing the correct solution.

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Types of Heuristics

- Three of the most widely used heuristics are:
  - The analogy approach
  - The means-ends heuristic
  - The hill-climbing heuristic

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Heuristics: The Analogy Approach

- Every day you use analogies to solve problems.
  - In statistics you refer to previous examples in your textbook to solve new ones.
  - When you write a paper, you use many of the same strategies that were helpful when you wrote a previous paper for different course.
- When you use the analogy approach in problem solving, you employ a solution to a similar, earlier problem to help in solving a new one.
- Analogies are also prominent in creative breakthroughs in domains such as art, politics, science, and engineering.
  - For example, Wilbur and Orville Wright designed some of the features of their airplanes by creating an analogy between the wings of a bird and the wings of an airplane.
  - Specifically, they noticed that birds could control their flight patterns by making small adjustments in the orientation of their wing tips.
  - They then designed airplane wing tips so that pilots could make subtle adjustments by using metal rods and gears.

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Heuristics:
The Problem with the Analogy Approach

- The challenge for people who use the analogy approach is to determine the real underlying problem.
- People tend to focus more on the superficial content of the problem than on its abstract, underlying meaning.
  - i.e., they pay more attention to the obvious surface features, the specific objects, and terms used in the question.
- These problem solvers may fail to emphasize the structural features, that are the underlying core of the problem.
- People often fail to see the analogy between a problem they have solved and a new problem that has similar structural features.
- They may also have trouble solving the same problem when it is “dressed up” with a superficially different cover story.
- People with limited problem-solving skills and limited metacognitive ability are especially likely to have difficulty using analogies.

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Heuristics: Means-Ends Approach

- This heuristic has 2 important components:
    1. You divide the problem into a number of smaller sub-problems.
    2. Then you try to reduce the difference between the initial state and the goal state for each sub-problem.

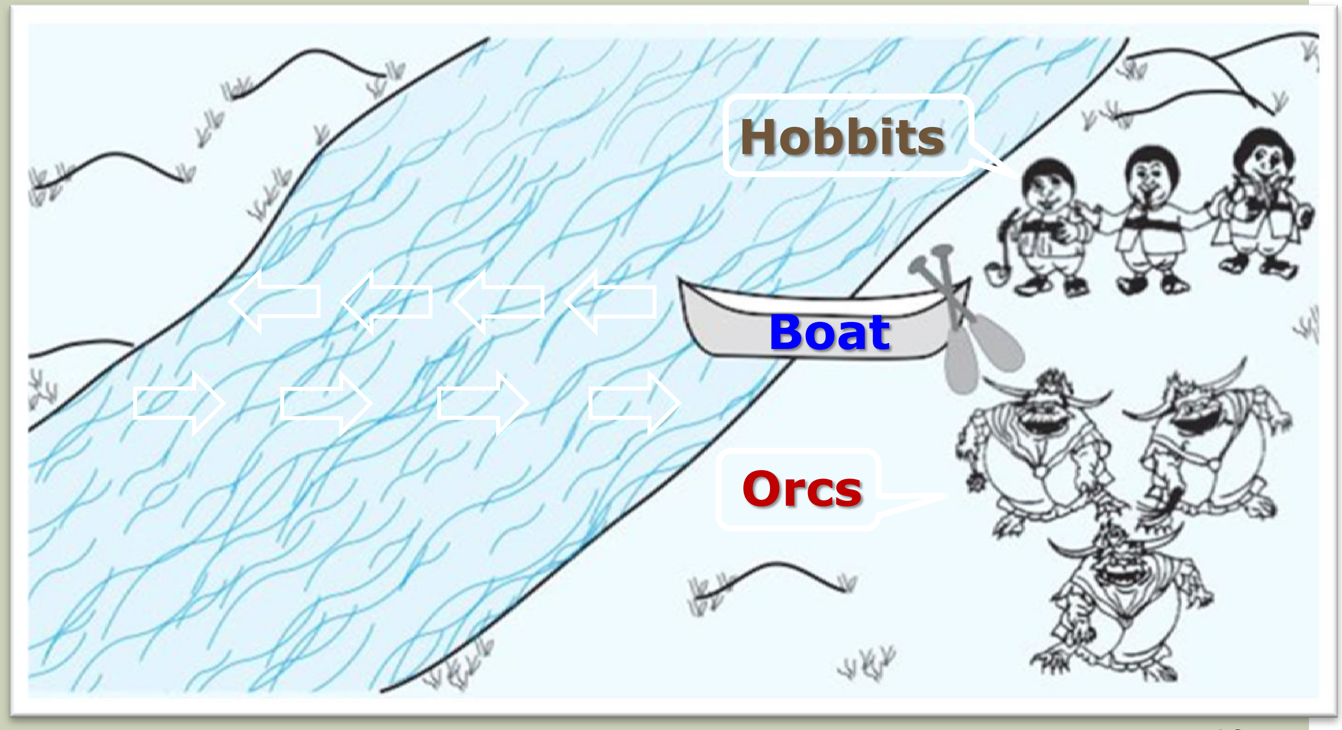
- The name is appropriate because it requires you to identify the “ends” you want and the “means” to reach those ends.

- This heuristic is one of the most effective and flexible problem-solving strategies.

Exploring Means-End Thinking

- The Hobbits & Orcs Problem
  - 3 Hobbits and 3 Orcs on right side of a riverbank.
  - You must figure out how to get them all on the left side of the bank using a boat that seats 2 creatures.

- The Rules
  - Orcs can never outnumber Hobbits or they will attack and eat them!
  - Both creature types can be trusted to bring the boat back for the next trip.



Means-End Heuristic

- Research on the Means-Ends Heuristic
  - Research demonstrates that people do organize problems in terms of sub-problems.
  - For example, researchers examined how people solve the Hobbits-and-Orcs problem.
  - Studies show that people pause at points in the problem when they begin to tackle a sub-problem and need to organize a sequence of moves.
  - Working memory is especially active when people are planning one of these move sequences.

- How do you solve the Hobbits-and-Orcs problem?
  - You concentrated on reducing the difference between the initial state (all on the right) and the goal state (all on the left).
  - With each move, you get closer to the goal state (more and more creatures on the left).
  - However, you can’t solve the problem unless you move 2 creatures backward across the river at some point (around the 6th step).

- Research confirms that people are reluctant to move away from the goal state — even if the correct solution depends on making this temporary detour.

Hobbits & Orcs Problem - Solution

Step	Right Bank	Journey	Left Bank
0	bHHHOOO		
1	bHHOO	bHO →	
2	bHHOO	← bH	O
3	bHHH	bOO →	O
4	bHHH	← bO	OO
5	bHO	bHH →	OO
6	bHO	← bHO	HO
7	bOO	bHH →	HO
8	bOO	← bO	HHH
9	bO	bOO →	HHH
10	bO	← bH	HHOO
11		bHO →	HHOO
12			HHHOOO

Heuristics: The Hill-Climbing Approach

one of the most straightforward problem-solving strategies

- To understand this heuristic, imagine that your goal is to follow a pathway leading to the top of a hill.
  - Just ahead, you see a fork in the path, but can't see far into the distance on either path.
  - Because your goal is to climb upward, you select the path that has the steepest incline.
- When using the hill-climbing heuristic, you simply select the alternative that seems to lead most directly toward your goal state.
- This can be useful when you don't have enough information available!
- However, like most heuristics, the hill-climbing heuristic can lead you astray.
- The drawback is that you must consistently choose the alternative that appears to lead most directly toward the goal.
- In doing so, they may fail to choose a less direct alternative, which may have greater long-term benefits
  - A path that seems to lead upward may quickly come to an abrupt end.
  - The hill-climbing heuristic certainly does not guarantee that you'll end up on the top of the hill.

Heuristics: The Problem with Hill-Climbing

- A scenario:
  - Imagine you are offered a job right out of college (at 40K), but would not allow you to continue to grad school.
  - Alternatively, going through grad school may yield greater long-term benefits (75K).
  - The difference of 35K annually is 1.4 MILLION dollars over your career!
- Remember, the hill-climbing heuristic encourages short-term goals, rather than long-term solutions.
- In many ways, the hill-climbing heuristic is similar to the means-ends heuristic in that:
  - People don't want to take a step backwards,
  - Even if that step ultimately winds up as a better long term solution.
- However, with the hill climbing heuristic we emphasize that only the next step is apparent at the time.
  - Conversely, with the means-ends heuristic we may have much more insight into the entire decision process in front of us.

Decision Making

Decision Making

- Modern information technology has a major impact on requirements for system design – particularly user interfaces
  - Hospitals utilize computer systems where patient monitoring and surgery are dependent on access to patient data (e.g., test results, lab analyses, patient histories)

- We are seeing increased levels of automation of elementary and routine work operations
  - This shifts user efforts to a higher decision making level
  - Automation can remove humans from higher level tasks of supervision, problem solving and decision making
  - How to automate these kinds of tasks? Models of higher level cognitive functions in complex environments are needed.

Content abstracted from Behavioral Research Methods in Human-Computer Interaction - Thomas K. Landauer

Interface Design Questions relevant to Cognitive Psychology

- What kind of mental models are effective for the various tasks and should be taken as a basis for display design?
- What are the differences between mental models supporting routine work versus performance during rare, risky events?
- What are the differences between experts and novices?

- What are the basic psychological mechanisms behind human errors?
- What information is necessary to ensure error detection and recovery during routine work as well as during rare and risky work conditions?

- Operator mistakes made during diagnosis and evaluation often lead to accidents. How can we augment human problem solving strategies? How can we compensate for human limitations?
- How do computer system users respond to advice from computerized expert systems? What are the requirements for such systems to gain user trust?

Artificial Intelligence

- Artificial intelligence includes a wide range of systems that can replicate human decision making for certain types of well-defined problems.
- One critical aspect of AI is to interact with humans.
  - Natural language processing allows a computer to understand and react to statements and commands in a human language, such as English. Many automated telephone services now include the option to speak your instructions instead of selecting options on your keypad. Some types of mobile phones and car navigation systems also allow you to speak your commands.
  - Learning systems are major elements of many AI systems. Learning systems use a combination of hardware and software to allow a computer to change how it functions or reacts based on feedback. Some computer-based games have this built in. If a computer does not win, it remembers not to make the same mistake twice. This is one reason why it is so hard to beat an advanced level computer chess game. It has learned from a large number of known chess matches.
  - An increasingly important aspect of AI systems is the use of neural networks. A neural network is a computer system that tries to simulate some of the functionality of the human brain. Using a mesh-like structure somewhat similar to a brain, neural networks can process many pieces of data simultaneously and learn to recognize patterns.

Expert Systems

- An alternative to trying to developing computer systems with true intelligent behavior is to use an expert system.
- Expert systems
  - Make it possible for a novice to perform at the level of an expert in very specific situations.
  - Take a much more limited view of what intelligence is and use a set of detailed rules. These rules are based on the documented expertise of one or more individuals. An expert system simulates the reasoning and decision making of these experts.
  - Reached their peak of popularity mid to late 1980s
- Characteristics of expert systems
  - Knowledge Base
    - A representation of facts about the particular (specific) domain
    - Stores the experiences and knowledge of human experts from various professional fields
  - Inference engine: automated reasoning system
    - Evaluates current state of knowledge base
    - Looks for information and relationships in the knowledge base to provide answers, predictions and suggestions
    - Applies relevant rules typically with a probability
    - Asserts new knowledge

EXPERT SYSTEM EXAMPLE: VP-EXPERT

- **Example Rule**

```
IF sore_throat = yes
AND temperature = high
OR temperature = very_high
THEN diagnosis = flu CNF 90;
```

(CNF stands for confidence, i.e. confidence of 90%)

- **Calculating certainties**
  - If two or more premises with confidences are linked by AND, then the overall confidence in their conjunction is the minimum of the confidences of the premises:
  - If two premises with confidences C1 and C2 are linked by OR, then the overall confidence in their disjunction is computed as:
    `C1 + C2 - (C1 * C2) / 100`

- **Example Input**
  - Do you have a sore throat?
    `sore_throat = yes CNF 70`
  - Do you have a high temperature?
    `temperature = high CNF 80`
  - Do you have a very high temperature?
    `temperature = very high CNF 60`

"I am 62% confident that you have the flu."

- **Example Calculation**
  - OR has higher precedence than AND. Confidence in `temperature = high OR temperature = very_high`
    `80 + 60 - (80 * 60)/100 = 92.`
  - Confidence in the Boolean AND (sore throat AND temperature)
    `MIN(70, 92) = 70.`
  - Confidence in the conclusion equals confidence in the premise times the confidence in the rule
    `70 * 90 / 100 = 62.`

Understanding "Decisions"

- Decision making is complex
  - An important aspect of decision making is the communication of intentional information and value structures.
  - Decisions are made based on much more than explicit knowledge (i.e., facts), but rather on implicit or tacit knowledge of intentions, values, and motives.

- Decisions are arrived at differently when comparing novices and experts
  - Both groups need to use rational analysis when faced with a **new** problem
    - What are the possible means to a particular end?
    - What are the cause and effect relationships between possible actions?
  - However, skilled experts can solve familiar problems with ease. Why?

Skill-, Knowledge- and Rule-Based Behavior

- Jens Rasmussen, a system safety and human factors professor at Risø National Laboratory for Sustainable Energy at the Technical University of Denmark, outlined the distinction between types of behavior.
  - **Skill-based behavior**: takes place without conscious control. Leverages highly integrated patterns of behavior
  - **Knowledge-based behavior**: a higher conceptual level in which performance is goal-oriented, based on analysis of the environment and the aims of the person

Knowledge-Based or "Conscious" Mode	Skill-Based or "Automatic" Mode
Unskilled or occasional decision maker	Skilled, regular decision maker
Novel environment	Familiar environment
Decisions are slow	Decisions are fast
Decisions are effortful	Decisions are effortless
Requires considerable feedback	Requires little feedback
Causes of error: • Overload • Manual variability* • Lack of knowledge of modes of use • Lack of awareness of consequences	**Causes of error:** • Strong habit intrusions • Frequently invoked rule is used inappropriately • Situational changes that do not trigger the need to change habits

**Manual Variability – an error mechanism in which an action is not performed with the required degree of precision (e.g., time, spatial accuracy, force)*

Skill-, Knowledge- and Rule-Based Behavior

- James T. Reason, specialist on human error and organizational processes, described the continuum between conscious and automatic behavior
- **Rule-based behavior**: the sequence of subroutines in a familiar work situation is consciously controlled by a stored rule or procedure that may have been:
  - derived from previous situations,
  - communicated from other people
  - prepared by conscious problem solving and planning.

Knowledge-Based

Improvisation in unfamiliar environments

No routines or rules available for handling situation

Rule-Based

Pre-packaged units of behavior released when the appropriate rule is applied.

```
IF the symptoms are X THEN the problem is Y
IF the problem is Y THEN do Z
```

Skill-Based

Automated routines requiring little conscious attention.

Conscious

Automatic

Design Implications of Decision-Making Behavior for Computer Systems

- The ways to support decision making depend on supporting effective skill-, rule- and knowledge-based behavior.
- The configuration of a display screen is generally designed to support mental activity
  - Configuration should be related to the user's know-how
  - Displays should shift as tasks move from familiar to unfamiliar