AI Problem-Solving Methods

Luger, Part II, Ch 3 & Reference Texts

Outline

- Classic AI
- Problem-solving methods
  - State space search
  - Search strategies
  - Blind searches

Intelligence and Symbol Systems

Physical symbol system hypothesis (Newell & Simon 76):

Intelligence resides in *physical symbol systems* (collections of patterns and processes)

→ Principles of traditional AI methods:

- *Symbols* – to describe the world
- *Searches* – to select a solution among alternative results from operations on symbol patterns
- *Architectures* – to support symbol systems in ways that do not depend on the implementation of symbols

AI as representation and search

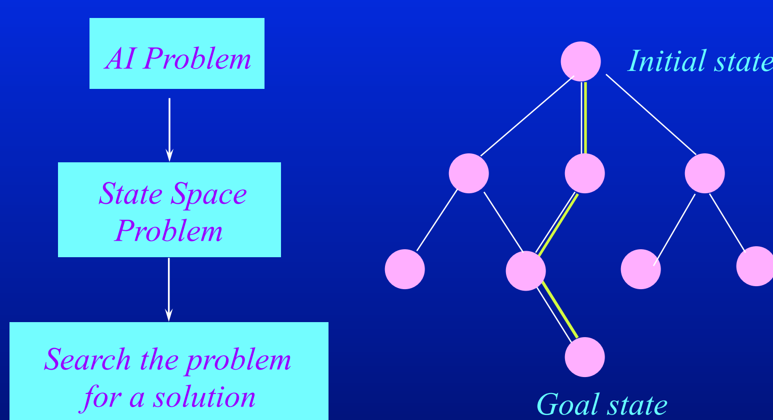
Given a problem, classic AI approaches:

- Define symbol structures & operations (actions)
- Develop efficient and correct search techniques

Building AI programs

- Define problem precisely
- Analyze & represent the task knowledge
- Choose & apply representation and reasoning techniques

Problem-solving techniques



State Space Problems

- A problem space consists of *states* and *operators*
- States – specify values of all attributes of interest in the world
- Operators – change one state into another – specified by
  - Preconditions:
    values certain attributes must have to enable operators application in a state
  - Postconditions:
    attributes of a state altered by an operator application

Problem Formulation: Example 1

A water jug problem

- Jugs have no scale measurement
- You can empty the jug or pour from one jug to fill the other

Can you formulate this problem into a state space search problem?

Example 1 (cont.)

Toy problem: Water jug problem

- *States:* amount of water in both jugs
- *Actions:* Empty large, Empty small, Pour from small to *(empty)* large, Pour from large to *(empty)* small
- *Goal:* specified amount of water in both jugs
- *Path cost:* total number of actions applied

Problem formulation: Example 2

Real-world problem:

Find a driving route from city A to city B

- *States:* location specified by city
- *Actions:* driving along the roads between cities
- *Goal:* city B
- *Path cost:* total distance or expected travel time

Problem formulation: Example 3

5	4	
6	1	8
7	3	2

Start state

1	2	3
8		4
7	6	5

Goal state

Toy problem: The 8-puzzle

- *States:* location of each tile and also the blank
- *Actions:* blank moves left, right, up or down
- *Goal:* state matches the goal configuration
- *Path cost:* length of path (each action step cost 1)

More Example Problems

Real world problems

- Touring and travelling salesman problems
- VLSI layout
- Robot navigation

Problem formulation

- Key elements
  - Representation of states and actions
  - Abstraction , i.e., removing details of representation while maintaining validity

↑Efficiency

State Space Problems: Representation

- Problem formulation → Representation → Search
- Representation
  - states
  - operator specifications

Example: a water jug problem

- *States:* amount of water in both jugs

(b, s) where b is amount of water in a big (5-gal) jug
s is amount of water in a small (2-gal) jug

say, initial state = (5, 2) and goal state = (1, 0)

Water Jug Problem (Cont.)

- *Operators:*

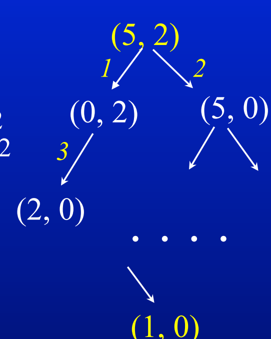
		Pre-conditions	*Post-conditions*
when one of the jug is not empty	*empty big*	b > 0	(0, s)
	empty small	s > 0	(b, 0)
when one of the jug is empty	*big is empty*	b = 0, s > 0	(s, 0)
	small is empty	b > 0, s = 0	(b-2, 2) if b ≥ 2 (0, b) b < 2

Water Jug Problem (Cont.)

- *Operators:*

	Pre-cond	*Post-cond*
1. *empty big*	b > 0	(0, s)
2. *empty small*	s > 0	(b, 0)
3. *big is empty*	b = 0, s > 0	(s, 0)
4. *small is empty*	b > 0, s = 0	(b-2, 2) if b ≥ 2 (0, b) b < 2

Init: (5, 2) goal: (1, 0)



Solution path: 2, 4, 2, 4, 2

Characterizing problems

Characterizing problems help find effective search strategies:

- *Decomposibility* → divide-conquer, parallelism

  Examples:

  Integration problem: $\int (3x + x^2 + 2)\, dx$

  $\int 3x\, dx \quad \int x^2\, dx \quad \int 2\, dx$

  Block world:

  O1: put_ontable(X)
  O2: stack(X, Y)

Characterizing problems (contd.)

- *Solution types*: a state or a path?

  Examples:

  Natural Language Understanding
  – search for interpretation of a sentence
  (e.g., pasta salad vs. dog food)

  Water jug problem

  Does the search need to record the path of the problem-solving process as it proceeds?

Characterizing problems (contd.)

- *Solution steps*:
  - *Ignorable?* – only care about the result
    (e.g., theorem proving)
    → search needs only "control"
  - *Recoverable?* – solution steps can be undone
    (e.g., 8 puzzle)
    → search additionally needs "backtrack" mechanisms
  - *Irrecoverable?* solution steps can't be undone
    (e.g., chess)
    → search needs "planning process"

Characterizing problems (contd.)

- *Solution quality*:
  - *Absolute?*
    (e.g., question answering problem – given a goal state)
    → search for optimal solution
  - *Relative?*
    (e.g., traveling salesman problem – no prior goal state)
    → search for any solution

Characterizing problems (contd.)

- *Predictability of the problem universe*
  - *Certain outcome?*
    (e.g., 8 puzzle)
    → search needs “planning” in open loop control
  - *Uncertain outcome?*
    (e.g., bridge due to incomplete information,
    non-deterministic natures of controlling robot arms)
    → search needs “planning” with revision
    (i.e., closed loop control)

Problem-solving techniques

- Good representations are the key to good problem-solving techniques
- Once a problem is described using appropriate representation, the problem is almost solved

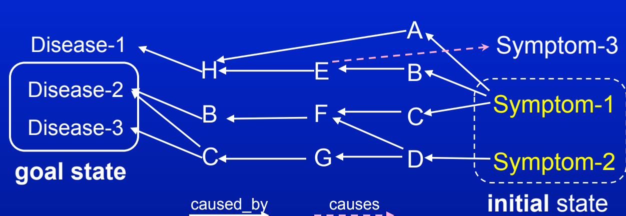
Problem-solving techniques (contd)

General problem-solving techniques:

- Generate and test
- Describe and match
- Means ends Analysis
- Problem Reduction

Generate and test

Used in analysis task e.g. diagnosis

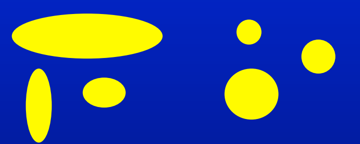


Good generator must be complete, non-redundant, informed
e.g., finding a combination lock of a three two-digit numbers

00-00-00 → 100^3 combinations
if we know that each number is prime → 25^3 combinations

Describe and Match

- Featured-based → classification



Describe:
What are the features to classify circle and ovals?

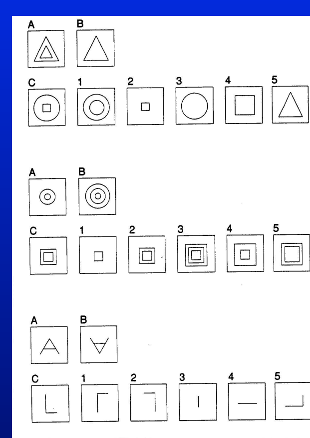
What about an image of a man vs. a woman?

Describe and Match *(contd)*

- Similarity-based → analogy
  [Winston, 97]

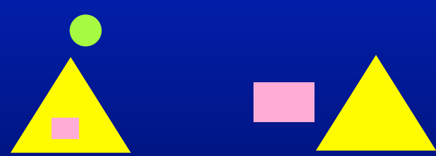
Example: Given A, B and C

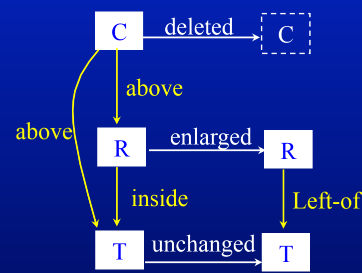
Which of the five choices is related to C similarly to how A relates to B?



Analogy Example

- Describe
  - How objects are arranged e.g., left-of, above
  - How each object is transformed e.g., smaller, disappear, rotated
- Representation

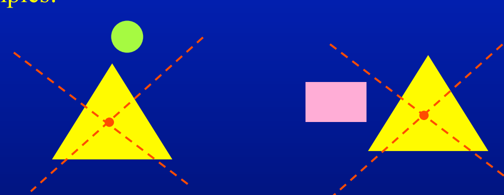




Analogy Example (contd)

- Detecting objects arrangement
  - Left-of, Right-of, Above, Below:
    compute center of area of an object
    then divide area into four quadrants

    Examples:



Above   left-of

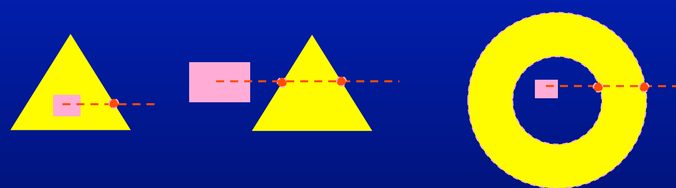
Analogy Example (contd)

- Detecting objects arrangement
  - Inside/Outside:

    Draw a line from center of one object to infinity

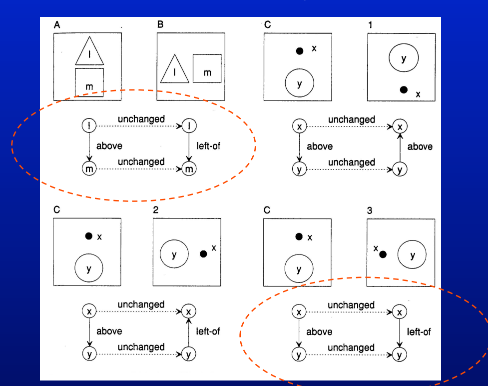
    If the line touches the other object odd number of times → inside

    Examples:



Analogy Example (contd)

- Match
  - Find associations of transformed objects
  - Match relations between associated objects



Analogy Example (contd)

Issues

- Graph matching is intractable

  # possible associations = $n!$ for n transformed objects

- Inexact match

  Rank similarity by measuring degree of overlapping

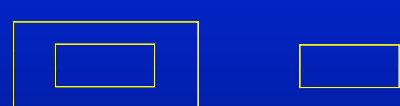
  e.g., transformations (e.g., unchanged, scaled, rotated) may have different weighting scores

- Ambiguity

Analogy Example (contd)

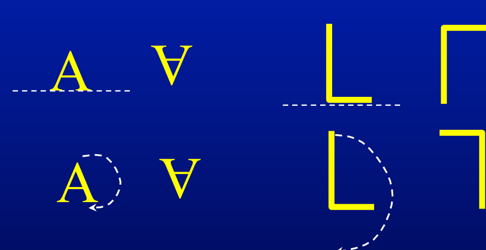
Issues

- Ambiguity



Delete large, or

Delete small and shrink size



Describe and Match *(contd)*

- Abstraction → summarization, story understanding

  Example: [Winston, 97]

  Thomas and Albert

  Thomas and Albert respect each other's technical judgment and decided to form a company together. Thomas learned that Albert was notoriously absentminded whereupon he insisted that Albert have nothing to do with the proposed company's finances. This angered Albert so much that he backed out of their agreement, hoping that Thomas would be disappointed.

  1. What is this story about?
  2. What is the result?
  3. In what way is this story like the story of John and Mary?

  John and Mary

  John and Mary loved each other and decided to be married. Just before the wedding, John discovered that Mary's father was secretly smuggling stolen art through Venice. After struggling with his conscience for days, John reported Mary's father to the police. Mary understood John's decision, but she despised him for it nevertheless; she broke their engagement knowing that he would suffer.

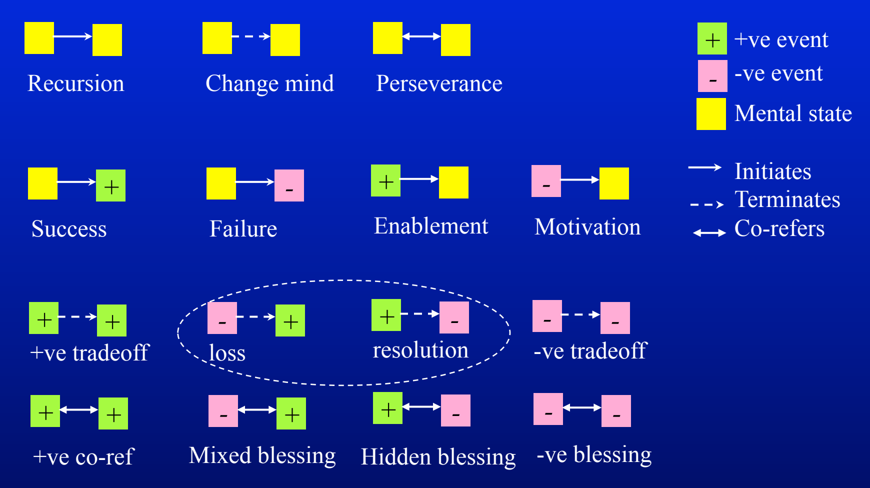
Abstraction

- Story can be abstracted as combinations of
  - mental states
  - events

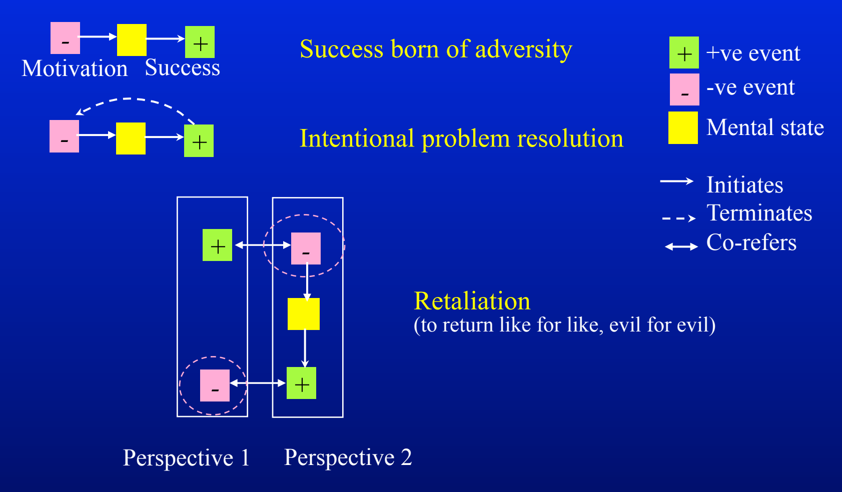
+ +ve event
- -ve event
Mental state

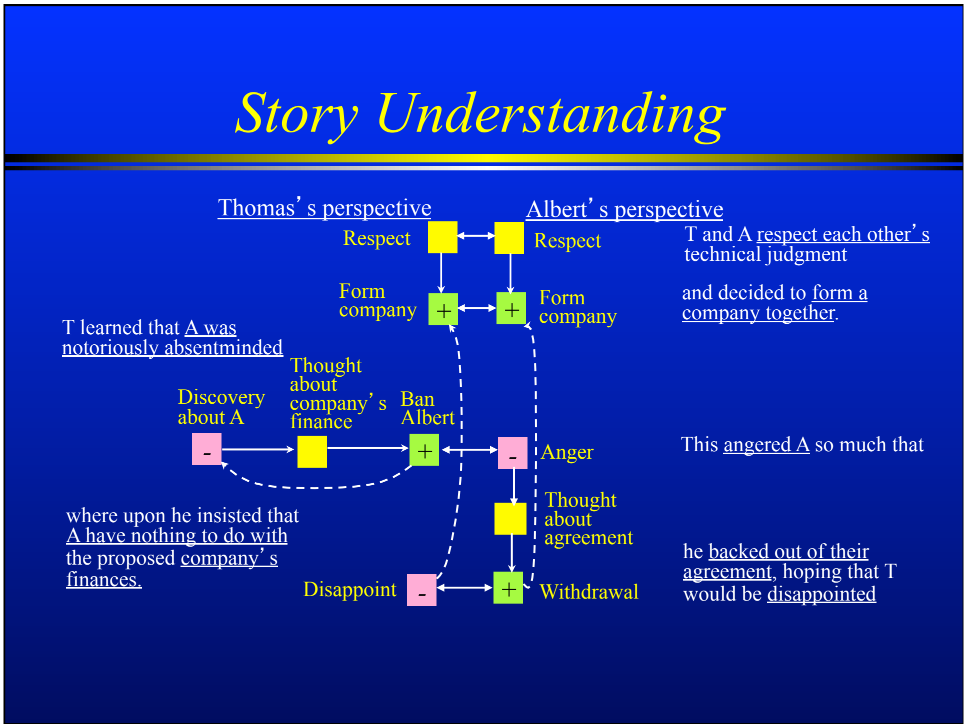
→ Initiates
- - → Terminates
↔ Co-refers

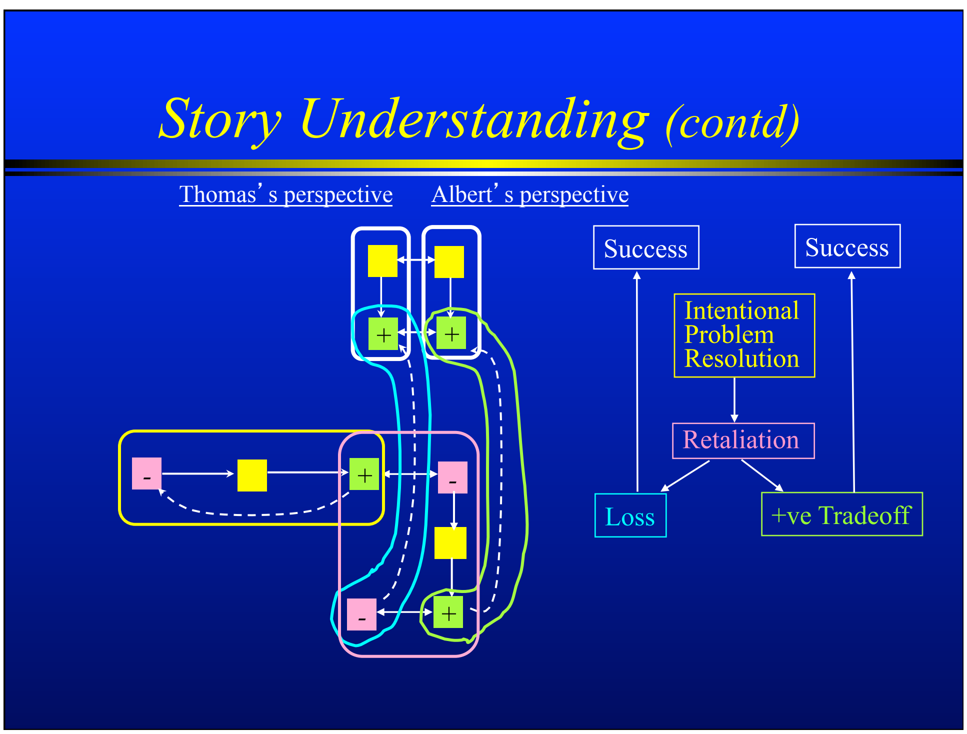
Mental States & Events



Mental States & Events (contd)




Story Understanding
Thomas's perspective
Albert's perspective
Respect
Respect
T and A respect each other's technical judgment
Form company
Form company
and decided to form a company together.
T learned that A was notoriously absentminded
Discovery about A
Thought about company's finance
Ban Albert
Anger
This angered A so much that
Thought about agreement
where upon he insisted that A have nothing to do with the proposed company's finances.
he backed out of their agreement, hoping that T would be disappointed
Disappoint
Withdrawal


Story Understanding (contd)
Thomas's perspective
Albert's perspective
Success
Success
Intentional Problem Resolution
Retaliation
Loss
+ve Tradeoff

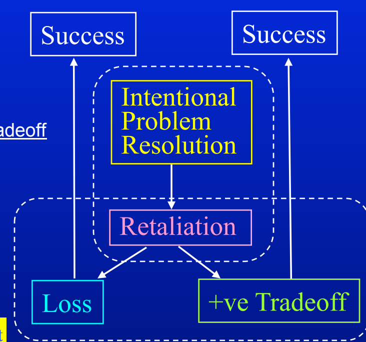
Story Understanding (contd)

Summary:

Albert retaliated against Thomas because Thomas went through an intentional problem resolution that was bad for Robert.

The retaliation caused a loss for Thomas and a positive tradeoff for Albert.

The loss reversed Thomas's previous success, and the positive tradeoff reversed Albert's previous success.

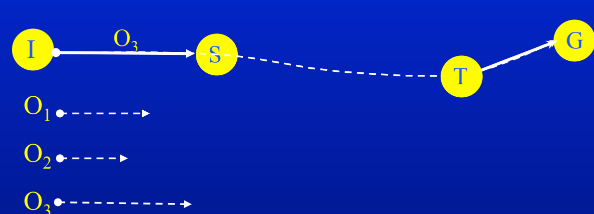


Question Answering:

1. What is this story about? most highly connected unit
   Retaliation
2. What is the result? top level units joined with central unit
   loss (Thomas) and positive tradeoff (Robert)
3. In what way is this story like the story of John and Mary? all common units
   Both involve retaliation, also success, intention problem resolution, loss and positive tradeoff

Means-ends Analysis

- Idea: to reduce "difference" between goal state and current state



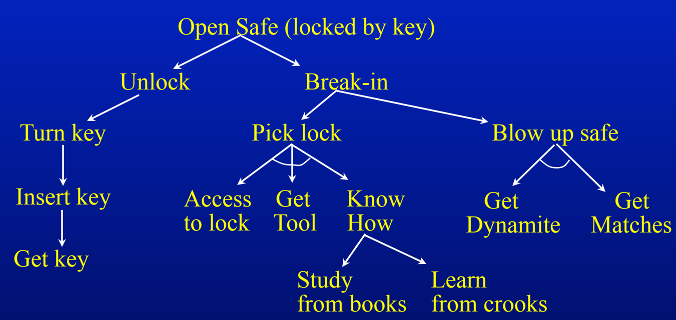
Continue until the path between I and G is connected

- Applied in planning

Problem Reduction

- Goal-directed: And-goals, Or-goals trees

  Examples: planning, expert system, theorem proving



Problem Reduction (contd)

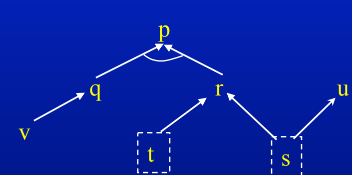
- Goal-directed: And-goals, Or-goals trees

  Examples: planning, expert system, theorem proving

Given: s, t true and the following implication rules

1. $q \rightarrow p$
2. $r \rightarrow p$
3. $v \rightarrow q$
4. $s \rightarrow r$
5. $t \rightarrow r$
6. $s \rightarrow u$

Prove or disprove p



Change the graph to AND graph, can you prove p *?*

Is $q \rightarrow p$ *and* $r \rightarrow p$ *the same as* $q \wedge r \rightarrow p$ *?*

Recap: Problem-solving techniques

General problem-solving techniques

- Generate and test
- Describe and match
  - abstraction
  - feature-based
  - similarity-based
- Means ends Analysis
- Problem Reduction

Representations
how to describe problem space
what to abstract

Search
choose best alternatives

Pattern matching
when to terminate search

Search Control

Control Problem: When searching for a solution path from an initial state, there may be many alternatives to move from one state to another.

How does the system select the appropriate state to move to?

– Try all - *exhaustive search*

– Try most likely one - *AI search using heuristics*