Lecture 2 of 42

Problem Solving by Search
Discussion: Term Projects 2 of 5

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KSOL course page: http://snipurl.com/v9v3
Course web site: http://www.kddresearch.org/Courses/CIS730
Instructor home page: http://www.cis.ksu.edu/~bhsu

Reading for Next Class:

Machine Problem 1 (posted Wednesday)
Sections 2.3 – 2.5, p. 39 – 56, Russell & Norvig 2nd edition
Section 3.1, p. 59 – 62, Russell & Norvig 2nd edition

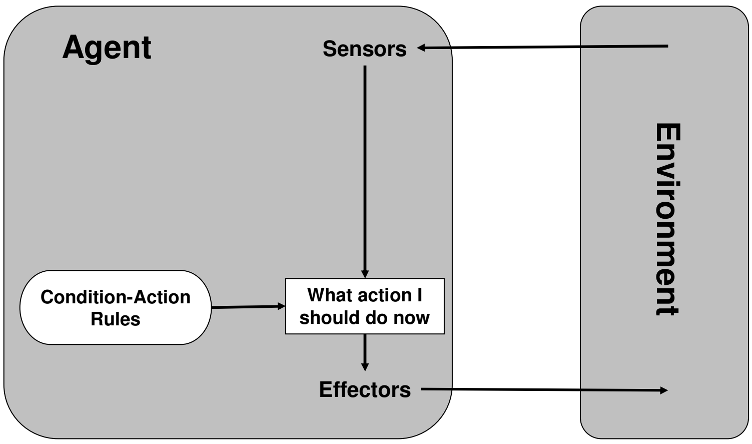
Search Topics (Review)

- Next Monday - Wednesday: Sections 3.1-3.4, Russell and Norvig
- Thinking Exercises (Discussion in Next Class): 3.3 (a, b, e), 3.9
- Solving Problems by Searching
  - Problem solving agents: design, specification, implementation
  - Specification: problem, solution, constraints
  - Measuring performance
- Formulating Problems as (State Space) Search
- Example Search Problems
  - Toy problems: 8-puzzle, N-queens, cryptarithmetic, toy robot worlds
  - Real-world problems: layout, scheduling
- Data Structures Used in Search
- Next Monday: Uninformed Search Strategies
  - State space search handout (Winston)
  - Search handouts (Ginsberg, Rich and Knight)

Term Project Topics (Review)

- 1. Game-playing Expert System
  - "Borg" for Angband computer role-playing game (CRPG)
  - http://www.thangorodrim.net/borg.html
- 2. Trading Agent Competition (TAC)
  - Supply Chain Management (TAC-SCM) scenario
  - http://www.sics.se/tac/
- 3. Machine Learning for Bioinformatics
  - Evidence ontology for genomics or proteomics
  - http://bioinformatics.ai.sri.com/evidence-ontology/

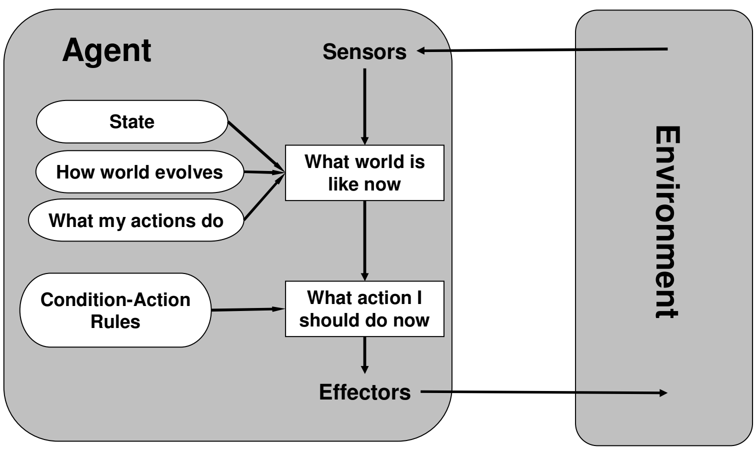
Agent Framework: Simple Reflex Agents [1]



Agent Framework: Simple Reflex Agents [2]

- **Implementation and Properties**
  - Instantiation of generic skeleton agent: Figs. 2.9 & 2.10, p. 47 R&N 2e
  - function *SimpleReflexAgent* (*percept*) returns action
    - static: *rules*, set of condition-action rules
    - *state* ← *Interpret-Input* (*percept*)
    - *rule* ← *Rule-Match* (*state, rules*)
    - *action* ← *Rule-Action* {*rule*}
    - return *action*
- **Advantages**
  - Selection of best action based only on rules, current state of world
  - Simple, very efficient
  - *Sometimes* robust
- **Limitations and Disadvantages**
  - No memory (doesn't keep track of world)
  - Limits range of applicability

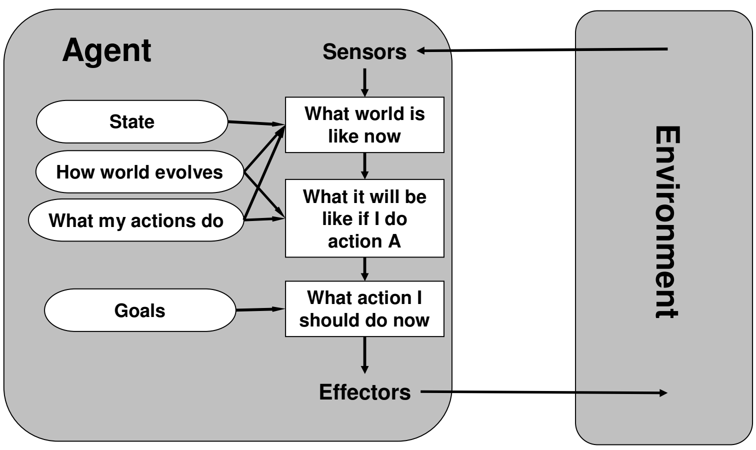
Agent Frameworks: (Reflex) Agents with State [1]



Agent Frameworks: (Reflex) Agents with State [2]

- **Implementation and Properties**
  - Instantiation of skeleton agent: Figures 2.11 & 2.12, p. 49 R&N 2[e]
  - function *ReflexAgentWithState* (*percept*) returns action
    - static: *state* description; *rules*, set of condition-action rules
    - *state* ← *Update-State* (*state, percept*)
    - *rule* ← *Rule-Match* (*state, rules*)
    - *action* ← *Rule-Action* {*rule*}
    - return *action*
- **Advantages**
  - Selection of best action based only on rules, current state of world
  - Able to reason over past states of world
  - Still efficient, *somewhat* more robust
- **Limitations and Disadvantages**
  - No way to express goals and preferences relative to goals
  - Still limited range of applicability

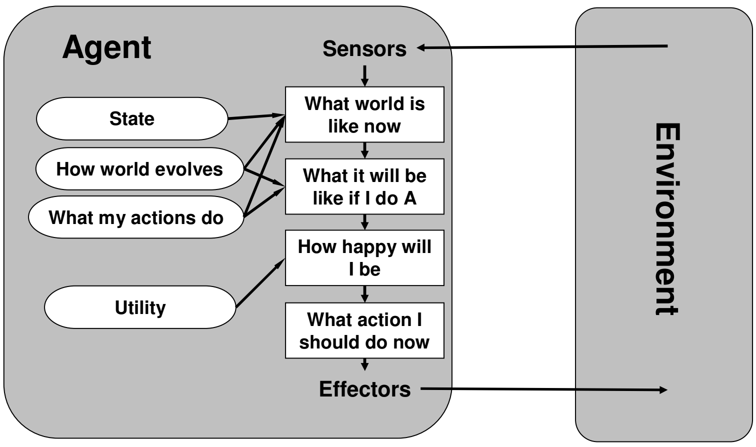
Agent Frameworks: Goal-Based Agents [1]



Agent Frameworks: Goal-Based Agents [2]

- **Implementation and Properties**
  - Instantiation of skeleton agent: Figure 2.13, p. 50 R&N 2e
  - Functional description
    - ⇨ Chapter 11-12 R&N 2e: classical planning
    - ⇨ Requires more formal specification
- **Advantages**
  - Able to reason over goal, intermediate, and initial states
  - Basis: automated reasoning
    - ⇨ One implementation: theorem proving (first-order logic)
    - ⇨ Powerful representation language and inference mechanism
- **Limitations and Disadvantages**
  - May be expensive: can't feasibly solve many general problems
  - No way to express preferences

Agent Frameworks: Utility-Based Agents [1]



AGENT FRAMEWORKS: UTILITY-BASED AGENTS [2]

- **Implementation and Properties**
  - Instantiation of skeleton agent: Figure 2.14, p. 53 R&N 2[e]
  - Functional description
    - ⇨ Chapter 16-17 R&N 2e: making decisions
    - ⇨ Requires representation of decision space
- **Advantages**
  - Able to acccount for uncertainty and agent preferences
  - Models value of goals: costs vs. benefits
  - Essential in economics, business; useful in many domains
- **Limitations and Disadvantages**
  - How to get utilities?
  - How to reason under uncertainty? (Examples?)

PROBLEM-SOLVING AGENTS [1]: GOALS

- **Justification**
  - Rational IA: act to *reach* environment that maximizes performance measure
  - Need to formalize, operationalize this definition
- **Practical Issues**
  - Hard to find appropriate *sequence of states*
  - Difficult to translate into IA design
- **Goals**
  - Translating agent specification to formal design
  - Chapter 2, R&N: decision loop simplifies task
  - First step in problem solving: formulation of goal(s)
  - Chapters 3-4, R&N: state space search
    - ⇨ Goal ≡ {world states | goal test is satisfied}
    - ⇨ Graph planning
  - Chapter 5: constraints – domain, rules, moves
  - Chapter 6: games – evaluation function

Problem-Solving Agents [2]: Definitions

- **Problem Formulation**
  - Given
    - Initial state
    - Desired goal
    - Specification of actions
  - Find
    - *Achievable* sequence of states (actions)
    - Represents mapping from initial to goal state
- **Search**
  - Actions
    - Cause transitions between world states
    - e.g., applying effectors
  - Typically specified in terms of finding sequence of states (operators)

Problem-Solving Agents [3]: Requirements and Specification

- **Input**
  - Informal objectives
  - Initial, intermediate, goal states
  - Actions
  - Leads to design requirements for state space search problem
- **Output**
  - Path from initial to goal state
  - Leads to design requirements for state space search problem
- **Logical Requirements**
  - States: representation of state of world (example: starting city, graph representation of Romanian map)
  - Operators: descriptors of possible actions (example: moving to adjacent city)
  - Goal test: state $\rightarrow$ boolean (example: at destination city?)
  - Path cost: *based on search, action costs* (example: number of edges traversed)

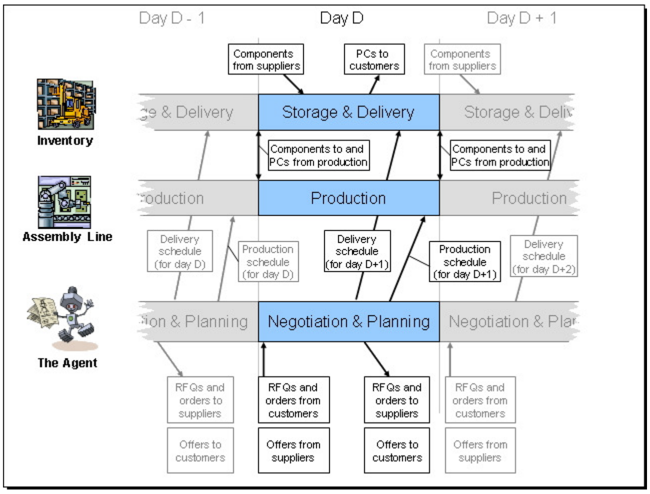
Problem-Solving Agents [4]: Objectives

- **Operational Requirements**
  - Search algorithm to find path
  - Objective criterion: minimum cost (this and next 3 lectures)
- **Environment**
  - Agent can search in environment according to specifications
  - May have full state and action descriptors
  - *Sometimes not*!

Problem-Solving Agents [5]: Implementation

- function *Simple-Problem-Solving-Agent* (*p*: percept) returns *a*: action
  - inputs: *p*, percept
  - static: *s*, action sequence (initially empty)
    state, description of current world state
    g, goal (initially null)
    problem, problem formulation
  - *state* ← *Update-State* (*state, p*)
  - if *s.Is-Empty*() then
    - ⇨ *g* ← *Formulate-Goal* (*state*) // focus of today's class
    - ⇨ *problem* ← *Formulate-Problem* (*state, g*) // today
    - ⇨ *s* ← *Search* (*problem*) // next week
  - *action* ← *Recommendation* (*s, state*)
  - *s* ← *Remainder* (*s, state*) // discussion: meaning?
  - return (*action*)
- Ch. 3-4: Implementation of *Simple-Problem-Solving-Agent*

Example: TAC-SCM Agent [1]
Project Topic 2 of 5



Trading Agent Competition Supply Chain Management Scenario
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Example: TAC-SCM Agent [2]
Problem Specification

- **Trading Agent Competition**
  - **Swedish Institute of Computer Science (SICS) Page**
    http://www.sics.se/tac/
  - **Supply chain management (SCM) scenario**
    http://www.sics.se/tac/page.php?id=13
- **Problem Specification**
  - **Study existing TAC-SCM agents**
  - **Develop a scheduling and utility-based reasoning system**
  - **Use SICS interface to develop a new TAC agent**
  - **Play it against other agents using competition server**

Formulating Problems [1]: Single-State

- **Single-State Problems**
  - Goal state is reachable in one action (one move)
  - World is fully accessible
  - Example: vacuum world (Figure 3.2, R&N) – simple robot world
- **Significance**
  - Initial step analysis
  - "Base case" for problem solving by regression
    - General Problem Solver
    - Means-ends analysis

Formulating Problems [2]: Multi-State

- **Multi-State Problems**
  - Goal state may not be reachable in one action
  - Assume limited access
    - effects of actions known
    - may or may not have sensors
- **Significance**
  - Need to reason over states that agent can get to
  - May be able to guarantee reachability of goal state anyway
- **Determining State Space Formulation**
  - State space – single-state problem
  - State set space – multi-state problems

General Search [1]: Overview

- **Generating Action Sequences**
  - Initialization: <u>start (initial) state</u>
  - Test for goal condition
    - ⇨ Membership in goal state set (explicitly enumerated)
    - ⇨ Constraints met (implicit)
  - Applying operators (when goal state not achieved)
    - ⇨ Implementation: <u>generate</u> new set of successor (child) states
    - ⇨ Conceptual process: <u>expand</u> state
    - ⇨ Result: *multiple branches* (e.g., Figure 3.8 R&N)
- **Intuitive Idea**
  - Select one option
  - <u>Ordering</u> (prioritizing / scheduling) others for later consideration
  - Iteration: choose, test, expand
  - Termination: solution is found *or* no states remain to be expanded
- **<u>Search Strategy</u>: Selection of State to Be Expanded**

General Search [2]: Algorithm

- **<u>function</u> *General-Search* (*problem, strategy*)**
  <u>returns</u> a solution <u>or</u> failure
  - initialize search tree using initial state of *problem*
  - <u>loop do</u>
    - ⇨ <u>if</u> there are no candidates for expansion <u>then</u> <u>return</u> failure
    - ⇨ choose leaf node for expansion according to *strategy*
    - ⇨ <u>If</u> node contains a goal state <u>then</u> <u>return</u> corresponding solution
    - ⇨ <u>else</u> expand node and add resulting nodes to search tree
  - <u>end</u>
- **Note: Downward <u>Fun</u>ction <u>Arg</u>ument (Funarg) *strategy***
- **Implementation of *General-Search***
  - Rest of Chapter 3, Chapter 4, R&N
  - See also:
    - ⇨ Ginsberg (handout in CIS library today)
    - ⇨ Rich and Knight
    - ⇨ Nilsson: *Principles of Artificial Intelligence*

Search Strategies: Criteria

- **Completeness**
  - *Is strategy guaranteed to find solution when one exists?*
  - Typical requirements/assumptions for guaranteed solution
    - Finite depth solution
    - Finite branch factor
    - Minimum unit cost (if paths can be infinite) – discussion: why?
- **Time Complexity**
  - *How long does it take to find solution in worst case?*
  - Asymptotic analysis
- **Space Complexity**
  - *How much memory does it take to perform search in worst case?*
  - Analysis based on data structure used to maintain frontier
- **Optimality**
  - *Finds highest-quality solution when more than one exists?*
  - Quality: defined in terms of node depth, path cost

Uninformed (Blind) Search Strategies

- **Breadth-First Search (BFS)**
  - Basic algorithm: breadth-first traversal of search tree
  - Intuitive idea: expand whole frontier first
  - Advantages: finds optimal (minimum-depth) solution for finite search spaces
  - Disadvantages: intractable (exponential complexity, high constants)
- **Depth-First Search (DFS)**
  - Basic algorithm: depth-first traversal of search tree
  - Intuitive idea: expand *one* path first and backtrack
  - Advantages: narrow frontier
  - Disadvantages: lot of backtracking in worst case; suboptimal and incomplete
- **Search Issues**
  - Criteria: completeness (convergence); optimality; time, space complexity
  - "Blind"
    - No information about number of steps or path cost from state *to goal*
    - *i.e.*, no path cost estimator function (heuristic)
- **Uniform-Cost, Depth-Limited, Iterative Deepening, Bidirectional**

Breadth-First Search: Algorithm

- **function** *Breadth-First-Search* (*problem*) **returns** a solution **or** failure
  - **return** *General-Search* (*problem*, *Enqueue-At-End*)
- **function** *Enqueue-At-End* (*e*: Element-Set) **returns** void
  - // Queue: priority queue data structure
  - **while** not (*e.Is-Empty*())
    - **if** not *queue.Is-Empty*() **then** *queue.last.next* ← *e.head*();
    - *queue.last* ← *e.head*();
    - *e.Pop-Element*();
  - **return**
- Implementation Details
  - Recall: *Enqueue-At-End* downward funarg for *Insert* argument of *General-Search*
  - Methods of *Queue* (priority queue)
    - *Make-Queue* (*Element-Set*) – constructor
    - *Is-Empty()* – boolean-valued method
    - *Remove-Front()* – element-valued method
    - *Insert(Element-Set)* – procedure, *aka Queuing-Fn*

Depth-First Search: Algorithm

- **function** *Depth-First-Search* (*problem*) **returns** a solution **or** failure
  - **return** *General-Search* (*problem*, *Enqueue-At-Front*)
- **function** *Enqueue-At-Front* (*e*: Element-Set) **returns** void
  - // Queue: priority queue data structure
  - **while** not (*e.Is-Empty*())
    - *temp* ← *queue.first*;
    - *queue.first* ← *e.head*();
    - *queue.first.next* ← *temp*;
    - *e.Pop-Element*();
  - **return**
- Implementation Details
  - *Enqueue-At-Front* downward funarg for *Insert* argument of *General-Search*
  - Otherwise similar in implementation to BFS
  - Exercise (easy)
    - Recursive implementation
    - See Cormen, Leiserson, Rivest, & Stein (2002)

Terminology

- **Agent Types**
  - Reflex *aka* "reactive"
  - Reflex with state (memory-based)
  - Goal-based *aka* "deliberative"
  - Preference-based *aka* "utility-based"
- **Decision Cycle**
- **Problem Solving Frameworks**
  - Regression, Means-ends analysis (MEA)
  - State space search, PEAS
  - Representations (later)
    - Plans
    - Constraint satisfaction problems
    - Policies and decision processes
    - Situation calculus

Summary Points

- **The Basic Decision Cycle for Intelligent Agents**
- **Agent Types**
  - Reflex *aka* "reactive"
  - Reflex with state (memory-based)
  - Goal-based *aka* "deliberative"
  - Preference-based *aka* "utility-based"
- **Problem Solving Frameworks**
  - Regression-based problem solving
  - Means-ends analysis (MEA)
  - PEAS framework
    - Performance
    - Environment
    - Actuators
    - Sensors
  - State space formulation