Foundations of Artificial Intelligence

Revision

Final Exam

- Venue: SR 1 (S16)
- Date: **Tuesday**, **26 April 2004**
- Time: 1:00 – 3:00 pm

Format

- One A4 sized sheet allowed to the test
- Eight questions, emphasizing material covered after the midterm
  - Yes, all material in the course will be covered on the exam

Outline

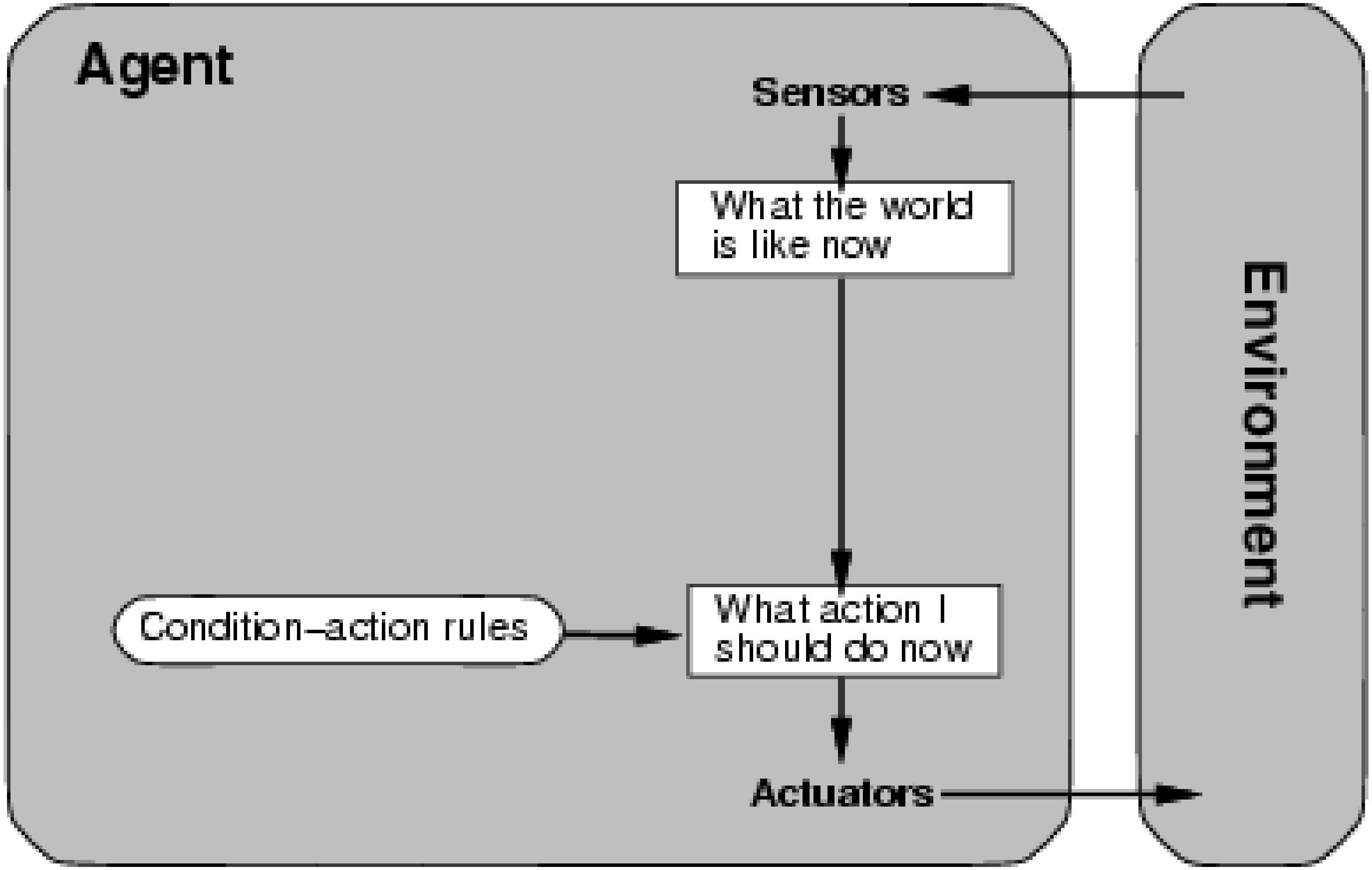
- Agents
- Search
  - Uninformed Search
  - Informed Search
- Adversarial Search
- Constraint Satisfaction
- Knowledge-Based Agents
- Uncertainty and Learning

Agent types

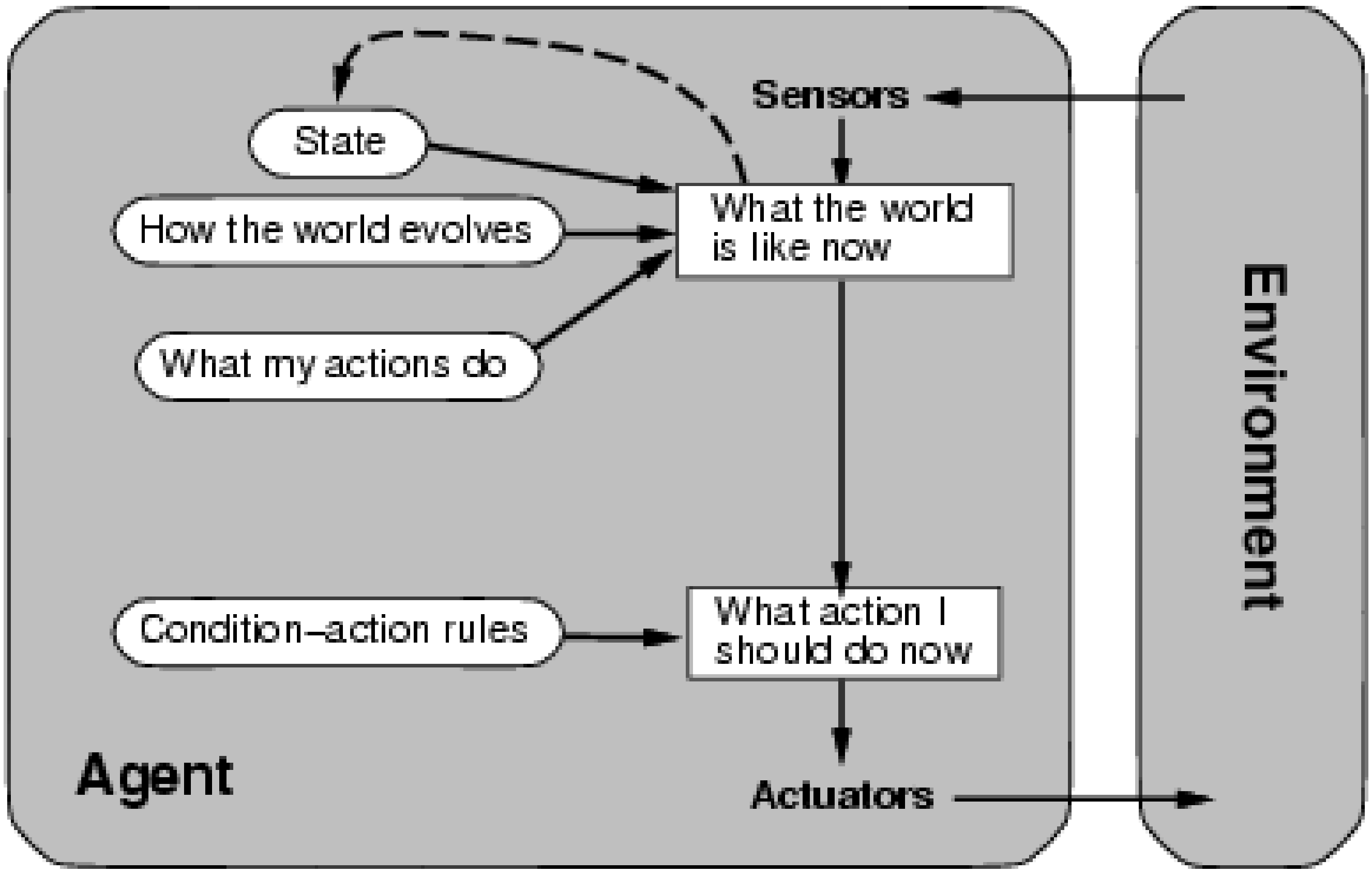
Four basic types in order of increasing generality:

- Simple reflex agents
- Model-based reflex agents
- Goal-based agents
- Utility-based agents

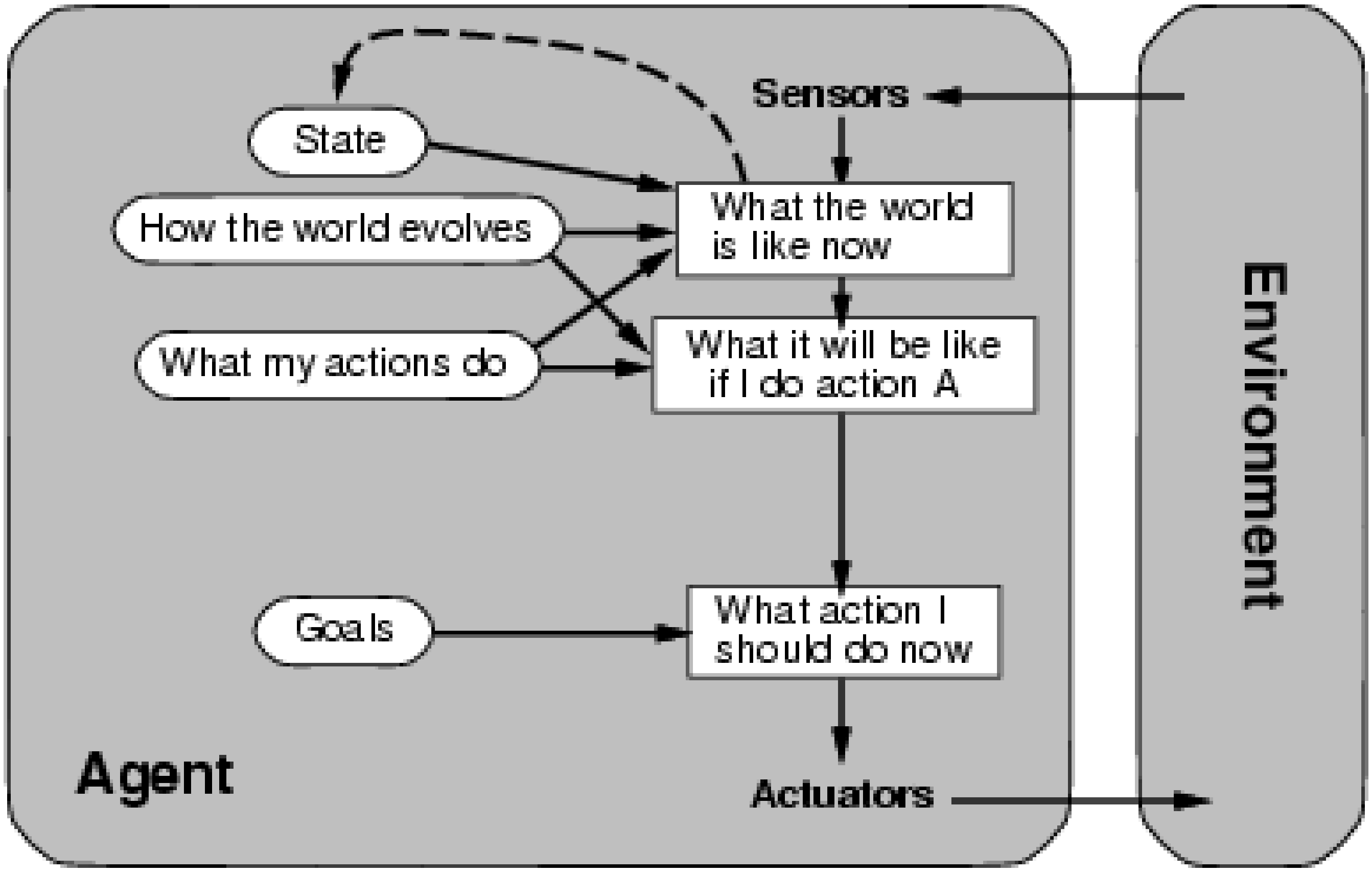
Simple reflex agents



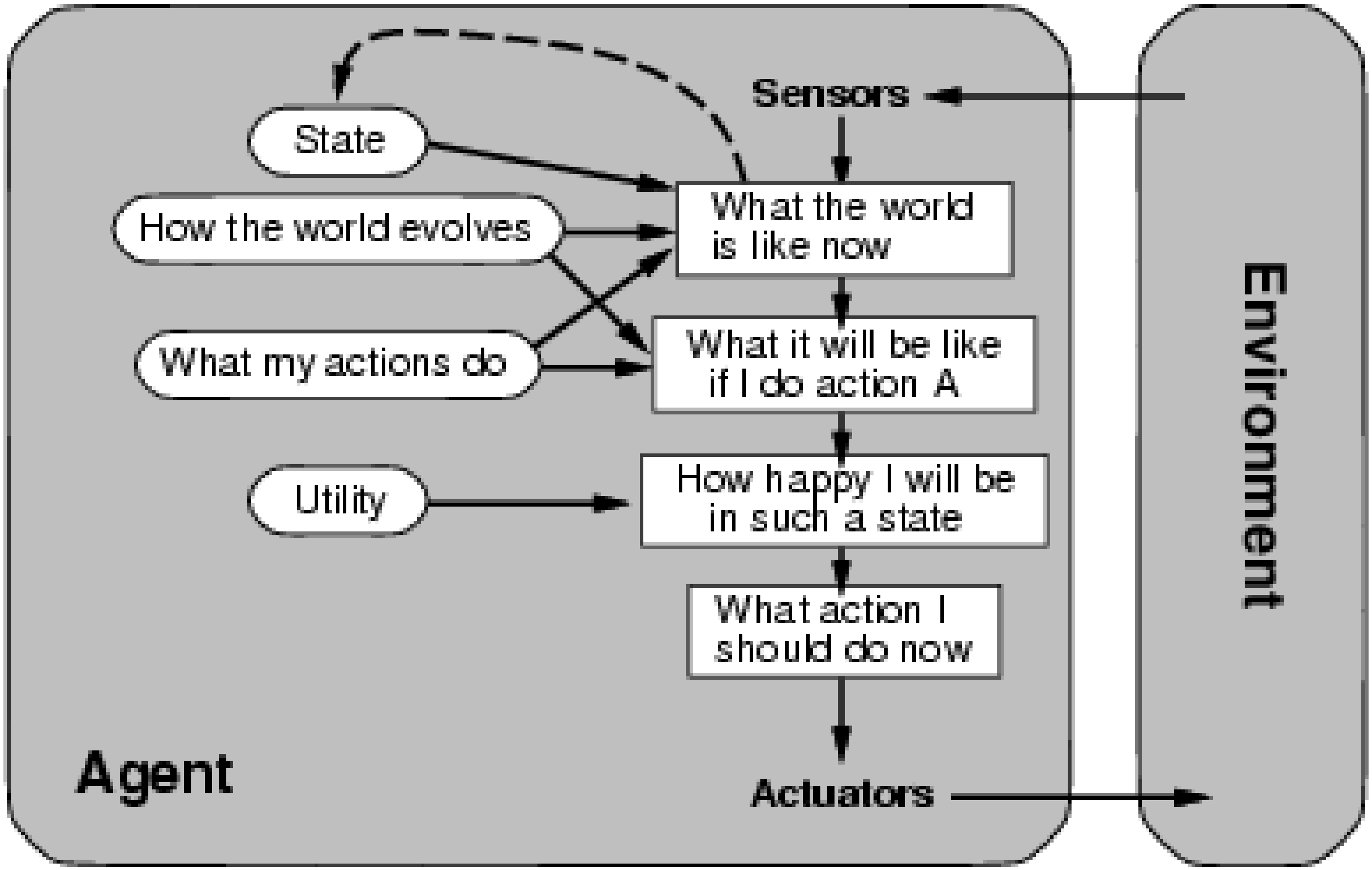
Model-based reflex agents



Goal-based agents



Utility-based agents

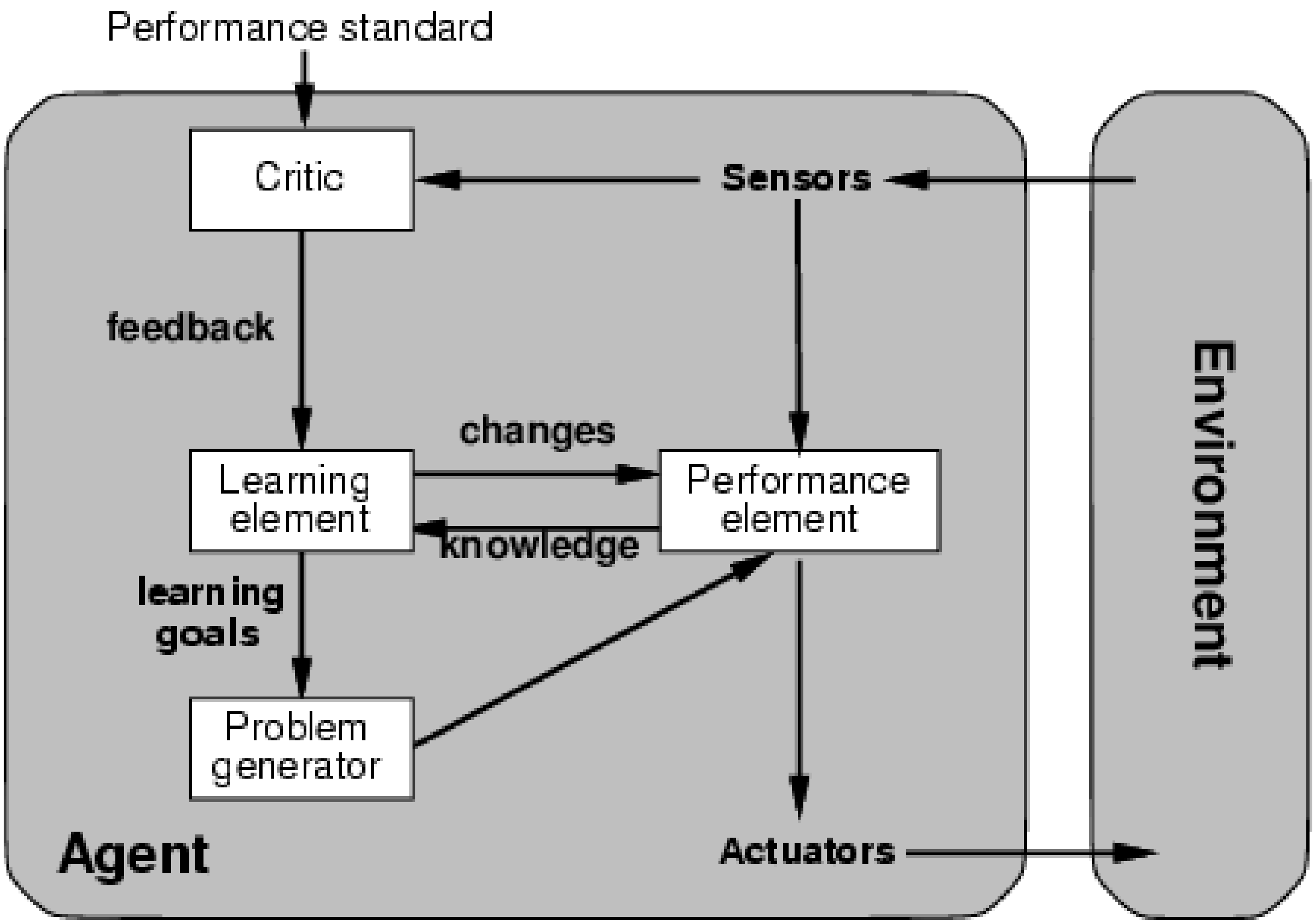


Creating agents

Where does the intelligence come from?

- Coded by the designers
  - Knowledge representation – predicate and first order logic
- Learned by the machine
  - Machine learning – expose naïve agent to examples to learn useful actions

Learning agents



Searching for solutions

In most agent architectures, deciding what action to take involves considering alternatives

- Searching is judged on optimality, completeness and complexity
- Do I have a way of gauging how close I am to a goal?
  - No: Uninformed Search
  - Yes: Informed Search

Uninformed search

- Formulate the problem, search and then execute actions
- Apply Tree-Search
- For environments that are
  - Deterministic
  - Fully observable
  - Static

Tree search algorithm

- Basic idea:
  - offline, simulated exploration of state space by generating successors of already-explored states

```
function TREE-SEARCH(problem, strategy) returns a solution, or failure
   initialize the search tree using the initial state of problem
   loop do
      if there are no candidates for expansion then return failure
      choose a leaf node for expansion according to strategy
      if the node contains a goal state then return the corresponding solution
      else expand the node and add the resulting nodes to the search tree
```

Summary of algorithms

- Breadth-First – FIFO order
- Uniform-Cost – in order of cost
- Depth-First – LIFO order
- Depth-Limited – DFS to a maximum depth
- Iterative Deepening – Iterative DLS.

- Bidirectional – also search from goal towards origin

Criterion	Breadth-First	Uniform Cost	Depth First	Depth Limited	Iterative Deepening	Bidirectional
Complete?	Yes	Yes	No	No	Yes	Yes
Time	$O(b^{d+1})$	$O(b^{\lceil C^*/e \rceil})$	$O(b^m)$	$O(b^l)$	$O(b^d)$	$O(b^{d/2})$
Space	$O(b^{d+1})$	$O(b^{\lceil C^*/e \rceil})$	$O(bm)$	$O(bl)$	$O(bd)$	$O(b^{d/2})$
Optimal?	Yes	Yes	No	No	Yes	Yes

Repeated states: Graph-Search

```
function GRAPH-SEARCH( problem, fringe) returns a solution, or failure
    closed ← an empty set
    fringe ← INSERT(MAKE-NODE(INITIAL-STATE[problem]), fringe)
    loop do
        if fringe is empty then return failure
        node ← REMOVE-FRONT(fringe)
        if GOAL-TEST[problem](STATE[node]) then return SOLUTION(node)
        if STATE[node] is not in closed then
            add STATE[node] to closed
            fringe ← INSERTALL(EXPAND(node, problem), fringe)
```

Informed search

- Heuristic function *h(n)* = estimated cost of the cheapest path from n to goal.

- Greedy Best First Search
  - Minimizing estimated cost to goal
- A* Search
  - Minimizing total cost

Properties of heuristic functions

- Admissible: never overestimates cost
- Consistent: estimated cost from node $n+1$ is $\geq$ than cost from node n + step cost.

- A* using Tree-Search is optimal if the heuristic used is admissible.
  - Graph-Search needs an consistent heuristic. Why?

Local search

- Good for solutions where the path to the solution doesn't matter
  - Often work on a complete state
  - Don't search systematically
  - Often require very little memory

- Correlated to online search
  - Have only access to the local state

Local search algorithms

- Hill climbing search – choose best successor
- Beam search – take the best *k* successor
- Simulated annealing – allow backward moves during beginning steps
- Genetic algorithm – breed *k* successors using crossover and mutation

Searching in specialized scenarios

- Properties of the problem often allow us to formulate
  - Better heuristics
  - Better search strategy and pruning
- Adversarial search
  - Working against an opponent
- Constraint satisfaction problem
  - Assigning values to variables
  - Path to solution doesn't matter
  - View this as an incremental search

Adversarial Search

- Turn-taking, two-player, zero-sum games
- Minimax algorithm:
  - One ply: agent's move then opponent's
  - Max nodes: agent's move, maximize utility
  - Min nodes: opponent's move, minimize utility
  - Alpha-Beta pruning: rid unnecessary computation.

Constraint Satisfaction

- Discrete or continuous solutions
  - Discretize and limit possible values

- Modeled as a constraint graph

- As the path to the solution doesn’t matter, *local search* can be very useful.

Techniques in CSPs

- Basic: backtracking search
  - DFS for CSP
  - A leaf node (at depth *v*) is a solution

- Speed ups
  - Choosing variables
    - Minimum remaining values
    - Most constrained variable / degree
  - Choosing values
    - Least constraining value

Pruning CSP search space

Before expanding node, can prune the search space

- Forward checking
  - Pruning values from remaining variables
- Arc consistency
  - Propagating stronger levels of consistency
  - E.g., AC-3 (applicable before searching and during search)

- Balancing arc consistency with actual searching.

Propositional and First Order Logic

- Propositional Logic
  - Facts are true or false
- First Order Logic
  - Relationships and properties of objects
  - More expressive and succinct
    - Quantifiers, functions
    - Equality operator
  - Can convert back to prop logic to do

Inference in logic

- Given a KB, what can be inferred?
  - Query- or goal-driven
    - Backward chaining, model checking (e.g. DPLL), resolution
  - Deducing new facts
    - Forward chaining
      - Efficiency: track # of literals of premise using a count or Rete networks

Inference in logic

- Chaining
  - Requires Definite Clauses or Horn Clauses
  - Uses Modus Ponens for sound reasoning
  - Forward or Backward types
- Resolution
  - Requires Conjunctive Normal Form
  - Uses Resolution for sound reasoning
  - Proof by Contradiction

Inference in FOL

- Don't have to propositionalize
  - Could lead to infinite sentences functions
- Use unification instead
  - Standardizing apart
  - Dropping quantifiers
    - Skolem constants and functions
- Inference is semidecidable
  - Can say yes to entailed sentences, but non-entailed sentences will never terminate

Connection to knowledge-based agents

- CSP can be formulated as logic problems and vice versa
- CSP search as model checking

Model checking (DPLL)	CSP Search
Pure Symbol	Least constraining value
Unit Clause	Most constrained value
Early Termination	
	Minimum remaining values

- Local search: WalkSAT with min-conflict heuristic

Inference and CSPs

- Solving a CSP via inference
  - Handles special constraints (e.g., AllDiff)
  - Can learn new constraints not expressed by KB designer
- Solving inference via CSP
  - Whether a query is true under all possible constraints (satisfiable)
- Melding the two: Constraint Logic Programming (CLP)

Uncertainty

- Leads us to use probabilistic agents
  - Only one of many possible methods!
- Modeled in terms of random variables
  - Again, we examined only the discrete case
- Answer questions based on full joint distribution

Inference by enumeration

Interested in the posterior joint distribution of *query variables* given specific values for *evidence variables*

- Summing over *hidden variables*
- Cons: Exponential complexity

- Look for absolute and conditional independence to reduce complexity

Prolog

- Engine for FOL

- Syntax
  - Variables
  - Relations
- Execution pattern in prolog
  - Which clauses?
  - Which goals?

Natural Language Processing

- Processing vs. Generation
- Deals mostly with one sentence at a time
- Main problem: ambiguity! (at many levels)

- Parsing: assigning structure to a sentence via re-write rules
  - Lexicon: nonterminal to terminal rules
  - Grammar: nonterminals to nonterminals

- Grammars can over/undergenerate

Parsing

- Bottom-up or top-down
  - Which is more efficient for what cases?
- Augmented Grammars
  - FOL version of parsing – parsing with parameters
  - Use unification to get agreement.

Bayesian networks

- One way to model dependencies
- Variable's probability only depends on its parents
- Use product rule and conditional dependence to calculate joint probabilities
- Easiest to structure causally
  - From root causes forward
  - Leads to easier modeling and lower complexity

Learning

- Inductive learning - based on past examples
- Learn a function *h()* that approximates real function *f(x)* on examples *x*

- Balance complexity of hypothesis with fidelity to the examples
  - Minimize α E(h,D) + (1-α) C(h)

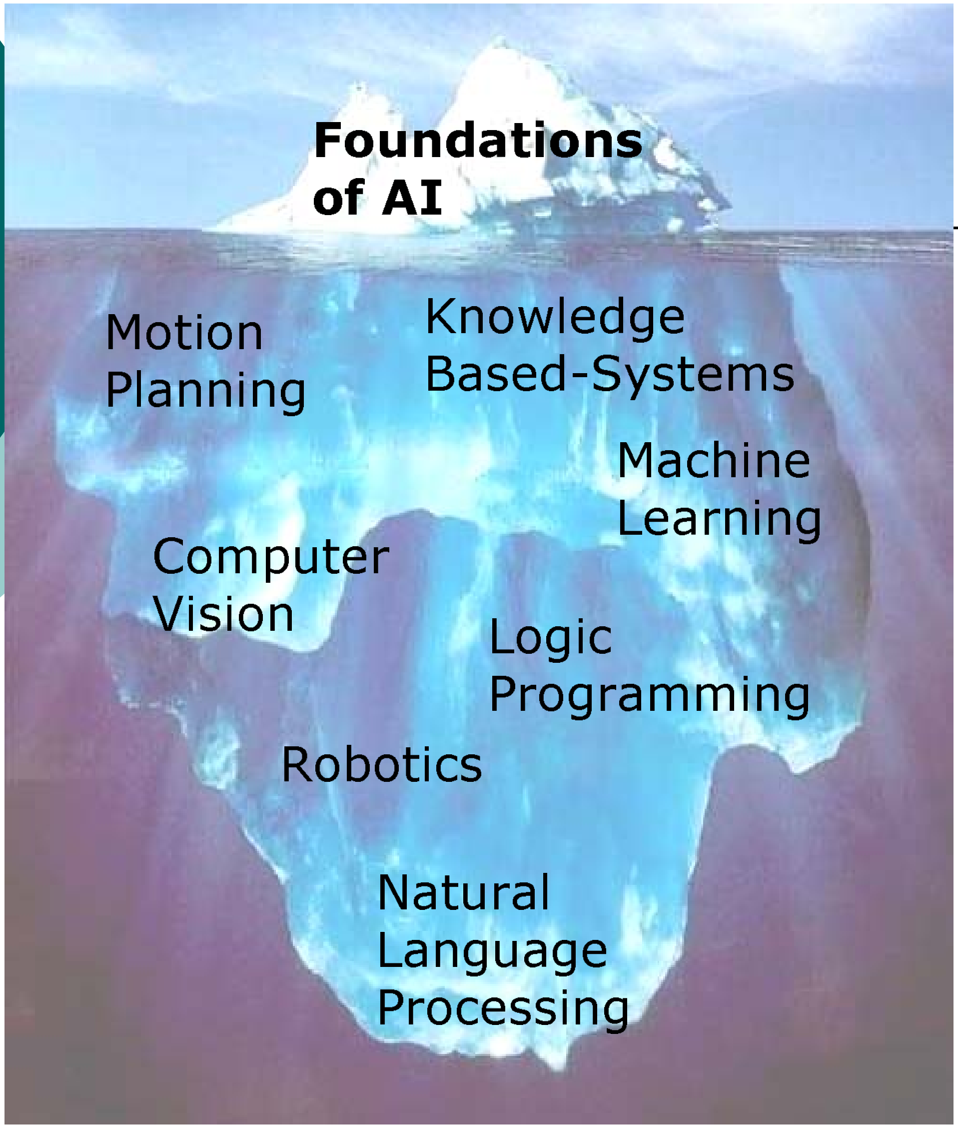
Learning Algorithms

Many out there but the basics are:

- K nearest neighbors
  - Instance-based
  - Ignores global information
- Naïve Bayes
  - Strong independence assumption
  - Scales well due to assumptions
  - Needs normalization when dealing with unseen feature values
- Decision Trees
  - Easy to understand its hypothesis
  - Decides feature based on information gain

Training and testing

- Judge induced h()'s quality by using a *test set*
- Training and test set must be separate; otherwise *peeking* occurs
- Modeling noise or specifics of the training data can lead to *overfitting*
  - Use pruning to remove parts of the hypothesis that aren't justifiable



Where to go from here?

- Just the tip of the iceberg
- Many advanced topics
  - Introduced only a few
  - Textbook can help in exploration of AI

That's it

- Thanks for your attention over the semester
- See you at the exam!