Principles of Autonomy and Decision Making

Brian C. Williams
16.410/16.413
December 10th, 2003
Outline

• Objectives

• Agents and Their Building Blocks

• Principles for Building Agents:
  – Modeling Formalisms
  – Algorithmic Principles

• Building an Agent:
  The Mars Exploration Rover
Course Objective 1: Principles of Agents

16.410/13: To learn the modeling and algorithmic building blocks for creating reasoning and learning agents:

• To formulate reasoning problems.
• To describe, analyze and demonstrate reasoning algorithms.
• To model and encode knowledge used by reasoning algorithms.
Course Objective 2: Building Agents

16.413: To appreciate the challenges of building a state of the art autonomous explorer:

• To model and encode knowledge needed to solve a state of the art challenge.
• To work through the process of autonomy systems integration.
• To assess the promise, frustrations and challenges of using (b)leading art technologies.
Outline

- Objectives
- Agents and Their Building Blocks
- Principles for Building Agents:
  - Modeling Formalisms
  - Algorithmic Principles
- Building an Agent:
  The Mars Exploration Rover
``Our vision in NASA is to open the Space Frontier . . . We must establish a virtual presence, in space, on planets, in aircraft and spacecraft.” - Daniel S. Goldin, NASA Administrator, May 29, 1996
Agent Building Blocks

- Activity Planning
- Execution/Monitoring
1. Engineering Agents

- 7 year cruise
- ~150 - 300 ground operators
- ~1 billion $
- 7 years to build

Affordable Missions

- 150 million $
- 2 year build
- 0 ground ops

Cassini Maps Titan

Houston, we have a problem ...

- Quintuple fault occurs (three shorts, tank-line and pressure jacket burst, panel flies off)
  - Diagnosis.
- Mattingly works in ground simulator to identify new sequence handling severe power limitations.
  - Planning & Resource Allocation
- Mattingly identifies novel reconfiguration, exploiting LEM batteries for power.
  - Reconfiguration and Repair
- Swaggert & Lovell work on Apollo 13 emergency rig lithium hydroxide unit.
  - Execution

Agent Building Blocks

- Activity Planning
- Execution/Monitoring
- Diagnosis
- Repair
- Scheduling
- Resource Allocation
2. Mobile Agents

Day 1
Long-Distance Traverse (<20-50 meters)

Day 2
Initial Position; Followed by “Close Approach”

Day 2 Traverse Estimated Error Circle

During the Day
Autonomous On-Board Navigation
Changes, as needed

Day 3
Science Prep (if Required)

Day 4
During the Day
Science Activities

Target

Day 2 Traverse Estimated Error Circle

Courtesy Kanna Rajan, NASA Ames. Used with permission.
Cooperative Vehicle Planning

Agent Building Blocks

- Activity Planning
- Execution/Monitoring
- Diagnosis
- Repair
- Scheduling
- Resource Allocation
- Global Path Planning
- Task Assignment
3. Agile Agents

Courtesy of Eric Feron. Used with permission.
Agent Building Blocks

- Activity Planning
- Execution/Monitoring
- Diagnosis
- Repair
- Scheduling
- Resource Allocation

- Global Path Planning
- Task Assignment
- Trajectory Design
- Policy Construction
Agent Paradigms

Figure adapted from Russell and Norvig.
Model-based Agents

Agent

Sensors

Environment

State

What the world is like now

What my actions do

How the world evolves

World Model

What action I should do now

Effectors

Figure adapted from Russell and Norvig.
Reflexive Agents

Environment

Agent

Sensors

Condition-action rules

What the world is like now

What action I should do now

Effectors

Figure adapted from Russell and Norvig.
Goal-Oriented Agents

- Environment
  - Agent
    - Sensors
      - State
      - What the world is like now
      - What it will be like if I do action A
    - How the world evolves
    - What my actions do
    - Goals
    - What action I should do now
  - Effectors

Figure adapted from Russell and Norvig.
Utility-Based Agents

Environment

Agent

Sensors

State

What the world is like now

How the world evolves

What it will be like if I do action A

What my actions do

How happy I will be in such a state

Utility

Effectors

What action I should do now

Figure adapted from Russell and Norvig.
Example of a Model-based Agent:

- Goal-directed
- First time correct
  - projective
  - reactive
- Commonsense models
- Heavily deductive
Outline

• Objective
• Agents and Their Building Blocks
• Principles for Building Agents:
  – Modeling Formalisms
  – Algorithmic Principles
• Building an Agent:
  The Mars Exploration Rover
Building Blocks to Models

- Activity Planning
- Execution/Monitoring
- Diagnosis
- Repair
- Scheduling

Goal and Feasibility-based:
- State Space Search
- Rules, First Order Logic
- Strips Operators
- Constraint Satisfaction Problems
- Propositional Logic

Utility-based:
- Weighted Graphs
- Linear Programs
- Mixed Integer Programs
- Markov Decision Processes

- Resource Allocation
- Global Path Planning
- Task Assignment
- Trajectory Design
- Policy Construction
Building Blocks from Models

- Activity Planning
  - Graphplan, SatPlan, Partial Order Planning
- Execution/Monitoring
- Diagnosis
  - Constraint Suspension
- Repair
  - Rule-based
- Scheduling
  - CSP-based
- Resource Allocation
  - LP-based

- Global Path Planning
  - Roadmap
- Task Assignment
- Trajectory Design
  - MILP
- Policy Construction
  - MDP
  - Reinforcement Learning
Models to Core Algorithms

Goal and Feasibility-based:
- State Space Search
- Rules, First Order Logic
- Strips Operators
- Constraint Satisfaction
- Propositional Logic

Utility-based:
- Weighted Graphs
- Linear Programs
- Mixed Integer Programs
- Markov Decision Processes

Uninformed Search:
- Depth First, Breadth First
- Iterative Deepening
- Backtrack Search
- Backtrack w Forward checking
- Conflict-directed Search

Informed Search:
- Single Source Shortest Bath
- Best First Search
  (A*, Hill Climbing, …)
- Simplex
- Branch and Bound
Algorithms to Principles

Goal and Feasibility-based:
- State Space Search
- Rules, First Order Logic
- Strips Operators
- Constraint Satisfaction
- Propositional Logic

Deduction:
- Unification
- Unit Clause Resolution
- Arc Consistency
- Gaussian Elimination

Relaxation
- Value Iteration
- Reinforcement Learning

Utility-based:
- Weighted Graphs
- Linear Programs
- Mixed Integer Programs
- Markov Decision Processes

Divide and Conquer
- Branching
- Sub-goaling
- Variable Splitting
- Dynamic Programming
- Uninformed & Informed

Abstraction:
- Conflicts
- Bounding
Outline

• Objectives
• Agents and Their Building Blocks
• Principles for Building Agents:
  – Modeling Formalisms
  – Algorithmic Principles
• Building an Agent:
  The Mars Exploration Rover
Mission Objectives:

• Learn about ancient water and climate on Mars.
• For each rover, analyze a total of 6-12 targets
  – Targets = natural rocks, abraded rocks, and soil
• Drive 200-1000 meters per rover
• Take 1-3 panoramas both with Pancam and mini-TES
• Take 5-15 daytime and 1-3 nighttime sky observations with mini-TES