Planning Agents

Chapter Overview

planning problems

from problem solving to planning

representations for planning problems

states, goals, actions, plans

partial-order planning

keep the number of plans tractable

abstract examples

shopping, blocks world, Shakey's world

practical planning

hierarchical decomposition, operators, resource constraints

real-world applications

space missions and spacecrafts, job shop scheduling

Search-Based Problem Solver

review from last chapter

actions

represented by programs that generate successor state descriptions

states

complete state descriptions are required

goals

goal test, heuristic functions as black boxes

plans

a solution is a sequence of actions

search algorithm generates only contiguous sequences

Planning Problems

from problem solving to planning

reasoning process

structured more flexibly

any part of the problem can be worked on

planning and execution

no necessary connection between the order of planning and the order of execution

decisions

important or obvious decisions can be made first

hierarchical decomposition

divide-and-conquer strategy

a plan is split up into largely independent subplans

Representations

for planning problems

states

conjunctions of function-free ground literals (predicates applied to possibly negated constant symbols)

state descriptions may be incomplete

goals

conjunctions of literals, possibly with variables

actions

described via operators

plans

sequences of actions

This representation is close to the STRIPS language, one of the first planning systems

Operators

descriptions of actions

description

name for an action

precondition

conjunction of atoms that must be true

effect

conjunction of literals describing the changed situation

Situation Space

traversed in order to reach the goal

progression planning

searches forward from initial to goal situation

often inefficient due to high branching factor and huge state space

regression planning

searches backward from goal to initial situation

possible because only partial descriptions of states are needed

complicated for conjunctions of goals

Partial Plan

simple, incomplete plan

operators

work on plans: add steps, impose ordering, instantiate variables, ...

refinement operators

constraints are added to a partial plan

equivalent to the elimination of possible plans

modification operators

plans are modified

incorrect plans can be "debugged"

Partial-Order Planning

keep the search focused

partial order

leave some ordering decisions open

total order

sequential list of steps, or linearization of a plan

Solution

executable plan that achieves the goal

complete

every precondition of every step is satisfied

consistent

no contradictions in the ordering or binding constraints

Plan

formal definition

plan steps

each step is one of the operators for the problem

ordering constraints

temporal order of the steps

variable binding constraints

no conflicts in instantiations

causal links

record the purpose of steps

graphical notation: boxes and arrows

Shopping

as an abstract planning problem

initial plan

start situation, goal situation

partial plan

insert steps that can be resolved right away

partial *order* plan

don't worry about the particular sequence of steps

solution

complete plan with all necessary ordering and binding constraints

see (??Russell:Norvig:95), pp. 349 ff

Blocks World

states

objects and their positions

goals

particular spatial relations between objects

actions

operators for moving blocks

plans

sequences of block movements

Practical Planners

operate in complex, realistic domains

planning methods

language and algorithms must be extended

search

must be focused for specific domains

real-world limitations

resources, time, uncertainty

Hierarchical Decomposition

different levels of abstraction

abstract operators

can be decomposed into a group of steps

primitive operator

can be directly executed

Language Extensions

operators classified into

- primitive
- nonprimitive

decomposition methods

- similar to subroutines or macros for operators

requires modification of the planner

Resource Constraints

representation and execution

resources

can be produced and consumed

measures

numeric values for quantifying resources

temporal constraints

time is just another resource

Distributed Problem Solving

collaboration among agents to achieve a common goal

example problems

tasks that seem suitable for distribution

task sharing

one agents offloads some of his tasks onto other agents

result sharing

several agents work on the same task, and their results are combined

Distributed Planning

specialization of distributed problem solving

distributed formulation of plans

the planning process itself is distributed

generation of plans for distributed activities

the plan is generated in such a way that the activities it specifies can be executed in a distributed way

distributed plan representation

methods for representing distributed plans in a coordinated manner

distributed execution of plans

combining coordination, planning, and execution

Centralized Planning

for distributed plans

partial order planning

no strict ordering is required between actions

these actions may be executed in parallel via threads

decomposition of a plan into subgoals

subplans should be self-contained

synchronization between subplans

frequently via communication

subplan allocation

different subplans are allocated to individual agents

can become complex for heterogeneous agents

plan execution

individual agents execute their subplans

may involve monitoring by the centralized planner

Distributed Planning

for centralized plans

cooperative planning

several agents work on the same plan

mostly interesting for very large or complex plans

variation of distributed problem solving where the problem happens to be a planning task

task decomposition

identification of largely independent subtasks that can be tackled by individual agents or teams of agents

task distribution

allocation of subtasks to (teams of) agents

subtask execution

individual agents work on their specific tasks

result sharing

contributions by individual agents are collected and synthesized into one comprehensive plan

Distributed Planning

for distributed plans

planning process and plan execution

are distributed

combines challenges from both

approaches

relatively immature field

many different approaches, but not much systematicity

Plan Merging

coordination of multiple individual plans

inherently distributed task

- no central agency to coordinate the planning task
- each agent has its own plan, but they are willing to coordinate their activities

identification of conflicts

- resource utilization
- expected results

resolution of conflicts

- analysis of the individual plans for conflicts
- centralized or distributed approaches
- variation of reachability analysis, which relies on the possibly intractable enumeration of states

identification of unsafe states

emphasis on actions performed by the agents

assumes that the "action space" is less complicated than the state space

Distributed Hierarchical Planning

variation of iterative plan formulation

levels of abstraction

agents formulate their plans at different levels

only higher levels are shared

can reduce the overall search space substantially by pruning away many details

conflicts

it is assumed that conflicts can be recognized and hopefully resolved at higher levels

is not always the case

Negotiation

in distributed planning

resolution of conflicts

once conflicts are discovered, the agents involved negotiate a plan that solves the conflicts

usually based on utility functions for agents

may require the revision of plans

preserves the autonomy of agents

extension of the planning space

negotiation often results in an even larger state space for the planning problem

self-interested agents

negotiation assumes that agents are willing to cooperate

incentives can be introduced to encourage

cooperation even for self-interested agents

Distributed Plan Representation

abstract description language for plans

compatibility of plans among different agents

agents may use different planning systems with various plan representation schemes

plan components

many of the individual components of a plan may require their own description languages (environment, agent capabilities, resources, plots, subplans, ...)

communication protocols

necessary for the exchange of plans

not sufficient for the description of plans

knwoledge exchange languages

in principle capable of representing and

exchanging plans, in practice they may be too general

Distributed Planning and Execution

pre-planning coordination

may impose constraints on the possible actions of agents

sometimes formulated as *social laws*

in general, agents may inform each other about their plans

post-planning coordination

coordination of plans during execution

agents may formulate *contingency plans* in advance, and choose the appropriate branch during execution

interleaving planning, coordination, execution

continual revision of plans in response to coordination decisions

observation-based plan coordination

agents that can't communicate can infer each other's plans

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