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Managing Temporal Relations in the MAESTRO Scheduling System*

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INTRODUCTION

Scheduling defined

Why scheduling is hard

Scheduling domains are information-rich

An effective scheduling approach - Use as much information as possible while keeping the computational workload manageable

MAESTRO adhers to this principle via resource opportunity calculation and temporal constraint propagation

How MAESTRO manages temporal relations

DEFINITIONS

Activity - A sequence of operations, steps or subtasks which, when executed, accomplishes one or more goals. Each activity has associated resource, conditions, state, and timing requirements, all of which must be met for the activity to accomplish its goal(s).

Scheduling - The specification of start and end times for subtasks making up activities, and the specification of resources to be used for each, if there are choices among them.

Viable Schedule - A timeline of activity performances on which all of the performances can successfully be executed, given the truth of the assumptions upon which that schedule was based.

Activity ATMOS - Atmospheric Spectroscopy

Activity Structure

subtasks	duration min	duration max	delay min	delay max
A1 - Power Up	3	3	n/a	n/a
A2 - Self test	1	1	0	0
A3 - Calibrate	4	6	0	5
A4 - Repoint	1	10	0	10
A5 - Collect Data	18	36	0	10
A6 - Power Down	3	3	0	0

Resource Use

subtasks \ resources	ATMOS Instrument	Power	Data	Vibration	Sun excl angle	Day/night
A1 - Power Up	X	100 w				
A2 - Self test	X	100 w	4 kbps			
A3 - Calibrate	X	250 w	1 kbps			
A4 - Repoint	X	400 w		causes 1000 μg		
A5 - Collect Data	X	200 w	2 kbps	< 650 μg	> 32 deg	daylight only
A6 - Power Down	X					

Temporal Constraint - Subtask A5 must start 2 - 5 minutes after SOLAR subtask S4 starts

Placement Preferences - Frontload, maximizing subtask durations and minimizing delays between subtasks

WHY SCHEDULING IS HARD

1) Desirability - Difficulty in determining when you've got a good schedule, given that different people, agencies, etc. have differing goals and priorities.

2) Stochasticity - Unpredictability in the domain that makes predictive scheduling problematical.

3) Tractability - Computational complexity of the domain, the "size" of the scheduling problem.

4) Decidability - It may be provably impossible to find an algorithm which produces an optimal schedule, depending on the definition of optimality chosen.

H. Van Dyke Parunak - "Why Scheduling Is Hard (And How To Do It Anyway)", *Proceedings of the 1987 Material Handling Focus (Research Forum)*, Georgia Institute of Technology, September 1987.

TRACTABILITY

Scheduling - searching a large, many-dimensional problem space, throughout which are scattered viable schedules.

Given 100 activities using any of 100 resources and starting at any of 100 times this space contains aproximately $10^{300,000}$ possible schedules.

Viable schedules make up a tiny percentage of all schedules.

"Good" schedules can constitute a small fraction of all viable schedules.

Optimal schedules can make up a small percentage of all "good" schedules.

SCHEDULING DOMAINS ARE INFORMATION-RICH

Activity structure

Activity temporal constraints

Resource types, use functions, availabilities

Preferences in activity placement, resource use, etc.

Schedule evaluation criteria (subjective)

Ways contingencies happen & can be dealt with

Domain Information Usable By A Scheduler

Some or all of the following is available in a typical scheduling domain. Other information may be available as well.

1) Structure of each activity (number of subtasks, operations or steps)
2) Subtask durations, delays between subtasks for each activity
3) Subtask resource and conditions requirements, choices between resources used
4) Relationships between subtask durations & resource use
5) Relationships between conditions availabilities and subtask durations
6) Effects of subtask execution on resource, condition and state availabilities
7) Time windows in which subtasks can be scheduled
8) Required temporal relations between subtasks, in an activity or between two or more activities
9) Temporal relations between subtasks and events or times
10) Alternative ways to satisfy temporal constraints
11) Alternate descriptions of activities
12) Resource and conditions availabilities
13) States of schedule-relevant objects
14) Interactions between resources
15) Position on timeline of events and already-scheduled activities
16) User preferences in activity or subtask placement
17) Preferences in subtask resource use
18) Preferences in ways to satisfy temporal constraints
19) Priority of each activity
20) Number of times each activity should be scheduled
21) Time period being scheduled over
22) Average frequencies of various failures
23) Typical times for repair& maintenance
24) Ways to continue an interrupted activity
25) Time available to create a schedule
26) Time available to modify a schedule being executed
27) Importance of minimally satisfying lots of requests vs that of "near-optimally" satisfying a few requests
28) Importance of getting on high-priority activity done vs getting several lower-priority ones done

The preceding information can be used to generate other potentially useful information:

29) Summed activity resource requirements
30) Ways two or more activities can fit together or will conflict
31) Time windows during which all resource requirements for a subtask are satisfiable.
32) Time windows from which to choose subtask starts and ends such that the whole activity can be placed
33) Percent resource use, percentage of activity requests satisfied, and other schedule evaluation metrics

In most scheduling domains an important piece of information cannot be determined - why an activity cannot be scheduled. It may be possible to list all the reasons why an activity cannot be scheduled at a particular time, with fixed durations for its subtasks and fixed delays between them, but this information cannot efficiently be determined for activities which allow variability in placement. Also, some of the information listed earlier will be subjectively determined, and these determinations can vary over time and between people, though this will not necessarily make this kind of information unuseful.

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AN APPROACH TO SCHEDULING

Represent all available domain information to scheduling system

Perform computations which analyze input info and synthesize other info while not incurring unacceptable overhead

Use domain info and synthesized info to incrementally make decisions which remove "bad" schedules from the search space while keeping "good" ones

Do not allow representable constraint violations, ruling out the vast majority of the search space implicitly

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THE MAESTRO SCHEDULING SYSTEM

Opportunity Calculation finds all places on a current partial schedule wherein each subtask can be executing w/resp to resources, conditions, states and time windows

Temporal Constraint Propagation uses this & other constraint info to specify time windows from which subtask starts and ends can be chosen such that a whole activity can be placed

An activity is selected to be scheduled using these results and user-specified criteria indicating importance of various heuristics

Selected activity is placed on the schedule using results of constraint propagation and placement preference info

User can select activity to schedule and/or can place selected activity using results of above computations

MANAGING TEMPORAL RELATIONS

A. Constraints on the Placement of a Single Activity

B. Constraints Between Activities

C. Soft Constraints

D. Contingency Handling

CONSTRAINTS ON THE PLACEMENT OF A SINGLE ACTIVITY

A. Resources and conditions

B. Time windows

C. Activity structure

1. durations and delays, with variability

2. nonadjacent subtask relations, activity duration

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CONSTRAINTS BETWEEN ACTIVITIES

A. Precedes, follows, starts, ends, and conflicts, with variable offsets

B. One-way versus two-way constraints

C. Constraint arities

D. Relations to events and to absolute times

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Soft Constraints

A. General preferences

1. loading
2. durations and delays

B. Specific preferences

1. maximize one duration
2. place subtask near to or far from a subtask, event or time

C. Random placement

D. User placement

CONTINGENCY HANDLING

A. Schedule late-arriving request

B. Unschedule (bump) to fit new request

C. Unschedule to reflect resource availability changes

D. Interrupt and restructure an activity in real time