Scheduling Research and Applications

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Overview

In the Scheduling Group at the Honeywell Technology Center (HTC), we are engaged in a wide variety of research and development projects related to scheduling for space and aviation. Most of these projects result in implemented systems, several of which have become, or will soon become, fielded applications, some of them solving problems substantially more complex and/or orders of magnitude larger than appear in the current applications literature. Our current research efforts are extending the utility of scheduling systems for complex dynamical models, for distributed applications, and for mixed-initiative systems.

For space applications, we have developed scheduling systems for Space Station experiment scheduling, information processing scheduling for the Earth Observing System (EOS), and ground support for satellite operations. In the aviation domain, we have completed or are currently pursuing applications in aircraft avionics, airport ground operations scheduling, and airline maintenance scheduling. Four of these applications are briefly described below.

Approach

Our technical approach to scheduling, along with most of our implemented systems, is based on Constraint Envelope Scheduling (CES). CES is a form of "least commitment" scheduling, in which schedule construction and modification is accomplished through the incremental addition and deletion of constraints on activities' temporal relations and resource usage. The result is a schedule in which each activity is only constrained to execute within a certain time window. Contrast this with conventional timeline approaches that place each "activity" at an exact location on a timeline. The CES approach allows for more flexible search, a focused analysis of bottlenecks or conflicts, and easier dynamic modifications to an existing schedule.

The CES approach was developed specifically to address some of the issues that arise in implementing scheduling systems for large organizational applications, for example manufacturing or spacecraft operations. The issues we were concerned with include large-scale problems (hundreds to tens of thousands of activities), mixed-initiative schedule generation, incremental, iterative rescheduling during schedule generation and execution, complex domain models, and the need to explain to a human user the reason for a scheduling conflict or infeasibility. This approach has now been demonstrated to provide benefits for those problems, across a wide range of application domains, with solution methods ranging from (almost) fully-automated search to manual scheduling with constraint-checking and culprit identification functions.

In our recent research, we have discovered additional benefits to CES, initially unlooked-for but turning out to be very promising. First, it turns out that modeling the scheduling process explicitly as the accumulation of additional constraints supports a flexible and natural semantics for distributed scheduling. This advantage holds for several interpretations of the term "distributed." In an application where multiple administrative or bureaucratic entities are modifying a common schedule (think Shuttle mission planning), the ability to tag added constraints with information regarding who added them and why permits us to support a principled negotiation between competing interests in the construction of a common schedule. For a more strongly-distributed application such as Air Traffic Control or supply chain management, explicit constraints provide a semantic basis for negotiated commitments among entities who may be unable or unwilling to share complete information regarding their local schedules or objective functions. For either of these cases, retaining flexibility in both schedule generation and execution (the "envelope" in CES) simplifies the negotiation process through the avoidance of premature commitment.

An additional strength of the CES approach has resulted from our explicit separation of the discrete and continuous aspects of scheduling problems. This "hybrid reasoning" approach has been accomplished through the implementation of a continuous-domain temporal reasoning engine with a very specific set of properties, including efficiency (millisecond incremental updates for constraint addition *and* deletion), completeness and correctness with respect to consistency, caching of partial information for incomplete constraint propagation back into the discrete model, and "culprit identification:" the ability to trace an inconsistency or infeasibility back to the set of interacting requirements or scheduling decisions that were responsible. Almost without recognizing what we were doing, we have ended up implementing a novel architecture for the principled solution of hybrid (mixed discrete and continuous) constraint problems, borrowing techniques from both AI and Operations research.

In current work, we are extending this architecture for the solution of problems with a more complex continuous model, for example refinery scheduling, which requires at least a general LP model, and possibly an NLP. Our preliminary results indicate that the LP integration, at least, is quite feasible, and that the resulting system will be able to solve complex scheduling and optimization problems at least a couple of orders of magnitude larger than the best "Mixed-Integer Linear Programming" models currently available. Some domains for which this increased expressive capability may be useful include manufacturing, aircraft mission planning and flight dynamics, and spacecraft or satellite operations explicitly incorporating orbital dynamics.

Application descriptions:

Satellite ground ops

HTC has developed a prototype satellite ground operations scheduling system. The targeted domain is a network of space-based satellites in various orbits with a network of ground-based earth stations. Each ground station and satellite has a set of both unique and shared resources. Activities are scheduled to use both satellite and ground stations based upon criteria of availability, ephemeris data, and resource constraints. The satellites orbit in various orbits (from LEO to GEO) imposing constraints on activities by their visibility windows. Ground stations contain the communication antennae. The ground-based equipment can either assigned to a ground station or shared across a network of ground stations. Activities have start and end times as well as a variable length duration. Each activity requests a set of possible ground stations as well as a set of equipment that it needs. The type of satellite necessary is also specified.

Distributed image data archiving and analysis

Under contract to the NASA Goddard Space Flight Center's (GSFC) Information Science and Technology Branch, HTC has developed a scheduling system for the Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Center (DAAC). One of the challenges is to ensure quick and easy retrieval of any data archived within the Distributed Active Archive Center Data Archive and Distributed System (DAAC DADS). Accessing that amount of information is a formidable task that will require innovative approaches. In order to improve the performance of the DADS, to make better use of limited resources, prevent backlog of data, and to provide information about resource bottlenecks and performance characteristics, a constraint-based task and resource scheduler was developed by the Honeywell Technology Center. This scheduler is in the process of being fielded by contractors for NASA Goddard.

Airline maintenance

HTC is developing an airline line maintenance scheduler for integration into an existing Honeywell product. The scheduler allows the human maintenance scheduler the ability to automatically generate a schedule, check consistency on manual changes, and a more useful graphical window into the operation of the airline. We have multiple activity types to model recurring checks and activities with deadlines based upon flight hours or takeoff/landing cycles. Multiple types of resources are modeled: labor (with work calendars), tools, labor, and maintenance stations (hangars, etc.). The schedule can also be generated with a mixed-initiative paradigm, the human being responsible for some of the heuristic information, while the scheduler is responsible for the rest of the heuristic information and the laborious activity of enforcing consistency between all of the activities. The user can generate reports such as a list of the activities to be accomplished on each aircraft or for each employee.

Aircraft avionics

Honeywell is now delivering the new Boeing 777 integrated Airplane Information Management System (AIMS). AIMS functions range from hard real-time to non-real-time, and include flight critical and non-essential functions, and must all reside on the same distributed multiprocessor system. This system, based on ARINC 659[1], allows for high resource utilization while providing strict partitioning and provable performance via pre-scheduling of processing and communication resources. This application was large, complex, and hard to solve. To be a little more concrete: "large" means almost 30,000 activities, "complex" means several activity types, periodic behavior, and assorted types of temporal constraints, and "hard to solve" means that we have been unable to eliminate backtracking through the use of search heuristics. The schedule generated by HTC is currently running on the 777 providing critical timing information for all AIMS processing tasks and communications messages.