Constraint-Based Motion Planning

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The Challenge

Motion planning is a classical problem in robotics, with applications to virtual prototyping, molecular modeling, computer animation, and many other areas. In this work, we pose the planning problem as follows: Given a complex environment of static and moving obstacles, one or more movable objects, which we refer to as the robots, and a set of constraints, find a collision-free path for the robots from their initial configurations (positions and orientations) to their goal configurations that respect all of the constraints. An example of this general problem framework would be to plan moving a collection of objects, constrained to behave as a single articulated robot arm, to avoid moving obstacles and reach a moving target location. In general, the motion planning problem is extremely difficult to solve. In complex planning scenarios, a robot with a complicated shape may have to move and twist through a maze of very tight passages while maintaining all of the constraints imposed on it. Also, because we allow obstacles in the scene to be dynamic, our planning strategy can only rely on limited precomputed information about the scene.

The Approach

We address the motion planning problem by treating it as a constrained dynamics simulation. Constraints are used to both enforce relationships between the objects in the scene, and also to guide the robots' behavior with heuristics that will help solve the planning task. The simulation is run until all robots reach their target locations. The final planned path is just the list of configurations taken by each robot in the simulation.

We classify the constraints in our system into two basic types:

Hard Constraints

These are constraints that must be maintained at every step of the simulation to ensure a valid path. In our implementation they are solved using Gauss-Siedel iterative relaxation. Example constraints include:

- object non-penetration
- articulated robot joint connectivity
- articulated robot joint angle limits

Highlights

- **Treat motion planning as a constrained dynamical simulation, where the constraint forces guide the robots to their goals.**
- **Motion planning in environments with dynamic obstacles and moving goals.**
- **Solves moderately complicated planning scenarios at interactive rates.**

Example Scenes

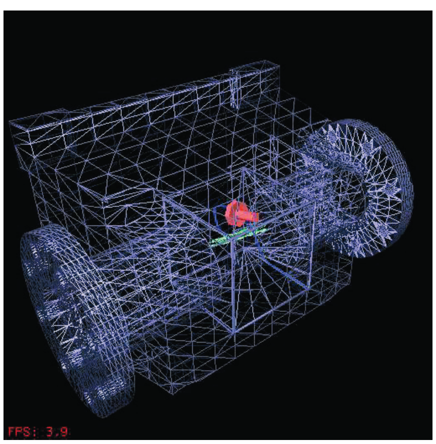

Figure 1. Maintainability Study
Two robots, a nut and a bolt, must avoid each other in the confines of a pump assembly for the bolt to be extracted.

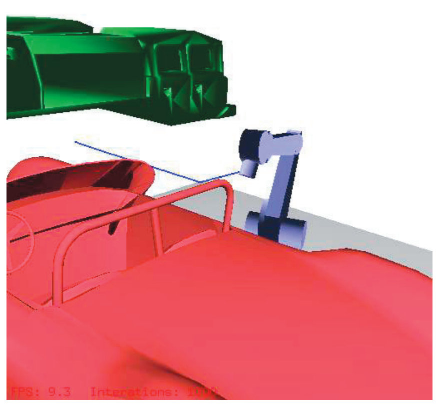

Figure 2. Auto Painting
The end effector of an articulated robot arm with 6 joints follows a path along the car body without colliding with nearby obstacles.

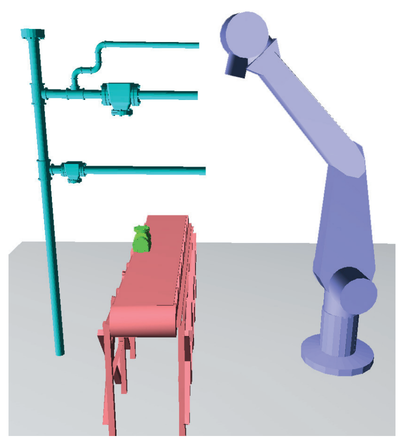

Figure 3. Assembly Line
The same articulated robot as in Figure 2 reaches for a moving part on a conveyer belt while avoiding a moving pipe structure.

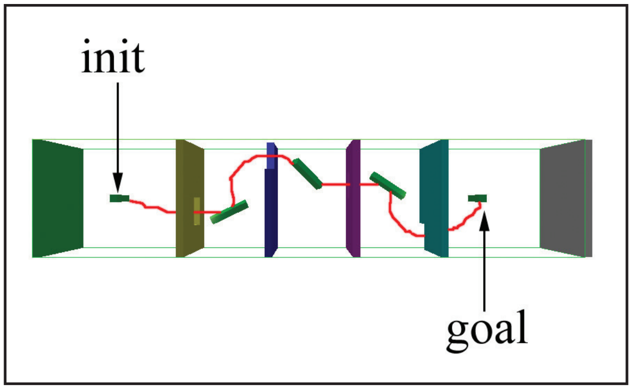

Figure 4. A narrow box robot passes through a series of walls containing square holes using vPlan.

Soft Constraints
These constraints allow the user to impose heuristics that will guide the robot to its planning solution. They are implemented in our work using penalty forces. Example constraints include:

- goal attraction
- obstacle repulsion
- following a precomputed estimated path

Related Work

Voronoi-Based Motion Planning
vPlan is a planner for free flying rigid robots in static 3D environments. In this approach, we use geometric information provided by the hardware-accelerated discrete Voronoi computation from which we can construct the Voronoi graph. By performing a graph search on the Voronoi graph, we find an estimated path for the robot that is maximally clear of obstacles in the scene. We perform a post-processing step in which the portions of the estimated path where the robot collides with obstacles are replaced by paths generated using a standard PRM Planner (Probabilistic Roadmap Planner).

Planning in Dynamic Environments
For a two-dimensional scene, the discrete Voronoi diagram can be computed many times a second. We exploited this ability to allow motion planning in the presence of moving obstacles. In each cycle, a new Voronoi diagram is generated, and information from the distance buffer is used to generate simulated forces that push the robot away from the obstacles. To draw the robot towards the goal, suitable points are chosen from the Voronoi graph to serve as sub goals. Since many 3D problems, like moving furniture through a house, can be expressed as 2D planning situations this approach has many useful applications.

Project Members

Ming C. Lin, professor
Maxim Garber, graduate student

Research Sponsors

Intel Corp.
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Selected Publications

Garber, M., and M. C. Lin. “Constraint-Based Motion Planning for Virtual Prototyping,” *Proc. ACM Symposium on Solid Modeling and Applications*, 2002.

Foskey, M., M. Garber, M. Lin, and D. Manocha. “A Voronoi-Based Hybrid Motion Planner,” *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2001.

Hoff III, K. E., T. Culver, J. Keyser, M. Lin, and D. Manocha. “Interactive Motion Planning Using Hardware-Accelerated Computation of Generalized Voronoi Diagrams,” *Proc. IEEE International Conference on Robotics and Automation*, 2000.

Related Work

- gamma.cs.unc.edu/planning/
- gamma.cs.unc.edu/voronoi/vplan/
- gamma.cs.unc.edu/voronoi/

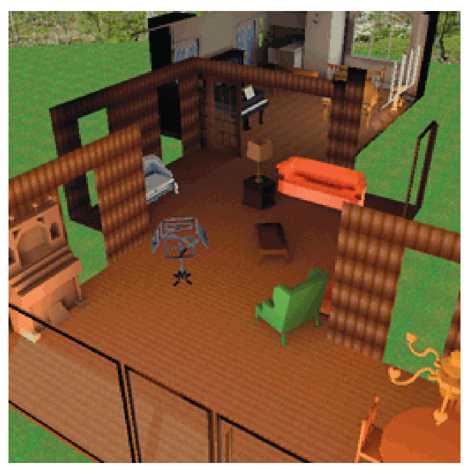

Figure 5. A piano stand avoids moving furniture as it navigates through a cluttered house using the 2D dynamic planner