Statement on Research and Teaching
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Research

My research interests and contributions are in the areas of motion planning, human-machine interaction and graphics and cover a broad range of application domains including animation of complex graphical characters, and simulation and manipulation of flexible and deformable objects, arising, e.g., in CAD/CAM or computational biology and chemistry. In the following, I first describe general motion planning techniques I have developed and then describe their application to virtual prototyping, ligand binding (drug design), animation of deformable objects and the simulation of complex group behaviors. The best way to illustrate my work is visually with movies. These can be found on my web page, http://parasol.tamu.edu/people/burchanb/.

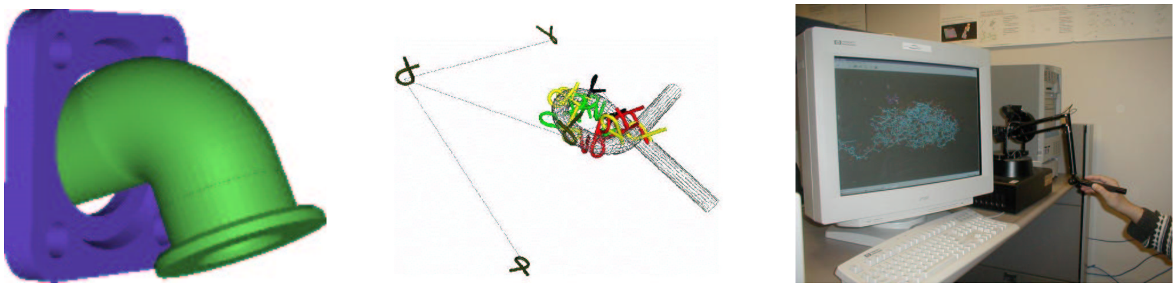
General Motion Planning Techniques

We encounter motion planning problems in our every day life. Finding an optimum route for a car we are driving, animating the migration of birds and simulating the motion of a DNA molecule can be formulated as motion planning problems. The most naive definition of motion planning is to find a path to move one object from one location to another. The movable object (robot) might be a car, a multi-link robotic arm, or a drug molecule. The complexity of a motion planning problem depends on several factors including the properties of the robot, the constraints it has to obey, and the complexity of the environment. Since most motion planning problems are NP-complete, deterministic solutions are infeasible in most cases. Recently, many difficult motion planning problems have been solved using Probabilistic Roadmap Methods (PRMs). We have proposed new PRM variants [1, 5, 10, 11] and have developed a framework called *Iterative Relaxation of Constraints* for iteratively transforming an invalid path into a valid path.

Probabilistic Roadmap Methods. PRMs work in so-called configuration space (C-space) where each point in this space (a configuration) completely describes the position and orientation of all robot components. PRMs construct a graph (or roadmap) in the robot's C-space, in which vertices correspond to feasible robot configurations and edges correspond to feasible motions between the corresponding configurations. Thus, PRM roadmaps provide a compact representation of feasible paths. Later, this roadmap can be utilized to find paths between any desired start and goal configuration.

We have developed a PRM variant called Obstacle Based PRM (OBPRM) [1]. OBPRM increases the probability of finding paths through narrow passages (which is a very challenging problem) by generating robot configurations close to constraint surfaces in C-Space. There are several factors affecting the success of PRMs, two of which are using suitable planning methods for connecting two nearby configurations (local planning) and good distance metrics in C-Space to identify nearby configurations. Although many algorithms have been suggested, my M.S. thesis was the first general comparison of them [2, 4]. In that work, we both applied some well-known algorithms and suggested some new ones. The results of our experiments were important since they showed other researchers the weaknesses and strengths of each algorithm in different conditions. The algorithms and the parameters determined in those studies are still used in our research group and have been instrumental in our application of PRMs to other domains, such as computational biology. We have also shown that complex group behaviors can be obtained by integrating roadmap-based planning with traditional emergent behavior techniques such as flocking [6, 7, 8].

Iterative Relaxation of Constraints. In our research, we found that although PRMs are very powerful, there are still some problems which they cannot solve efficiently. In particular, they sometimes fail



(a) (b) (c)

Figure 1: (a) Elbow-hole, goal is to move elbow inside the hole in *virtual prototyping*. (b) A sample roadmap visualization. Big tube is an obstacle, small tubes are roadmap nodes showing position and orientation information for a tube robot. (c) Haptic feedback in *ligand binding*.

due to the difficulty of discovering 'critical' configurations of the 'robot' that are in tight, or crowded, regions but which are crucial configurations in the resulting path. To address this problem, we have developed techniques aimed at helping an automated planner concentrate its exploration on critical regions of C-space. In this approach, instead of directly solving the original problem, we first try to solve a relaxed (easier) problem. The planner uses the solution for the relaxed version to guide its search for a solution to the original problem. This approach can be applied iteratively, so that a solution to each relaxed version is used as a guide for solving the succeeding version.

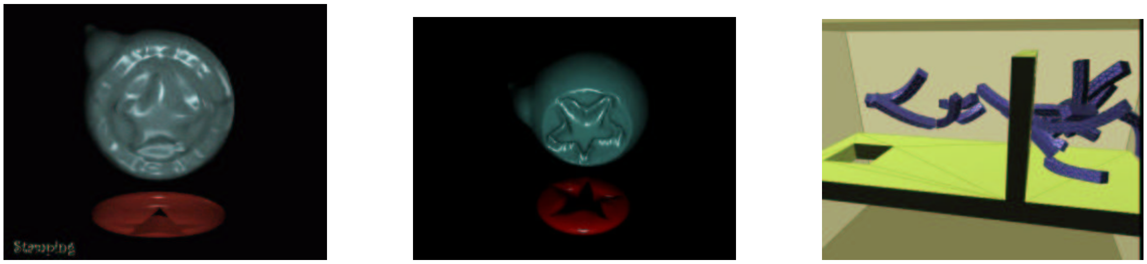
In fact, we have found this approach which we call *Iterative Relaxation of Constraints (IRC)* to be so effective, it is the topic of my dissertation. As described below, we have successfully applied IRC to several domains: virtual prototyping [3, 9, 10], ligand binding [11, 12], and deformable objects [5].

Applications

The widespread applicability of motion planning has provided me with the unique opportunity to apply my techniques to problems in many diverse domains, such as CAD/CAM, Graphics and Animation, and Computational Biology. This experience has helped me to develop the necessary skills to quickly move into new research areas. Below, I describe some of the applications on which I have worked.

Human-Computer Interaction. As previously mentioned, automated planners sometimes fail to solve problems in which the solution path is required to pass through narrow passages. In some such cases the general structure of the solution is naturally apparent to a human observer. IRC provides a natural paradigm to exploit such human intuition without requiring the human to generate the complete solution. We have investigated strategies for integrating human guidance and automated planning [3, 9, 10, 11, 12]. Ours was first work which sought to combine automatic motion planning with human input. We have implemented novel human-computer interaction methods to facilitate collection of user input with a haptic device for virtual prototyping and ligand binding (drug design).

Virtual Prototyping. We solved several problems using the IRC technique and human-computer interaction methods which were infeasible for traditional automated planners [3, 9, 10]. These problems were drawn from the domain of *virtual prototyping*, and in particular, design for maintainability studies. A design would have better maintainability if the parts are accessible from outside. Usually, the accessibility of particular parts is tested using physical mock-ups of the system. Our work, which treats the parts to be removed as robots and applies motion planning techniques, could ultimately remove the need for physical mock-ups by enabling such tests to be performed virtually on three–dimensional CAD/CAM models (see Figure 1(a)). In our experiments we solved several problems which were infeasible for fully automated planners. Indeed,



(a) (b) (c)

Figure 2: (a) and (b) Two different deformation methods for *deformable objects*, (c) deformable objects with flocking behavior.

with a human operator's guidance, our automated planner was able to find accessibility paths for parts in very confined situations such as in a mechanical design. To help the human operator's perception of the environment we used a haptic device (PHANToM) which let the user sense the virtual object as if the user were touching it. Almost all haptic interaction applications concentrate on simple representations of virtual objects. One of our achievements in this research was to develop an algorithm to provide a realistic sense of touch for very complex 3D virtual object pairs. We also developed some simple visualization techniques to illustrate the planner's progress (see Figure 1(b)). These techniques are still used in our group to understand the planner's behavior and several other researchers have expressed their interest. Whether starting from user-generated or automatically generated paths, we showed that the IRC technique enabled faster solution. In our experiments, easier versions of the problem were generated by reducing the size of the robot. We found that IRC and human hints are complementary to each other and human computer interaction can improve the performance of the planner.

Bioinformatics (Ligand Binding). Motion planning techniques inspired by PRMs have been successfully applied to biochemistry problems such as protein folding and ligand binding (also known as molecular docking used in drug design). Our work in ligand binding is one of the early studies of this topic and we look forward to further developing this technique.

In [11, 12], we applied the PRM motion planning techniques to the ligand binding problem. In this case, the robot was a flexible drug molecule and the goal was to find a binding site in a given protein molecule. The problem is very high dimensional with constraints imposed by energy related, geometrical and biochemical properties. In this research we successfully generated configurations within a few angstroms of the original site (which is considered to be in the binding site). Unlike most known docking algorithms, our algorithm does not require *a priori* knowledge of the studied molecules. Similar to our work in *virtual prototyping*, we used a haptic device to generate user input. Using the haptic device, an operator felt the molecular forces applied on the drug molecule as it was moved around the protein and was able to suggest some binding sites. The haptic device also helped the user to understand the molecular interactions and the binding process. There are few haptic applications implemented for this challenging problem and even in its preliminary stage, our implementation is promising. We have been collaborating with researchers from the Department of Biochemistry to improve our algorithms.

Graphics and Animation. Motion of objects plays an important role in computer animation. For example, the movement of an artificial character requires finding the individual joint angles for the body posture. Motion planning is also an important part of several artificial life problems which require individual or group movements such as simulation of a flock of birds, a school of fish, or ant movements. We have successfully applied motion planning algorithms to such problems in our research.

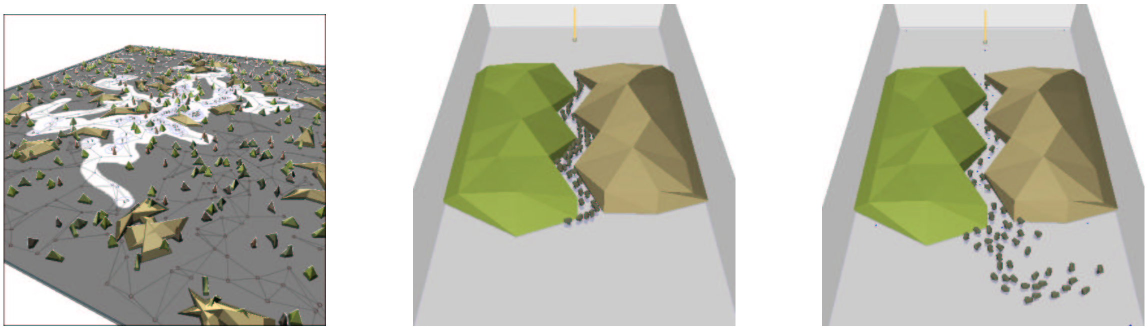

(a) (b) (c)

Figure 3: (a) Exploring with roadmaps, white areas are the explored areas, (b) Passing through a narrow passage as a flock (c)Passing through a narrow passage with a FOLLOW-THE-LEADER strategy.

Deformable Objects. There are some problems which require the object to deform. For example, finding a cutting path for a surgical blade would require the tissue and veins to deform based on the motion of the blade. The IRC paradigm can be applied to plan motions for deformable objects. In [5], we studied methods to find paths for a robot which is allowed to change its shape to avoid collision with obstacles. The motion planning problem for deformable objects is hard since there are an infinite number of possibilities for the form of a deformable object and random sampling can cover only a very small fraction of them. In our approach, we first found a path for a non-deformable (rigid) version of the robot. This path may contain colliding configurations, i.e., we relaxed the collision free constraint in IRC. Later, we deformed the robot to avoid collision. We have developed several strategies to generate the initial path which may involve small collisions. We have also developed two different techniques to deform the robot (see Figure 2). We believe our research in this area will pioneer an advance in several areas including deformable robots, animation and simulation.

Simulating Group Behaviors. In recent work, I'm developing better group behaviors using rule-based roadmap methods. This work has application in animation and artificial life problems. In [8], we show that roadmaps can be used to implement better flocking behaviors in complex environments than the current techniques. In particular we were able to simulate the following behaviors: *(i)* homing (where a flock tries to reach a goal whose location is known), *(ii)* goal searching (where a flock tries to locate a goal), *(iii)* covering (where a flock tries to visit every region of the environment, see Figure 3(a)) and *(iv)* shepherding (where an external agent steers a flock towards the goal). The advantage of our roadmap-based approach over the traditional techniques is that a roadmap stores global information of the scene and can be used as a simple communication media between flock members. Later, we developed the concept of adding rules to the roadmap to distinguish different behaviors in different regions of the roadmap [6, 7]. In this work we show that character behavior can be influenced by rules encoded in the characters and the roadmaps. For example, if a basic homing behavior is used to pass through a narrow passage, the passage may become too crowded (Figure 3(b)), where as if we have a follow-the-leader behavior in the narrow passage, the flock members can leave some separation between succeeding and preceding members (Figure 3(c)). Our approach to group behaviors has received interest from researchers in robotics [6], graphics [8] and artificial life [7]. We are currently considering applying these techniques to mobile robots.

Future work

Probabilistic Roadmap Methods are very powerful techniques and their limits have yet to be discovered. In our research group, they are applied to several domains which were initially thought to be unrelated to motion planning, such as protein folding, ligand binding, neuron construction, etc. I plan to continue my research on motion planning, and I'm particularly interested in continuing to explore the applicability of PRM-based techniques in bioinformatics. I plan to investigate how optimization techniques such as machine learning and genetic algorithms can be combined with PRMs. I believe that hybrid systems incorporating the strengths of these various methods will enable still more problems to be solved using motion planning methods.

Teaching and Mentoring

I have always enjoyed teaching, and I look forward to this aspect of my academic career. I enjoy interactions with undergraduate and graduate students and have experience in both classroom teaching and research mentoring.

Teaching

In Fall 2002, I've been given the opportunity to be the primary instructor for CPSC 311-502, the required Analysis of Algorithms course for Computer Science and Computer Engineering undergraduate majors at Texas A&M University. Instructing one of the most fundamental and most feared courses in Computer Science challenges me to inspire and motivate the students and enables me to prepare myself for an academic career. I am enjoying learning techniques that enable me to engage the students in the class. I believe my dynamic teaching style and availability lets the students not only enjoy the class but encourages them to consider broader issues in Computer Science. This is emphasized by my use of "Computer Science Culture" assignments where the students are encouraged to attend several research seminars during the semester.

My teaching experience is not limited to CPSC-311. Since my early graduate studies at Middle East Technical University (METU) in Turkey, I have been in continuous interaction with undergraduate students. During my assistantship at METU, I enjoyed being a lab instructor for the microprocessor class for which I designed several experiments. I was also a teaching assistant for a 'C' programming course which required continuous interaction with the students not only during the lab hours but also during non-office hours. Although in my later semesters I was only responsible for the Department of Computer Engineering's students, in my first semester, I was fortunate enough to be a lab instructor for a university wide computer languages class (including Fortran, Pascal and C). For a military project which aimed to increase the number of computer scientists in the military, I was selected as a lab instructor and helped several officers with ranks from 1st Lieutenant to Major learn 'C' programming. I was also an organizer and instructor for several introductory computer classes offered by the METU Computer Club (for which I served as vice president) during my sophomore and junior years. Those classes were open to any student that lacked computer background. Such opportunities helped me understand and teach students with diverse backgrounds.

Research Mentoring

Although my teaching experience gave me invaluable insights about teaching in an academic environment, this is not the only way I have interacted with students. During my graduate study at Texas A&M University, I used my teaching experience in my interactions with several undergraduate students who were members of our research group. I was the primary supervisor and research mentor for several undergraduate research projects. As one of the system administrators of our group, I was responsible for their acquaintance with the system. Since I was one of the most senior students in our group (always, since my adviser was a new assistant professor), I was also teaching them the basic motion planning algorithms as well as the internal structure of our algorithms and project code. On several occasions I suggested new technologies to them which helped them not only in our research projects but also in their own work. During my graduate study, I enjoyed my interaction with undergraduate students and I look forward to continuing this activity as a faculty member.

Teaching Interests

I have a wide range of teaching interests. I can teach any undergraduate class, any core graduate class and specialty graduate courses in my areas of expertise. I look forward to giving back the knowledge I acquired through the years of my study, especially the topics related to robotics, machine learning, computer graphics, algorithms, data structures and programming languages.

Finally, I would like to note that Middle East Technical University is one of the top universities in Turkey and its students are a select few among from millions of candidates entering nationwide placement exam each year. This makes the students very demanding in all respects. I believe my experience there, as well as my interactions and teaching experience with the students at Texas A&M University, has left me prepared to teach at any undergraduate or graduate institute.

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