Robot Motion Planning and Multi-Agent Simulation

COMP 790-058 (Fall 2013)

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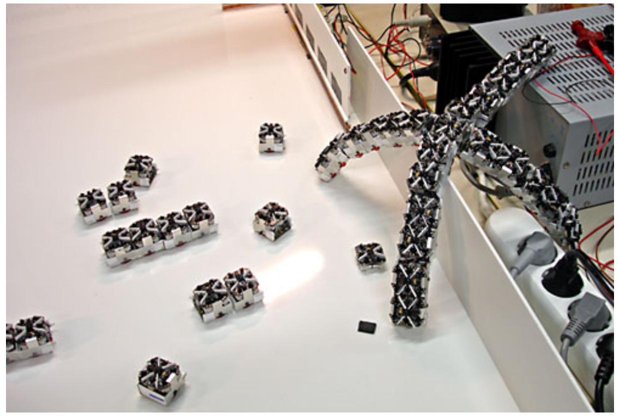
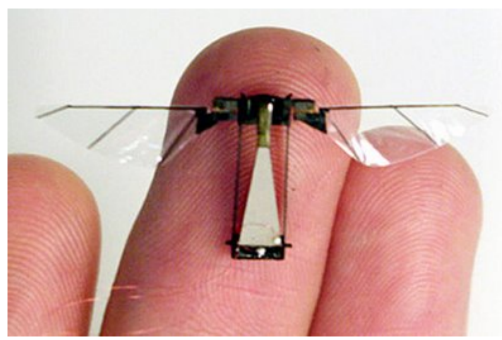
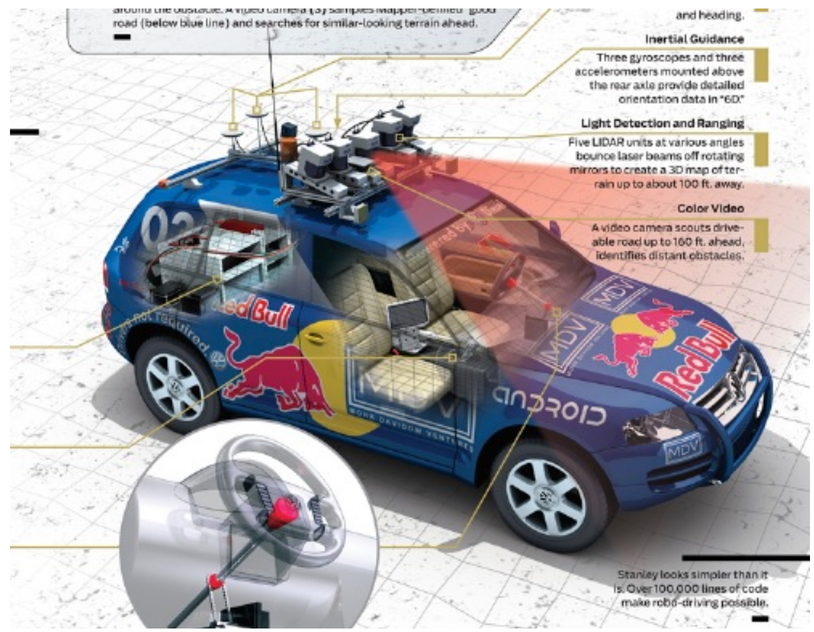
http://gamma.cs.unc.edu/courses/planning-f13/

Robot Era is Coming!





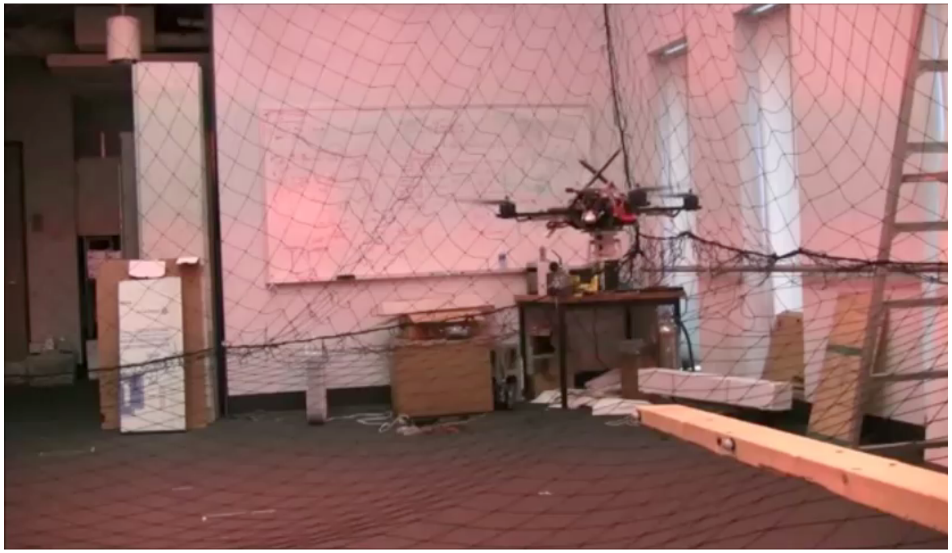
Robot Era is Coming



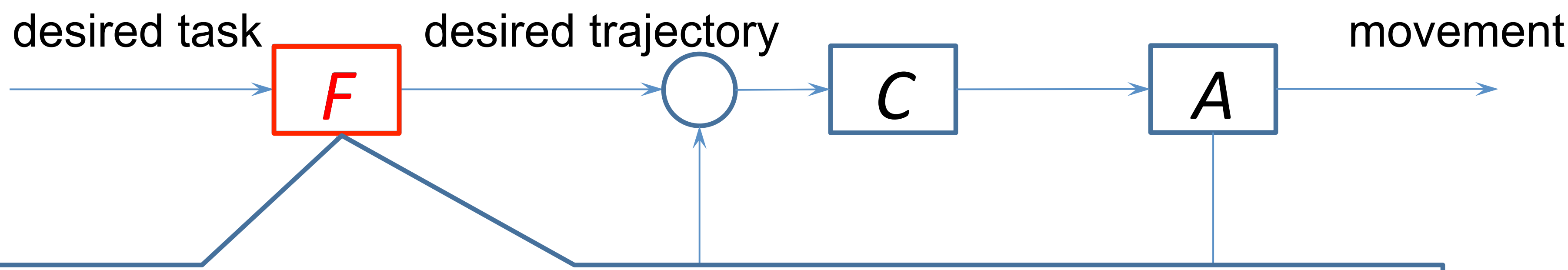
Motion of Real Robots

Robot Era is Coming!

Robot Era is Coming?



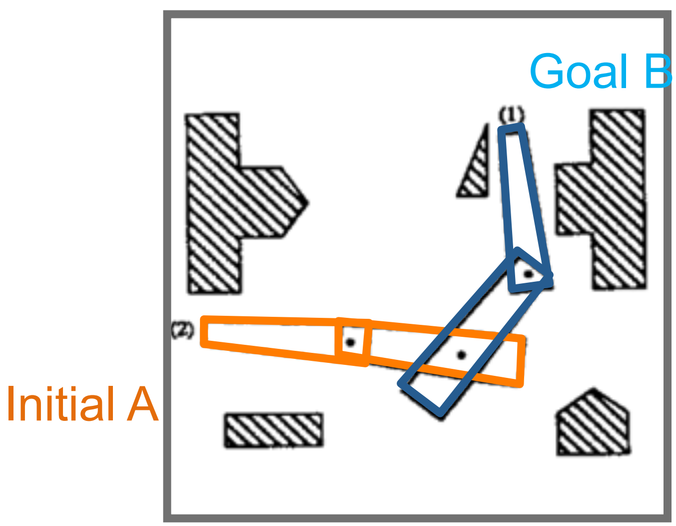
Robot System

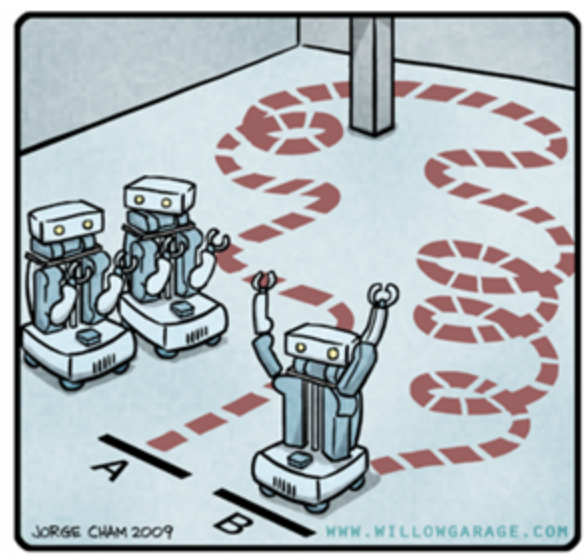


motion planning and trajectory generation

Robot Motion Planning

- Given initial setting A of the robot, find a valid or optimal trajectory for the robot to reach goal B
  - Collision-free
  - Other constraints (balance)
  - Optimal criteria (shortest path, min-time ...)

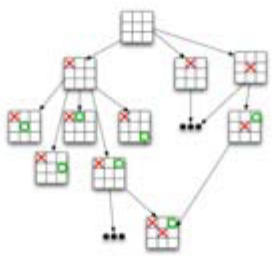




Motion Planning

Motion planning (a.k.a., the "navigation problem", the "piano mover's problem") is a term used in robotics for the process of detailing a task into discrete motions (Wikipedia)

Motion Planning (the words)



- **Planning**: a matter of symbols and graph search

- **Motion**: a continuous function from time to space

- **Motion Planning**: a computational topology problem

Motion in Virtual Worlds

- Computer games
- Computer generated simulations
- Virtual prototyping systems

Examples: 1.
http://www.plm.automation.siemens.com/en_us/products/open/kineo/index.shtml (Kineo)

2. http://youtube.com/watch?v=5-UQmVjFdqs

3. http://www.massivesoftware.com/

Smart Robots or Agents

- Autonomous agents that sense, plan, and act in real and/or virtual worlds
- Algorithms and systems for representing, capturing, planning, controlling, and rendering motions of physical objects
- Applications:
  - Manufacturing
  - Mobile robots
  - Computational biology
  - Computer-assisted surgery
  - Digital actors

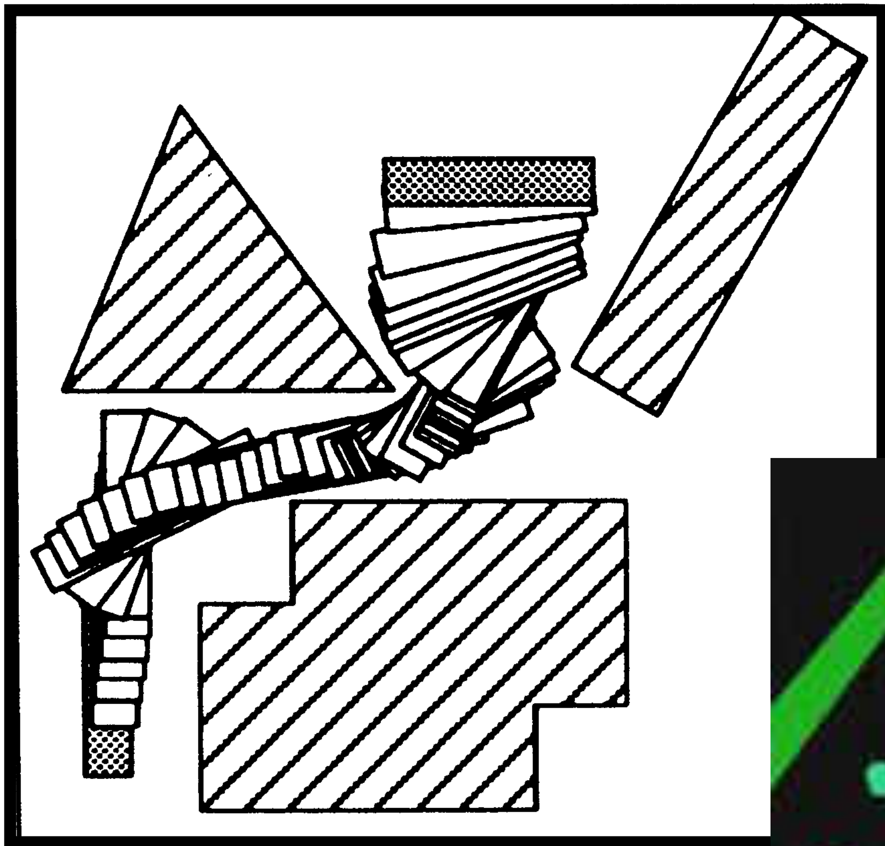
Goal of Motion Planning

- Compute **motion strategies**, e.g.:
  - geometric paths
  - time-parameterized trajectories
  - sequence of sensor-based motion commands
  - aesthetic constraints
- To achieve **high-level goals**, e.g.:
  - go to A without colliding with obstacles
  - assemble product P
  - build map of environment E
  - find object O

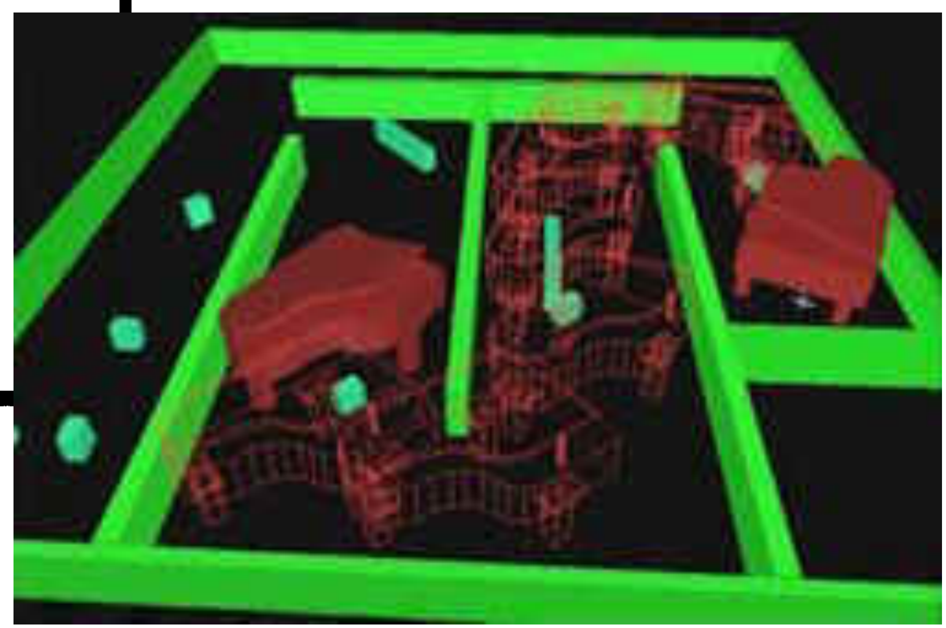
Basic Motion Planning Problem

- Statement:
  Compute a collision-free path for an object (the robot) among obstacles subject to CONSTRAINTS
- Inputs:
  - ♦ Geometry of robot and obstacles
  - ♦ Kinematics of robot (degrees of freedom)
  - ♦ Initial and goal robot configurations (placements)
- Outputs:
  - ♦ Continuous sequence of collision-free robot configurations connecting the initial and goal configurations

Examples with Rigid Object

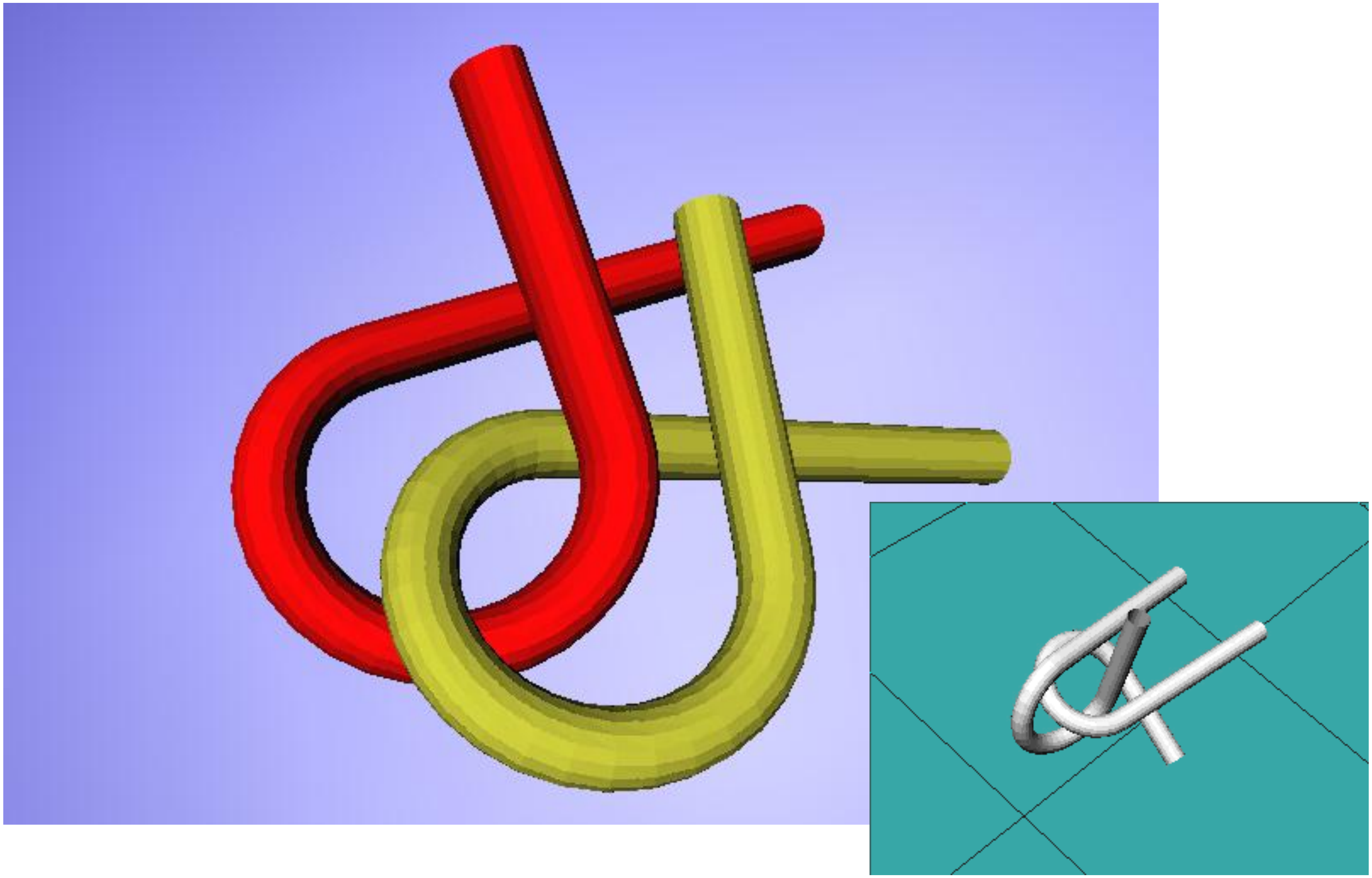


→ Ladder problem

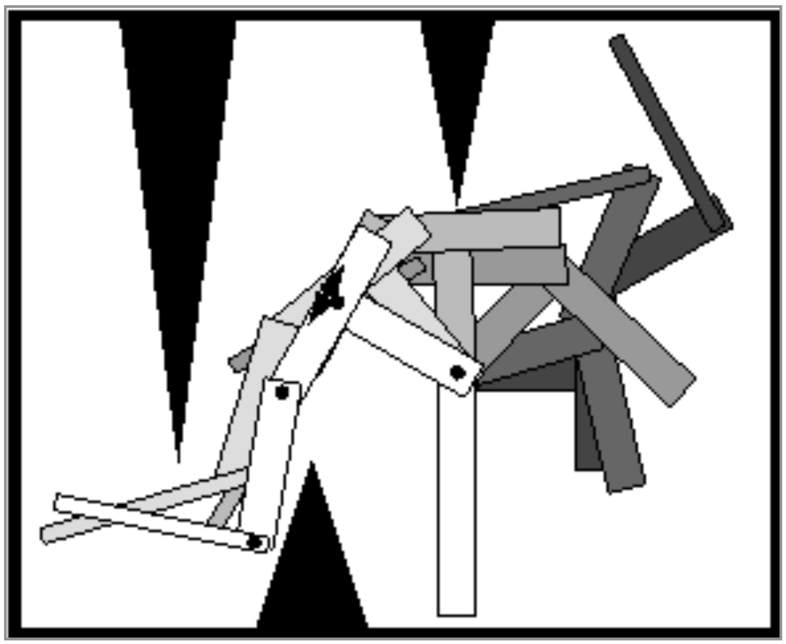


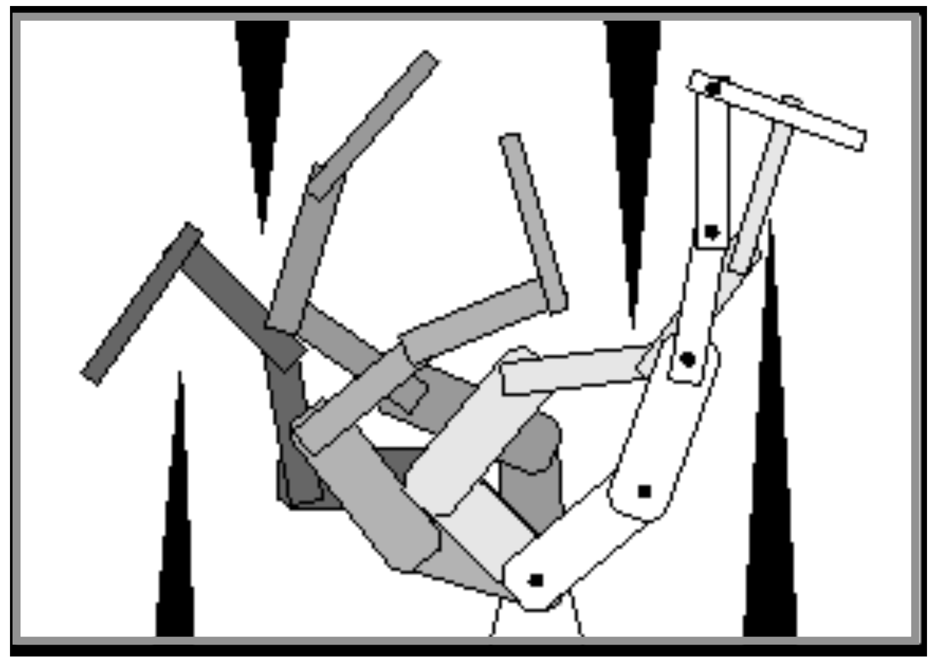
Piano-mover problem ←

Is It Easy?



Example with Articulated Object





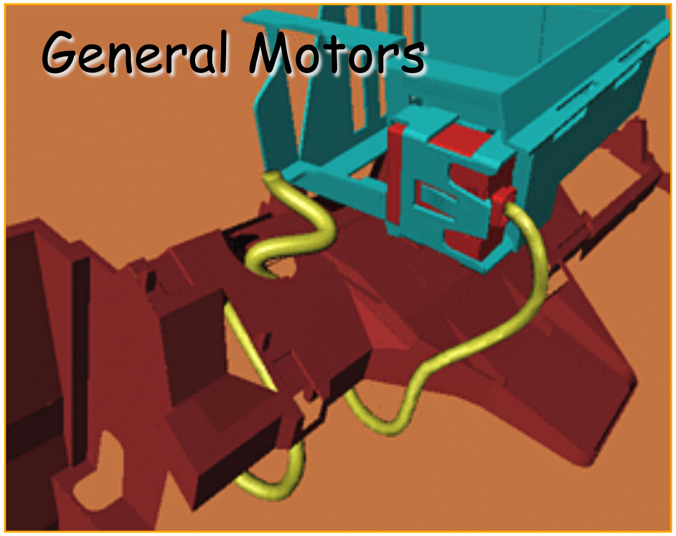
Some Extensions of Basic Problem

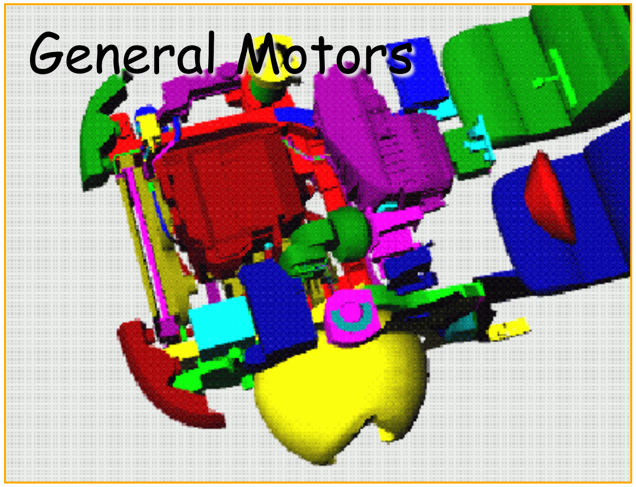
- Moving obstacles
- Multiple robots
- Movable objects
- Assembly planning
- Goal is to acquire information by sensing
  - Model building
  - Object finding/tracking
  - Inspection
- Nonholonomic constraints
- Dynamic constraints
- Stability constraints
- Optimal planning
- Uncertainty in model, control and sensing
- Exploiting task mechanics (sensorless motions, under-actualted systems)
- Physical models and deformable objects
- Integration of planning and control
- Integration with higher-level planning

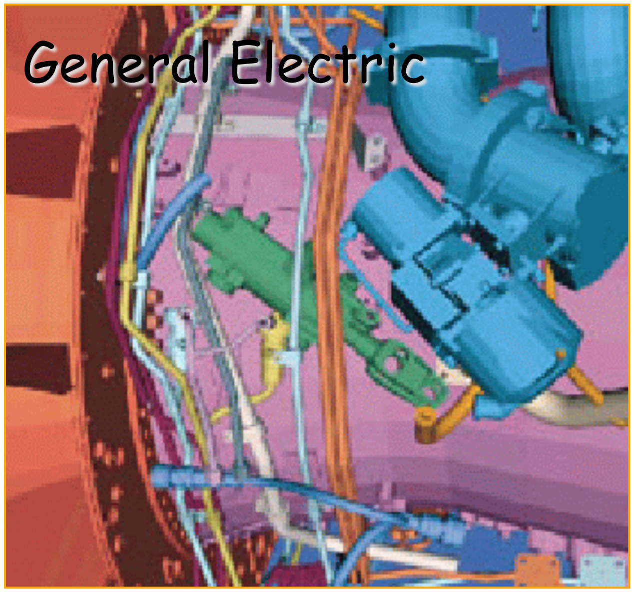
Examples of Applications

- Manufacturing:
  - Robot programming
  - Robot placement
  - Design of part feeders
- Design for manufacturing and servicing
- Design of pipe layouts and cable harnesses
- Autonomous mobile robots planetary exploration, surveillance, military scouting
- Graphic animation of "digital actors" for video games, movies, and webpages
- Virtual walkthru
- Medical surgery planning
- Generation of plausible molecule motions, e.g., docking and folding motions
- Building code verification

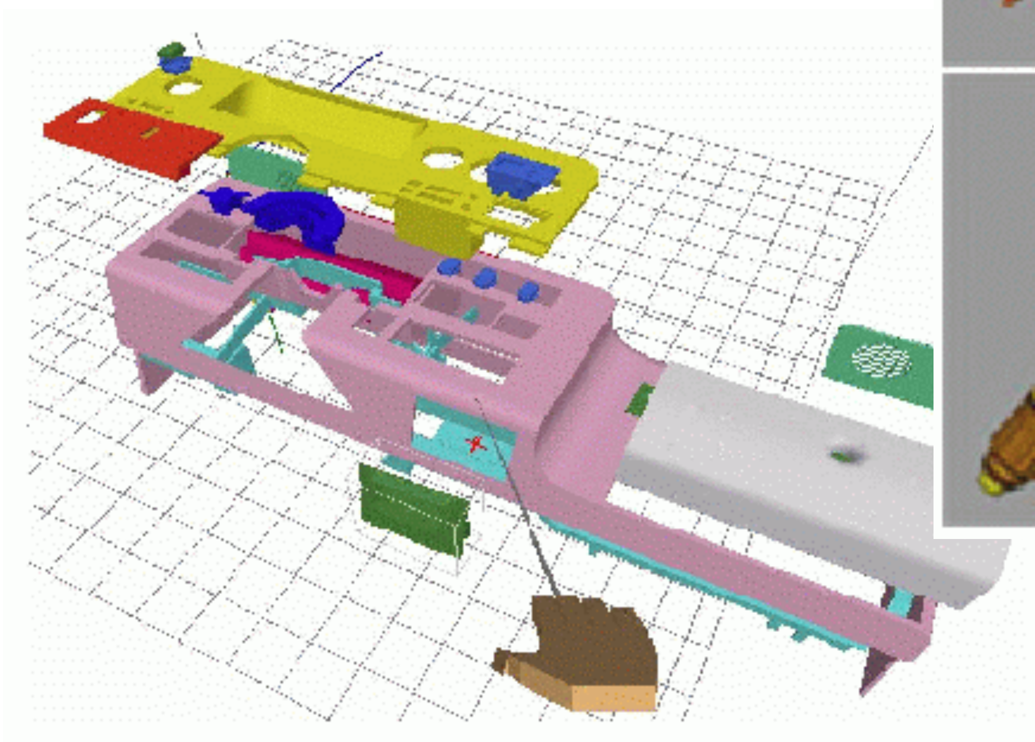
Design for Manufacturing/ Servicing

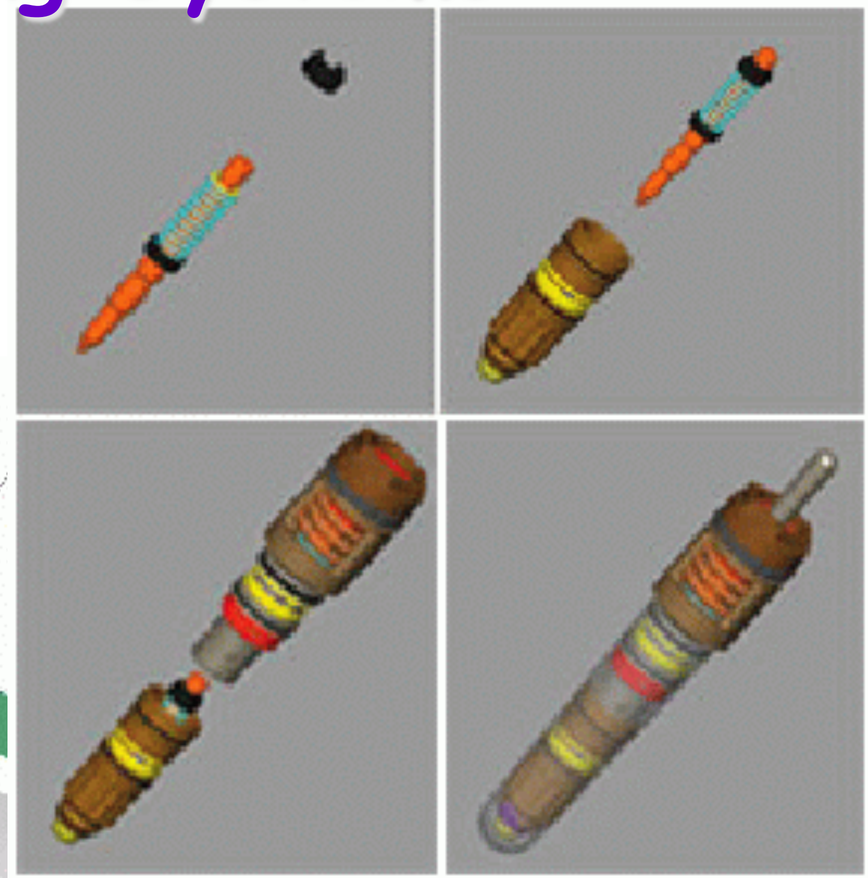






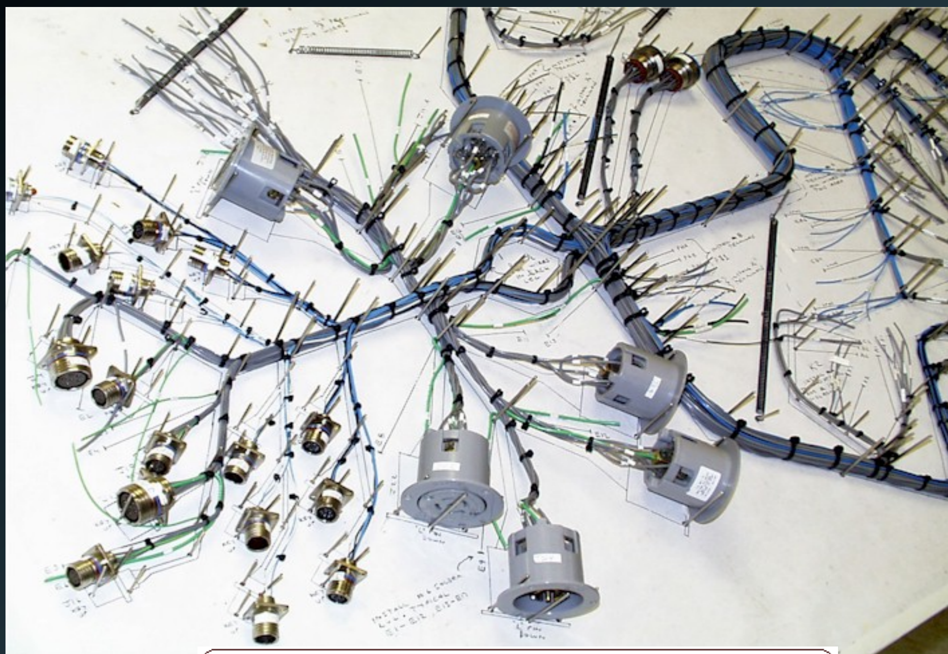
Assembly Planning and Design of Manufacturing Systems

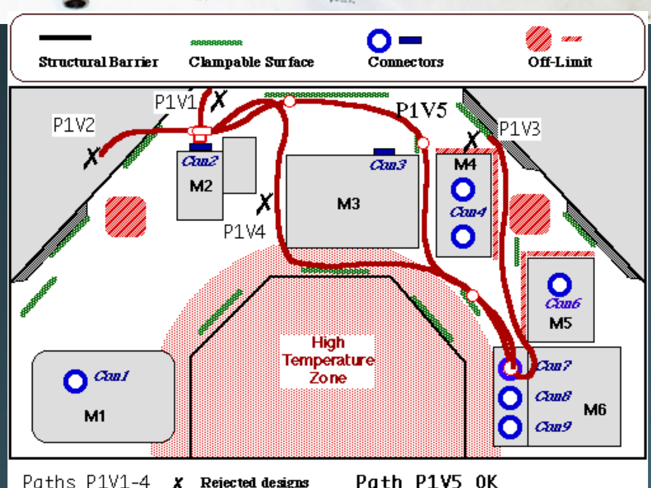




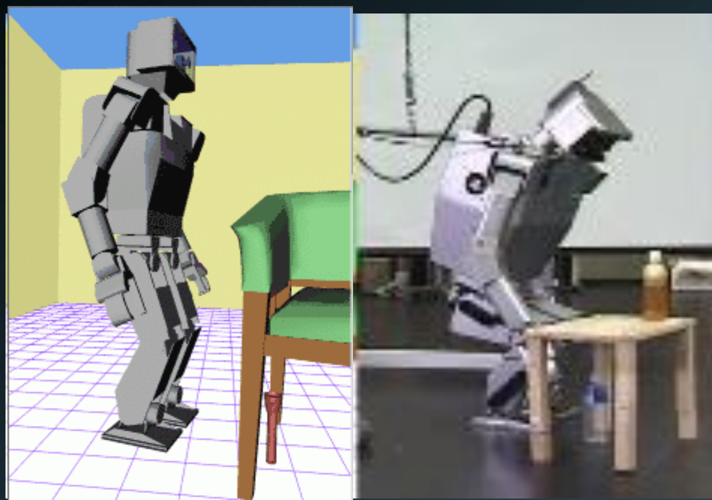
Application: Checking Building Code

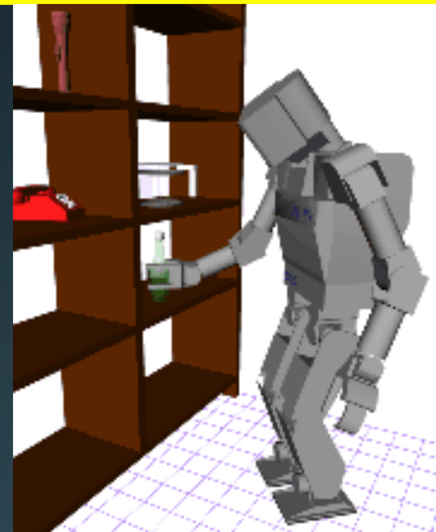
Cable Harness/ Pipe design





Humanoid Robot

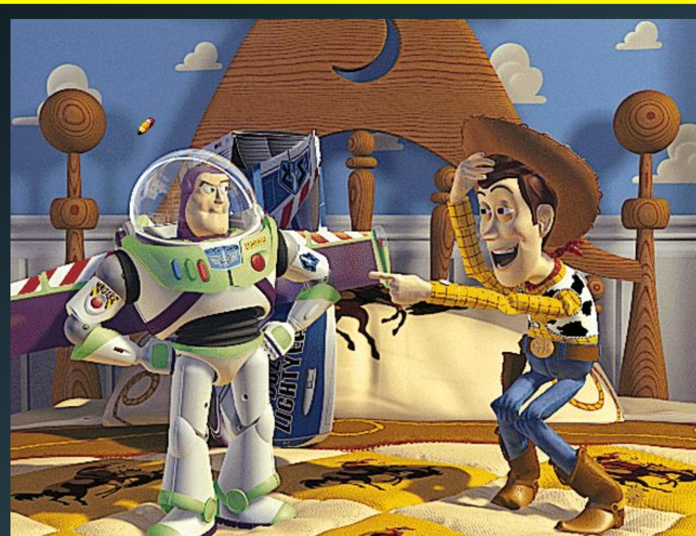




[Kuffner and Inoue, 2000] (U. Tokyo)

Digital Actors

A Bug's Life (Pixar/Disney)



Toy Story (Pixar/Disney)

Antz (Dreamworks)

Tomb Raider 3 (Eidos Interactive)

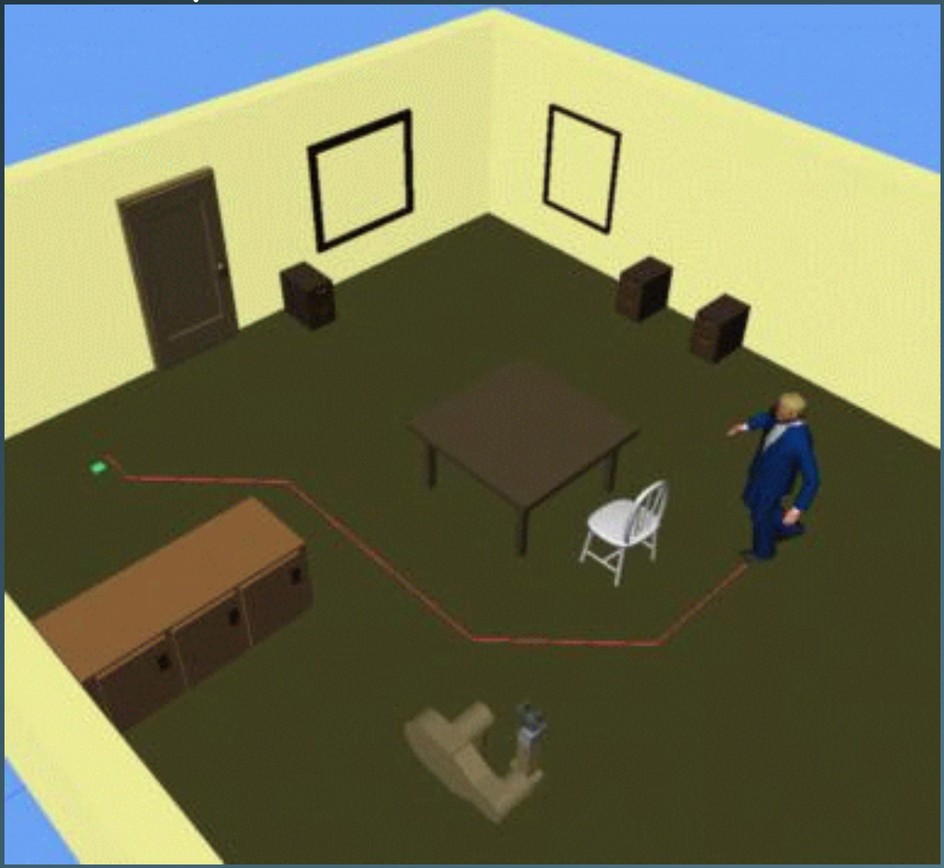
The Legend of Zelda (Nintendo)

Final Fantasy VIII (SquareOne)

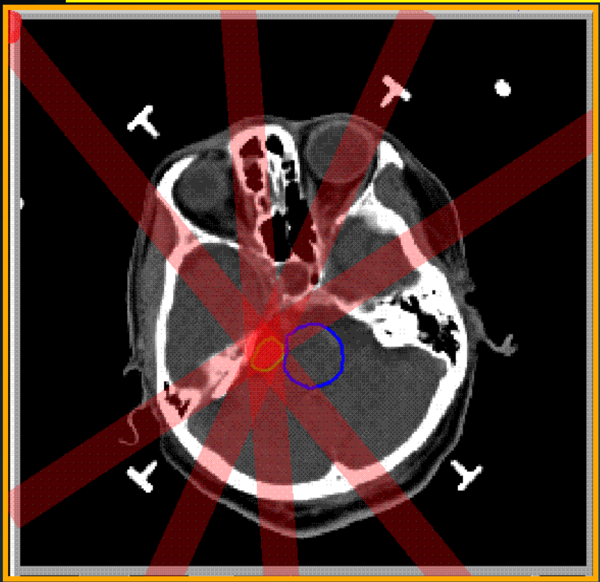
Motion Planning for Digital Actors

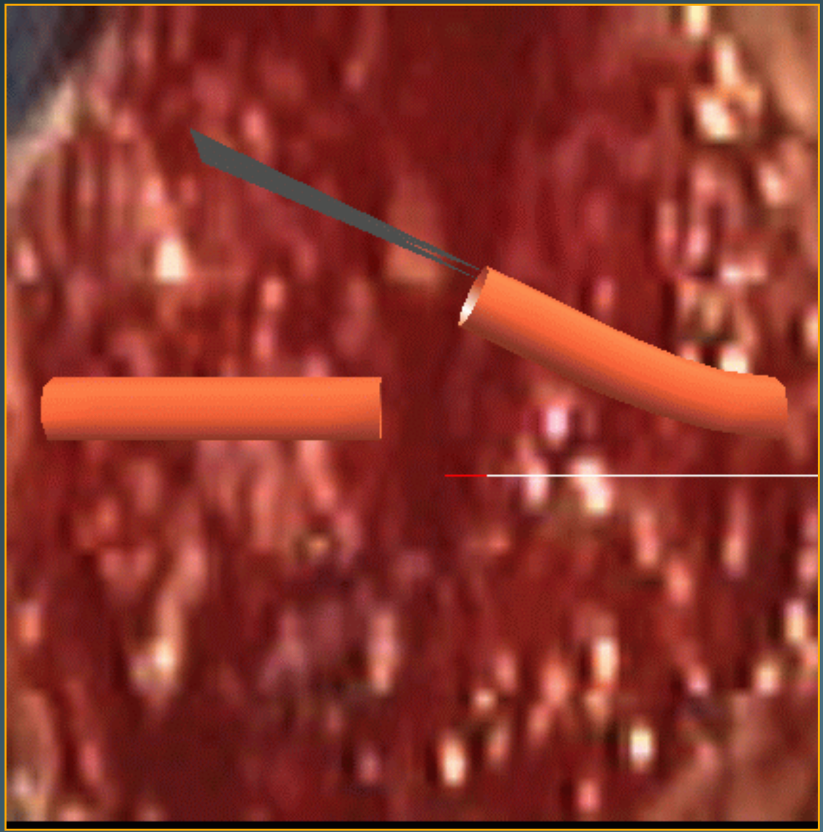
Manipulation

Sensory-based locomotion

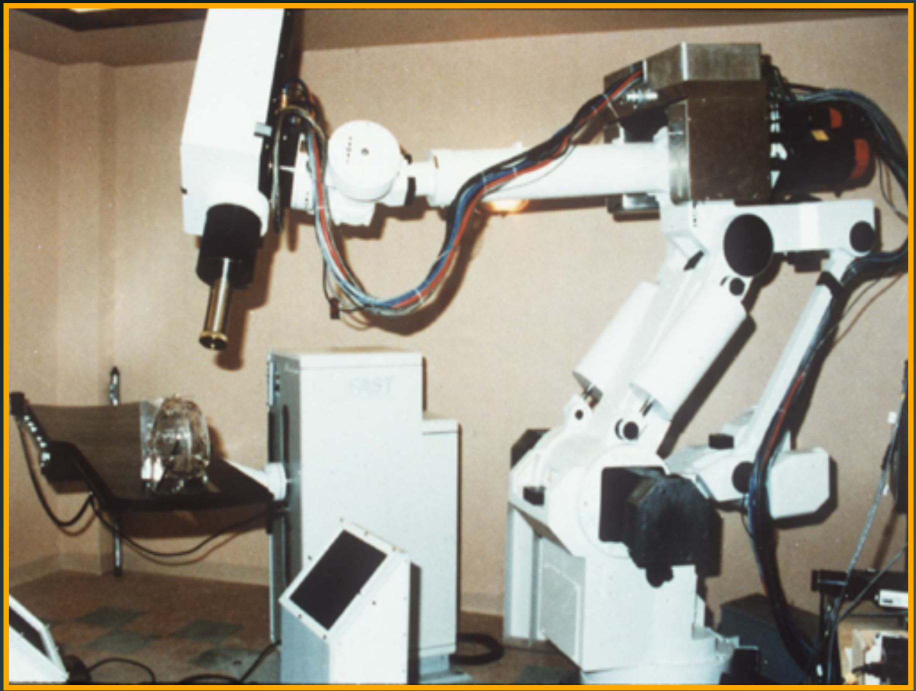


Application: Computer-Assisted Surgical Planning

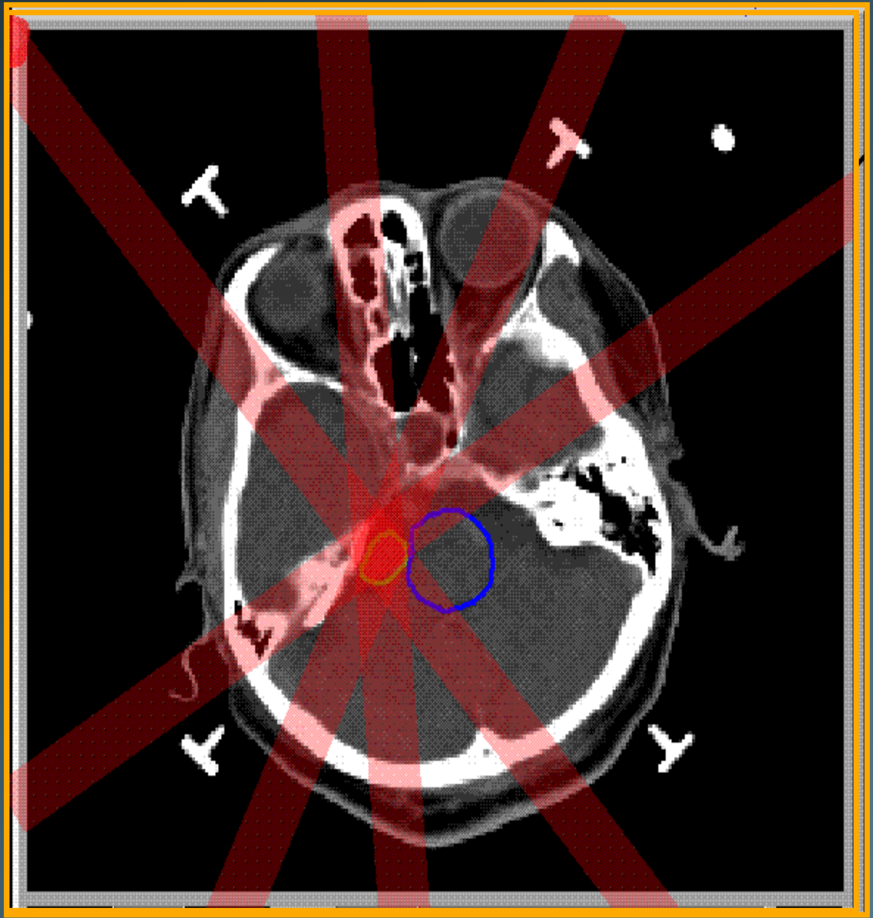




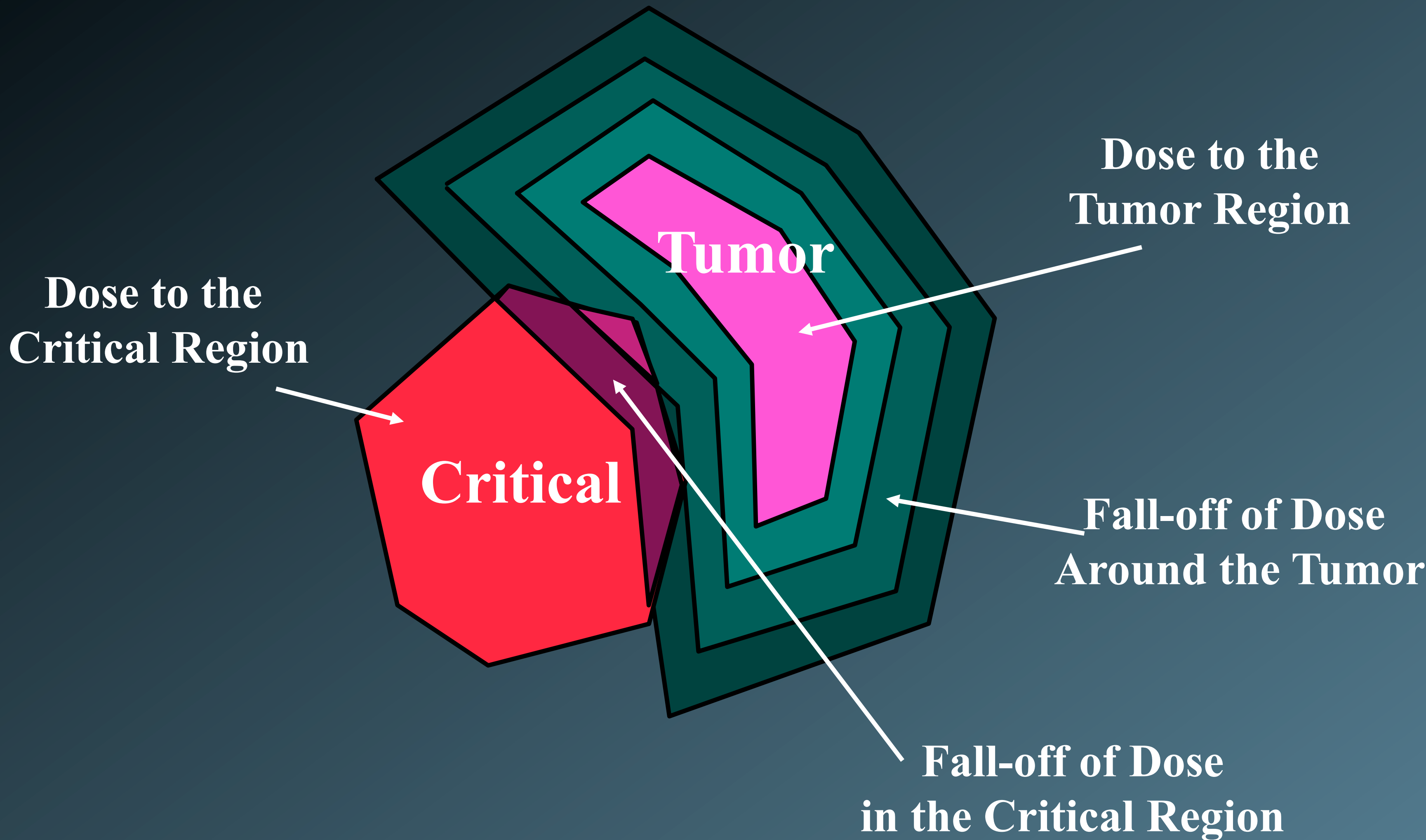
Radiosurgical Planning



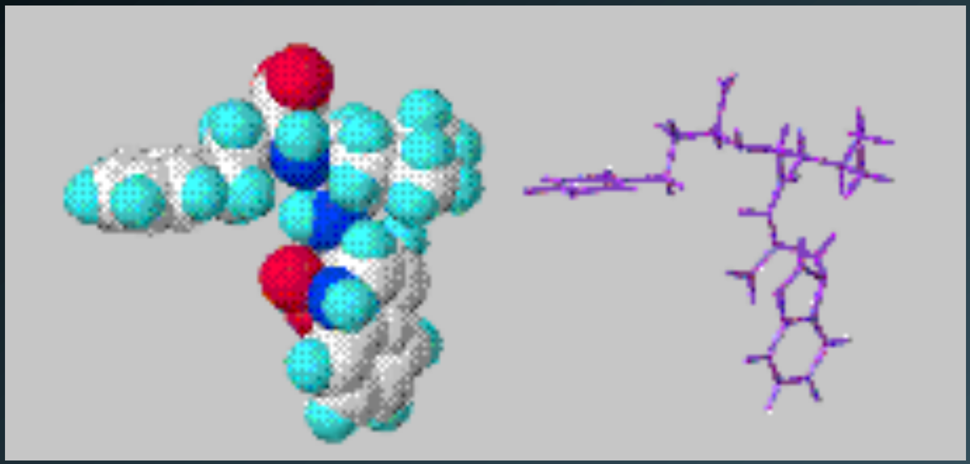
Cyberknife



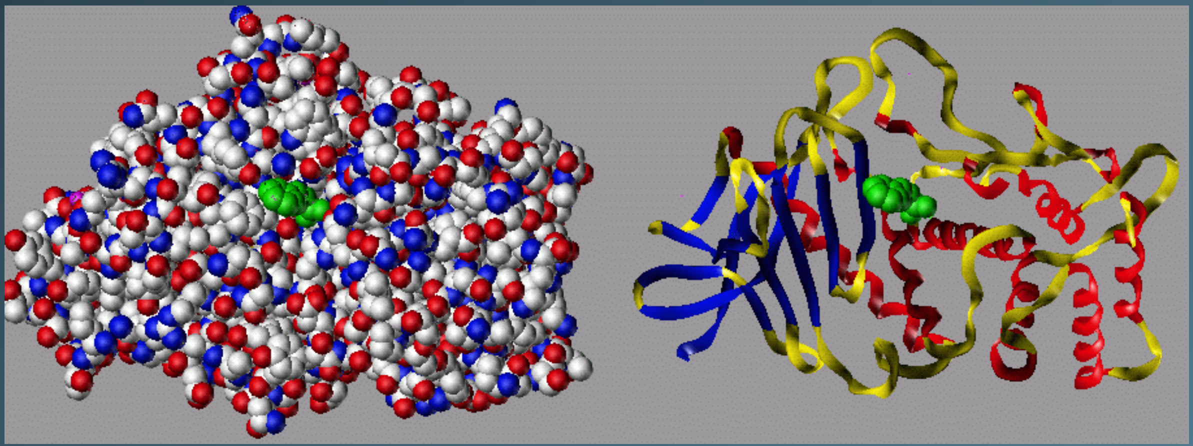
Surgeon Specifies Dose Constraints



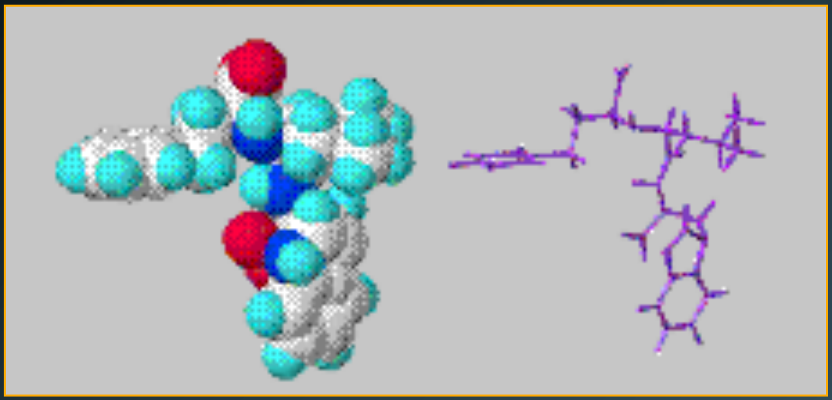
Study of the Motion of Bio-Molecules

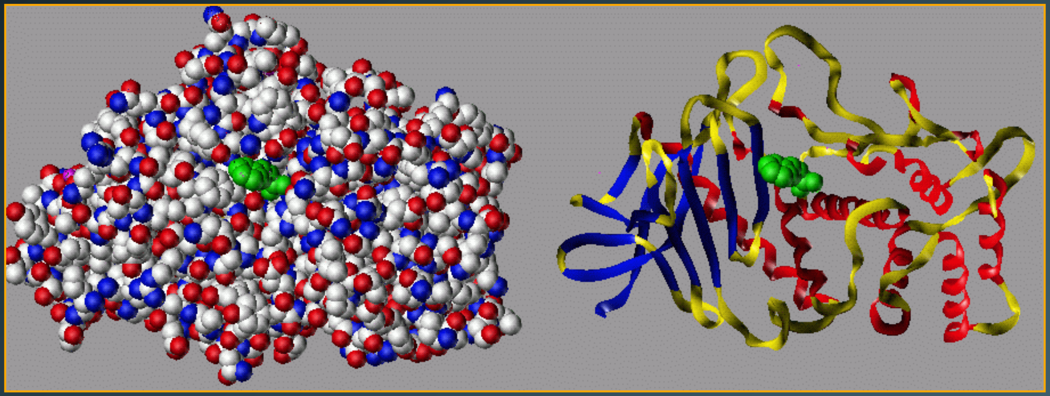


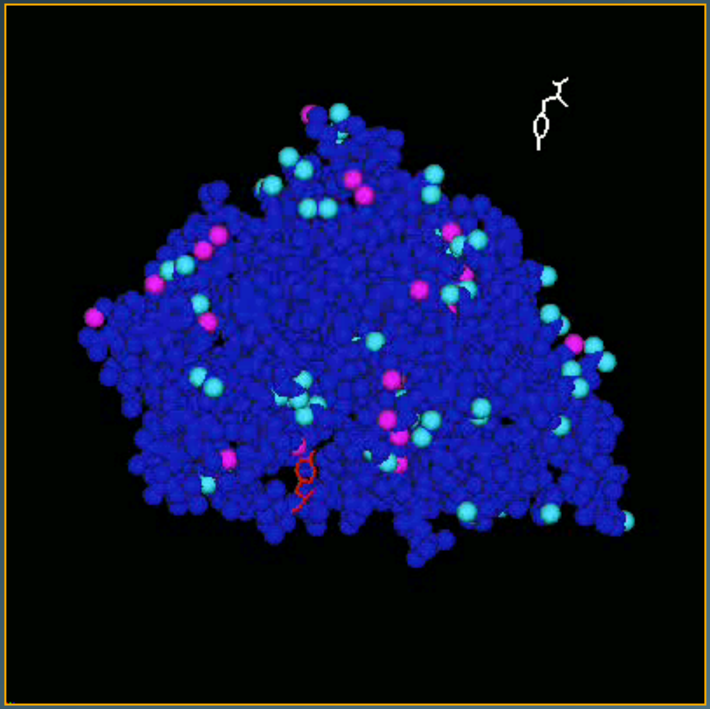
- Protein folding
- Ligand binding



Application: Prediction of Molecular Motions







DARPA Grand Challenge

Planning for a collision-free 132 mile path in a desert

What is this course about?

- ♦ Underlying geometric concepts of motion planning
  - Configuration space
- ♦ Motion planning algorithms:
  - Complete motion planning
  - Randomized approaches
- ♦ Kineodynamic (Physics) constraints
- ♦ Character motion in virtual environments
- ♦ Multi-agent and Crowd simulation
- ♦ Local and global collision avoidance

Do I have the right background?

- Undergraduate algorithms course
- Exposure to geometric concepts
- Motion dynamics (Laws of motion)
- Willingness to read about new concepts and applications!

Course Load & Grading

- 4-6 assignments (40%)
  - Geometric concepts (problems)
  - Implementing randomized motion planning algorithms
  - Multi-agent simulation: programming assignments
- Class participation and a lecture (15%)
  - Lecture topic (consult the instructor)
- Course Project (45%)

Course Project

- Any topic related to robot motion planning and multi-agent simulation
- Must have some novelty to it!
- Can work by yourself or in small groups (2-3)
- Can combine with course projects in other courses
- Start thinking now of possible course project

Course Project Schedule

- Project topic proposal (September 20)
- Monthly updates
- Mid semester project update (end of October)
- Final project presentation (During the finals week)
- Scope for extra credit + publications!

Multi-Agent Simulation

Sean Curtis

Physical Robots @ UNC: Plan Motion Strategies

Baxter Robot ($22K)

Meka Robot ($300K): Expected

Motion Planning @ UNC

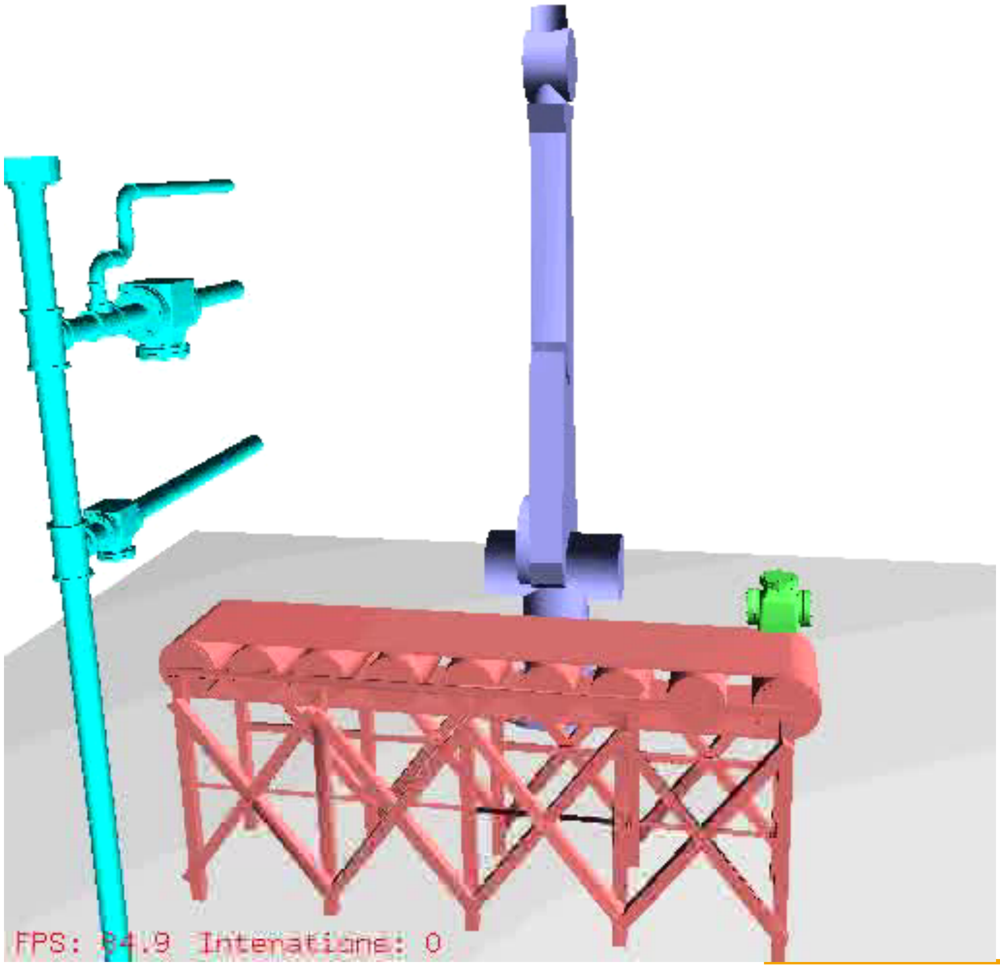
- **Robot Motion Planning**

http://gamma.cs.unc.edu/research/robotics/

- **Multi-Agent Simulation**

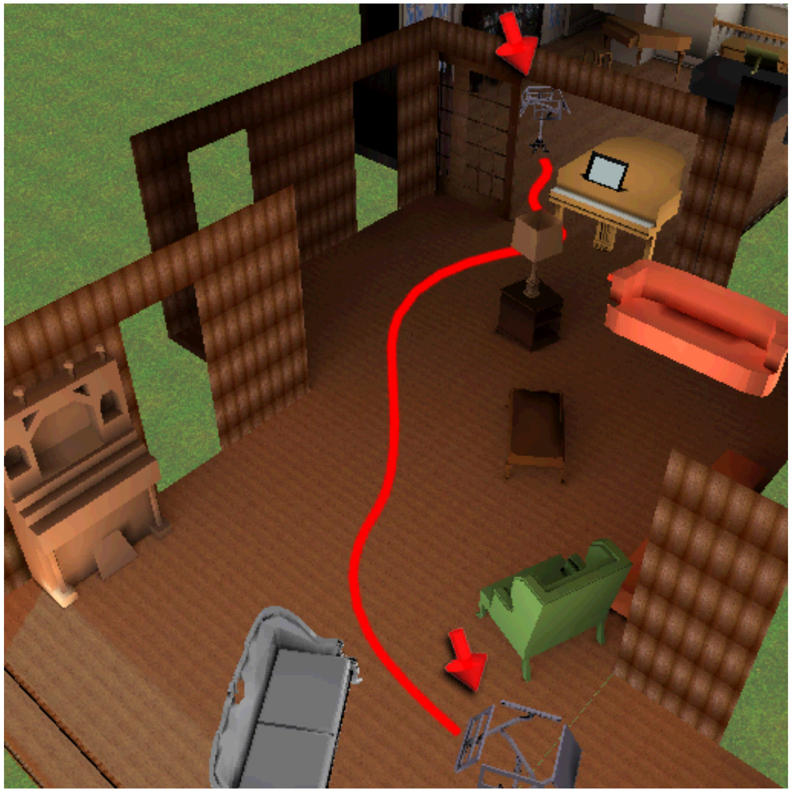
http://gamma.cs.unc.edu/research/crowds/

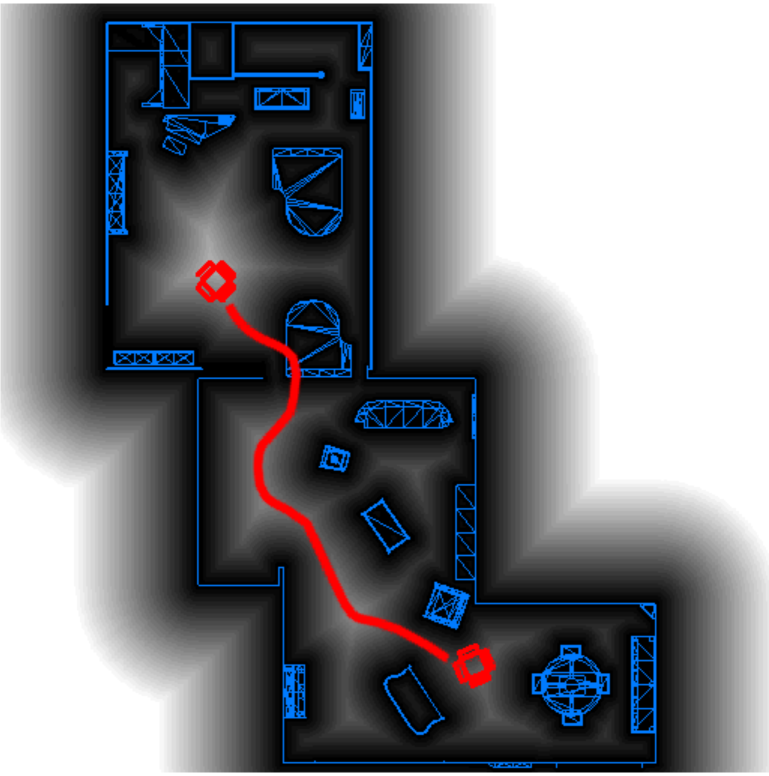
Virtual Prototyping



Motion Planning in Dynamic Environments

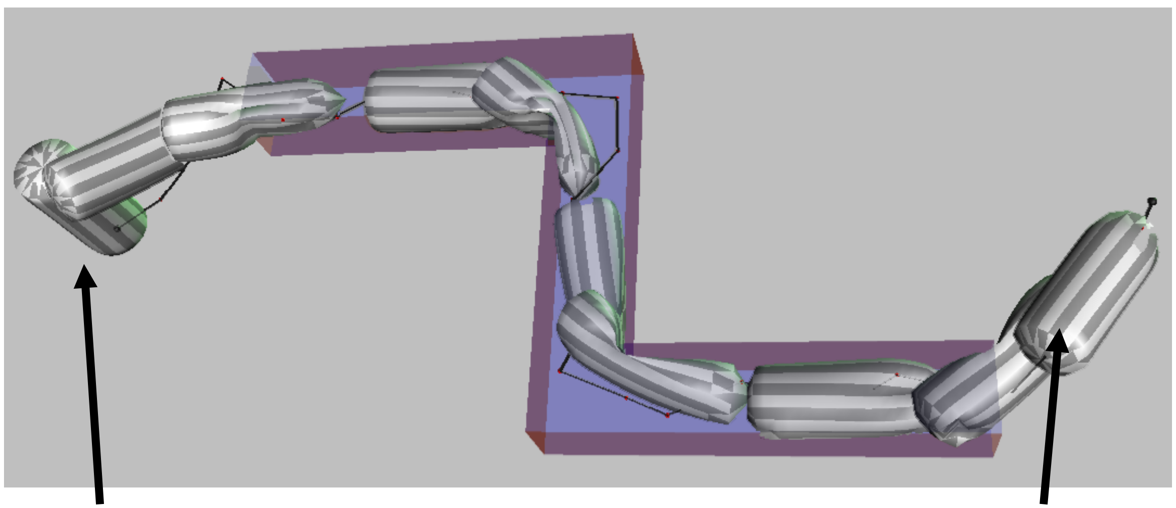
Given the initial & goal configurations, find a viable path with moving obstacles





Planning of Deformable Robots

- Extend the classical motion planning problem by allowing the robot to deform in order to follow a path while maintaining physical constraints



An example planning solution. Note that the robot must deform in order to successfully navigate the turns in the tunnel.

Starting position

Final position

Motivation

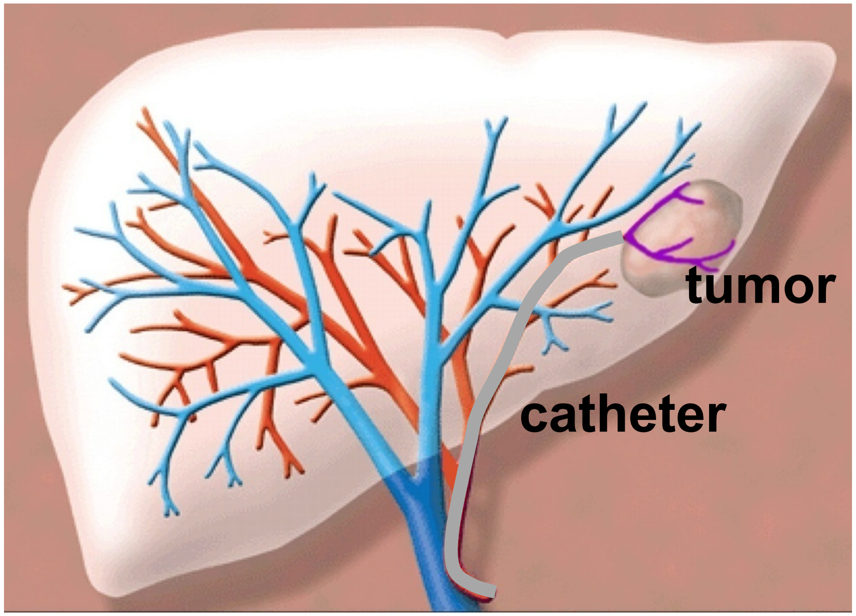
- Surgical planning
- Search and rescue
- Layout for mechanical/electrical systems in complex structures
- Planning of reconfigurable robots

Path Planning to Aid Catheterization Procedures

- In medical and surgical procedures, flexible catheters are often inserted in human vessels to
  - ♦ Obtain diagnostic information (blood pressure or flow)
  - ♦ Enhance imaging with the injection of contrast agents
  - ♦ Provide a mechanism to deliver treatment to a specific area

Liver Chemoembolization

- Catheter is used to inject chemotherapy drugs directly to the blood vessel supplying a liver tumor
- Catheter is inserted into the femoral artery (near the groin) and advanced into the selected liver artery
  - ◆ **A fluoroscopic display and the resistance felt from the catheter are used to determine how it should be advanced, withdrawn, or rotated**
- Chemotherapy drugs followed by embolizing agents are injected through the catheter into the liver tumor



Liver Chemoembolization

- During this procedure, careful selection and manipulation of catheters is essential
  - **Reduced flow and the possibility of reflux of the chemotherapy agent into other arteries may occur if the catheter has a cross-sectional area close to that of the vessel being traversed**
  - **Spasms frequently result from the movement of catheters in small vessels, which can also reduce flow in the catheter**

Planning for Liver Chemoembolization

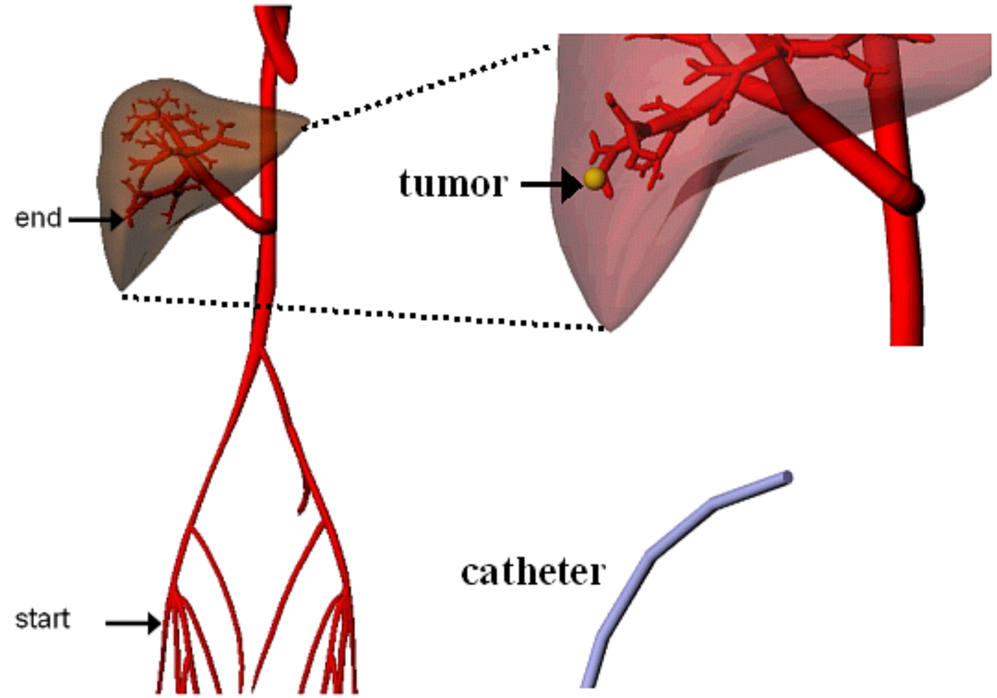
- Accurate motion planning studies with deformable models can provide a vital tool to aid in the catheterization procedure
- Preoperatively, they may be used as part of surgical planning techniques to ***help choose the size and properties of the catheter*** used
- During the actual procedure, they can be used ***to compute the optimal path of the catheter*** to the targeted area, ensuring the best possible outcome for the patient

Motion Planning Application

- **We have been investigating the application of our algorithm to plan the path of a flexible catheter, inserted at the femoral artery, to a specific liver artery supplying a tumor**

◆ **Environment:** 3D models of the liver and blood vessels obtained from the 4D NCAT phantom, a realistic computer model of the human body

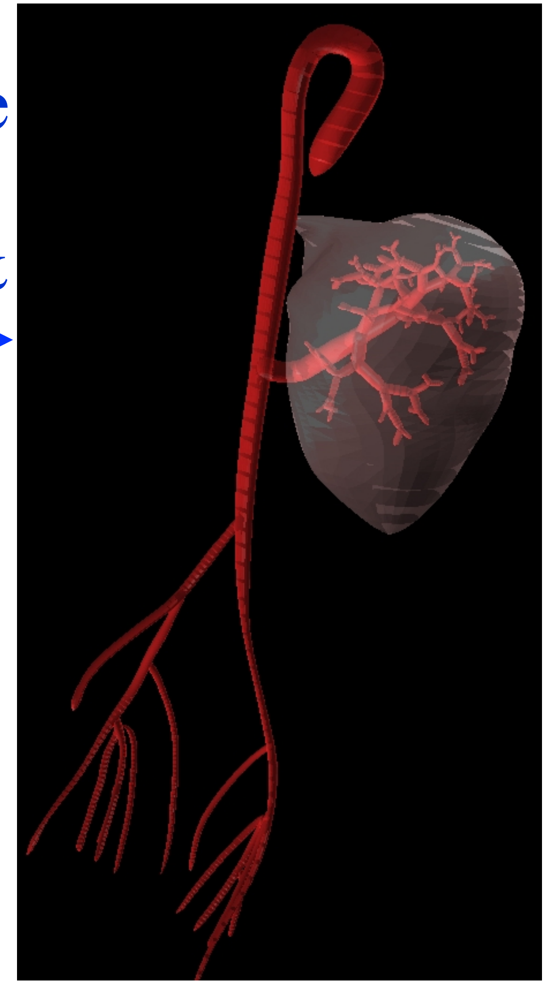
◆ **Deformable robot:** Catheter was modeled as a cylinder with a length of 100 cm and a diameter of 1.35 mm



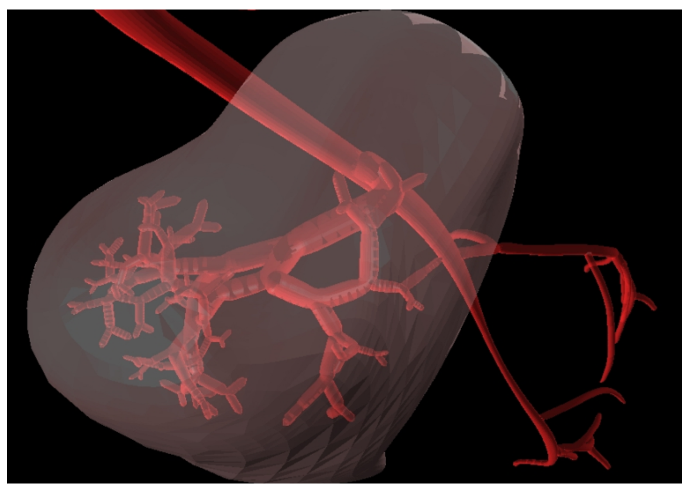
Benchmark: Liver

A catheter enters the left artery.

A bird’s eye view of the entire live & arteries →



A closer view of liver and its internal arteries



Motion Planning for Catheterization Procedures

Path Planning for
Deformable Robots in
Complex Environments