CTU

CZECH TECHNICAL UNIVERSITY IN PRAGUE

Robotics: Task and Motion Planning

Vladimír Petrík

vladimir.petrik@cvut.cz

13.11.2023

Motivation

- We know how to plan motion for a robot in robot's configuration space
  - manually define handle on object
  - computer grasp and pre-grasp for detected object's pose
  - plan motion to pre-grasp
  - interpolate to grasp, grasp
  - interpolate to pre-grasp
  - plan motion to pre-place, place, release, pre-place

Motivation

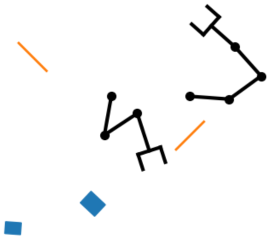
- We know how to plan motion for a robot in robot's configuration space
  - manually define handle on object
  - computer grasp and pre-grasp for detected object's pose
  - plan motion to pre-grasp
  - interpolate to grasp, grasp
  - interpolate to pre-grasp
  - plan motion to pre-place, place, release, pre-place
- What if we have many handles? Many objects?
- **Manipulation Task and Motion Planning (TAMP)**

Motivation

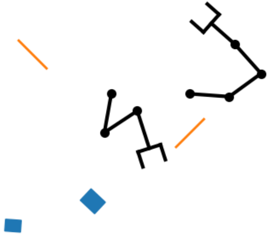
- We know how to plan motion for a robot in robot's configuration space
  - manually define handle on object
  - computer grasp and pre-grasp for detected object's pose
  - plan motion to pre-grasp
  - interpolate to grasp, grasp
  - interpolate to pre-grasp
  - plan motion to pre-place, place, release, pre-place
- What if we have many handles? Many objects?
- **Manipulation Task and Motion Planning (TAMP)**
  - simultaneously plan task and motion solutions
  - task is the sequence of grasps and placements (discrete space)
  - motion is the sequence of robot configurations (continuous space)
  - Humanoid Path Planning (HPP) software approach

Configuration Space

- Multiple grippers connected to robots
- Environment surfaces that can be used for placing an object
- Multiple objects
  - multiple handles per object
  - multiple contact surfaces per object

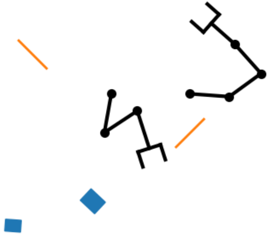


Configuration Space



- Multiple grippers connected to robots
- Environment surfaces that can be used for placing an object
- Multiple objects
  - multiple handles per object
  - multiple contact surfaces per object
- Configuration space is the set of all possible configurations of all objects and robots
  - $\mathcal{C} = \mathbb{R}^{N_1} \times \mathbb{R}^{N_2} \ldots \times SE(3)^M$
  - N_i DoF of the i-th robot
  - M number of objects

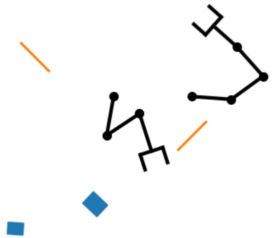
Configuration Space



- Multiple grippers connected to robots
- Environment surfaces that can be used for placing an object
- Multiple objects
  - multiple handles per object
  - multiple contact surfaces per object
- Configuration space is the set of all possible configurations of all objects and robots
  - $\mathcal{C} = \mathbb{R}^{N_1} \times \mathbb{R}^{N_2} \ldots \times SE(3)^M$
  - N_i DoF of the i-th robot
  - M number of objects
  - however, not all configuration are feasible
  - constraints are used to define feasible configurations

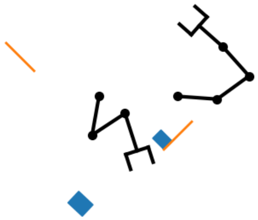
Constraints

- Object is placed or grasped, i.e. cannot fly

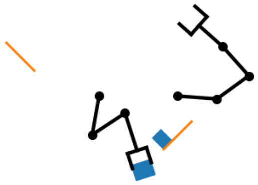


Constraints

- Object is placed or grasped, i.e. cannot fly
- Placement constraint
  - object lies on a surface
  - numerical constraints
  - **object surface** is placed on an **environment surface**



Constraints



- Object is placed or grasped, i.e. cannot fly
- Placement constraint
  - object lies on a surface
  - numerical constraints
  - **object surface** is placed on an **environment surface**
- Grasp constraint
  - object is grasped by a gripper
  - numerical constraint
  - **handle frame** equals **gripper frame**

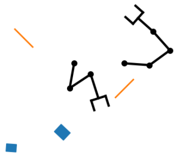
Stav (state)

- State is a set of constraints
- Manifold of feasible configurations in the configuration space
- For example, one state can be defined by constraining both objects
  - object O_1 is placed on the surface E_1 via object surface S_1
  - object O_2 is grasped by the gripper G_1 via handle H_1

Stav (state)

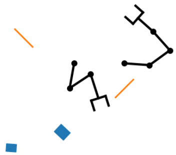
- State is a set of constraints
- Manifold of feasible configurations in the configuration space
- For example, one state can be defined by constraining both objects
  - object O_1 is placed on the surface E_1 via object surface S_1
  - object O_2 is grasped by the gripper G_1 via handle H_1
- How to sample configuration from a state?
  - sample from the $\mathcal{C}$
  - geometric projection to satisfy all the constraints
  - numerical optimization (Newton-Raphson) to satisfy all the constraints

Sampling from states

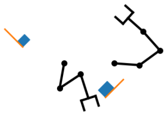


Sample from $\mathcal{C}$

Sampling from states

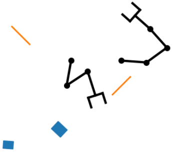


Sample from $\mathcal{C}$

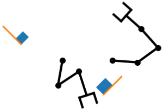


- Project to state:
  - O_1 placed on E_1 via S_1
  - O_2 placed on E_2 via S_1

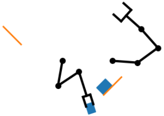
Sampling from states



Sample from $\mathcal{C}$



- Project to state:
  - O_1 placed on E_1 via S_1
  - O_2 placed on E_2 via S_1



- Project to state:
  - O_1 grasped by G_1 via H_1
  - O_2 placed on E_2 via S_1

Transitions

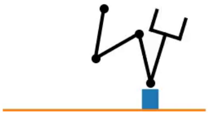
- Transition defines motion between two states
  - identity transition allows to move robot inside the state
  - place transition allows to move object from the gripper to the surface
  - grasp transition allows to move object from the surface to the gripper

Transitions

- Transition defines motion between two states
  - identity transition allows to move robot inside the state
  - place transition allows to move object from the gripper to the surface
  - grasp transition allows to move object from the surface to the gripper
- Sampling on transitions vs sampling on states
  - transition respect constraints from the given state
  - for example, identity on place state will not move object (sampling on state can move object)
  - grasp transition is specified to move via pre-grasp
  - place transition is specified to move via pre-place

Interpolation on transition

- Interpolate between two configurations but respect constraints of the states/transition



Identity on place

Interpolation on transition

- Interpolate between two configurations but respect constraints of the states/transition

Identity on place

Identity on grasp

Interpolation on transition

- Interpolate between two configurations but respect constraints of the states/transition

Grasp

Interpolation on transition

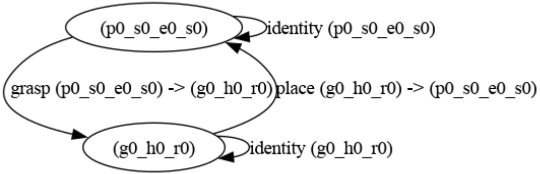
- Interpolate between two configurations but respect constraints of the states/transition

Grasp

Place

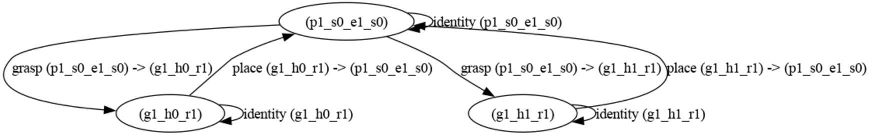
Constraint graph

- Defines all possible transitions between existing states
- Example: single arm, one object



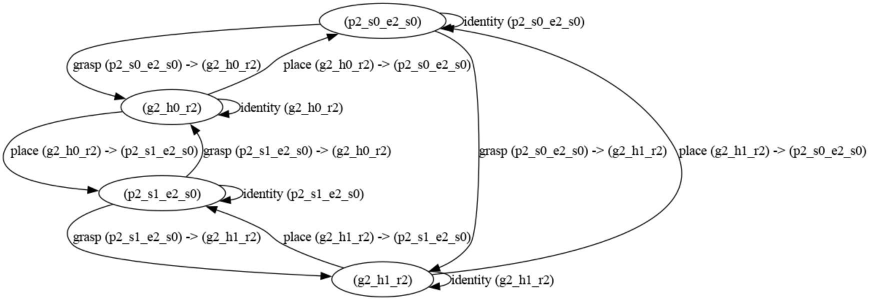
Constraint graph

- Defines all possible transitions between existing states
- Example: single arm, one object



Constraint graph

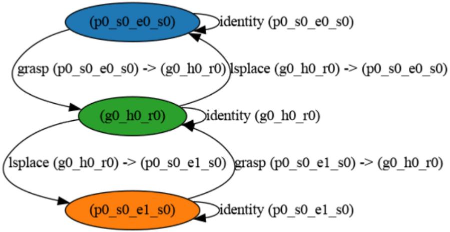
- Defines all possible transitions between existing states
- Example: single arm, one object

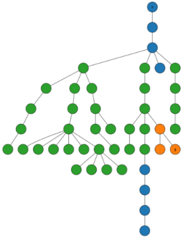


RRT on constraint graph

- Random sampling q_{rand}
  - sample random transition
  - select random existing configuration from the transition source
  - sample random configuration from the transition target reachable from beginning
- Nearest neighbor q_{tree}
  - node that is closest to q_{rand} via interpolation on the transition
- Local planner uses interpolation on transition

RRT on constraint graph





Conclusion

- Configuration space for TAMP is complex
  - discrete set of states
  - continuous motion
  - encoded by constraint graph that allow us to use RRT

Conclusion

- Configuration space for TAMP is complex
  - discrete set of states
  - continuous motion
  - encoded by constraint graph that allow us to use RRT
- Usually not used in industry
  - task space sequence is hard-coded by programmers
  - only motion is found by motion planners (if cannot be hard-coded)

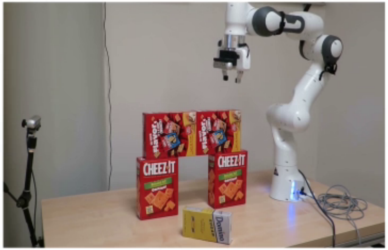
Conclusion

- Configuration space for TAMP is complex
  - discrete set of states
  - continuous motion
  - encoded by constraint graph that allow us to use RRT
- Usually not used in industry
  - task space sequence is hard-coded by programmers
  - only motion is found by motion planners (if cannot be hard-coded)
- How to avoid hard-coding? Video demonstration.

Conclusion

Multi-Contact Task and Motion Planning Guided by Video Demonstration

Kateryna Zorina ♣ David Kovar ♣ Florent Lamiraux ♢ Nicolas Mansard ♢
Justin Carpentier ♥ Josef Sivic ♣ Vladimir Petrik ♣



♣ CIIRC, Czech Technical University in Prague
♢ LAAS-CNRS, Universite de Toulouse, CNRS, Toulouse
♥ INRIA, Paris

Laboratories

- Consultation on the final project
- Final project is now described on the course web page
- New interface for Bosch robot [optional]
  - fixed FK, IK
  - you can install it on your computer, to use FK and IK offline for debugging