Planning Techniques for Robotics

Planning Representations:
Lattice-based Graphs, Explicit vs. Implicit Graphs

Maxim Likhachev
Robotics Institute
Carnegie Mellon University
Beyond Planning for Omnidirectional Robots

*What’s wrong with using Grid-based Graphs when planning for non-omnidirectional robots?*
Beyond Planning for Omnidirectional Robots

What’s wrong with using Grid-based Graphs when planning for non-omnidirectional robots?

“Can’t turn in place”

e.g., constraints on the minimum turning radius (still **kinematic** planning)

e.g., constraints on turning rate (rate of change in wheel orientation) and inertial constraints (**kinodynamic** planning)
What’s wrong with using Grid-based Graphs when planning for non-omnidirectional robots?

“Can’t turn in place”

e.g., constraints on the minimum turning radius (still *kinematic* planning)
e.g., constraints on turning rate (rate of change in wheel orientation) and inertial constraints (*kinodynamic* planning)

**Kinodynamic planning:**
Planning representation includes \( \{X, \dot{X}\} \), where \( X \)-configuration and \( \dot{X} \)-derivative of \( X \) (dynamics of \( X \))
Beyond Planning for Omnidirectional Robots

$(x,y,\theta,v)$ planning

with Anytime $D^*$ (Anytime Incremental $A^*$) on Lattice Graphs
Beyond Planning for Omnidirectional Robots

\((x,y,\Theta)\) planning with ARA*-based algorithm on Lattice Graphs

Joint work with V. Kumar (Upenn), I. Kaminer (NPS) and V. Dobrokhodov (NPS)
[thakur et al., ‘13]
Lattice Graphs

- Graph $\{V, E\}$ where
  - $V$: centers of the grid-cells
  - $E$: motion primitives that connect centers of cells via short-term feasible motions

Each transition is feasible (typically, constructed beforehand)

Motion primitives

Outcome state is the center of the corresponding cell in a grid
Lattice Graphs

- Graph \( \{V, E\} \) where
  - \( V \): centers of the grid-cells
  - \( E \): motion primitives that connect centers of cells via short-term feasible motions

motion primitives

replicate it during planning to generate lattice graph
Lattice Graphs

- Graph \( \{V, E\} \) where
  - \( V \): centers of the grid-cells
  - \( E \): motion primitives that connect centers of cells via short-term feasible motions

**motion primitives**

How do edge costs get assigned?

replicate it during planning to generate lattice graph
Lattice Graphs

- **Board example** for \((x,y,\Theta)\) planning for a unicycle model (minimum turning radius)
1. Construct a graph representing the planning problem

2. Search the graph for a (hopefully, close-to-optimal) path

The two steps above are often interleaved
1. Construct a graph representing the planning problem

2. Search the graph for a (hopefully, close-to-optimal) path

The two steps above are often interleaved
Interleaving Search and Graph Construction

Graph Search using an **Explicit Graph** (allocated prior to the search itself):

1. *Create the graph* $G = \{V, E\}$ *in-memory*

2. *Search the graph*

**Using Explicit Graphs**

*is typical for low-D (i.e., 2D) problems in Robotics (with the exception of PRMs, covered in a later lecture)*
Interleaving Search and Graph Construction

Graph Search using an **Implicit Graph** (allocated as needed by the search):

1. *Instantiate Start state*

2. *Start searching with the Start state using functions*

   a) \textit{Succs} = \textit{GetSuccessors} (State \( s \), Action)
   
b) \textit{ComputeEdgeCost} (State \( s \), Action \( a \), State \( s' \))

and allocating memory for the generated states

*Using Implicit Graphs is critical for most (>2D) problems in Robotics*
Interleaving Search and Graph Construction

- **Board example** for deciding whether to use an Explicit graph or Implicit graph

- Planning for \((x,y,\Theta,v)\) for
  - 20 by 20 m environment discretized into 25 cm cells with 8 heading \(\Theta\) values and 2 velocity \(v\) values for a point robot

*Is it feasible to use Explicit Graph (memory and pre-computation time reqs)?*
Interleaving Search and Graph Construction

- **Board example** for deciding whether to use an Explicit graph or Implicit graph

- Planning for \((x,y,\Theta,v)\) for
  - 200 by 200 m environment discretized into 25 cm cells with 16 heading \(\Theta\) values and 2 velocity \(v\) values for a real vehicle

**Is it feasible to use Explicit Graph (memory and pre-computation time reqs)?**
What You Should Know…

• What are Lattice graphs and how they get constructed

• Explicit vs. Implicit graphs and pros/cons of each