16-350
Planning Techniques for Robotics

Case Study:
Planning for
Mobile Manipulation and Articulated Robots

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Two Examples

- Planning for Mobile Manipulation
- Planning for Articulated Robots

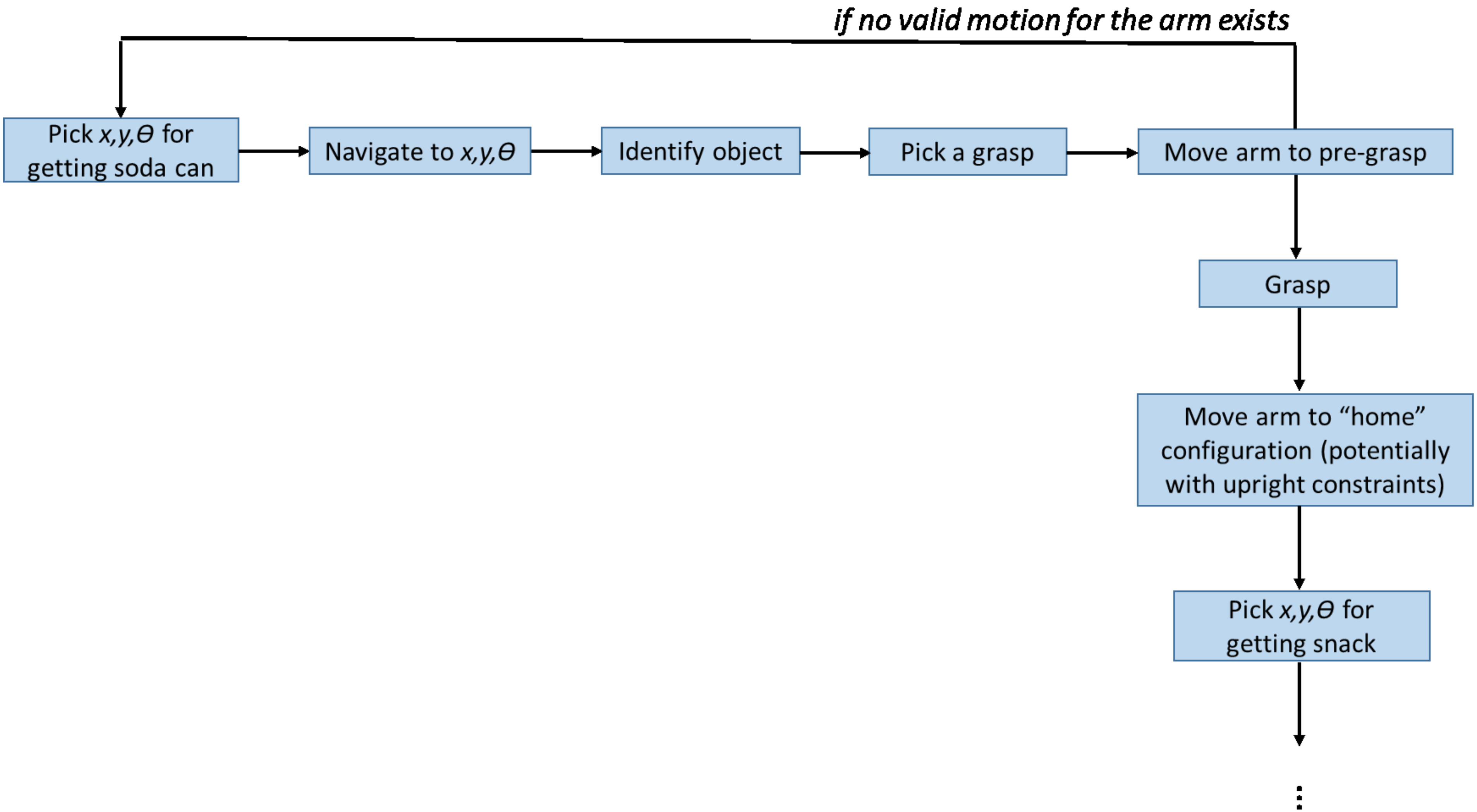
Two Examples

- Planning for Mobile Manipulation
- Planning for Articulated Robots

Robotic Bartender Demo ([Phillips et al.])

- Robot takes in a command from User Interface as to what soda can and snack to deliver

Typical Sequence of Operations (State Machine)



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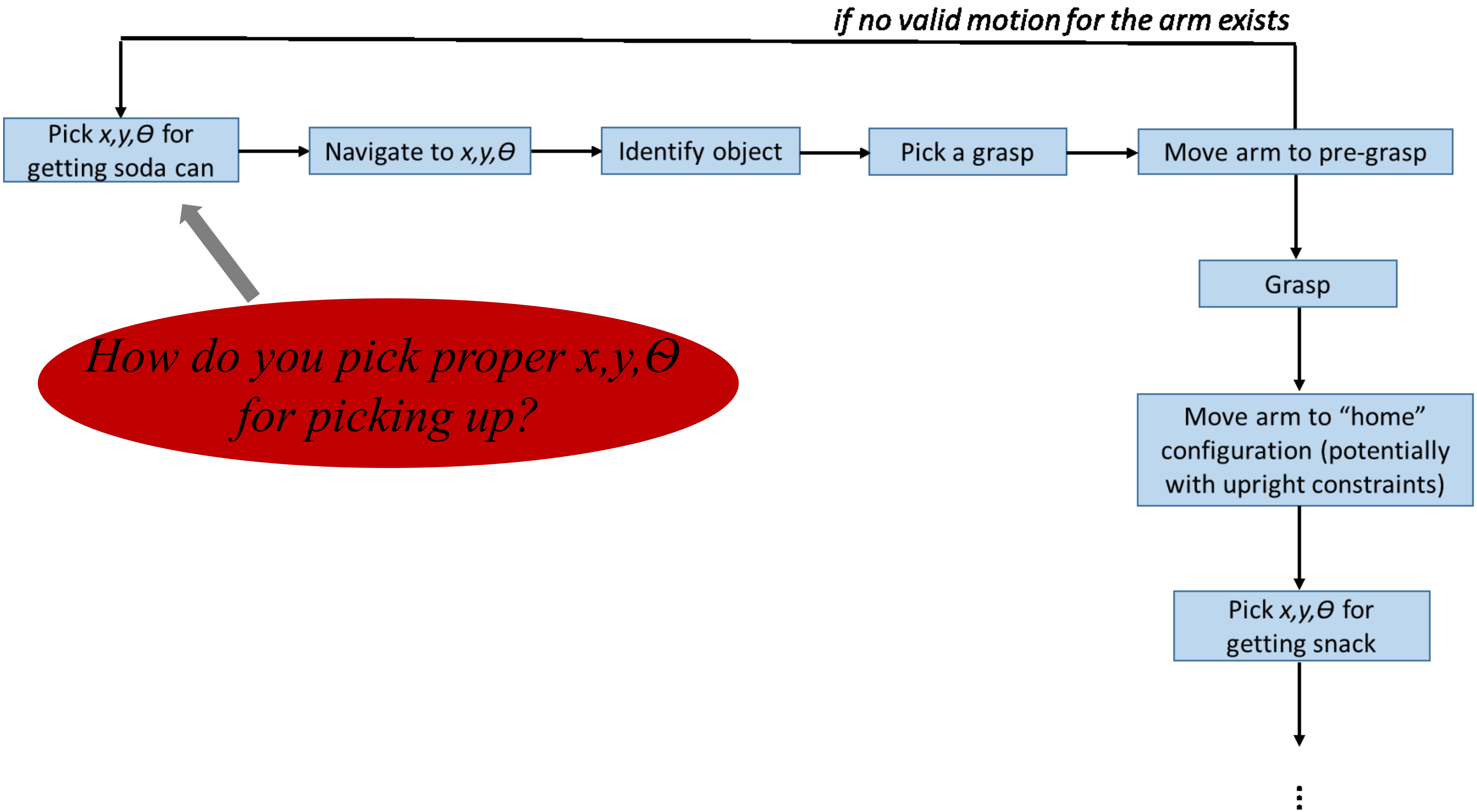

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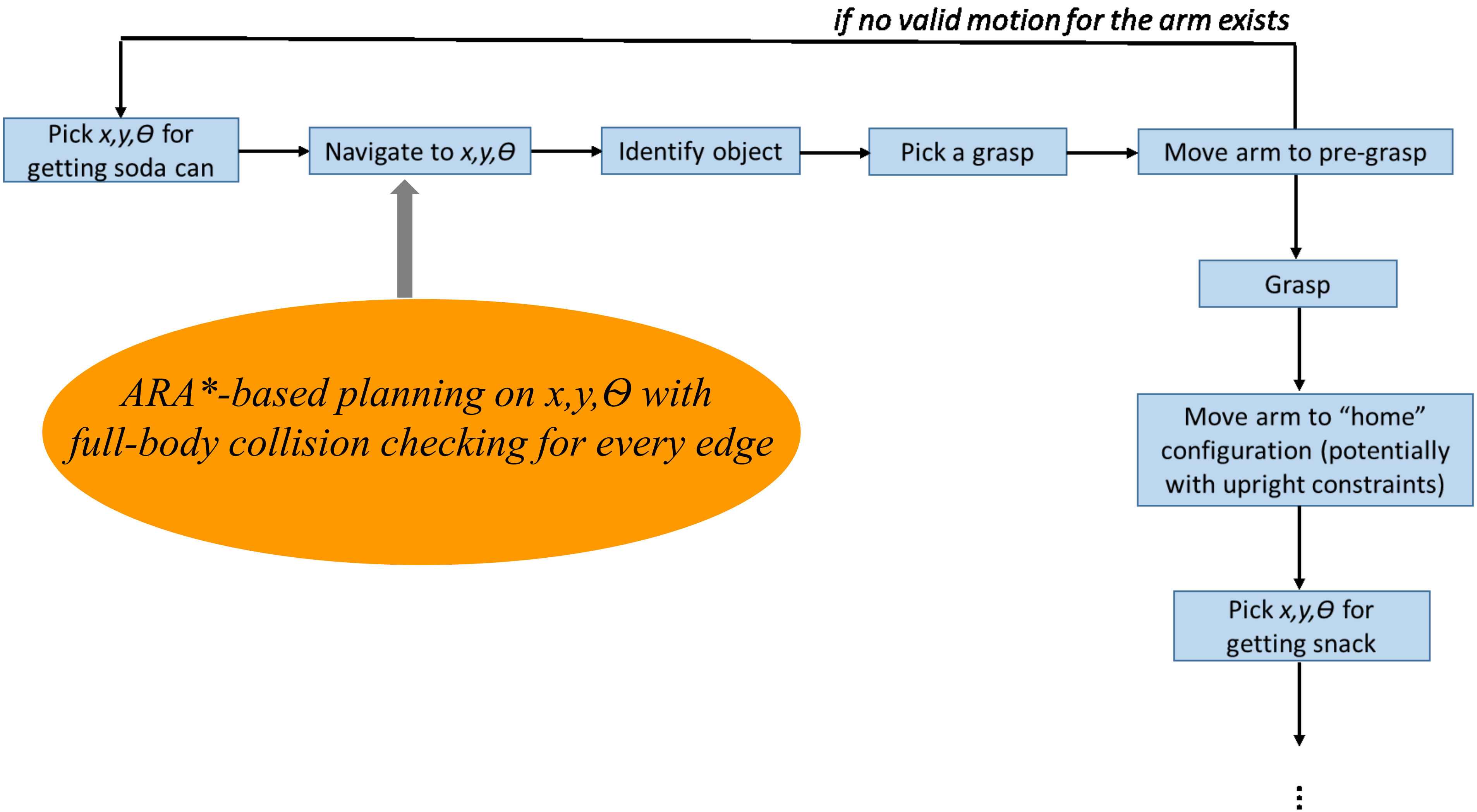
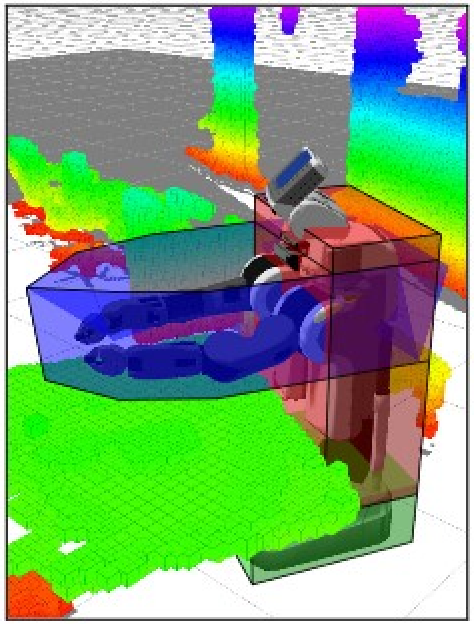


Graph for Navigation with Complex 3D Body [Hornung et al., '12]

- 3D (x,y,θ) lattice-based graph representation for full-body collision checking
  - takes set of motion primitives as input
  - takes N footprints of the robot defined as polygons as input
  - each footprint corresponds to the projection of a part of the body onto x,y plane
  - collision checking/cost computation is done for each footprint at the corresponding projection of the 3D map



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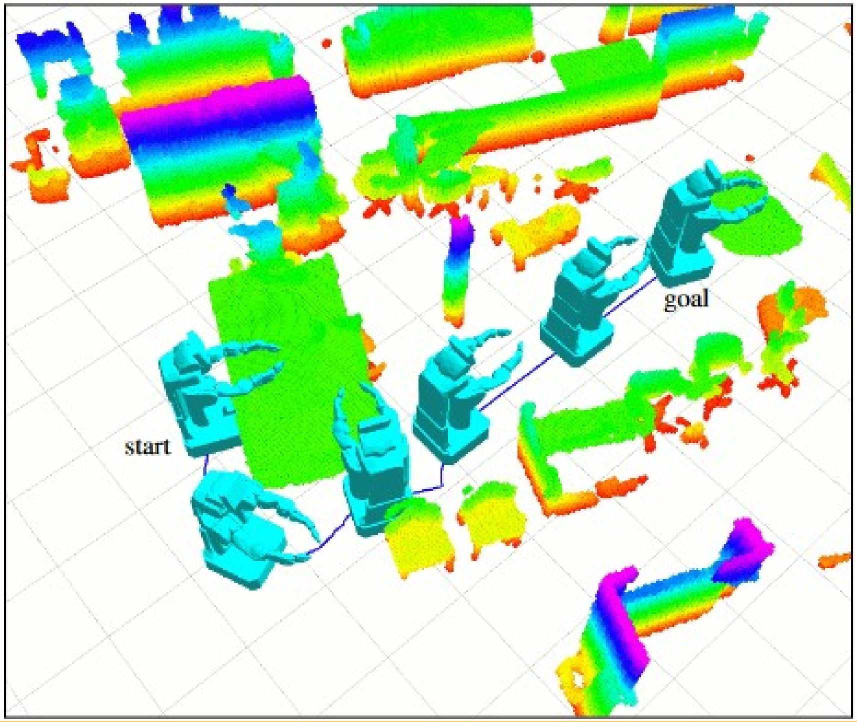

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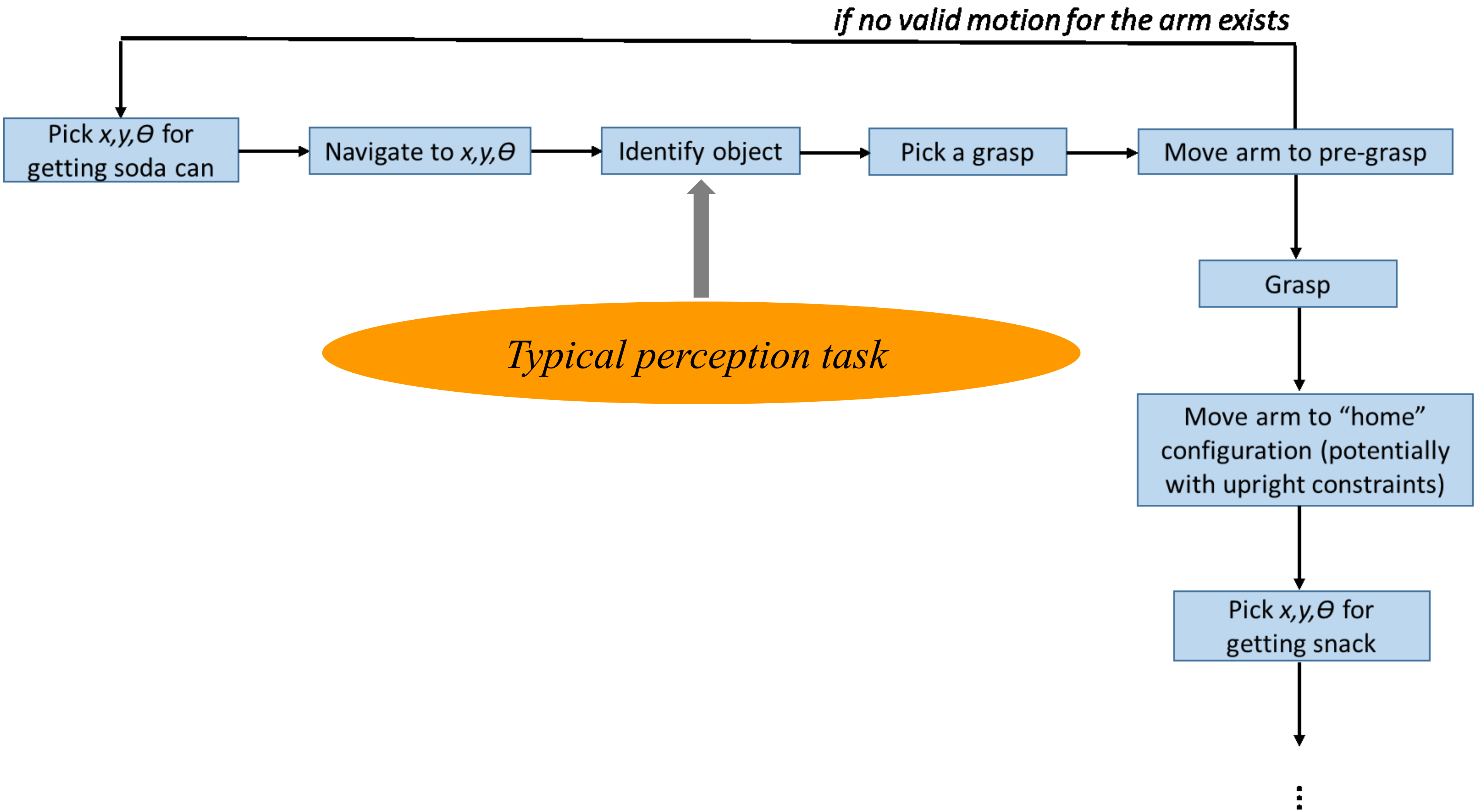

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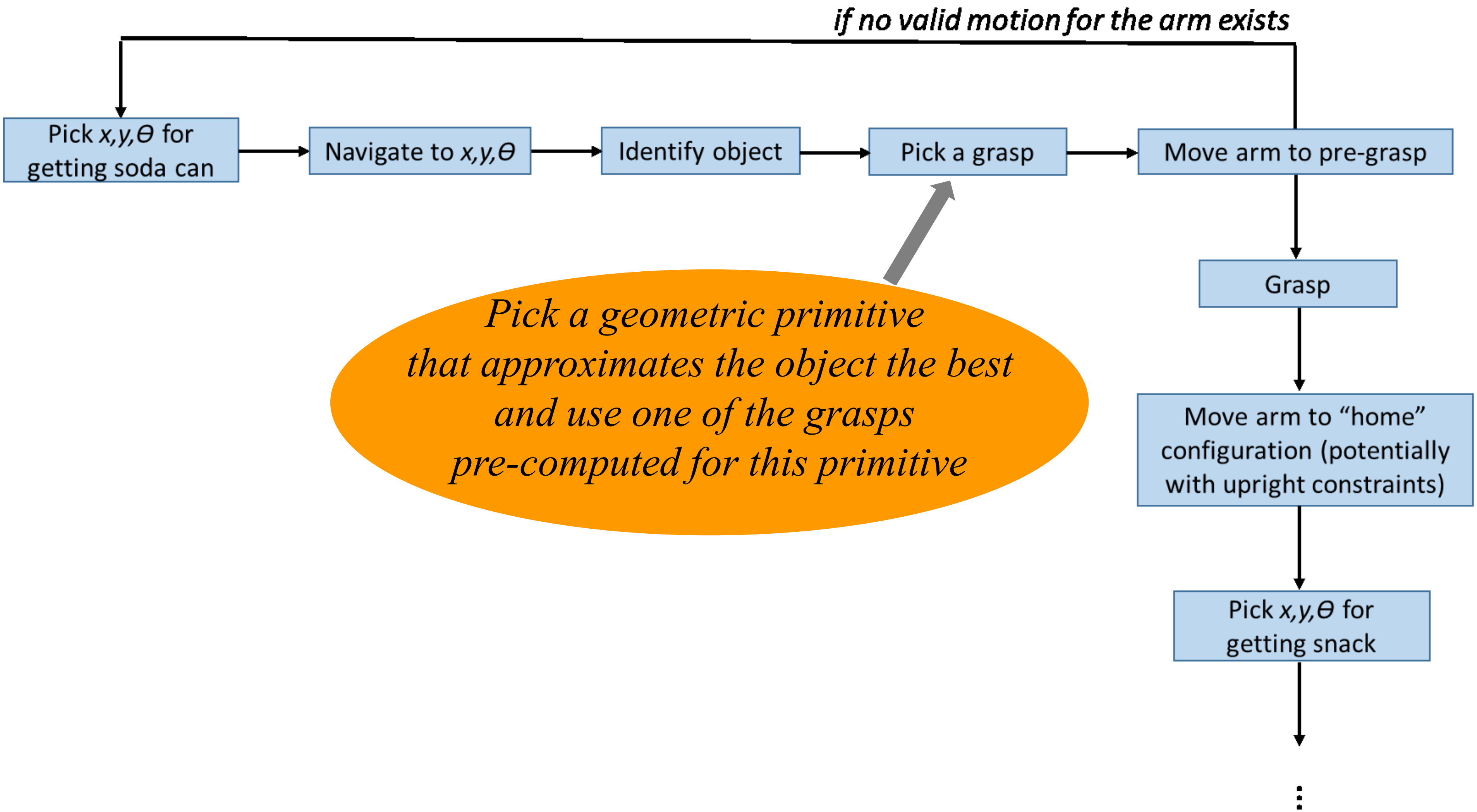

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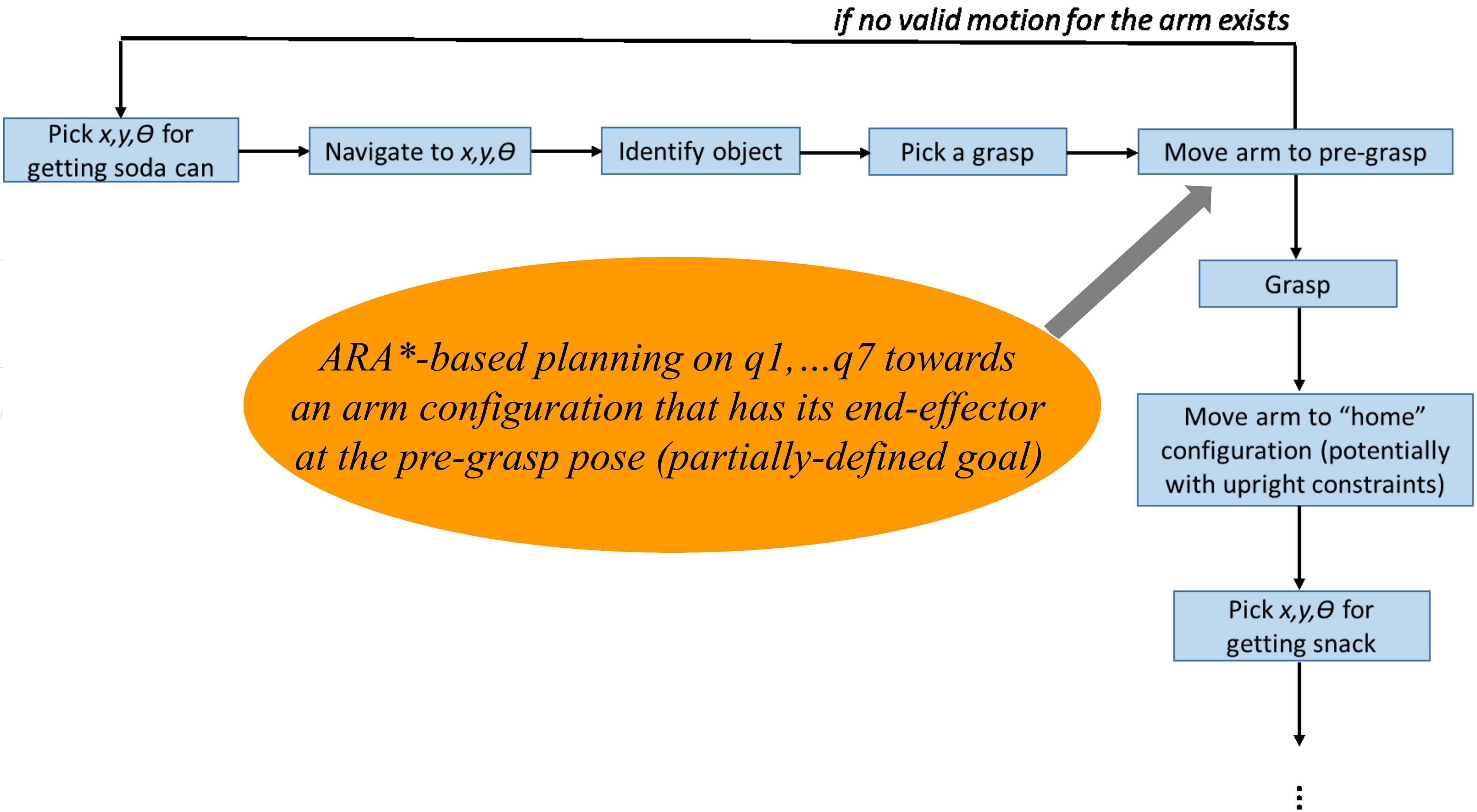

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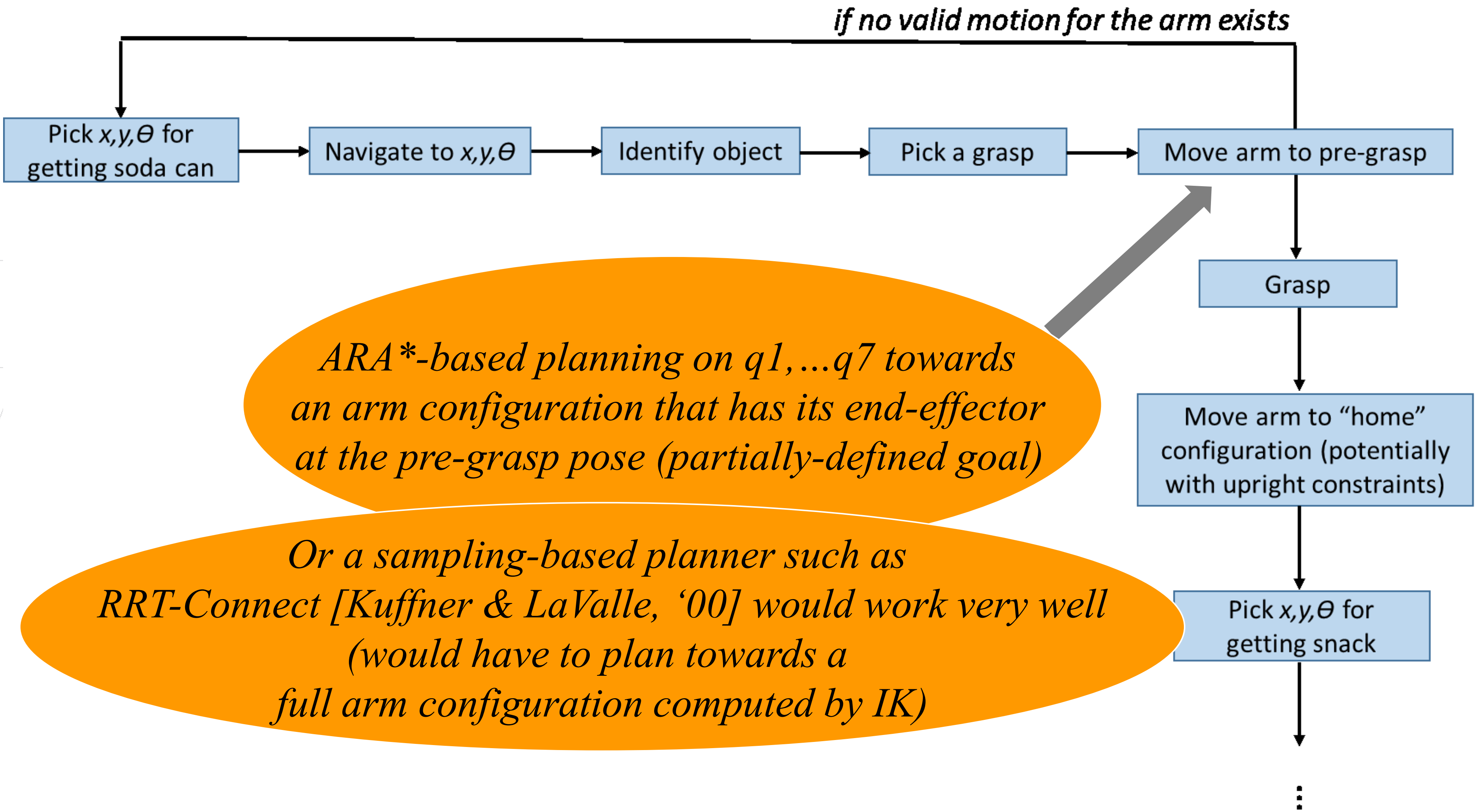

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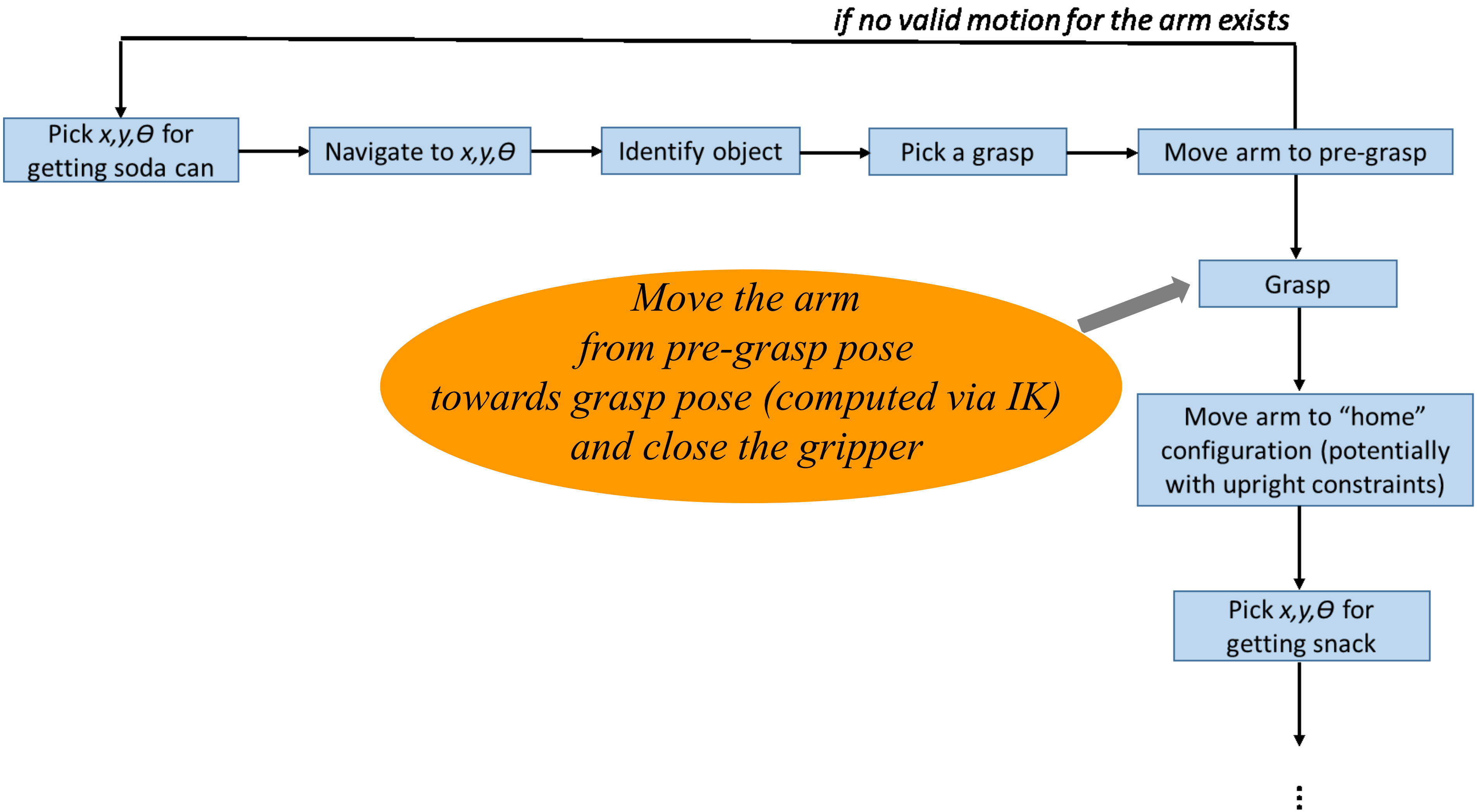

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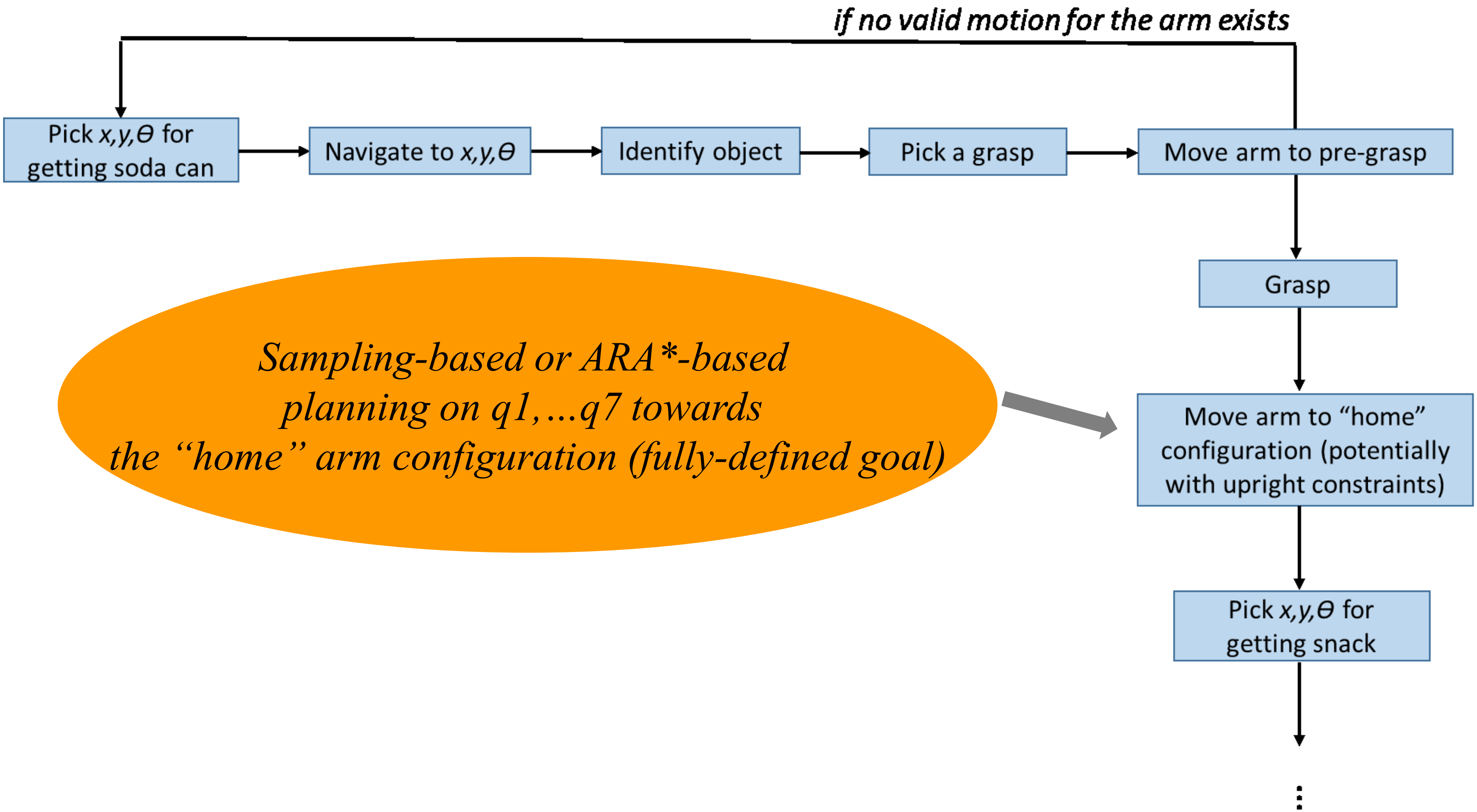


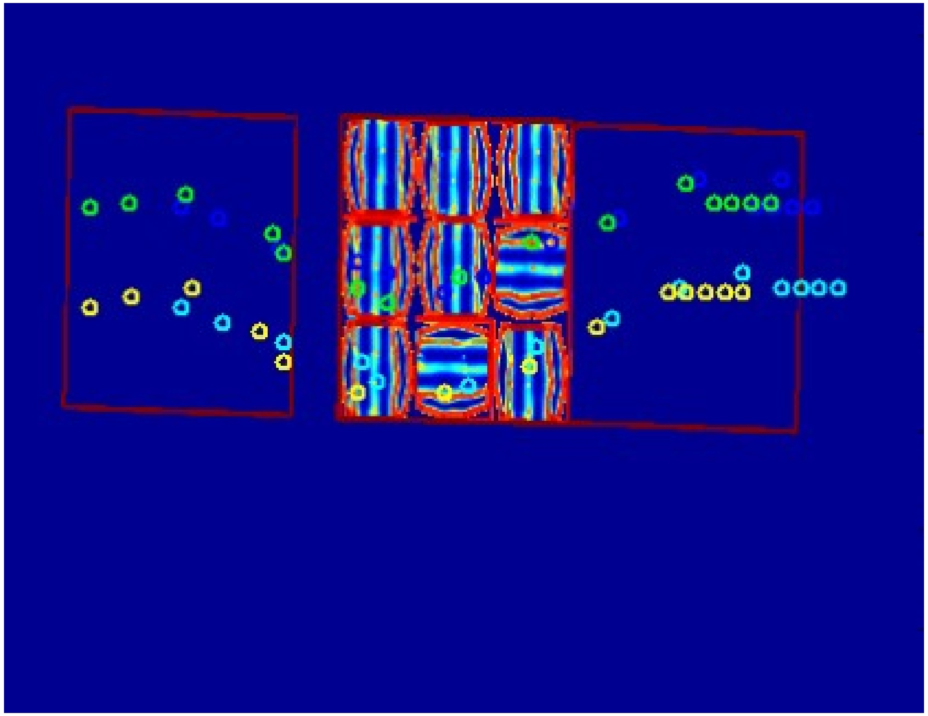
Two Examples

- Planning for Mobile Manipulation
- Planning for Articulated Robots

Little Dog Demo [Vernaza et al., '09]

- Little Dog robot needs to traverse a fully-known terrain

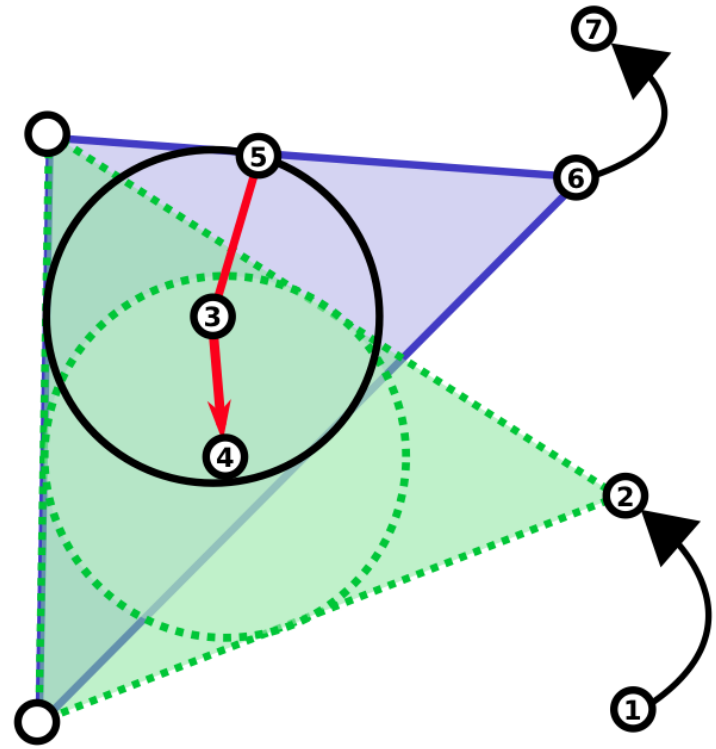
- Planning
  - Plans footsteps first with an anytime variant of A*
  - Compute COM of the robot afterwards to support execution



Footstep Planner [Vernaza et al., '09]

Assumptions of the planner:

- Only one leg lifted at a time to ensure static stability
- Center of mass shifts during quad-support phase to prevent tipping
- Footholds chosen deliberately to maximize stability



Footstep Planner [Vernaza et al., '09]

Planner builds Graph:

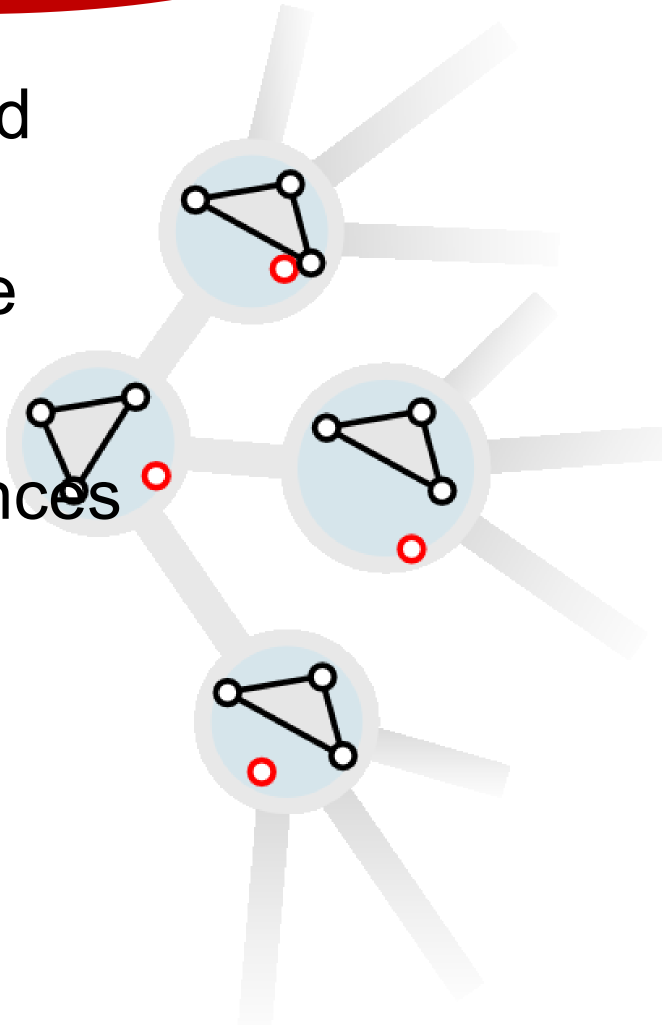
Implicit or explicit graph?

- **Node (stance):** 9-dimensional foothold configuration

  - feet positions and current gait phase

- **Edge**: feasible transition between stances

- **Edge costs** for transitions computed based on risk, anticipated delay

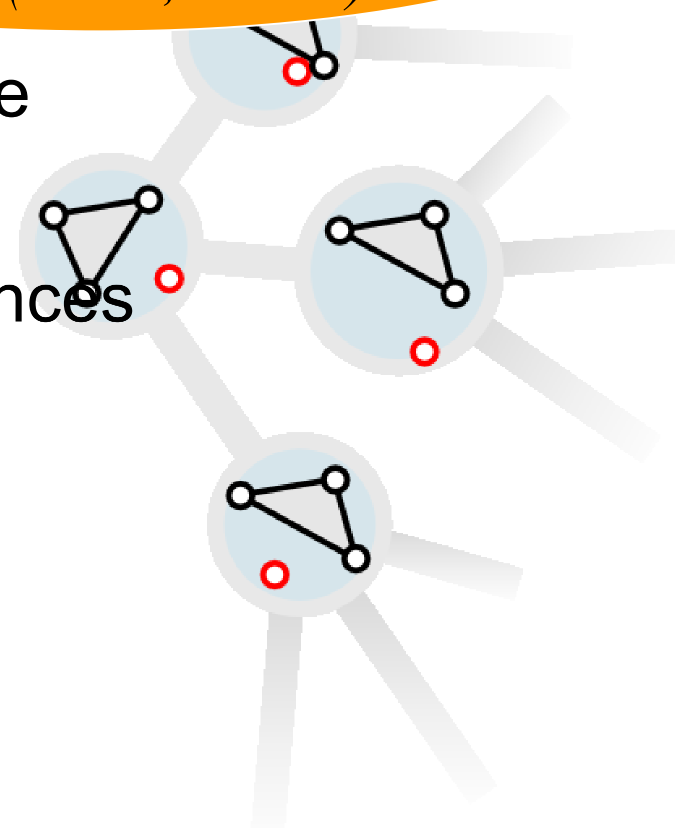


Planner builds (<u>implicit</u>) Graph:

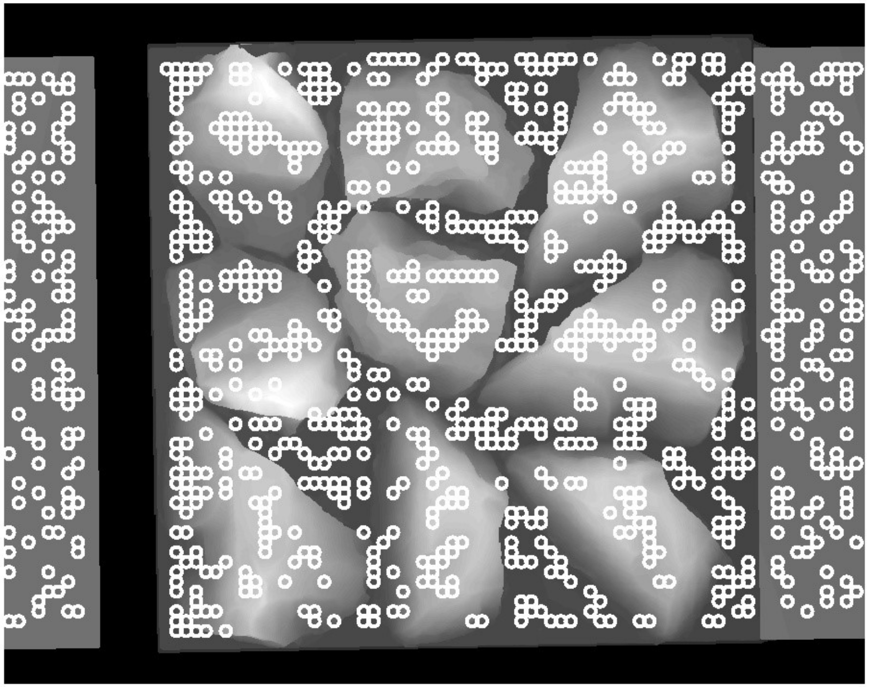
Requires definition of:

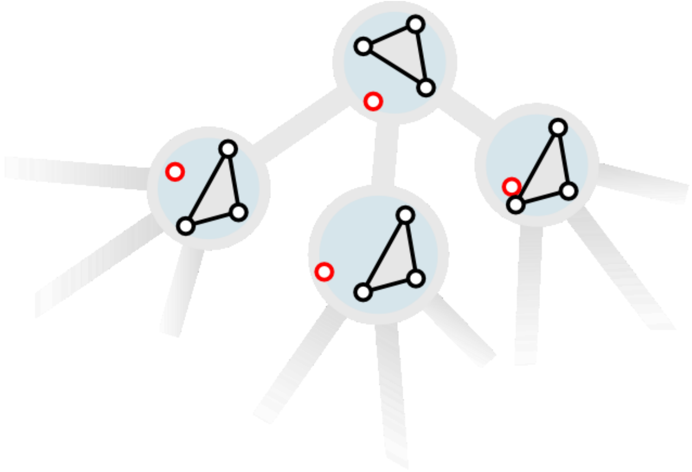
GetSuccessors(state S)
GetCost(state S, state S’)

- **Node (stance):** 9-dime configuration
  - feet positions and current gait phase
- **Edge**: feasible transition between stances
- **Edge costs** for transitions computed based on risk, anticipated delay



Implementation of *GetSuccessors(s)* Function





- Finite set of good quality candidate footholds selected prior to planning
- Valid stances are kinematically feasible 4-tuples of candidate footholds
- Successors of a given stance computed by:
  - determining reachable candidate footholds that result in a valid stance

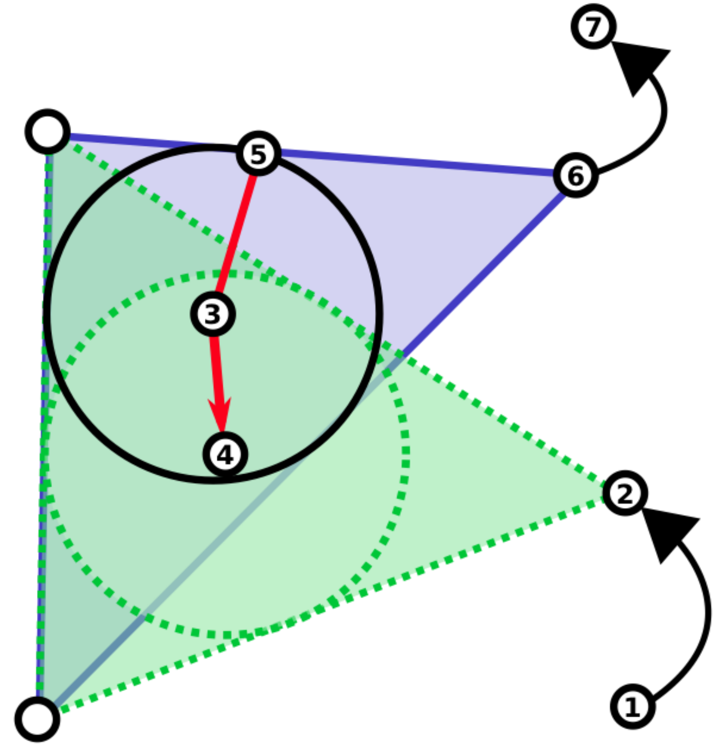
Implementation of *GetCost(s,s')* Function

- Edgecosts are weighted sum of:

Any thoughts?

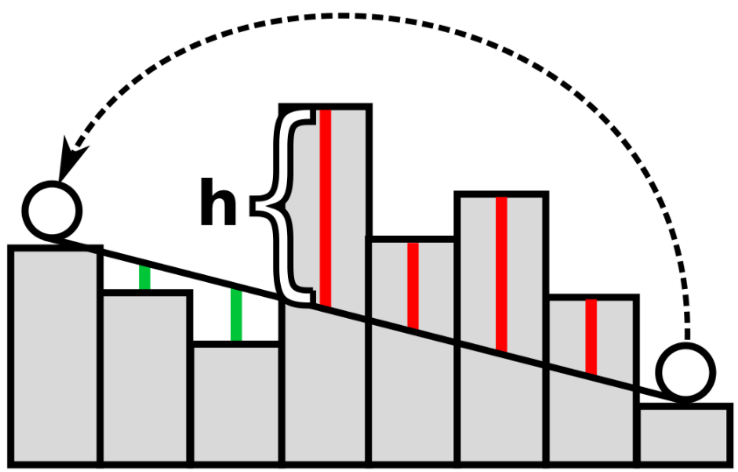
Implementation of *GetCost(s,s')* Function

- Edgecosts are weighted sum of:
  - **Overhead**
    - Fixed cost per step
  - **Center of mass travel**
    - Discourages backwards motion of COM
  - **Incircle radius**
    - Farthest distance from interior to exterior of support triangle



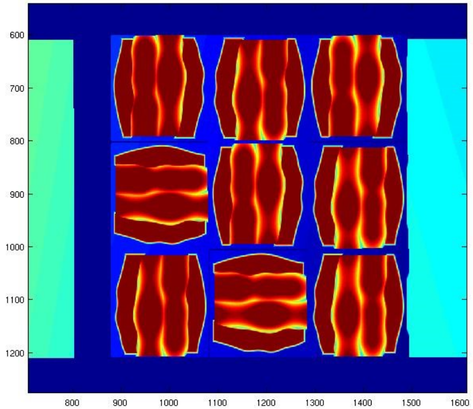
Implementation of *GetCost(s,s')* Function

- Edgecosts are weighted sum of:
  - **Collision**
    - Risk of body/foot colliding with terrain
  - **Foot height variance**
    - Encourages robot to stay level



Implementation of *GetCost(s,s')* Function

- Edgecosts are weighted sum of:
  - **Reachability**
    - Robot's ability to reach next foothold, switch to next support triangle without dragging feet
  - **Terrain slope**
    - Ensures terrain slope supports direction of motion
  - **Terrain cost**
    - Considers slippage potential given terrain



Implementation of *GetCost(s,s')* Function

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    - Robot's ability to
      support triangle withou

Lots of features make up the cost function.
Fine tuning them is not fun ☹

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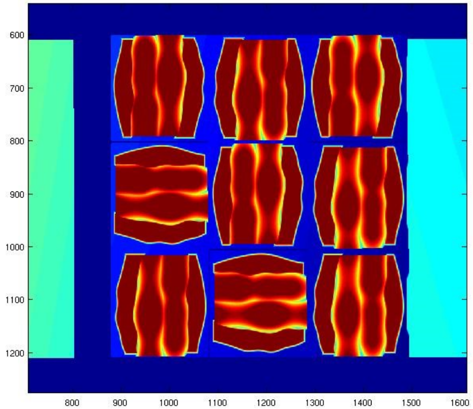

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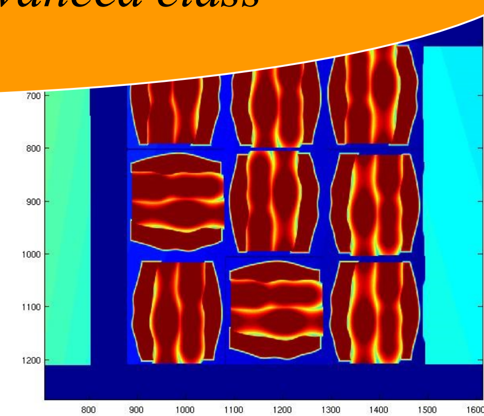
There are ways to learn them
but this is a topic for an advanced class



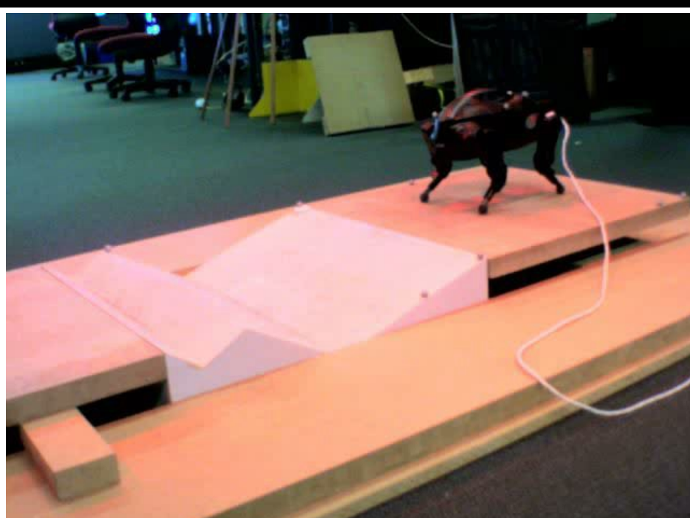
Sometimes smart but often stupid

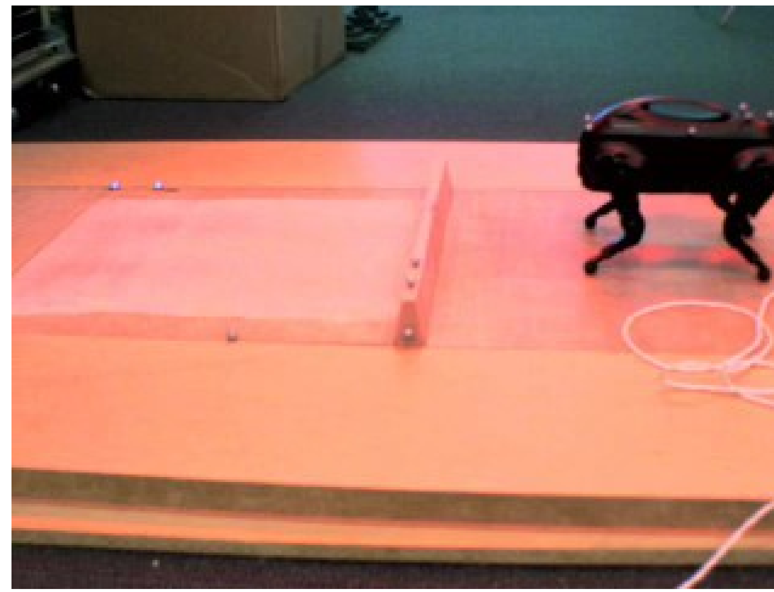
Search-based planning for a legged robot over rough terrain

Paul Vernaza, Maxim Likhachev, Subhrajit Bhattacharya, Sachin Chitta*, Aleksandr Kushleyev, Daniel D. Lee

GRASP Laboratory
University of Pennsylvania

*Willow Garage, Inc.





no footstep planning

Summary

- Multiple planners used for both domains
- Cost is really complex in planning for articulated robots (e.g., quadrupeds and humanoids)
- Planning is higher-dimensional but has more time to complete than on ground and aerial vehicles