16-782
Planning & Decision-making in Robotics

Case Study: Planning for Mobile Manipulation and Legged Robots

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Two Examples

- Planning for Mobile Manipulation
- Planning for Legged Robots

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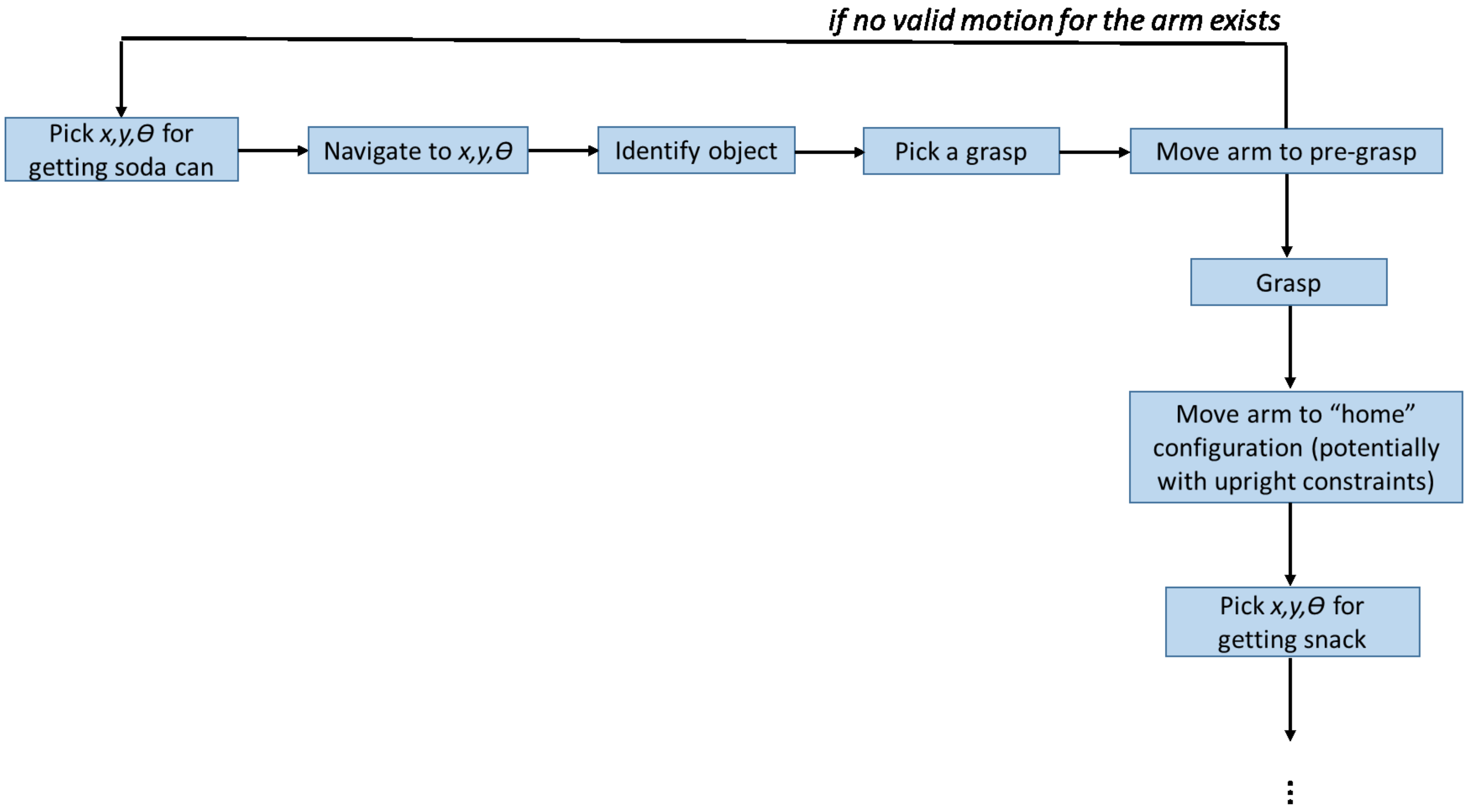
- Planning for Mobile Manipulation
- Planning for Legged Robots

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)


if no valid motion for the arm exists
Pick *x,y,ϴ* for getting soda can
Navigate to *x,y,ϴ*
Identify object
Pick a grasp
Move arm to pre-grasp
Grasp
Move arm to “home” configuration (potentially with upright constraints)
Pick *x,y,ϴ* for getting snack
⋮

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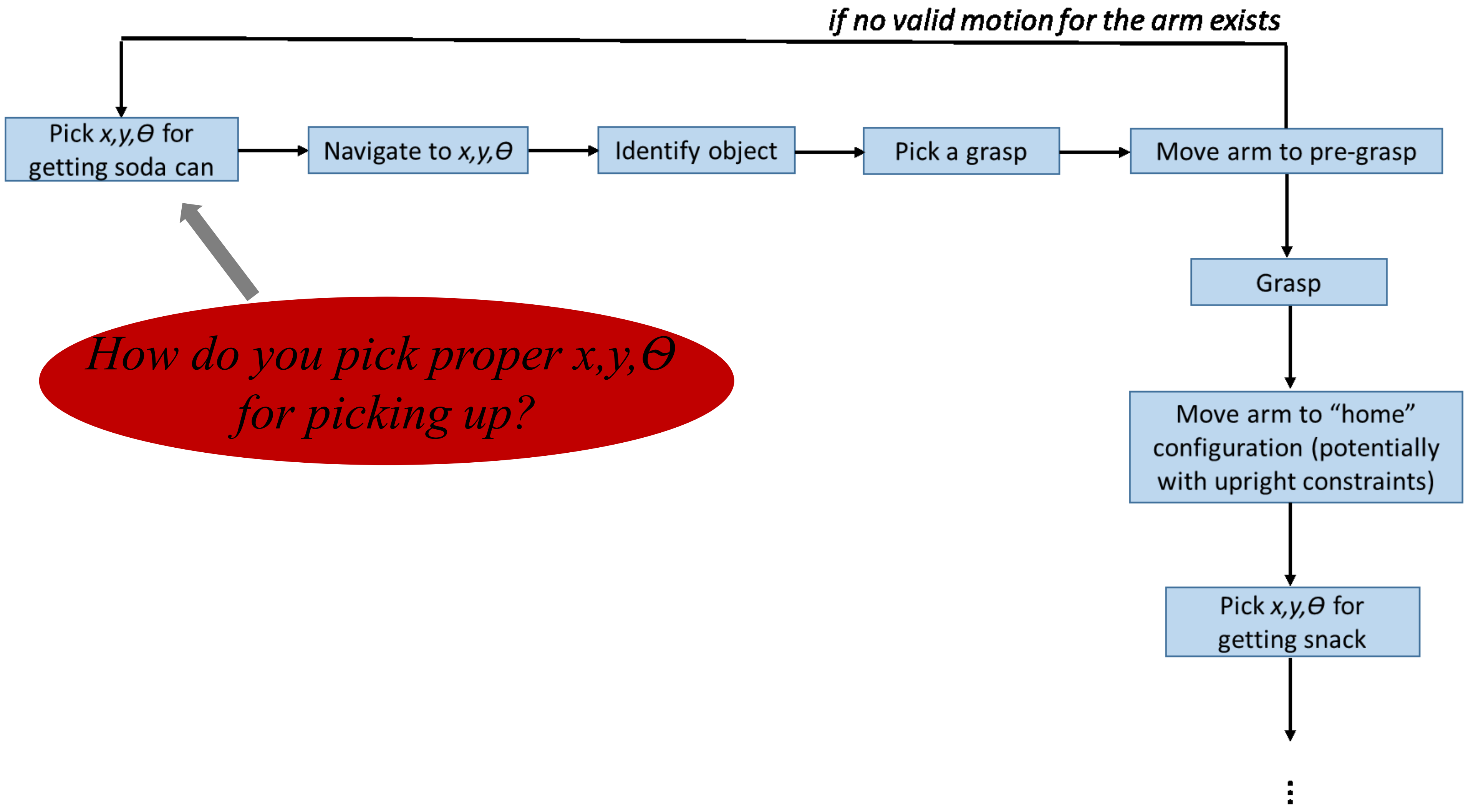
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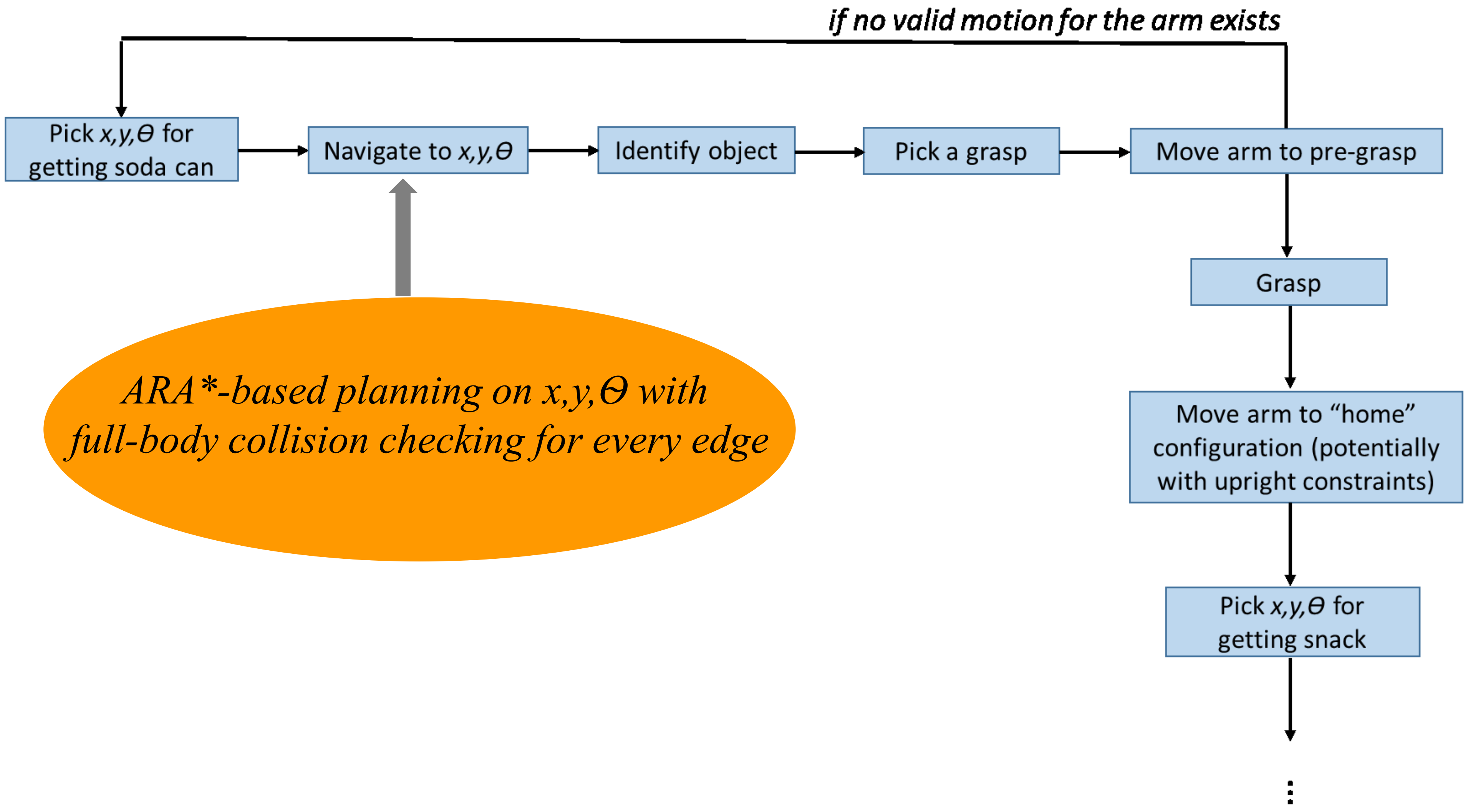
⋮
How do you pick proper x,y,Θ for picking up?

Typical Sequence of Operations (State Machine)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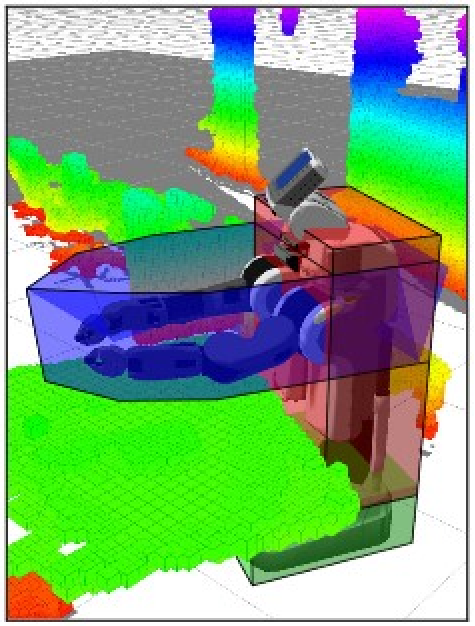
⋮
ARA*-based planning on x,y,Θ with full-body collision checking for every edge

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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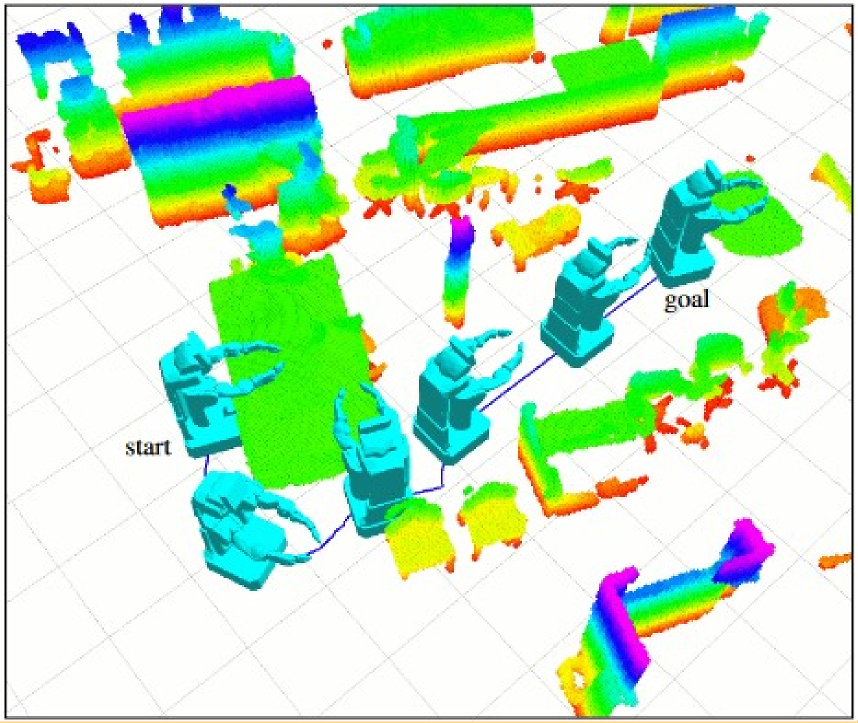

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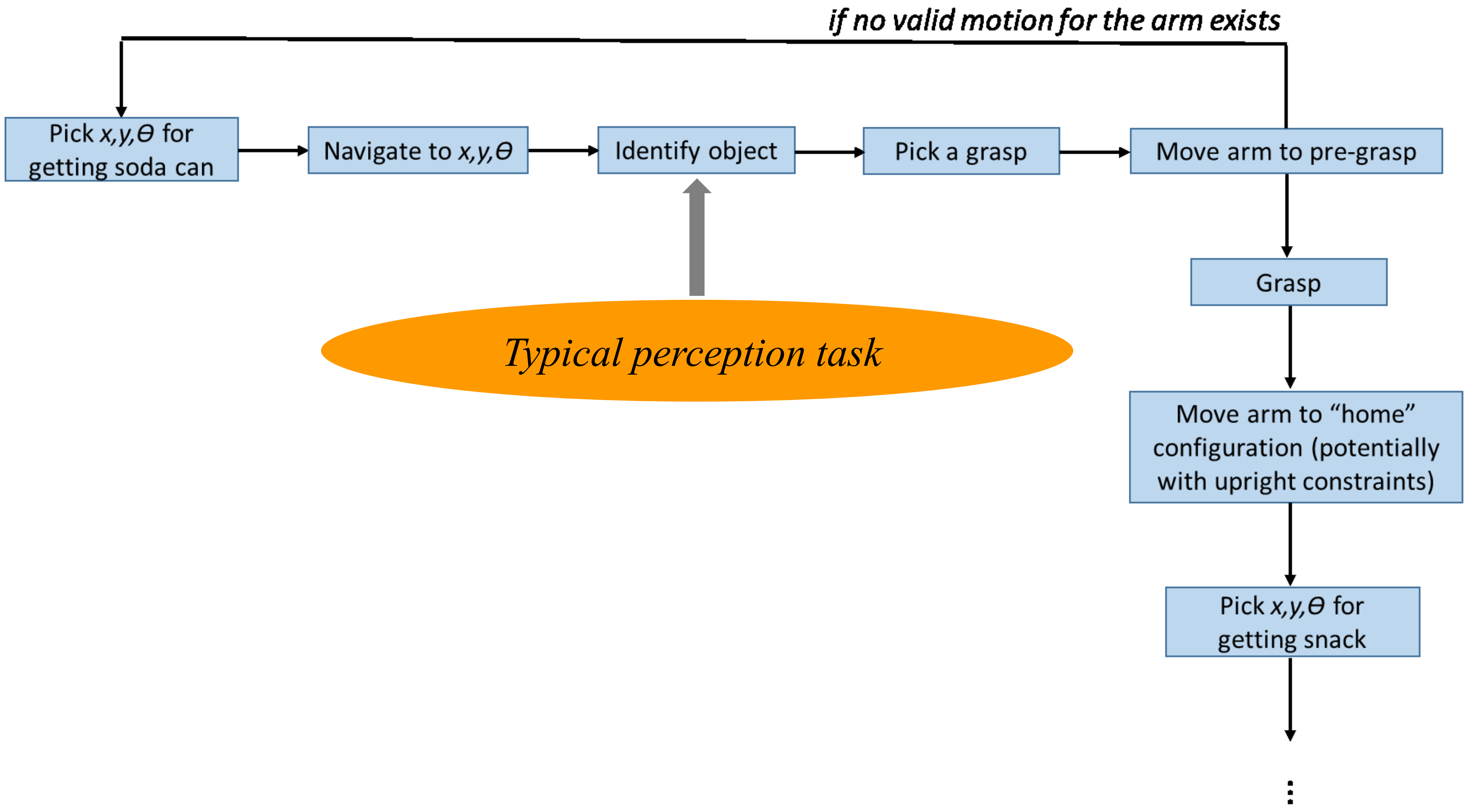

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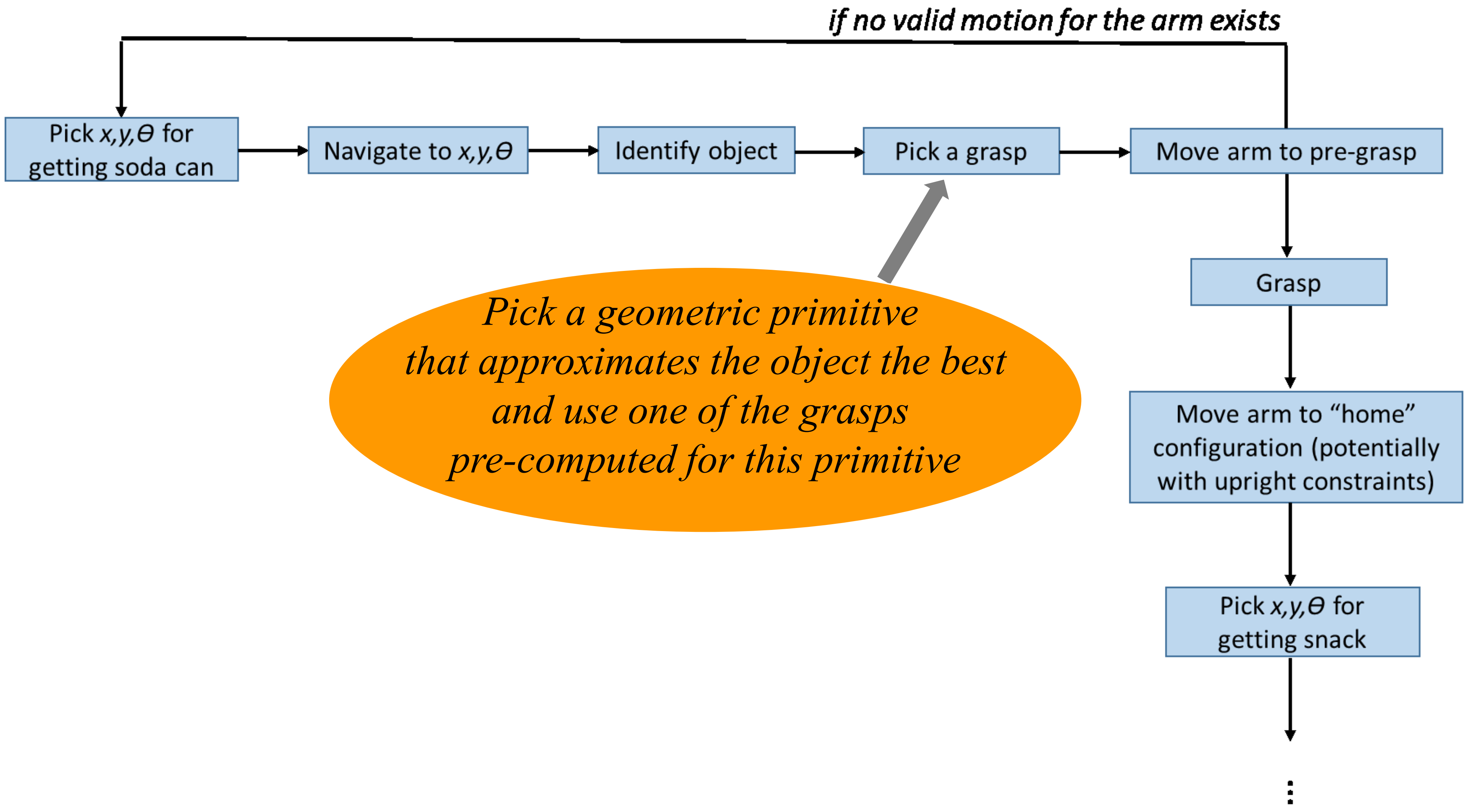
Typical perception task

Typical Sequence of Operations (State Machine)



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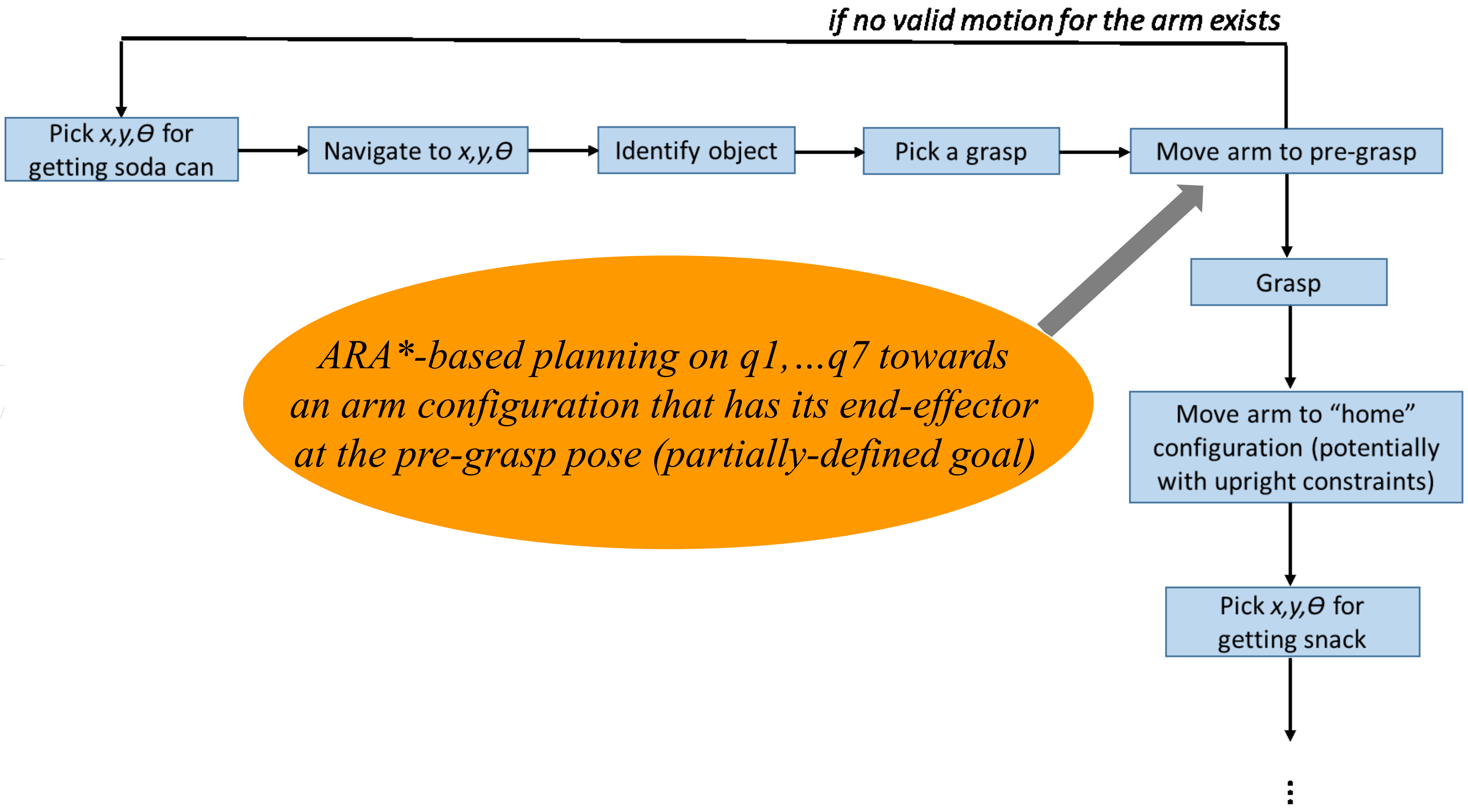
Pick a geometric primitive that approximates the object the best and use one of the grasps pre-computed for this primitive

Typical Sequence of Operations (State Machine)



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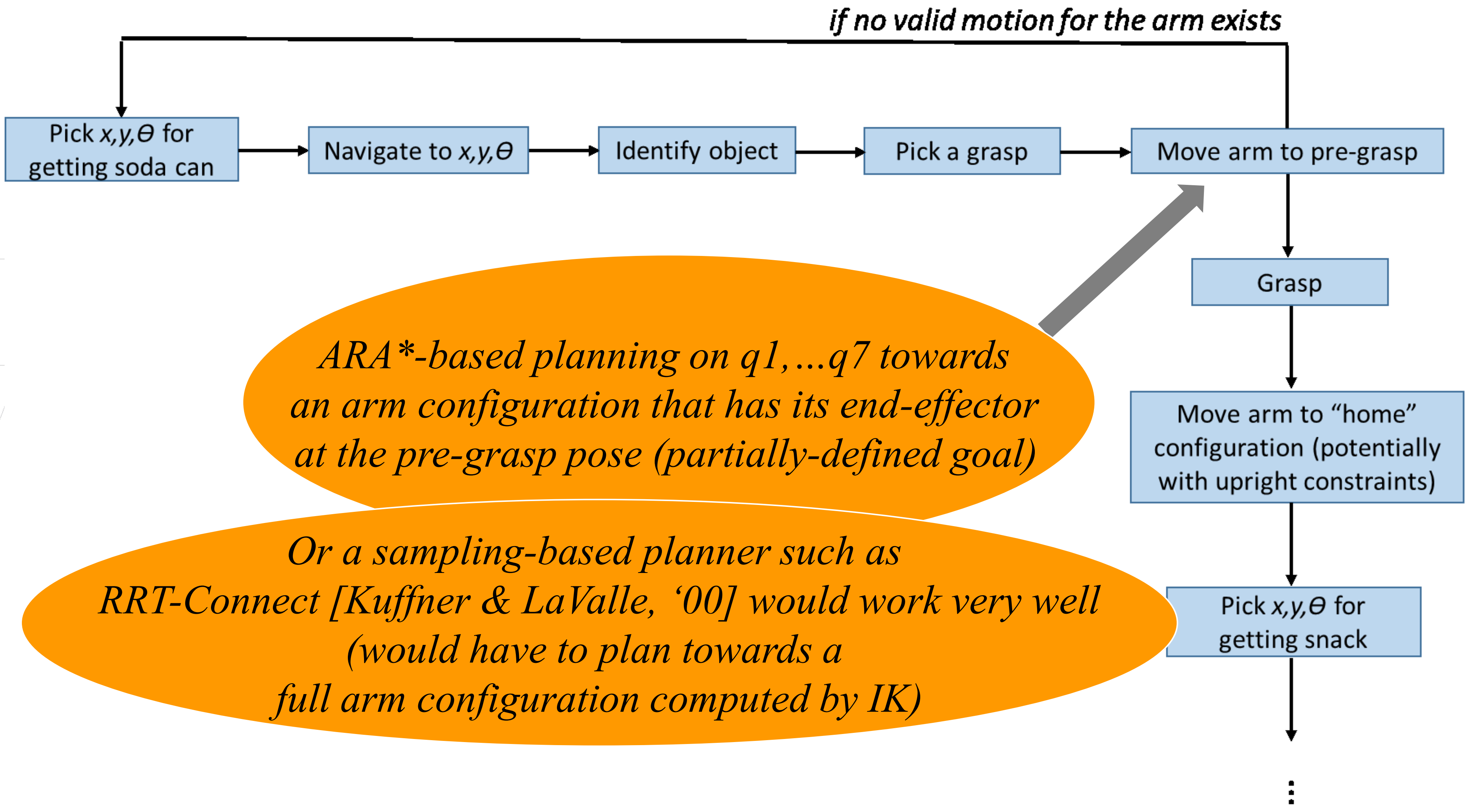
ARA*-based planning on q1,…q7 towards an arm configuration that has its end-effector at the pre-grasp pose (partially-defined goal)

Typical Sequence of Operations (State Machine)



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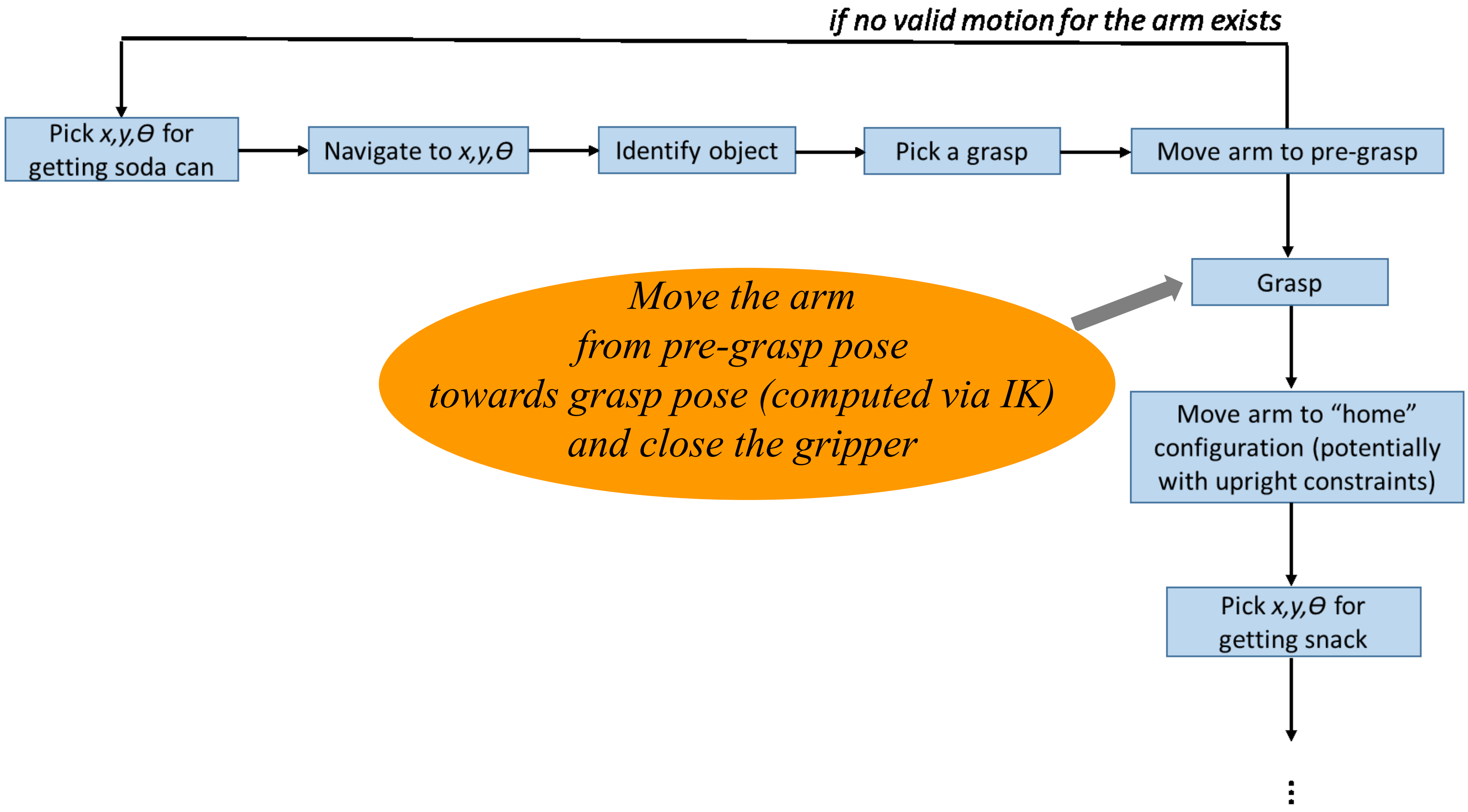
ARA-based planning on q1,…q7 towards an arm configuration that has its end-effector at the pre-grasp pose (partially-defined goal)*

Or a sampling-based planner such as RRT-Connect [Kuffner & LaValle, '00] would work very well (would have to plan towards a full arm configuration computed by IK)

Typical Sequence of Operations (State Machine)



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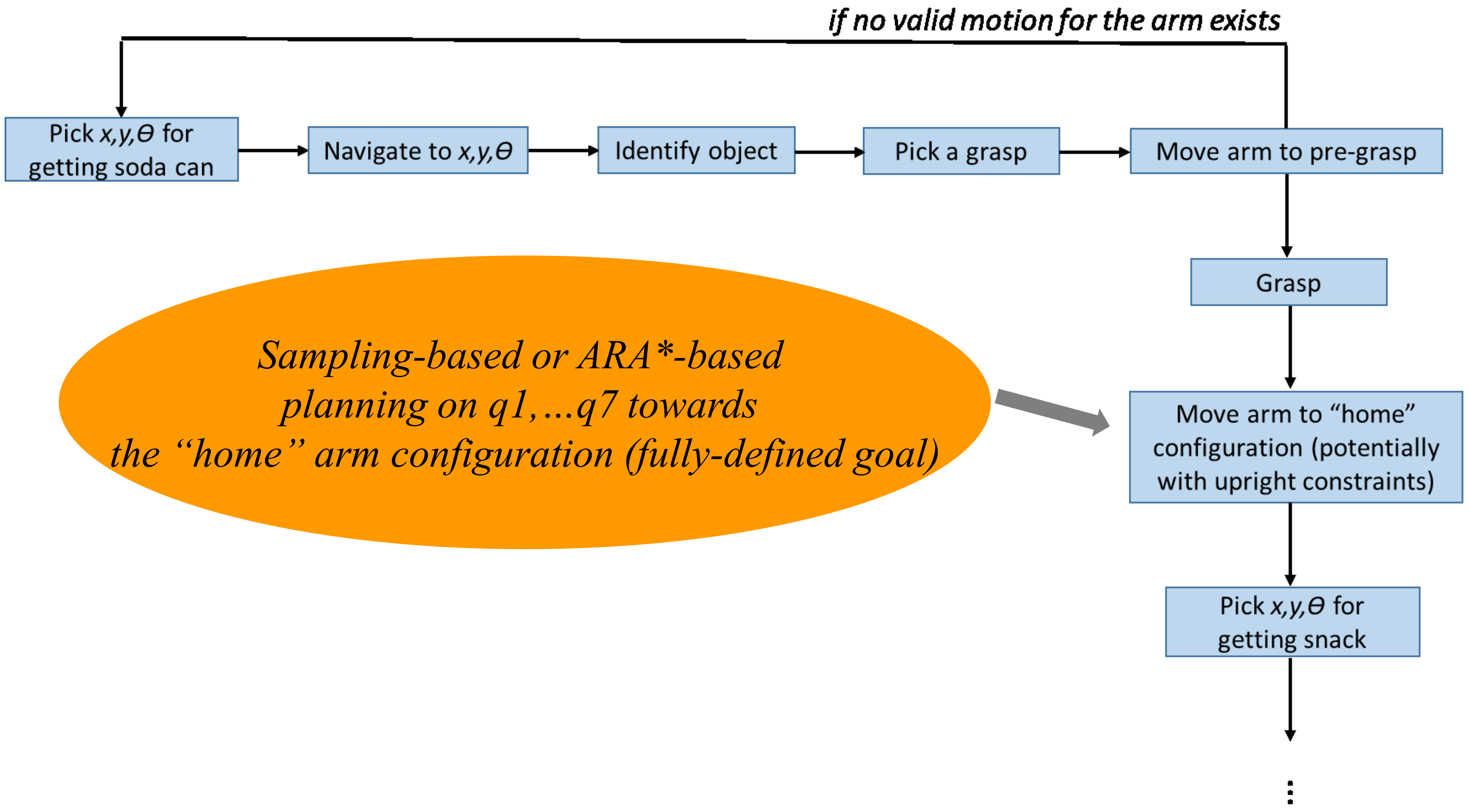
Move the arm from pre-grasp pose towards grasp pose (computed via IK) and close the gripper

Typical Sequence of Operations (State Machine)



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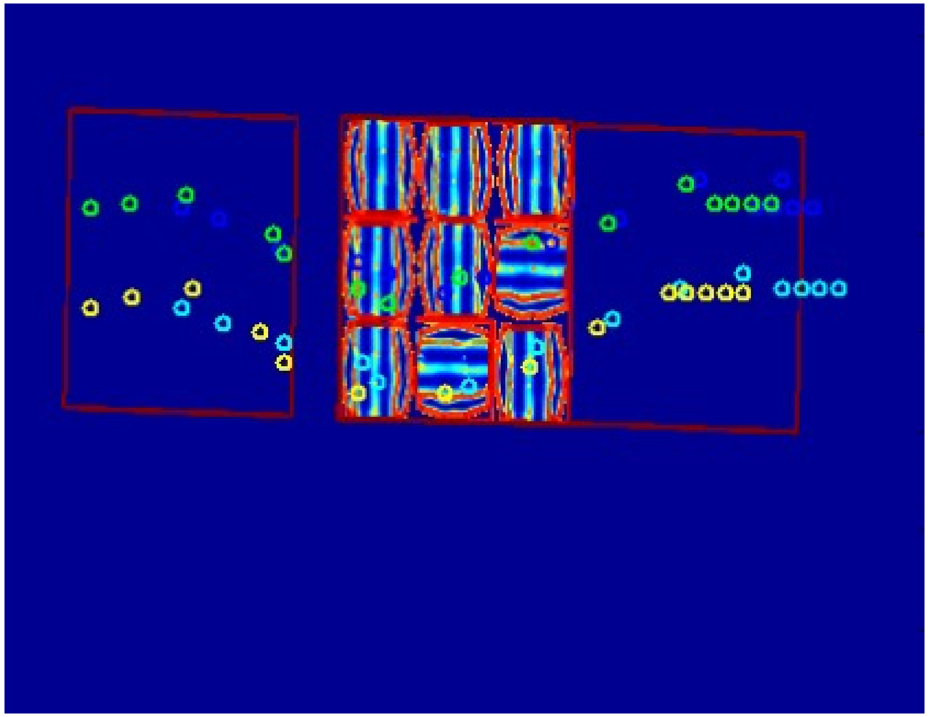
Sampling-based or ARA-based planning on q1,…q7 towards the "home" arm configuration (fully-defined goal)*

Two Examples

- Planning for Mobile Manipulation
- Planning for Legged Robots

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

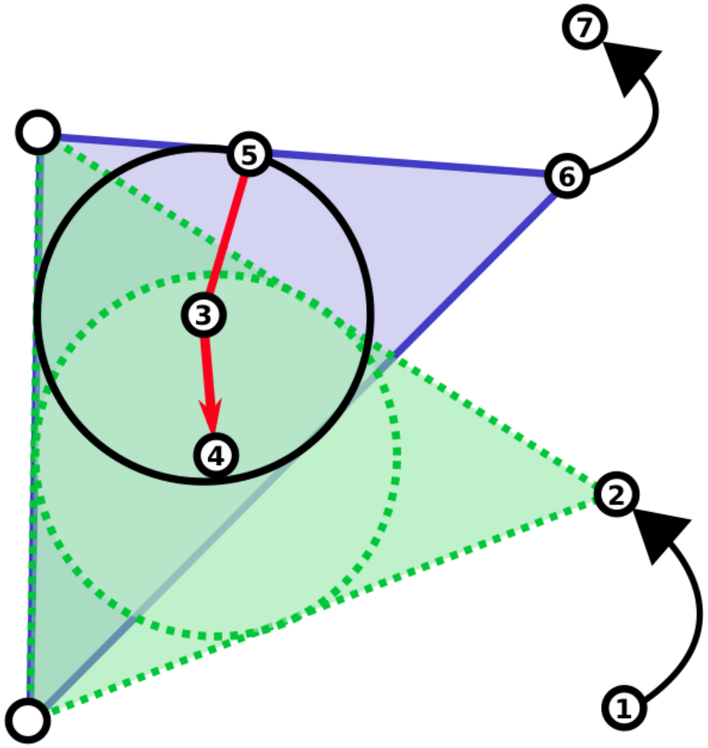
- Little Dog robot needs to traverse a fully-known terrain
- Planning
  - Plans footsteps first with an anytime variant of A*
  - Compute COM of the robot afterwards to support execution



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:

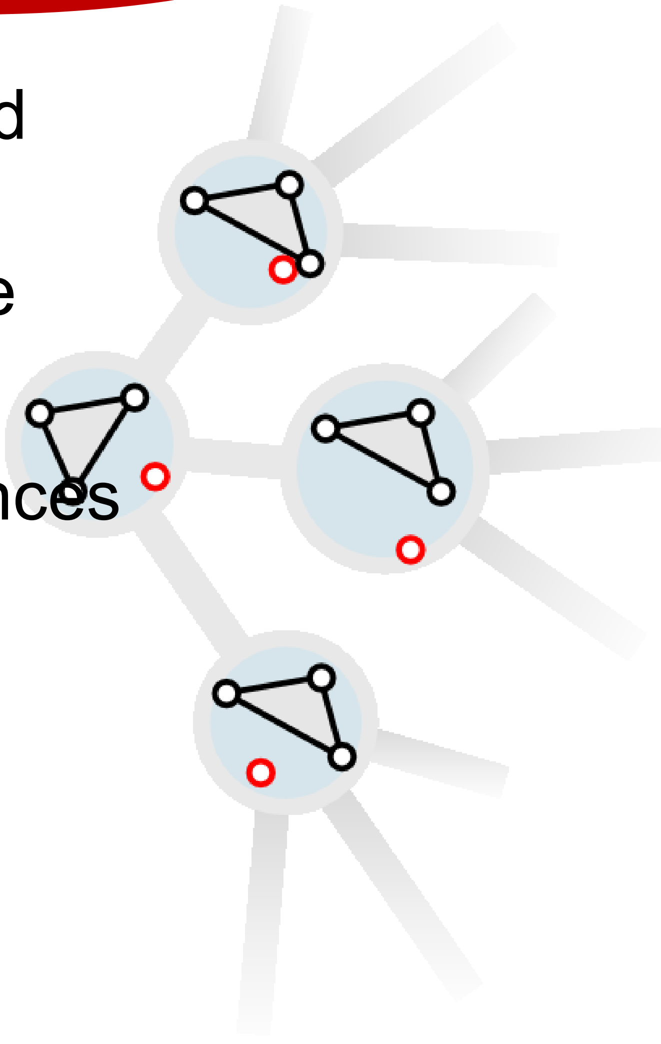
What are states?
What are edges?

Footstep Planner [Vernaza et al., ‘09]

Planner builds Graph:

Implicit or explicit graph?

- **State (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



Footstep Planner [Vernaza et al., '09]

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

Requires definition of:

GetSuccessors(state S)
GetCost(state S, state S')

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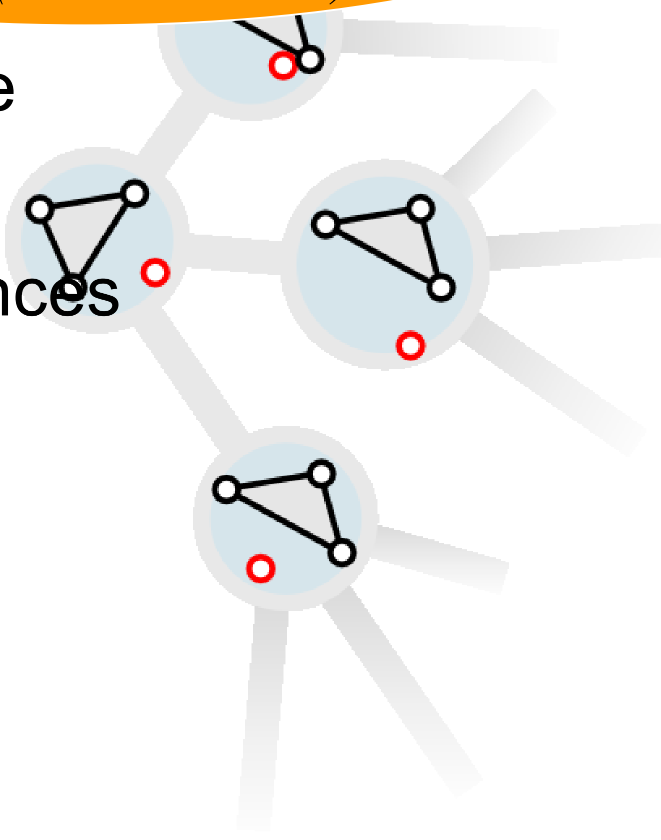
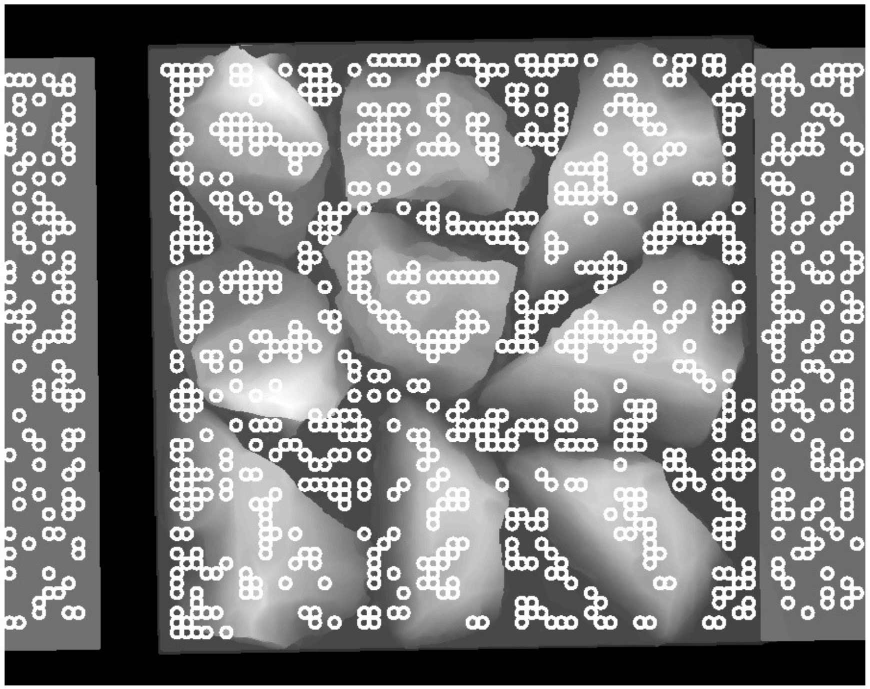
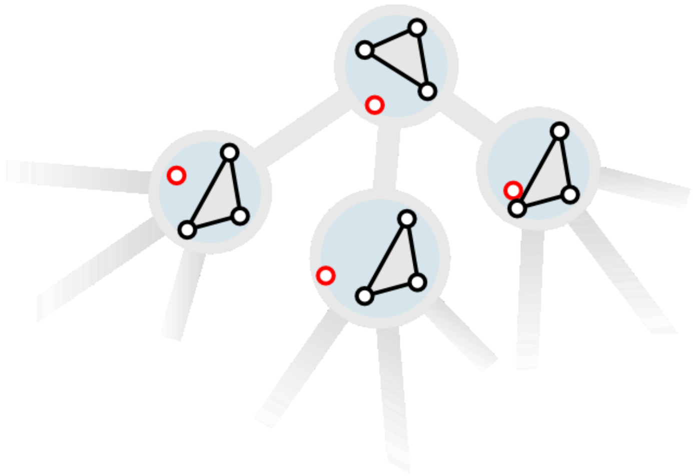


Implementation of *GetSuccessors(s)* Function





- 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

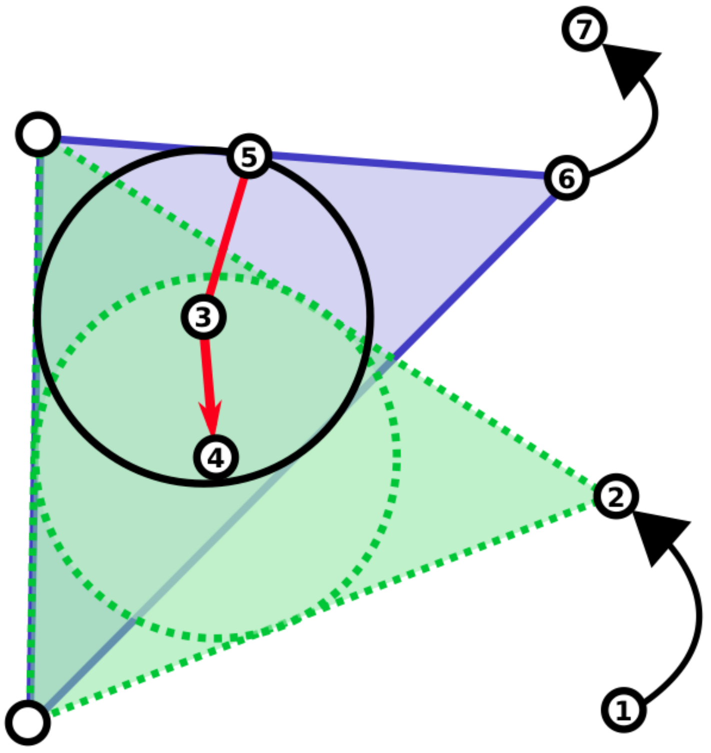
Implementation of *GetCost(s,s')* Function

- Edgecosts are weighted sum of:

Any thoughts?

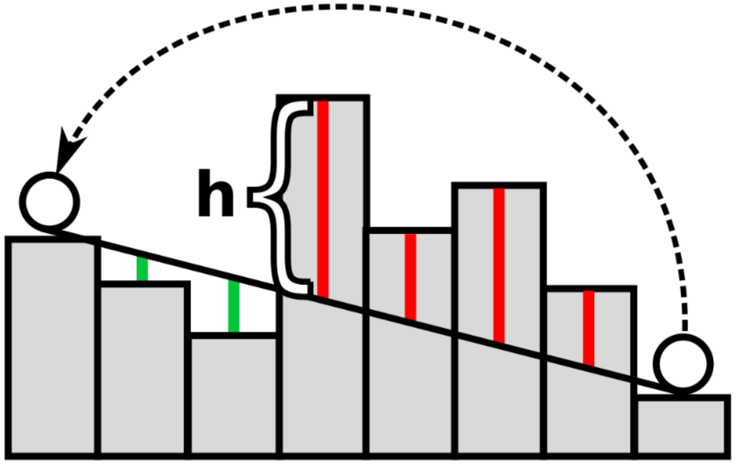
Implementation of *GetCost(s,s')* Function

- Edgecosts are weighted sum of:
  - **Fixed cost per step**
    - Minimizes # of steps in the plan
  - **Center of mass travel**
    - Discourages unnecessary motion of COM
  - **Incircle radius**
    - Discourages stances with small incircle radii (distance from point 3 to point 5 in the picture)



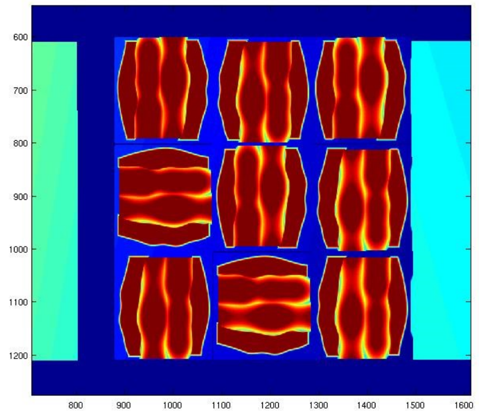
Implementation of *GetCost(s,s')* Function

- 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



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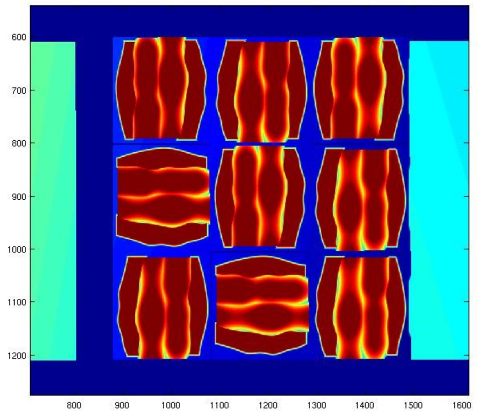
Lots of features make up the cost function.
Fine tuning them is not fun ☹



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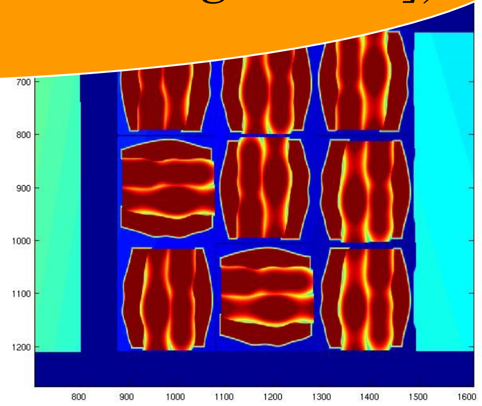
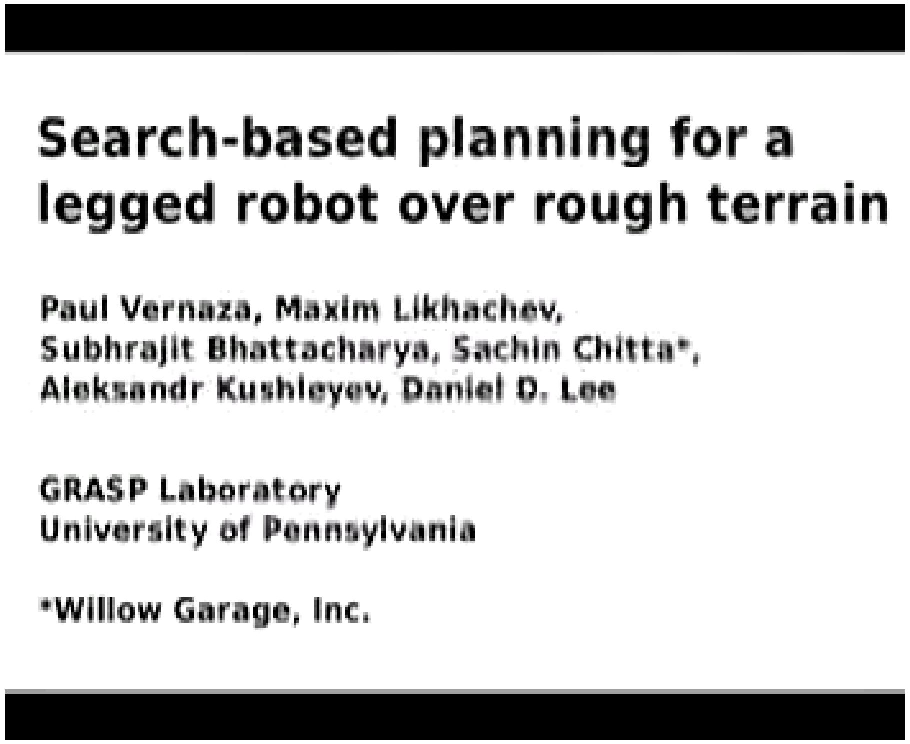
There are ways to learn the weights
(e.g., Learning to Search [Ratliff, Silver & Bagnell, '09])



Sometimes smart but often stupid

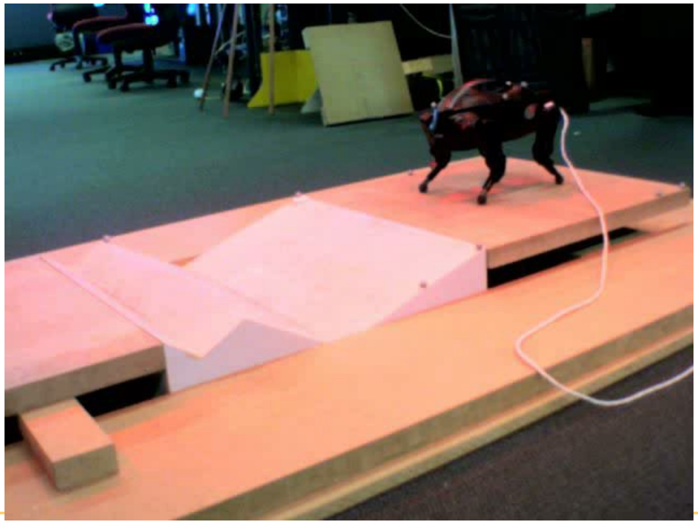


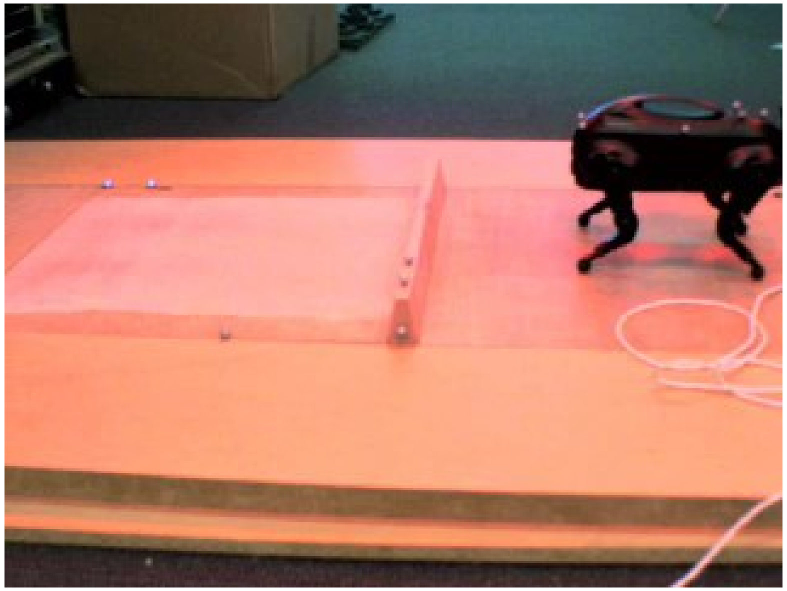
Search-based planning for a legged robot over rough terrain

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

GRASP Laboratory
University of Pennsylvania

*Willow Garage, Inc.





no footstep planning

What You Should Know…

- General state machine for mobile manipulation
- The dimensionality when planning footsteps for quadrupedal (and bipedal) robots
- Appreciate the complexity of cost components when planning for quadrupedal (and bipedal) robots