Learning Deep Heuristic for Robot Planning

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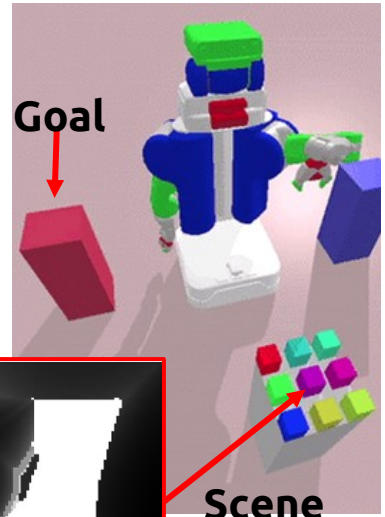
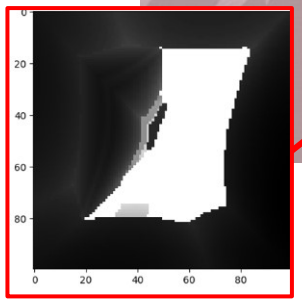
Task: object transportation

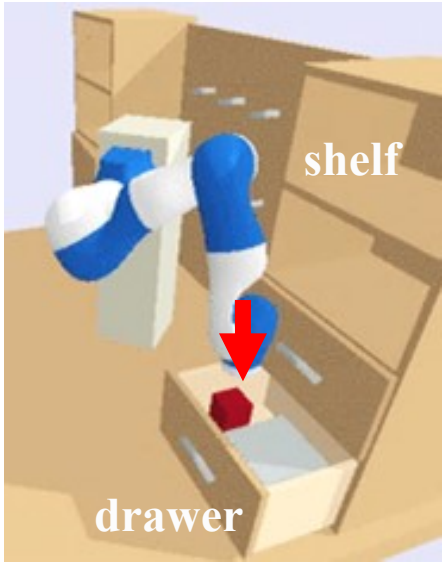


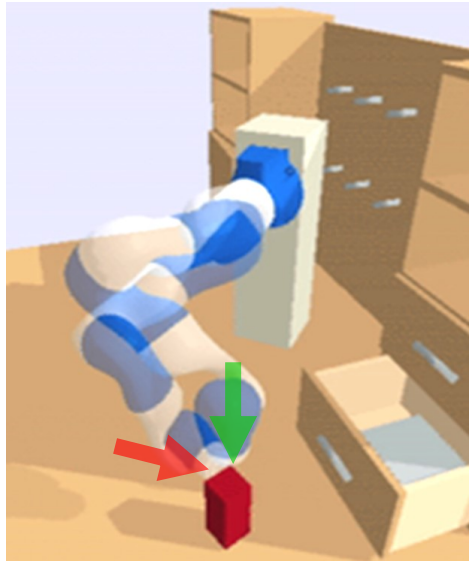


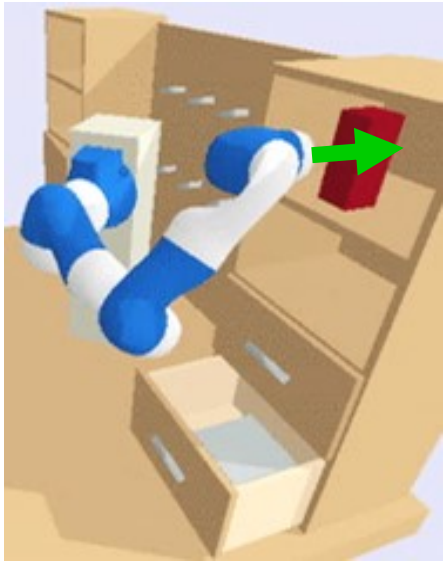
- **Sample-based Planner:** making sequential decisions on
  - robot base pose
  - grasping direction
- **Universal Heuristic:** guiding the search of decision variables
  - Learn a approximator that predicts the feasibility
  - The scene is encoded by deep visual data

[1] Driess, Danny, et al. "Deep visual heuristics: Learning feasibility of mixed-integer programs for manipulation planning." 2020 IEEE International Conference on Robotics and Automation (ICRA). IEEE, 2020.

What is
Task and Motion Planning (TAMP) ?







Symbolic description

Approach and pick → Carry and place to table → Regrasp → Carry and place to shelf → Goal

Task plan

Approach and pick	Carry and place to table	Regrasp	Carry and place to shelf
Sample-grasp-direction(·,·)→#	Sample-place(·,·)→#	Sample-grasp-direction(·,#)→#	Sample-place(·,·)→#
Inverse-kinematics(·,·,#)→#,#	Inverse-kinematics(·,·,#)→#,#	Inverse-kinematics(·,#,#)→#,#	Inverse-kinematics(·,#,#)→#,#
Plan-free-motion(·,#)→#	Plan-holding-motion(#,#,·,#)→#	Plan-free-motion(#,#)→#	Plan-holding-motion(#,#,·,#)→#
Move-free(·,#,#)	Move-holding(#,#,·,#,#)	Move-free(#,#,#)	Move-holding(#,#,#,#,#)
Pick(·,·,#,#,#)	Place(·,#,·,#,#,#)	Pick(·,#,#,#,#)	Place(·,#,·,#,#,#)

Motion plan

trajectory1 → trajectory2 → trajectory3 → trajectory4

Selection

of task plans
(skeletons)

Sampling

of variables
for motion plans

Extended root **decision**

skeleton1

Approach and pick	Sample-grasp-direction(·,·)→#
	Inverse-kinematics(·,·,#)→#,#
	Plan-free-motion(·,#)→#
	Move-free(·,#,#)
	Pick(·,·,#,#,#)
Carry and place to shelf	Sample-place(·,·)→#
	Inverse-kinematics(·,·,#)→#,#
	Plan-holding-motion(#,#,·,#)→#
	Move-holding(#,#,·,#,#)
	Place(·,#,·,#,#,#)
Back to home	Plan-free-motion(#,·)→#
	Move-free(#,·,#)

skeleton2 **decision**

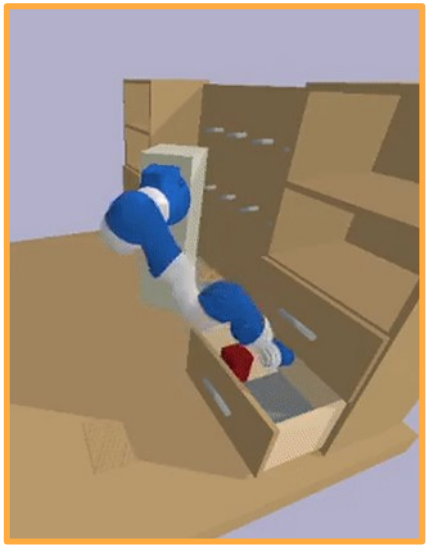
Approach and pick	Sample-grasp-direction(·,·)→#
	Inverse-kinematics(·,·,#)→#,#
	Plan-free-motion(·,#)→#
	Move-free(·,#,#)
	Pick(·,·,#,#,#)
Carry and place to table	Sample-place(·,·)→#
	Inverse-kinematics(·,·,#)→#,#
	Plan-holding-motion(#,#,·,#)→#
	Move-holding(#,#,·,#,#)
	Place(·,#,·,#,#,#)
Regrasp	Sample-grasp-direction(·,#)→#
	Inverse-kinematics(·,#,#)→#,#
	Plan-free-motion(#,#)→#
	Move-free(#,#,#
	Pick(·,#,#,#,#)
Carry and place to shelf	Sample-place(·,·)→#
	Inverse-kinematics(·,#,#)→#,#
	Plan-holding-motion(#,#,·,#)→#
	Move-holding(#,#,#,#,#)
	Place(·,#,·,#,#,#
Back to home	Plan-free-motion(#,·)→#
	Move-free(#,·,#)

e.g., dir = top

simulation

e.g., pose = (0.1, 0.1, 0.3)

Success!

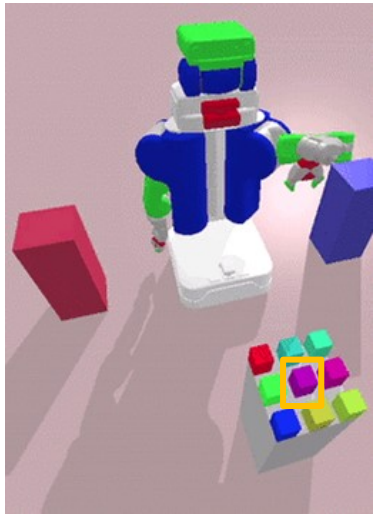


What is

heuristic doing here ?

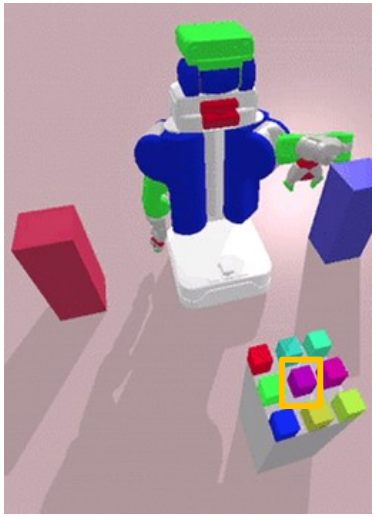
skeleton =

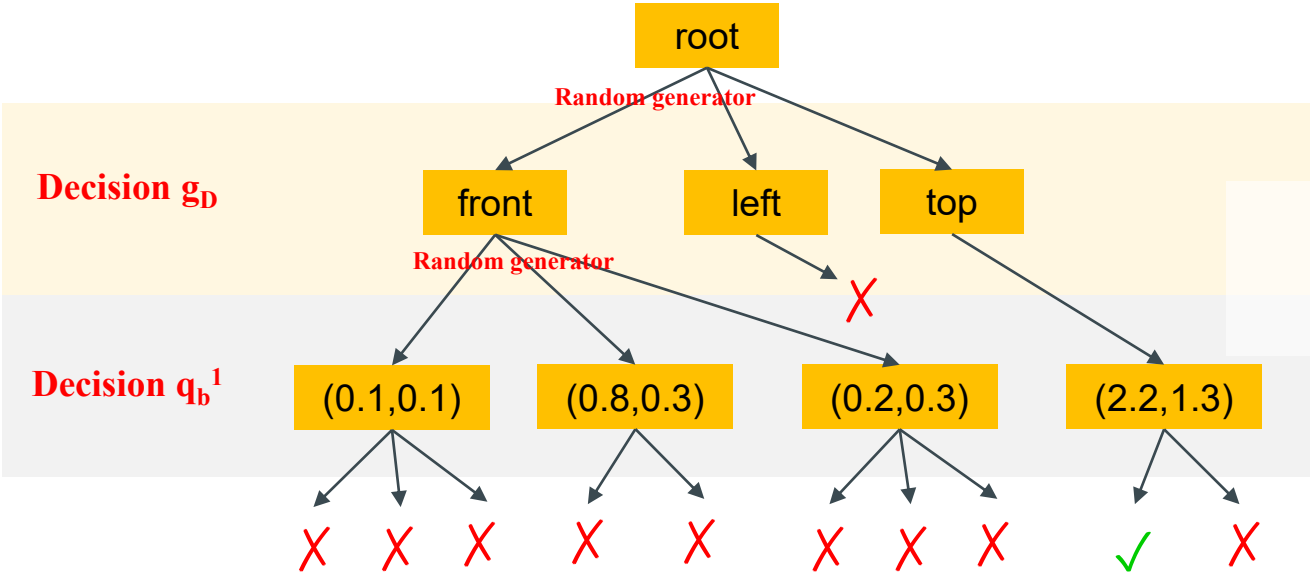
$$[\texttt{grasps(D)} \rightarrow \boldsymbol{g_D}, \texttt{inv-reach(D,} p_D^0, \boldsymbol{g_D}) \rightarrow \boldsymbol{q_b^1},$$
$$\texttt{inv-kin(D,} p_D^0, \boldsymbol{g_D}, \boldsymbol{q_b^1}) \rightarrow \boldsymbol{q_a^1}, \texttt{motion(base,} q_b^0, \boldsymbol{q_b^1}) \rightarrow \boldsymbol{t_b^1},$$
$$\texttt{motion(arm,} q_a^0, \boldsymbol{q_a^1}) \rightarrow \boldsymbol{t_a^1}].$$



skeleton =

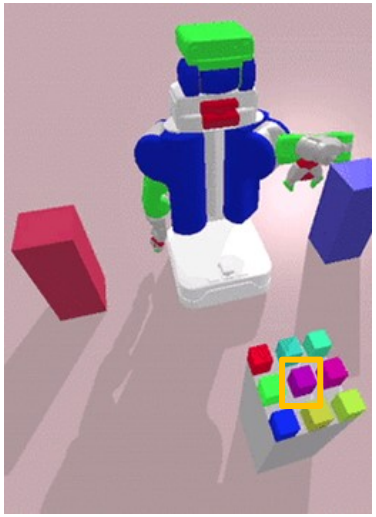
$$[\texttt{grasps(D)} \rightarrow \boldsymbol{g_D}, \texttt{inv-reach(D,} p_D^0, \boldsymbol{g_D}\texttt{)} \rightarrow \boldsymbol{q_b^1},$$
$$\texttt{inv-kin(D,} p_D^0, \boldsymbol{g_D}, \boldsymbol{q_b^1}\texttt{)} \rightarrow \boldsymbol{q_a^1}, \texttt{motion(base,} q_b^0, \boldsymbol{q_b^1}\texttt{)} \rightarrow \boldsymbol{t_b^1},$$
$$\texttt{motion(arm,} q_a^0, \boldsymbol{q_a^1}\texttt{)} \rightarrow \boldsymbol{t_a^1}].$$

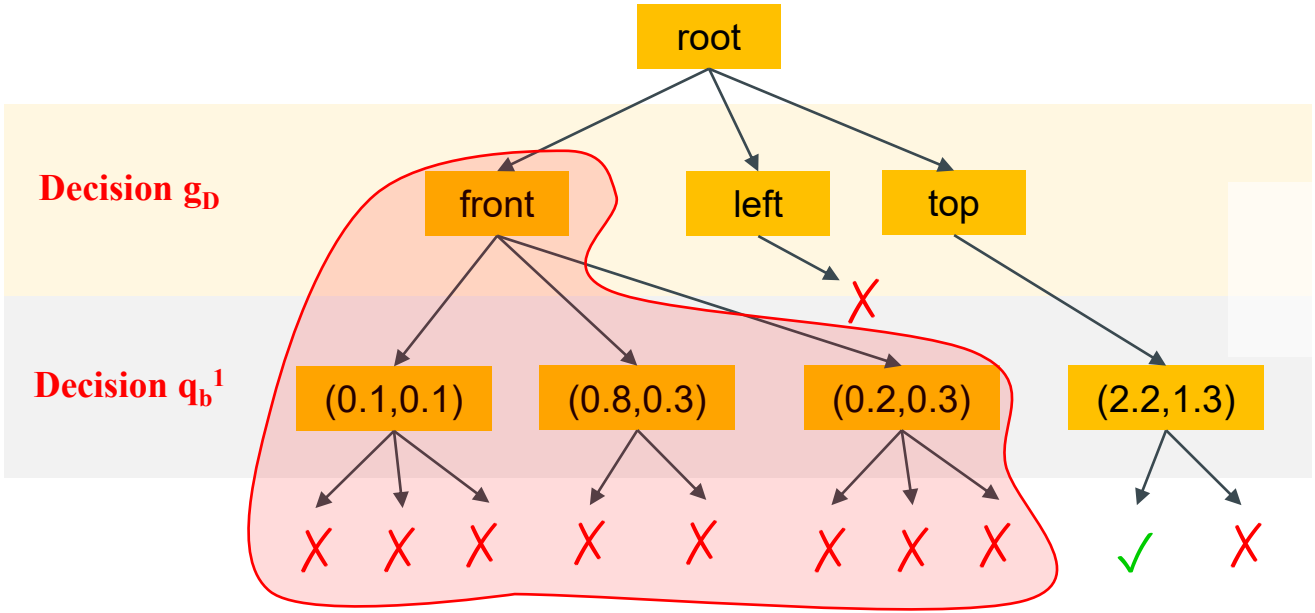




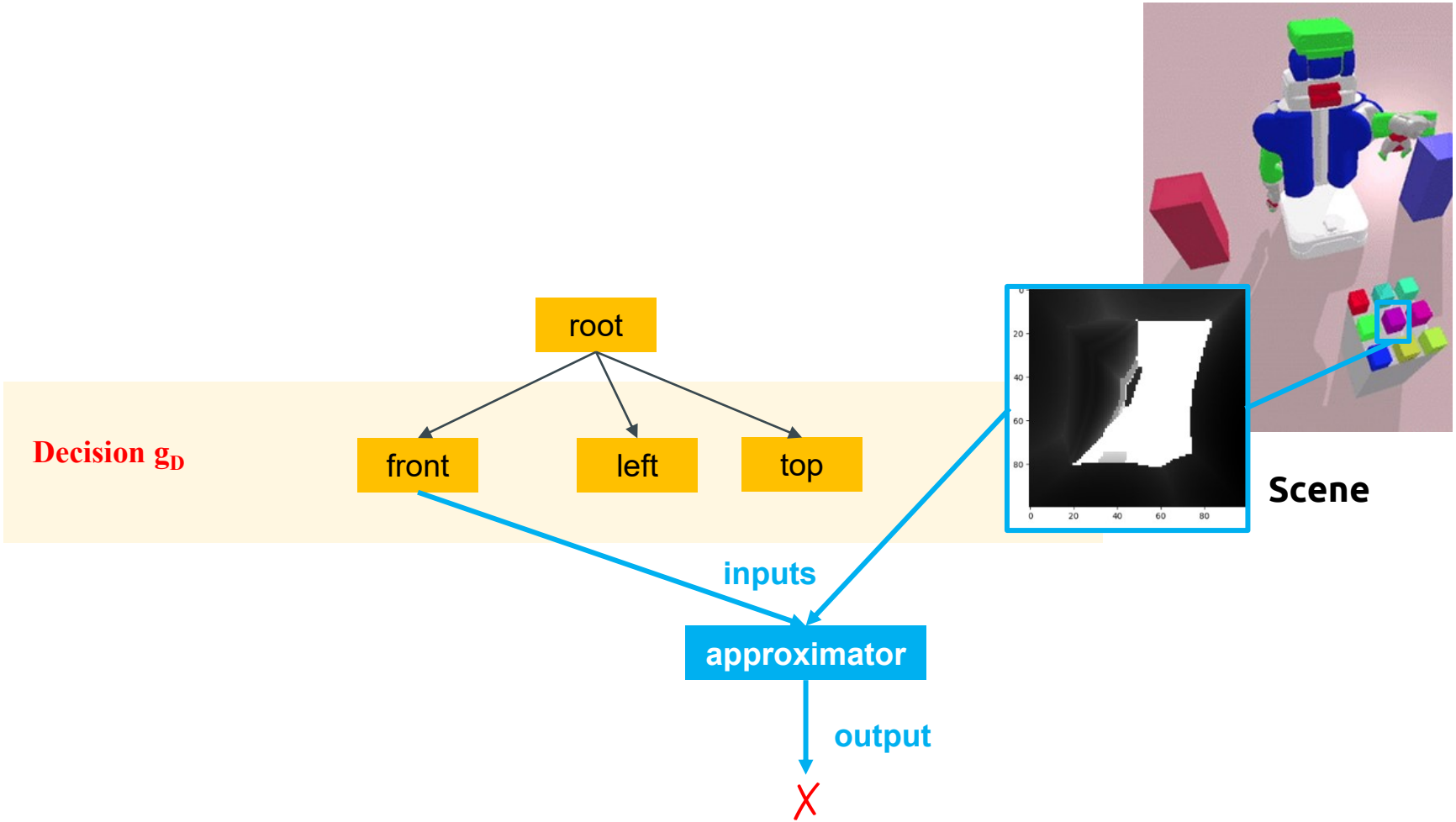
Huge search space

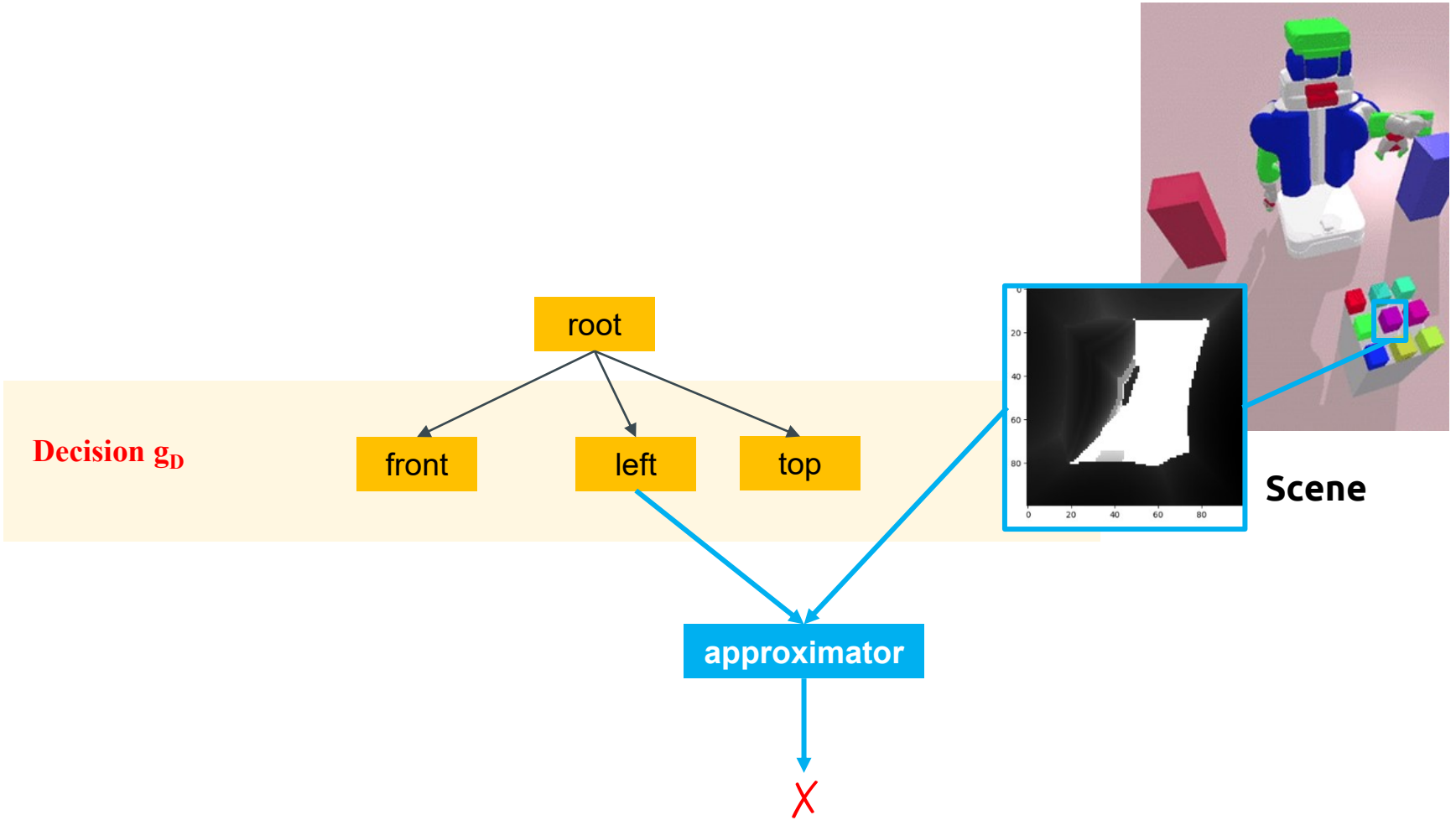
Prune unpromising branches by heuristics

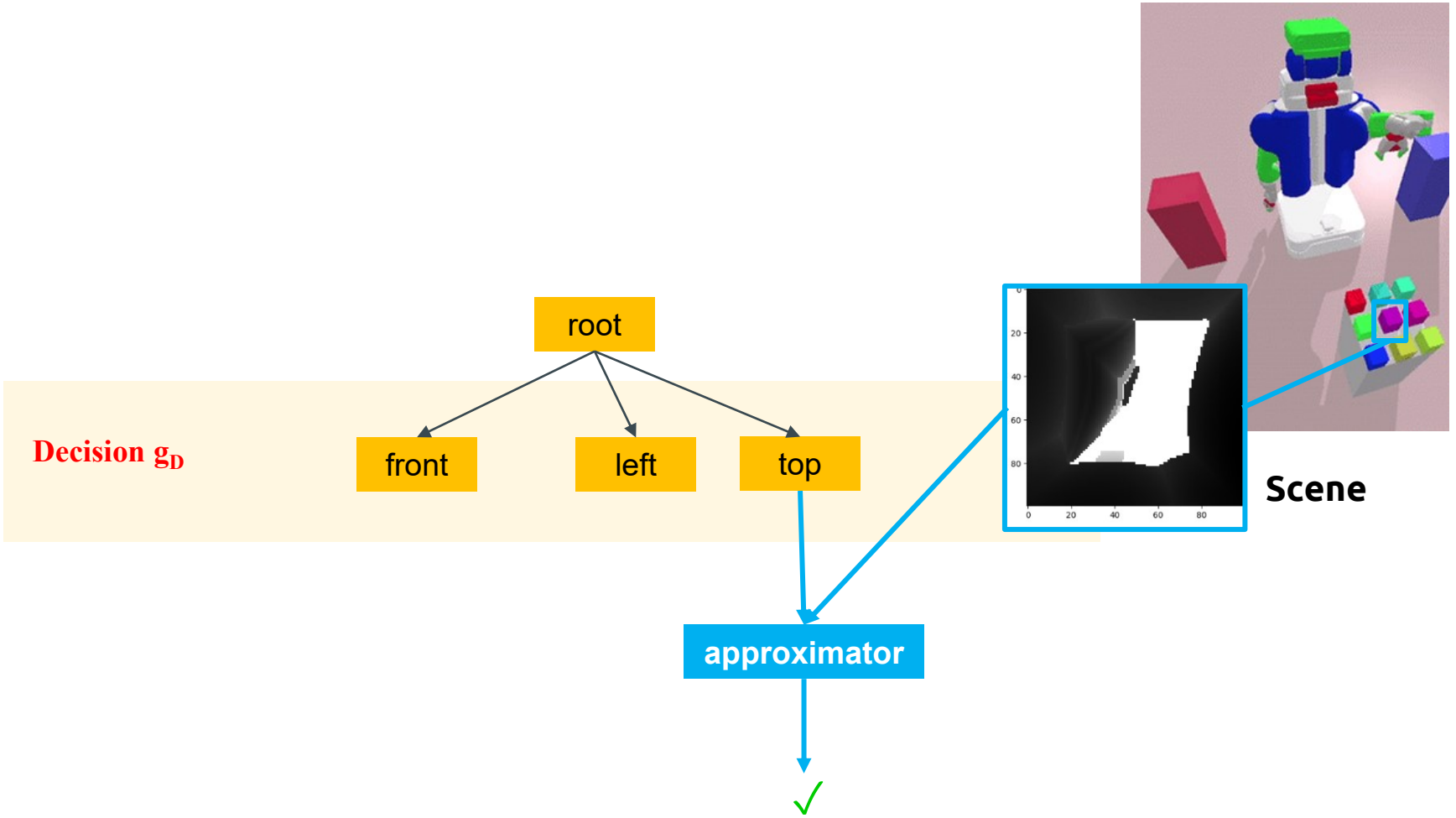


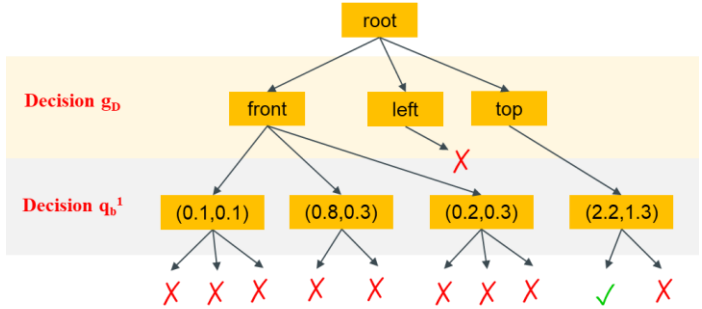


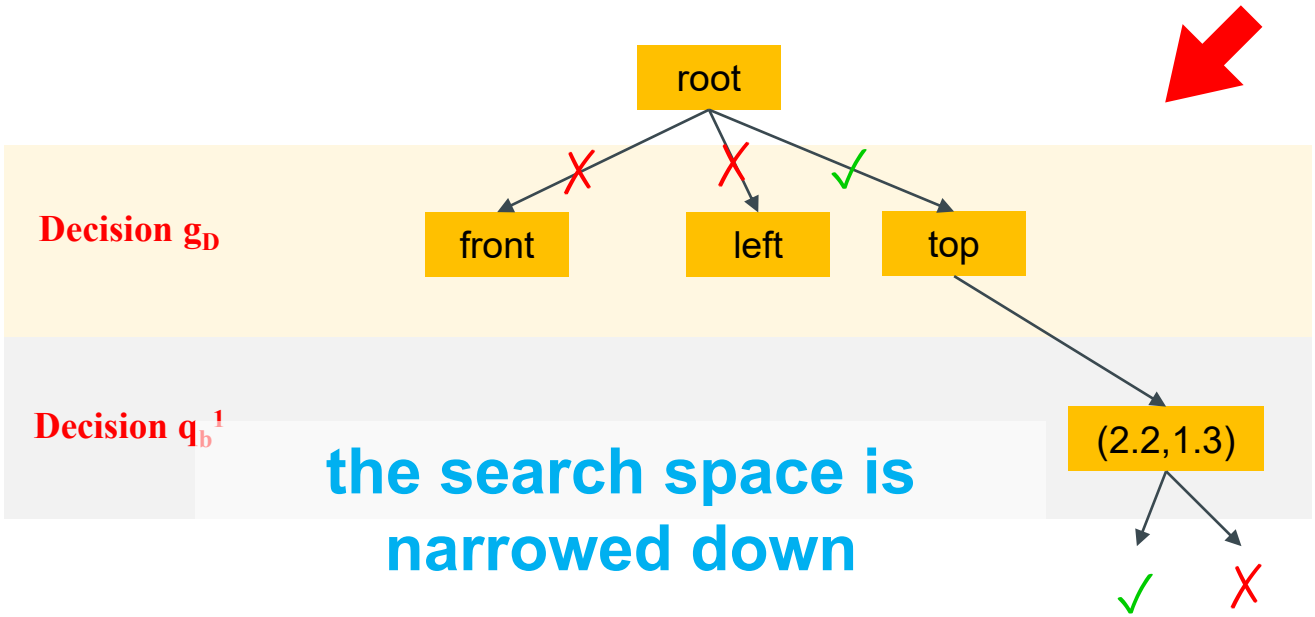
Huge search space


Decision g_D
root
front
left
top
Scene
inputs
approximator
output

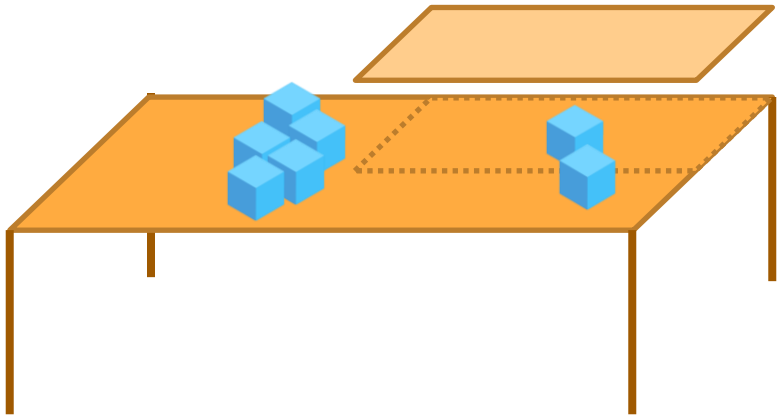

Decision g_D
root
front
left
top
approximator
Scene


Decision g_D
root
front
left
top
approximator
Scene


root
Decision g_D
front
left
top
Decision q_b^1
(0.1,0.1)
(0.8,0.3)
(0.2,0.3)
(2.2,1.3)


root
Decision g_D
front
left
top
Decision q_b^1
(2.2,1.3)
the search space is narrowed down

Toy problem (scen1):



skeleton =

$$[\texttt{grasps(D)}\rightarrow \boldsymbol{g_D}, \texttt{inv-reach(D,}\, p^0_D, \boldsymbol{g_D}\texttt{)}\rightarrow \boldsymbol{q^1_b},$$
$$\texttt{inv-kin(D,}\, p^0_D, \boldsymbol{g_D}, \boldsymbol{q^1_b}\texttt{)}\rightarrow \boldsymbol{q^1_a}, \texttt{motion(base,}\, q^0_b, \boldsymbol{q^1_b}\texttt{)}\rightarrow \boldsymbol{t^1_b},$$
$$\texttt{motion(arm,}\, q^0_a, \boldsymbol{q^1_a}\texttt{)}\rightarrow \boldsymbol{t^1_a}].$$

Work content

Task scenario 1 with Tiago robot

operators: streams, actions

UCT for motion variables

Evaluation in scen1 and scen2

robot simulation:

? feasibility

objective function

object-oriented scene encoder

train heuristic and optimize encoder

compare accuracy with baseline [1]

deep heuristic:

scene

decision