Hierarchical Task and Motion Planning in the Now

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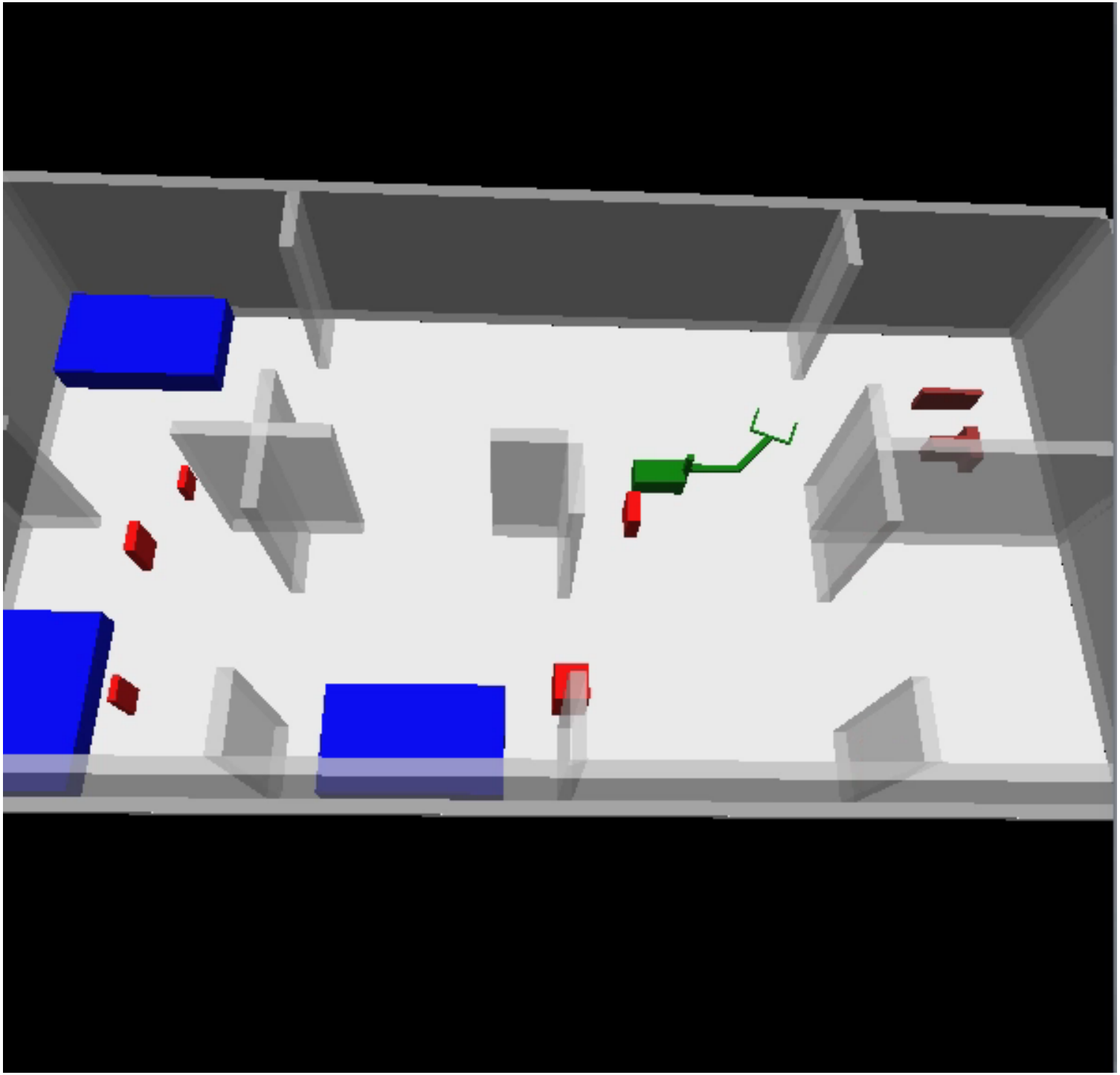
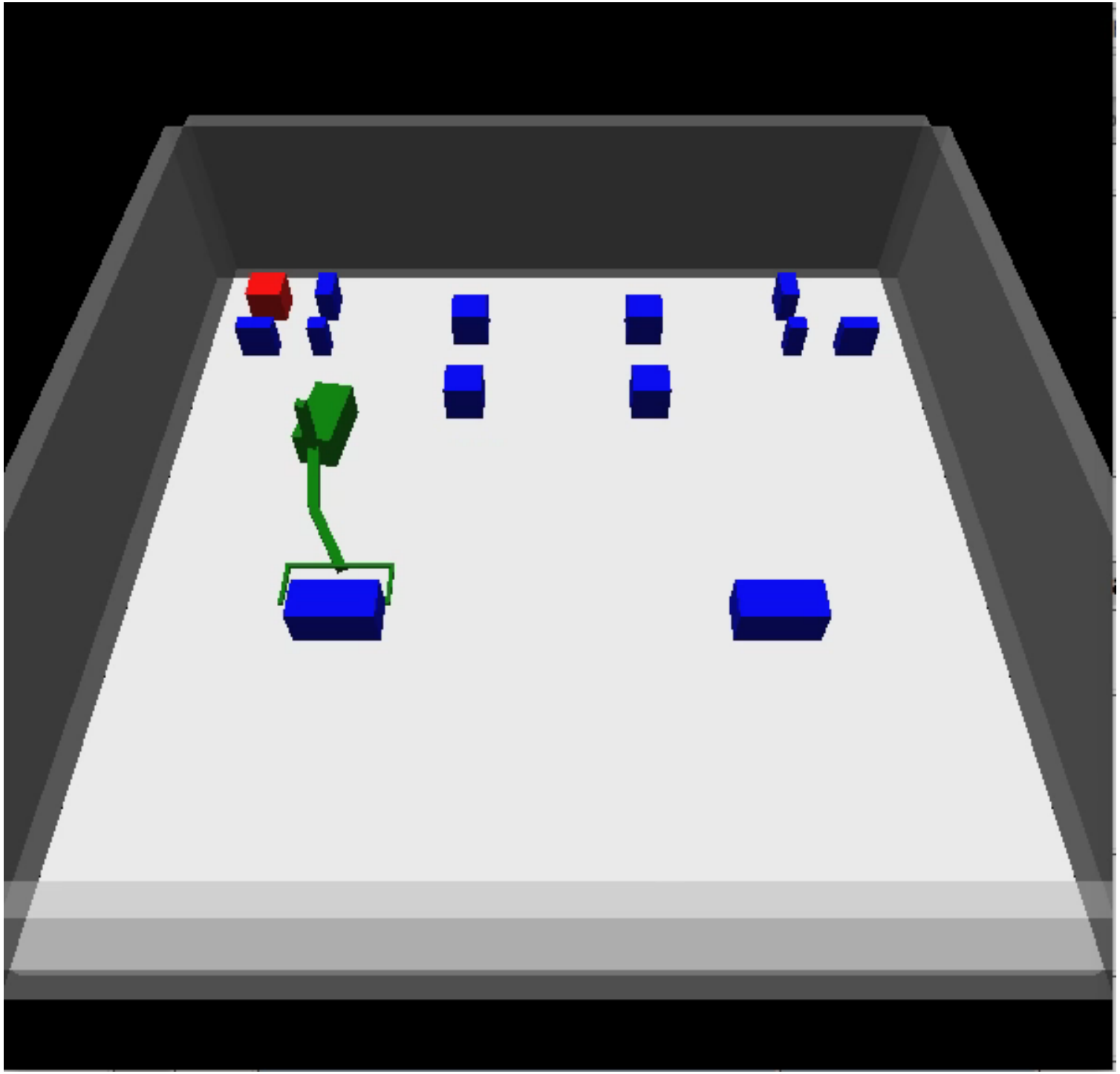
What next?





Bridging the gap

Problem is hard:

- very high dimensional configuration space
- very long planning horizon

We can solve:

- discrete search problems
- short horizons

A bridge to somewhere

Two insights:

- **Regression-based planning**
  lets us construct an appropriate finite search space on the fly

- **Hierarchical planning and execution**
  reduces one long-horizon problem to many short ones

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Symbols to Angles

Initial state known in geometric detail

Goal set is abstract, symbolic

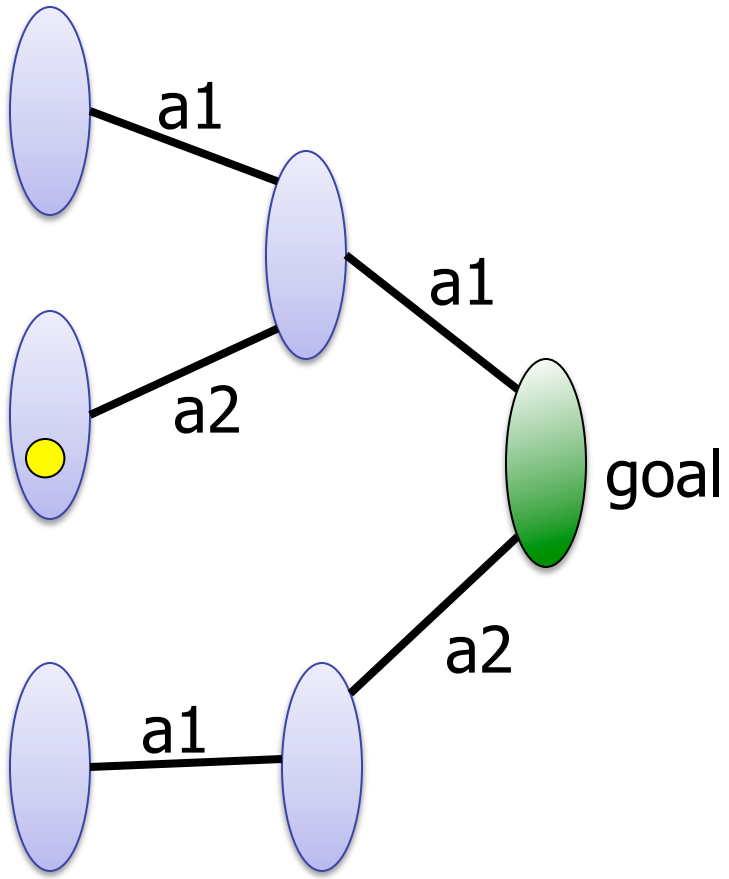
tidy(house) ∧ charged(robot)

Goal Regression

Weakest precondition of goal set under each action sequence

Test whether start state is in a pre-image

Represent goal and pre-images as conjunctions of predicates



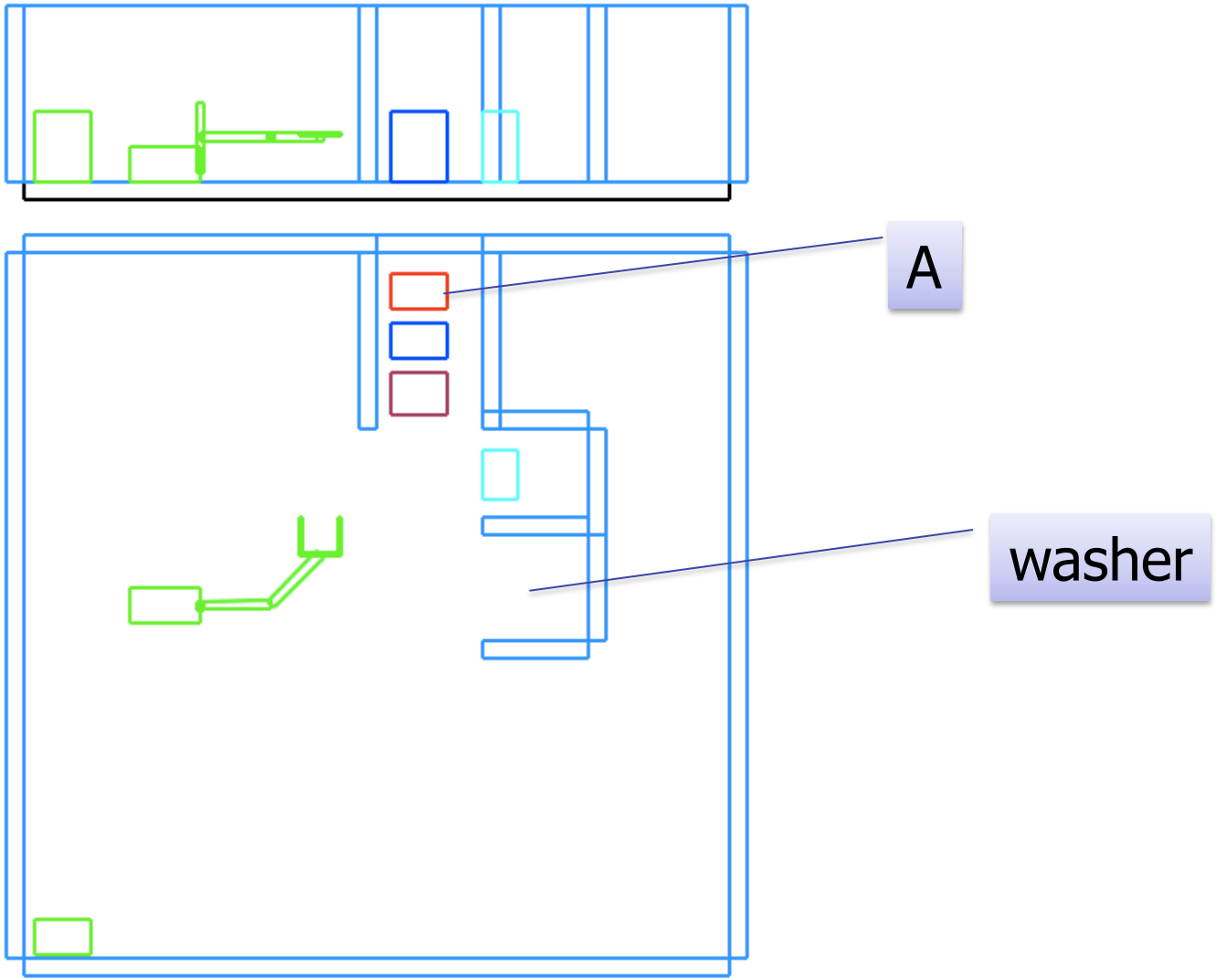
Why regression?

Can't construct a complete representation of the start state and plan forward symbolically

- infinitely many geometrical regions
- too many objects

Only need to test whether logical conditions defining pre-image are true in geometric start state

Wash object A

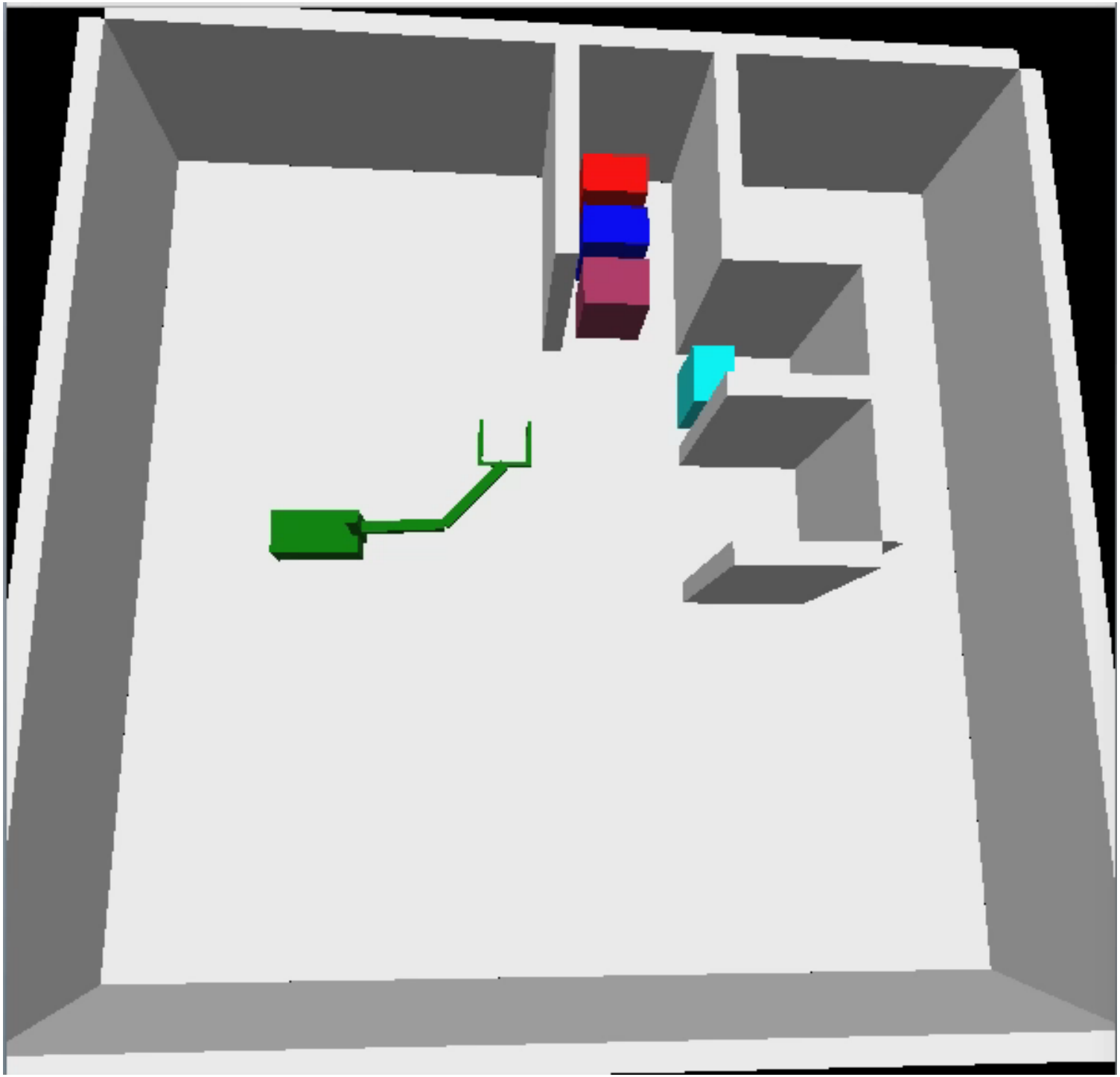


Primitive operations

Pick and place (object, targetRegion)

- pick object pose in targetRegion
- pick grasp
- plan paths with RRT

Run washer



Planning operators

PickAndPlace(O, S, R):

exists: S ∈ {currentLoc(O), parkingFor(O)}

exists: P ∈ pathFor(O, S, R)

pre: ClearX(sweptVol(P), O), In(O, S)

result: In(O, R)

refinement: PandPPrim(O, R)

Not STRIPS:

- domain of objects not known a priori
- add / delete 'lists' are infinite

Suggesters

PickAndPlace(O, S, R):

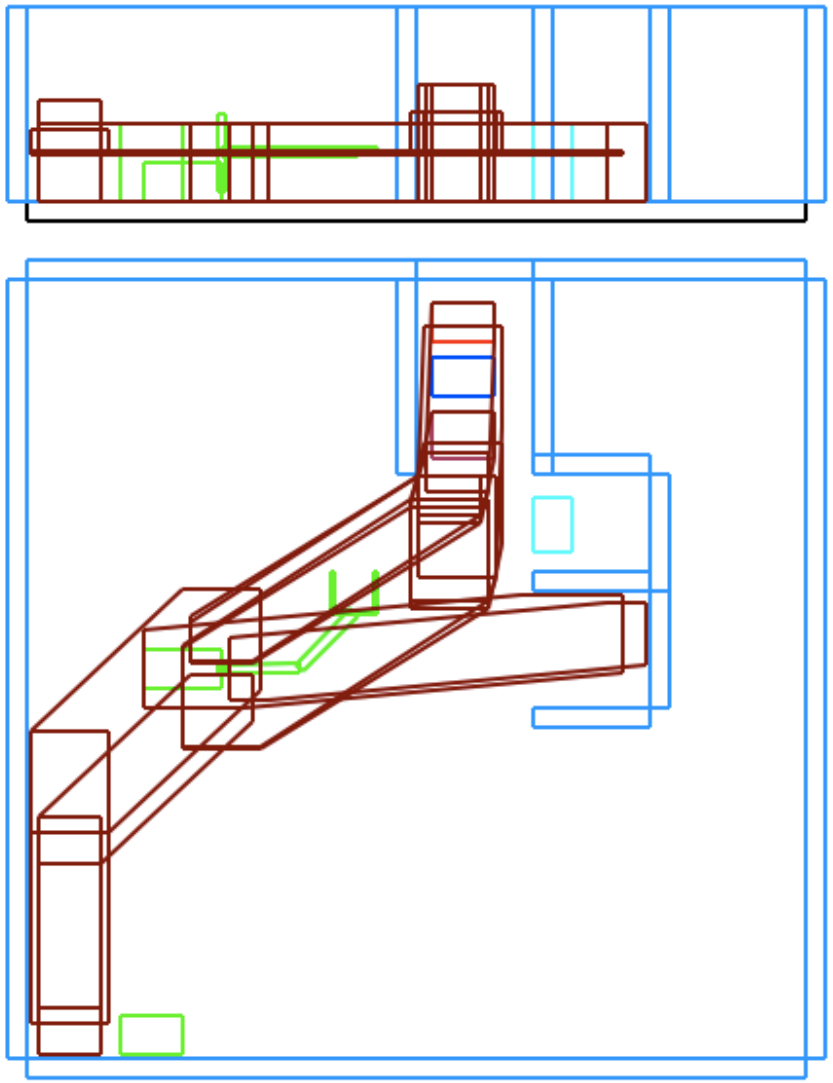
exists: S ∈ {currentLoc(O), **parkingFor(O, tabus)**}

exists: P ∈ **pathFor(O, S, R)**

…

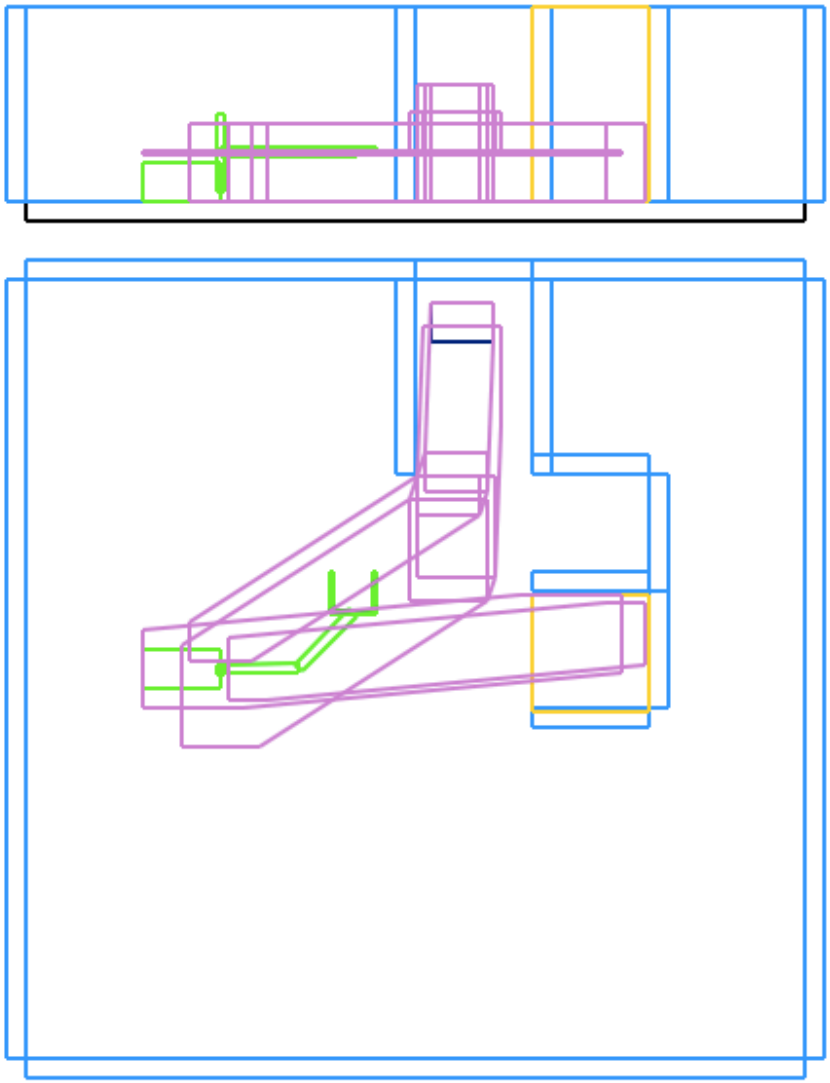
- Can't enumerate all possible places from which we might have moved the object to its destination
- Make suggestions based on current geometry
- Respect constraints derived from current planning context, e.g. tabus

Parking suggestion



Brown: tabu regions
Green: parking

Path suggestion



Gold: target region
Purple: path

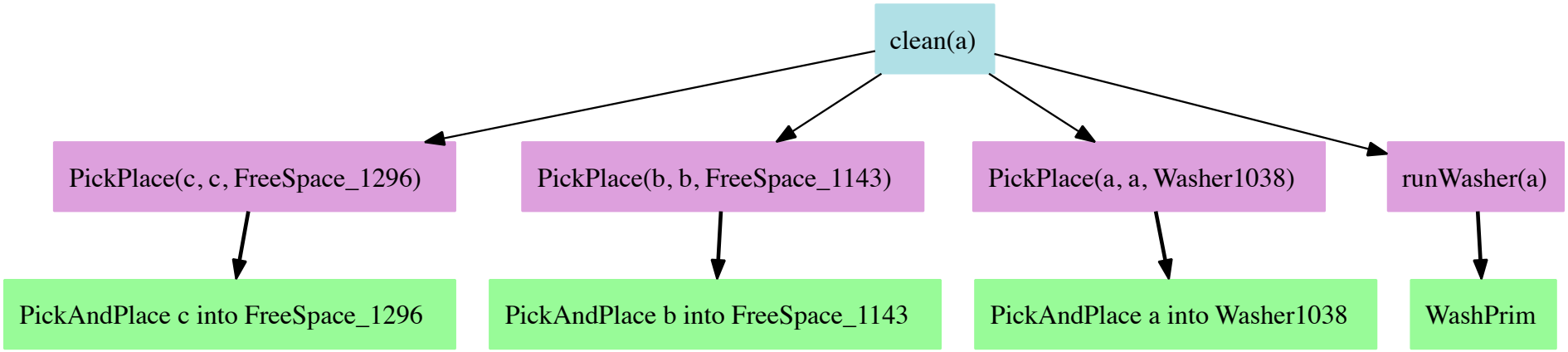
Geometric inference

Computing weakest preconditions

- STRIPS uses finite lists of fluents that are changed by an operation
- We provide procedures that test pairs of geometric fluents for contradiction and entailment

In(O1, R1) contradicts ClearX(R2, Obs2) iff …

Regression plan



One planning problem:

- 4 primitive steps
- 7 operators
- 155 search nodes

blue: goal
orchid: operator
green: primitive

A bridge to somewhere

Two insights:

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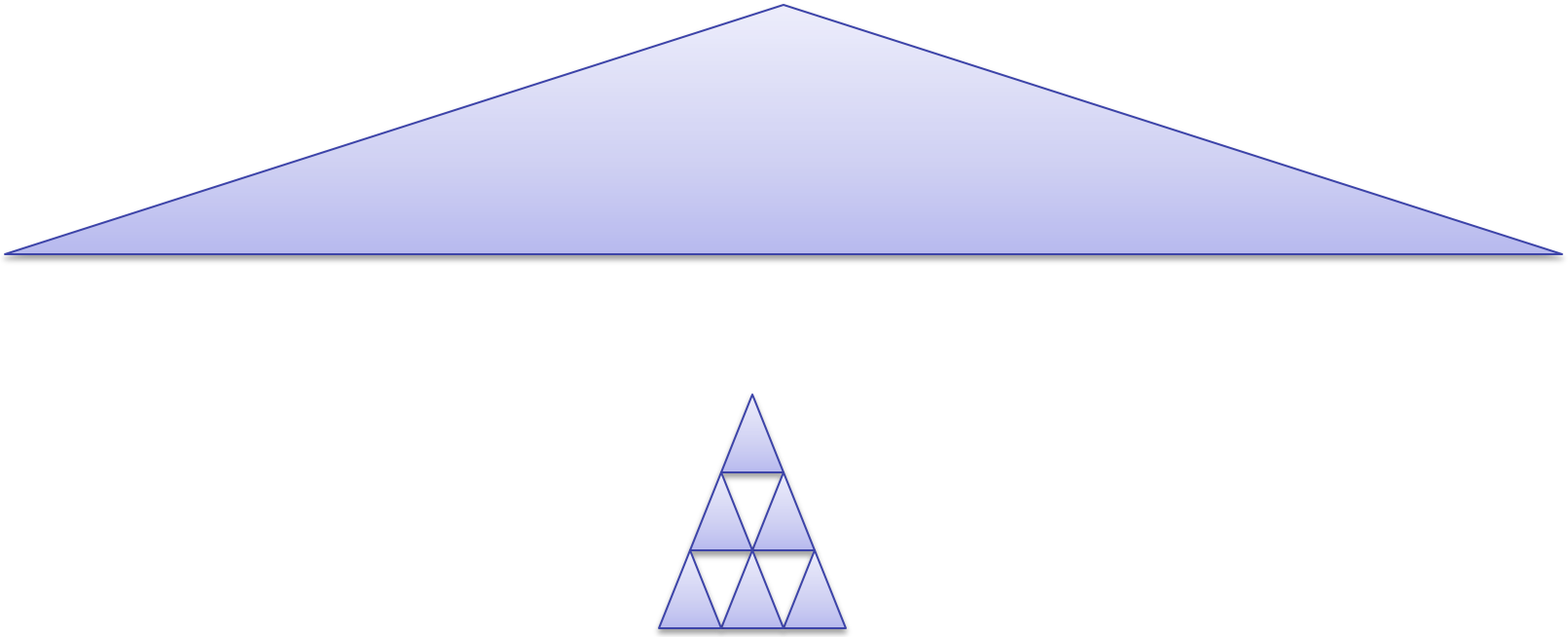
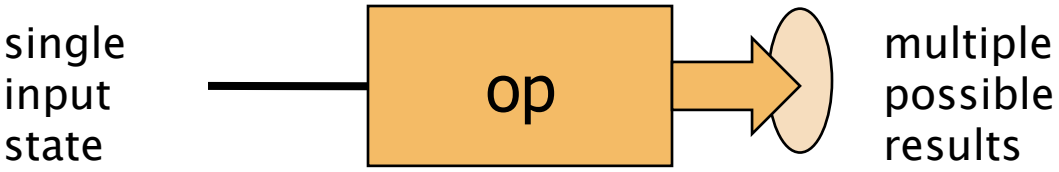
Hierarchy can reduce search space



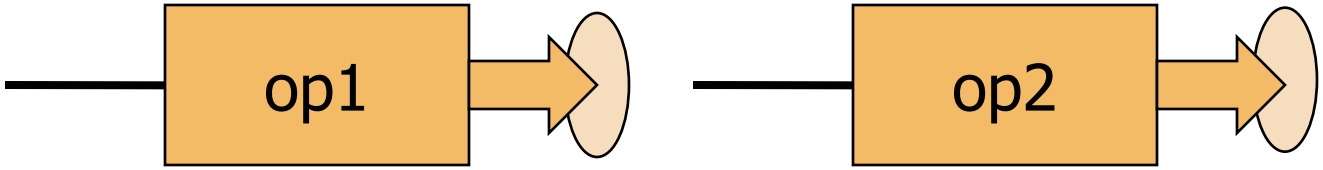
Subtrees represent **serializable subgoals**

Hierarchical semantics

Subgoal is an abstract operator:



What does it mean to sequence two subgoals?



Depends on who gets to choose the outcome:

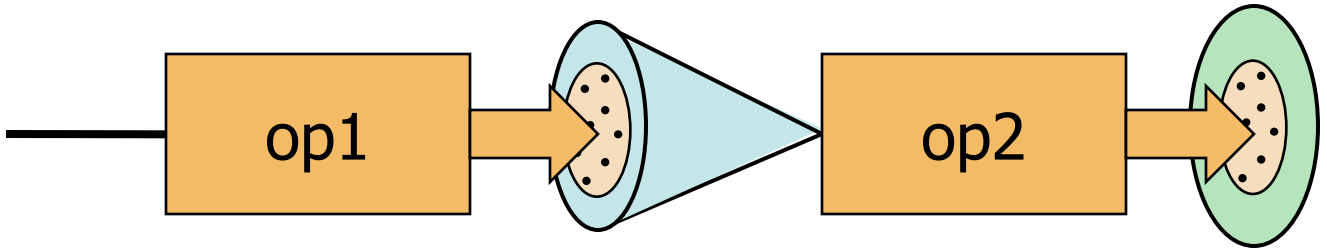
us

nature

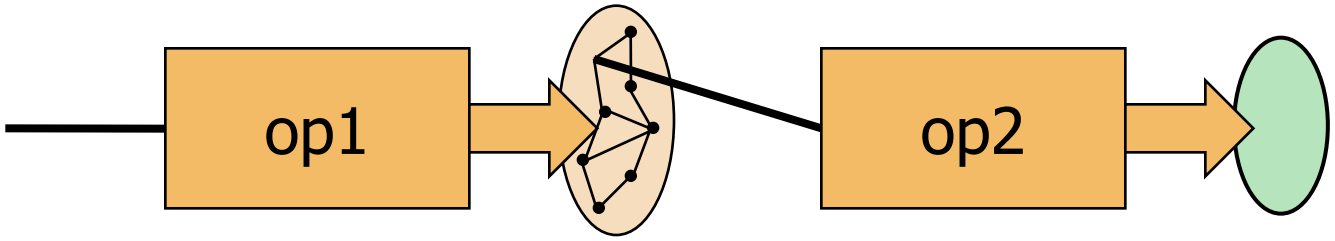
Marthi, Russell, Wolfe

Satanic Semantics

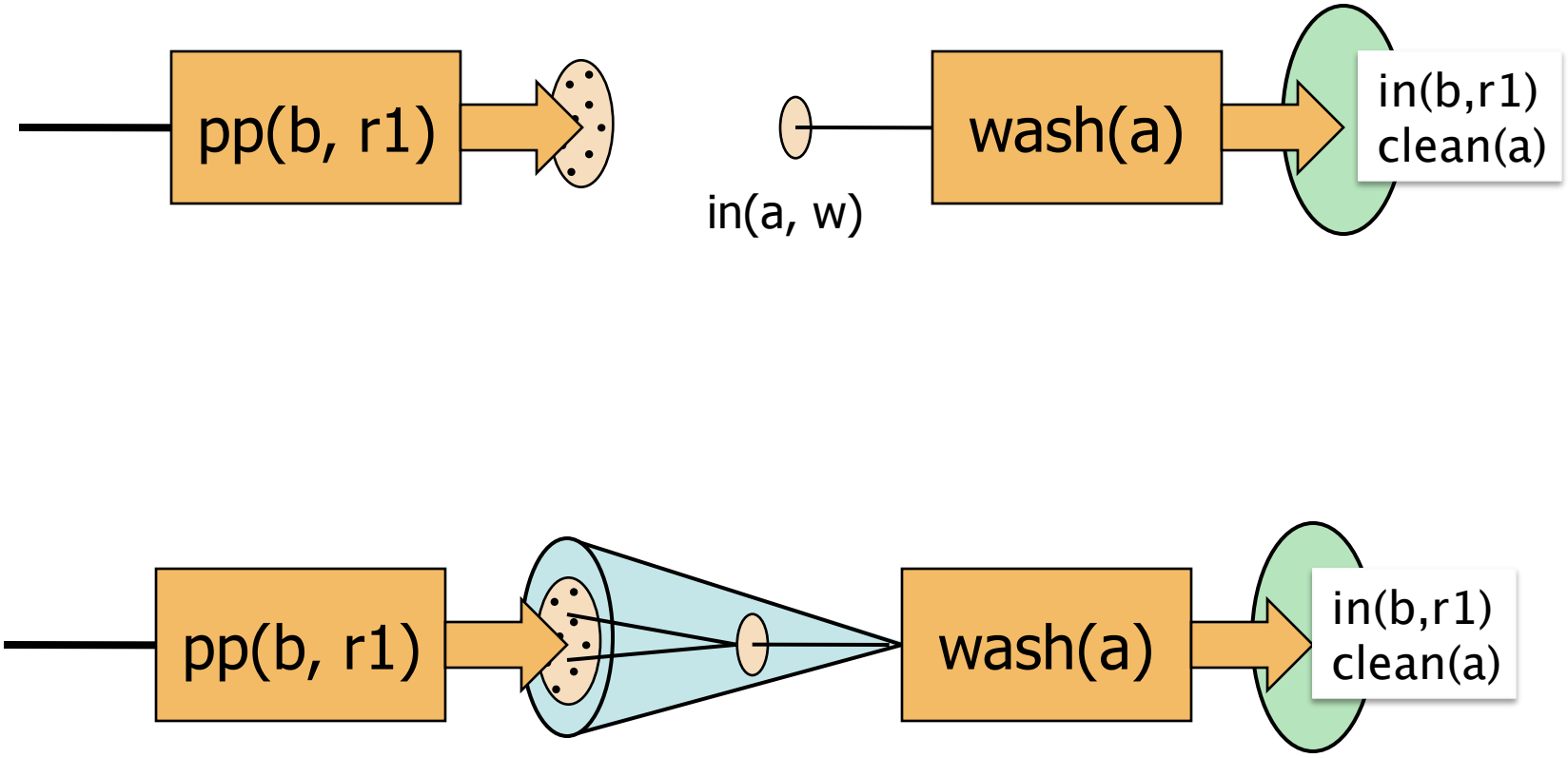
We have to handle any outcome the devil picks



Preconditions of op2 can be achieved from any state resulting from op1

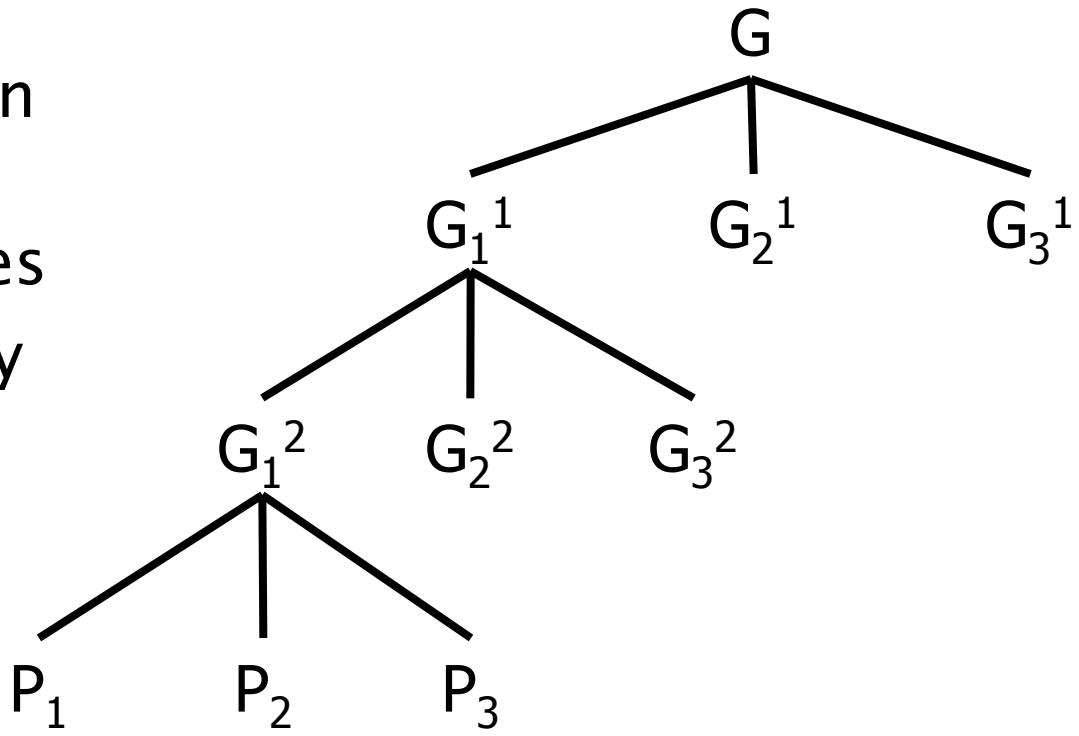


Fold preconds into operator

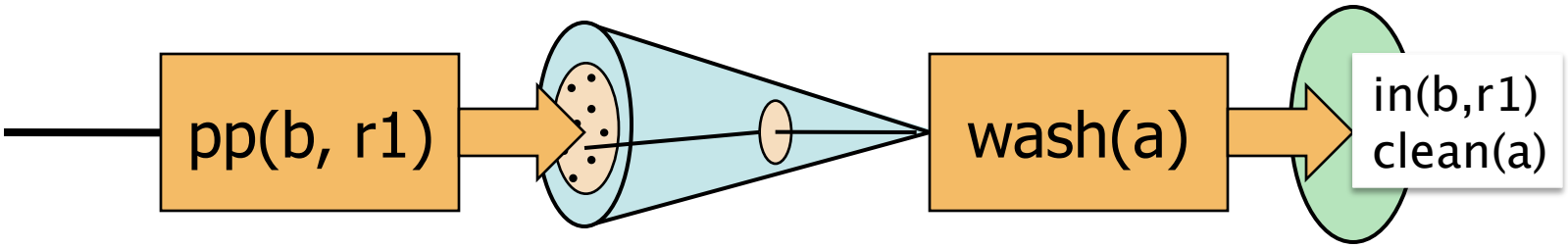


Planning in the now

- maintain left expansion of plan tree
- execute primitives
- plan as necessary



In the now

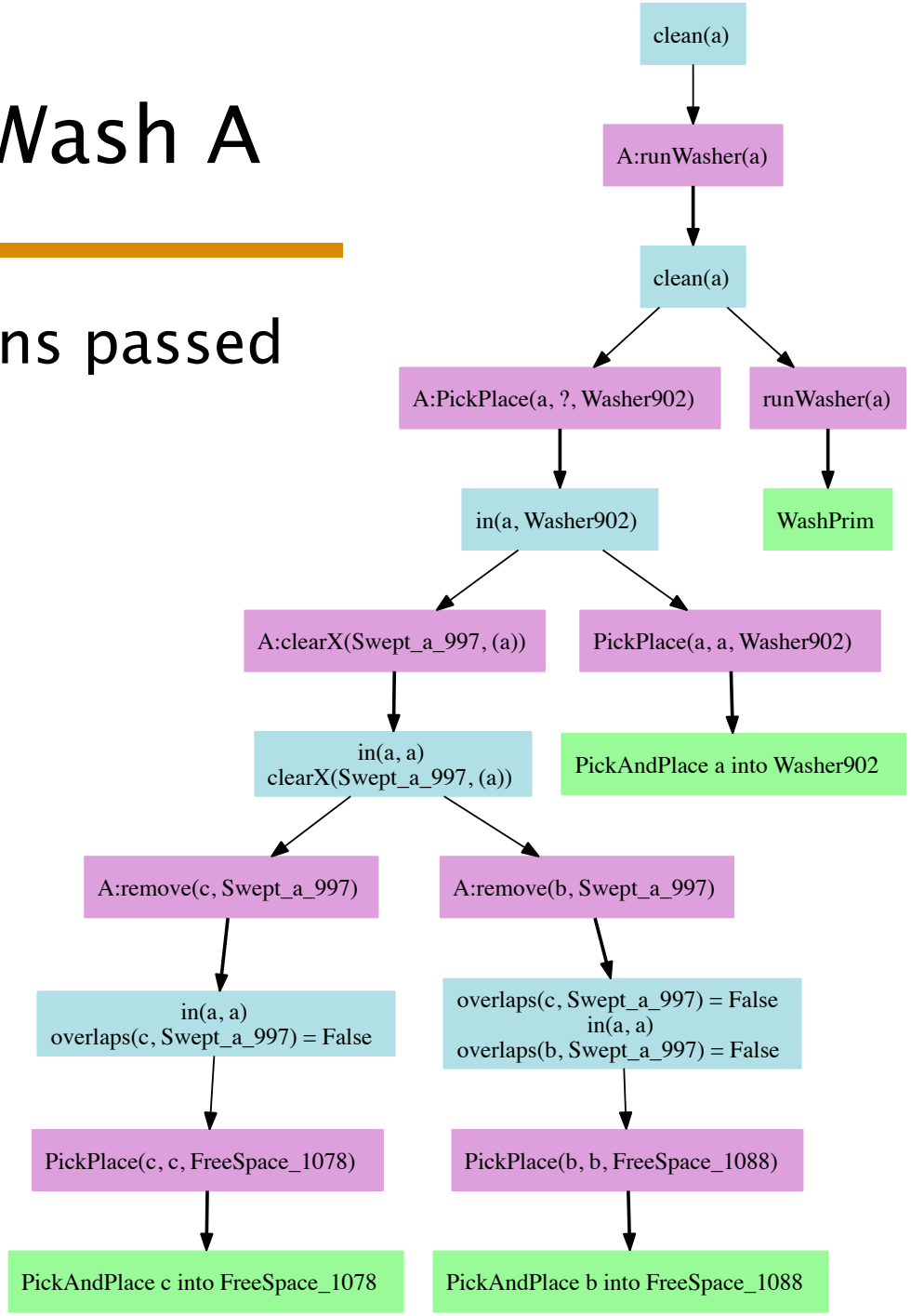


- Don't think about all the ways pp(b, r1) could have terminated
- When it is time to plan for clean(a), whatever resulted will be our start state

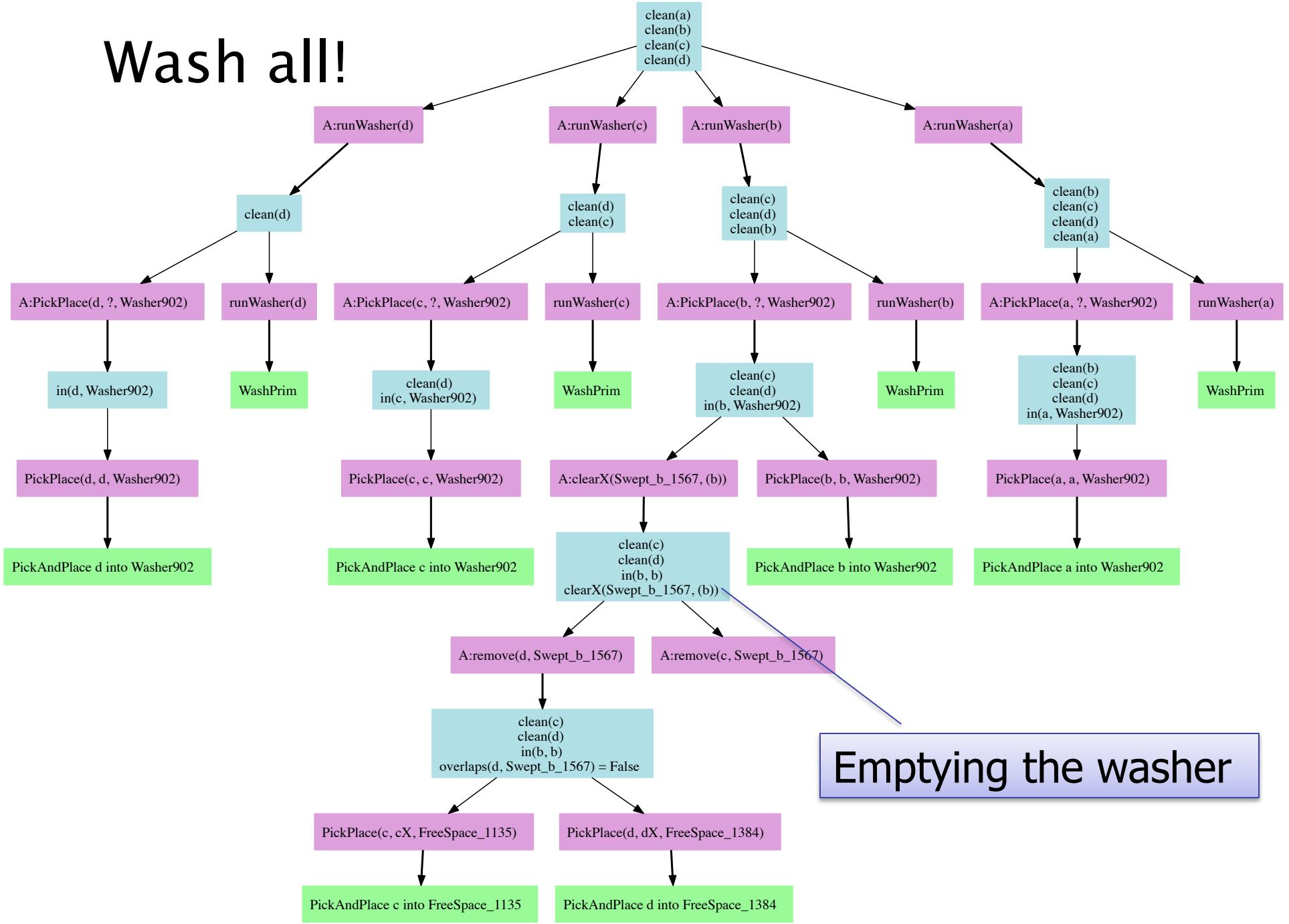
Wash A

Maintenance conditions passed down and back

Six planning problems:
- 4 primitive steps
- 34 search nodes, total



Wash all!


clean(a)
clean(b)
clean(c)
clean(d)
A:runWasher(d)
A:runWasher(c)
A:runWasher(b)
A:runWasher(a)
clean(d)
clean(d)
clean(c)
clean(c)
clean(d)
clean(b)
clean(b)
clean(c)
clean(d)
clean(a)
A:PickPlace(d, ?, Washer902)
runWasher(d)
A:PickPlace(c, ?, Washer902)
runWasher(c)
A:PickPlace(b, ?, Washer902)
runWasher(b)
A:PickPlace(a, ?, Washer902)
runWasher(a)
in(d, Washer902)
WashPrim
clean(d)
in(c, Washer902)
WashPrim
clean(c)
clean(d)
in(b, Washer902)
WashPrim
clean(b)
clean(c)
clean(d)
in(a, Washer902)
WashPrim
PickPlace(d, d, Washer902)
PickPlace(c, c, Washer902)
A:clearX(Swept_b_1567, (b))
PickPlace(b, b, Washer902)
PickPlace(a, a, Washer902)
PickAndPlace d into Washer902
PickAndPlace c into Washer902
clean(c)
clean(d)
in(b, b)
clearX(Swept_b_1567, (b))
PickAndPlace b into Washer902
PickAndPlace a into Washer902
A:remove(d, Swept_b_1567)
A:remove(c, Swept_b_1567)
clean(c)
clean(d)
in(b, b)
overlaps(d, Swept_b_1567) = False
PickPlace(c, cX, FreeSpace_1135)
PickPlace(d, dX, FreeSpace_1384)
PickAndPlace c into FreeSpace_1135
PickAndPlace d into FreeSpace_1384
Emptying the washer

Recovery from assumptions

Serialization:

- Because maintenance conditions are propagated forward, eventually entire joint planning problem will be solved

Suggestion violates constraints:

- Call real planner

Suggestions are insufficient:

- Sample or enumerate possible values

Framework generalizations

- Uncertainty
  - act to gain information
  - expectation wrt current and future states
- Learning
  - which preconditions don't serialize
  - cost function
  - heuristic
  - suggesters

What next?


clean(kitchen)
clean(stove)
putAway(pan)
move(board)
pick(board)
moveTo(Θ)

Related work

- Cambon, Alami and Gravot – intertwined STRIPS + motion planner
- Plaku and Hager – STRIPS planner as heuristic
- Stilman and Kuffner – movable obstacles
- Hauser and Latombe – task + PRM
- Choi and Amir – generate symbolic operators from motion planner
- Dornhege et. al – semantic attachment to STRIPS planner
- Wolfe, Marthi and Russell – hierarchical STRIPS planning
- Sacerdoti –hierarchical STRIPS planning
- Nourbahksh – interleaved plan and execute