

OMPL: The Open Motion Planning Library

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Intended use

- Education
- Motion planning research
- Industry

Design objectives

- Clarity of concepts
- Efficiency
- Simple integration with other software packages
- Straightforward integration of external contributions

Other motion planning software

- **MPK**, Schwarzer, Saha, Latombe
- **MSL**, LaValle et al.
- **OpenRAVE**, Diankov & Kuffner
- **KineoWorks**, Laumond et al.
- **OOPSMP**, Plaku et al.

Other related robotics software

- ROS
- Player/Stage, Player/Gazebo
- Webots
- MORSE
- Microsoft Robotics Developer Studio

Main features of OMPL

OMPL in a nutshell

- Common core for sampling-based motion planners
- Includes commonly-used heuristics
- Takes care of many low-level details often skipped in corresponding papers

Abstract interface to *all* core motion planning concepts

- state space / control space
- state validator (e.g., collision checker)
- sampler
- goal (problem definition)
- planner
- ...

except robot & workspace...



States & state spaces

abstract state space

States & state spaces

abstract state space

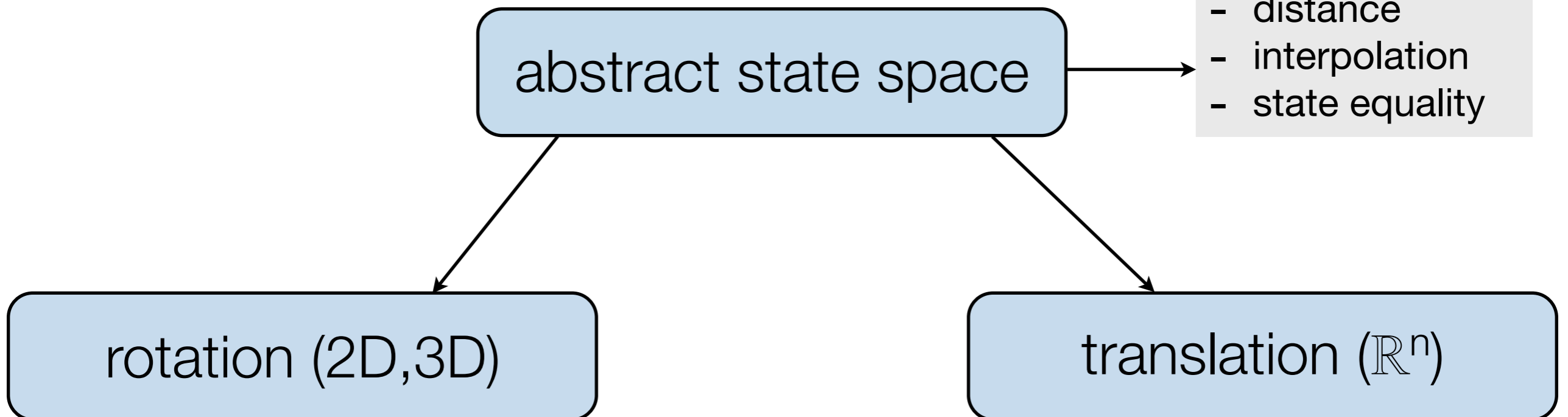


API requirements:

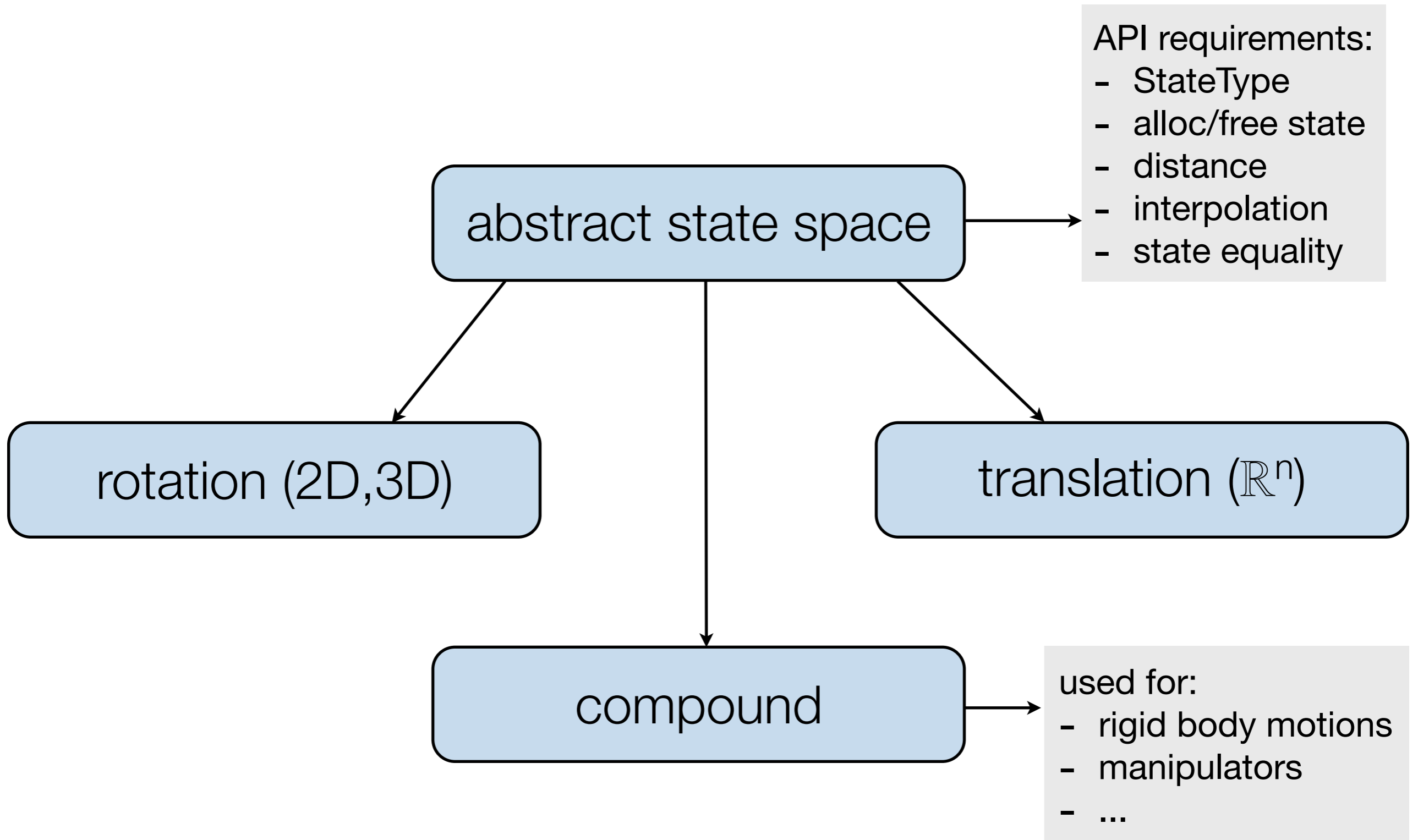
- StateType
- alloc/free state
- distance
- interpolation
- state equality

States & state spaces

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 - state equality

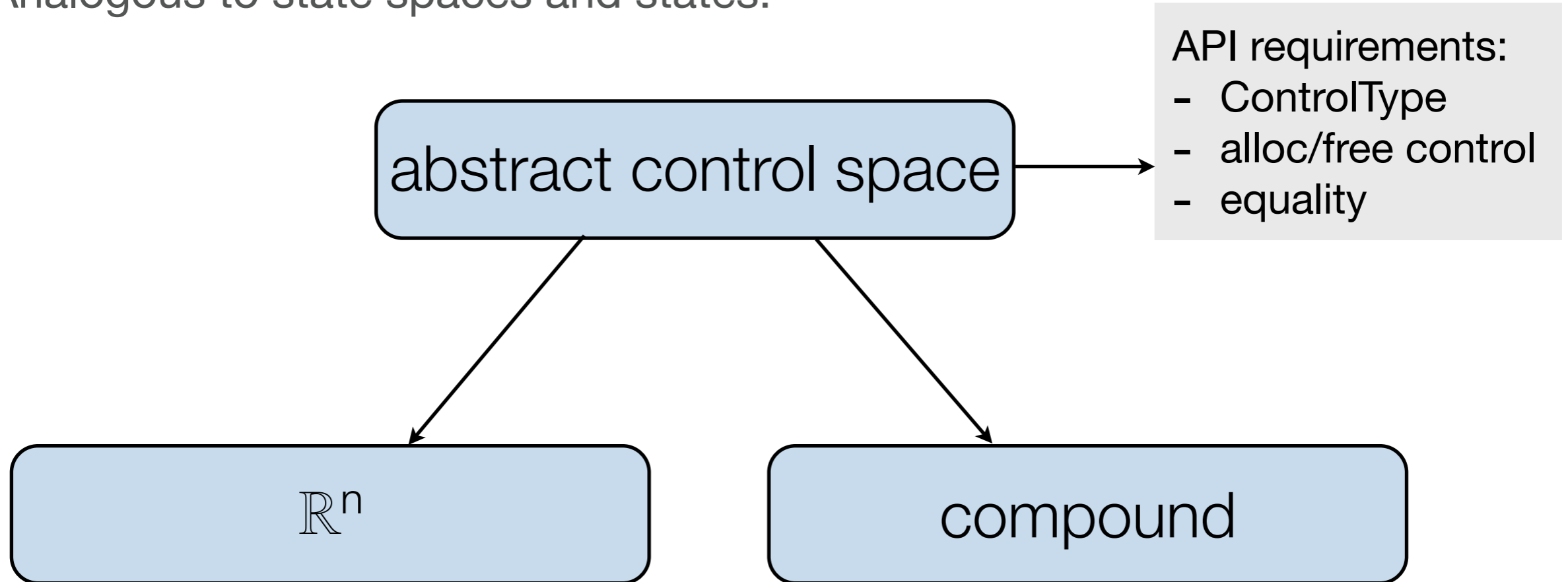


States & state spaces



Control spaces & controls

- Needed only for control-based planning
- Analogous to state spaces and states:



State validators

- Problem-specific; **must** be defined by user **or** defined by layer on top of OMPL core → **ompl_ros_interface**
- Checks whether state is collision-free, joint angles and velocities are within bounds, etc.
- **Optionally**, specific state validator implementations can return
 - distance to nearest invalid state (i.e., nearest obstacle)
 - gradient of distance

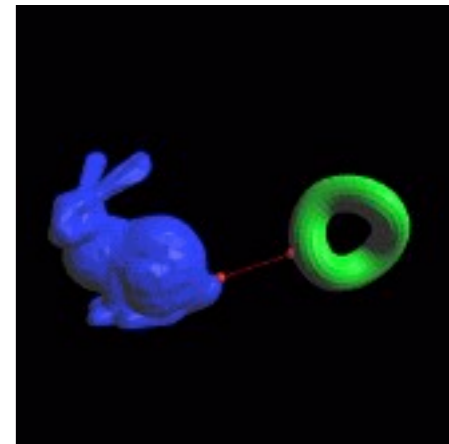
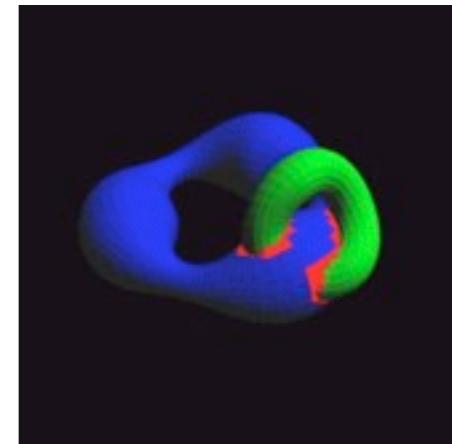
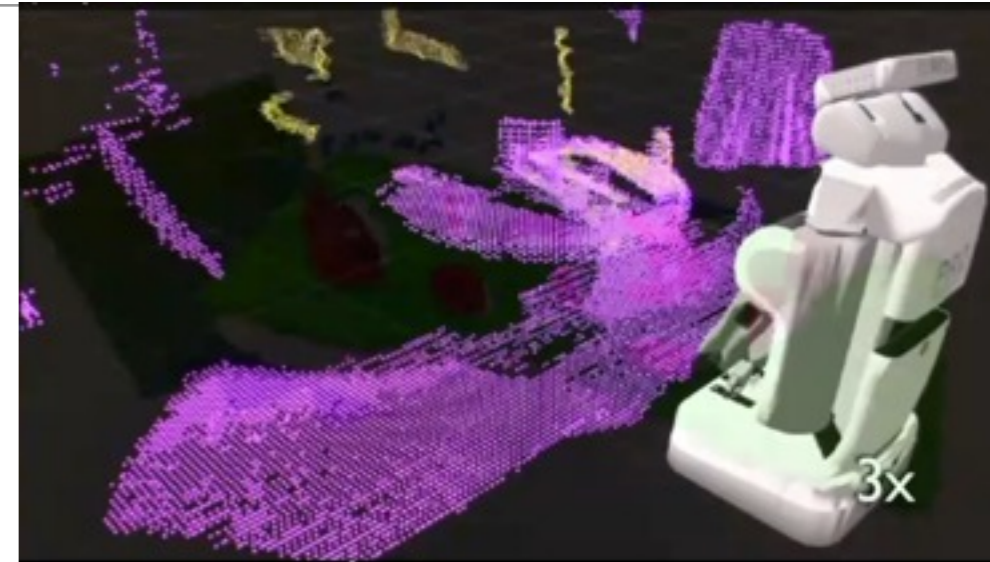
Can be exploited by planners / samplers!

Most common state validator: collision checker

image from pointclouds.org

Several options:

- Implemented in ROS on top of sensor-derived world model
- Implemented in OMPL.app for triangle meshes using PQP library
- Easy to add wrappers for other libraries



images from PQP web site

*Need to define **specific** world representation to implement collision checking*

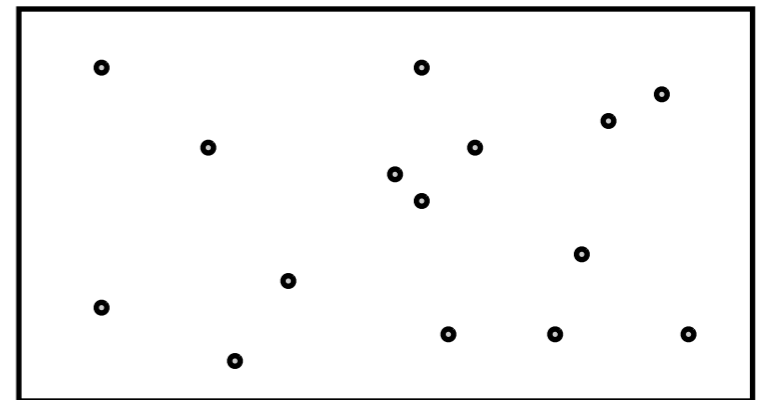
Samplers

- For every **state space** there needs to be a **state sampler**
- State samplers need to support the following:

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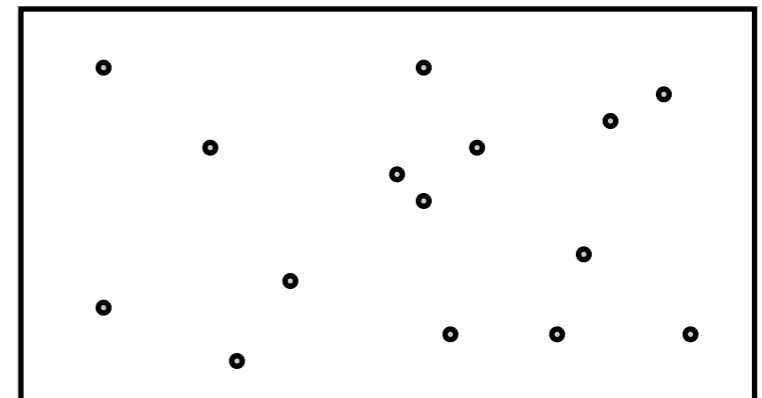
- sample uniform



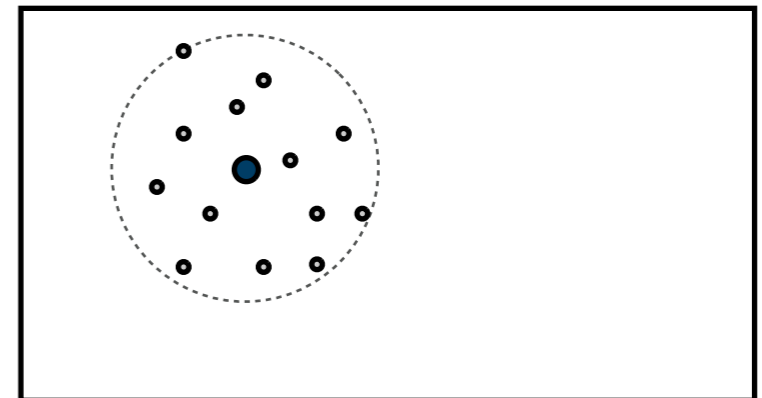
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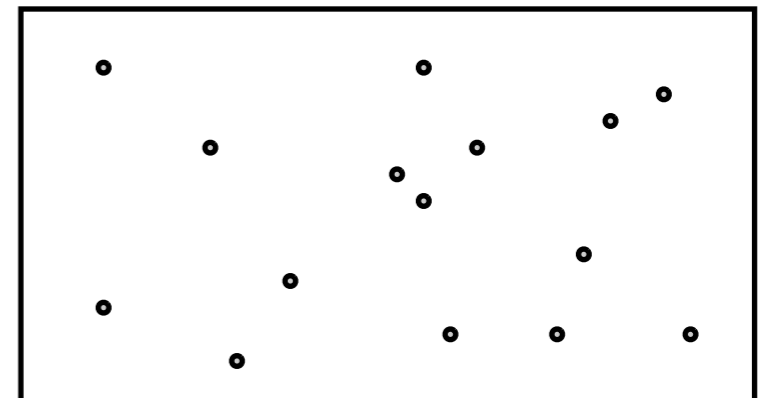
- sample uniform near given state



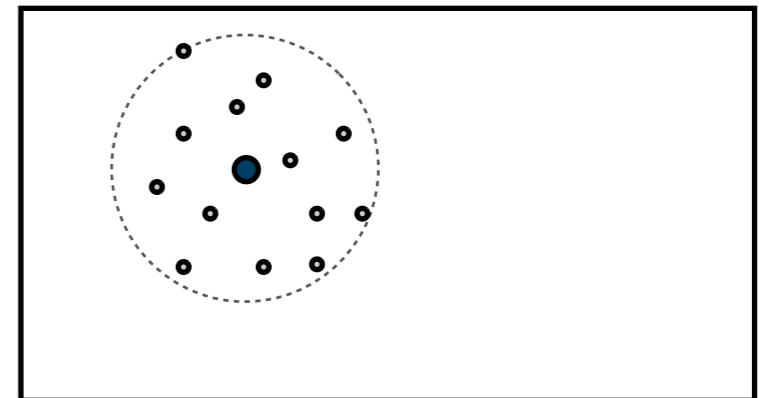
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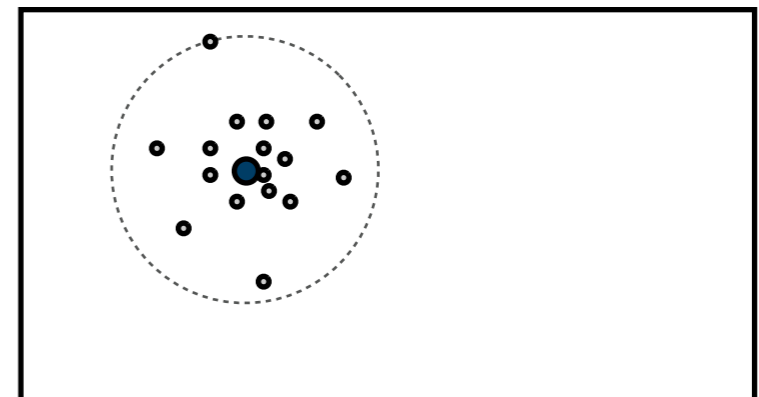
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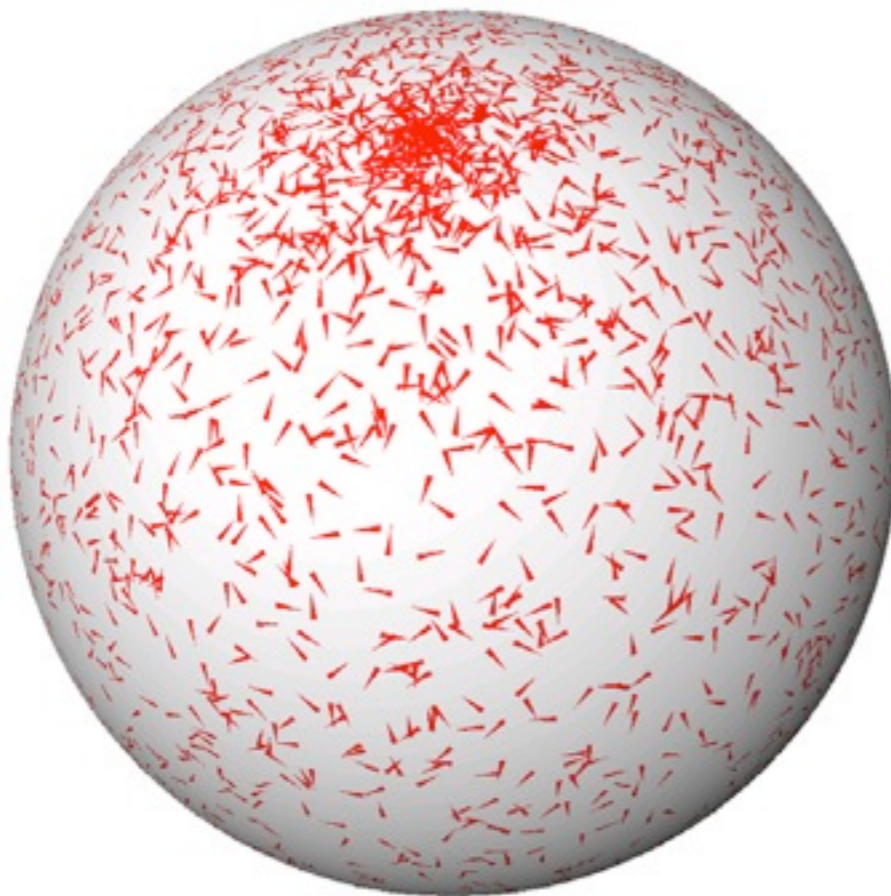
- sample from Gaussian centered at given state



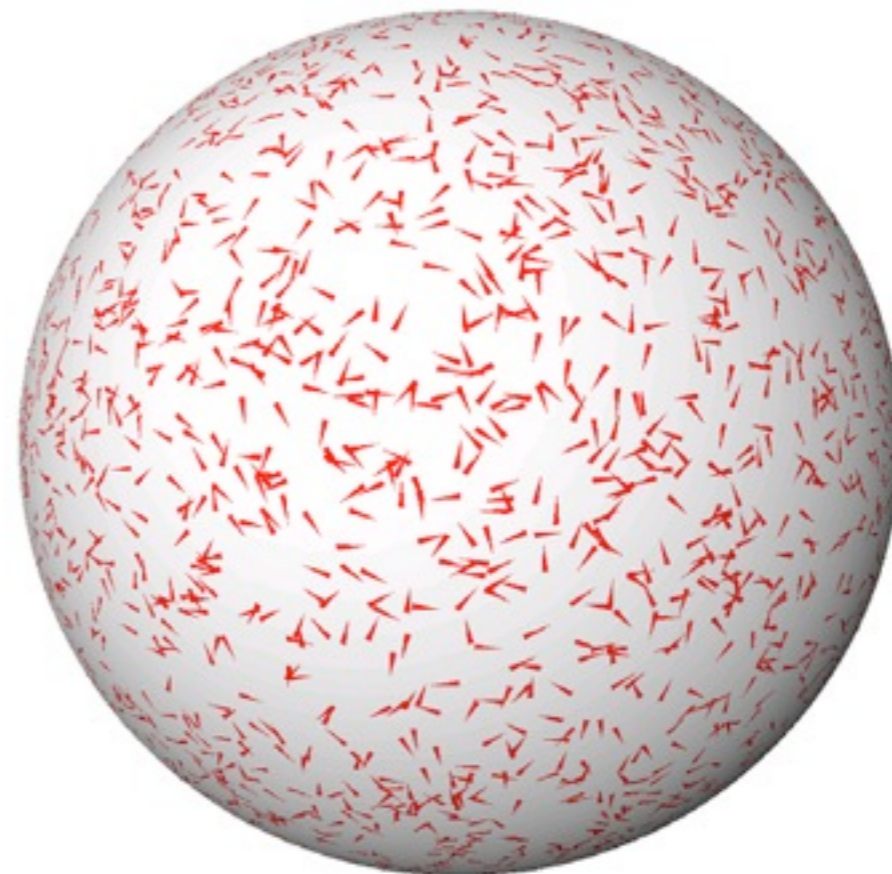
Many ways to get sampling wrong

Example: uniformly sampling 3D orientations

naïve & wrong:



correct:

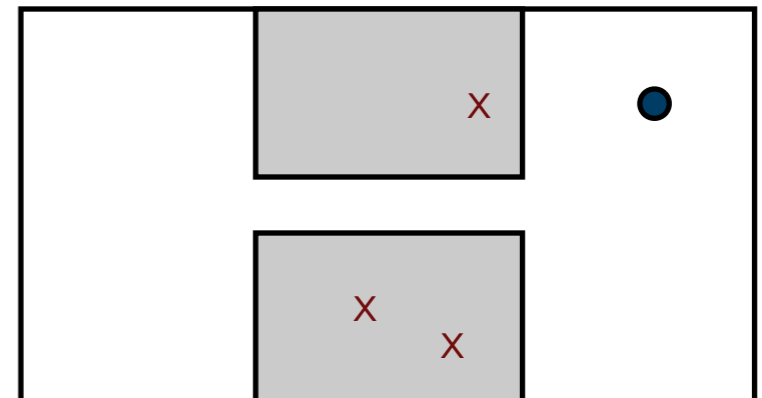


Similar issues occur for nearest neighbors

- k nearest neighbors can be computed efficiently with *kd*-trees in **low-dimensional, Euclidean** spaces.
- In high-dimensional spaces **approximate** nearest neighbors much better
- In **non-Euclidean** spaces (e.g., any space that includes **rotations**), other data structures are necessary

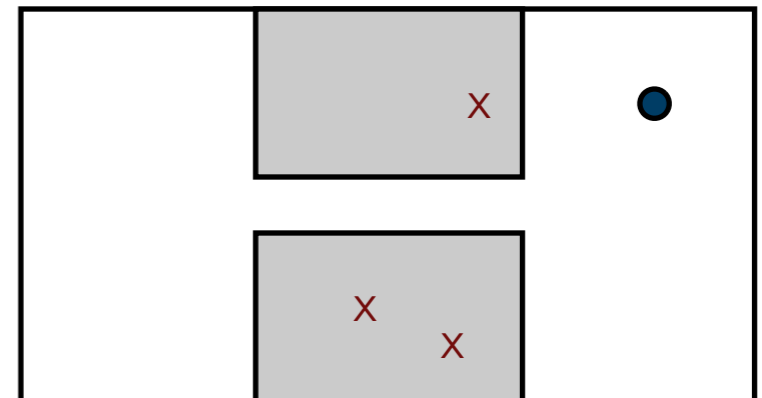
Valid state samplers

- **Valid state samplers** combine low-level **state samplers** with the **validity checker**
- Simplest form: sample at most n times to get valid state or else return failure



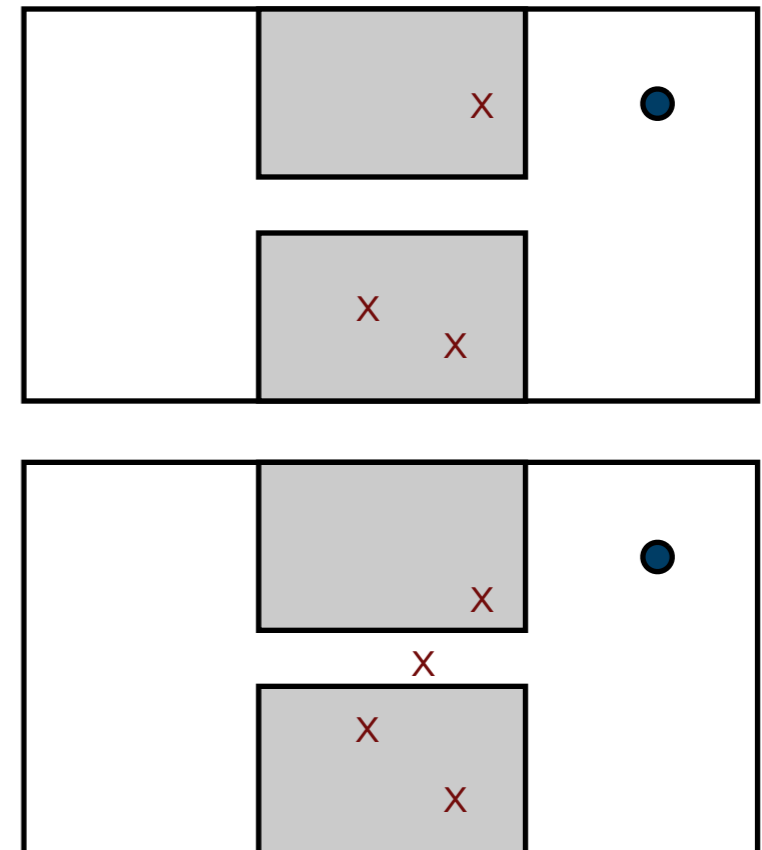
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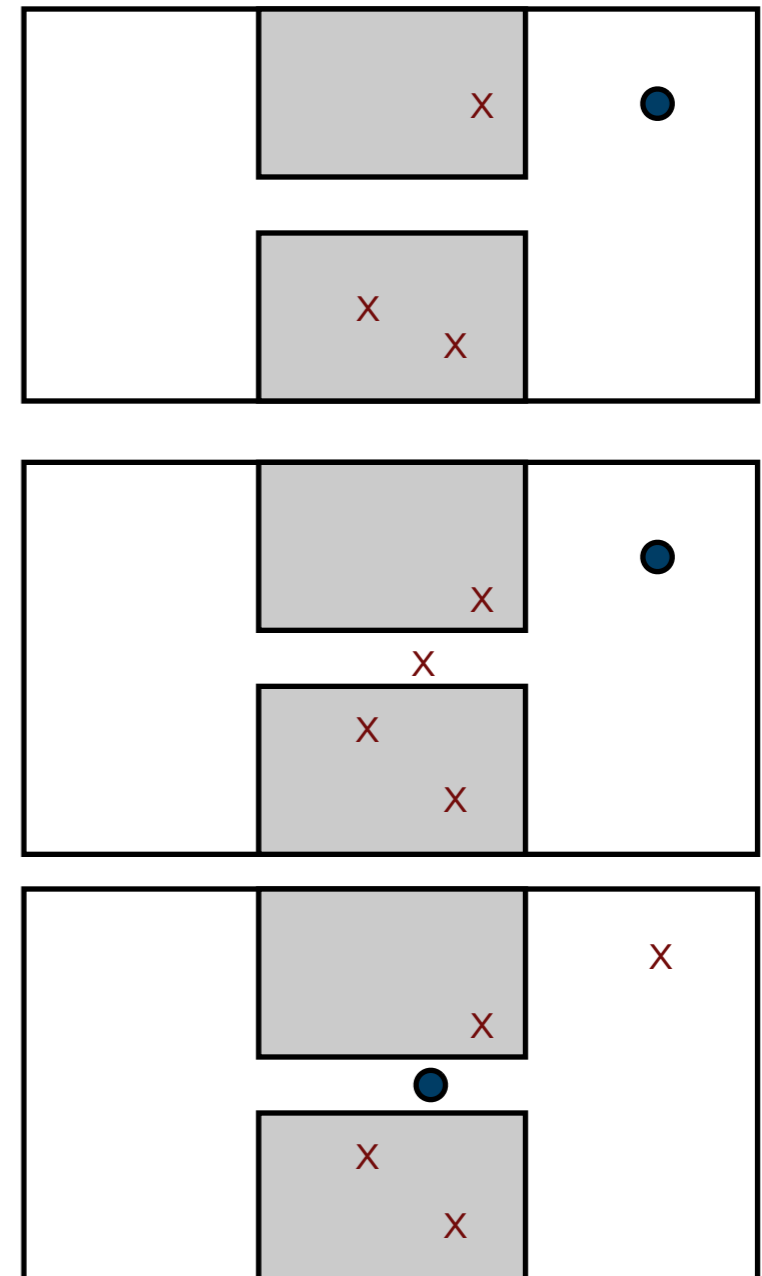
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 - Try to find samples with a large clearance

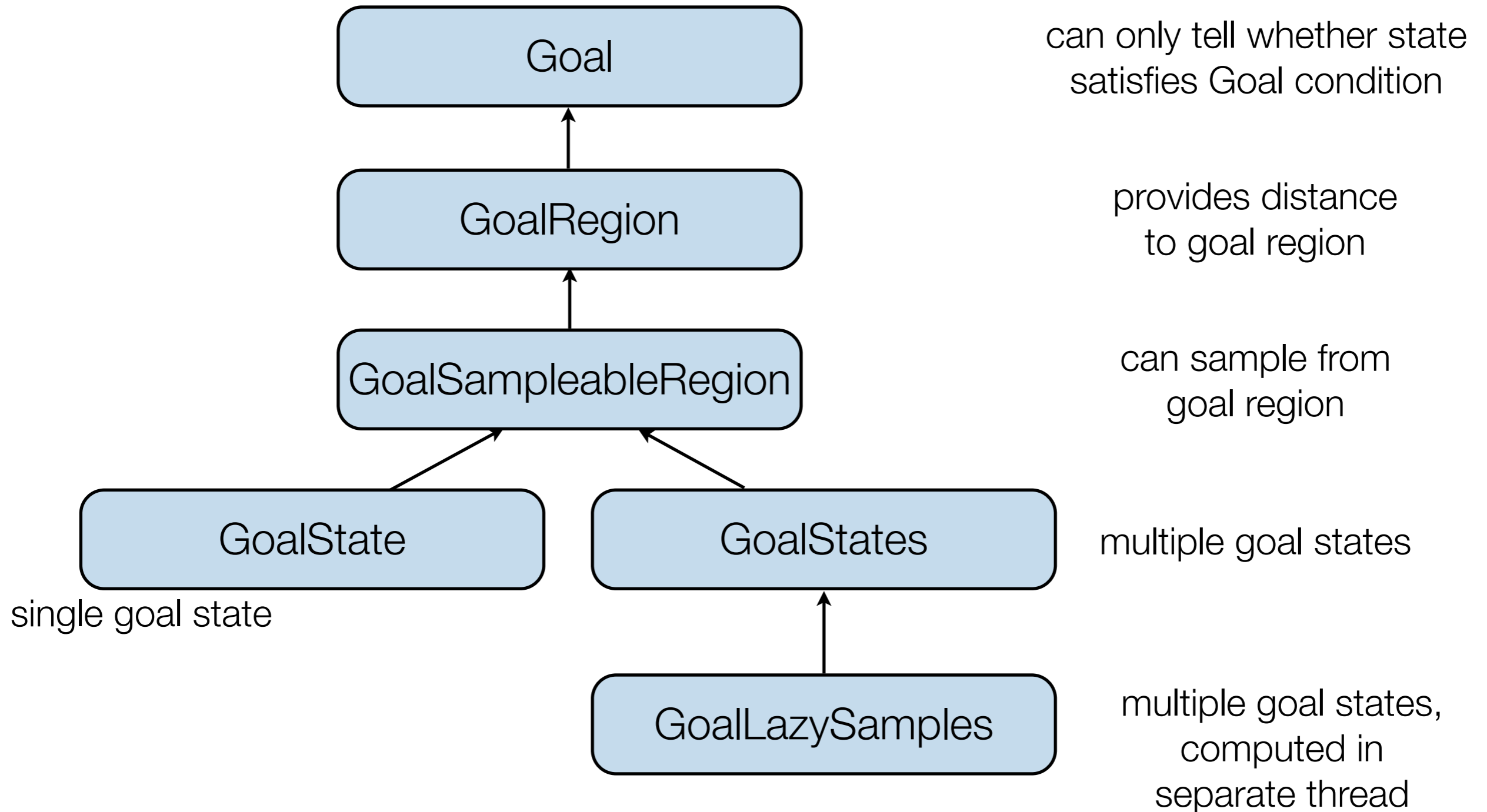


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- Simplest form: sample at most n times to get valid state or else return failure
- Other sampling strategies:
 - Try to find samples with a large clearance
 - Try to find samples near obstacles (more dense sampling in/near narrow passages)



Goals



Planners

- Take as input a **problem definition:**
object with one or more **start states** and a **goal object**
- Planners need to implement two methods:
 - **solve:**
 - takes **PlannerTerminationCondition** object as argument
 - termination can be based on timer, external events, ...
 - **clear:**
clear internal data structures, free memory, ready to run solve again

Many planners available in OMPL

Planner

```
graph TD; Planner[Planner] --> GP[geometric planning]; Planner --> PC[planning with controls]; GP --> PRM[PRM]; GP --> RRT1[RRT]; GP --> EST[EST]; GP --> SBL[SBL]; GP --> KPIECE1[KPIECE]; GP --> BKPIECE[BKPIECE]; GP --> LBKPIECE[LBKPIECE]; GP --> LazyRRT[LazyRRT]; GP --> RRTConnect[RRTConnect]; PC --> RRT2[RRT]; PC --> KPIECE2[KPIECE];
```

geometric planning

planning with controls

PRM

RRT

EST

RRT

SBL

KPIECE

BKPIECE

KPIECE

LBKPIECE

LazyRRT

RRTConnect

Many planners available in OMPL

Planner

geometric planning

planning with controls

PRM

RRT

EST

RRT

SBL

KPIECE

BKPIECE

KPIECE

LBKPIECE

LazyRRT

RRTConnect

SyCLoP

RRT*

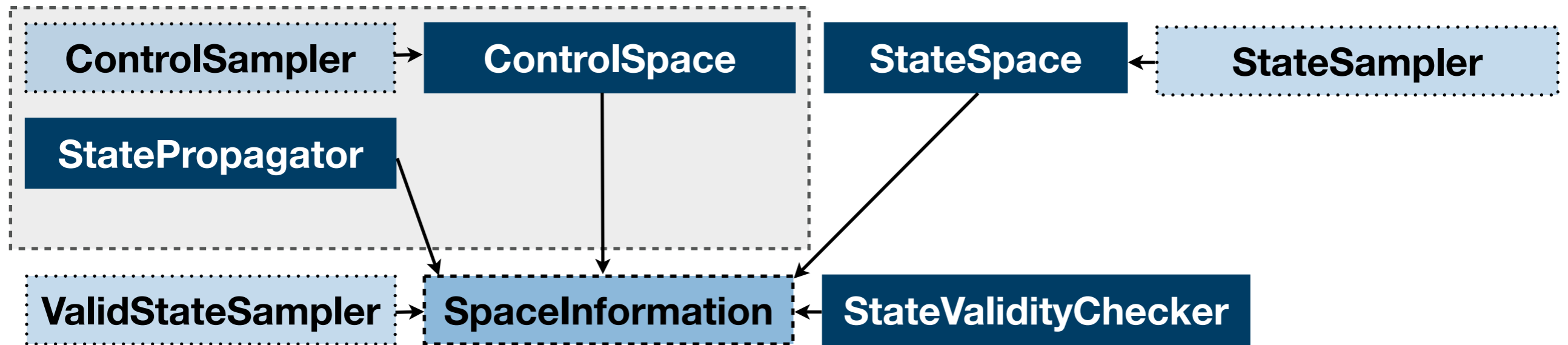
BallTreeRRT*

coming soon!

just added!

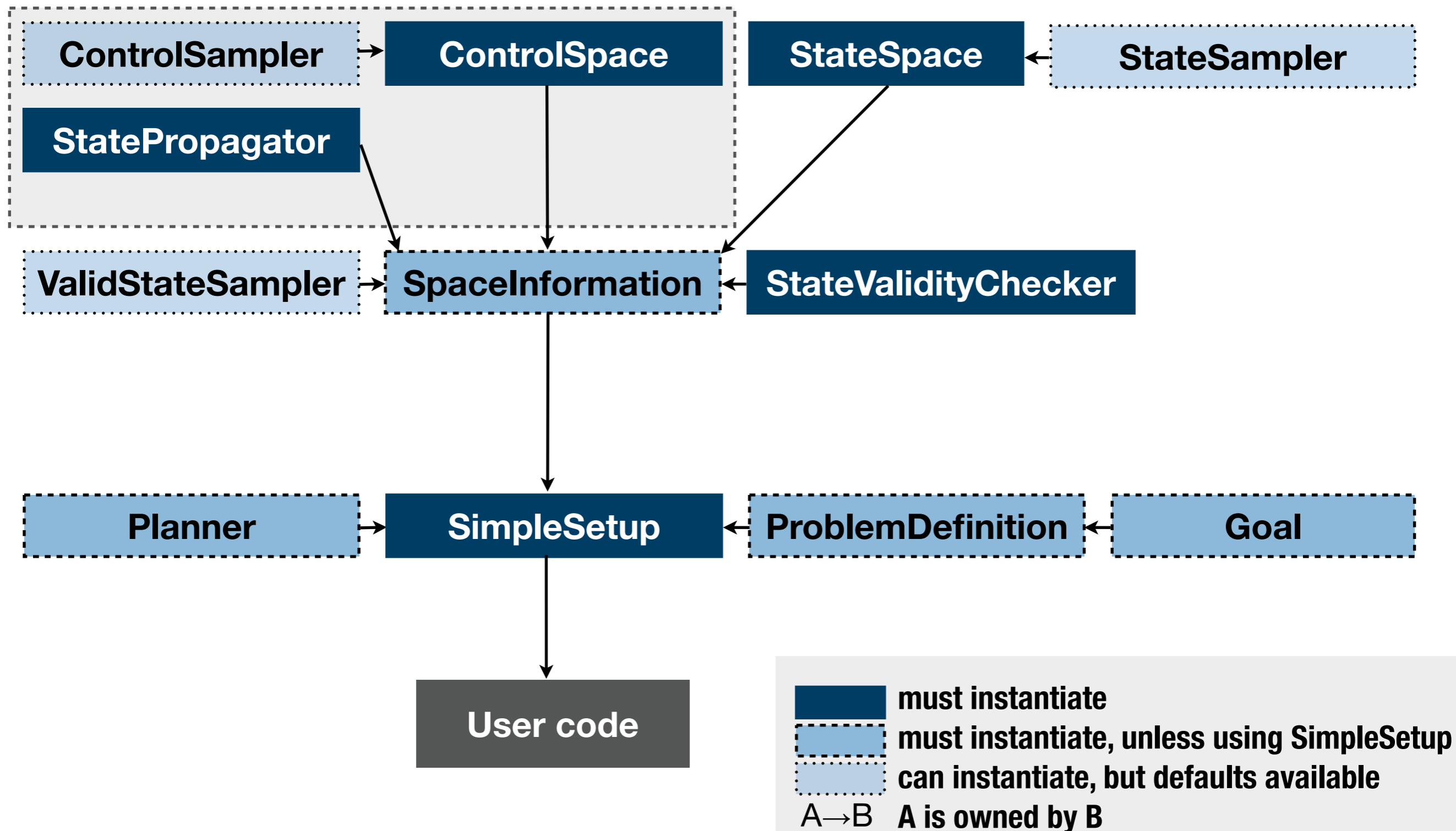
API overview

only when planning with differential constraints



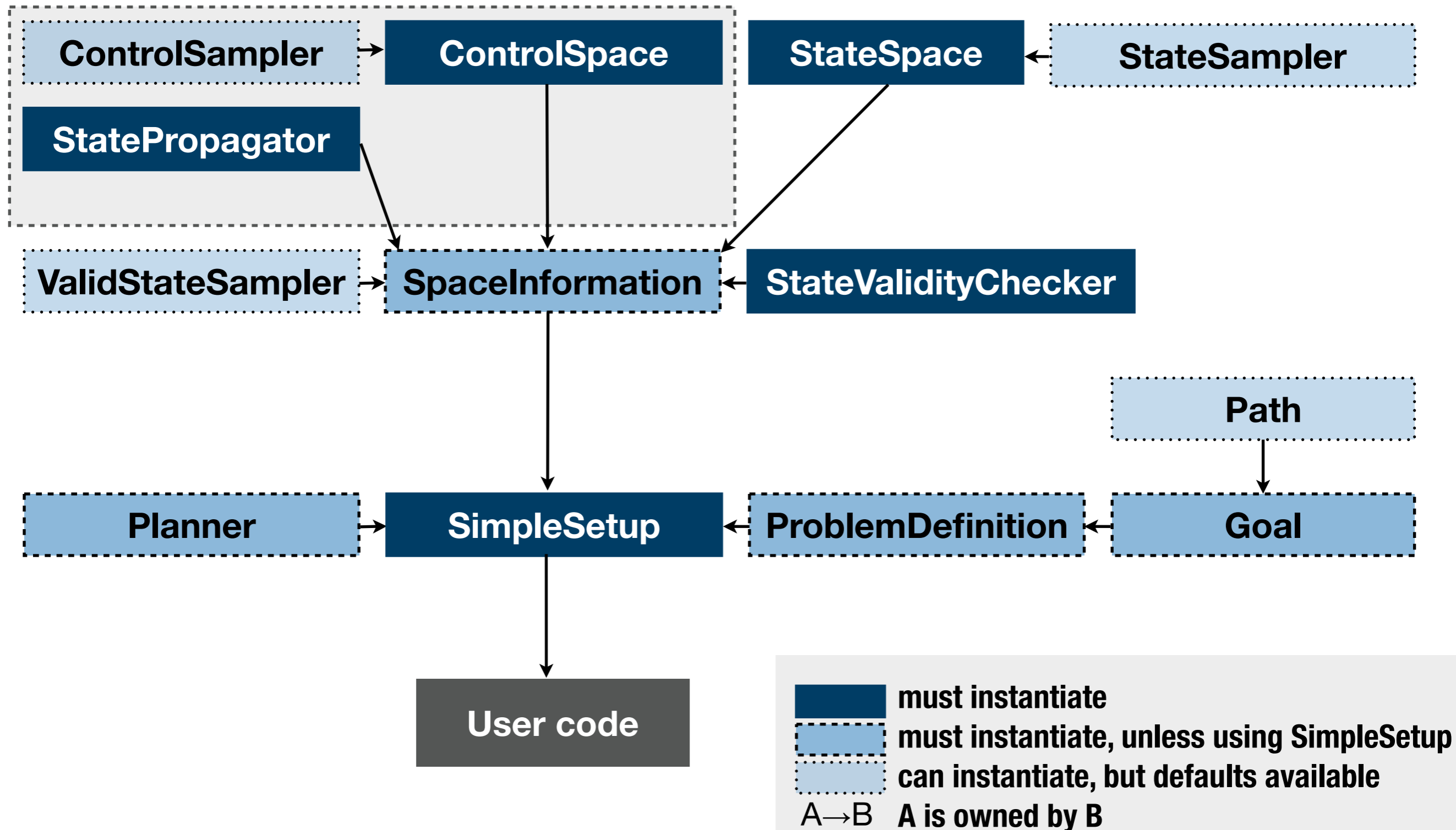
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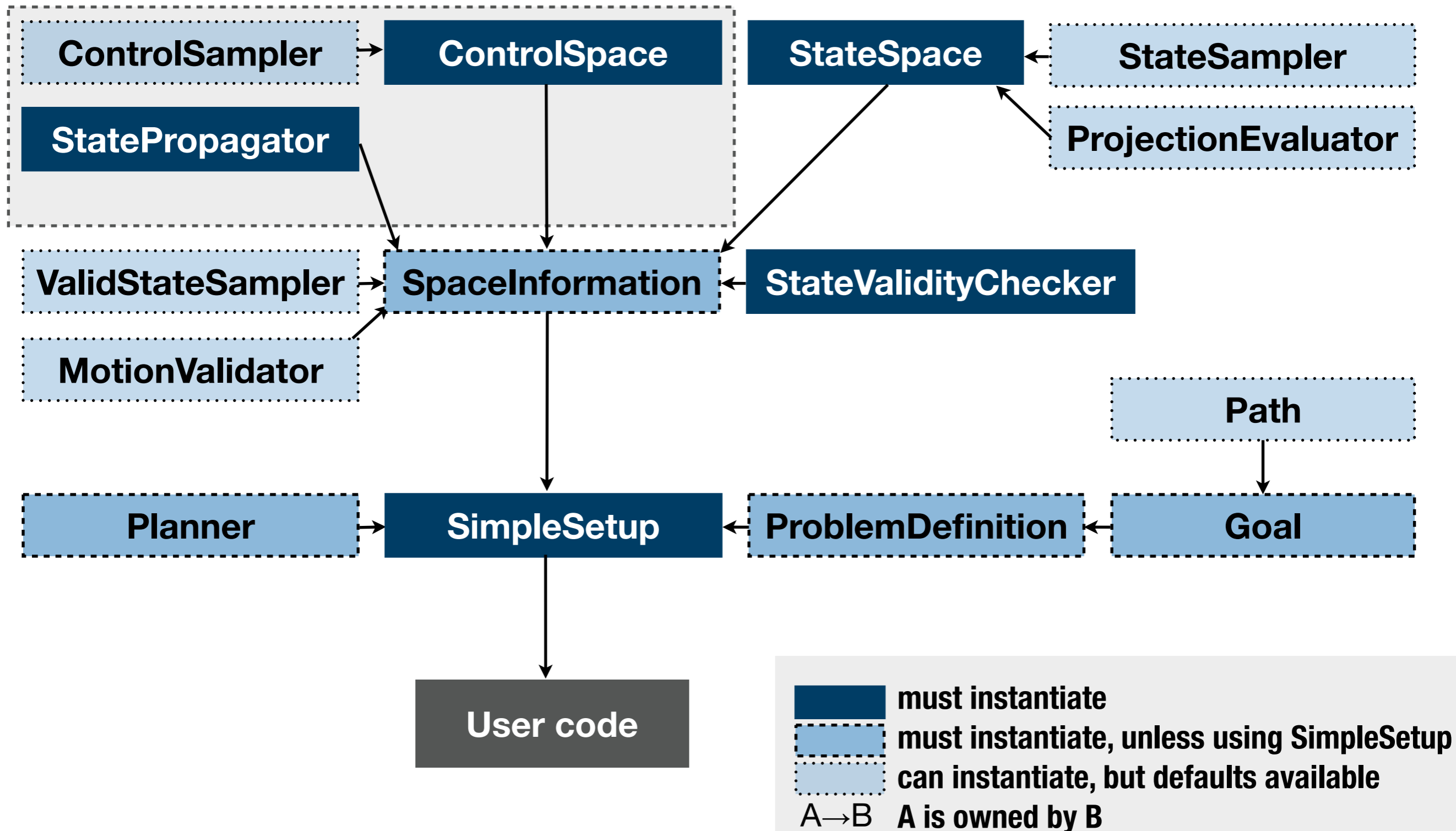
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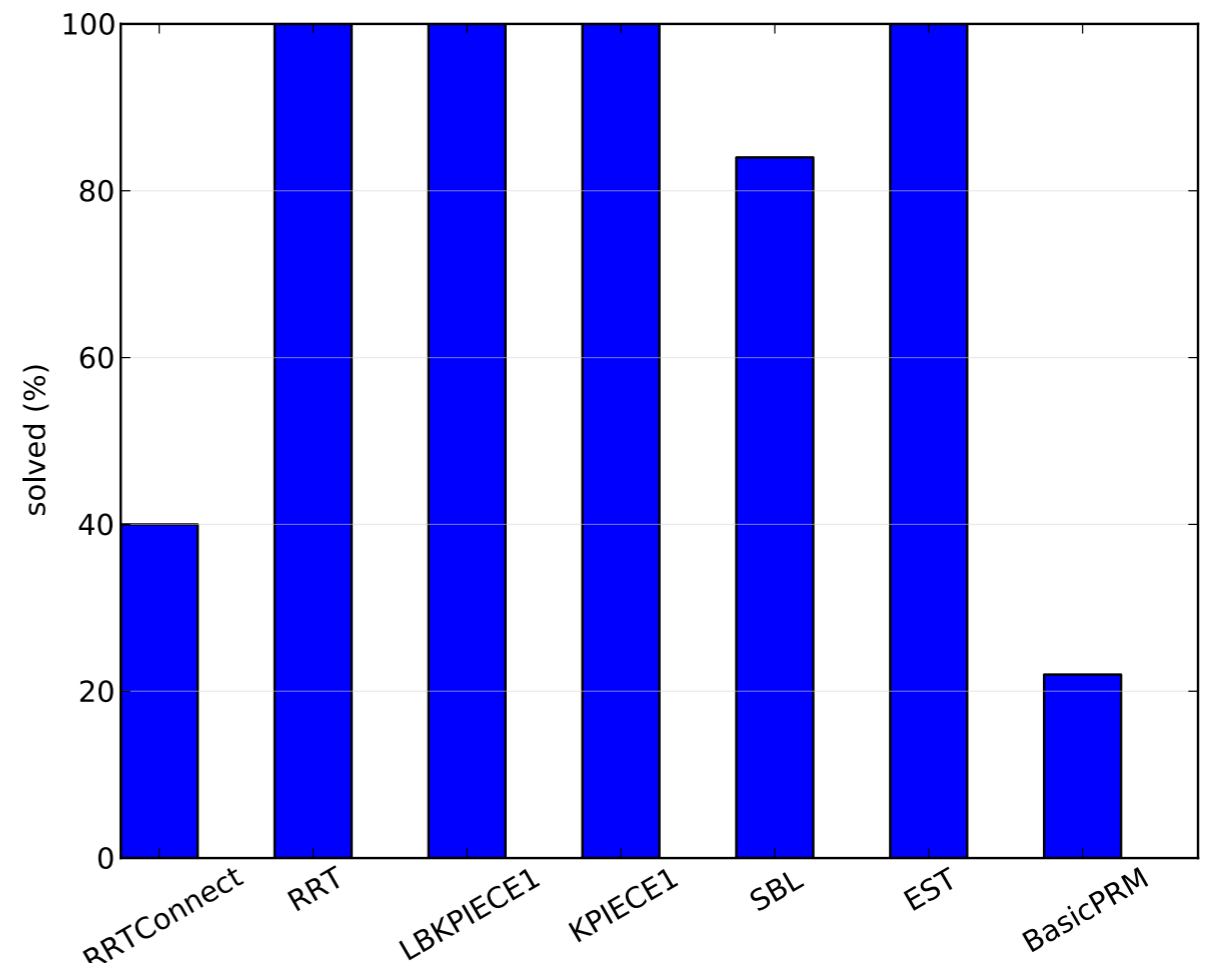
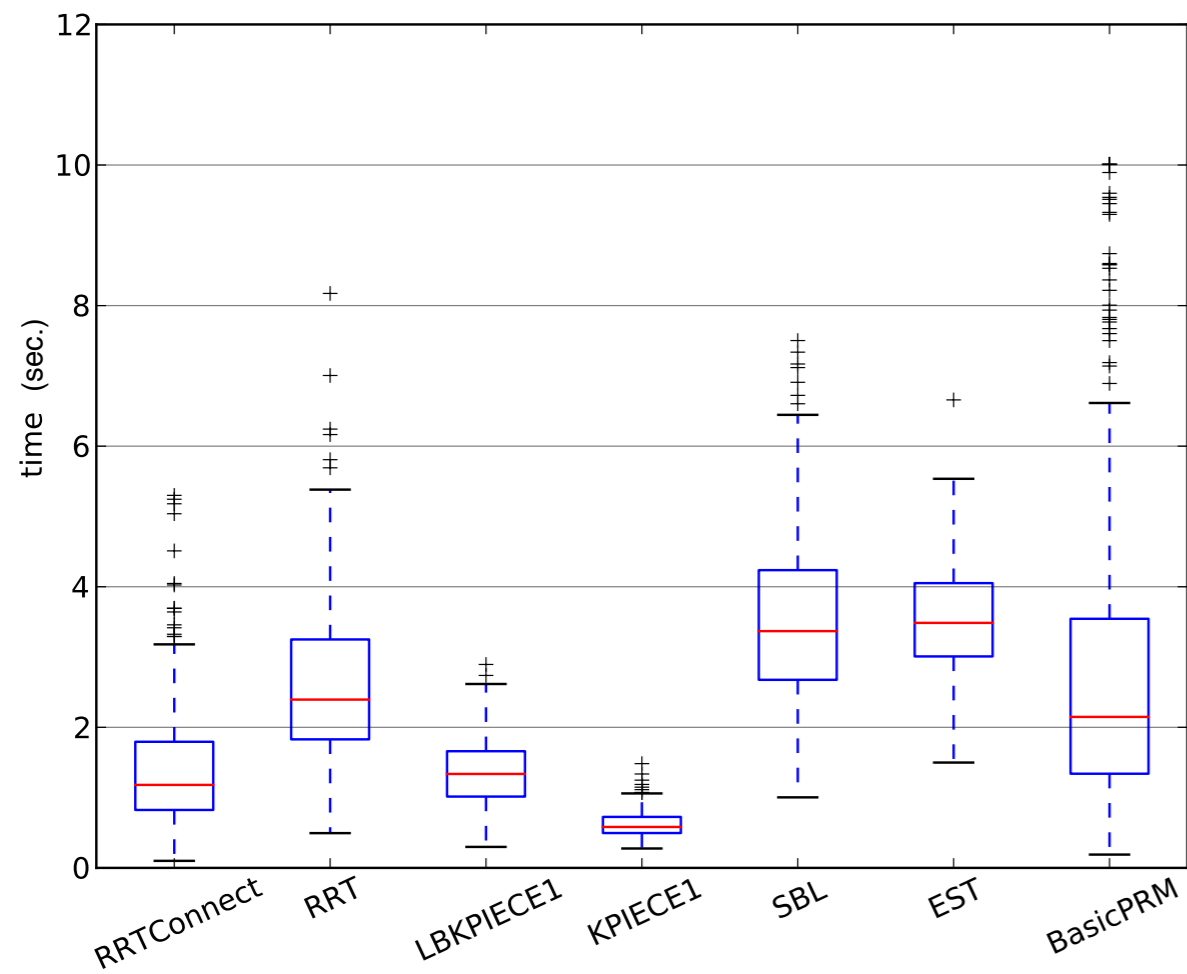
Minimal code example

```
1  space = SE3StateSpace()
2  # set the bounds (code omitted)
3
4  ss = SimpleSetup(space)
5  # "isStateValid" is a user-supplied function
6  ss.setStateValidityChecker(isStateValid)
7
8  start = State(space)
9  goal = State(space)
10 # set the start & goal states to some values
11 # (code omitted)
12
13 ss.setStartAndGoalStates(start, goal)
14 solved = ss.solve(1.0)
15 if solved:
16     print setup.getSolutionPath()
```

Minimal code example

```
1  StateSpacePtr space(new SE3StateSpace());
2  // set the bounds (code omitted)
3
4  SimpleSetup ss(space);
5  // "isStateValid" is a user-supplied function
6  ss.setStateValidityChecker(isStateValid);
7
8  ScopedState<SE3StateSpace> start(space);
9  ScopedState<SE3StateSpace> goal(space);
10 // set the start & goal states to some values
11 // (code omitted)
12
13 ss.setStartAndGoalStates(start, goal);
14 bool solved = ss.solve(1.0);
15 if (solved)
16     setup.getSolutionPath().print(std::cout);
```

Benchmarking



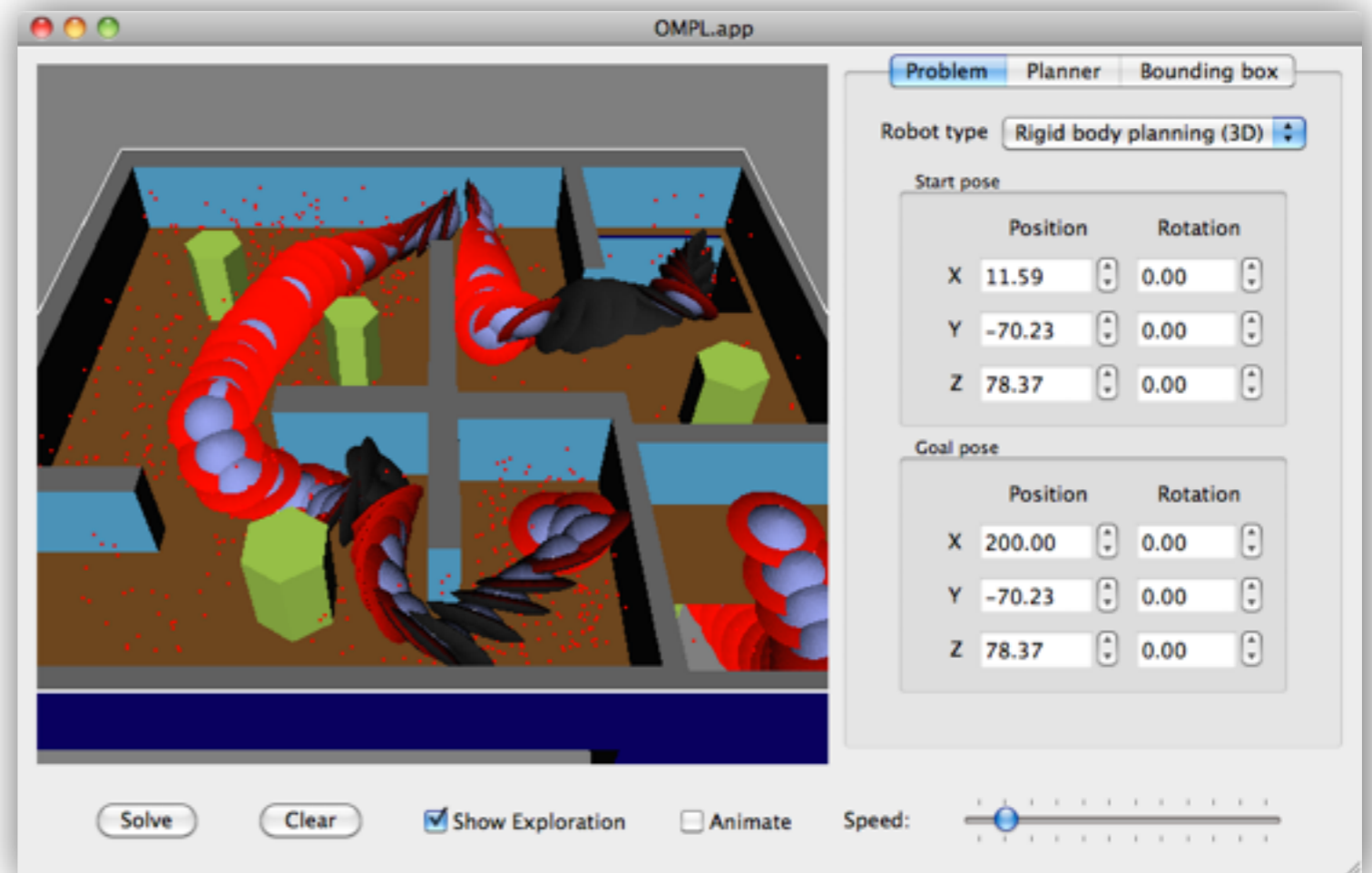
Benchmarking

```
SimpleSetup setup;  
// motion planning problem setup code omitted  
Benchmark b(setup, "My First Benchmark");  
  
b.addPlanner(base::PlannerPtr(new geometric::RRT(setup.getSpaceInformation())));  
b.addPlanner(base::PlannerPtr(new geometric::KPIECE1(setup.getSpaceInformation())));  
b.addPlanner(base::PlannerPtr(new geometric::SBL(setup.getSpaceInformation())));  
b.addPlanner(base::PlannerPtr(new geometric::EST(setup.getSpaceInformation())));  
b.addPlanner(base::PlannerPtr(new geometric::PRM(setup.getSpaceInformation())));  
  
b.benchmark(runtime_limit, memory_limit, run_count, true);  
b.saveResultsToFile();
```

**Script post-processes benchmark log files
to create/update SQLite database and plots**

OMPL.app

- Front-end that demonstrates integration with libraries for collision checking, 3D mesh loading, GUI toolkit
- Easy-to-use tool for novices to get started
- Alternative to `ompl_ros_interface`



OMPL.app demo / screencast

```
mmoll ~ Prana:~ -- bash  
[Prana:~] _
```


Resources to get started with OMPL

OMPL online

- **Web site:**

<http://ompl.kavrakilab.org>

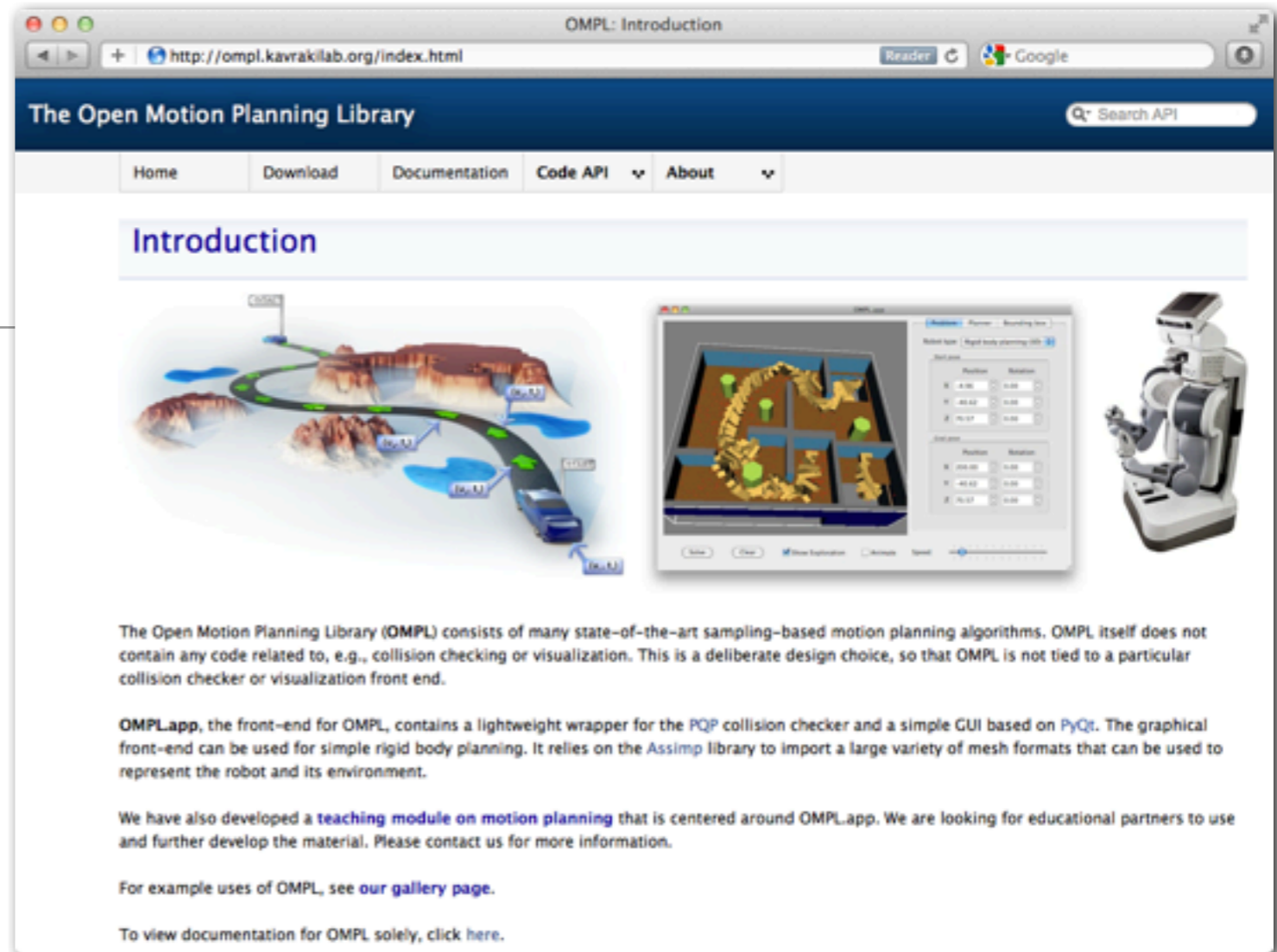
- **Mailing lists:**

- Developers: ompl-devel@lists.sourceforge.net

- Users: ompl-users@lists.sourceforge.net

- **Public Mercurial repository:**

<http://ompl.hg.sourceforge.net:8000/hgroot/ompl/ompl>



The screenshot shows a web browser window displaying the OMPL website. The browser's address bar shows the URL <http://ompl.kavrakilab.org/index.html>. The website has a dark blue header with the text "The Open Motion Planning Library" and a search bar labeled "Search API". Below the header is a navigation menu with links for "Home", "Download", "Documentation", "Code API", and "About". The main content area is titled "Introduction" and features three images: a 3D landscape with a green path and a blue car, a 2D top-down view of a robot in a maze-like environment, and a 3D model of a robot arm. Below the images is a paragraph of text explaining that OMPL consists of many state-of-the-art sampling-based motion planning algorithms and that it does not contain any code related to collision checking or visualization. It also mentions OMPLapp, a front-end for OMPL, and a teaching module on motion planning. At the bottom, there are links for example uses of OMPL and documentation.

The Open Motion Planning Library (OMPL) consists of many state-of-the-art sampling-based motion planning algorithms. OMPL itself does not contain any code related to, e.g., collision checking or visualization. This is a deliberate design choice, so that OMPL is not tied to a particular collision checker or visualization front end.

OMPLapp, the front-end for OMPL, contains a lightweight wrapper for the PQP collision checker and a simple GUI based on PyQt. The graphical front-end can be used for simple rigid body planning. It relies on the Assimp library to import a large variety of mesh formats that can be used to represent the robot and its environment.

We have also developed a **teaching module on motion planning** that is centered around OMPLapp. We are looking for educational partners to use and further develop the material. Please contact us for more information.

For example uses of OMPL, see [our gallery page](#).

To view documentation for OMPL solely, click [here](#).

OMPL for education

- Programming assignments centered around OMPL, available upon request.
- Ongoing educational assessment.
- Already in use in several robotics / motion planning classes.

Happy OMPL users: students in the Algorithmic Robotics class at Rice, Fall 2010



OMPL tutorials

Step-by-step walkthroughs for:

- geometric planning for rigid body in 3D
- working with states and state spaces
- representing goals
- benchmarking
- creating new planning algorithms

OMPL examples

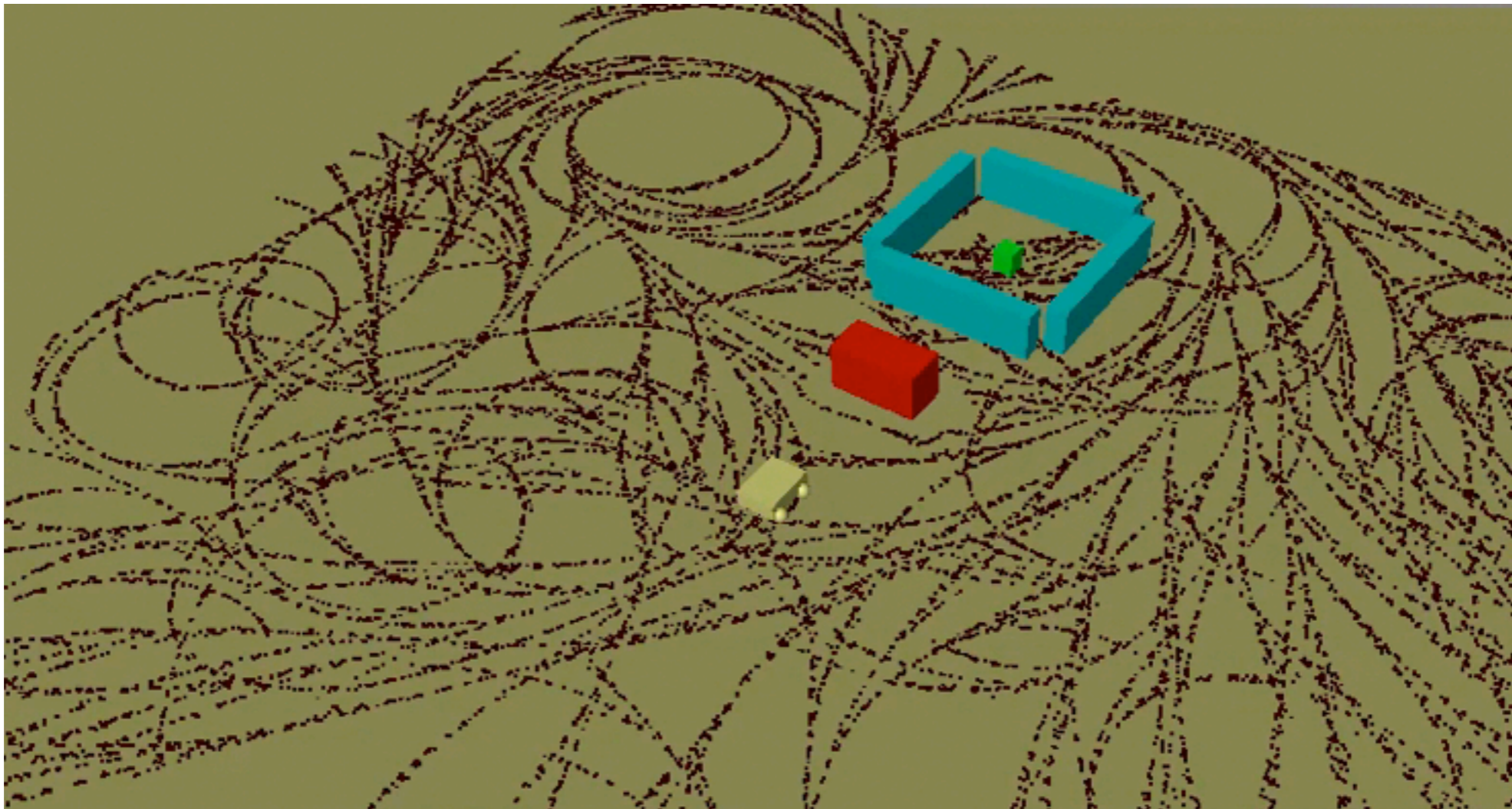
- Many demos for basic usage patterns, often available in both C++ and Python
- Demos for advanced features:
 1. **Lazy goal sampler, generic numerical IK solver**
 2. **Using the Open Dynamics Engine**

Example 1: lazy goal sampler + IK

- Spawn thread responsible for generating goal states
 - generate as many goal states as user wants
 - OMPL comes with Genetic Algorithm-based IK solver, but other types of solvers can be used
- Planner waits until at least one goal state is available
- Can use bi-directional planner with implicit goal region in state space
- Same approach is used in ROS for end-effector constraints

Example 2: OMPL + ODE

- Treat ODE physics engine as a black box state propagation function:
Given state, controls, and time duration, ODE produces new state
- Can plan for systems with movable objects, various contact modes, etc.
- Same approach can be used for other physics engines



Discussion

- OMPL actively developed, but ready for general use
- Can easily implement new algorithms from many reusable components
- Simple high-level interface:
 - Can treat motion planner almost as a black box
 - Easy enough that non-experts can use it
- Interface generic enough to be extensible in many ways

We want your contributions!

Acknowledgements

Rice University:

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Willow Garage