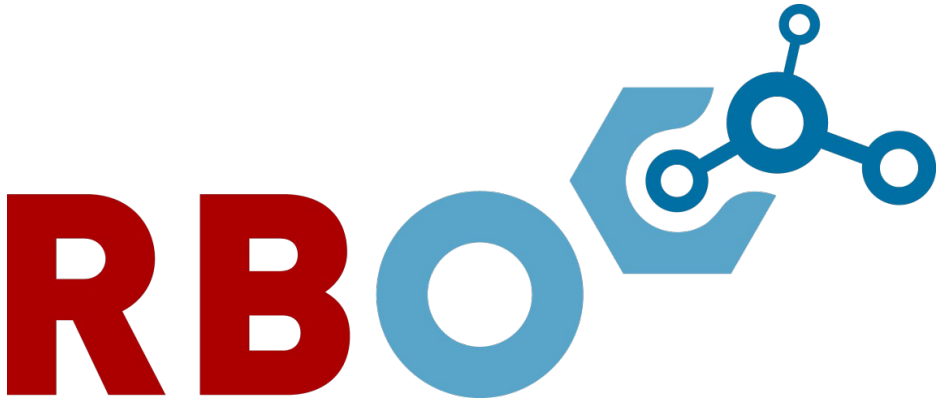
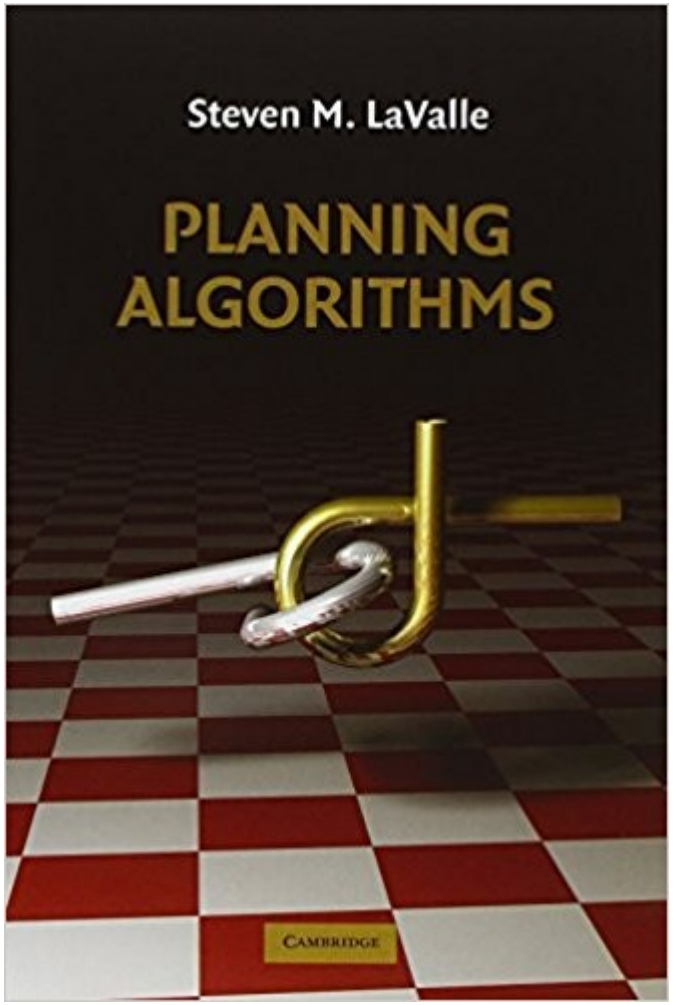


Motion Planning: Rapidly-Exploring Random Trees

Adrian Sieler, adrian.sieler@tu-berlin.de

Technische Universität Berlin

Book recommendation



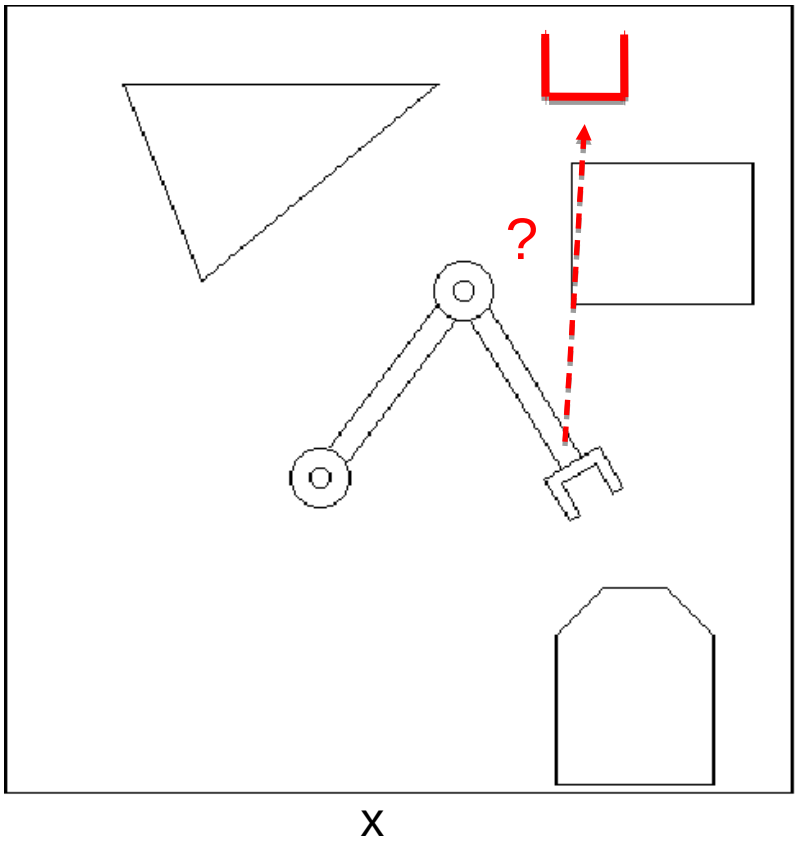
Available for free - online!

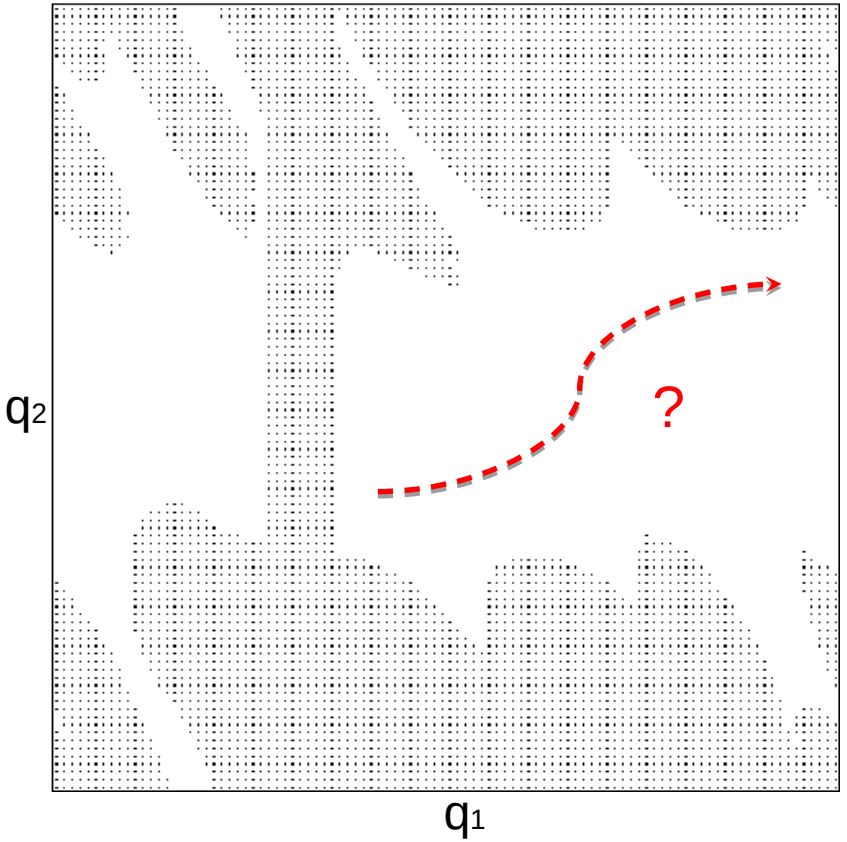
http://planning.cs.uiuc.edu/

Chapter:

Sampling-based Motion Planning

Motion planning

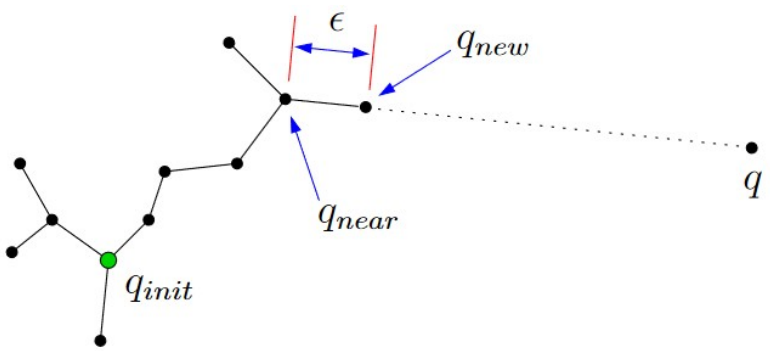




Rapidly-Exploring Random Trees

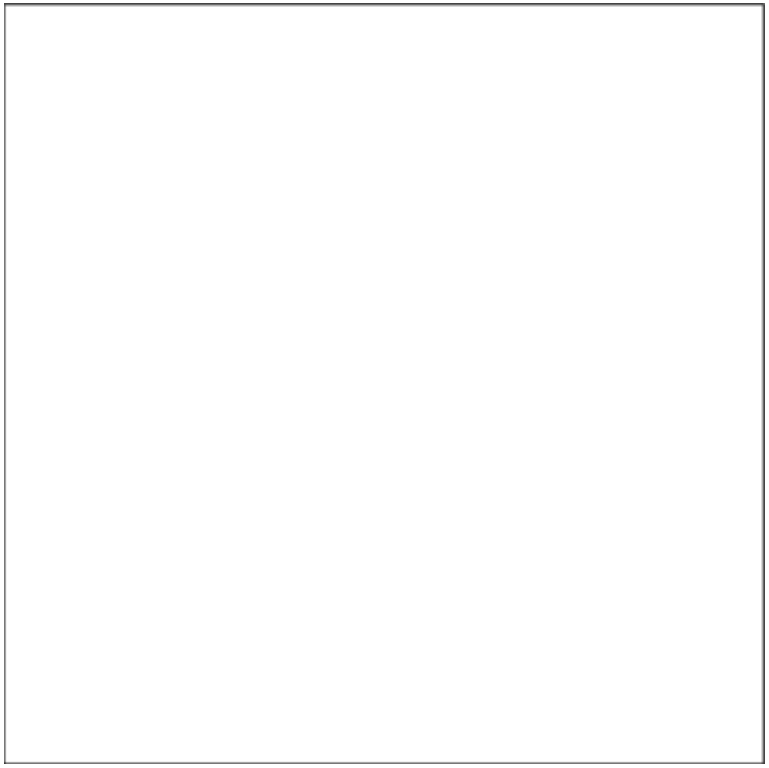
```
BUILD_RRT(q_init)
 1  T.init(q_init);
 2  for k = 1 to K do
 3       q_rand ← RANDOM_CONFIG();
 4       EXTEND(T, q_rand);
 5  Return T
```

```
EXTEND(T, q)
 1  q_near ← NEAREST_NEIGHBOR(q, T);
 2  if NEW_CONFIG(q, q_near, q_new) then
 3       T.add_vertex(q_new);
 4       T.add_edge(q_near, q_new);
 5       if q_new = q then
 6            Return Reached;
 7       else
 8            Return Advanced;
 9  Return Trapped;
```

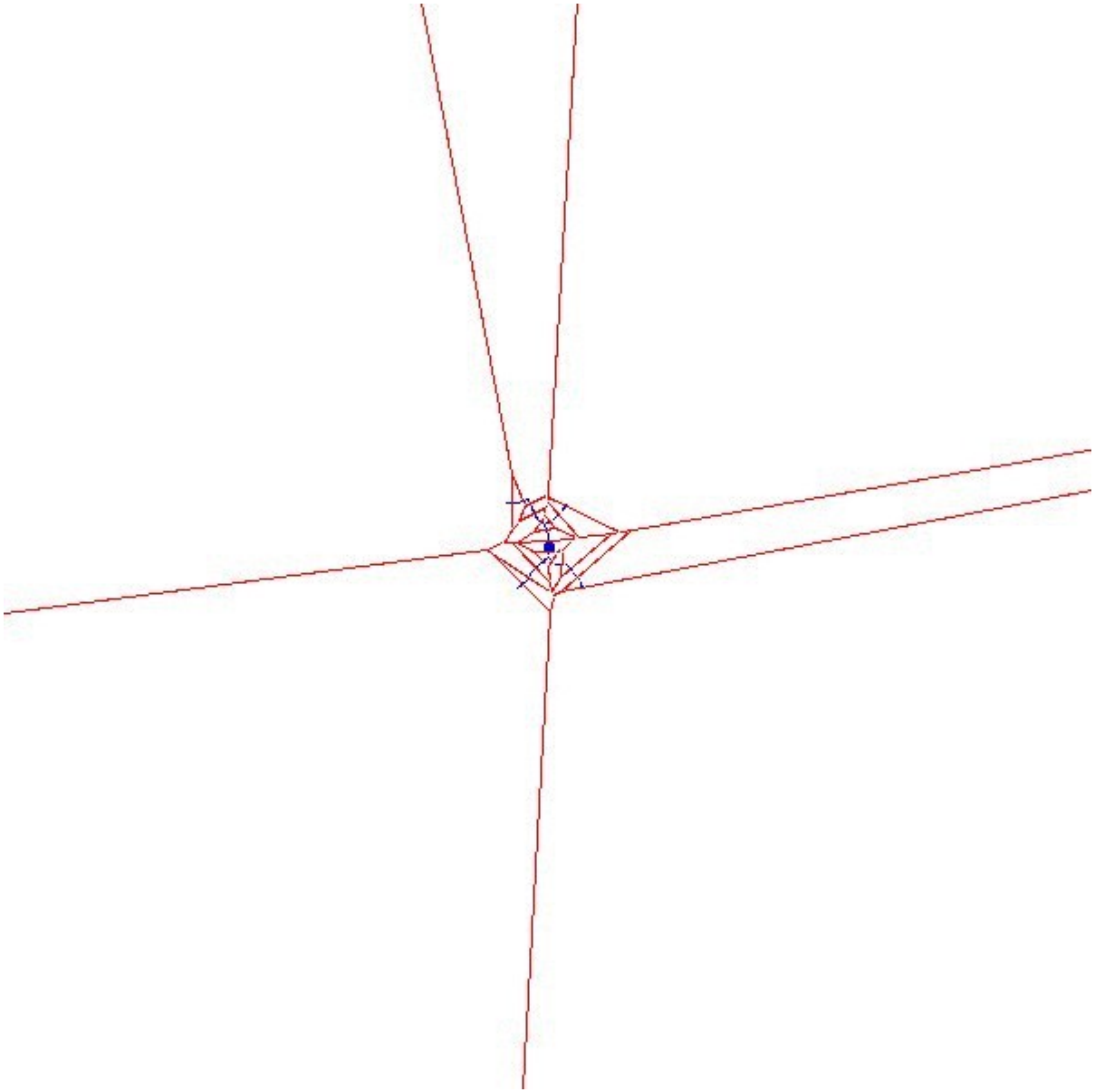


Rapidly-Exploring Random Trees

- Sampling based - no fixed grid needed
- Explores free space rapidly (Voronoi bias)
- Can handle differential constraints
- Probabilistic complete



Voronoi Bias



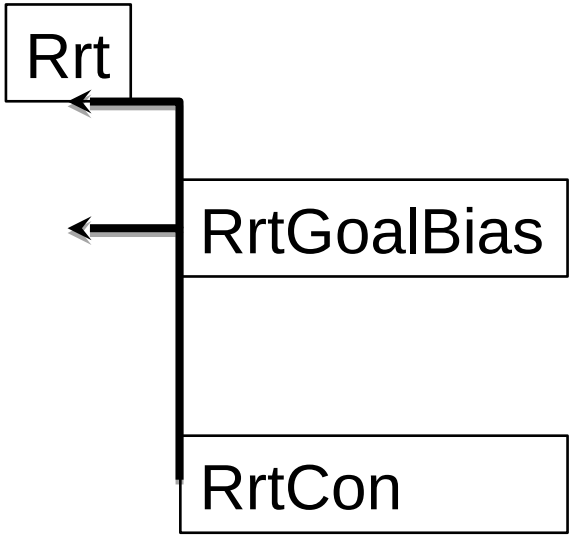
Exploration versus Exploitation

Exploration seeks **understanding of the state space**, irrespective of a particular task.
In motion planning, the process **exploration** seeks to understand the connectivity of the configuration space, irrespective of solving a particular motion planning problem.

Guided exploration seeks **efficient understanding of the state space**, irrespective a particular task, by **leveraging available information**.

Exploitation strives to **accomplish a particular task** as **efficiently as possible** by **leveraging available information**.
In motion planning, **exploitation** seeks a valid path for a **particular task**, based on available information.

RrtGoalBias/RrtCon



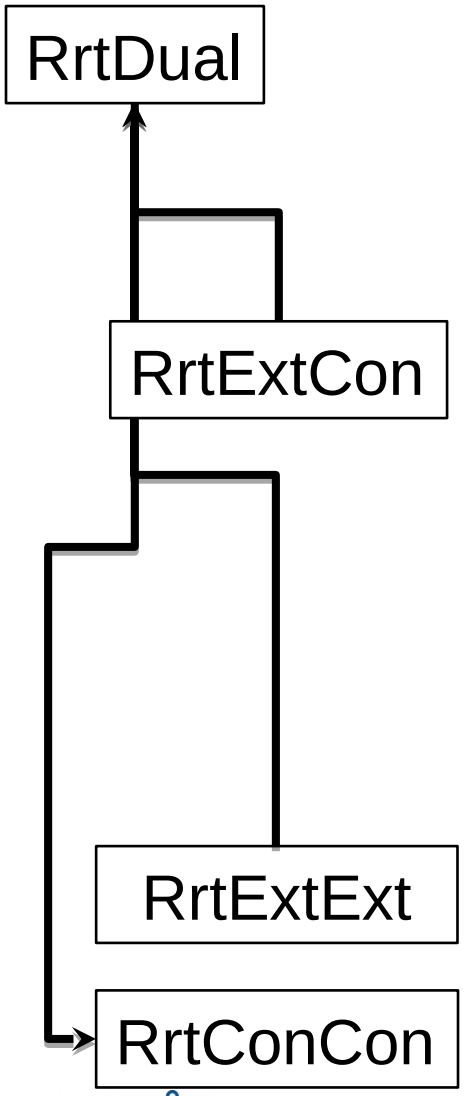
: uses the goal instead of qrand in each iteration with some probability

: uses CONNECT instead of EXTEND

CONNECT($\mathcal{T}, q$)

1 **repeat**
2 $\quad S \leftarrow$ EXTEND($\mathcal{T}, q$);
3 **until not** ($S = Advanced$)
4 Return S;

Using two trees



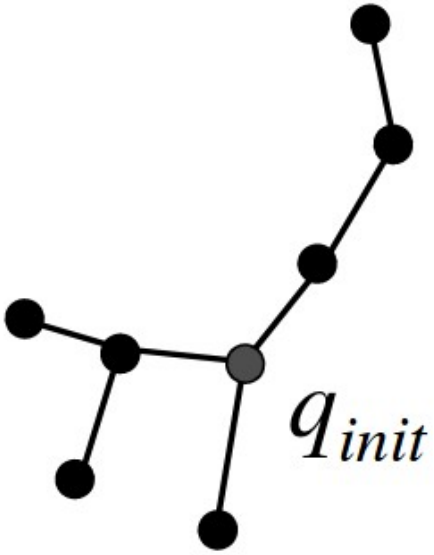
RRT_BIDIRECTIONAL(x_{init}, x_{goal})

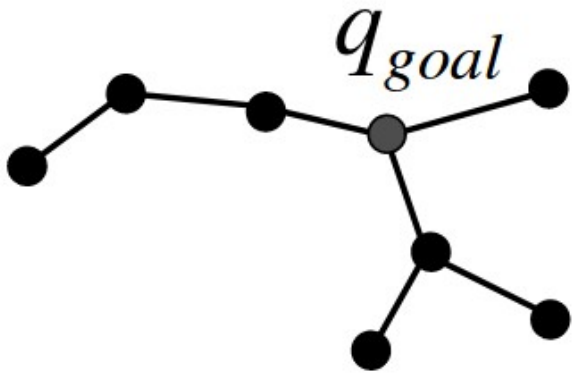
1 $\mathcal{T}_a$.init(x_{init}); $\mathcal{T}_b$.init(x_{goal});
2 **for** $k = 1$ **to** K **do**
3 $x_{rand} \leftarrow$ RANDOM_STATE();
4 **if not** (EXTEND($\mathcal{T}_a, x_{rand}$) = *Trapped*) **then**
5 **if** (EXTEND($\mathcal{T}_b, x_{new}$) = *Reached*) **then**
6 Return PATH($\mathcal{T}_a, \mathcal{T}_b$);
7 SWAP($\mathcal{T}_a, \mathcal{T}_b$);
8 Return *Failure*

RrtExtExt : replaces CONNECT by EXTEND

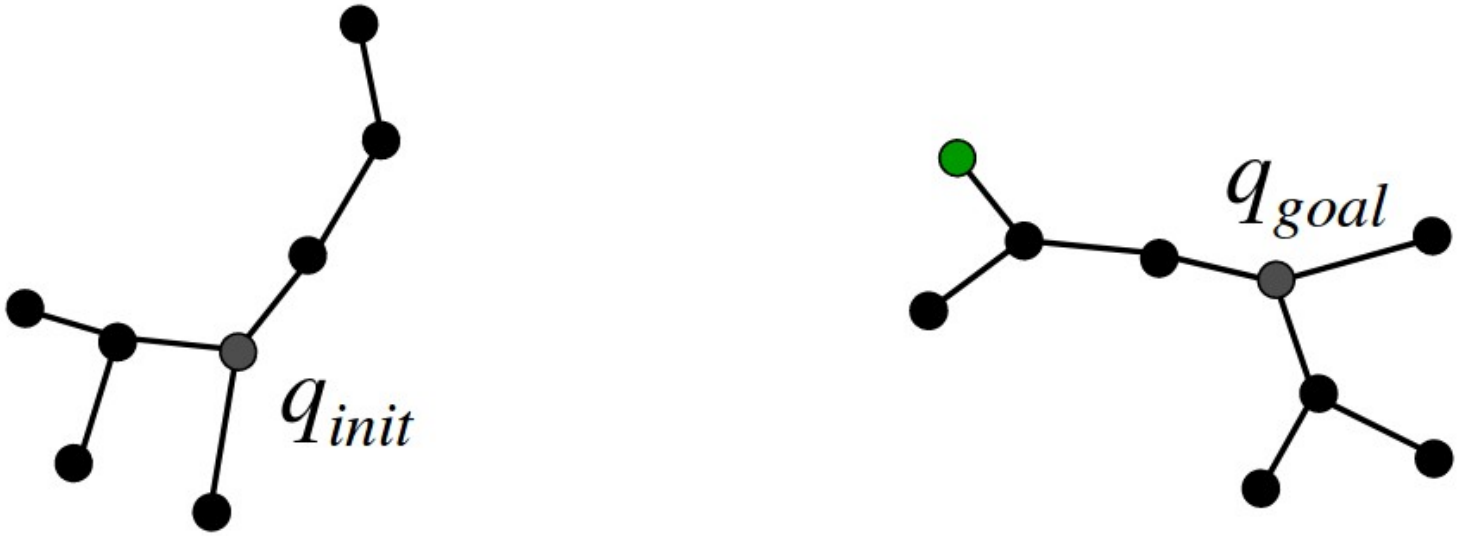
RrtConCon : replaces EXTEND by CONNECT

Bi-directional RRT Connect (RRTConCon)

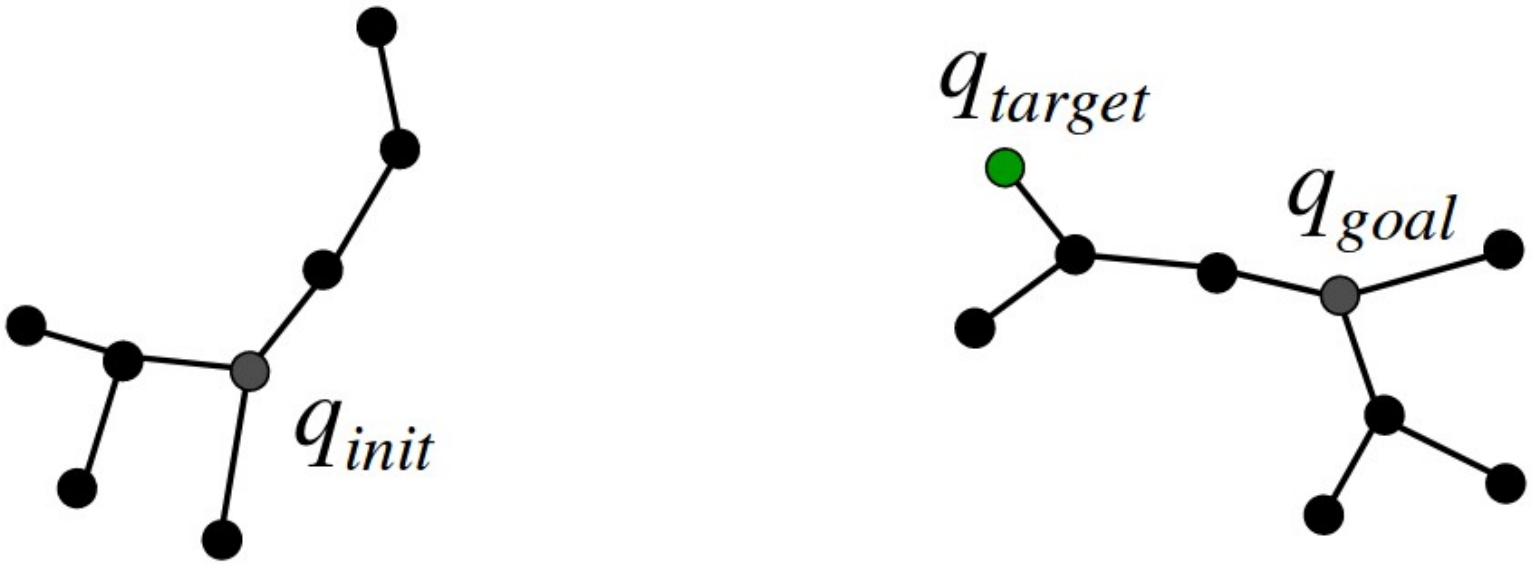




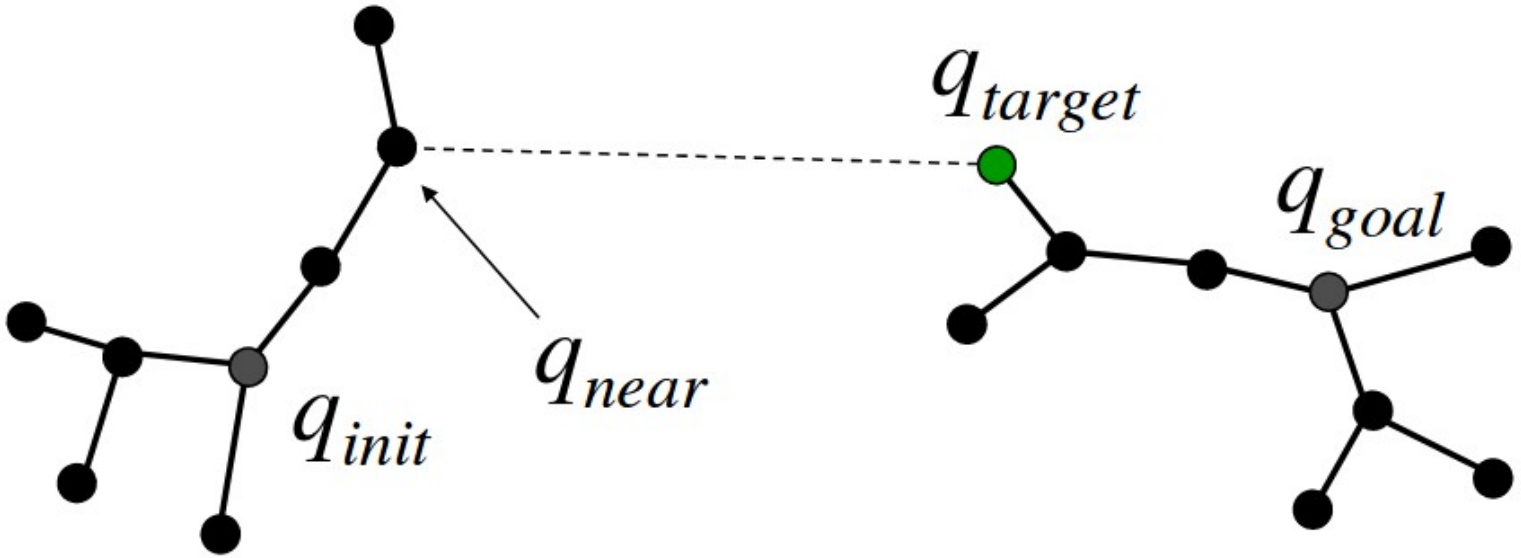
Bi-directional RRT Connect



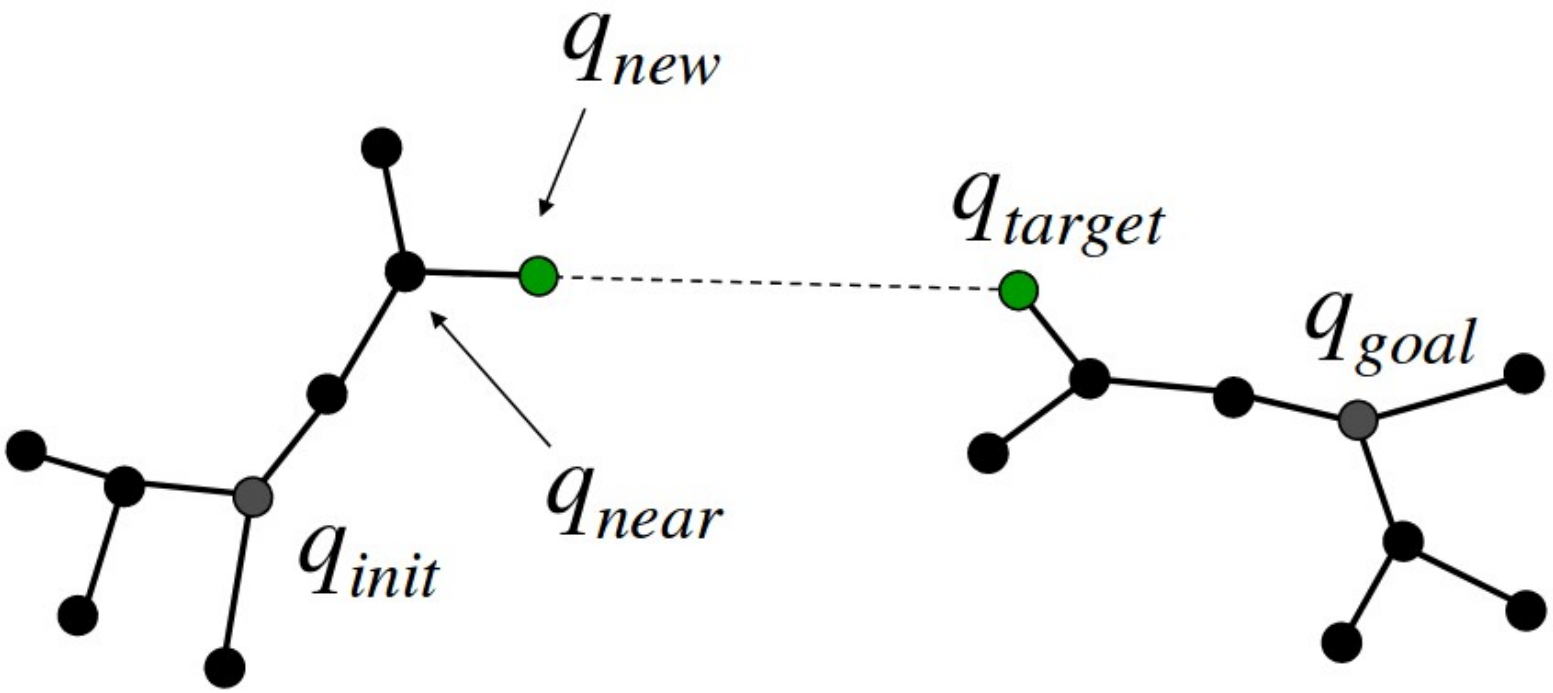
Bi-directional RRT Connect



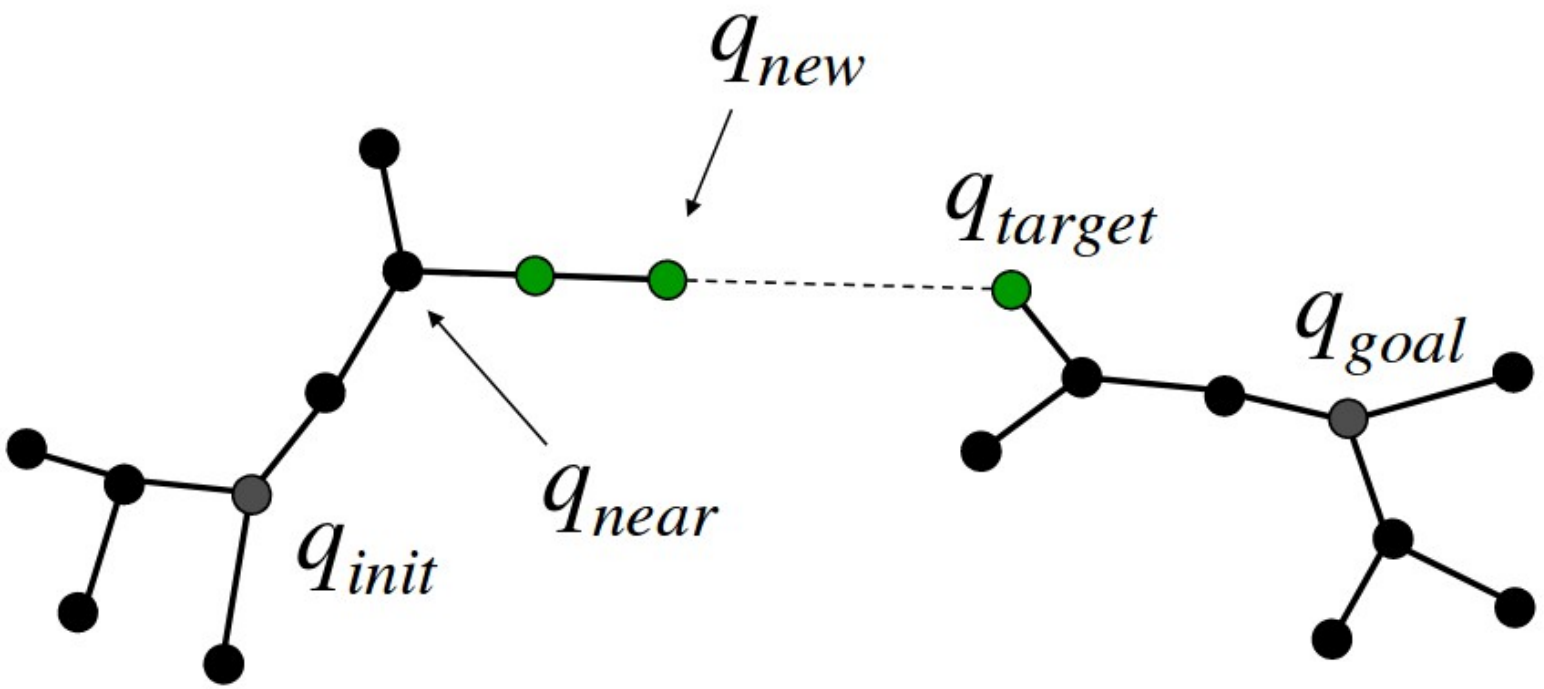
Bi-directional RRT Connect



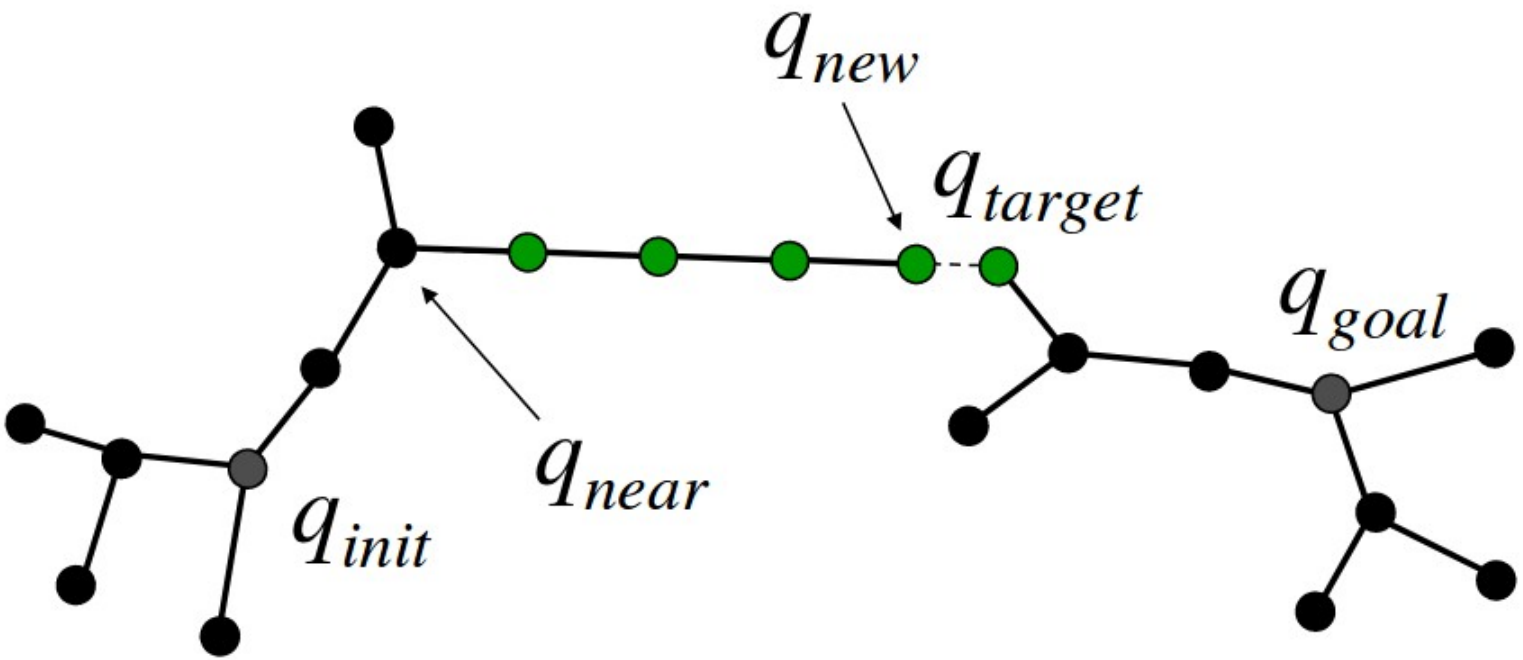
Bi-directional RRT Connect



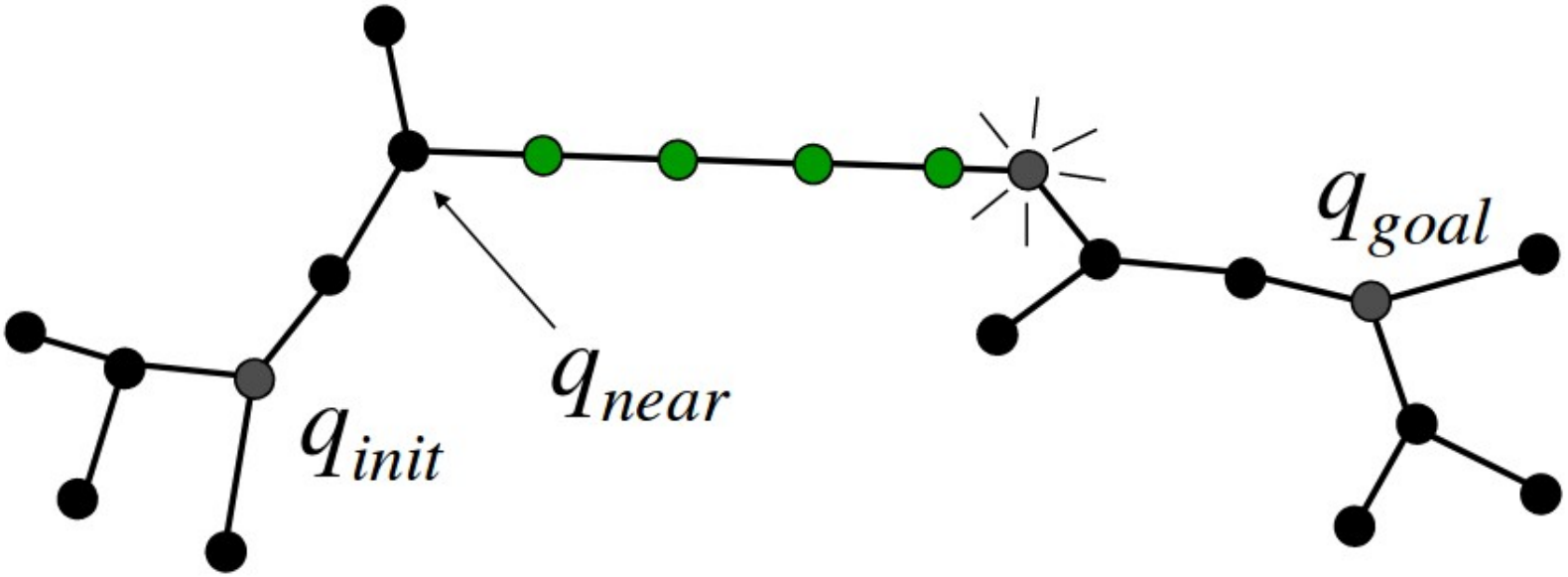
Bi-directional RRT Connect



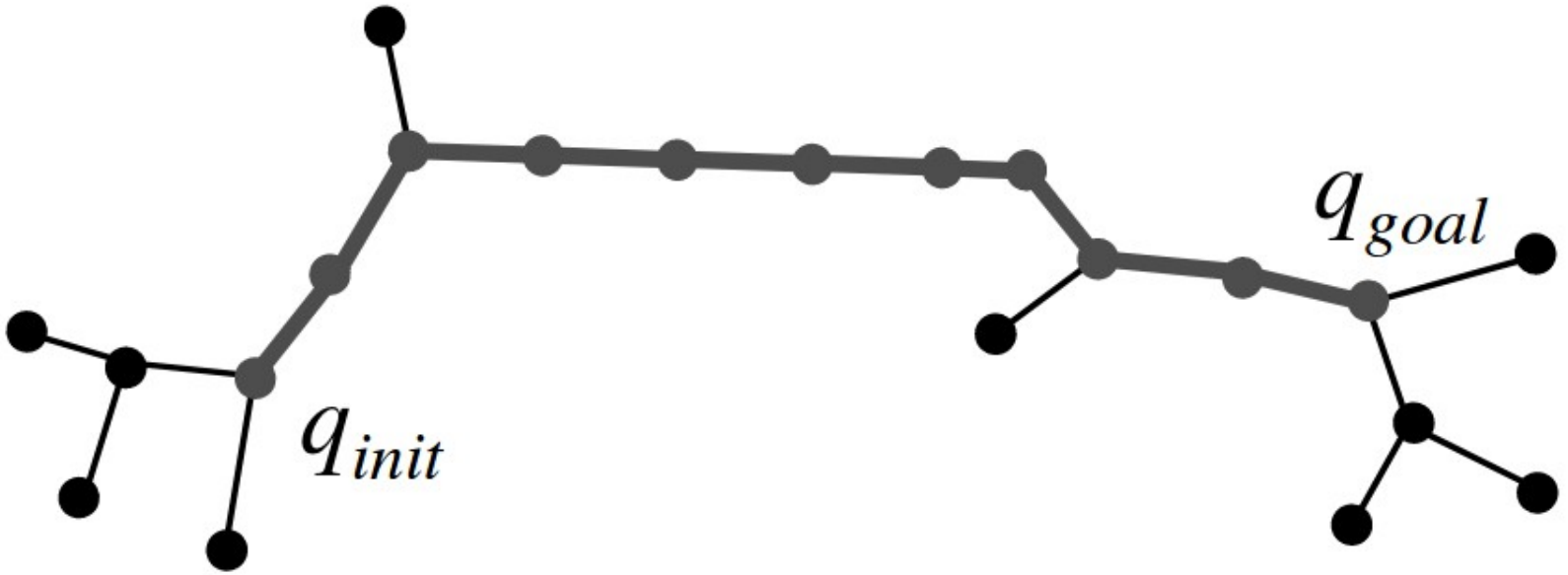
Bi-directional RRT Connect



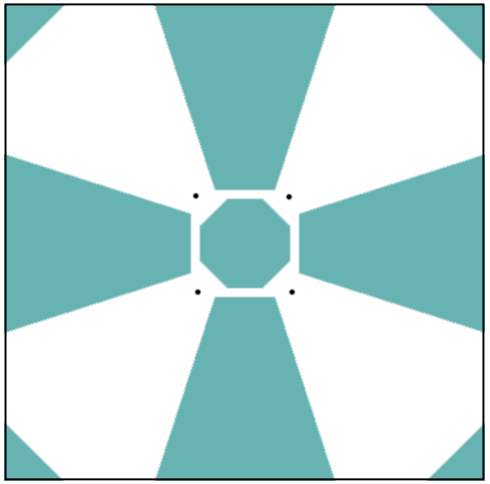
Bi-directional RRT Connect



Bi-directional RRT Connect



Different Sampling Strategies



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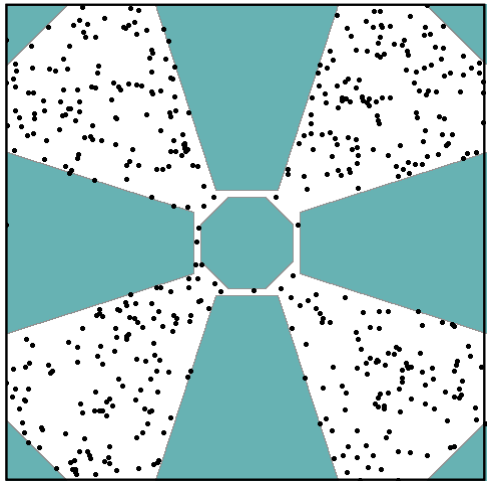

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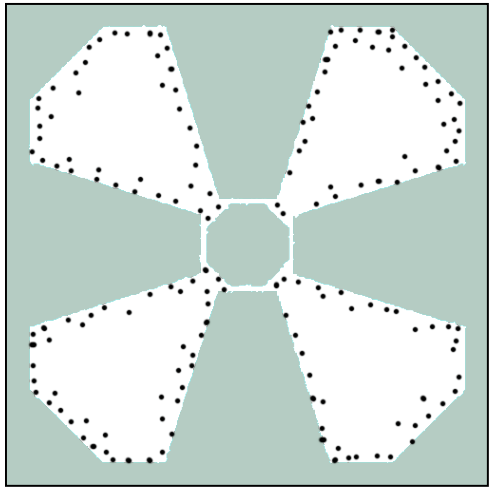

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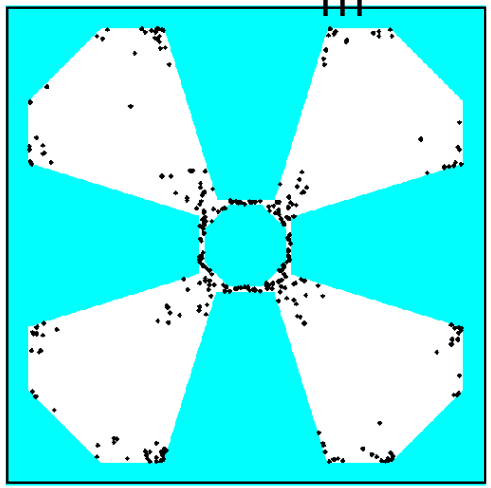

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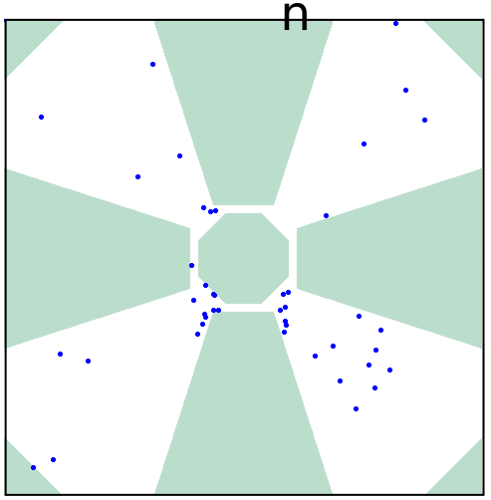


Utilit
y

Robotics Library: www.roboticslibrary.org

- A framework for developing robotics applications

math Mathematics	**util** Timers, Threads, Mutexes, …	**xml** XML Abstraction
hal Hardware Abstraction	**kin** DH-Kinematics	**mdl** Rigid Body Kinematics/Dynamics
sg Scene Graph Abstraction	**plan** Motion Planning	**ctrl** Operational Space Control

- Pro: All models we need are already included
- Con: only sparse documentation
  (there are doxygen docs)

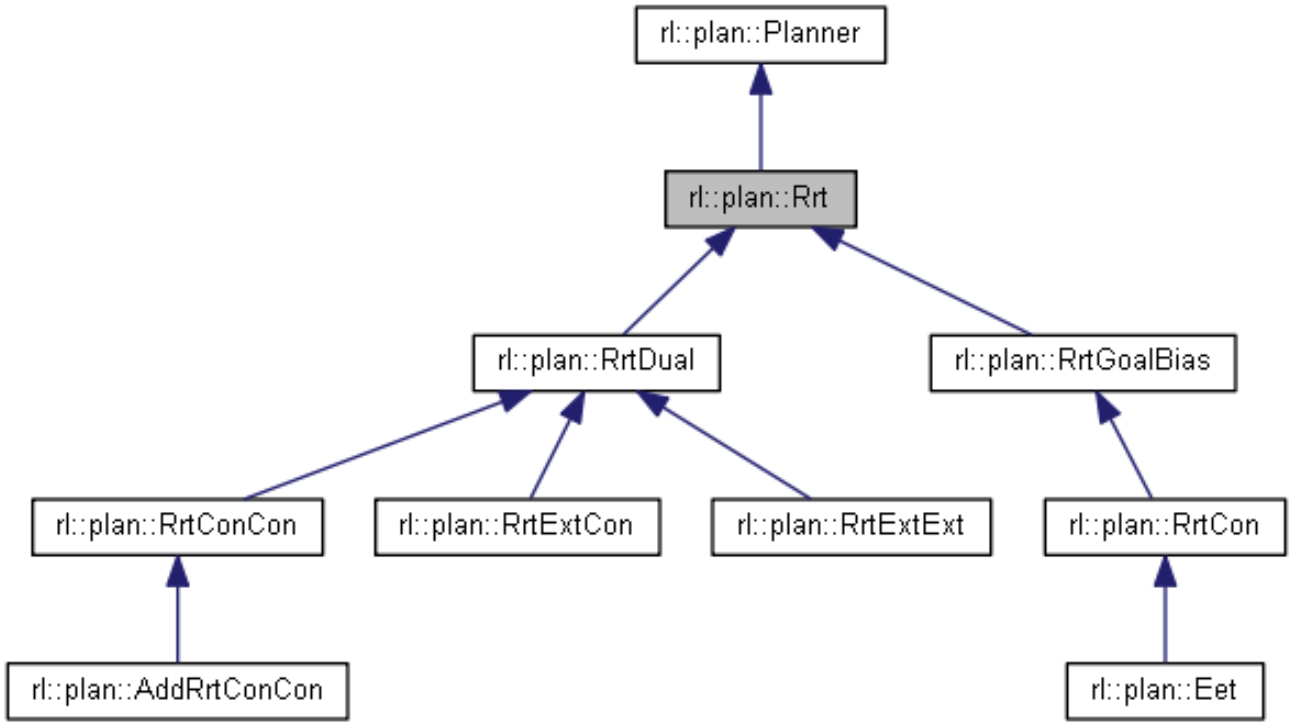
rl::plan::Rrt Class Reference

Classes | Public Member Functions | Public Attributes | Pr
Protected Member Functions | Static Protected Member Functions | Prote
List

Rapidly-Exploring Random Trees. More...

```
#include <Rrt.h>
```

Inheritance diagram for rl::plan::Rrt:



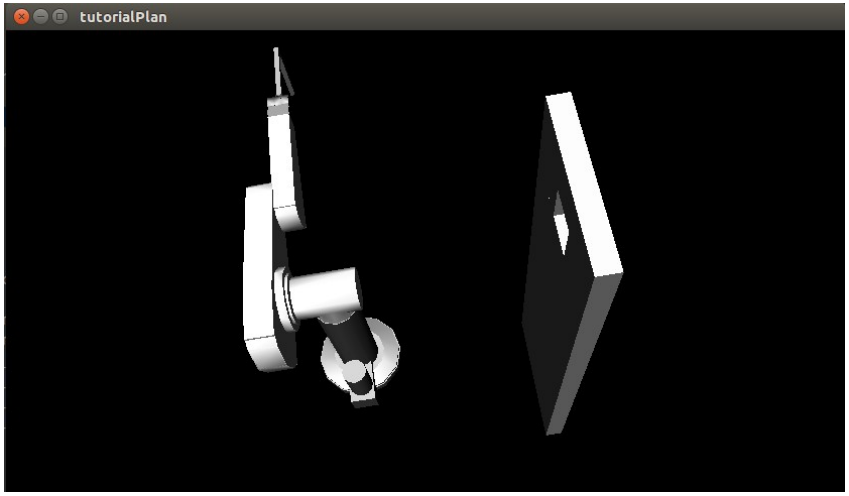
You can easily install RobLib on Ubuntu

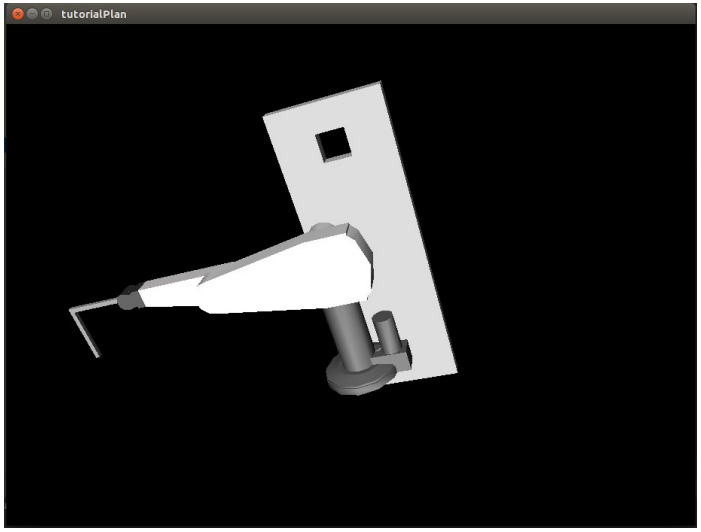
- Install prerequisites
  - `sudo add-apt-repository ppa:roblib/ppa`
  - `sudo apt-get update`
  - `sudo apt-get install librl-dev`
  - Download and extract tutorialPlan.zip:
  - `tar xfz tutorialPlan.zip`
- Build
  - `cd tutorialPlan/build`
  - `cmake ..`
  - `make`
- Test:
  - `cd tutorialPlan/build`
  - `./tutorialPlan - Press space to start planning, F12 to reset`

https://www.roboticslibrary.org/tutorials/install-ubuntu/

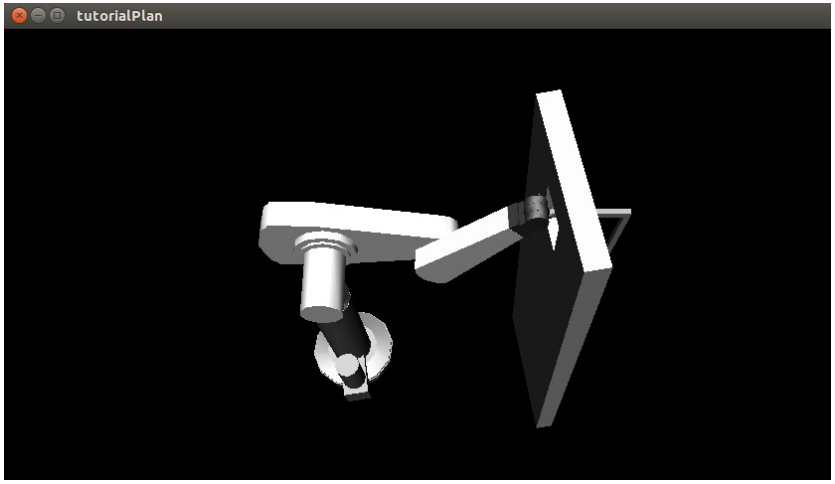
Puma Environment

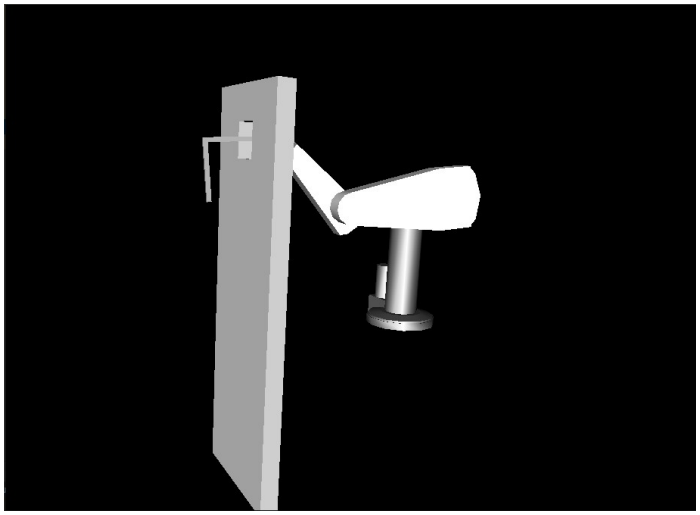
- Start Configuration





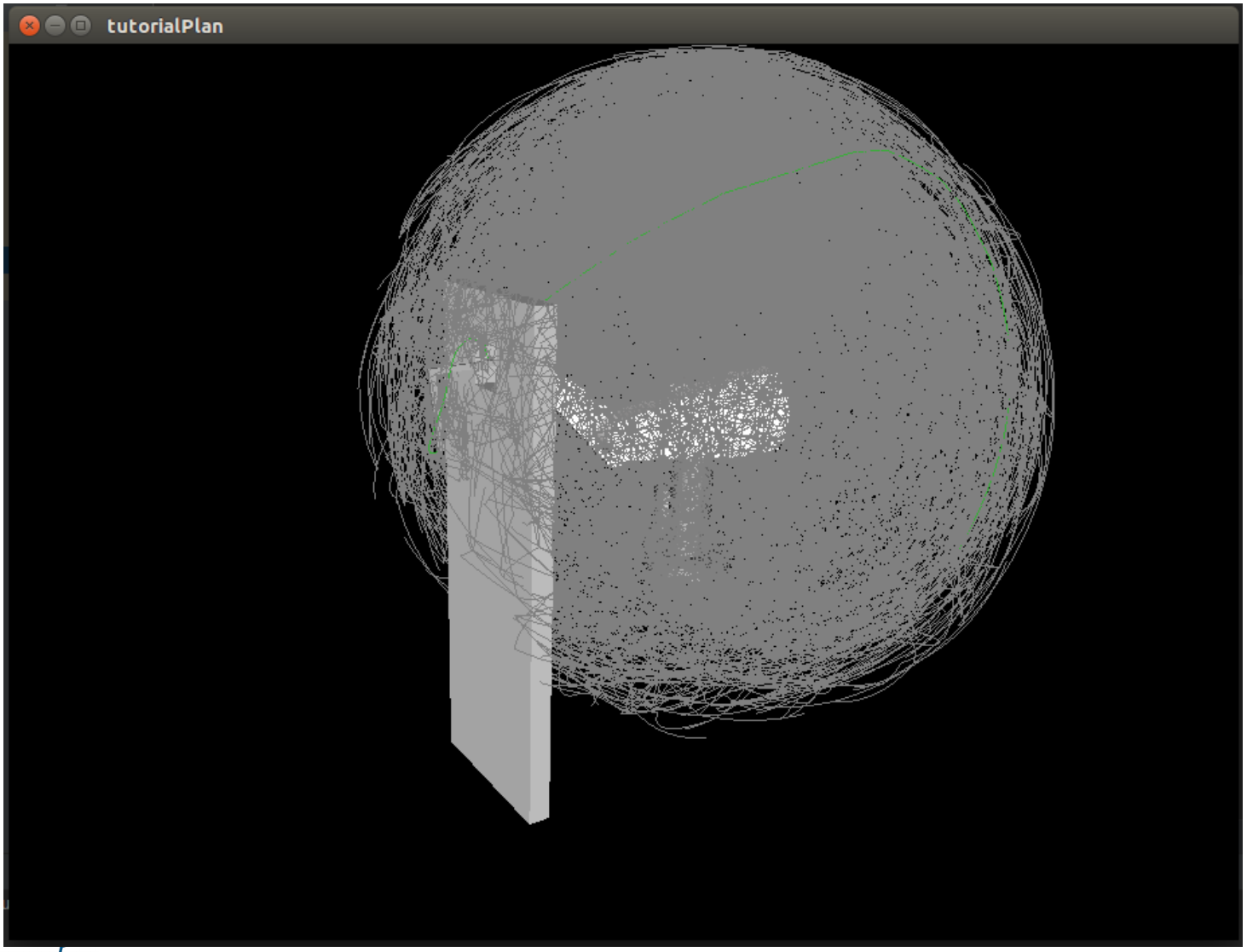
- Goal Configuration





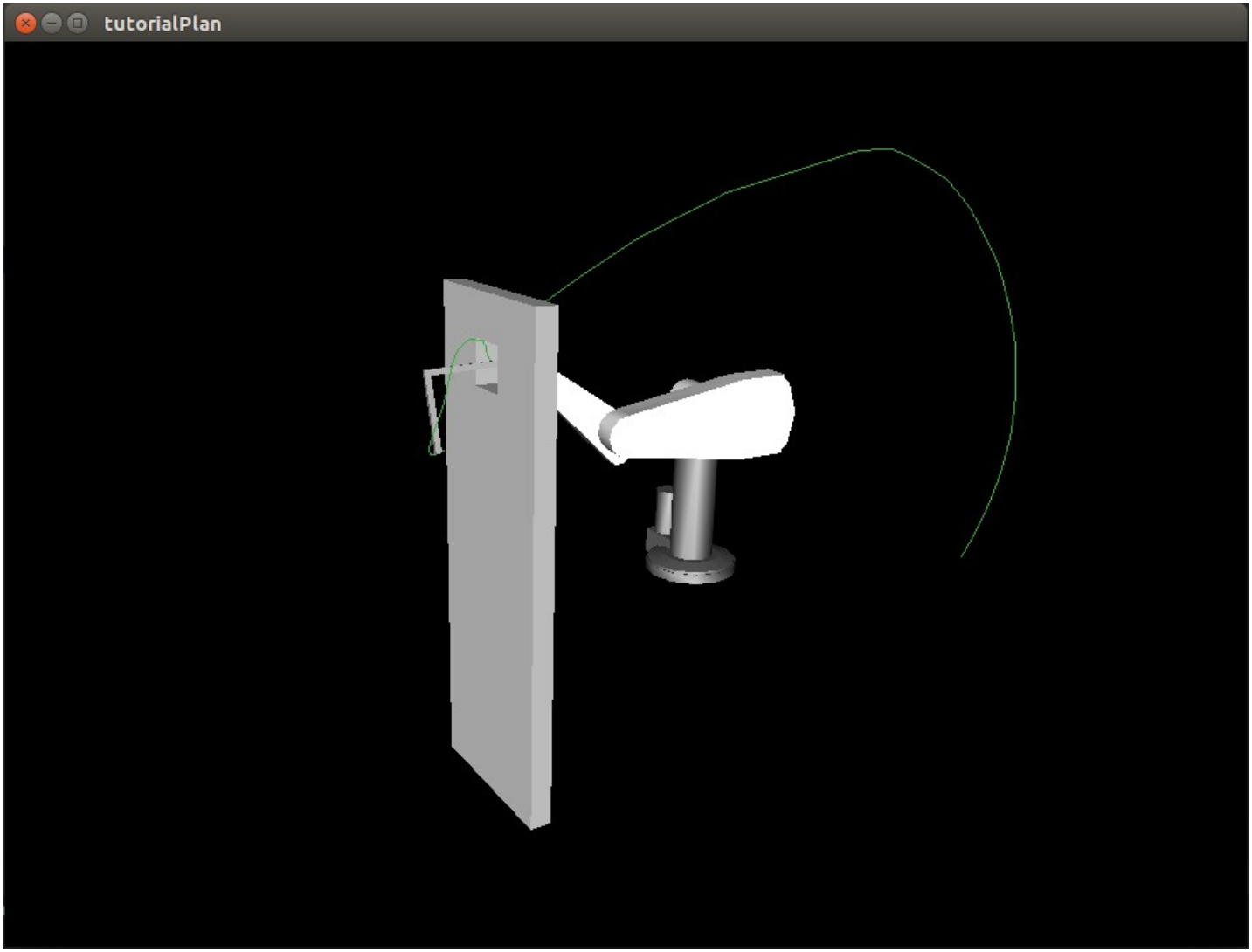
https://www.roboticslibrary.org/tutorials/install-ubuntu/

Puma - Motion Planning Execution (1)



https://www.roboticslibrary.org/tutorials/install-ubuntu/

Puma - Motion Planning Execution (2)

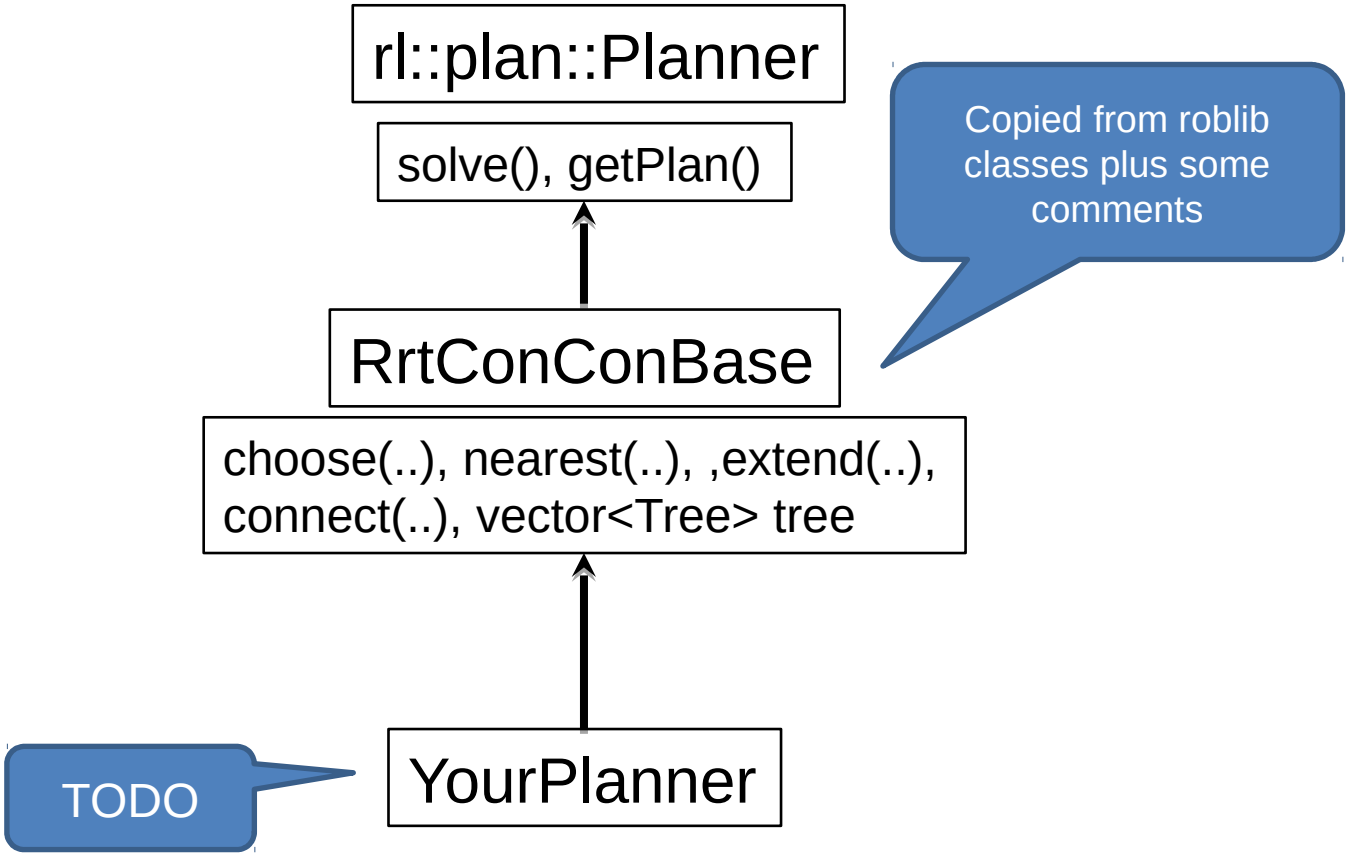


https://www.roboticslibrary.org/tutorials/install-ubuntu/

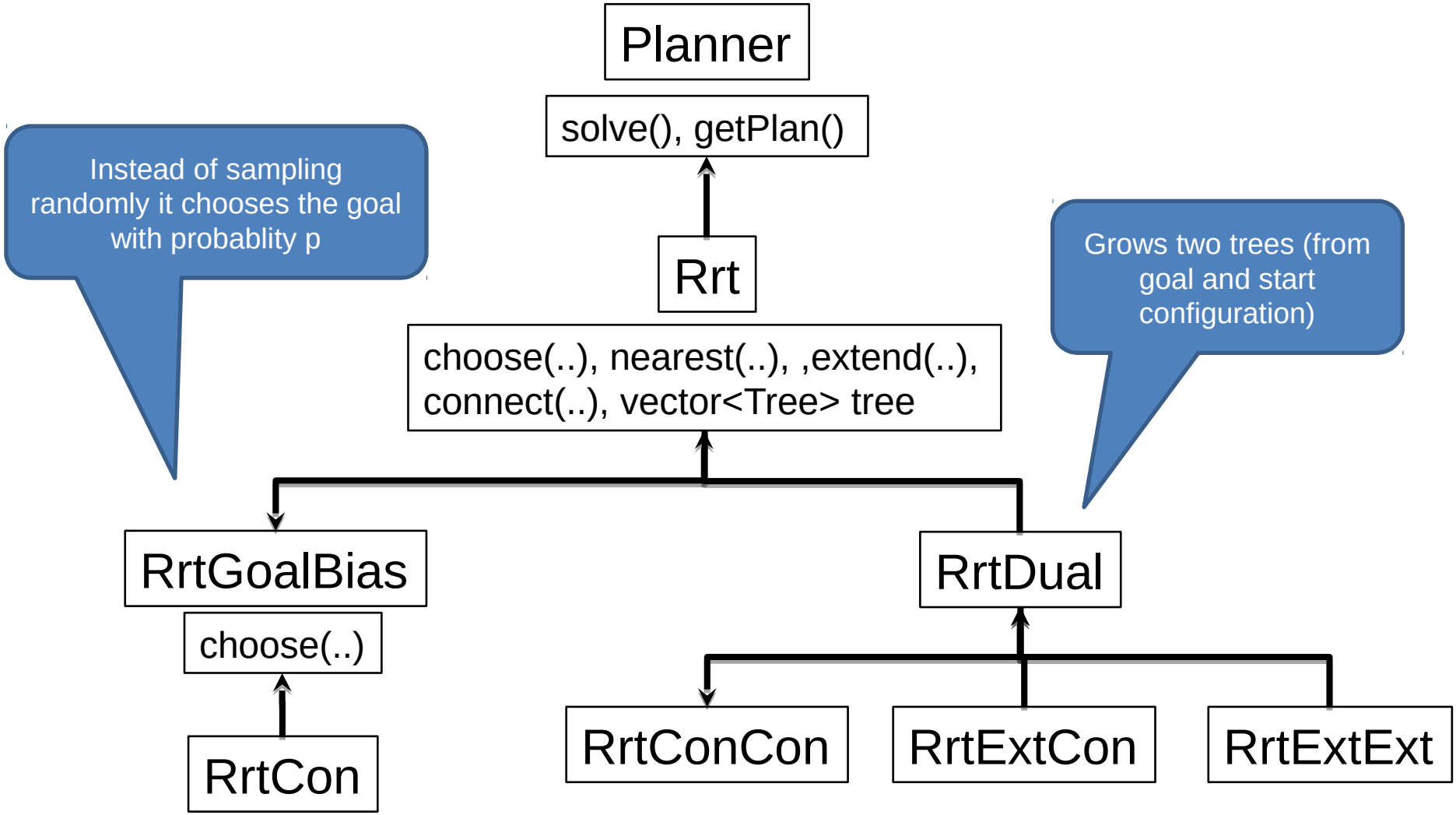
Windows (VS2010) installation is also possible

- Install prerequisites
  - Install Visual Studio 2010 (Express is fine)
  - Install Cmake
  - Install Qt http://download.qt-project.org/archive/qt/4.8/4.8.5/qt-win-opensource-4.8.5-vs2010.exe
  - Install roblib http://www.roboticslibrary.org/tutorials/install-windows follow all instructions on the page!
  - Download and extract tutorialPlan.zip:
- Build:
  - Open tutorialPlan/CMakeLists.txt in CMake - generate Visual Studio 10 project files in the build directory
  - Open build/tutorialPlan.sln in Visual Studio 2010
  - Compile RelWithDebInfo (Debug is not supported - sorry)
- Test:
  - press F5 or open build/RelWithDebugInfo/tutorialPlan.exe - Press space to start planning, F12 to reset

Hierarchy of RRT Classes for assignment



Hierarchy of RRT Classes in rl::plan



Writing Your Planner

- Modify YourPlanner.cpp
- Inherit from RrtConConBase (or any other RRT based planner in rl::plan)
- Set parameters of your algorithm in TutorialPlanSystem.cpp
- Implement better choose(), connect(), extend(), solve()
- You can add parameters for vertices in RrtConConBase::VertexBundle

Evaluating your algorithm

- Every time you run `./tutorialPlan` an entry is added to `benchmark.csv`
- This entry shows: computation time needed to solve the problem, number of nodes and edges created, number of queries needed to construct them, etc.
- Take a look into `~/roblib/examples/tutorialPlan/tutorialPlanSystem.cpp` to see the details and/or to edit them
- Run your algorithm at least ten times! – Change start and goal!

Writing the Documentation

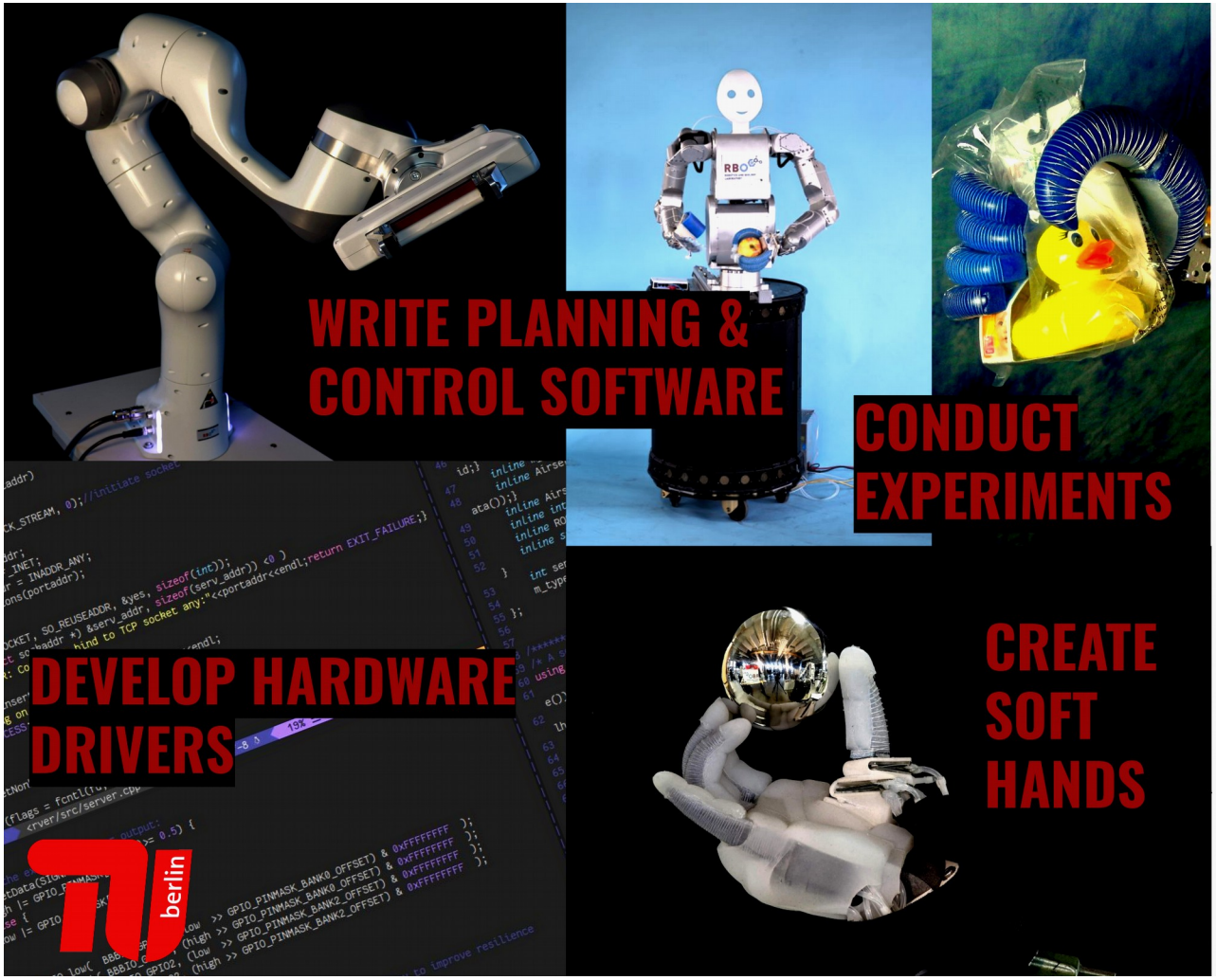
- Explanation of the proposed extensions with a code snipped
- Reasoning about extensions that have not improved the runtime
- Performance evaluation of your final algorithm
- (Optional) Extra points can be gained by performing an ablation study of your extensions with regard to the runtime

References

- http://roboticslibrary.org
- Robotics library examples: https://github.com/roboticslibrary/rl-examples
- Introduction to RRTs: msl.cs.uiuc.edu/rrt/
- Planning Book: Sections in 5.5 and 14.4 in planning.cs.uiuc.edu
- RRTExtCon: http://msl.cs.uiuc.edu/~lavalle/papers/KufLav00.pdf
- Avoid exhausted Nodes: http://homepages.laas.fr/jcortes/Papers/icra07paper.pdf
- Avoid Voronoi bias: http://ieeexplore.ieee.org/iel5/10495/33250/01570709.pdf

RBO

TU berlin



STUDENT ASSISTANTS WANTED

robotics.tu-berlin.de/menue/open_positions

ROBOTICS AND BIOLOGY LABORATORY

Skills:

- C++ / Python
- Linux
- English