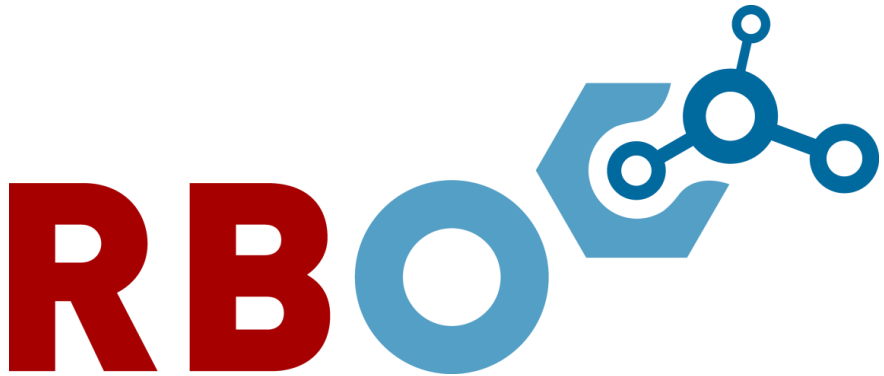
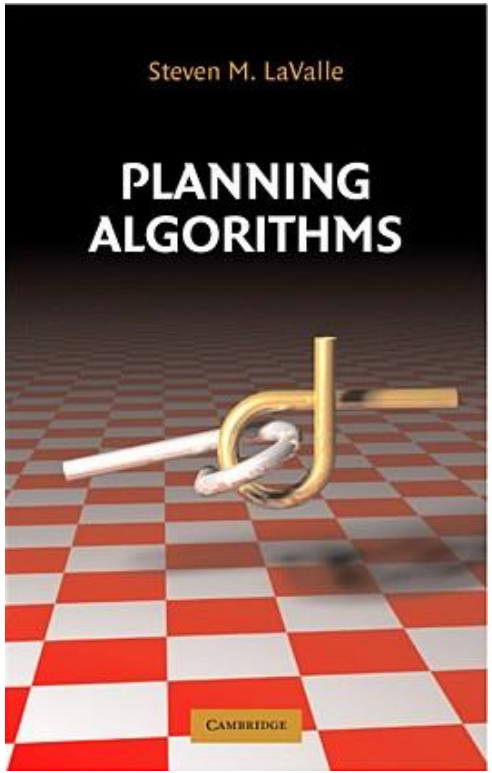



# Motion Planning: Rapidly-Exploring Random Trees

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

Technische Universität Berlin

# Book Recommendation




Available for free - online!

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

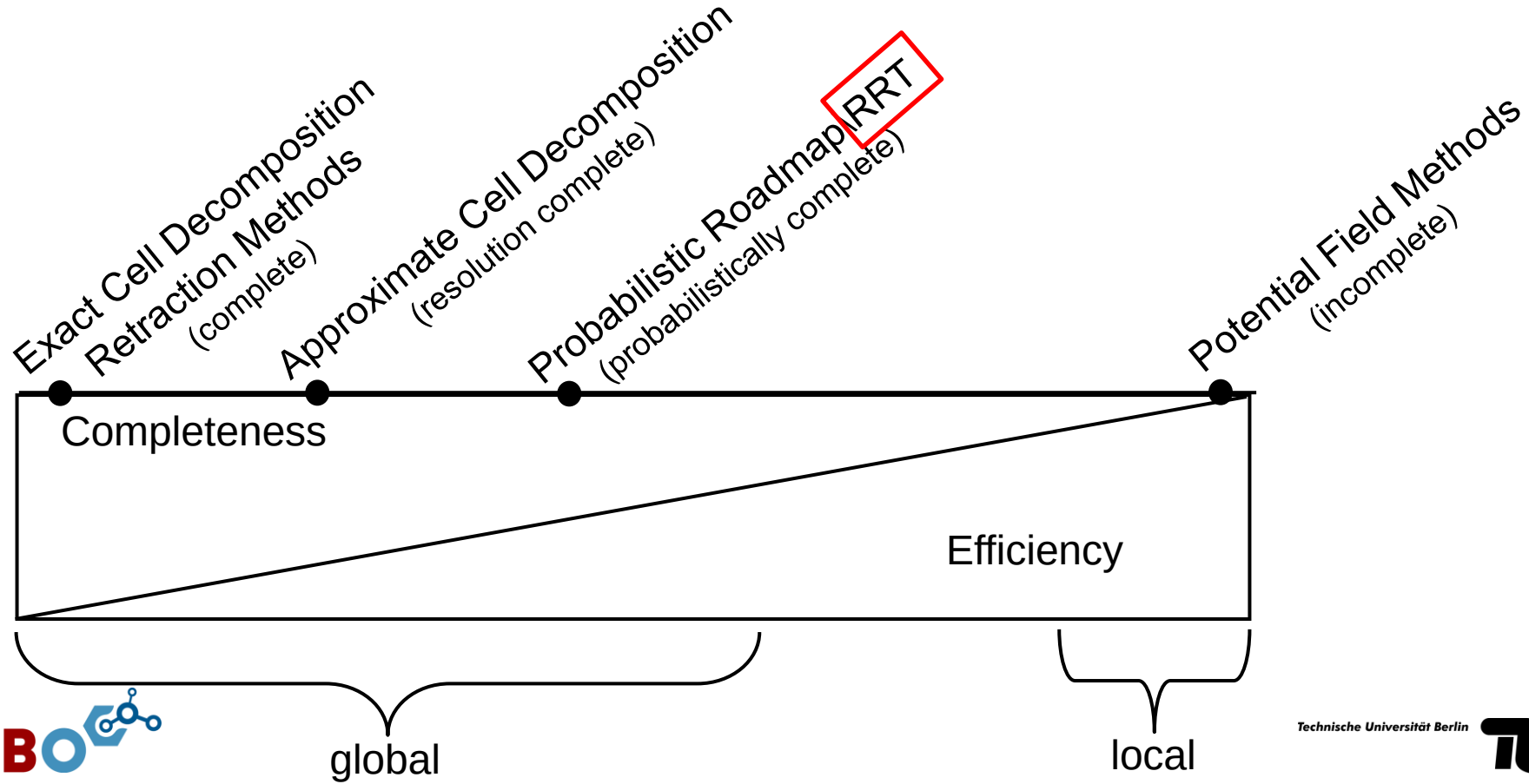
Chapter:

- **Sampling-based**
- **Motion Planning**

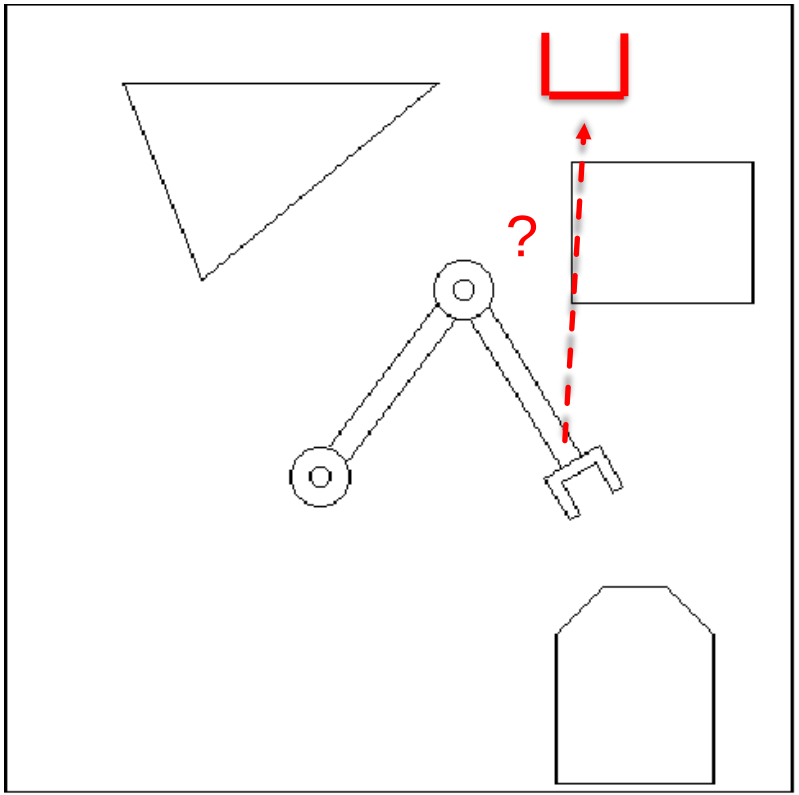
# The Motion Planning Problem

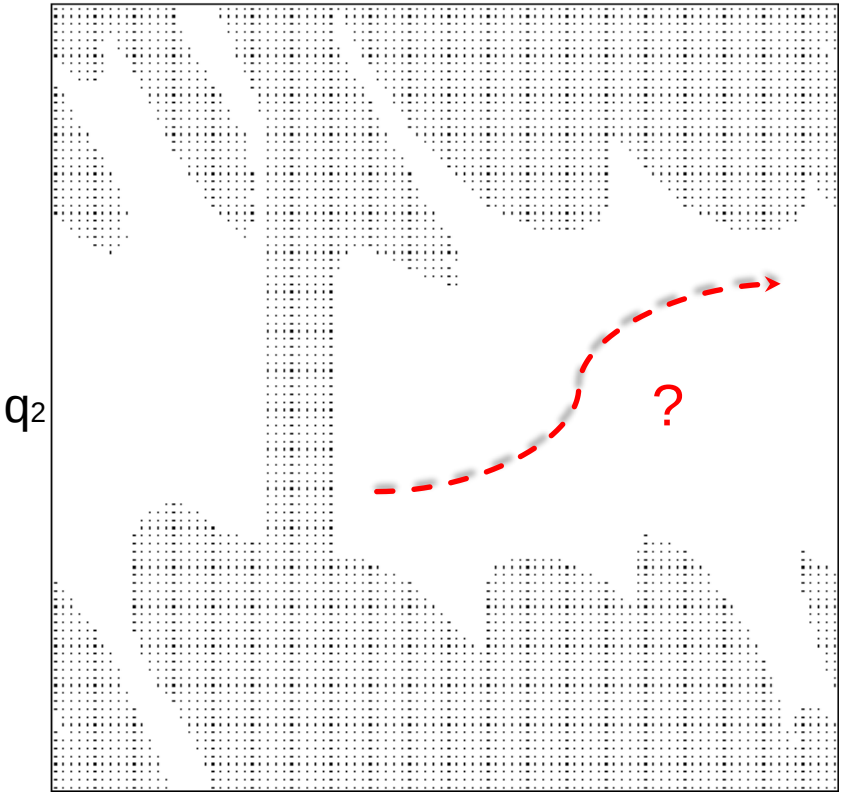
- $R$ : robot with $n$ degrees of freedom
- $B_{1,\ldots,m}$ : obstacles, rigid objects
- $W$ : workspace $\mathrm{R}^2$ or $\mathrm{R}^3$
- $C$ : configuration space
- $R, B_{1,\ldots,m} \in W$
- $q_{\text{initial}}, q_{\text{final}}$
- Find a free path $\tau$ so that $R$ moves from $q_{\text{initial}}$ to $q_{\text{final}}$ without touching any $B_i$

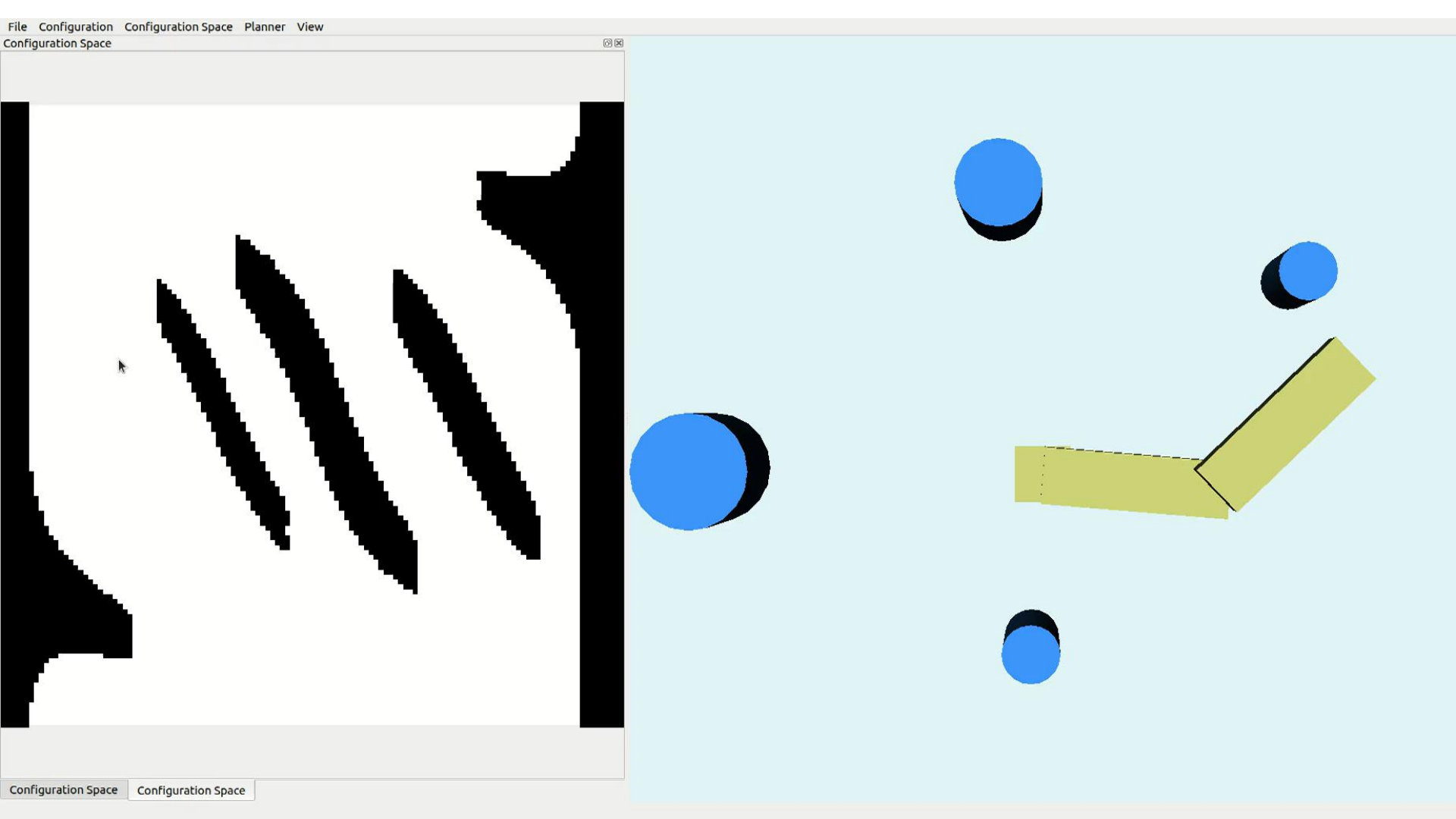
# Different Approaches to Motion Planning



# Motion Planning - Illustrated



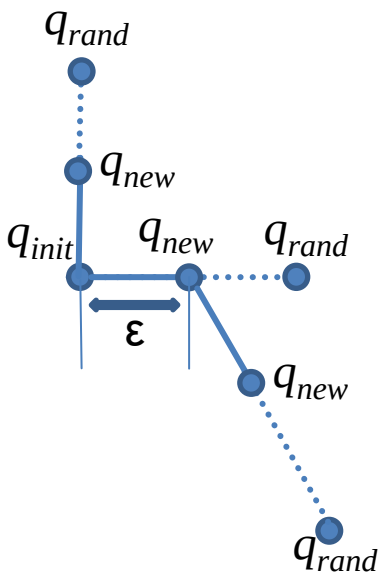



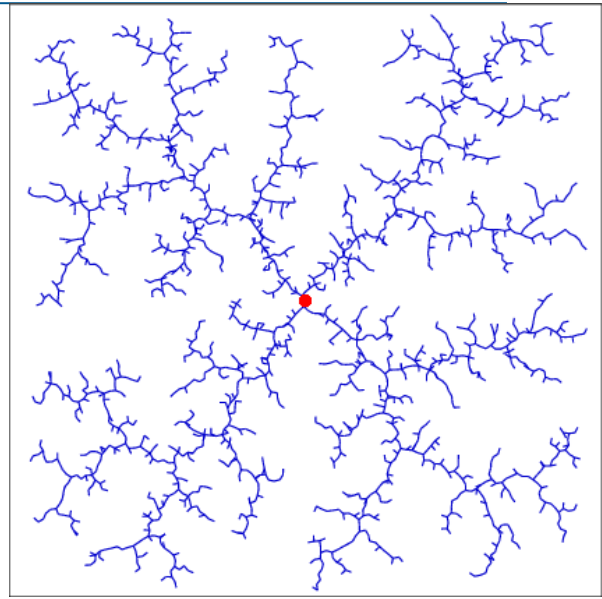

File Configuration Configuration Space Planner View
Configuration Space
Configuration Space
Configuration Space

# Rapidly-Exploring Random Trees

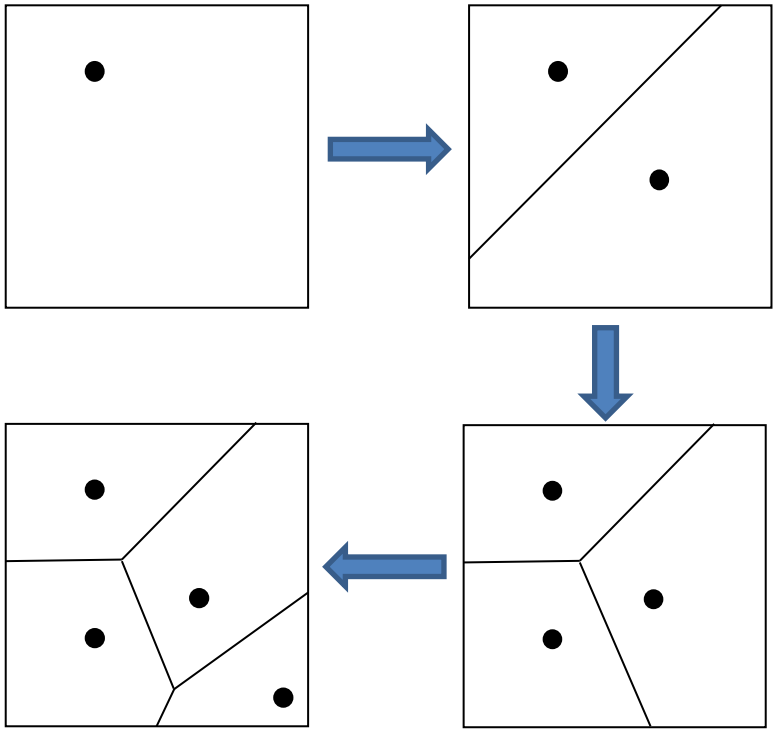
```
BUILD_RRT(q_init)
1  T.init(q_init);
2  for k = 1 to K do
3      q_rand ← RANDOM_CONFIG();
4      EXTEND(T, q_rand);
5  Return T
```

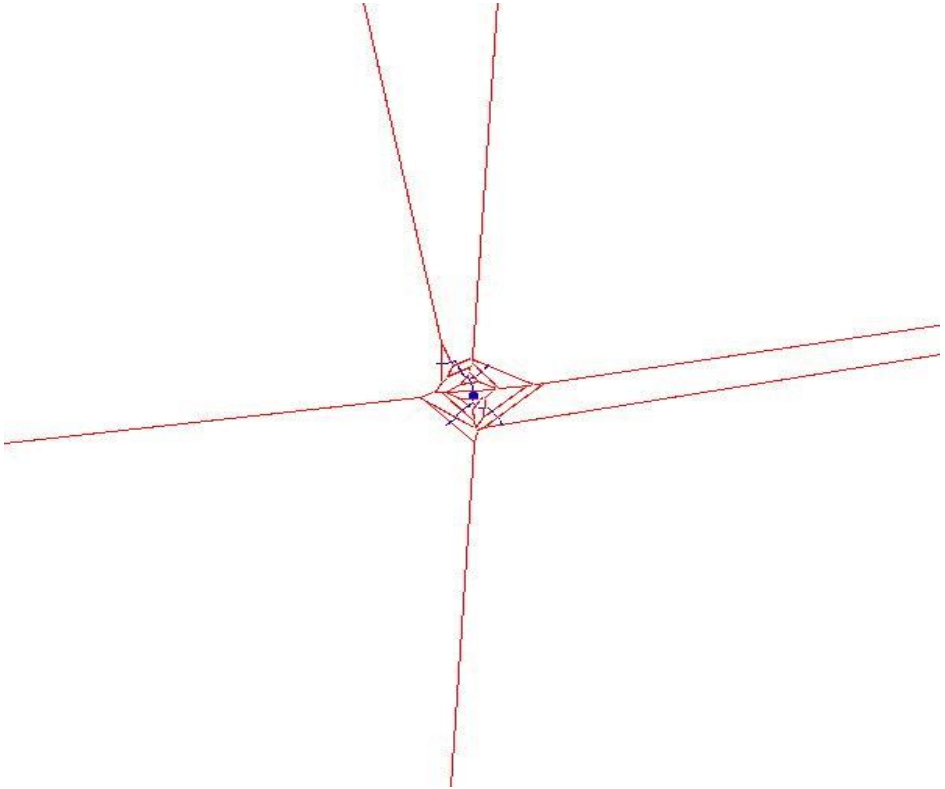
```
EXTEND(T, q)
1  q_near ← NEAREST_NEIGHBOR(q, T);
2  if NEW_CONFIG(q, q_near, q_new) then
3      T.add_vertex(q_new);
4      T.add_edge(q_near, q_new);
5      if q_new = q then
6          Return Reached;
7      else
8          Return Advanced;
9  Return Trapped;
```



# The Voronoi Bias





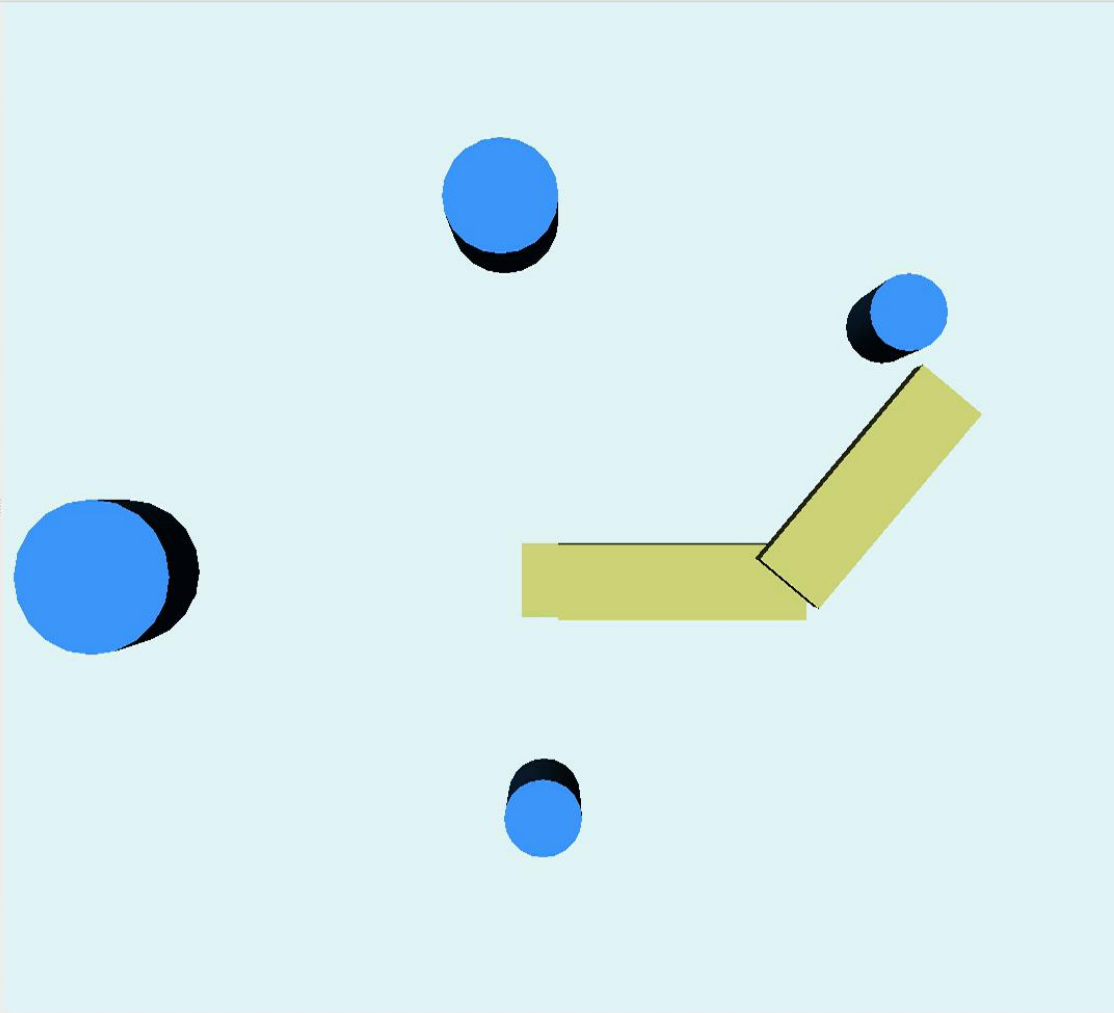
RBO

Technische Universität Berlin

File Configuration Configuration Space Planner View

Configuration Space

Configuration Space Configuration Space

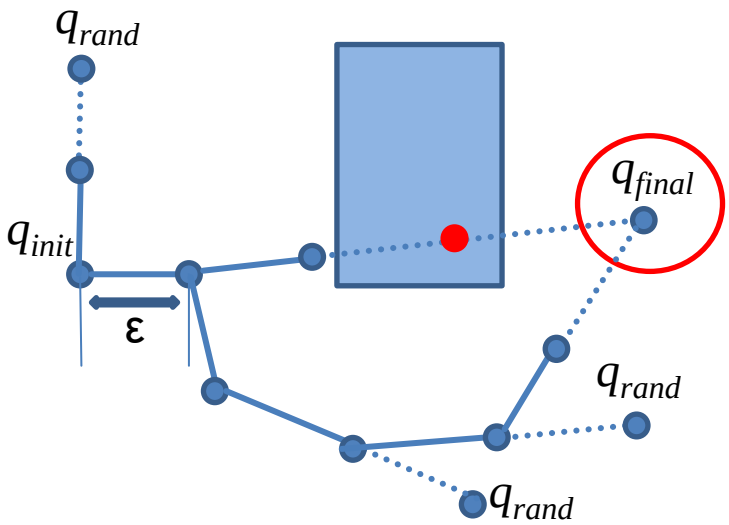


# RRT Extensions (1) – Goal Bias

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

**RANDOM_GOAL_BIAS(p)**

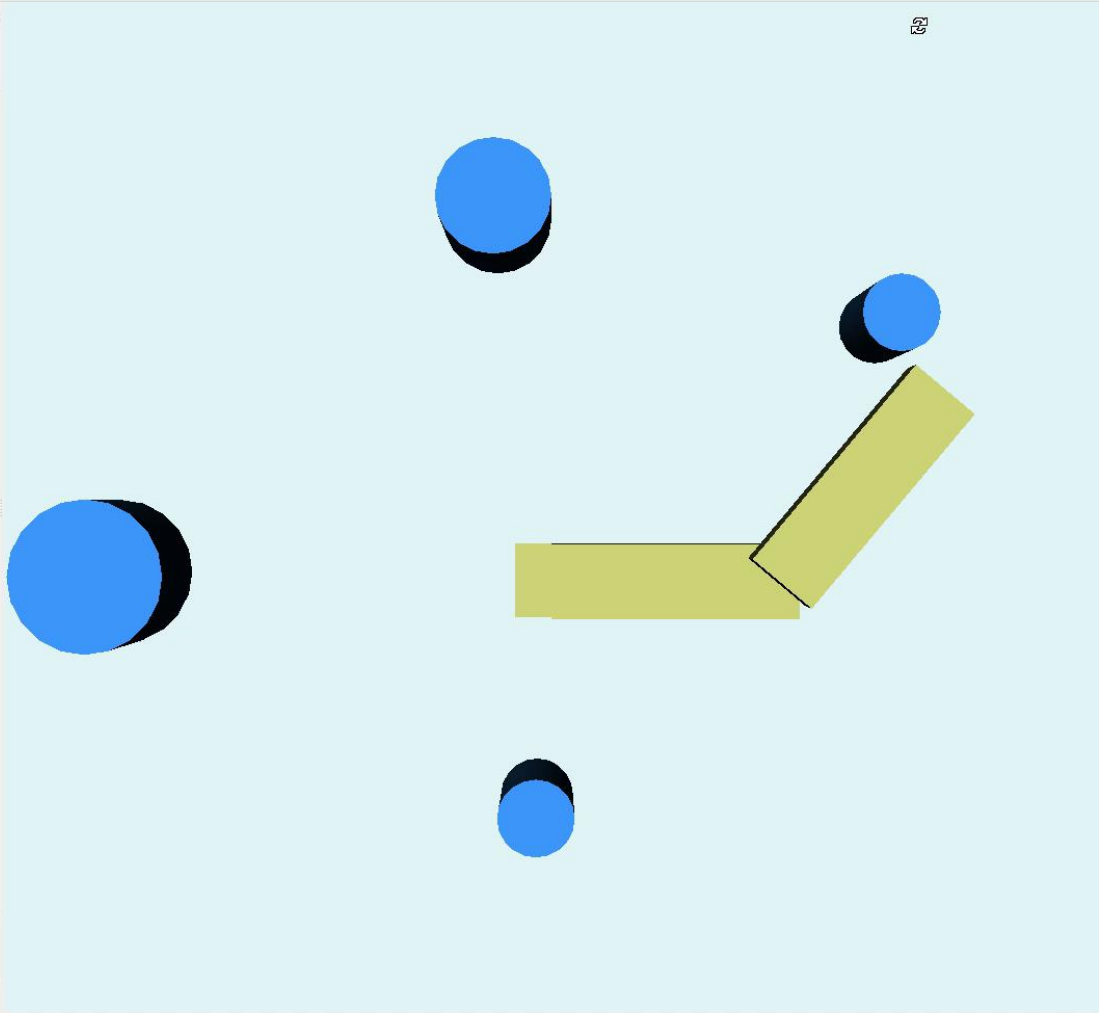
- Sample **random configuration** with probability **1-p**
- Sample **goal configuration** with probability **p**



File Configuration Configuration Space Planner View

Configuration Space

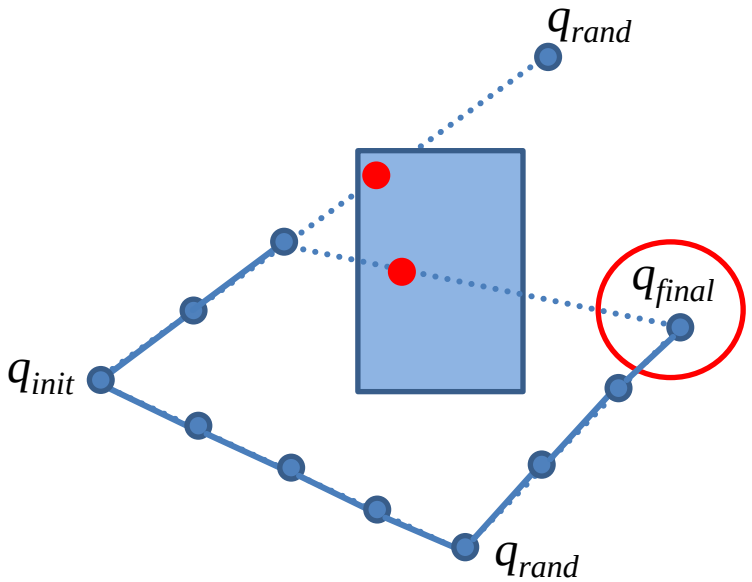
Configuration Space Configuration Space



# RRT Extensions (2) – Connect

BUILD_RRT($q_{init}$, $q_{final}$, p)
1 $\mathcal{T}$.init($q_{init}$);
2 **for** $k = 1$ **to** $K$ **do**
3 $q_{rand} \leftarrow$ RANDOM_GOAL_BIAS(p);
4 CONNECT(T, $q_{rand}$)
5 Return $\mathcal{T}$

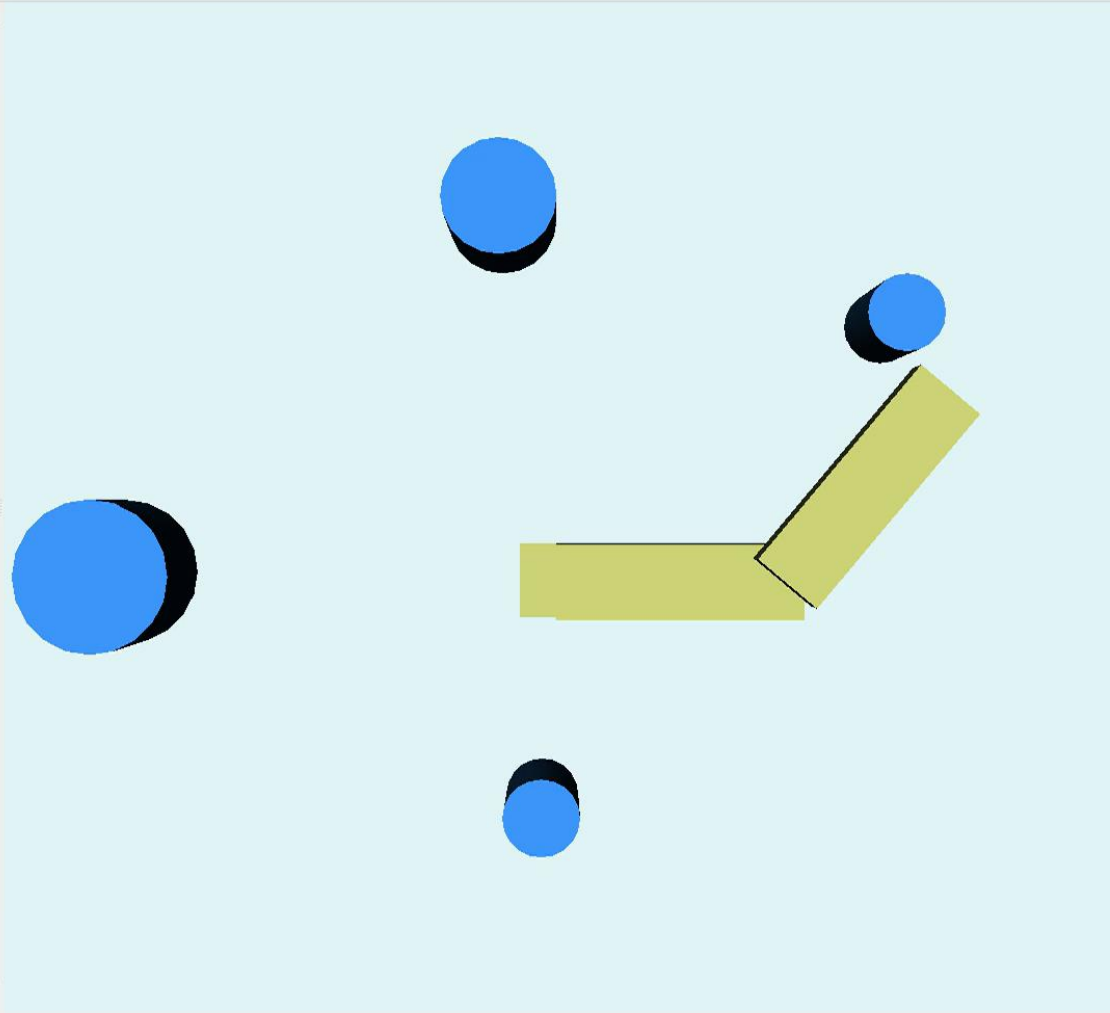
CONNECT($\mathcal{T}, q$)
1 **repeat**
2 $S \leftarrow$ EXTEND($\mathcal{T}, q$);
3 **until not** ($S = Advanced$)
4 Return $S$;



File Configuration Configuration Space Planner View

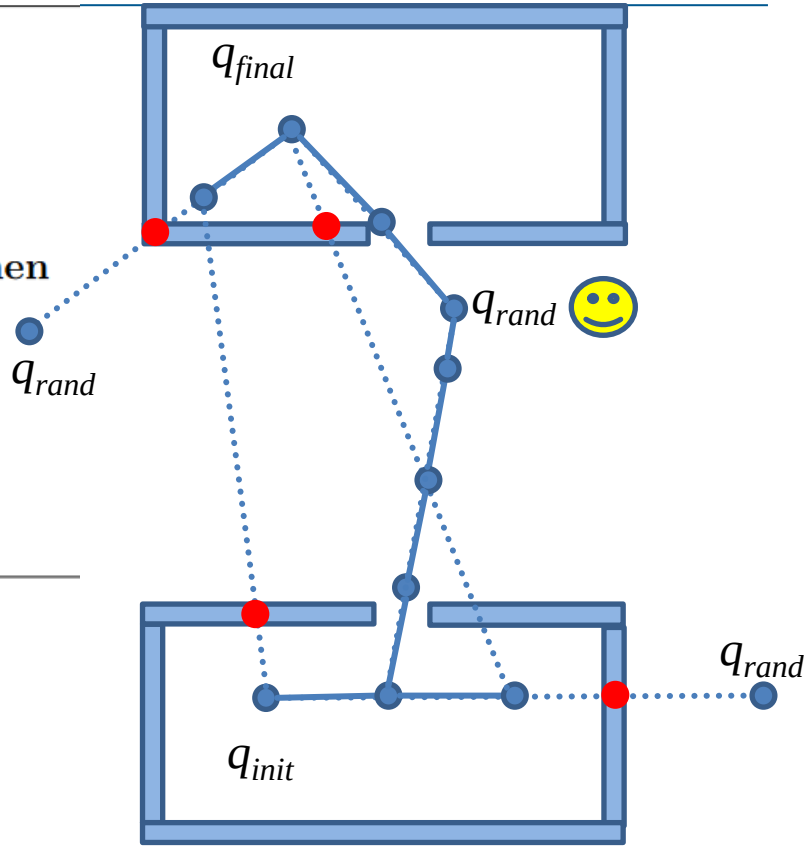
Configuration Space

Configuration Space Configuration Space



# RRT Extensions (3) – Using Two Trees

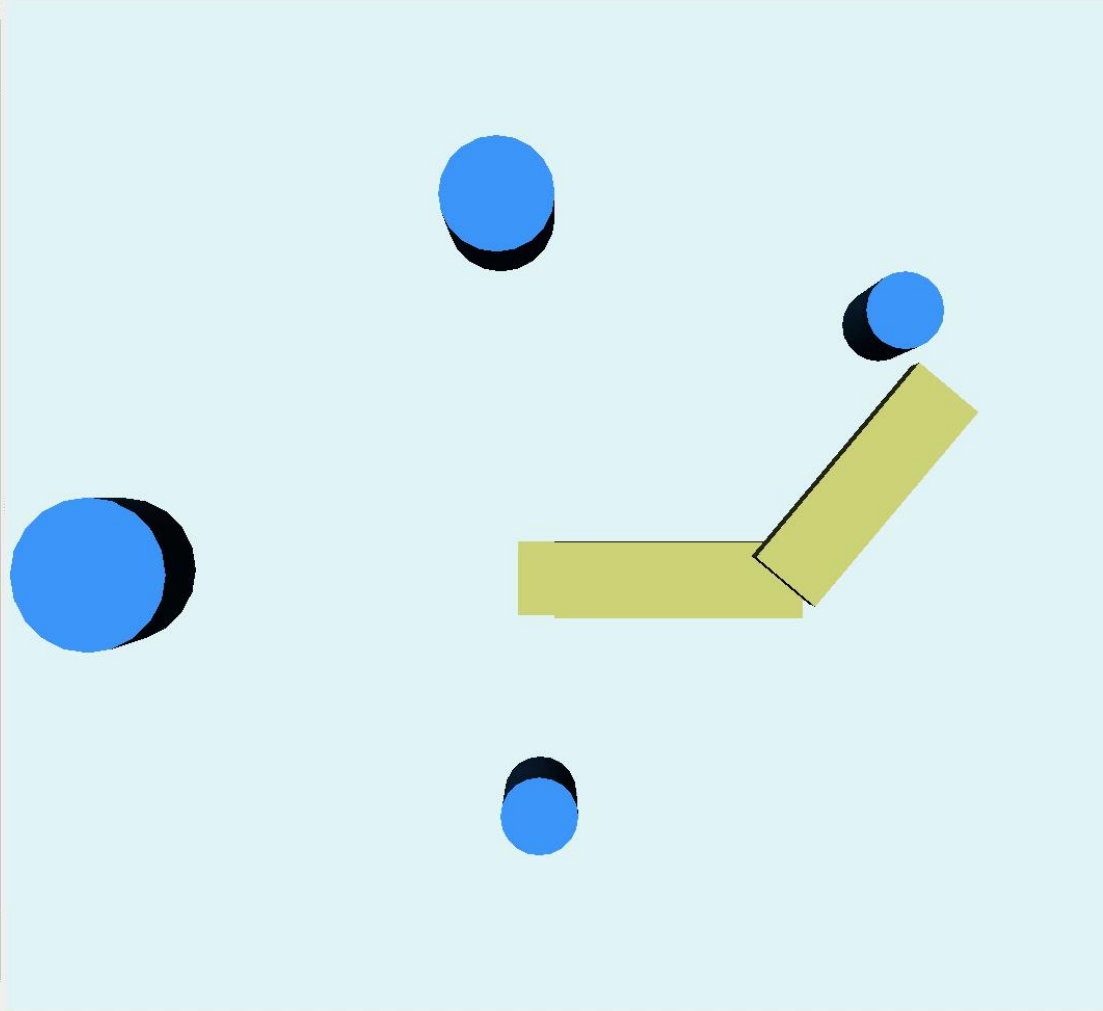
```
1: function RRT_BIDIRECTIONAL(q_init, q_final)
2:     T_a.init(q_init); T_b.init(q_final);
3:     for k = 1 to K do
4:         q_rand ← RANDOM_CONFIGURATION();
5:         CONNECT(T_a, q_rand);
6:         if q_new AND CONNECT(T_b, q_new) == Reached then
7:             Return PATH(T_a, T_b);
8:         end if
9:         SWAP(T_a, T_b);
10:    end for
11:    Return Failure;
12: end function
```



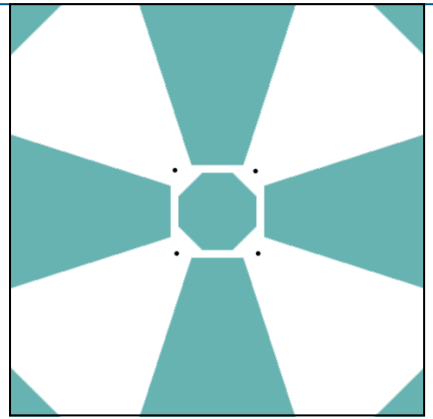
File Configuration Configuration Space Planner View

Configuration Space

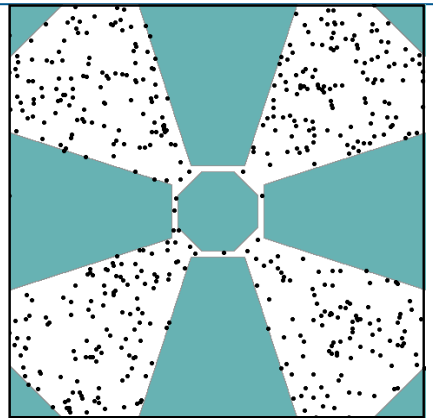
Configuration Space Configuration Space



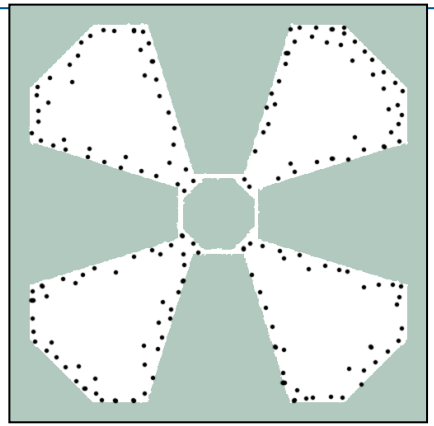
# Different Sampling Strategies



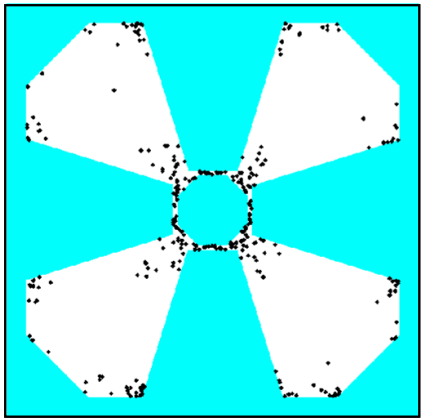
ideal



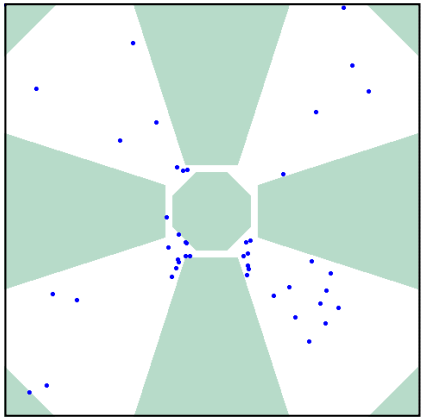
uniform



Gaussian



Bridge



Utility

# 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.