Constrained Motion Planning

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Outline

Problem

Sometimes, moving from A to B without colliding is not the only requirement of a movement.

Hardware constraints

- Joints may have dependencies to each other

Task constraints

- Holding a glass of water without spilling
- Keep robot away from specific places
- Moving a specific joint might be undesirable
- Grasped object may be attached to another object

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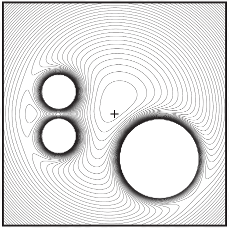
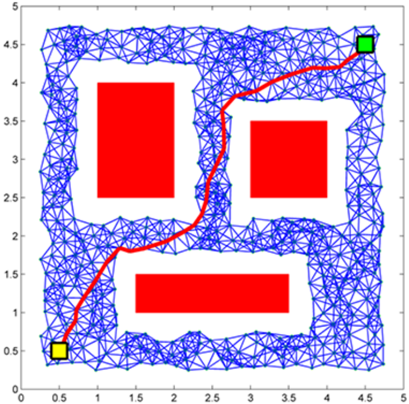
Non-sampling based motion planning

- Instead of planning ahead, start and react to problems
- Using potential fields for path planning
- These methods are prone to get trapped in local minima and are not necessarily complete

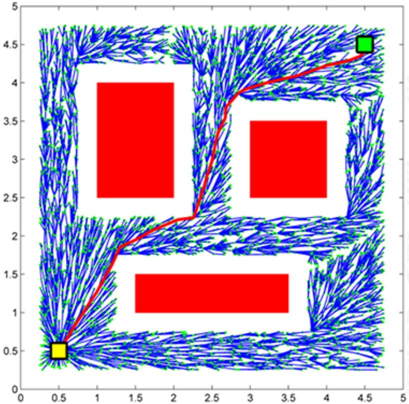
Potential field 3D view



Potential field 2D view[LP17]



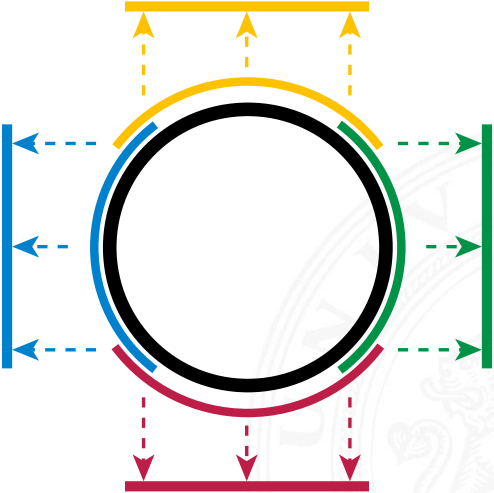
Probabilistic Road Map PRM



Rapidly-exploring Random Trees RRT

Graph-based and tree-based sampling.[KMK20]

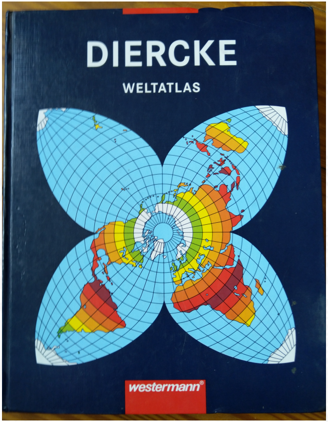
Manifolds



The circle border is a 1D manifold in 2D space.[Pbr08]

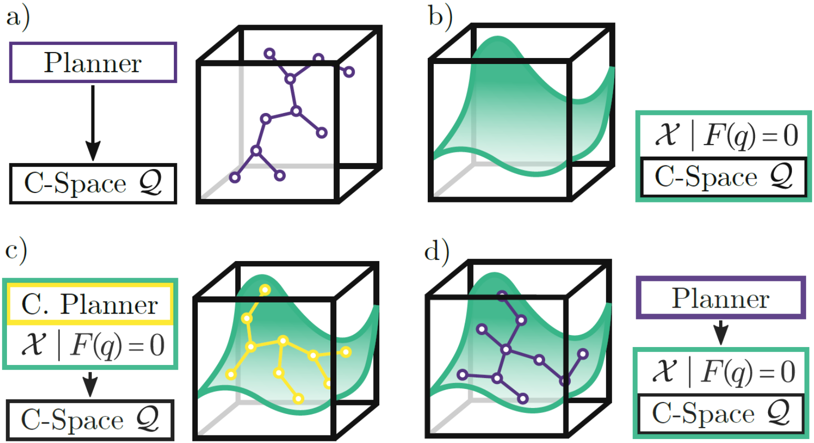
Manifolds

The surface of the earth is a 2D manifold in 3D space.[Nas06]



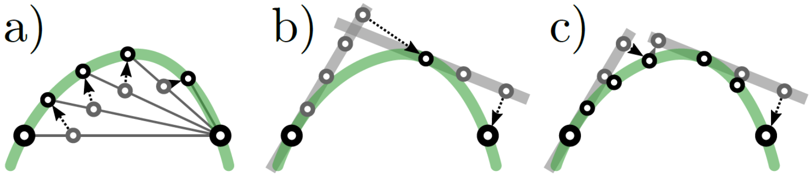
A collection of 2D maps covering the entire sphere.

Manifolds



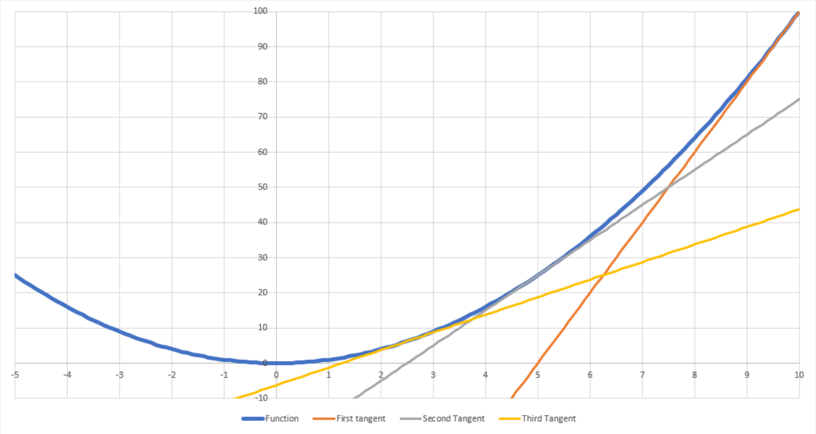
Left: The planner works on the full space and considers the manifold — Right: The planner works on the manifold

Manifold approximation



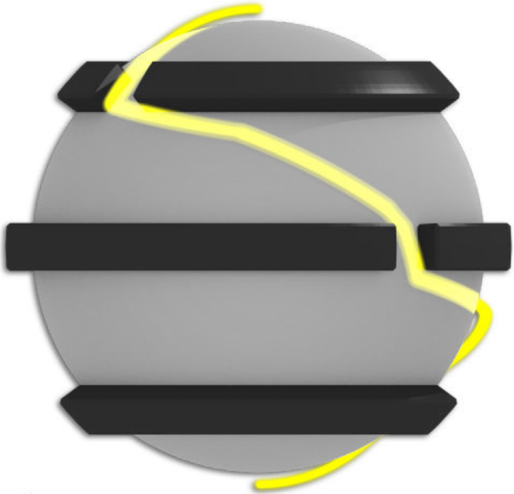
Geodesic interpolation based on a) Projection b) Tangent bundle c) Atlas

Newton’s method

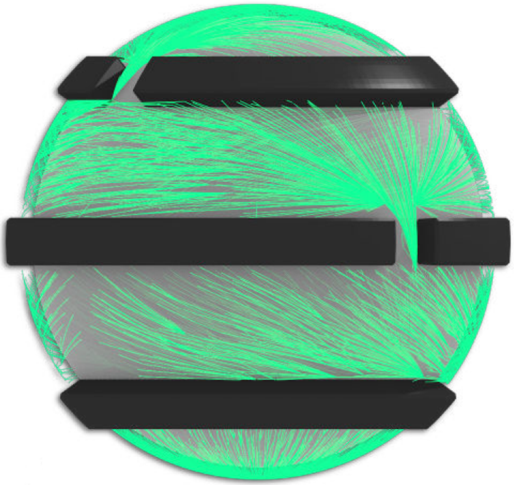


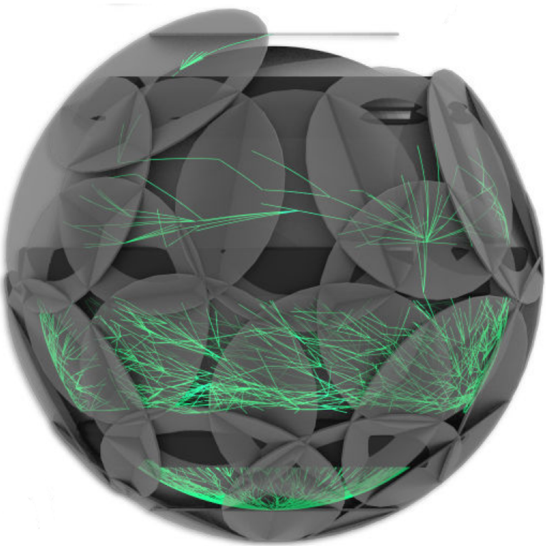
Approximating zeros of functions using gradien descent

Base, obstacles and ideal path (Bottom to top)

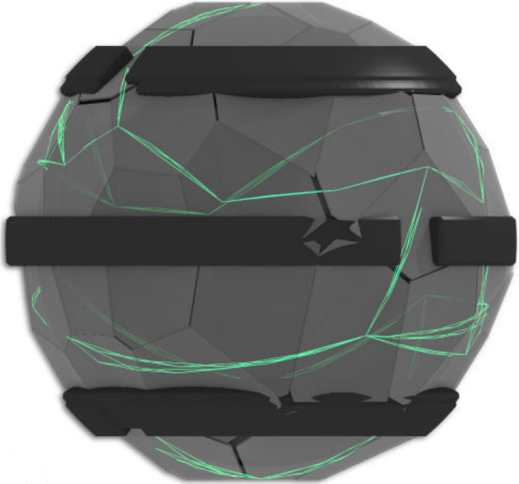


Planning based on projection using RRT

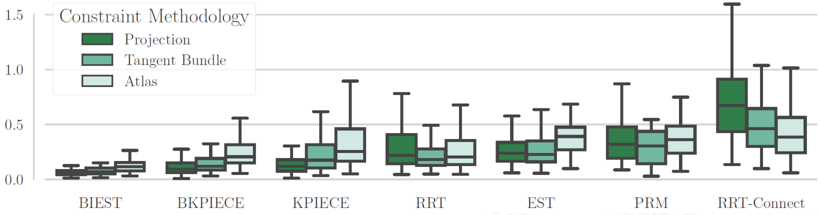




Planning based on atlas layout using SPARS



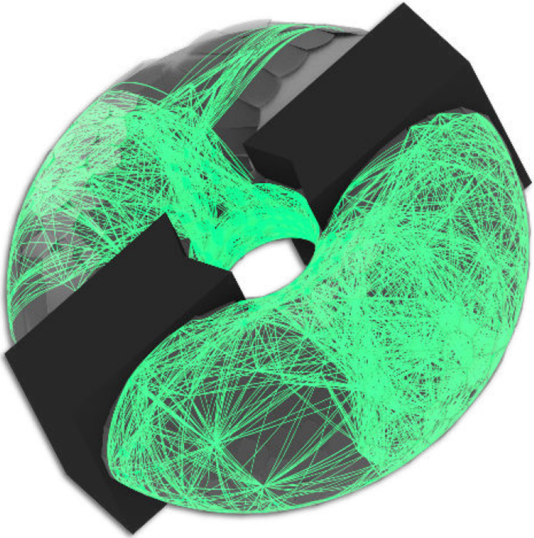
Performance



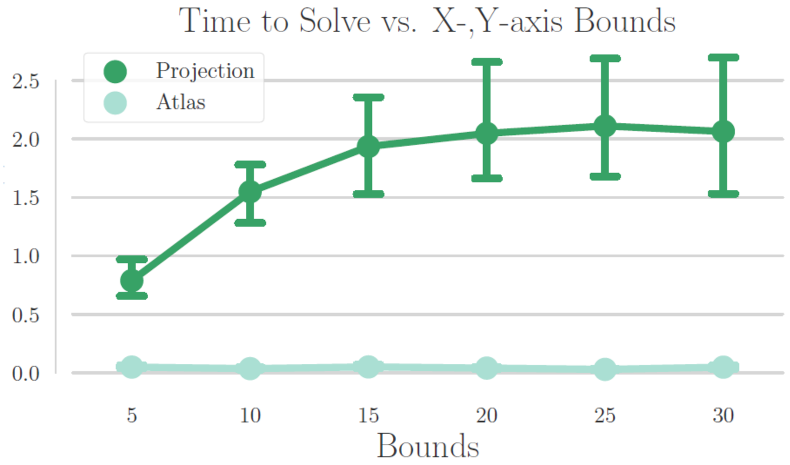
Different Planners using the constrained spaces. Y-axis units are seconds.

(BI)EST	(Bidirectional) Expansive Space Trees
(B)KPIECE	(Bidirectional) Kinodynamic Motion Planning by Interior-Exterior Cell Exploration
PRM	Probabilistic Roadmap
RRT(-Connect)	Rapidly-Exploring Random Trees

Torus



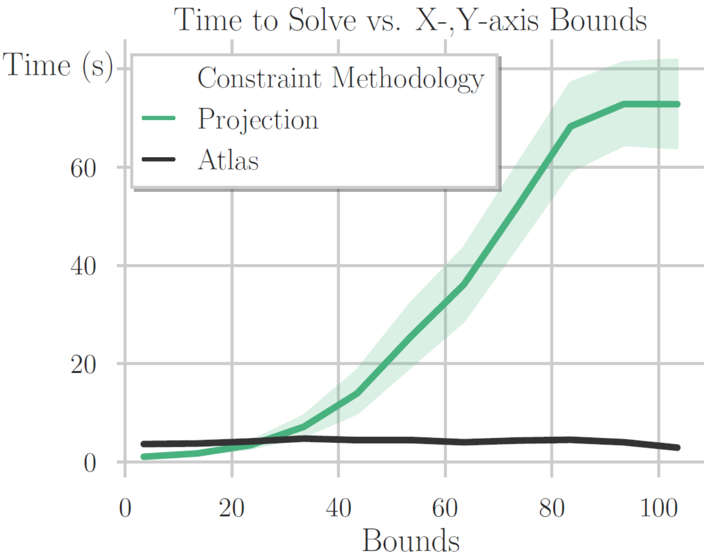
Torus



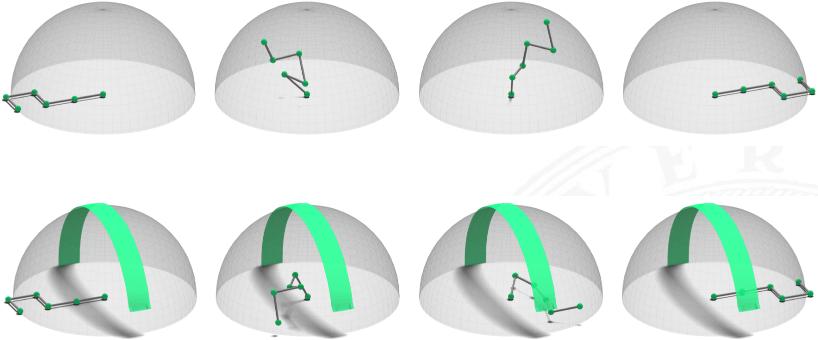
Performance of a Probabilistic Road Map (PRM). Y-axis units are seconds.

Torus - two years later

Torus - two years later



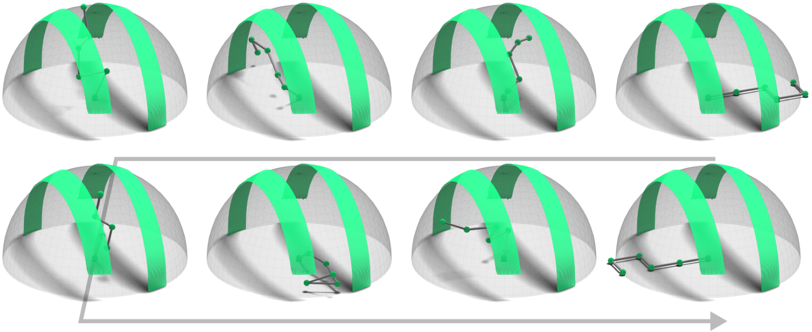
Hemisphere



Robot with 15 Degrees of freedom, 3 in each joint. The end effector can only move on the surface on the hemisphere.

Also, three joints have dependencies to each other. (1 and 2 must have same z-value, 2 and 3 must have same x-value, 3 and 4 must have same z-value)[KMK20]

Hemisphere



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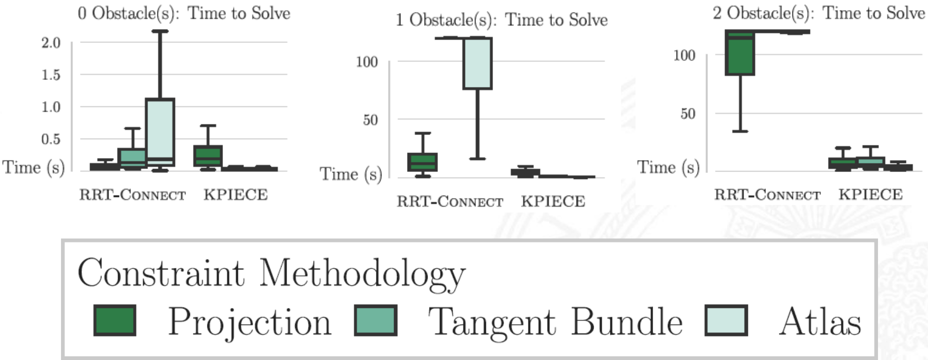
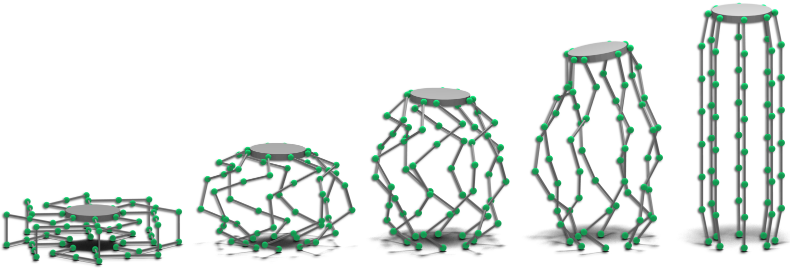
Hemisphere Performance

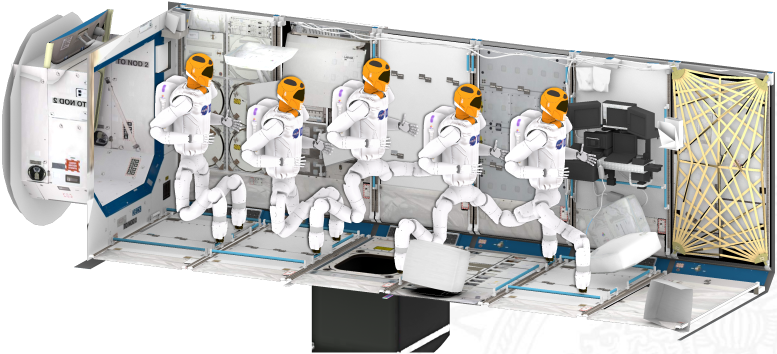


Highdimensional Robot



Robot with a 168-dimensional configuration space and a 99-dimensional constrained configuration space. Constrained planning can improve calculation time for a motion to stand upright from at least 10 minutes to about 15 seconds.[KMK20]

Astronaut robot



A robot which needs to have the torso in a fixed orientation and always needs hold on to handrails in a specific orientation[KMK20]

Conclusion

- Framework for motion planning in a constrained space
- Faster than conventional planning and subsequent verification
- Easier and more future-proof than developing a new "Constraint-aware path planner"
- Ability to use preexisting planners on a modified space
- Some planners work better together with specific constraint methologies and constraint shapes – This framework allows great interchangeability for that

Appendix

Additional video sources

RRT* Animation	https://www.youtube.com/watch?v=YKiQTJpPFkA
RRT* Animation	https://www.youtube.com/watch?v=QLNSkFnBYuM
Random Tree vs RRT vs RRT*	https://www.youtube.com/watch?v=Ob3BIJkQJEw
PRM	https://www.youtube.com/watch?v=RPzGEh6cOiM
BIT	https://www.youtube.com/watch?v=d7dX5MvDYTc

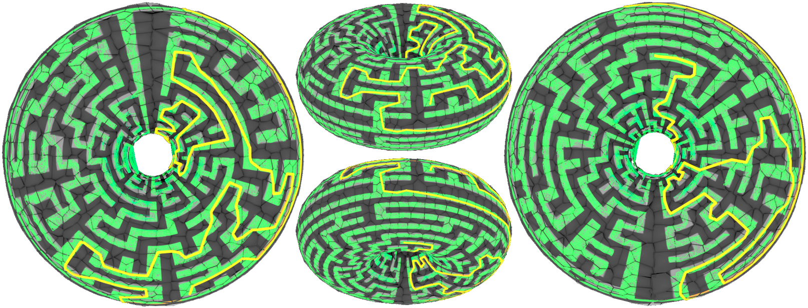
Additional information

Optimization based path planning can work on manifolds, as of now, now comprehensive comparis between these two approaches have been made due to the recency of this research.

The sphere environment

- The planners on each sphere uses a different algorithm, hence the very different path previews. The algorithms are:
  1. Rapidly-exploring Random Trees `RRT`
  2. Batch informed trees `BIT`
  3. Sparse roadmap spanners `SPARS`

Torus expanded



Literature

[KMK20] Zachary Kingston, Mark Moll, and Lydia Kavraki.
Decoupling Constraints from Sampling-Based Planners, pages 913–928.
Spinger International, 01 2020.

[LP17] Kevin M. Lynch and Frank C. Park.
Modern Robotics: Mechanics, Planning, and Control.
Cambridge University Press, USA, 1st edition, 2017.

[Nas06] Nasa.
The earth seen from apollo 17 with white background., 2006.
[Online; accessed 08-06-2020].

Literature (cont.)

[Pbr08] Pbroks13.
Figure 1: The four charts each map part of the circle to an open interval, and together cover the whole circle., 2008.
[Online; accessed 07-06-2020].