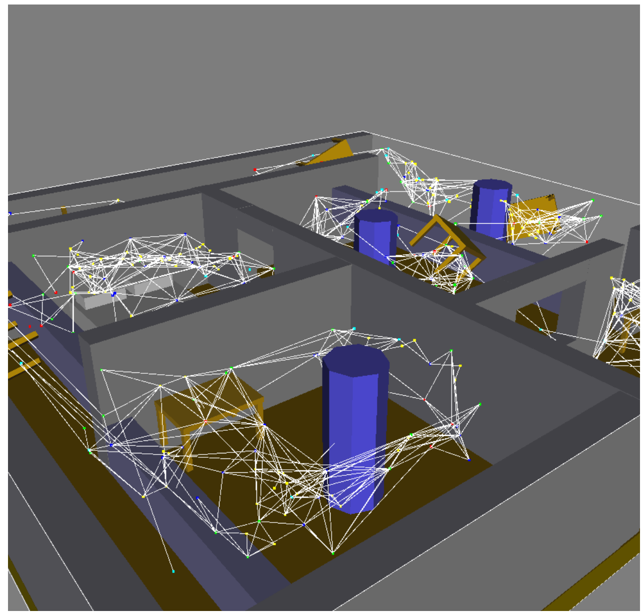
Roadmap Spanners



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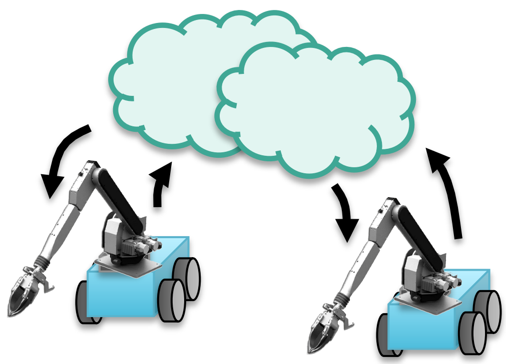
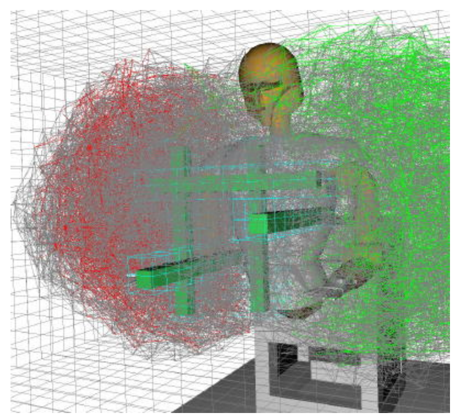
Joint work with Andrew Dobson and James Marble
Department of Computer Science
Rutgers University
May 10th, 2013

Why Roadmaps and Roadmap Spanners?

Produce sparse graphical representations that:
- reflect the connectivity of the configuration space
- and can be used to efficiently answer online queries with good quality paths

- Posed as an important challenge for motion planning [Agarwal, '11]
- Good for resource constrained robots, potentially interfacing with a computing cloud





From the work on "Dynamic Roadmaps" by Kallmann, Mataric

- Useful in higher-dimensional challenges such as mobile manipulation:
  - Roadmaps can store experience! They are path libraries!

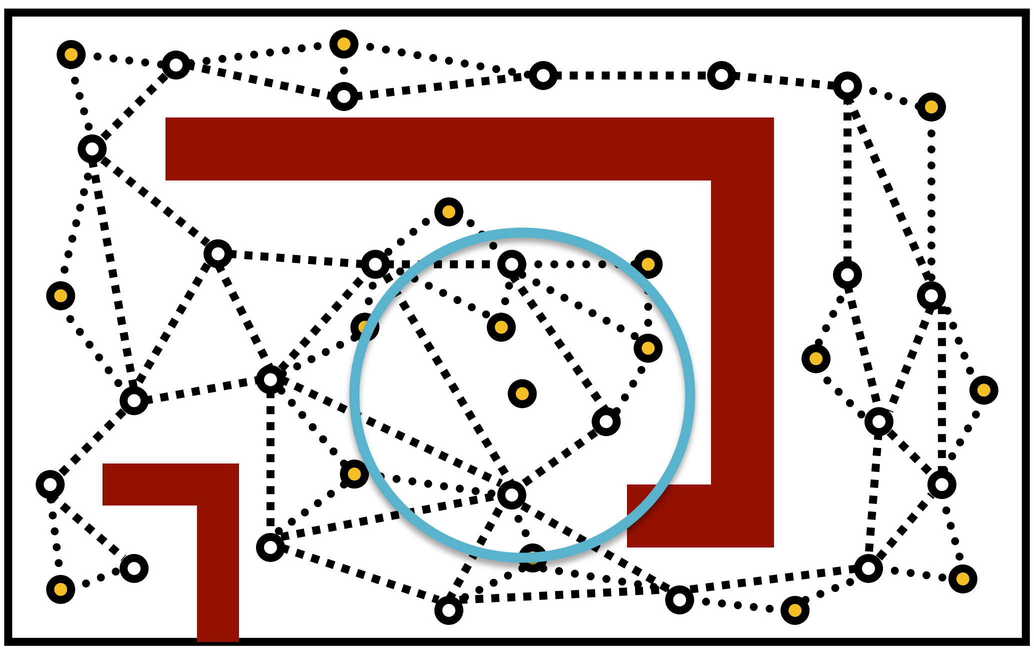
NEAR-

OPTIMAL

MOTION

Roadmaps and Path Quality

- A fully connected graph gives asymptotically optimal solutions
  - Resembles exhaustive search, results quickly in a huge data structure
- Connecting to *k* closest neighbors is efficient [PRM, Kavraki et al. '96]
  - Doesn't result in an asymptotically optimal solution for constant k



<u>From percolation theory</u>

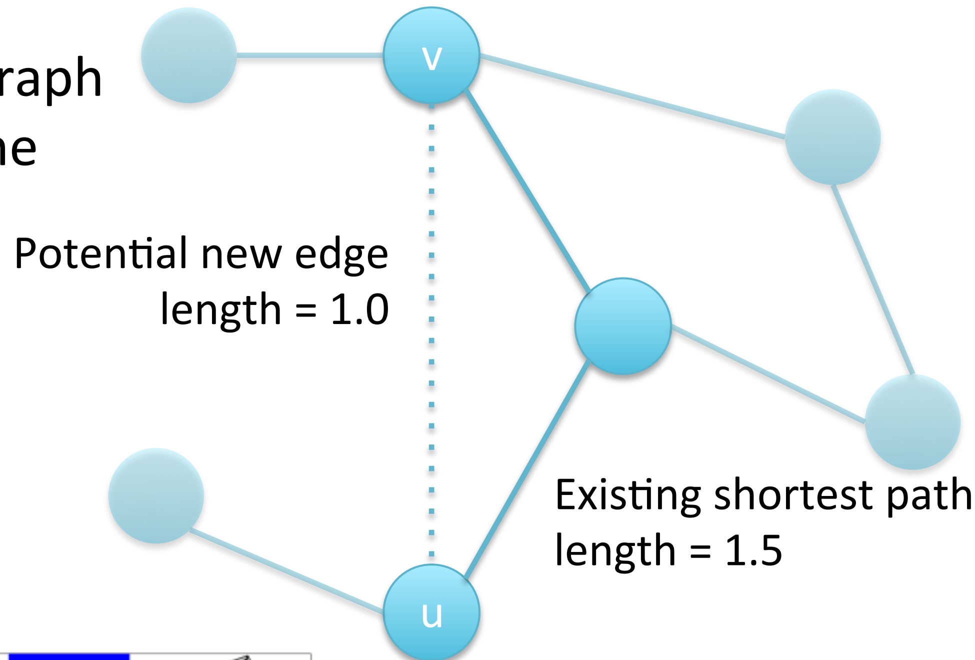
It is sufficient if we attempt to connect any new sample with approximately *k=logn* neighbors, where *n* is the number of nodes in the roadmap.

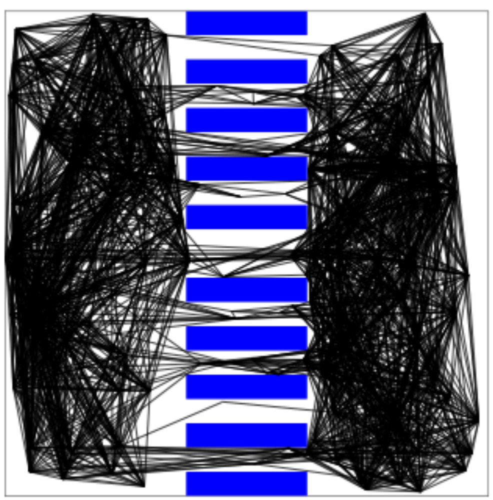
[kPRM* - Karaman, Frazzoli '11]

- Efficiency challenge
  - Asymptotically optimal roadmaps are large and dense

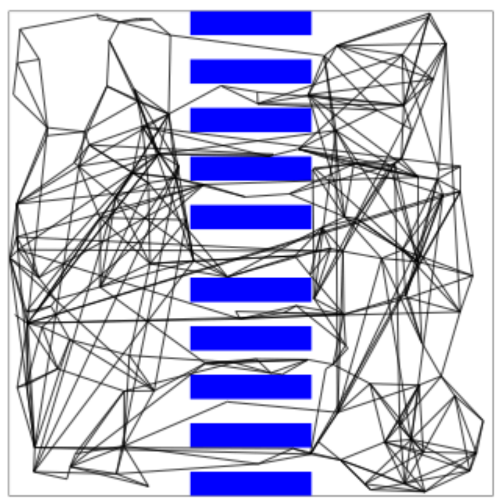
Asymptotic Near-Optimality & Graph Spanners

- A *t*-spanner is a sparse subgraph
- For every shortest path in the original graph
  – There is a path in the spanner that is no longer than *t* times the original length





(a) Roadmap with 2346 edges



(b) Spanner with 470 edges

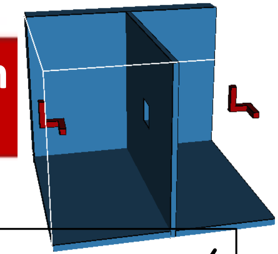
Giving rise to a sequential approach:

- Compute k-PRM*
- Return its spanner

[Marble, Bekris IROS '11]
[Based on the graph spanner approach by Baswana, Sen '07]

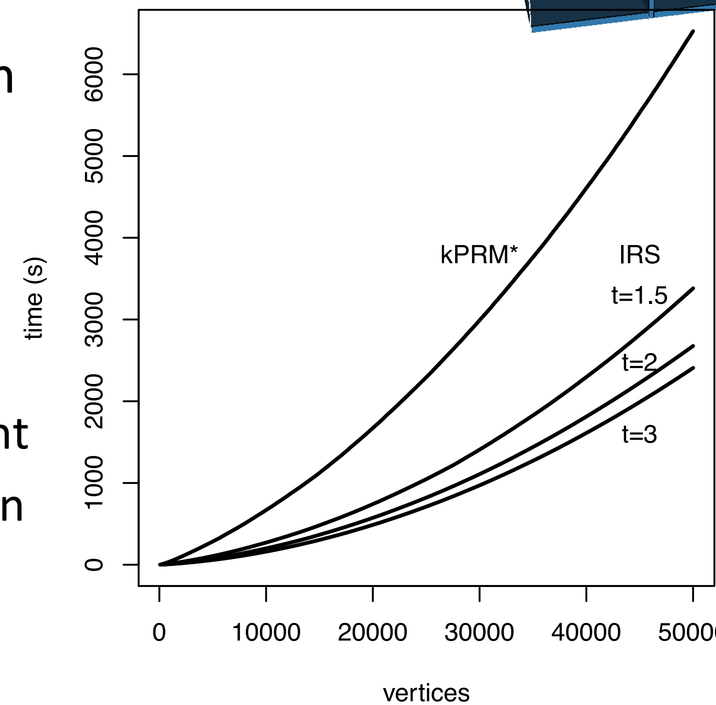
Incremental Roadmap Spanner

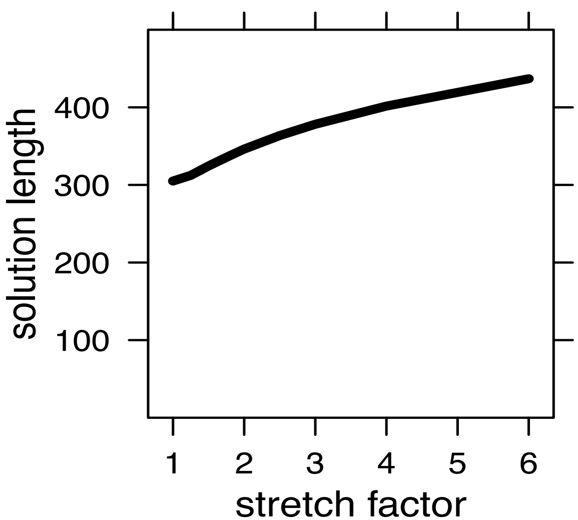
Results on OMPL

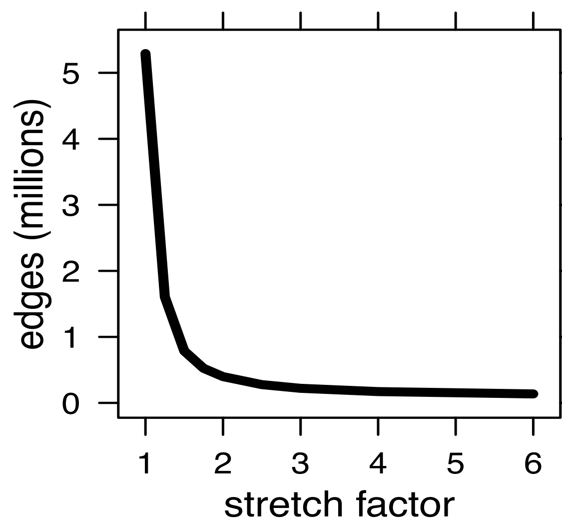


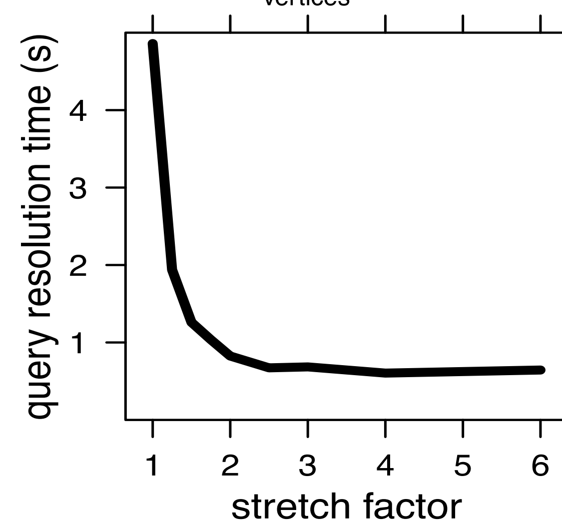
- Start with the asymptotically optimal k-PRM*
- Interleave an incremental spanner algorithm
- Result: An asymptotically *near*-optimal planner
  - Smaller average increase in path length than the stretch factor
  - Sparse roadmap with smaller memory footprint
  - Faster construction and online query resolution

[Marble, Bekris ISRR '11,
IEEE Transactions on Robotics '13]







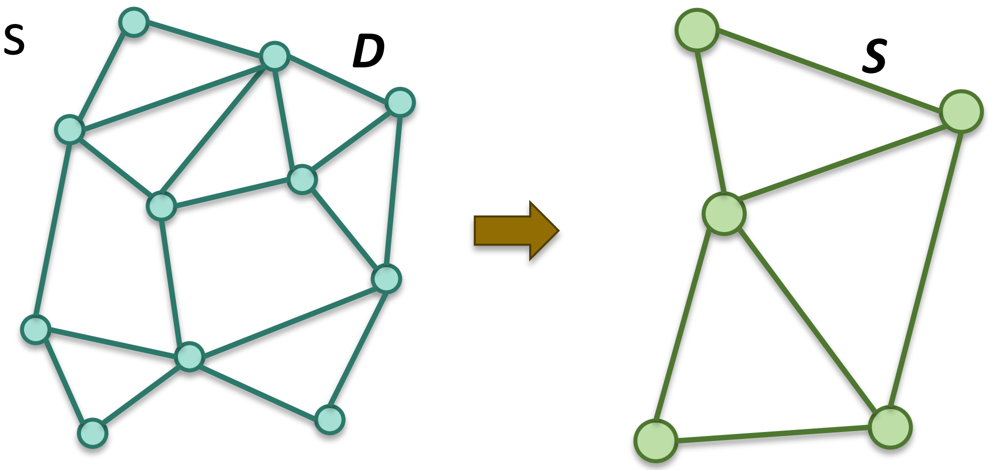


Sparse Roadmap Spanner (SPARS)

- Up to this point: Solutions add all samples in the roadmap
- Idea: Asymptotic Near-Optimality with Additive Cost

[Dobson, Krontiris, Bekris WAFR '12, IJRR '13 (accepted)]

- Consider two graphs in parallel:



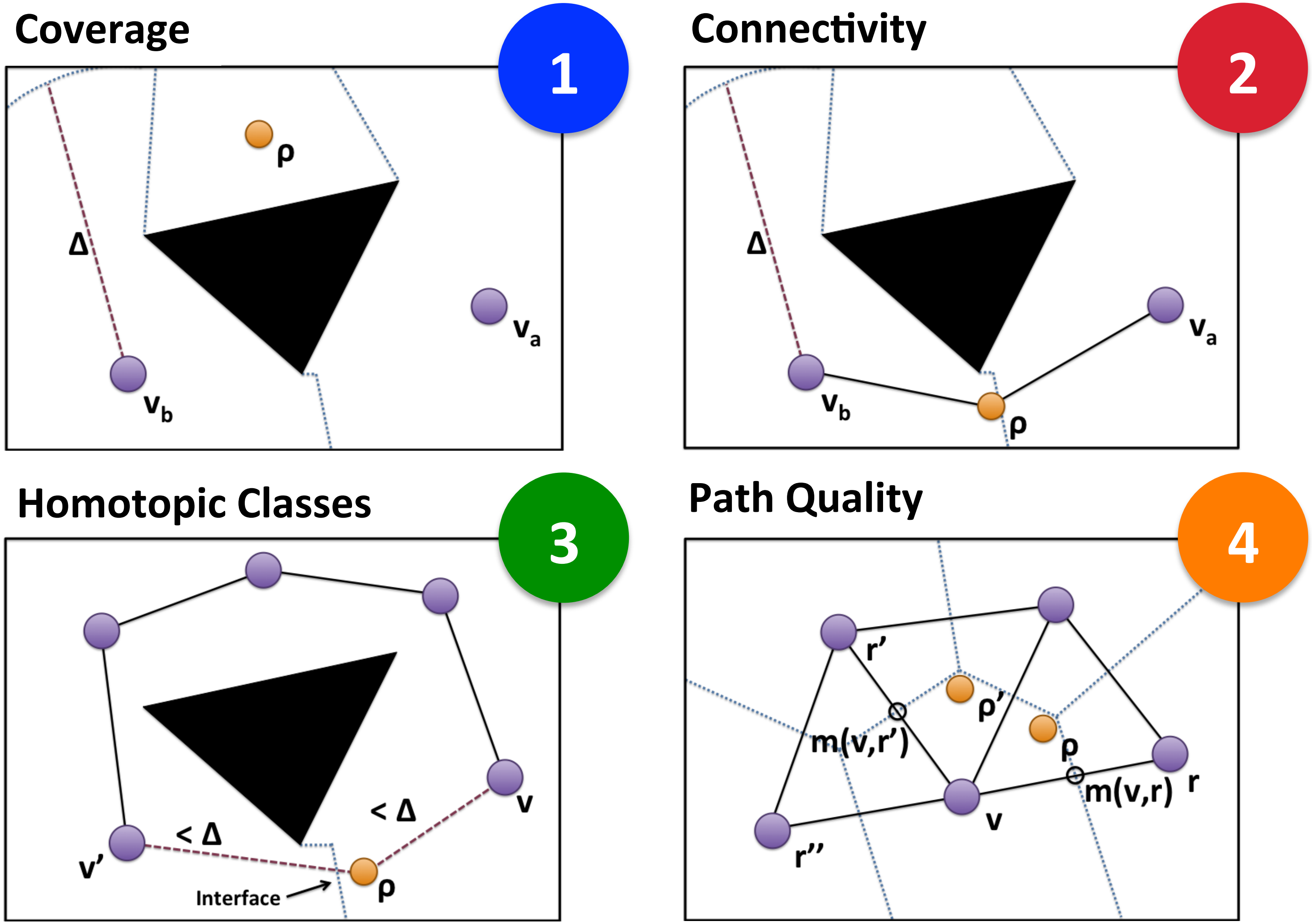
Dense Graph:
– Asymptotically Optimal (δ-PRM*)

Roadmap Spanner:
– Asympt. Near-Optimal
– Not all nodes added (!)

- When should samples be added to *S*?
  – If necessary for coverage, connectivity, optimality
- When should the sampling stop?
  – Criterion: After M consecutive failures to add a node

Similar objectives in recent work by Salzman, Agarwal, Halperin, Shaharabani ICRA '13

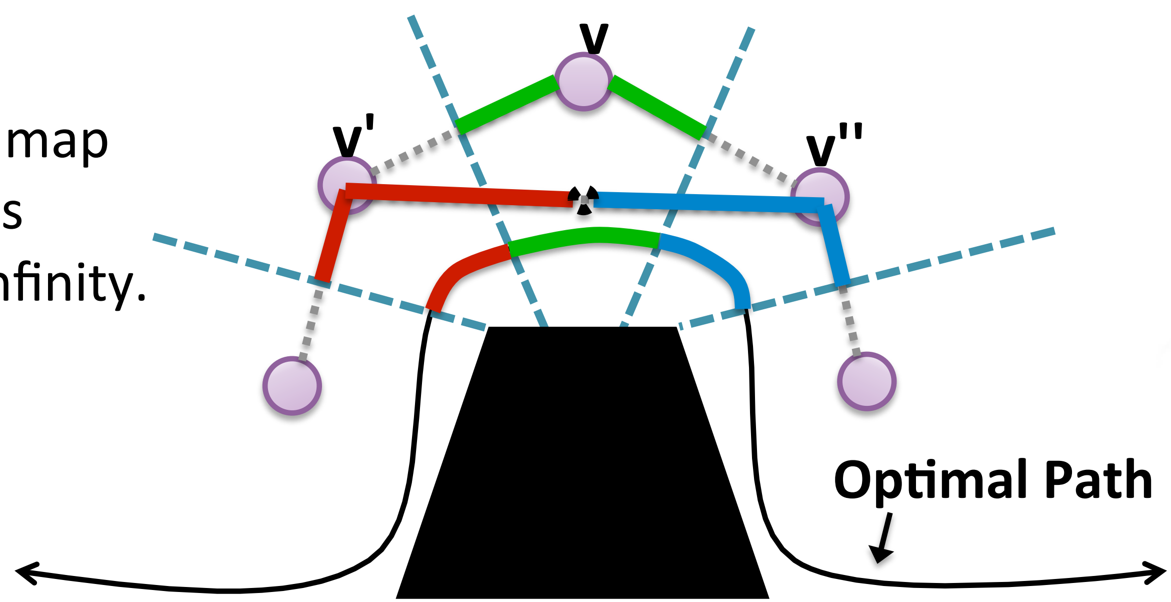
SPARS: Node Selection



Can be achieved even without storing the dense graph [Dobson, Bekris ICRA'13]

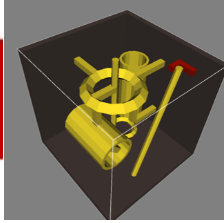
Properties of SPARS methods

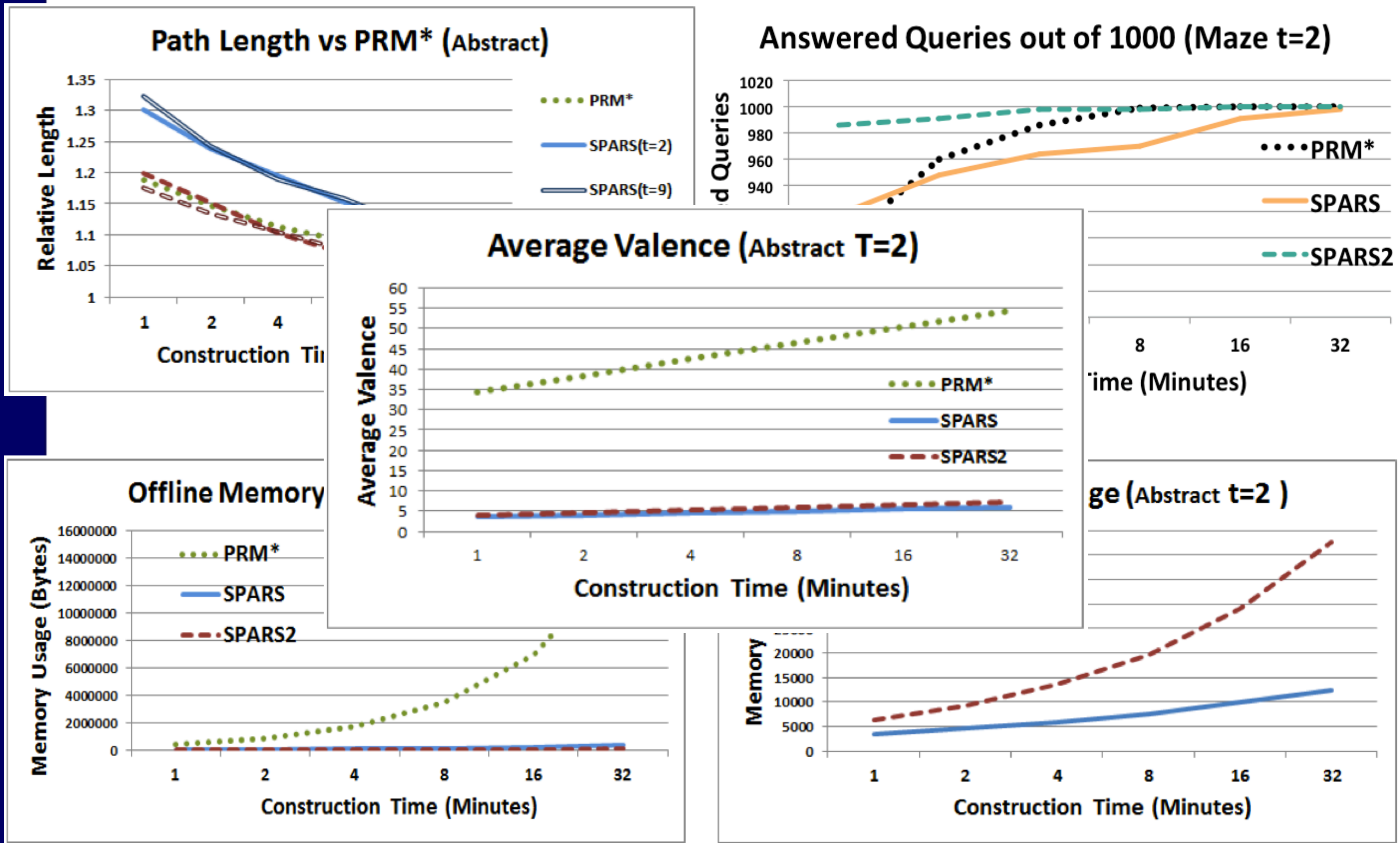
- Achieves **probabilistic completeness** through coverage and connectivity criteria, as visibility-based PRM.
- With probability approaching 1 as consecutive failures, M, goes to infinity, SPARS2 will **cover all arbitrary optimal paths**.
- Paths in the Roadmap Spanner have **length bounded** by an input stretch factor, *t*, with probability approaching 1.
- SPARS2 grows the roadmap **with probability zero** as iterations increase to infinity.



Evaluation

Abstract environment in the
Open Motion Planning Library:





Conclusion/Future Work

www.pracsyslab.org

<u>Roadmap spanners are practical solutions with desirable properties for high-dim motion planning</u>

- Available in the next release of OMPL
- Work in progress:
  - Show manipulation solutions using MoveIt
  - Study roadmaps with directed edges
  - Finite time properties of sampling-based planners

Thank you!

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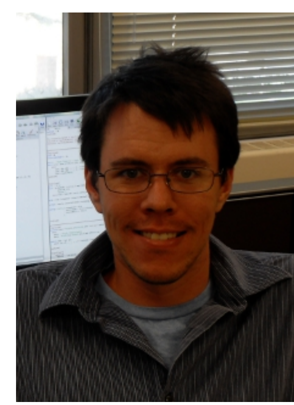
- NSF CNS 0932423

Andrew Dobson



James Marble