Path Planning

15-494 Cognitive Robotics
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Outline

- Path planning as state space search

- RRTs: Rapidly-exploring Random Trees

- The RRT-Connect algorithm

- Collision detection

- Smoothing

- Path planning with constraints

- Path planning in Tekkotsu

Path Planning in Robotics

1. Navigation path planning

- How to get from the robot's current location to a goal.

- Avoid obstacles.

- Provide for localization.

2. Manipulation path planning

- Move an arm to grasp and manipulate an object.

- Avoid obstacles.

- Obey constraints (e.g., don't spill the coffee).

Navigation Planning

- 2D state space: (x,y) coordinates of the robot

    – Treat the robot as a point or a circle.

Obstacle inflation
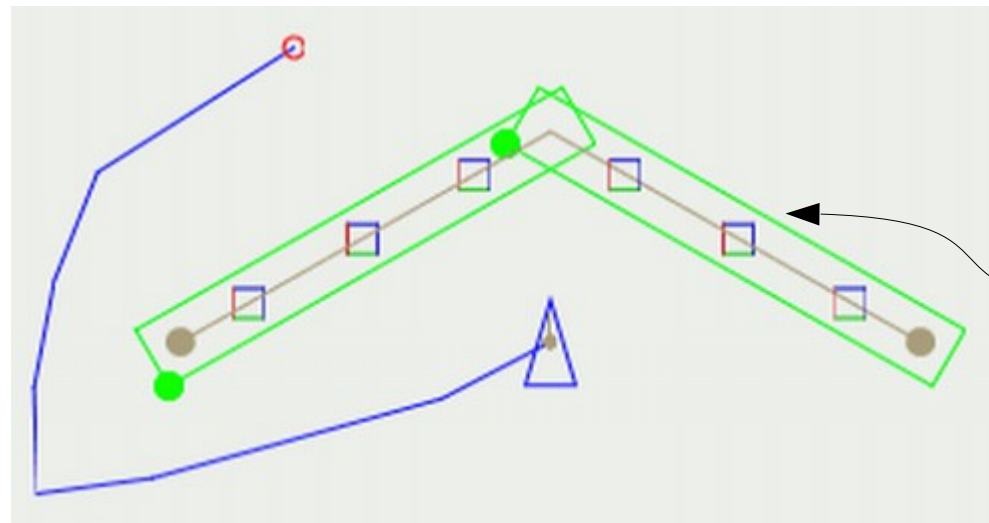
- 3D state space: (x,y,θ) pose of the robot

    – Heading matters when the robot is asymmetric

    – Heading matters when the robot's motion is constrained

Cspace Transform

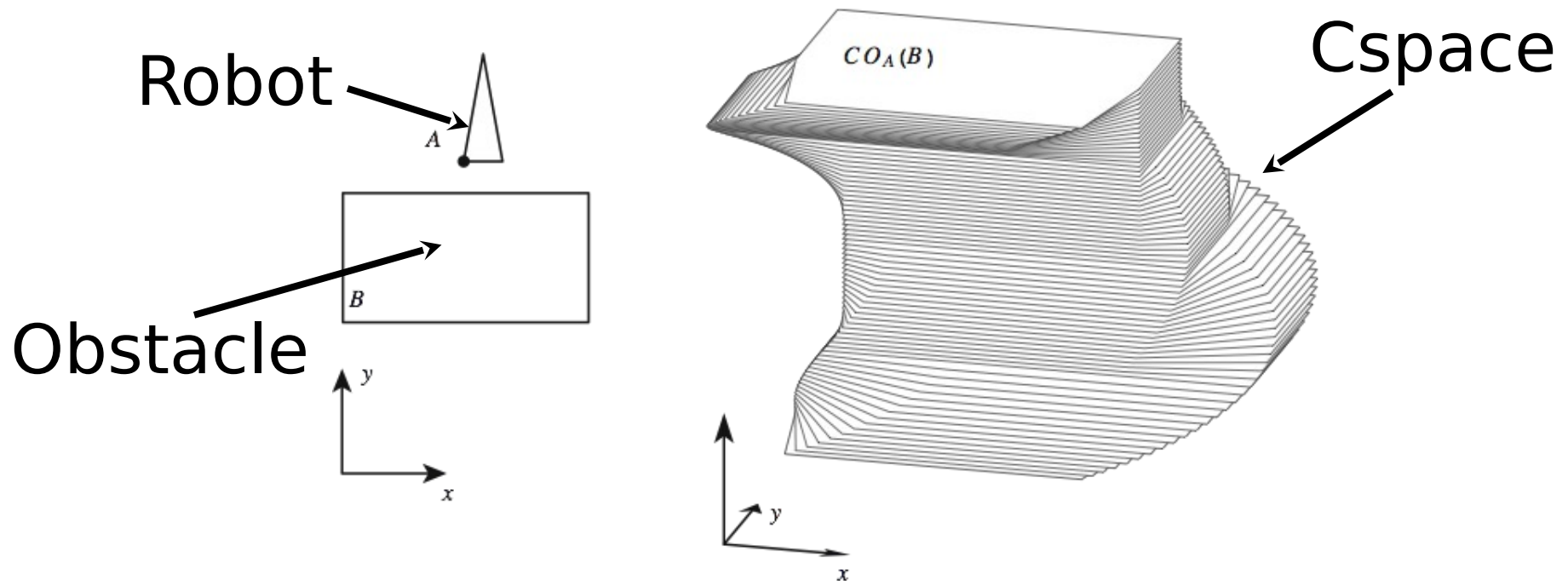- The area around an obstacle that would cause a collision with the robot.

Robot

Cspace

Obstacle

$CO_A(B)$

Figure 4.4 - Mason, Mechanics Of Robotic Manipulation

Arm Path Planning

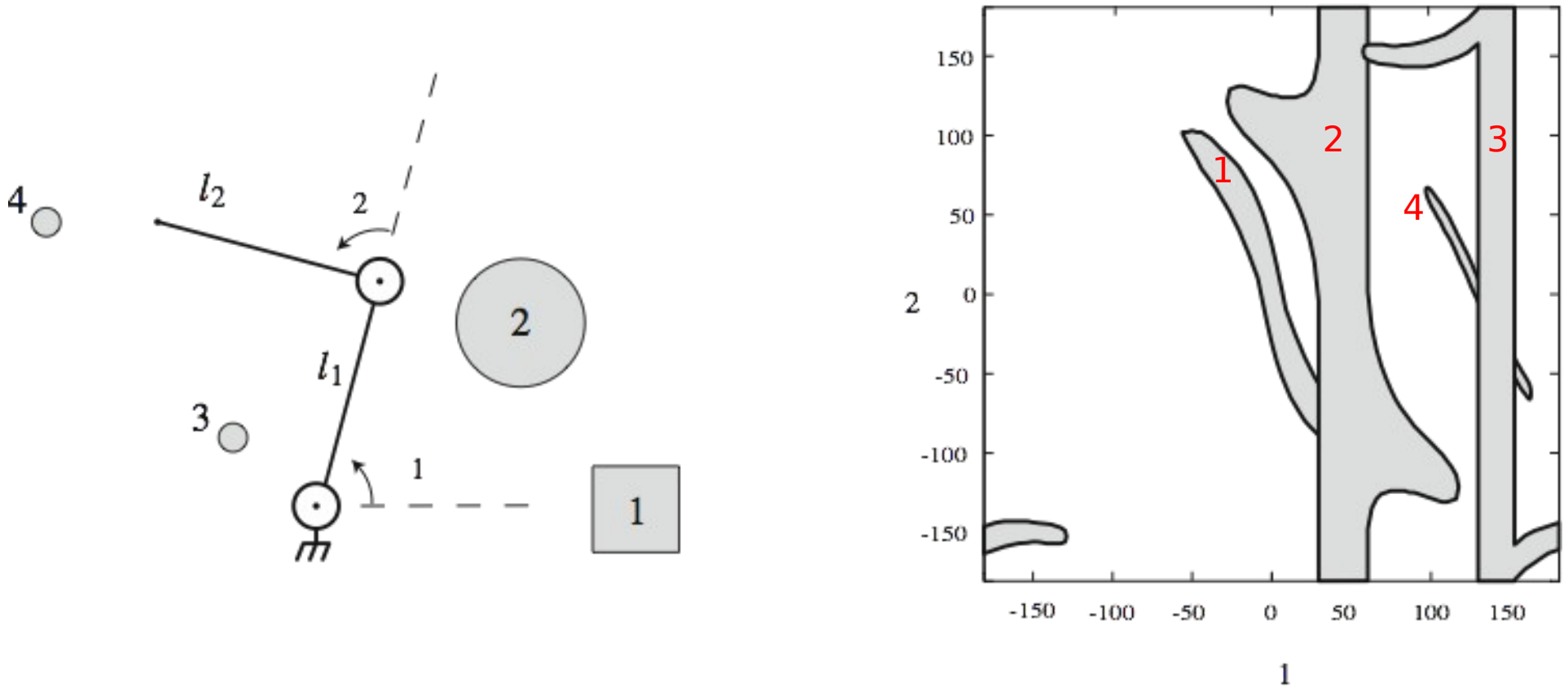- Cspace transform blocks out regions of joint space

Figure 4.5 - Mason, Mechanics Of Robotic Manipulation

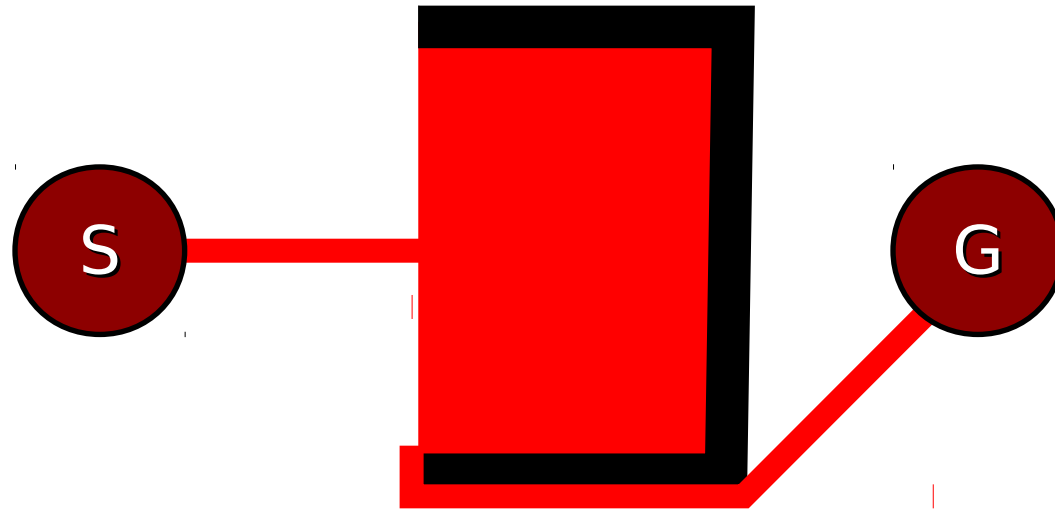# State Space Search

The path planning problem:

Given an n-dimensional state space and

- a start state $S=[s_1,s_2,...,s_n]$

- a goal state $G=[g_1,g_2,...,g_n]$

- an admissibility predicate P (collision test + constraints)

find a path from S to G such that every state on the path satisfies P.

Best First Search

- Can get trapped in a cul de sac for a long time.


- Random search might be faster.

Rapidly-exploring Random Trees

- Described in LaValle (1998), Kuffner & LaValle (2000)

- Create a tree with start state S as the root.

- Repeat up to K times:
  - Pick a point **q** in configuration space:
    - Sometimes **q** should be a random point
    - Sometimes **q** should be the goal state G
  - Find **n**, the closest tree node to **q**
  - Add a new node **n'** some distance Δ toward **q**; make it a child of **n**
 - If **n'** is close enough to the goal state G, return.

RRT Algorithm

- Rapidly samples the state space.

- Cannot get trapped in local minima.

- Works well in high-dimensional spaces.

- Does not generate smooth paths.

- Can't tell when no solution exists; only quits when it exceeds the iteration limit K.

http://msl.cs.uiuc.edu/rrt/treemovie.gif
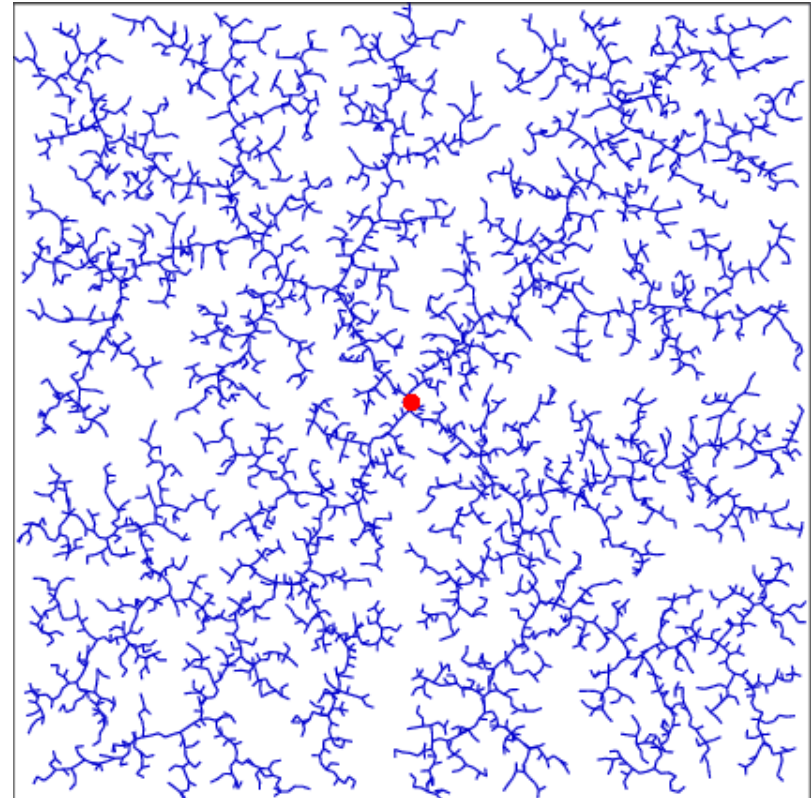
RRTs for Arm Path Planning

- Each node encodes an arm configuration in joint space.

- Only add nodes that don't cause collisions (with self or obstacles).

- Alternately (i) extend the tree in random directions and (ii) move toward the goal.

Start configuration
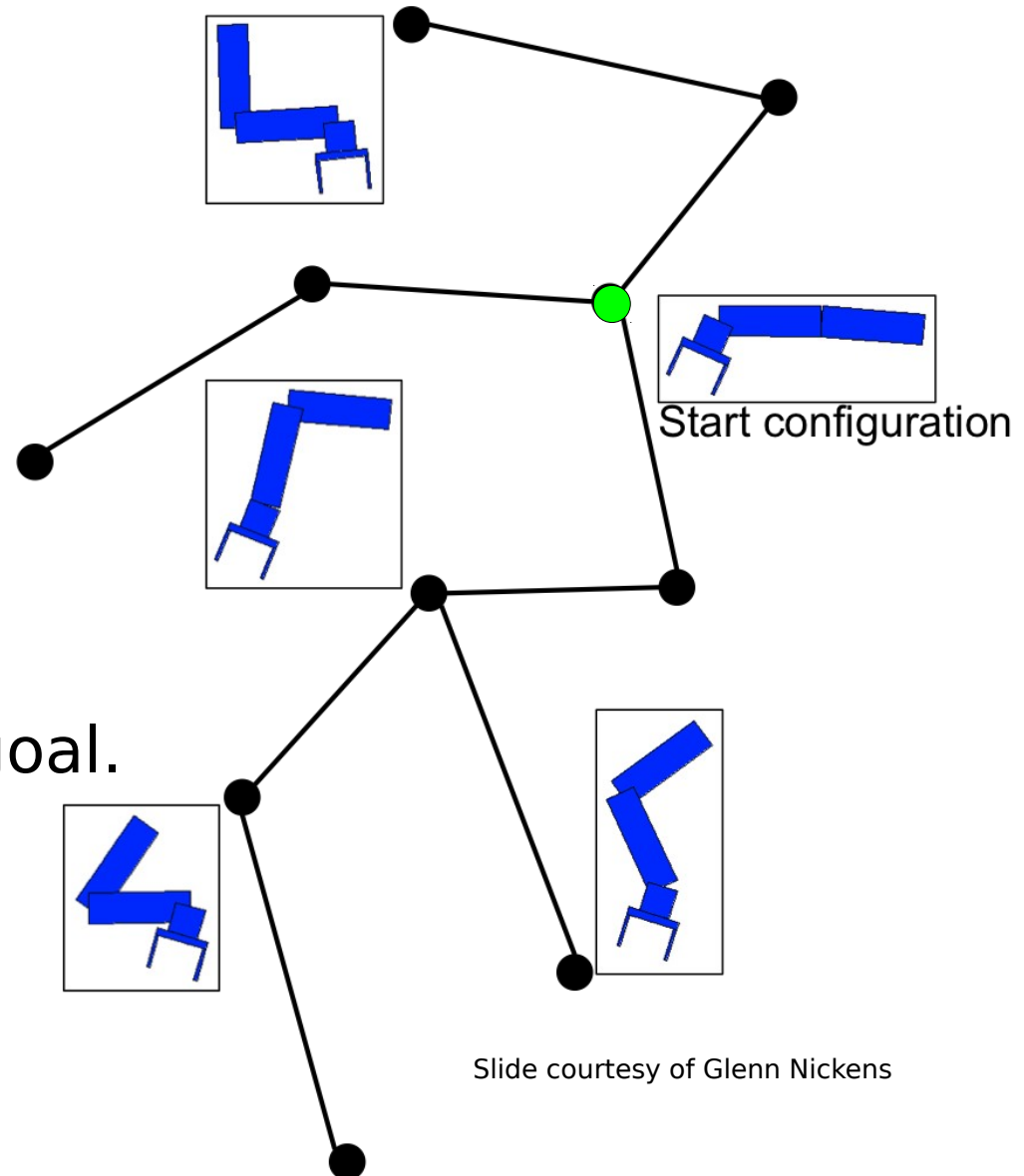
Slide courtesy of Glenn Nickens

Implementation Notes

- Finding **n**, the nearest node in the tree to **q**, is the most expensive part of the algorithm.

    - Use K-D trees to efficiently find **n**?

    - In practice, K-D trees are slower unless you have a huge number of nodes (several thousand).

- Why only go a distance Δ toward the goal state G? Why not go as far as we can, in steps of Δ?

    - With no obstacles, this reaches the goal very quickly, but random search will get there nearly as quickly as we keep extending the nearest node to the goal.

    - But when obstacles are present, this can waste time filling out branches that will ultimately fail.

    - Generating lots of extra nodes bloats the tree, which slows down the algorithm.
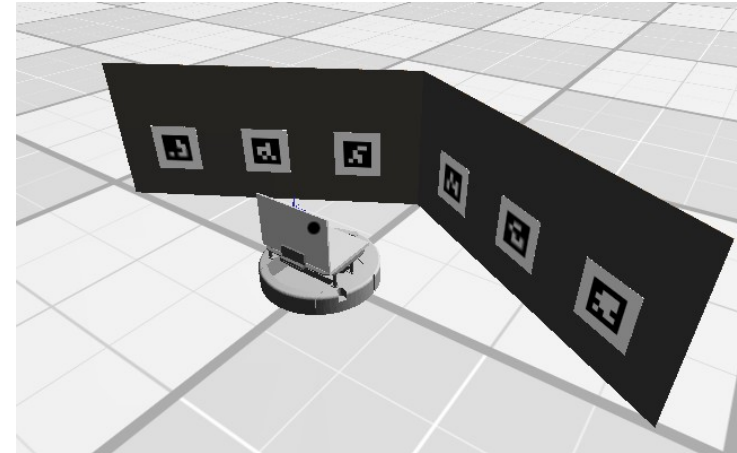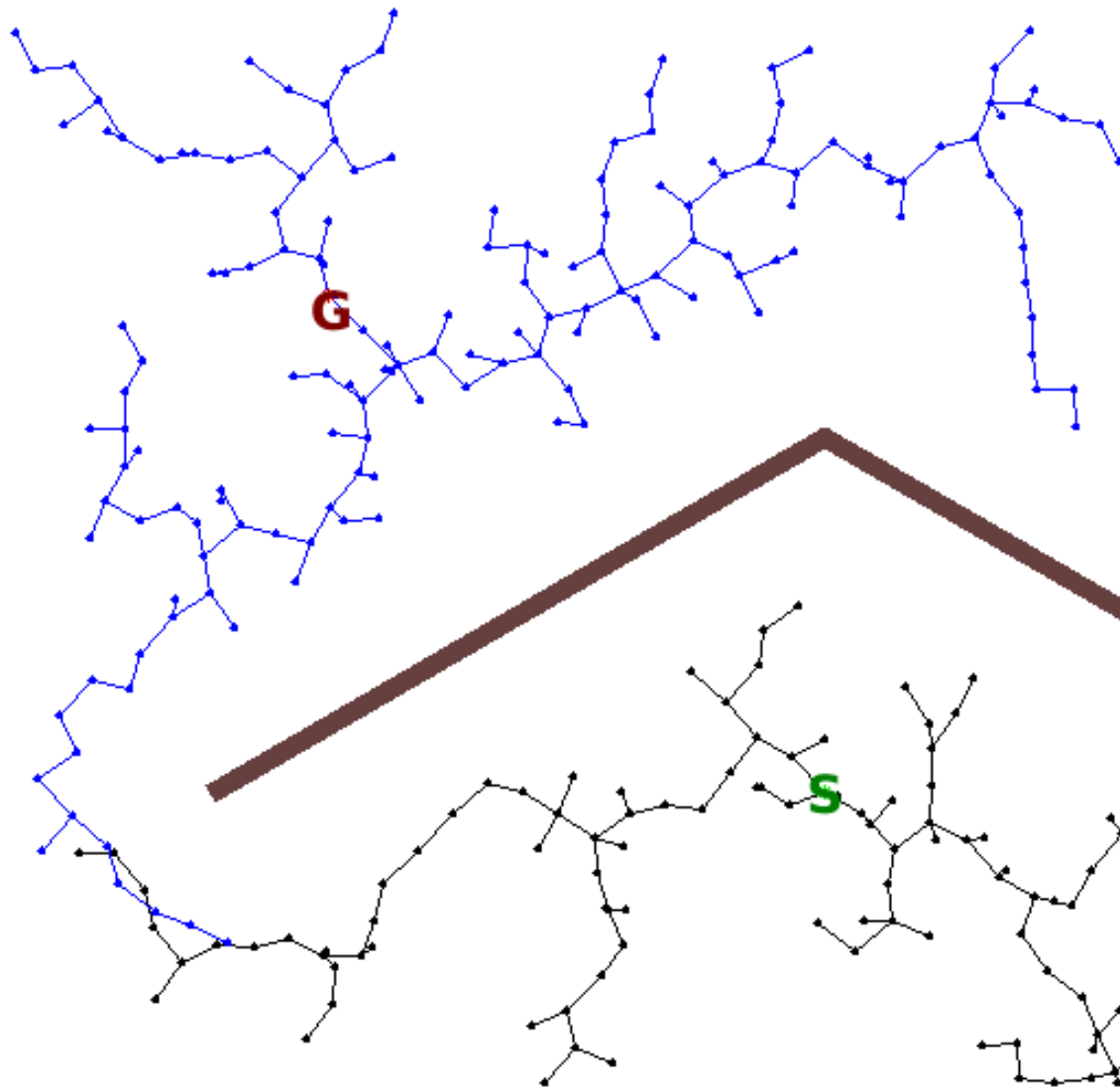
RRT-Connect Algorithm

- Variant of RRT that grows two trees:
  - one from the start state toward the goal
  - one from the goal state toward the start

- When the two trees connect, a solution has been found.

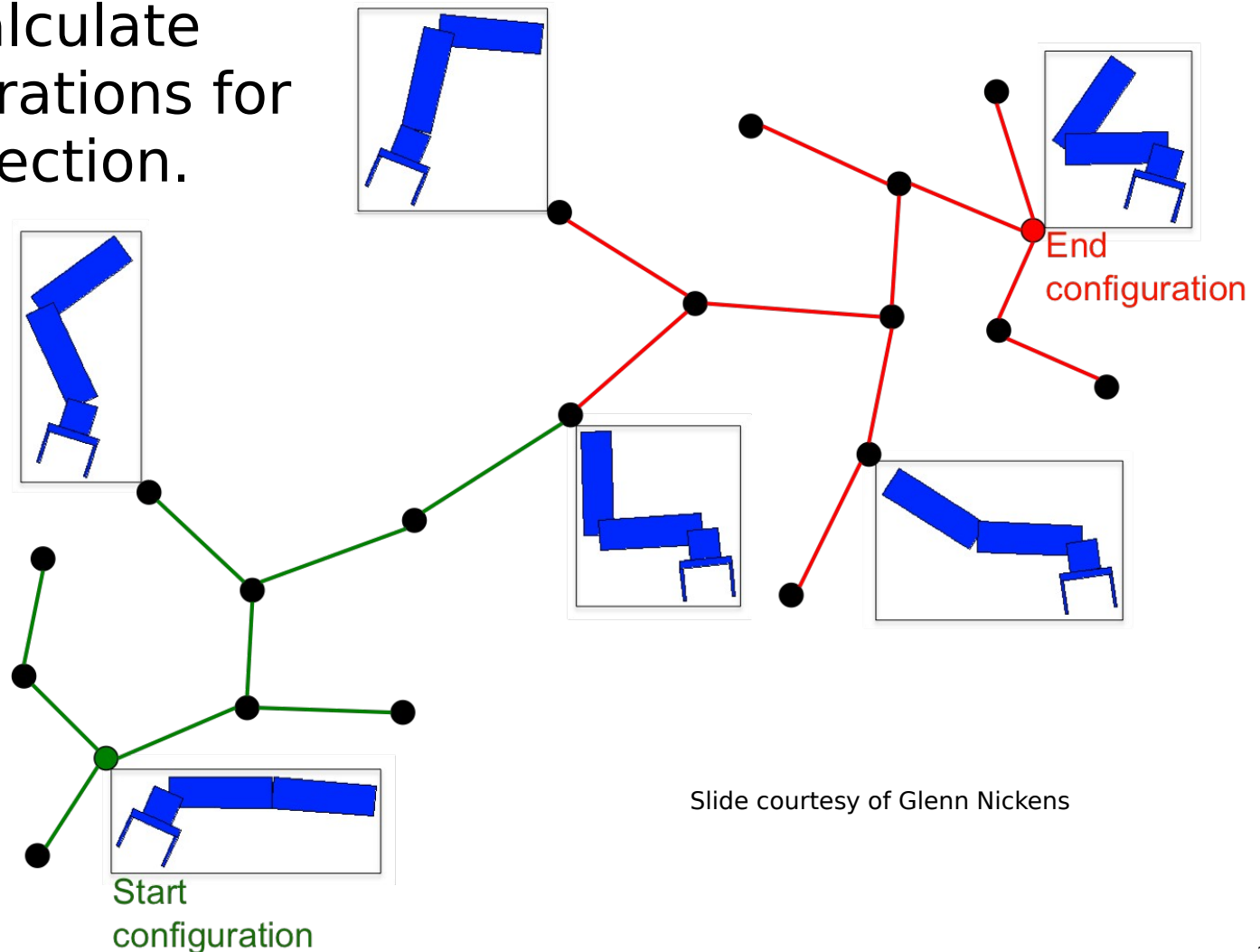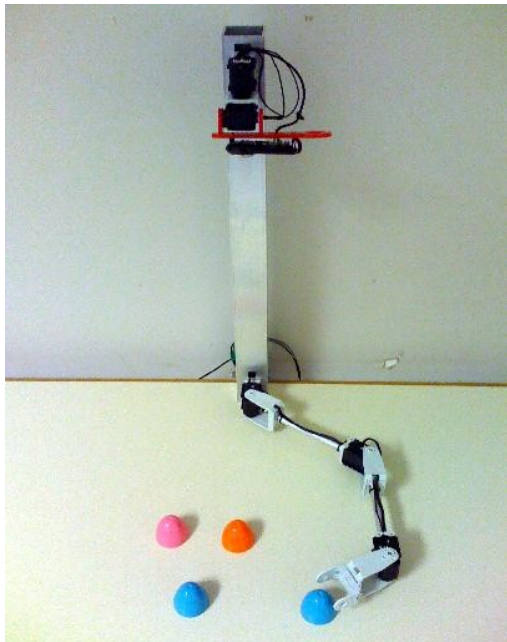- Not guaranteed to be better than RRT, but often helps.
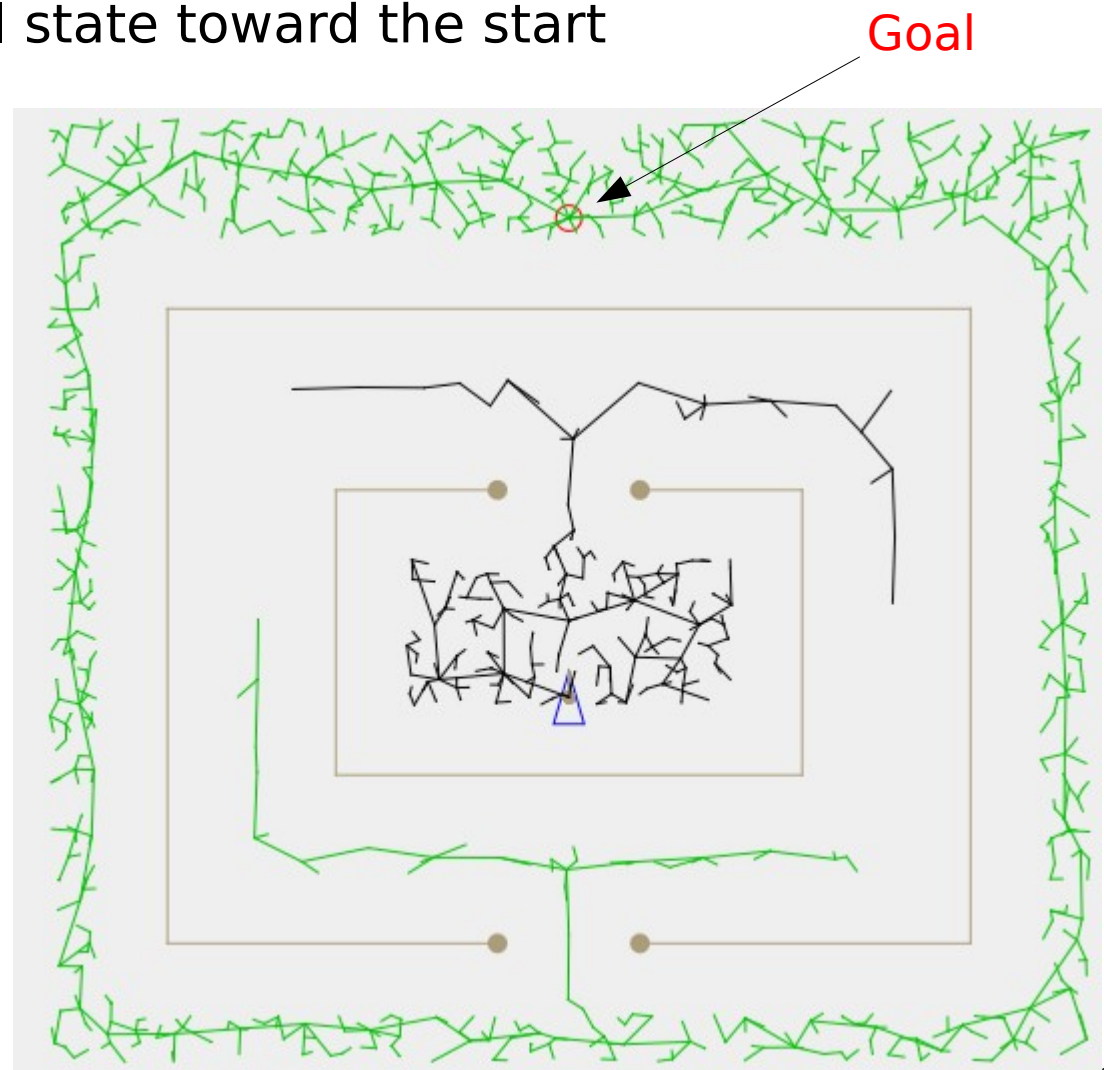
Goal

RRTs in the VeeTags World

G

S

RRT-Connect For Arms

- Use IK to calculate the goal configuration.

- Use FK to calculate arm configurations for collision detection.

End configuration

Slide courtesy of Glenn Nickens

Start configuration

Collision Detection

- Represent the robot and the obstacles as **convex polygons**.

- In 2D, use the Separating Axis Theorem to check for collisions.

    - Easy to code

    - Fast to compute

- In 3D, things get more complex.

    - Tekkotsu uses the GJK (Gilbert-Johnson-Keerthi) algorithm, used in many physics engines for video games.
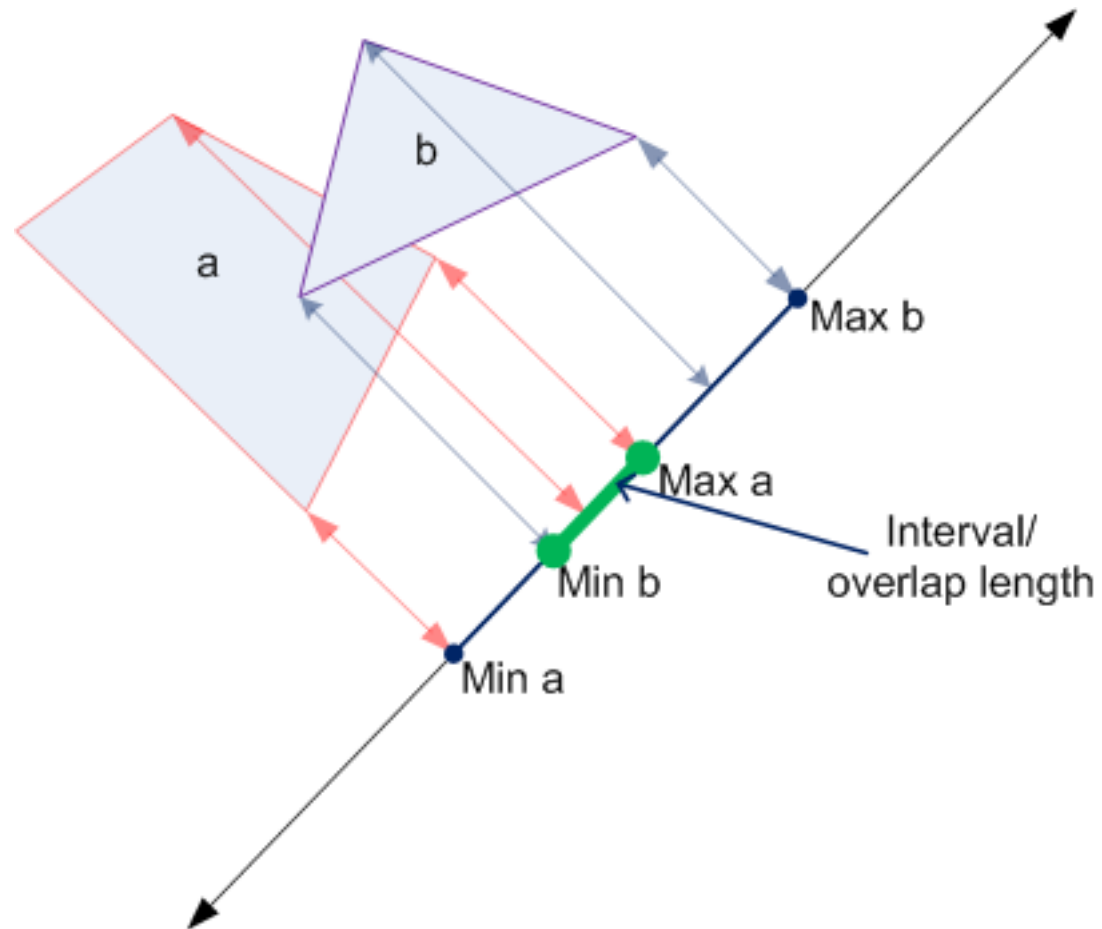
Separating Axis Theorem
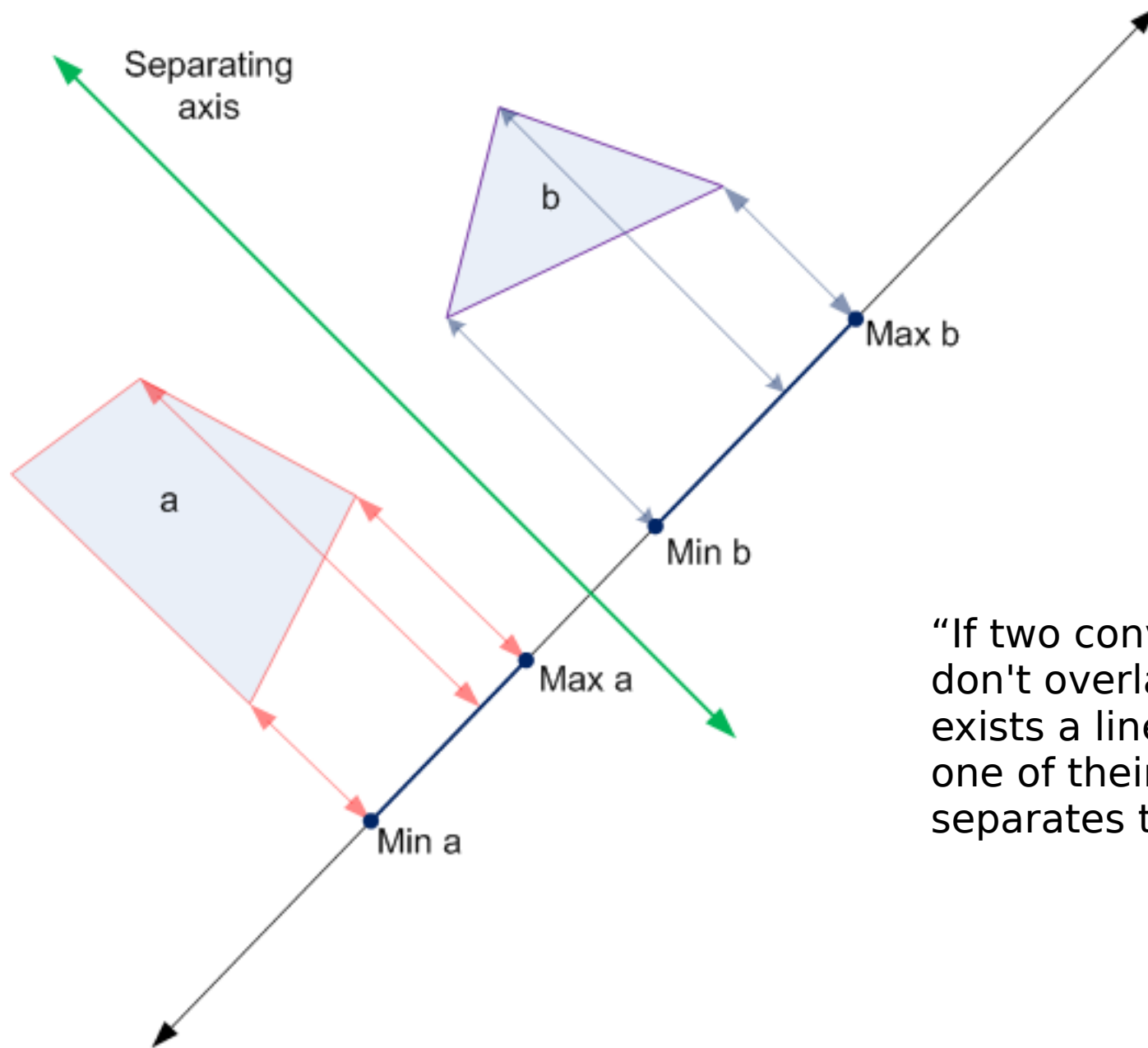
"If two convex polygons don't overlap, then there exists a line, parallel to one of their edges that separates them."

Separating Axis Theorem

Algorithm to Apply the SAT

- For every edge of polygon A and of polygon B:

  - Project all the vertices onto the line normal to that edge.

  - Calculate the min and max coordinates for each polygon

  - If minA < minB and maxA > minB OR
    if minB < minA and maxB > minA
    then the polygons collide.

- If you find any edge projection in which the ranges don't overlap, the polygons do not collide.

Arm Collision Detection

- Represent each link as a separate polygon.

- Check for:

    - Self-collisions other than link *n* with link *n+1*

   - Collisions of a link with an obstacle
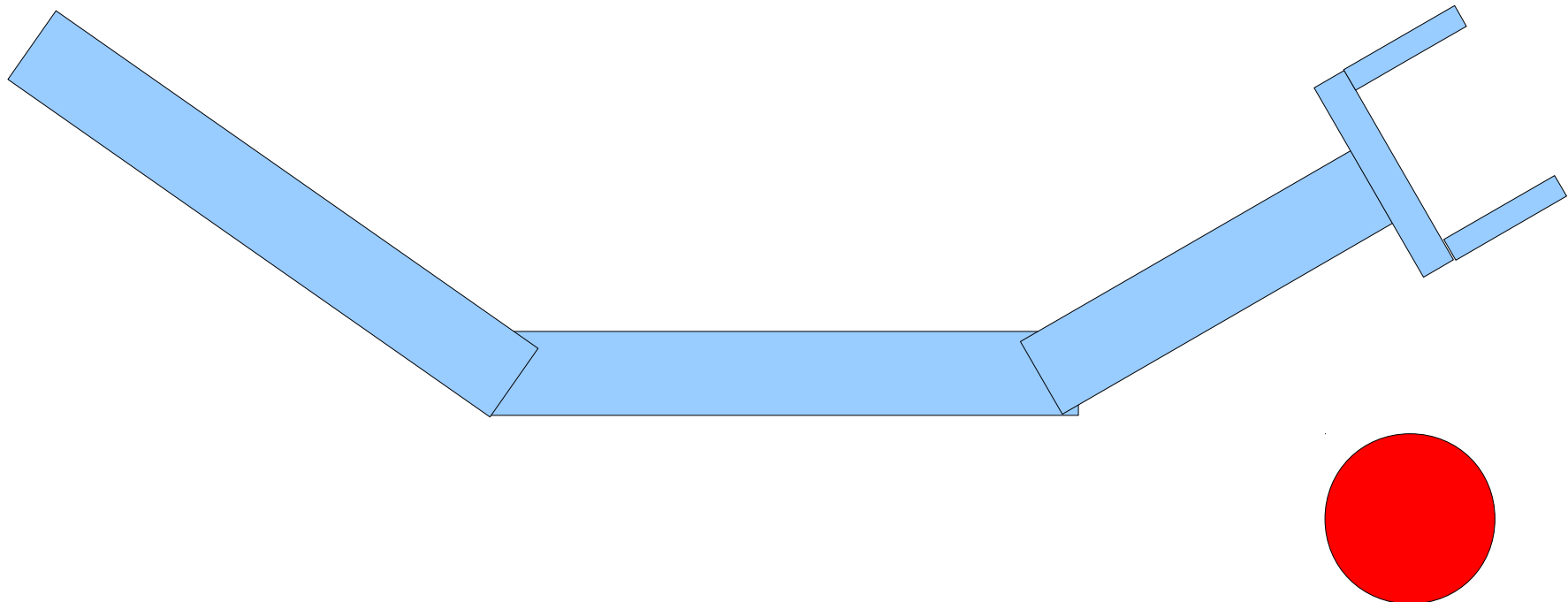
Path Smoothing

- The random component of RRT-Connect search often results in a jerky and meandering solution.

- Solution: apply a path smoothing algorithm.

- Repeat N times:

  – Pick two points on the path at random

  – See if we can linearly interpolate between those points without collisions.

  – If so, then snip out that segment of the path.
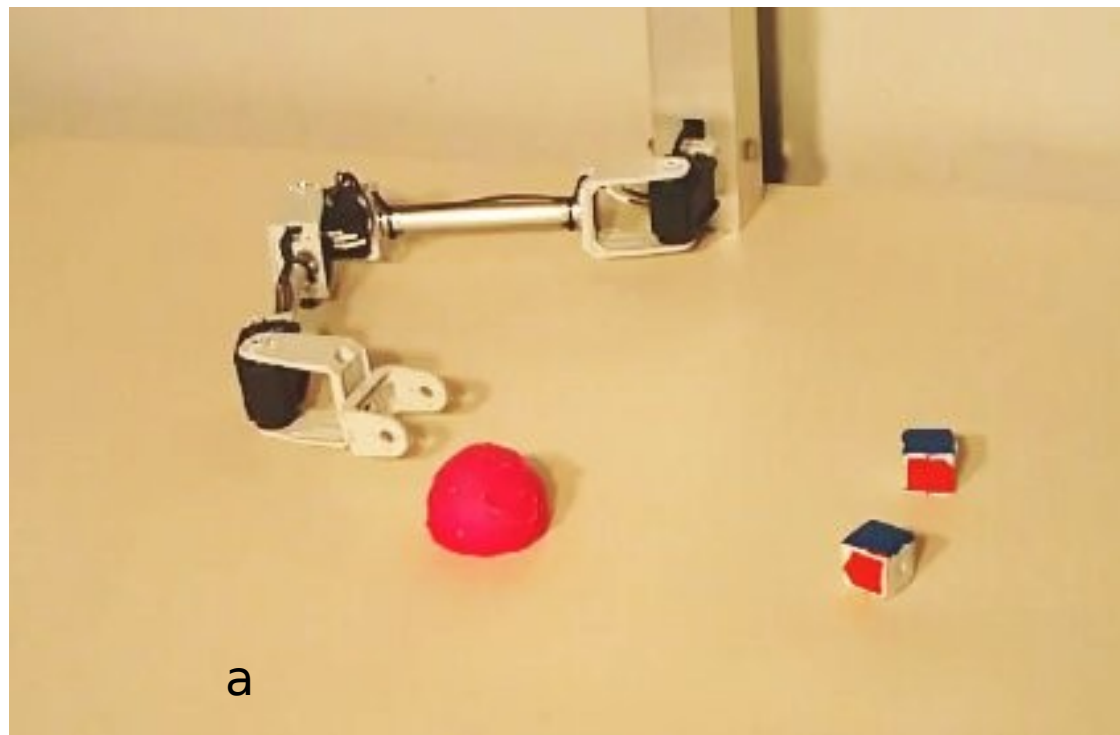
Smoothing An Arm Trajectory

- **Start state**
- **Intermed. states**
- **End state**

Original

Smoothed version
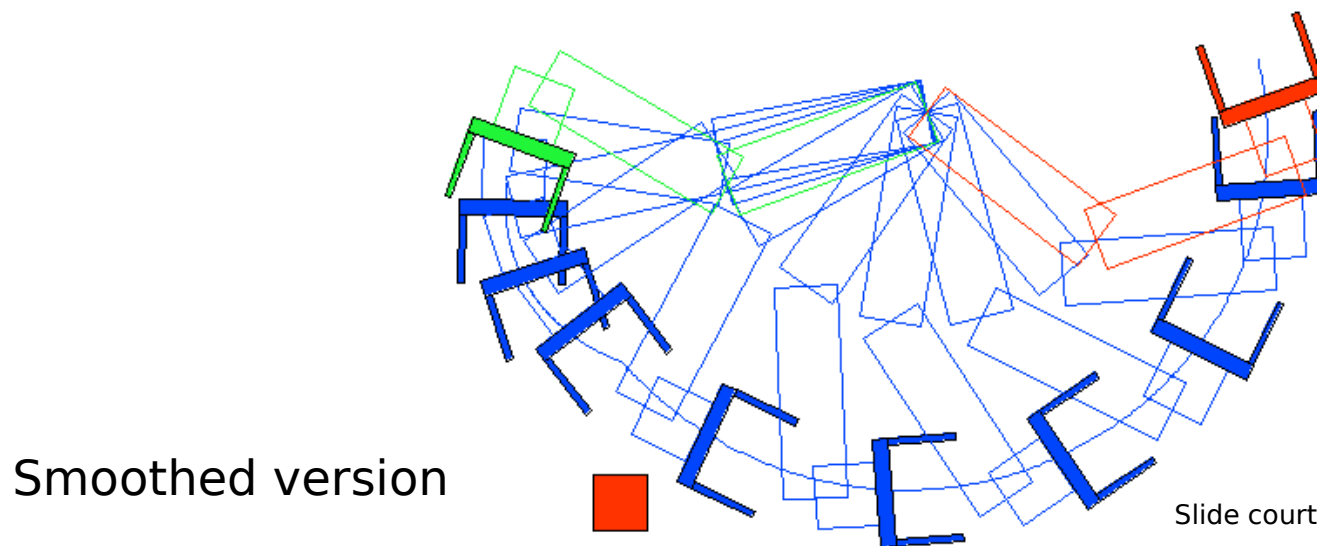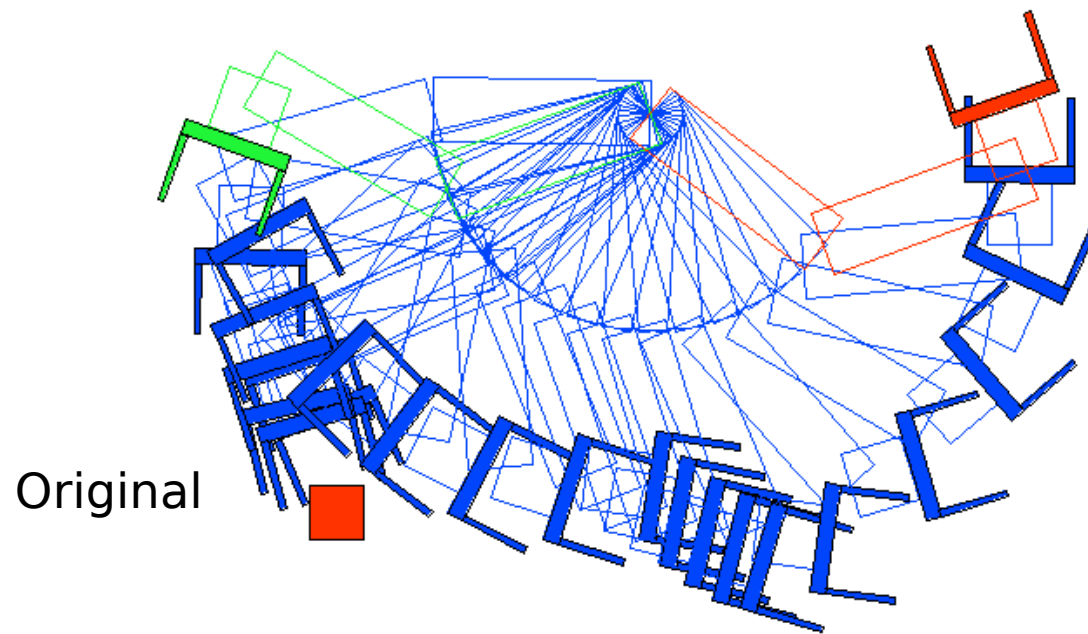
Slide courtesy of Glenn Nickens

Path Planning With Constraints

- With no closeable fingers, arm motion is constrained to be within about 60º of finger direction or we'll lose the object.

a

(video)

http://www.youtube.com/watch?v=9oDQ754YVoc

Implementing Constraints

- Each time we generate a new state **n'**:

  - Check to see if **n'** obeys the constraint

  - For finger motion constraint, check if the direction of motion from parent state **n** to new state **n'** is within 60° of the finger direction.

- What if **n'** doesn't obey the constraint?

  - Reject it and generate a new random **q**.

 - Or try to "fix" it by perturbing its value slightly so as to satisfy the constraint.

RRTs in Tekkotsu

- Tekkotsu/Planners/RRT/GenericRRT.h
- Works for any state space

- class RRTNodeBase
    - Subclass this to create a NodeValue_t to describe **q**
    - Define a CollisionChecker class

- class GenericRRT<typename NODE, size_t N>
    - Instantiate this template to create an RRT planner
    - NODE must be a subclass of RRTNodeBase
    - Define an AdmissibilityPredicate class
    - Define the extend(…) method to extend the tree

Planners in Tekkotsu

- Navigation/ShapeSpacePlannerXY
  - 2D navigation planner

- Navigation/ShapeSpacePlannerXYTheta
  - 2D + heading navigation planner

- Manipulation/ShapeSpacePlanner2DR
  - 2D planner for N-joint planar arm with revolute joints

- Manipulation/ShapeSpacePlanner3DR
  - 3D planner for N-joint planar arm with revolute joints

Path Planning Failure:
Goal State Is In Collision
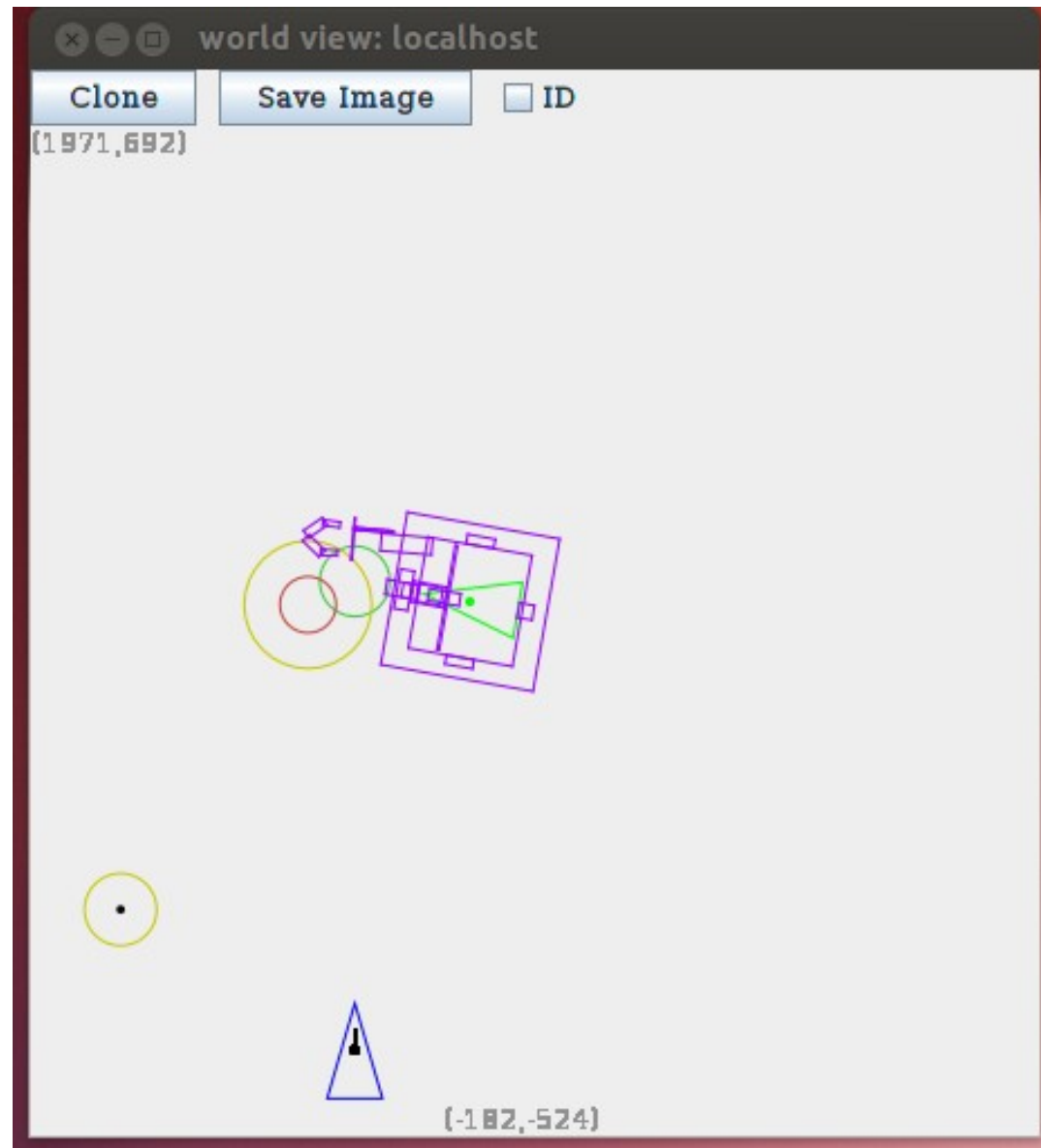
The Grasper

- Does arm path planning
  - Initially developed for planar arms
  - Now does 3D arm path planning for Calliope5KP

- Does manipulation planning
  - How to grasp an object
  - How to move an object without losing it
  - How to release an object

- Many other manipulation operations are possible.

- Use a GrasperNode to submit a GrasperRequest.