EECS 367 & ROB 320 Lab KinEval RRT Stencil and AABB Collision Detection

Michigan EECS 367 Introduction to Autonomous Robotics | ROB 320 Robot Operating Systems



Administrative

- Hand grading for assignments 3 and 4
 - Will be pushed to grade is tomorrow
- Lab section Friday, April 1
 - Connect to Fetch via rosbridge (optional)
 - In robotics building

Assignment 6 Overview

4

6

2

- Assignment 6: Motion Planning
- **Collision detection**
- 2D RRT-Connect
- **Configuration space RRT-Connect**

Assignment 7 Overview

Assignment 7: The best use of robotics?

Slides due 11:59pm, Friday, April 8, 2022 Presentation due 1:30pm, Monday, April 11, 2022

Scenario: An investor is considering giving you 20 million dollars (cold hard USD cash, figuratively). This investor has been impressed by your work with KinEval and other accomplishments while at the University of Michigan. They are convinced you have the technical ability to make a compelling robot technology... but, they are unsure how this technology could produce something useful. Your task is to make a convincing pitch for a robotics project that would yield a high return on investment, as measured by some metric (financial profit, good for society, creation of new knowledge, etc.).

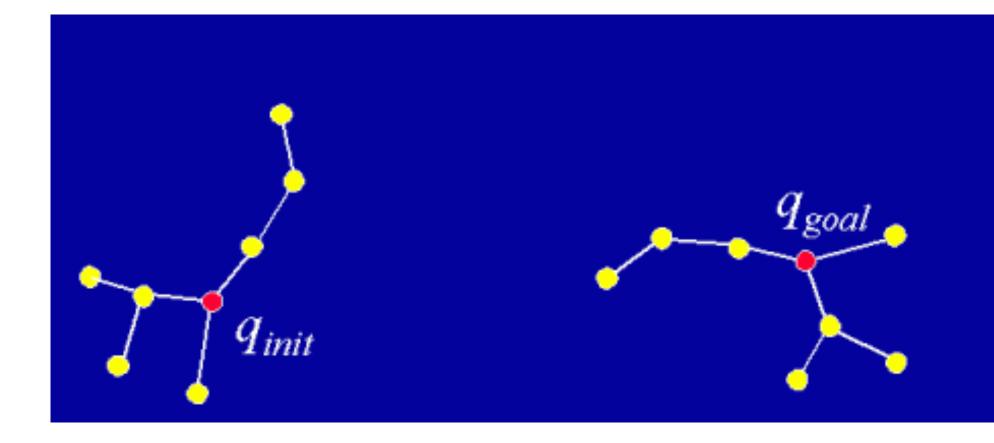
• Worth 12 points as an assignment

Lab Takeaways

- RRT connect review 1.
- 2. 2D RRT connect stencil
- 3. C-space RRT connect review
- 4. AABB collision detection
- \rightarrow How to implement all assignment 6 features

0) Use 2 trees (A and B) rooted at start and goal configurations

RRT_CONNECT_PLANNER(q_{init}, q_{goal}) $\mathcal{T}_a.\operatorname{init}(q_{init}); \mathcal{T}_b.\operatorname{init}(q_{goal});$ for k = 1 to K do 2 $q_{rand} \leftarrow \text{RANDOM_CONFIG}();$ 3 if not $(EXTEND(\mathcal{T}_a, q_{rand}) = Trapped)$ then 4 if (CONNECT(\mathcal{T}_b, q_{new}) = Reached) then 5Return PATH $(\mathcal{T}_a, \mathcal{T}_b)$; 6 $\mathrm{SWAP}(\mathcal{T}_a, \mathcal{T}_b);$ Return Failure

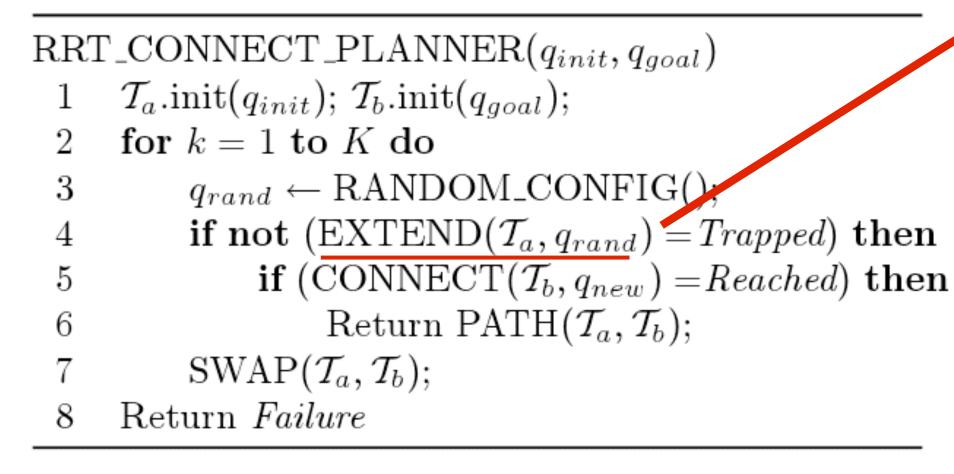


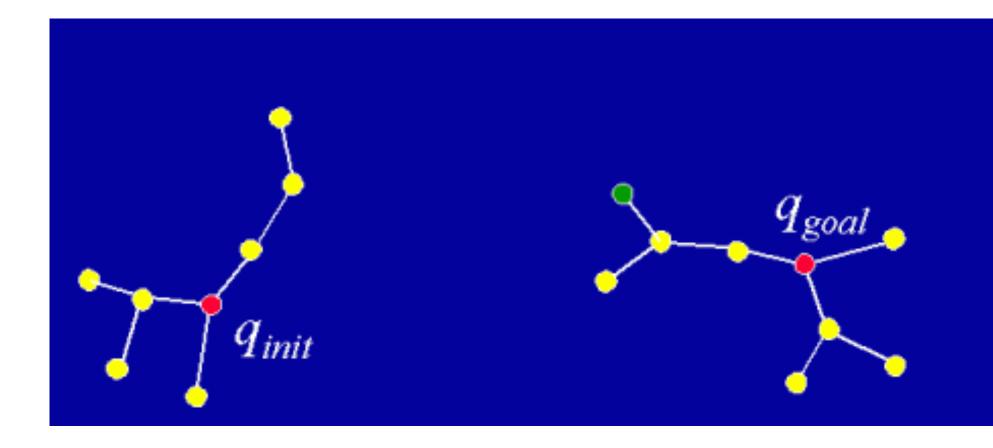
[Kuffner, LaValle 2000]

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0) Use 2 trees (A and B) rooted at start and goal configurations





[Kuffner, LaValle 2000]

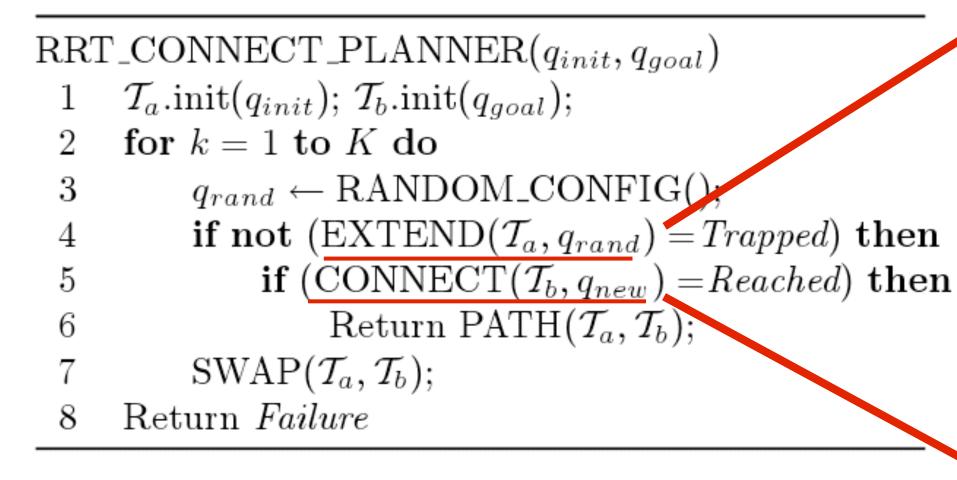
1	$q_{near} \leftarrow \text{NEAREST_NEIGHBOR}(q, T);$
2	if NEW_CONFIG(q, q _{near} , q _{new}) then
3	$T.add_vertex(q_{new});$
4	$T.add_edge(q_{near}, q_{new});$
5	if $q_{new} = q$ then
6	Return Reached;
7	else
8	Return Advanced;
9	Return Trapped;

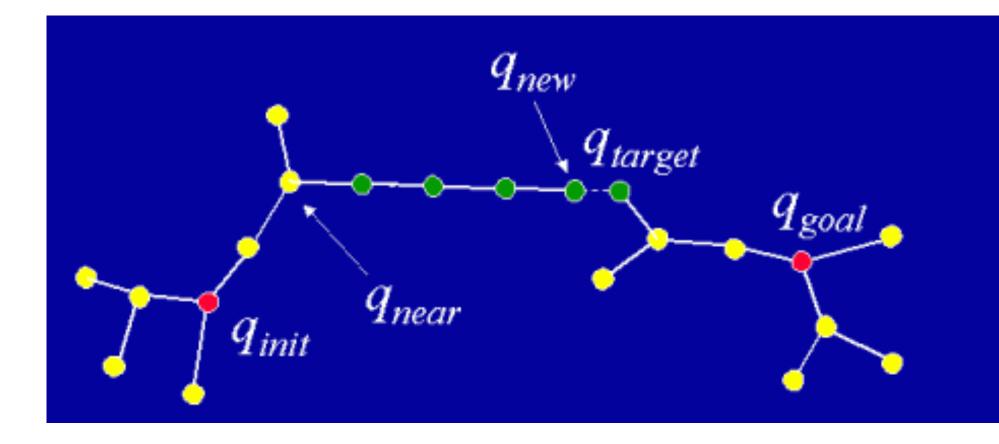
I) Extend tree A towards a random configuration

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0) Use 2 trees (A and B) rooted at start and goal configurations





[Kuffner, LaValle 2000]

EXT	$\Gamma END(T,q)$
1	$q_{near} \leftarrow \text{NEAREST_NEIGHBOR}(q, T);$
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;

configuration

CONNECT(\mathcal{T}, q)

repeat

2
$$S \leftarrow \text{EXTEND}(\mathcal{T}, q);$$

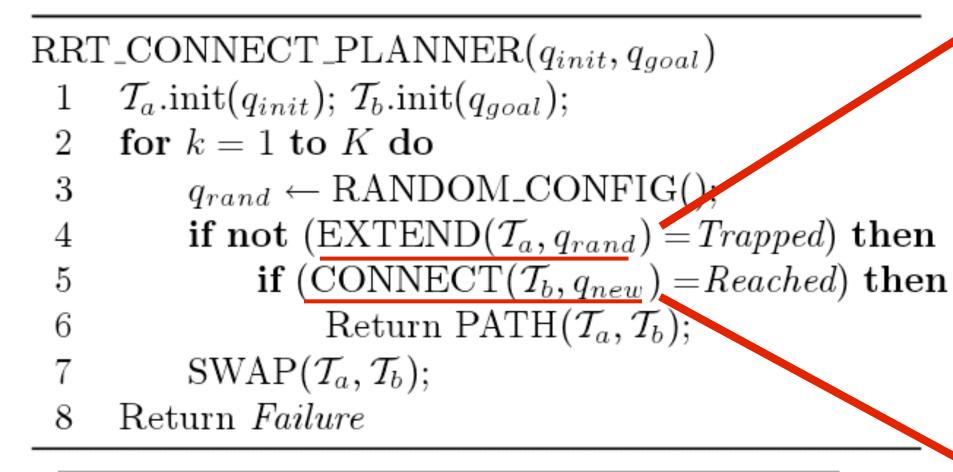
- until not (S = Advanced)3
- Return S; 4

2) Try to connect tree B to tree A by extending repeatedly from its nearest neighbor Michigan Robotics 367/320 - autorob.org

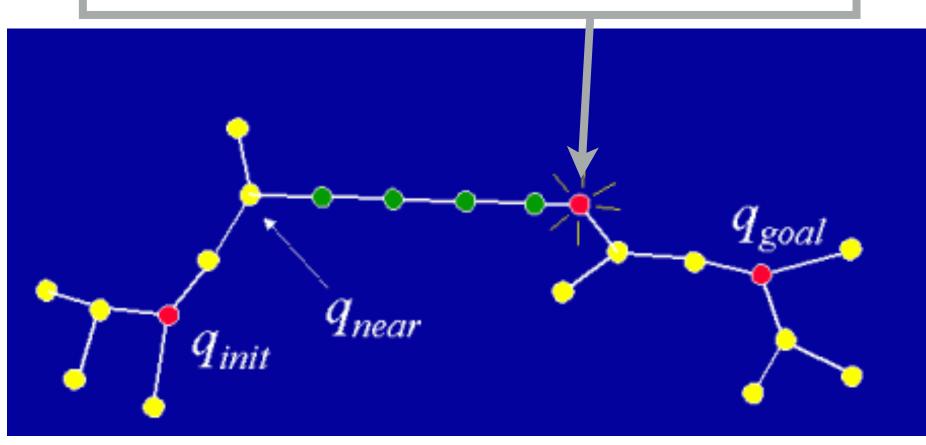




0) Use 2 trees (A and B) rooted at start and goal configurations



search succeeds if trees connect



[Kuffner, LaValle 2000]

EXT	$\Gamma END(\mathcal{T}, q)$
1	$q_{near} \leftarrow \text{NEAREST_NEIGHBOR}(q, T);$
2	if NEW_CONFIG(q, q _{near} , q _{new}) then
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5	if $q_{new} = q$ then
6	Return Reached;
7	else
8	Return Advanced;
9	Return Trapped;

configuration

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

repeat

2
$$S \leftarrow \text{EXTEND}(\mathcal{T}, q);$$

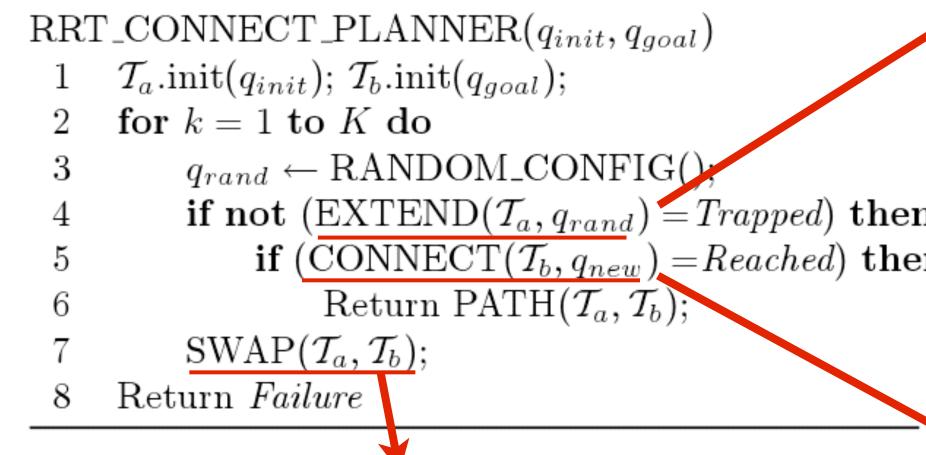
- until not (S = Advanced)
- Return S;

2) Try to connect tree B to tree A by extending repeatedly from its nearest neighbor Michigan Robotics 367/320 - autorob.org

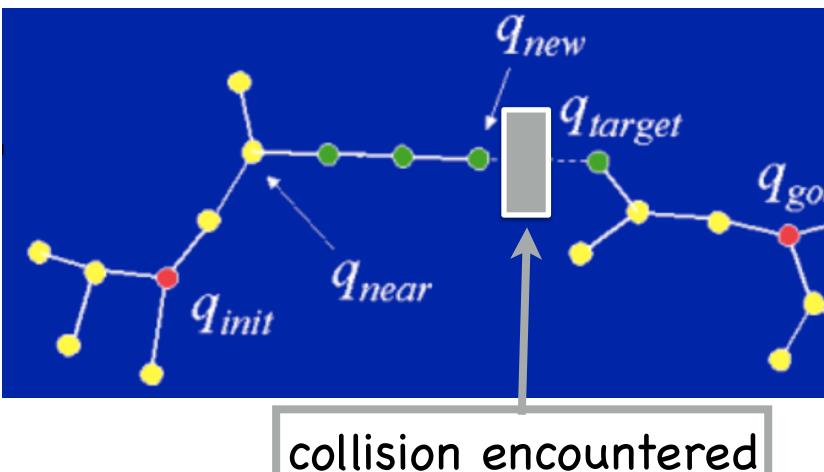




0) Use 2 trees (A and B) rooted at start and goal configurations



3) reverse roles for trees A and B and repe



[Kuffner, LaValle 2000]

_	
E	$\operatorname{XTEND}(\mathcal{T}, q)$
	1 $q_{near} \leftarrow NEAREST_NEIGHBOR(q, T);$
	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;
_	 9 Return Trappea; 1) Extend tree A towards a random
_	1) Extend tree A towards a random
_	
	1) Extend tree A towards a random
	 Extend tree A towards a random configuration CONNECT(T,q) repeat
	 Extend tree A towards a random configuration CONNECT(T,q) repeat
	 Extend tree A towards a random configuration CONNECT(T,q) repeat

2) Try to connect tree B to tree A by extending repeatedly from its nearest neighbor Michigan Robotics 367/320 - <u>autorob.org</u>





Lab Takeaways

- 1. RRT connect review
- 2. 2D RRT connect stencil
- 3. C-space RRT connect review
- 4. AABB collision detection
- \rightarrow How to implement all assignment 6 features

Revisiting the Search Canvas

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project_pendularm	fixed control set to 0 and 2d array proble				
in robots	initial commit Fall 2018				
tutorial_heapsort	initial commit Fall 2018				
tutorial_js	initial commit Fall 2018				
worlds	initial commit Fall 2018				
LICENSE	add refactor of assignment2, tested with				
README.md	initial commit Fall 2018				
home.html	Factorize kineval stencil for FK gradining				

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	2 years ago	in JavaScript/HTML5
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re like assignment 1 for fa	3 days ago	View license
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	2 years ago	2D RRT-Star [Grad] features
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Revisiting the Search Canvas

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infrastructure.js	Makes assignment 6 drawing work more like assignment 1 f	or familiarity.	3 days ago
rrt.js	Adds refactored stencil files for project 1.		3 months ago
search_canvas.html	Adds refactored stencil files for project 1.		3 months ago
	de for 2D RRT-Connect ar D RRT-Star [Grad] feature		

ZD MNI-Star [Urau] reatures

2D RRT-Connect

	rrt.js	
45	function	<pre>iterateRRTConnect() {</pre>
46		
47		
48	// S1	<code>FENCIL: implement a single i</code>
49	//	An asynch timing mechanism
50	//	blocking and non-responsive
51	//	
52	//	Return "failed" if the sear
53	//	Return "succeeded" if the s
54	//	Return "extended" otherwise
55	//	
56	//	Provided support functions:
57	//	
58	//	testCollision - returns whe
59	//	<pre>insertTreeVertex - adds and</pre>
60	//	<pre>insertTreeEdge - adds and d</pre>
61	//	drawHighlightedPath - rende
62	}	

Similar to Assignment 1 search algorithms, implement as a single step within the iterative algorithm

iteration of an RRT-Connect algorithm. is used instead of a for loop to avoid eness in the browser.

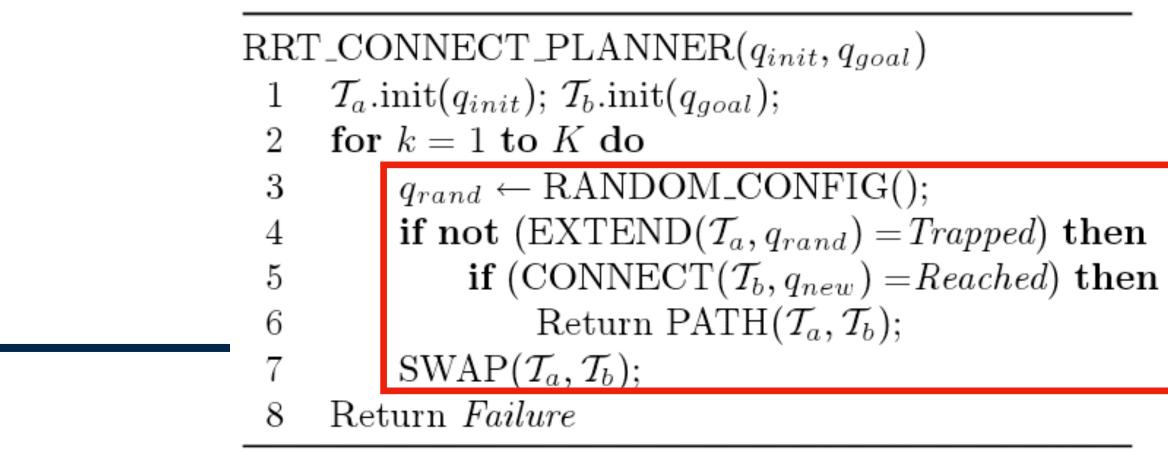
rch fails on this iteration. search succeeds on this iteration. e.

ether a given configuration is in collision d displays new configuration vertex for a tree displays new tree edge between configurations ers a highlighted path in a tree



2D RRT-Connect

	rrt.js	
45	function	<pre>iterateRRTConnect() {</pre>
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57	//	
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62	}	



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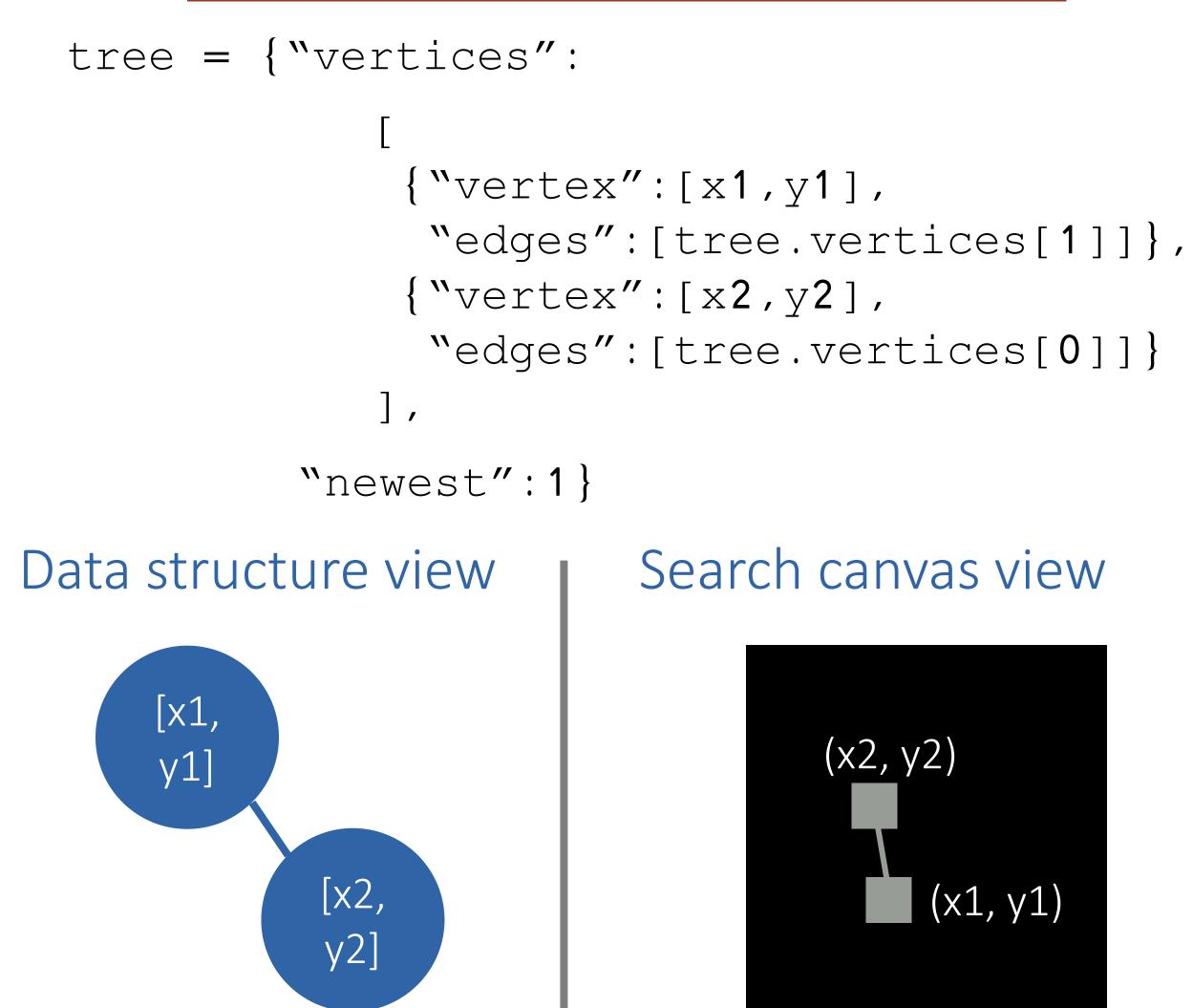


RRT Data Structure

infrastructure.js

64	<pre>function initRRT(q) {</pre>
65	
66	// create tree object
67	<pre>var tree = {};</pre>
68	
69	<pre>// initialize with vertex for given configuration</pre>
70	<pre>tree.vertices = [];</pre>
71	<pre>tree.vertices[0] = {};</pre>
72	<pre>tree.vertices[0].vertex = q;</pre>
73	<pre>tree.vertices[0].edges = [];</pre>
74	
75	<pre>// maintain index of newest vertex added to tree</pre>
76	tree.newest = 0;
77	
78	return tree;
79	}
80	
81	<pre>function insertTreeVertex(tree,q) {</pre>
82	

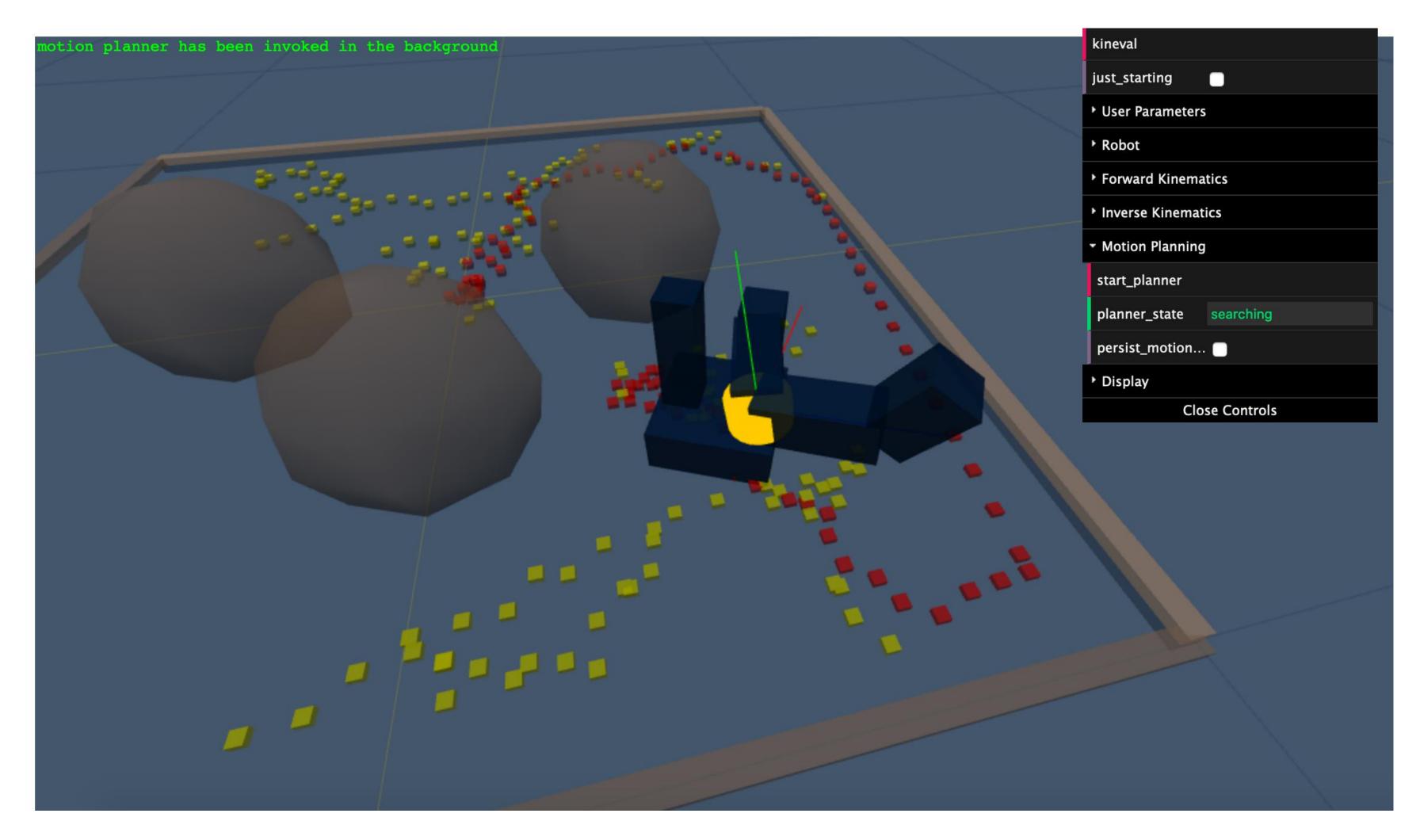
Tree implemented as a JavaScript object with array of vertices



Lab Takeaways

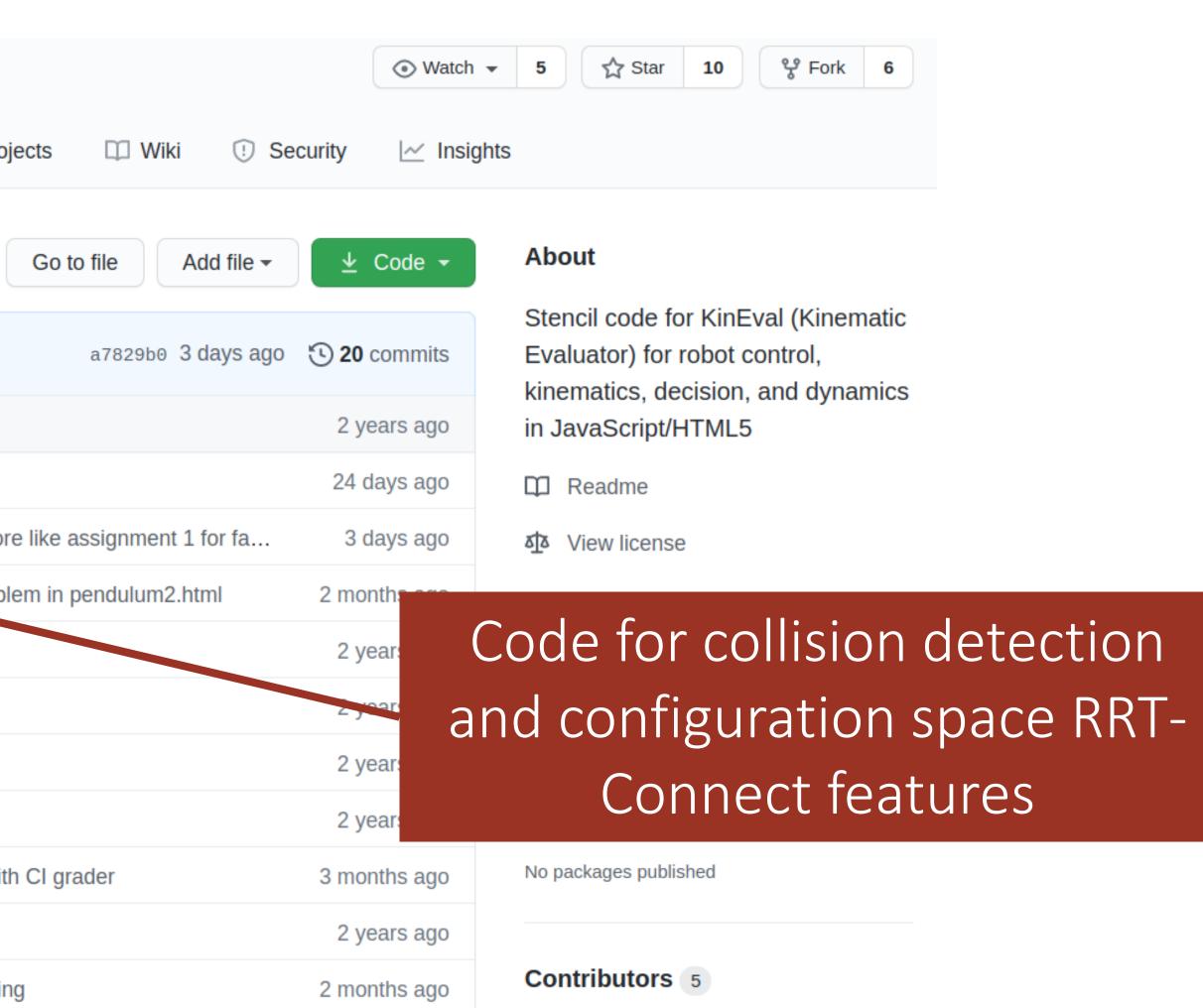
- 1. RRT connect review
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- \rightarrow How to implement all assignment 6 features

Configuration Space RRT



KinEval Overview

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LICENSE	add refactor of assignment2, tested with			
README.md	initial commit Fall 2018			
home.html	Factorize kineval stencil for FK gradining			





KinEval Overview

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ion detection on space RRTfeatures



kineval_rrt.js

	kineval_	_rrt.js	
132	function r	obot_rrt_plan	ner_iterate() {
133			
134	var i;		
135	rrt_a]	lg = 1; // 0:	basic rrt (OPTI
136			
137	if (rr	t_iterate &&	(Date.now()-cur_t
138	CL	ır_time = <mark>Date</mark>	.now();
139			
140	// STE	NCIL: impleme	nt single rrt ite
141	// i	ls used instea	d of a for loop t
142	// i	In the browser	
143	//		
144	// 0	once plan is f	ound, highlight
145	//	tree.vertice	s[i].vertex[j].ge
146	//		
147	// p	orovided suppo	rt functions:
148	//		
149	// k	ineval.poseIs	Collision - retu
150	// t	ree_init - cr	eates a tree of o
151	// t	ree_add_verte	x - adds and disp
152	// t	ree_add_edge	- adds and displa
153	}		
154			

155

Implement

robot_rrt_planner_iterate() as a single iteration of the RRT-Connect planning algorithm

(OPTIONAL), 1: rrt_connect (REQUIRED)

```
()-cur_time > 10)) {
```

rrt iteration here. an asynch timing mechanism r loop to avoid blocking and non-responsiveness

```
hlight vertices of found path by:
ex[j].geom.material.color = {r:1,g:0,b:0};
```

```
- returns if a configuration is in collision
ree of configurations
```

and displays new configuration vertex for a tree d displays new tree edge between configurations

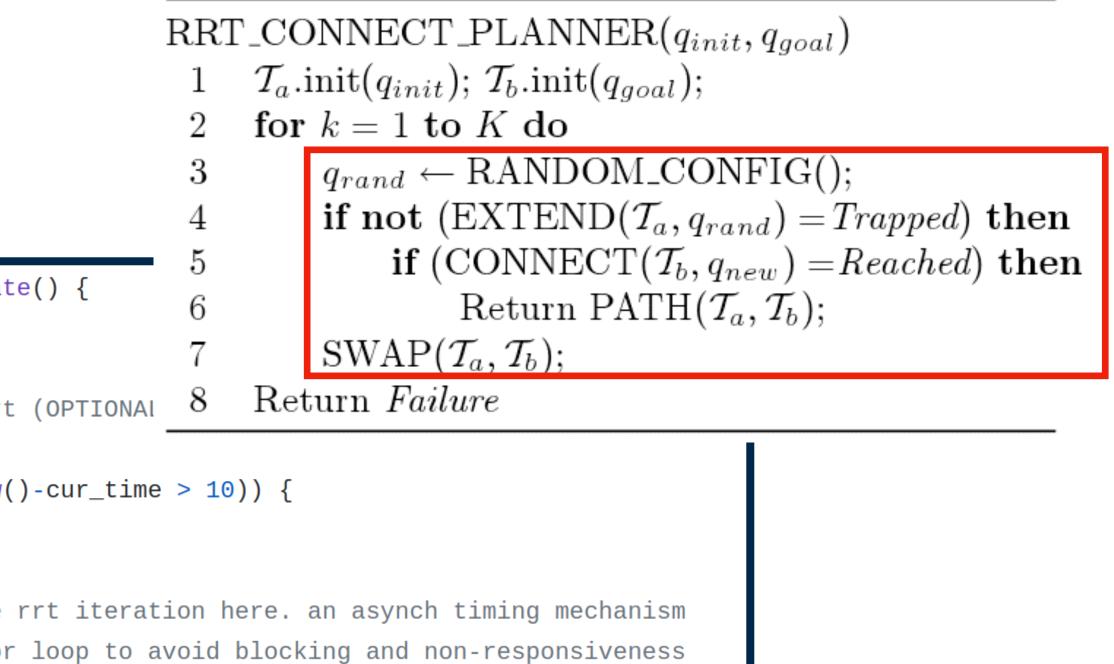
Include any helper functions in this file



kineval_rrt.js

	kineval_rrt.js
132	<pre>function robot_rrt_planner_iterat</pre>
133	
134	var i;
135	<pre>rrt_alg = 1; // 0: basic rrt</pre>
136	
137	<pre>if (rrt_iterate && (Date.now(</pre>
138	<pre>cur_time = Date.now();</pre>
139	
140	<pre>// STENCIL: implement single</pre>
141	<pre>// is used instead of a for</pre>
142	<pre>// in the browser.</pre>
143	//
144	<pre>// once plan is found, high</pre>
145	<pre>// tree.vertices[i].verte</pre>
146	//
147	<pre>// provided support functio</pre>
148	//
149	<pre>// kineval.poseIsCollision</pre>
150	<pre>// tree_init - creates a tr</pre>
151	<pre>// tree_add_vertex - adds a</pre>
152	<pre>// tree_add_edge - adds and</pre>
153	}
154	

155



```
hlight vertices of found path by:
ex[j].geom.material.color = {r:1,g:0,b:0};
```

ons:

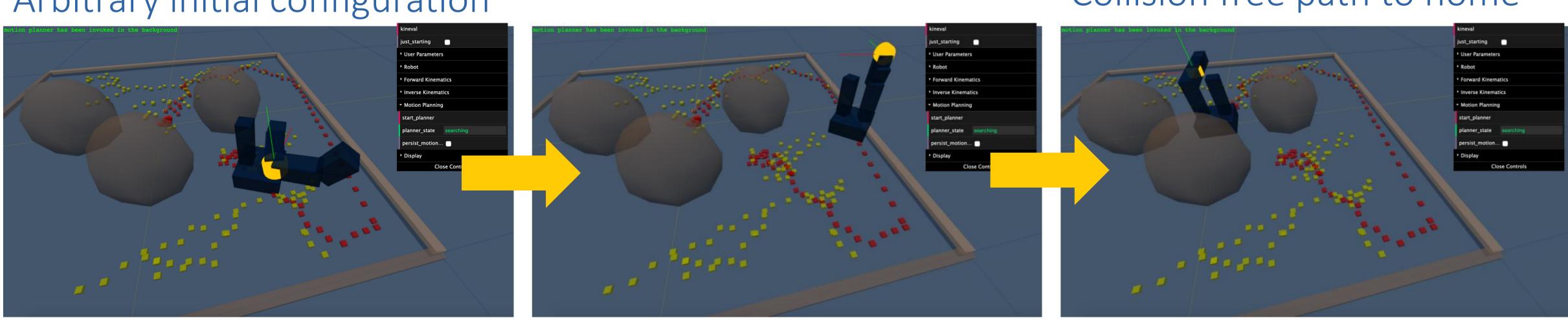
- returns if a configuration is in collision ree of configurations

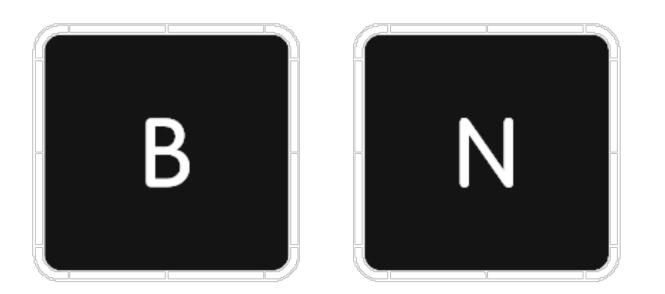
and displays new configuration vertex for a tree d displays new tree edge between configurations

Include any helper functions in this file

Desired Result

Arbitrary initial configuration





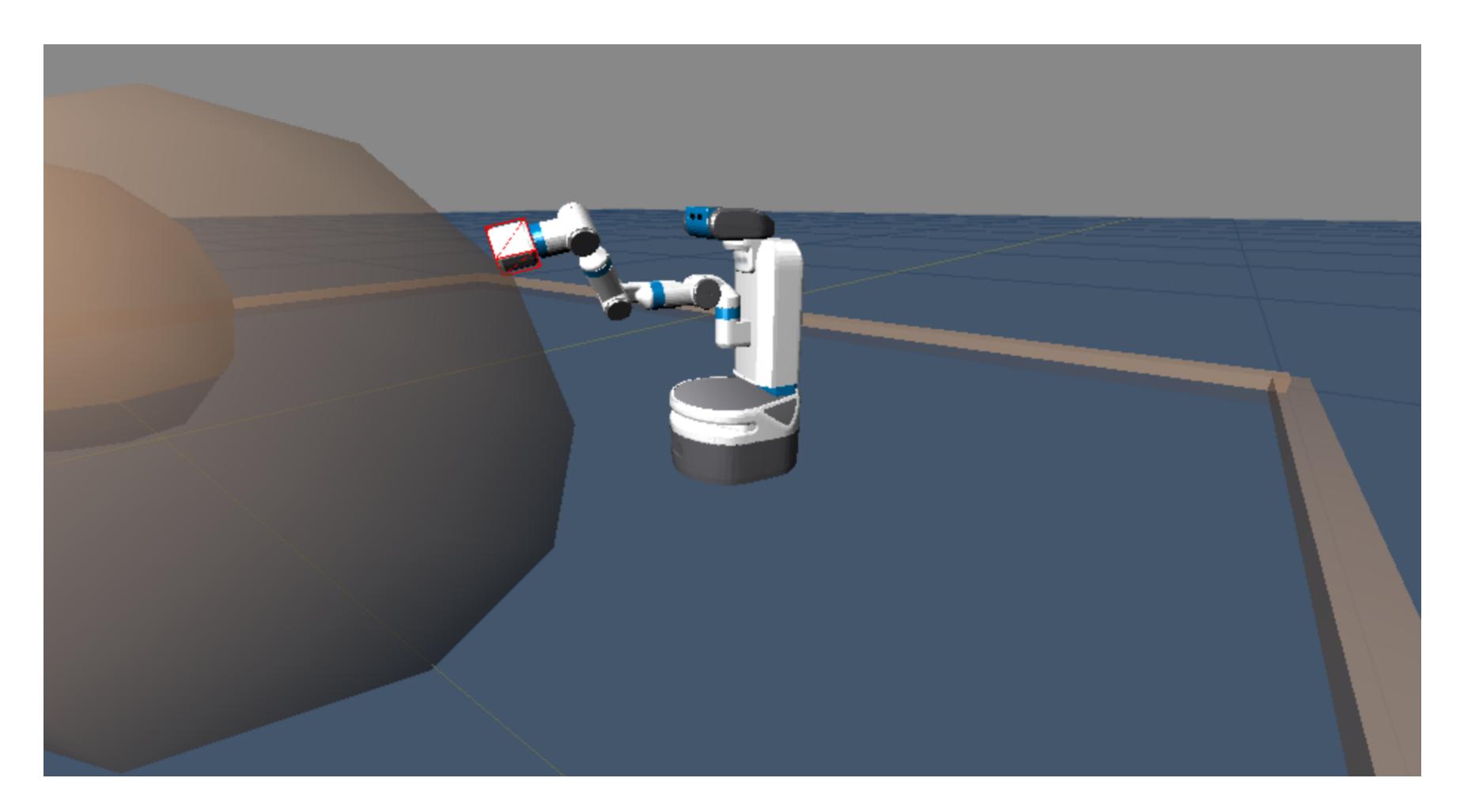
Backward stepForward stepalong motion planalong motion plan

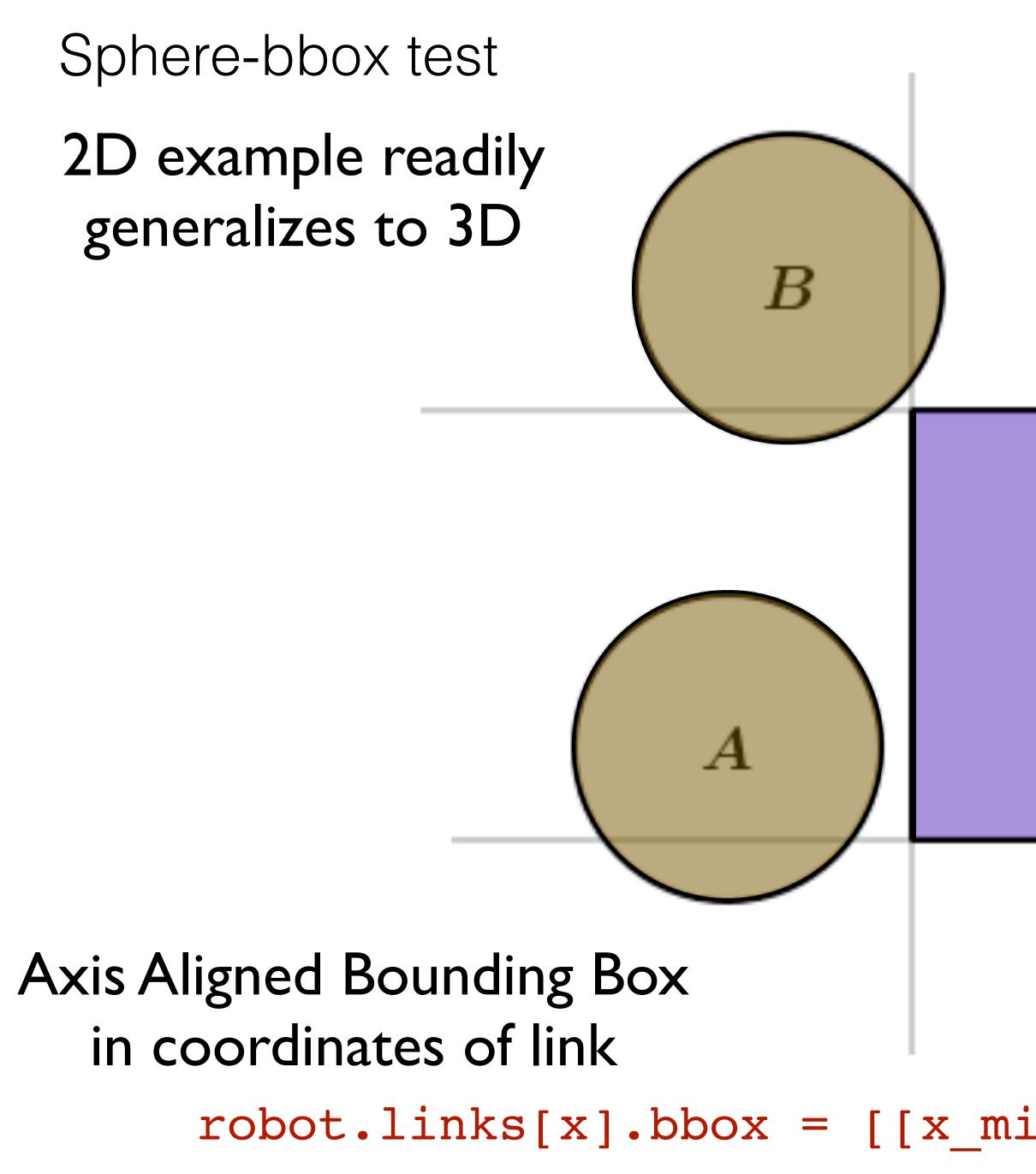
Collision free path to home

Lab Takeaways

- 1. RRT connect review
- 2. 2D RRT connect stencil
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- \rightarrow How to implement all assignment 6 features

Consider AABB link tested against spherical obstacles in link frame





robot obstacles[i]

Sphere obstacles with location and radius in world coordinates

robot.links[x].bbox = [[x_min,y_min,z_min], [x_max,y_max,z_max]]

C

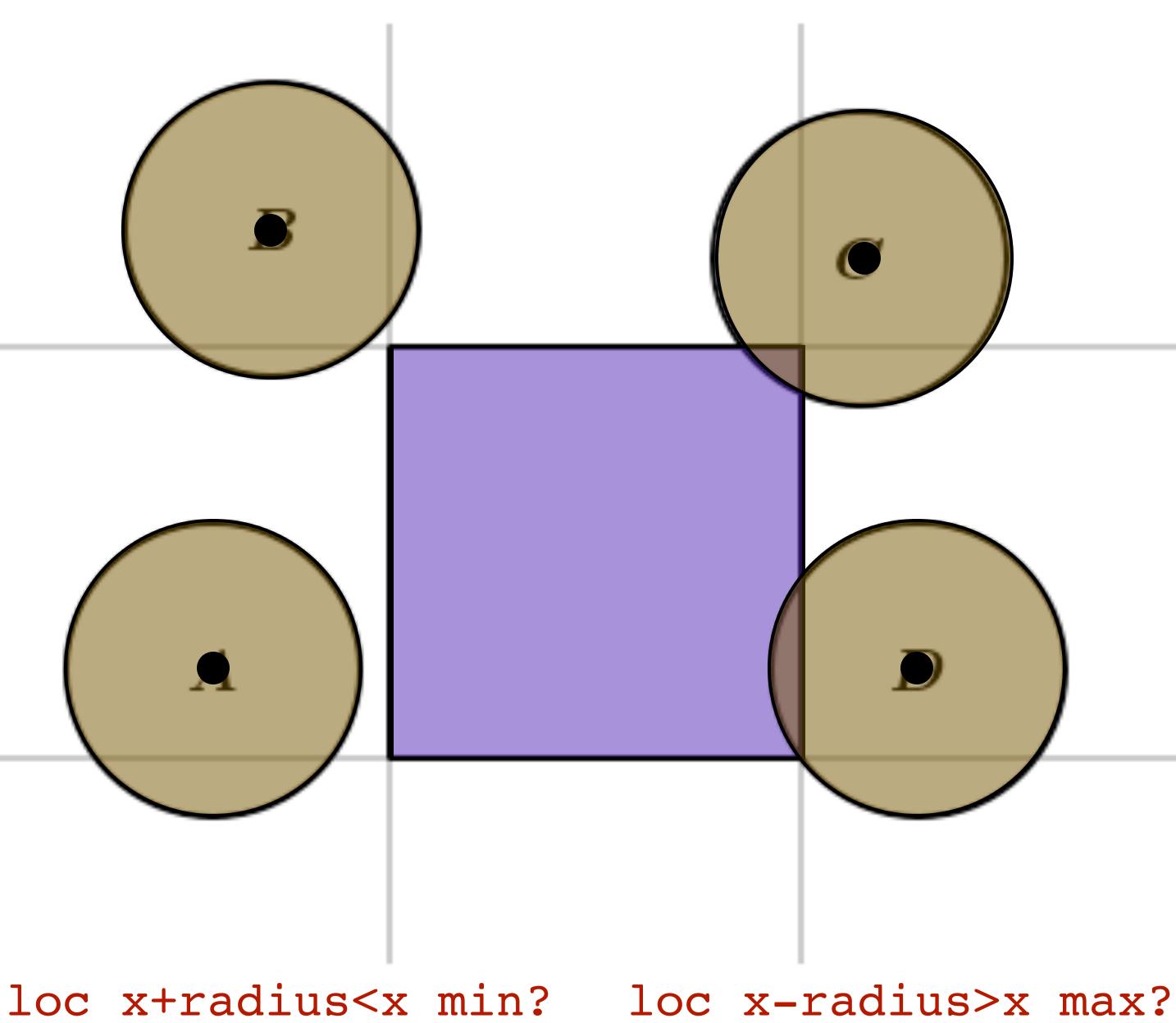
D

Sphere-bbox test If sphere separable from AABB in any dimension, return no collision

loc y-radius>y_max?

loc y+radius<y min?</pre>

If sphere collides on all tests, return collision



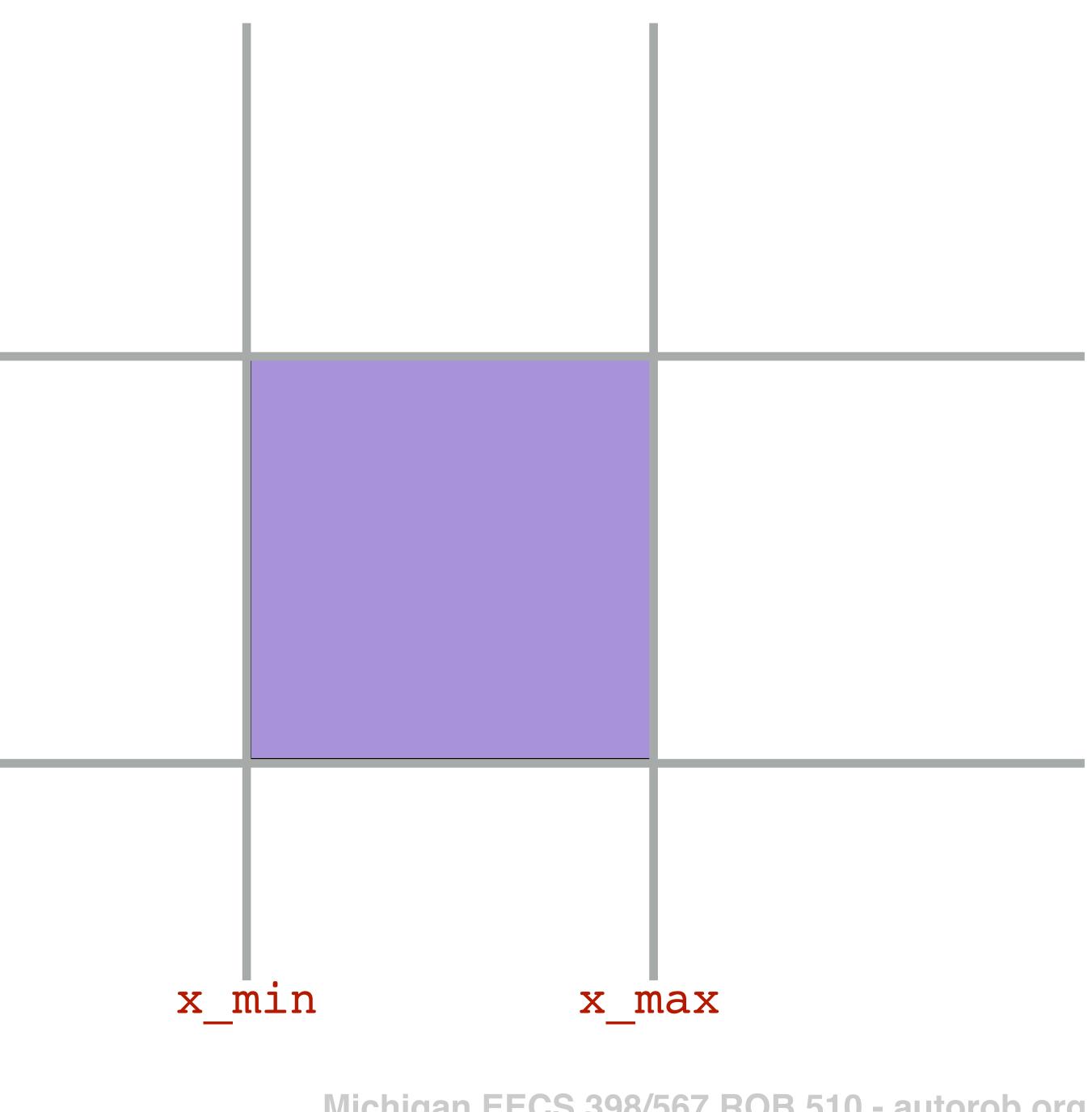




Separating planes

y_max

y_min

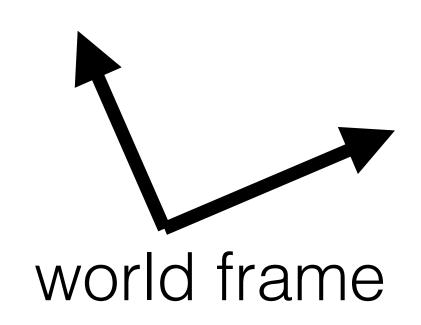


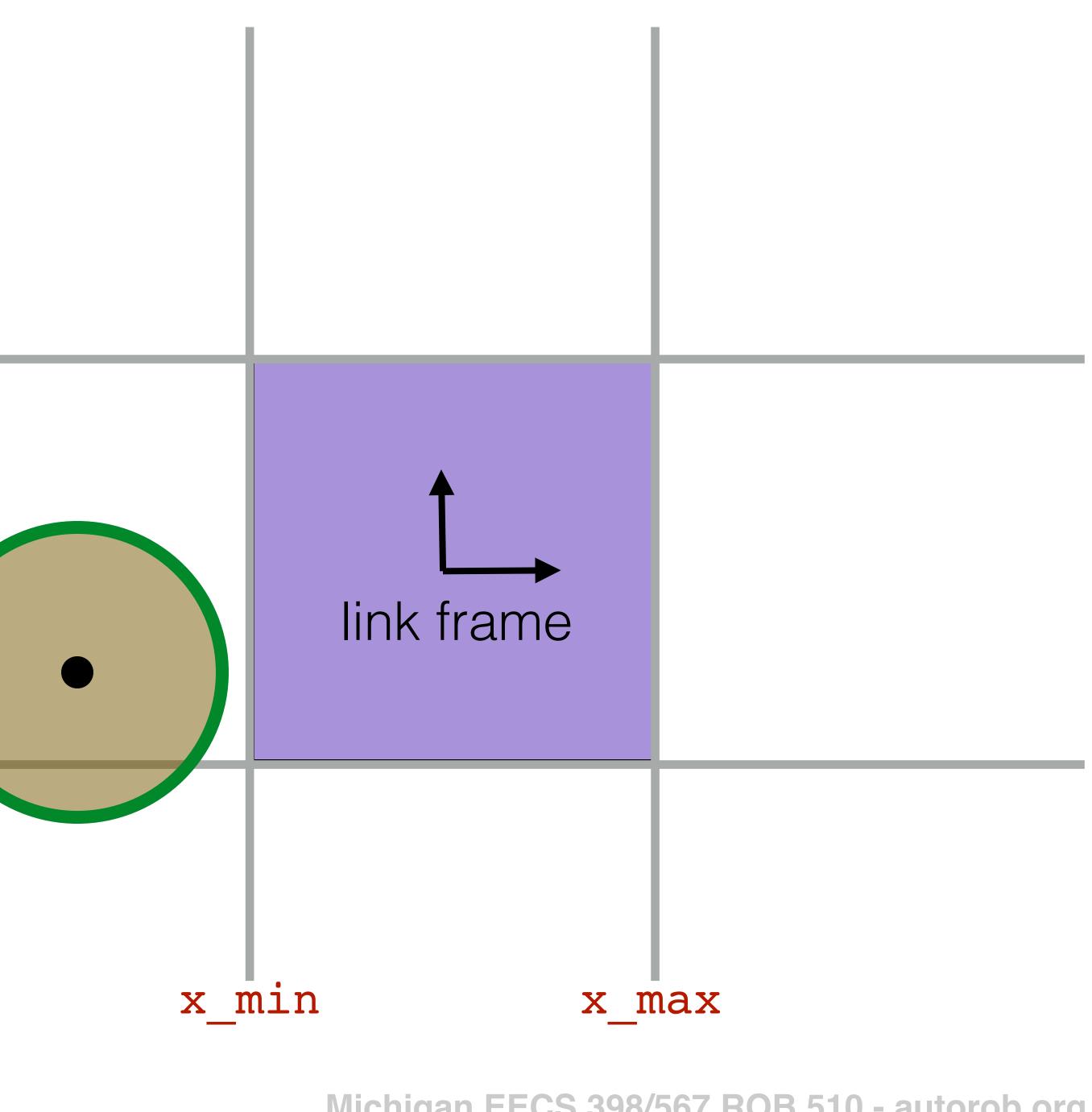
Transform centers of sphere obstacles into link coordinates

(Remember inverse of homogeneous y max transform?)

 $p^{link} = (T^{world}_{link})^{-1} p^{world}$

y_min

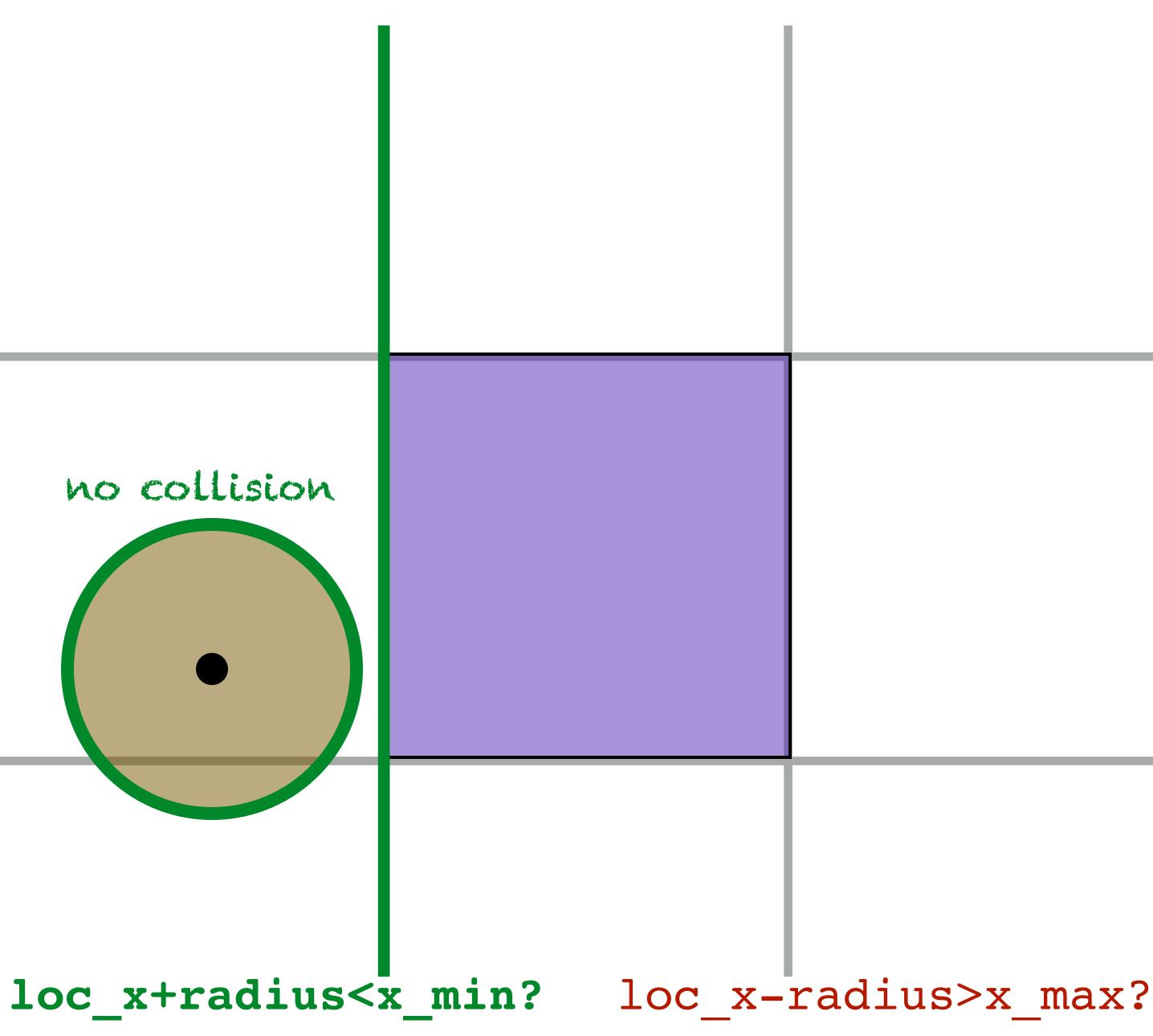


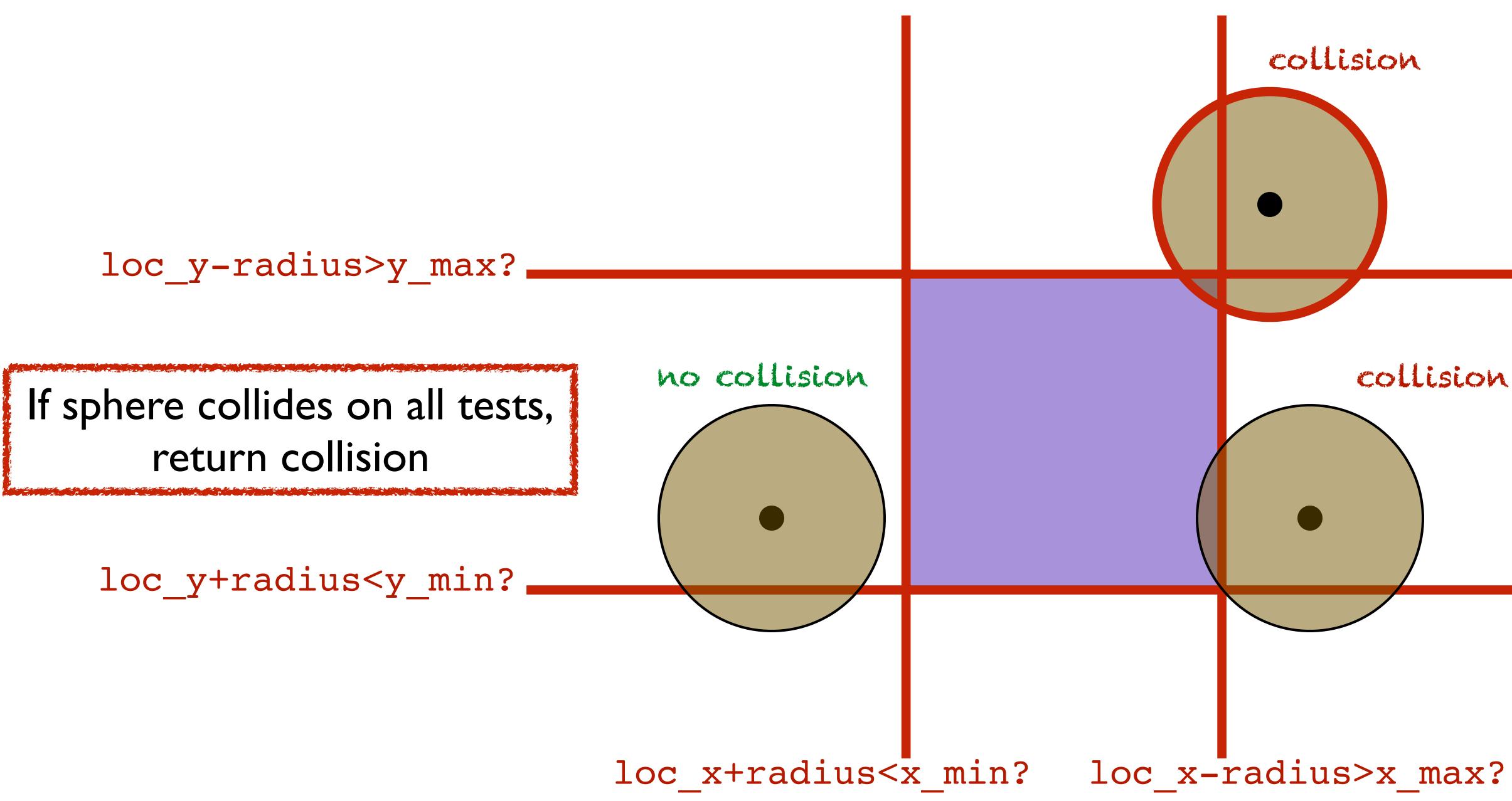


loc y-radius>y_max?

If sphere separable from AABB in any dimension, return no collision

loc y+radius<y min?</pre>



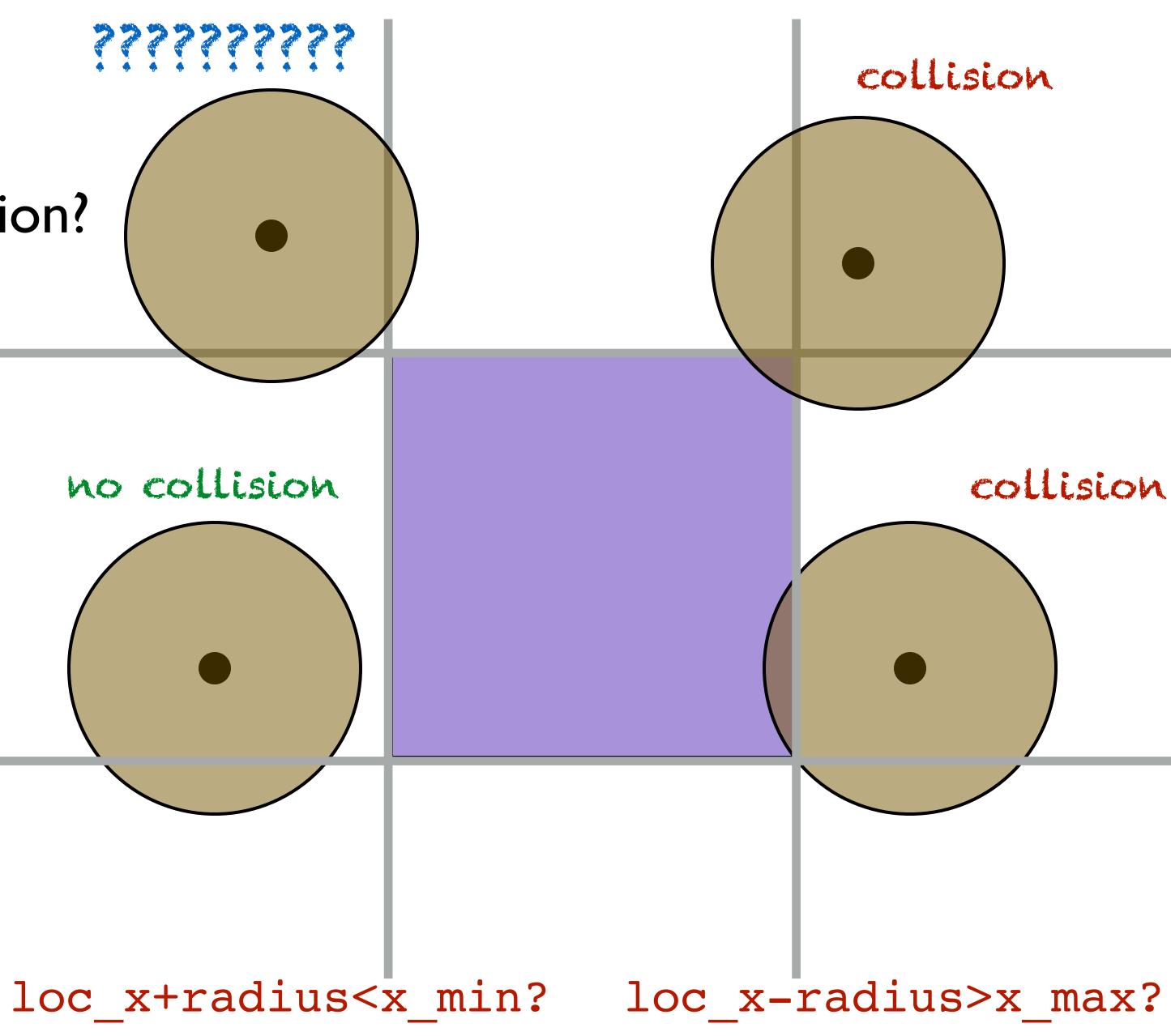




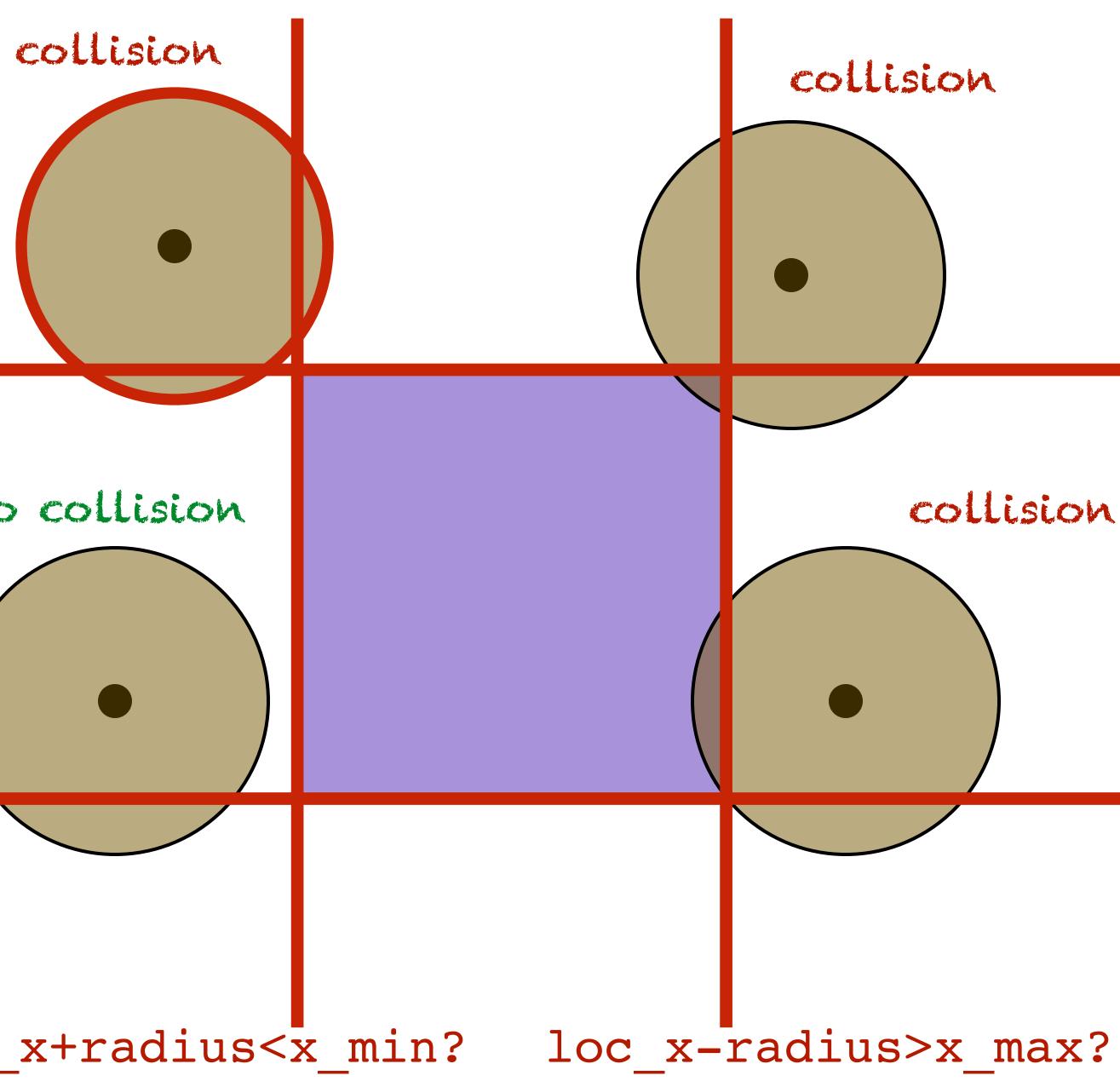
Is this obstacle in collision?

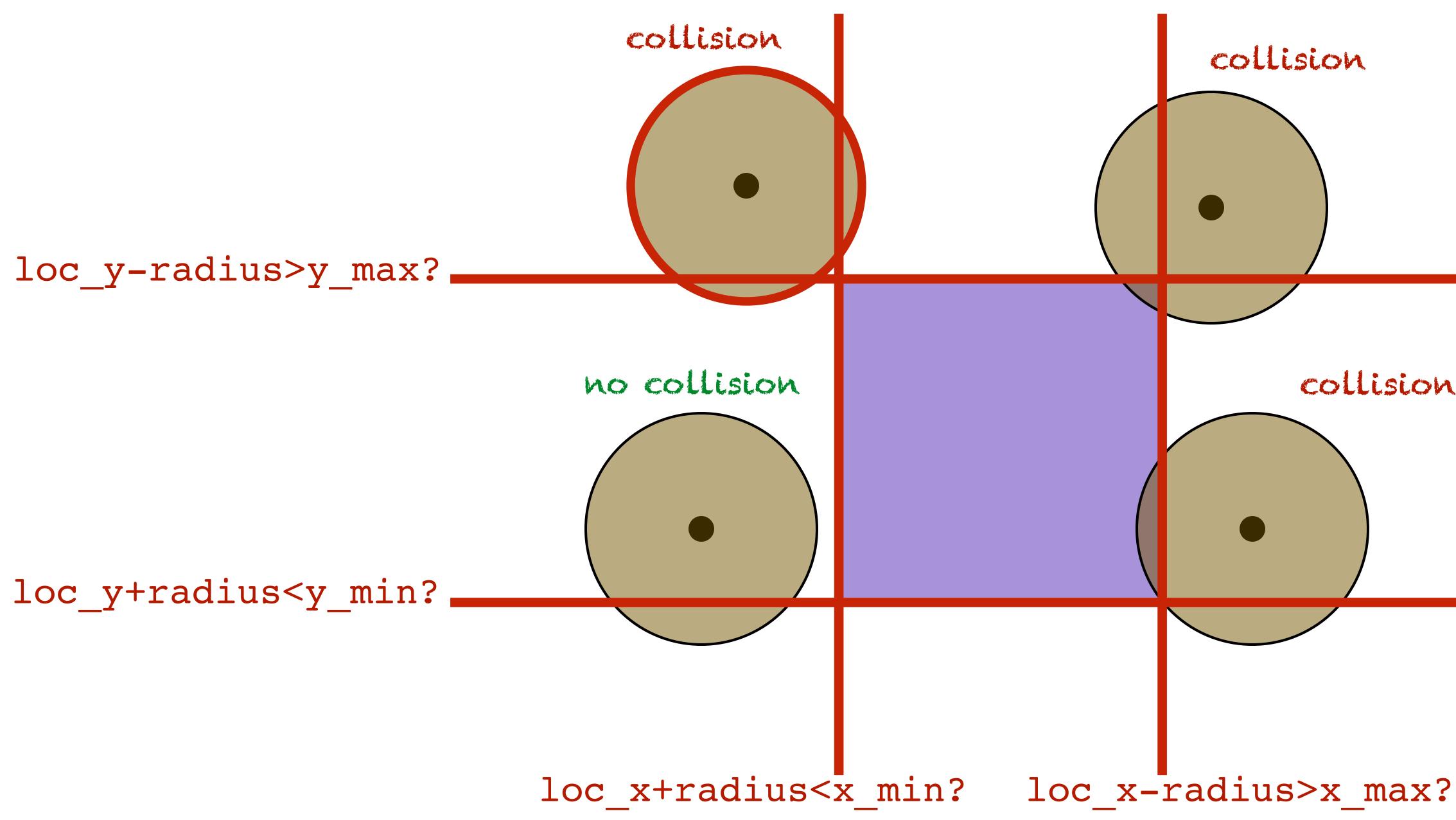
loc y-radius>y_max?







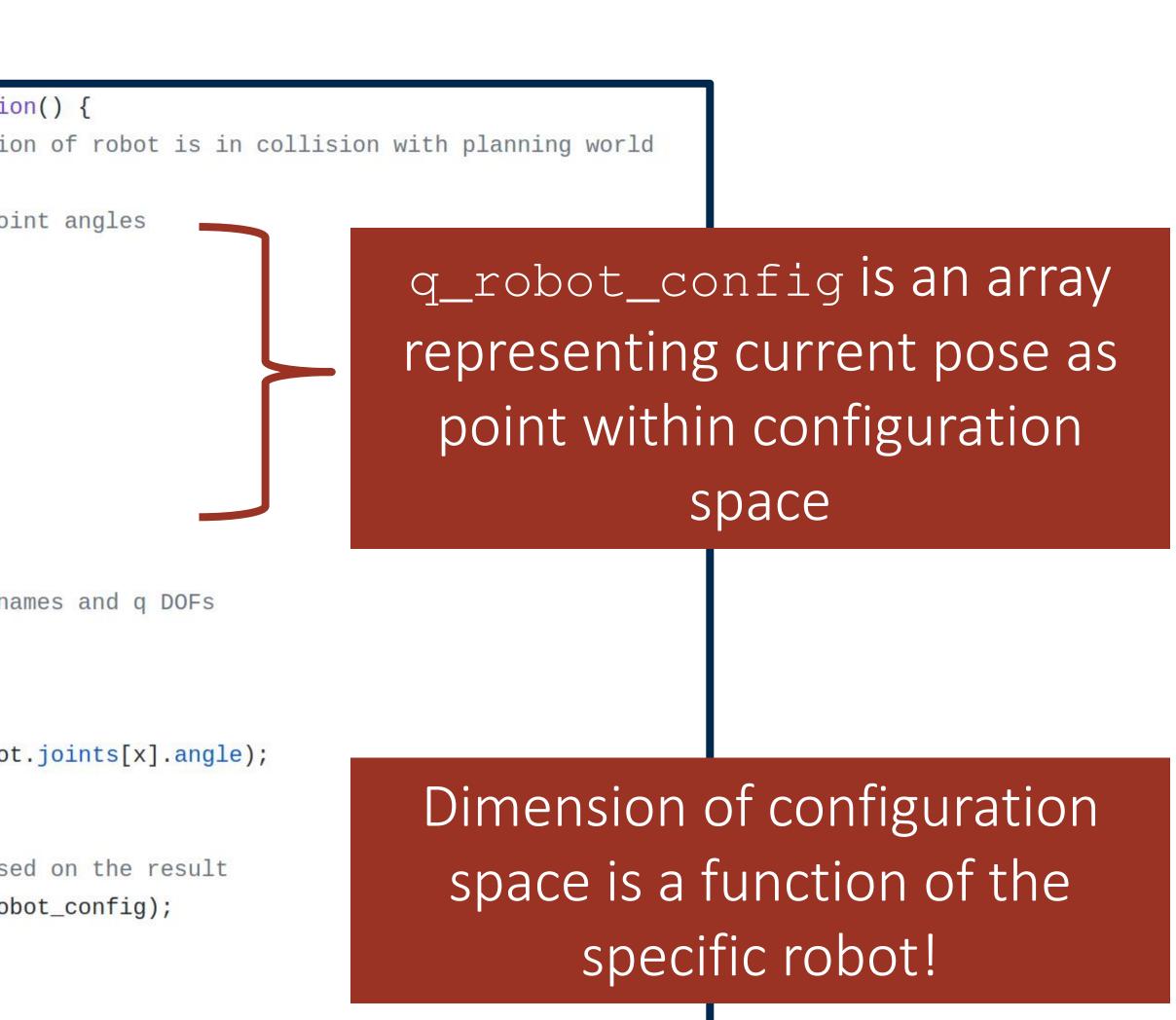




kineval_collision.js

kineval_collision.js

22	<pre>kineval.robotIsCollision = function robot_iscollision</pre>
23	<pre>// test whether geometry of current configuration</pre>
24	
25	<pre>// form configuration from base location and jo</pre>
26	<pre>var q_robot_config = [</pre>
27	<pre>robot.origin.xyz[0],</pre>
28	<pre>robot.origin.xyz[1],</pre>
29	<pre>robot.origin.xyz[2],</pre>
30	<pre>robot.origin.rpy[0],</pre>
31	<pre>robot.origin.rpy[1],</pre>
32	<pre>robot.origin.rpy[2]</pre>
33];
34	
35	<pre>q_names = {}; // store mapping between joint na</pre>
36	
37	<pre>for (x in robot.joints) {</pre>
38	q_names[x] = q_robot_config.length;
39	<pre>q_robot_config = q_robot_config.concat(robo</pre>
40	}
41	
42	<pre>// test for collision and change base color base</pre>
43	<pre>collision_result = kineval.poseIsCollision(q_rol</pre>
44	
45	<pre>robot.collision = collision_result;</pre>
46	}



kineval_collision.js

kineval	col	lision	.js
	·		J

49	<pre>kineval.poseIsCollision = function robot_collision_test(</pre>
50	<pre>// perform collision test of robot geometry against</pre>
51	
52	// test base origin (not extents) against world boun
53	<pre>if ((q[0]<robot_boundary[0][0]) (q[0]>robot_boundar</robot_boundary[0][0]) (q[0]></pre>
54	<pre>return robot.base;</pre>
55	
56	<pre>// traverse robot kinematics to test each body for c</pre>
57	<pre>// STENCIL: implement forward kinematics for collisi</pre>
58	<pre>//return robot_collision_forward_kinematics(q);</pre>
59	
60	}



STENCIL: Check each link for collision with spherical obstacles

ndary extents ry[1][0])||(q[2]<robot_boundary[0][2])||(q[2]>robot_boundary[1][2]))

collision ion detection

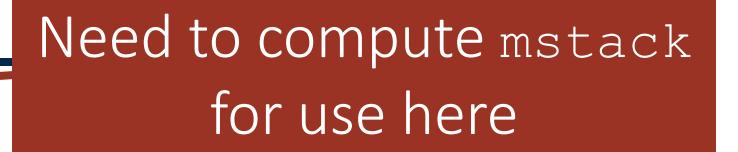
> Collision detection pseudocode: For each link in robot For each obstacle in world If intersection(link, obstacle) Return link is in collision Return no collision



kineval_collision.js

kineval_collision.js

64	fund	ction traverse_collision_forward_kinematics_link(link,mstack,q) { <
65		
66		/* test collision FK
67		<pre>console.log(link);</pre>
68		*/
69		<pre>if (typeof link.visual !== 'undefined') {</pre>
70		<pre>var local_link_xform = matrix_multiply(mstack,generate_transl</pre>
71		}
72		else {
73		<pre>var local_link_xform = matrix_multiply(mstack,generate_identi</pre>
74		}
75		
76		<pre>// test collision by transforming obstacles in world to link spac</pre>
77	/*	
78		<pre>mstack_inv = matrix_invert_affine(mstack);</pre>
79	*/	
80		<pre>mstack_inv = numeric.inv(mstack);</pre>
81		
82		var i;
83		var j;
84		
85		<pre>// test each obstacle against link bbox geometry by transforming</pre>
86		//for (j=0;j <robot_obstacles.length;j++) td="" {<=""></robot_obstacles.length;j++)>
87		<pre>for (j in robot_obstacles) {</pre>
88		
89		<pre>var obstacle_local = matrix_multiply(mstack_inv,robot_obstacl</pre>
90		
91		<pre>// assume link is in collision as default</pre>
92		<pre>var in_collision = true;</pre>



_translation_matrix(link.visual.origin.xyz[0],link

_identity());

nk space

AABB collision check for a link provided for you in this function, but you need to add the rest of FK traversal

orming obstacle into link frame and testing agains

obstacles[j].location);



Lab Takeaways

- 1. RRT connect review
- 2. 2D RRT connect stencil
- 3. C-space RRT connect review
- 4. AABB collision detection
- \rightarrow How to implement all assignment 6 features

Best use of robotics?

- What are some compelling use cases for robotics?
- Discuss with neighbors
 - Then share possible ideas