



autorob.org

Initialization

EECS 367
Intro. to Autonomous Robotics

ME/EECS 567 ROB 510
Robot Modeling and Control

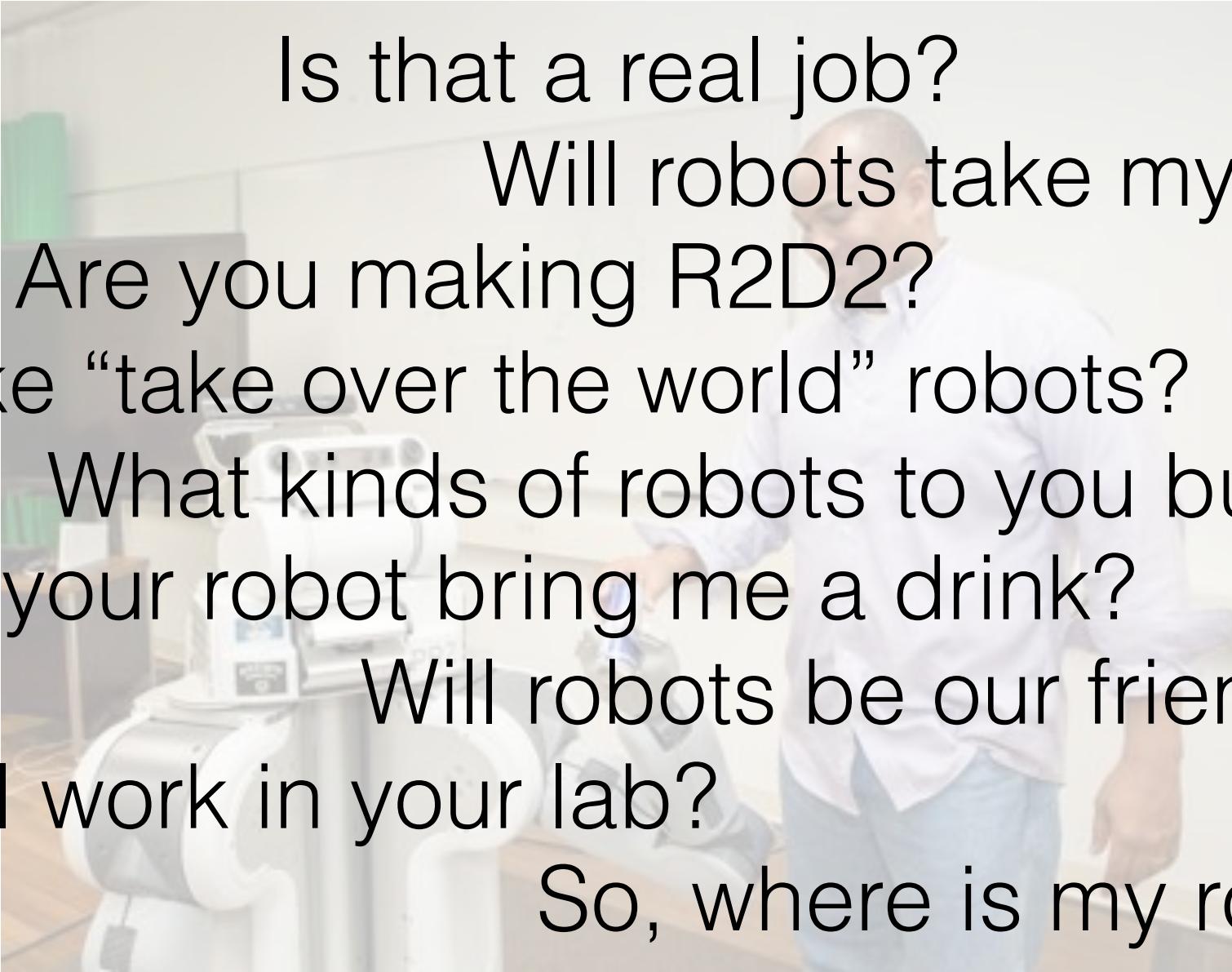
Fall 2019

Michigan Robotics 367/510/567 - autorob.org

Agenda

- So, where is my robot?
- Roadmap for autonomous robotics
- Course administrative overview
- Assignment 1 (Path Planning) assigned today, due Sep 18 11:59pm
 - JavaScript/HTML5 and git covered this and next lecture
- Action items: what I need from you now





Is that a real job?

Will robots take my job?

Are you making R2D2?

Like “take over the world” robots?

What kinds of robots do you build?

Can your robot bring me a drink?

Will robots be our friends?

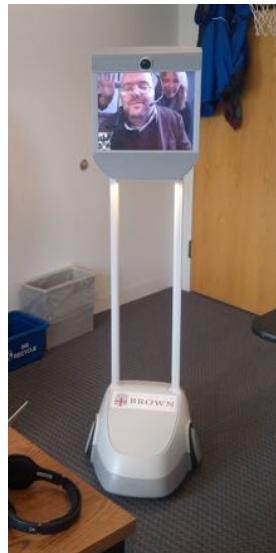
Can I work in your lab?

So, where is my robot?

So, where is my robot?



So where is my robot?



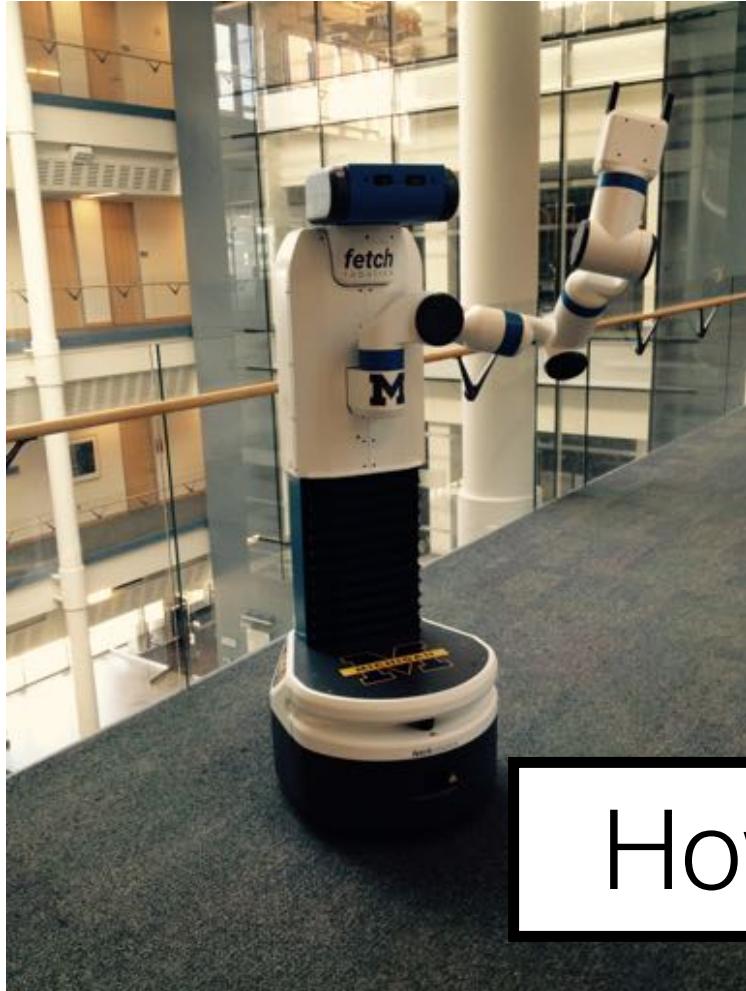
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Mobile Manipulation Robots

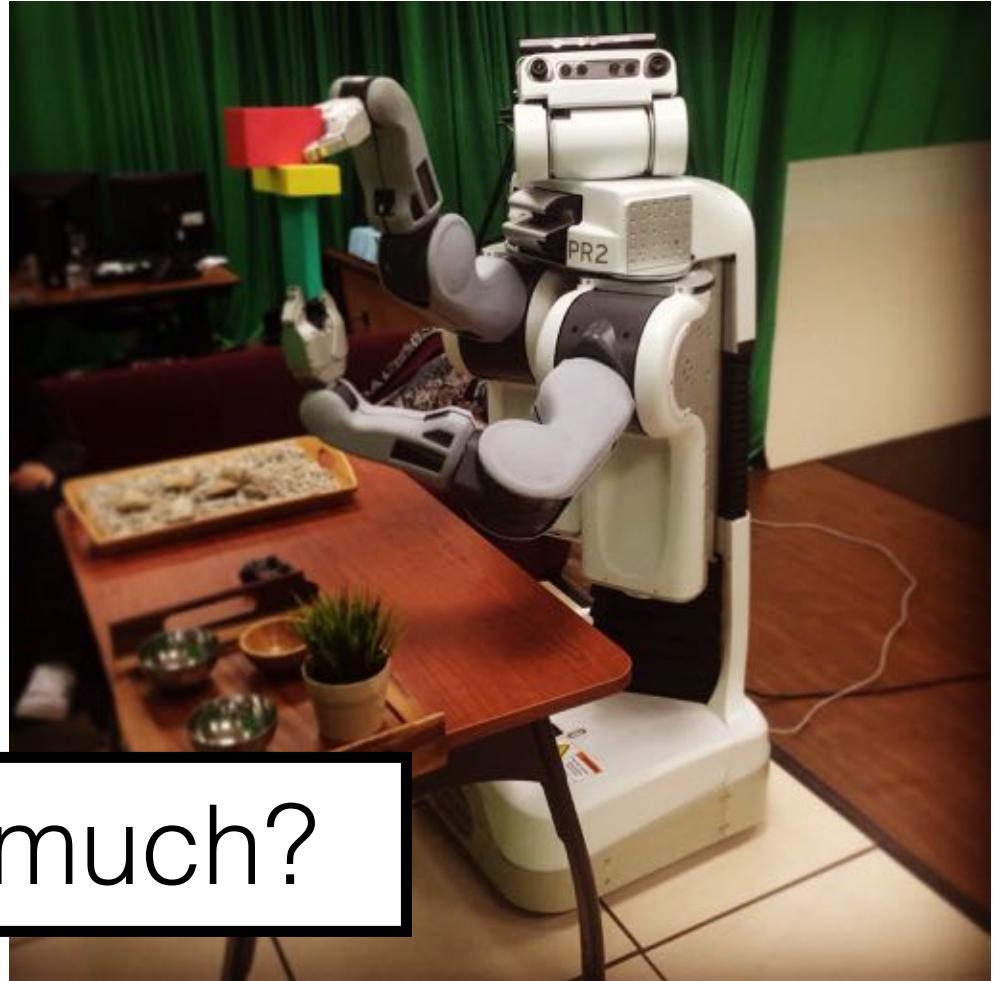




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How much?



Cost

\$400K

\$100K

Willow Garage PR2



Fetch



2009

2015

Time



2002

\$400K

\$100K



2009

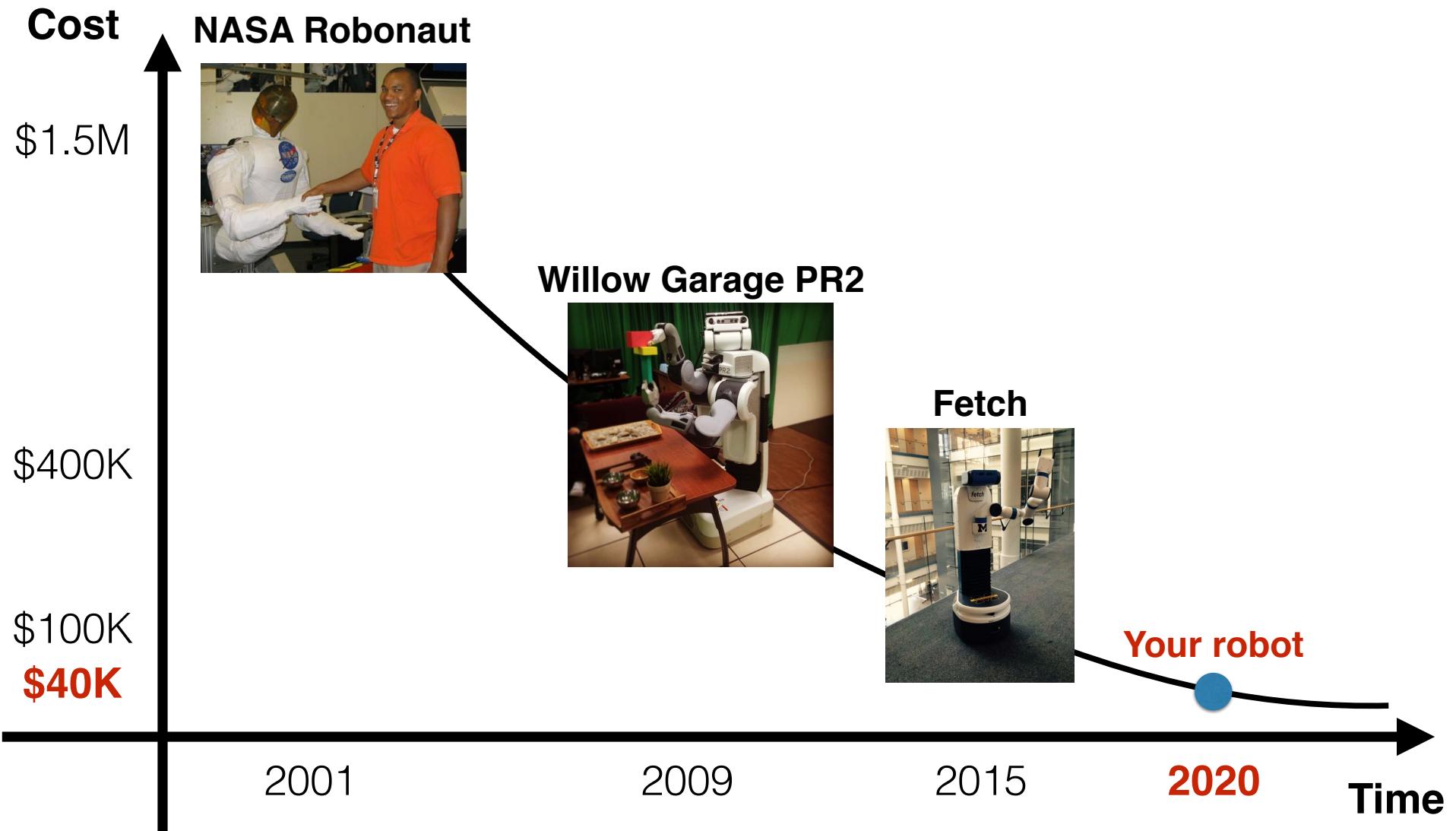
2015

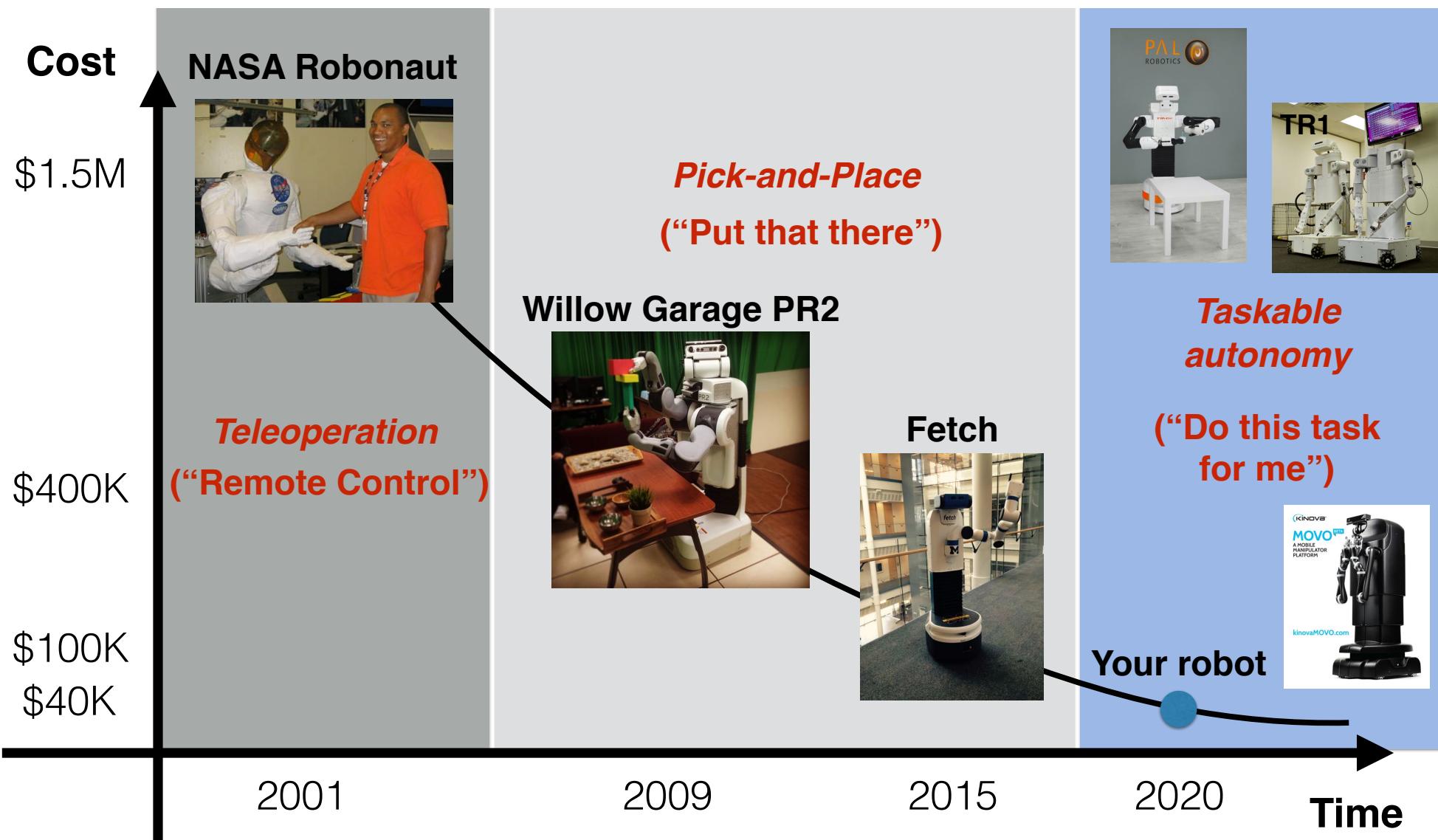
Willow Garage PR2



Fetch







“Do this task for me”

Can we make your
world programmable ?



Use x robot

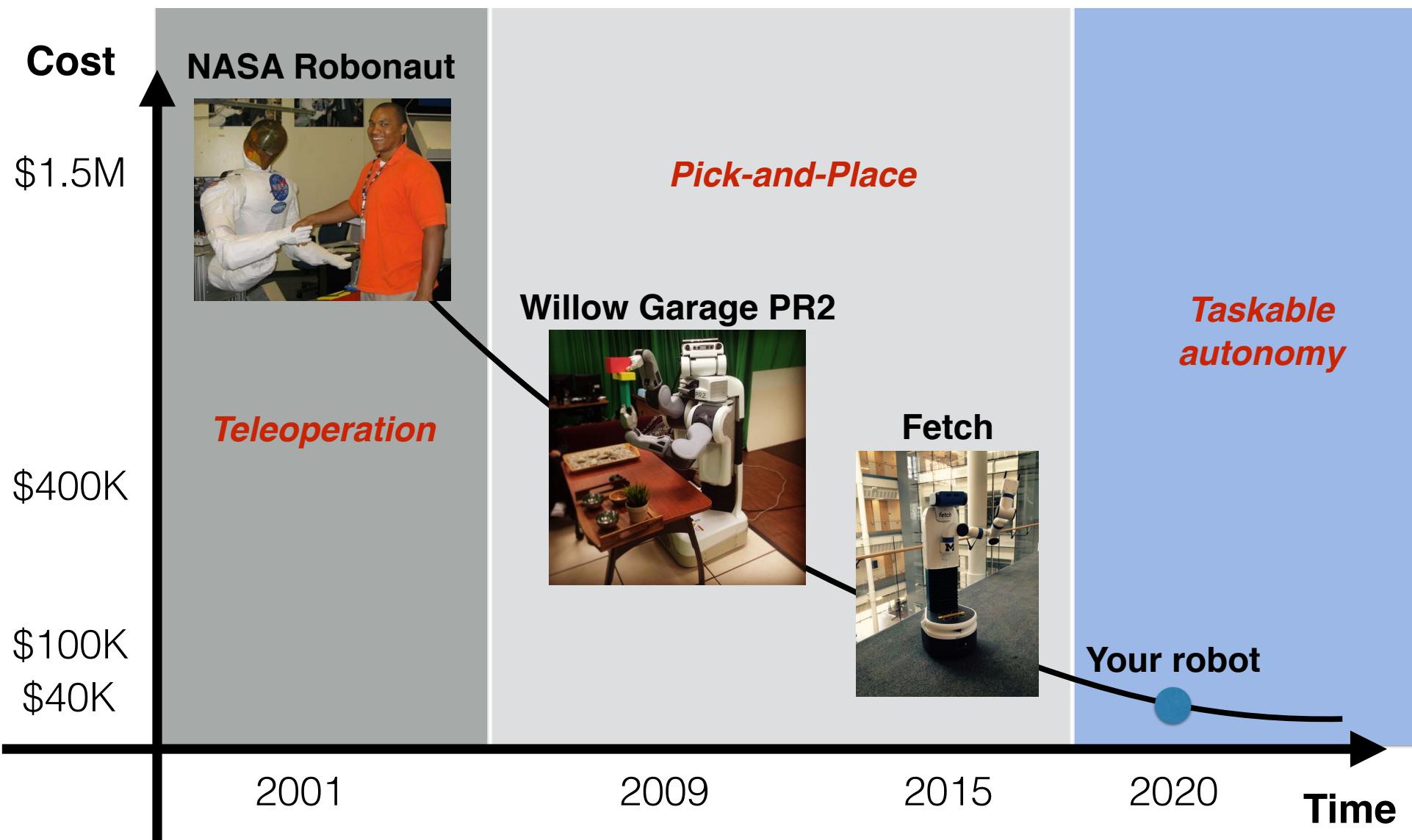


to perform task y



in z environment





Teleoperation



NASA Robonaut

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**NASA Robonaut 2 on the
International Space Station**



Michigan Robotics 367/510/567 - autorob.org

Wearable wireless motion capture for robot teleoperation



[Miller, Jenkins, et al., 2004, "Motion Capture from Inertial Sensing for Untethered Humanoid Teleoperation"]
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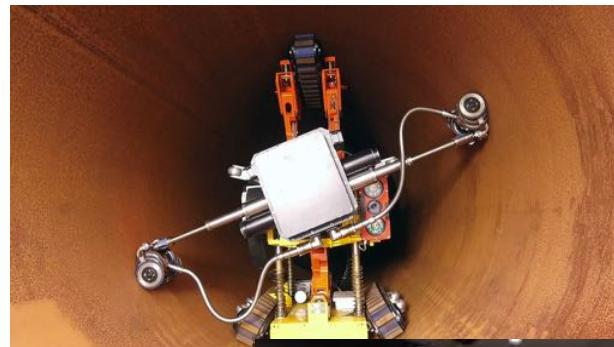
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The 3Ds: Dirty, Dull, and Dangerous

“Autonomous” Driving



Infrastructure inspection

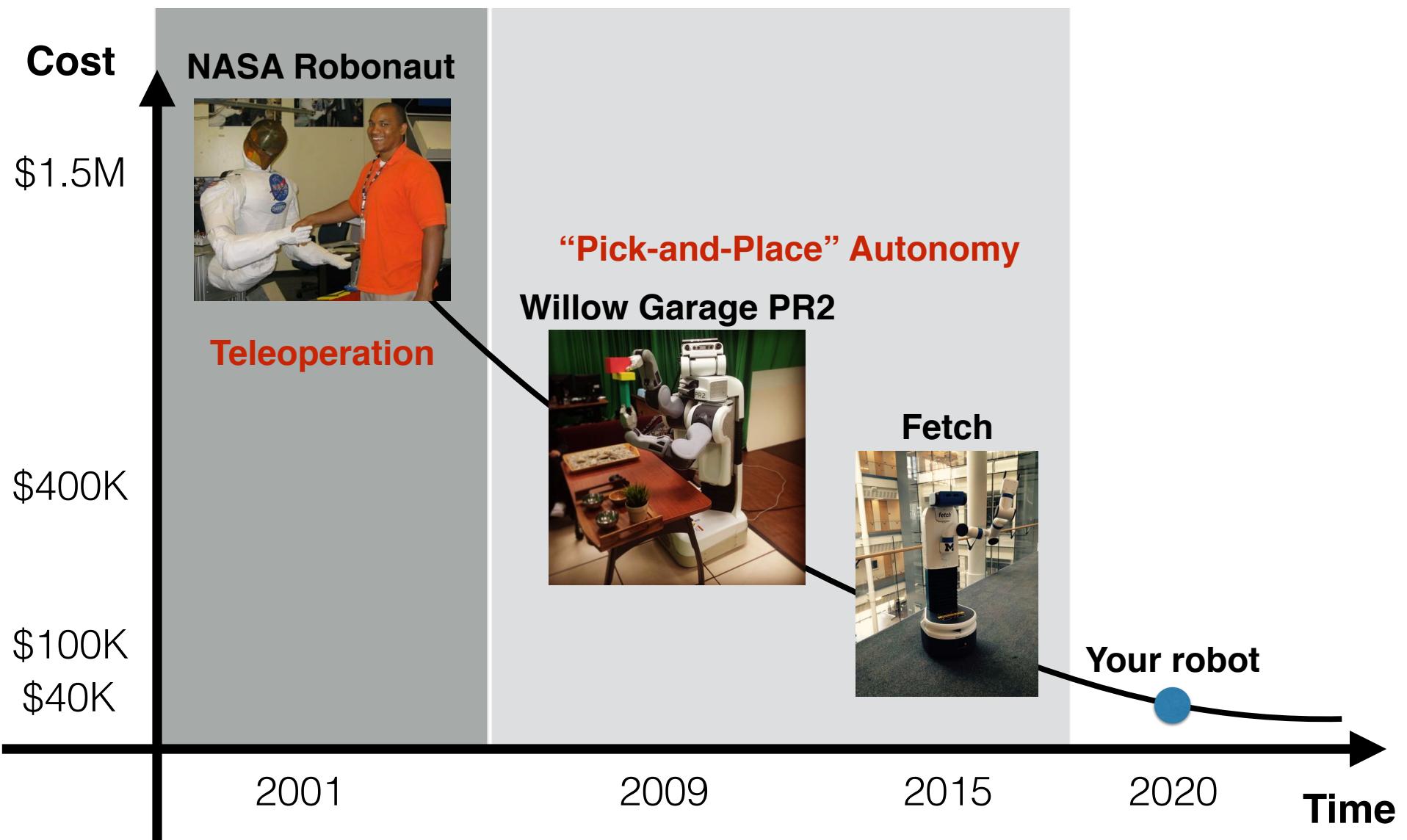


Nuclear cleanup



<https://www.shadowrobot.com/blog/robots-saving-humans-from-dangerous-jobs/>

<https://techcrunch.com/2018/06/05/remote-control-driverless-car-startup-partners-with-vehicle-manufacturers/>



Autonomous Robotics in 3 words

Sense.

Plan.

Act.

Autonomous Robotics in 3 words

Sense. **Perceive** a model of the current world state.

Plan. **Search** over actions towards a goal state.

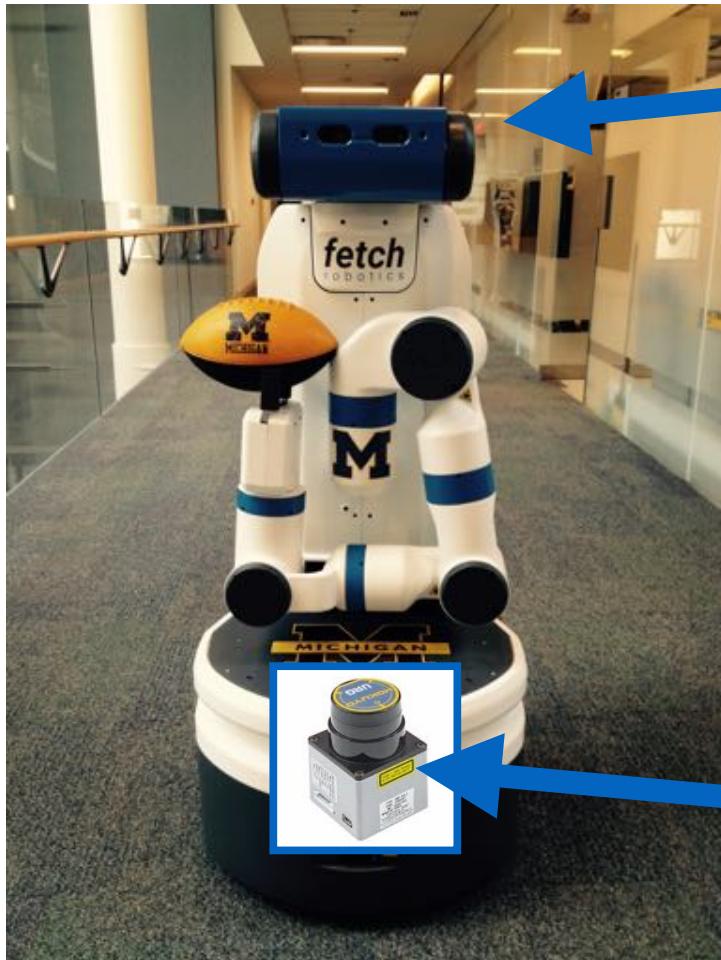
Act. **Execute** actions through forces at robot's motors



Color+Depth Camera



Laser Rangefinder
Michigan Robotics 367/510/567 - autorob.org



Color+Depth Camera

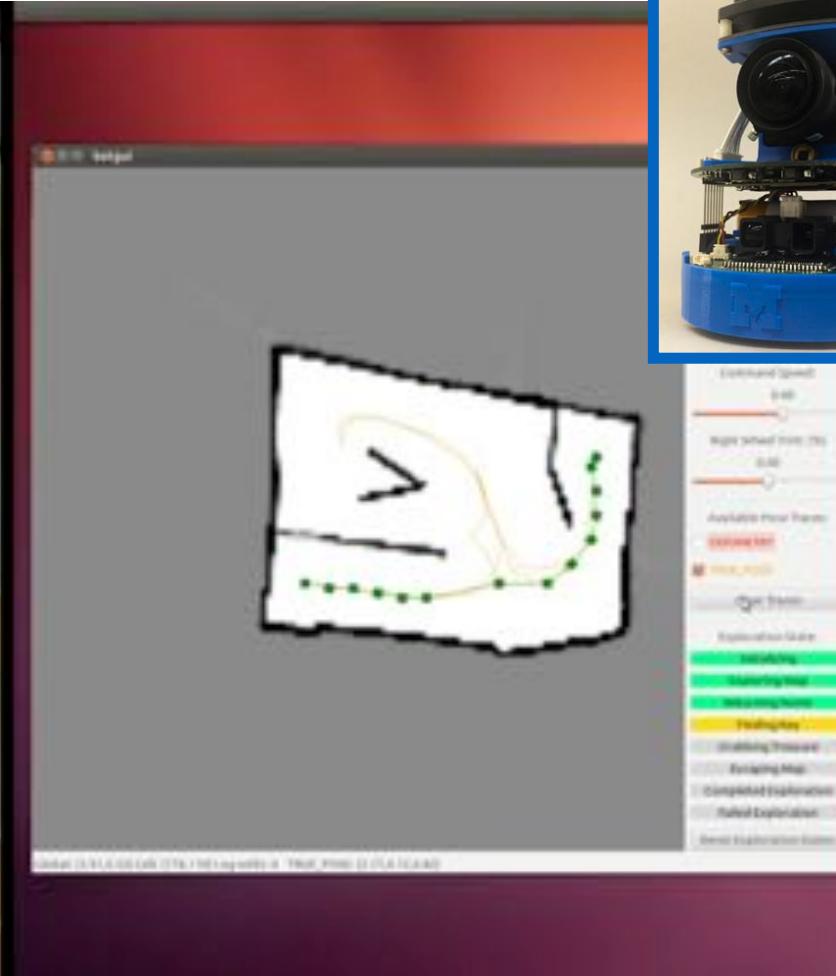
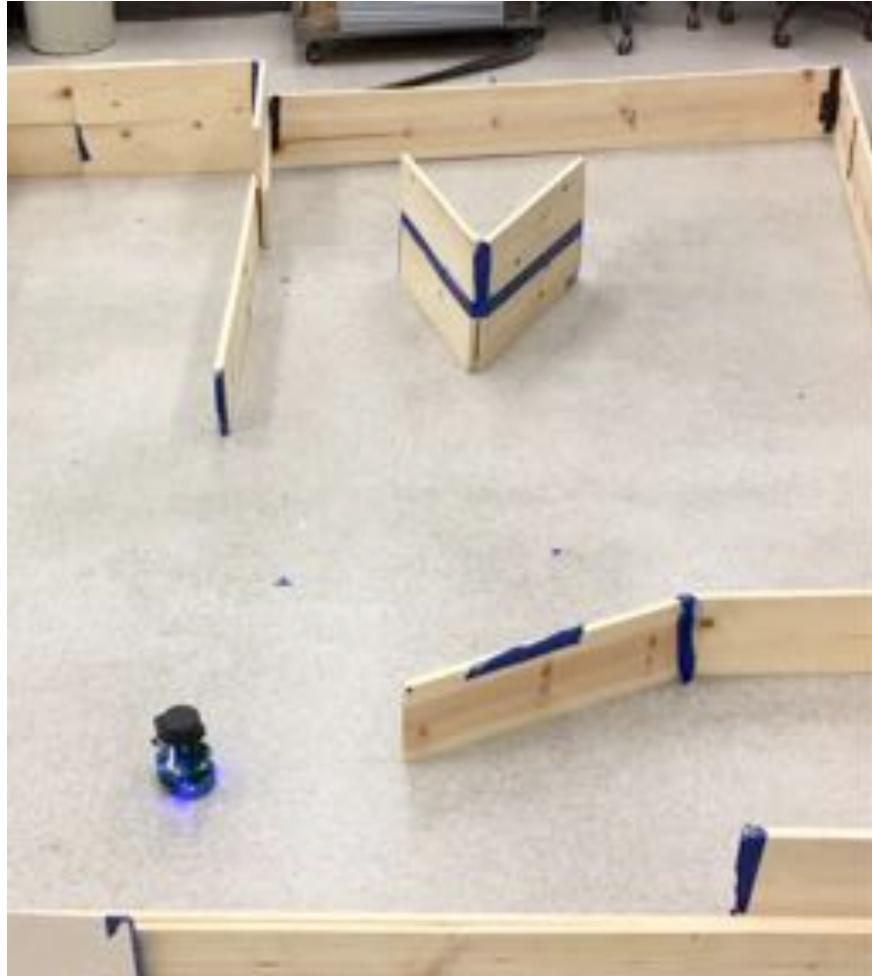


Laser Rangefinder
Michigan Robotics 367/510/567 - autorob.org





ROB 550 BotLab / EECS 467 Escape Challenge 2016-17



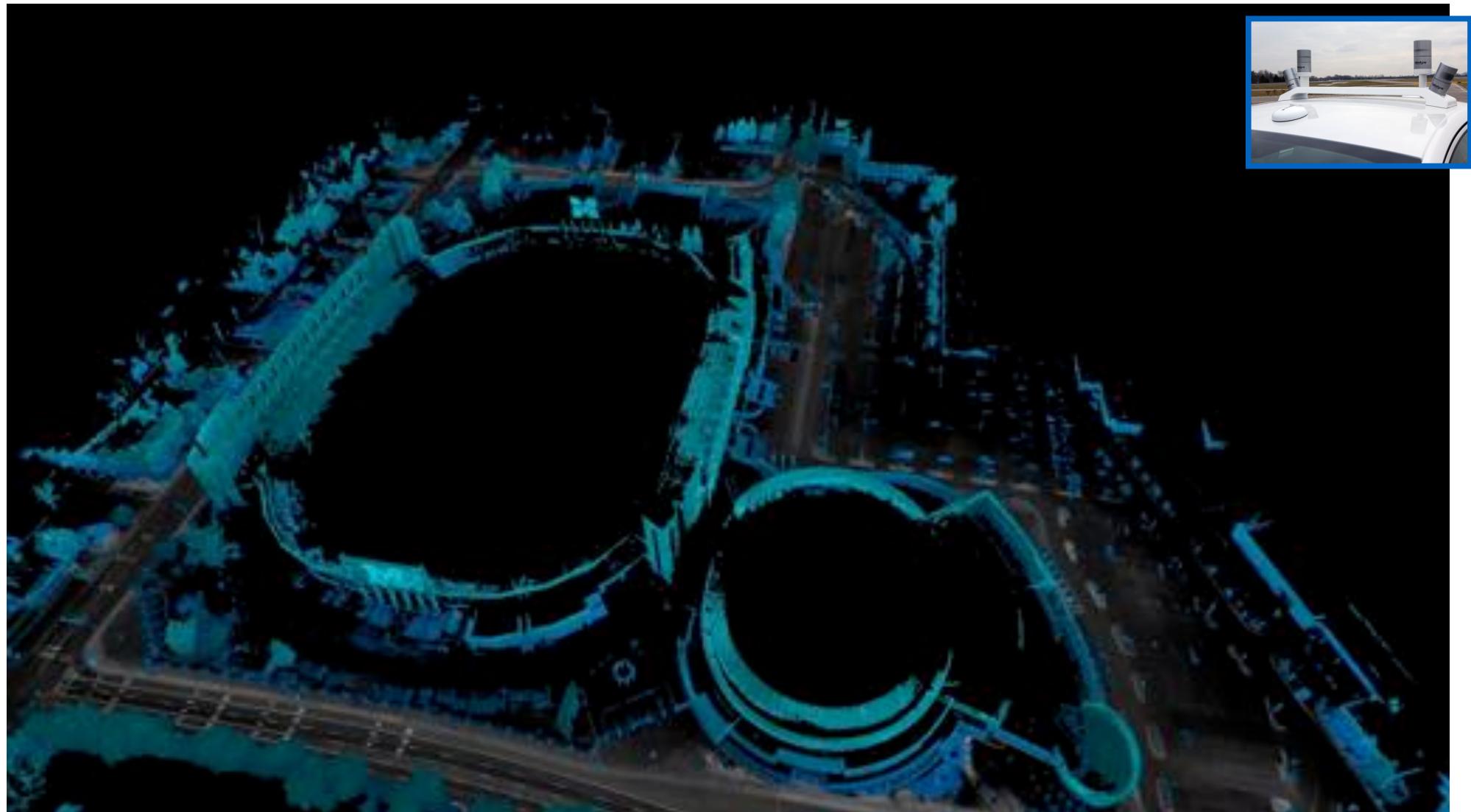
Jasmine Liu et al.

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Michigan Next Generation Vehicle (Olson, Eustice, et al.)

Michigan Robotics 06/16/2017 autorobot.org



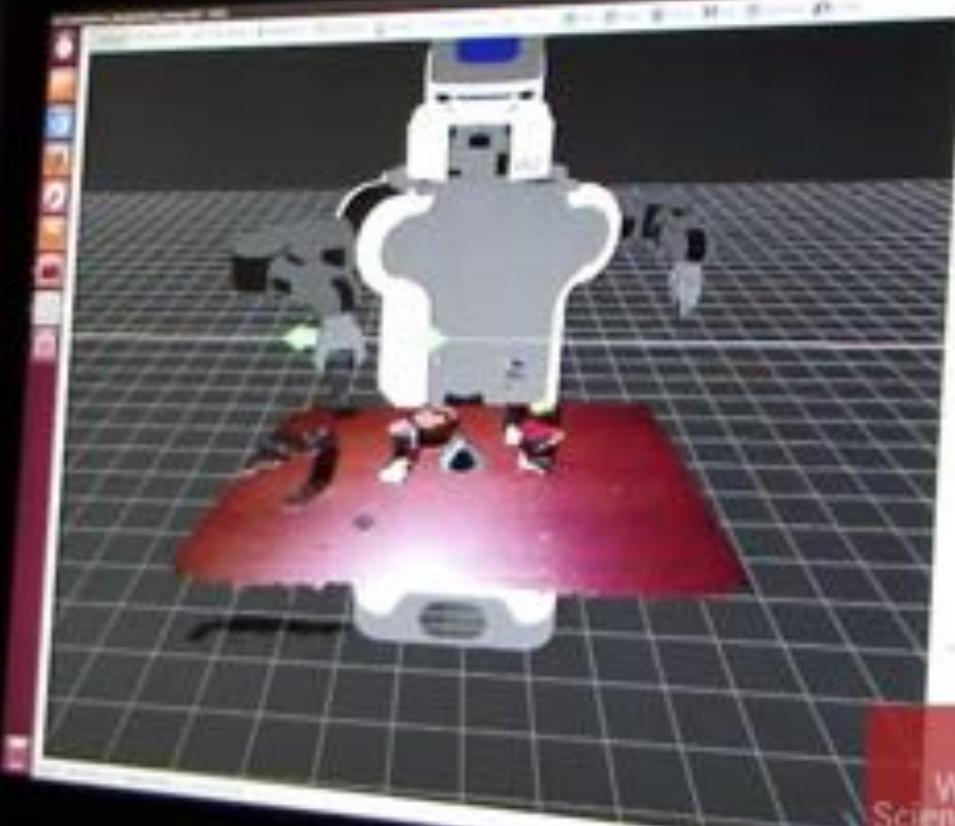
Michigan Next Generation Vehicle (Olson et al.)



Color+Depth Camera



Laser Rangefinder
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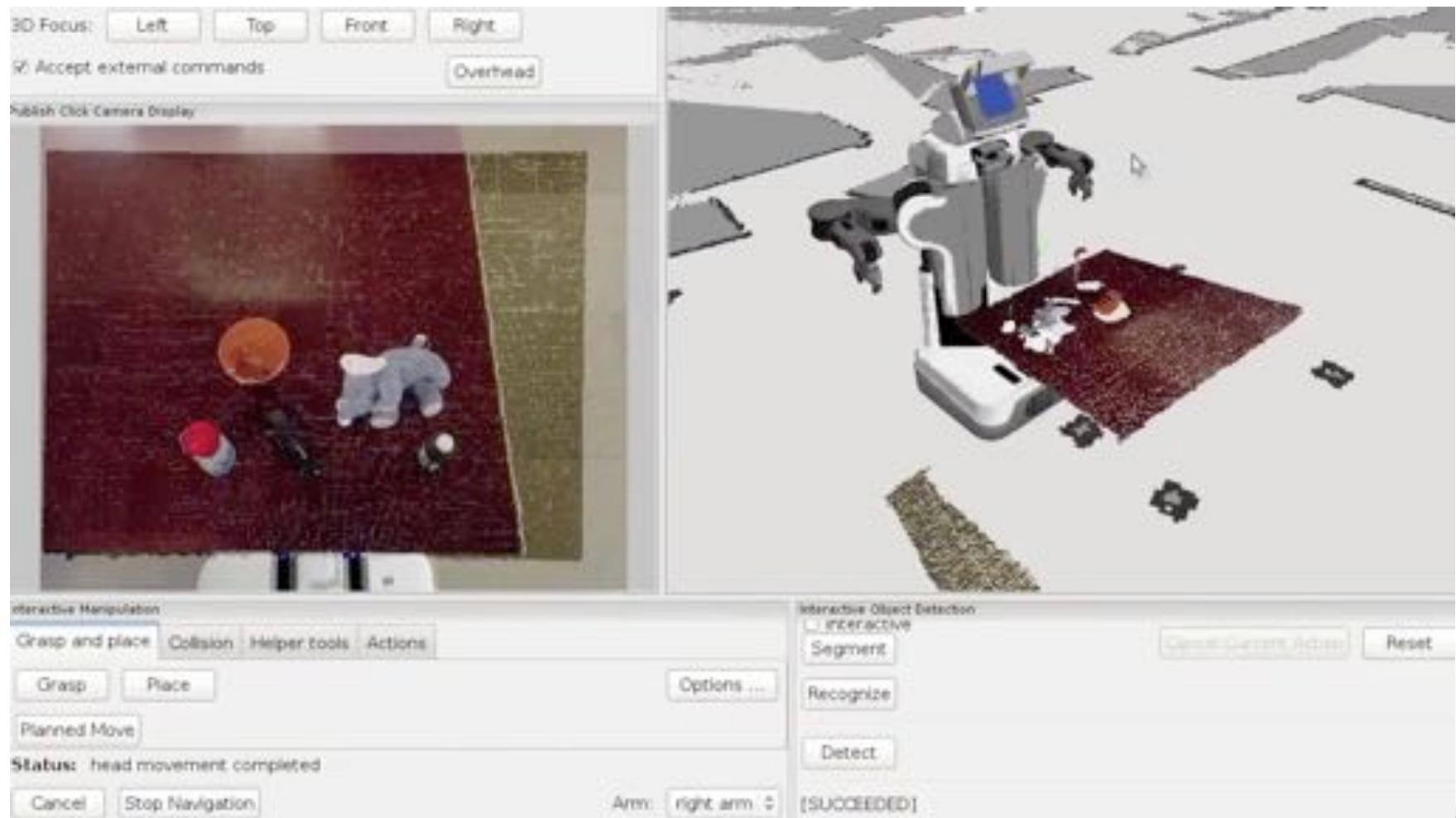


World
Science
Festival



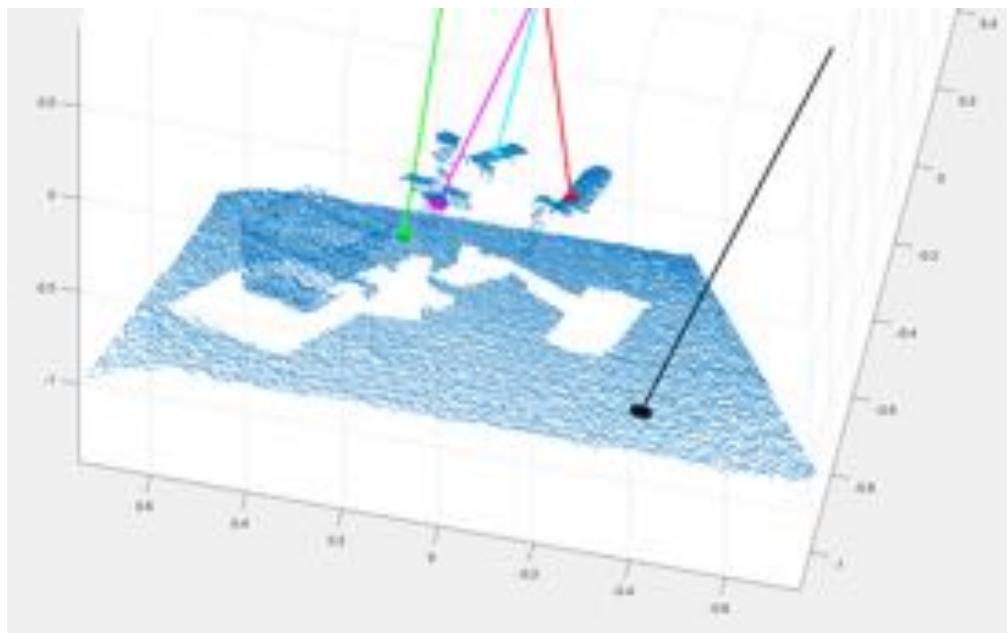
Object Manipulation

Willow Garage



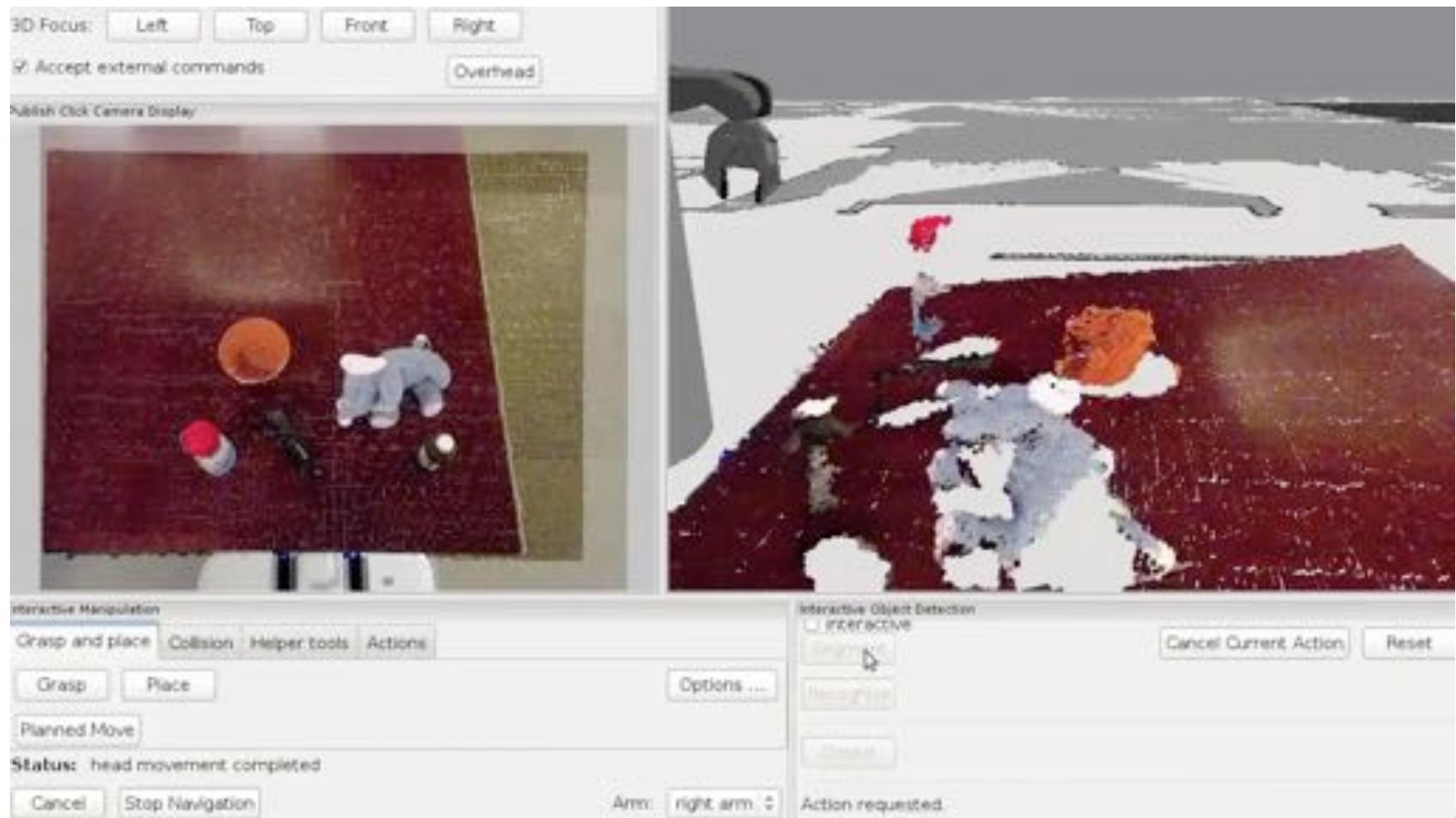
Point Cloud Processing (briefly)

- For every point:
 - compute nearest neighbors
 - compute principal components in neighborhood
`eig(cov(nbhd(:, 1:3)))`
 - surface normal is eigenvector for smallest eigenvalue
- Cluster points based on direction similarity of normal



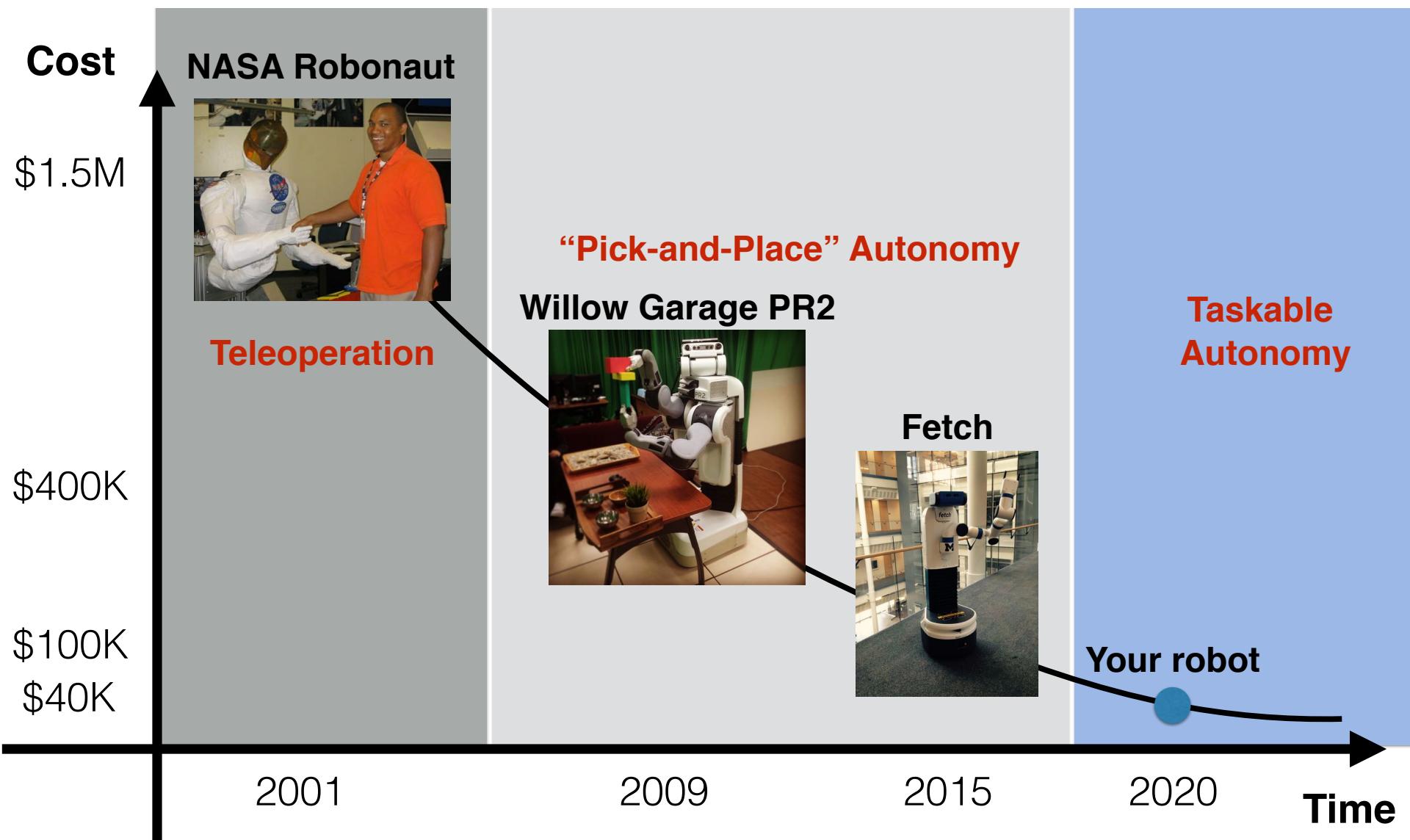
Object Manipulation

Willow Garage



[Sui, Jenkins, et al. IROS 2017]





Taskable Manipulation



Initial Scene → Goal Scene

“put small objects in bin”



“put small objects in bin”

[Sui, Xiang, Jenkins, Desingh, IJRR 2017]

Semantic Robot Programming

[Zeng, Jenkins, et al. ICRA 2018]



Enable natural user programming of robots
by demonstration of intended goal scenes



Goals shown in upper left corners

8x

Agenda

- So, where is my robot?
- Roadmap for autonomous robotics
- **Course administrative overview**
- Assignment 1 (Path Planning) assigned today
 - JavaScript/HTML5 and git covered this and next lecture

Course Staff

- Instructor: Chad Jenkins (ocj)
 - Office hours (Beyster 3644)
 - Monday 3-5pm, Tuesday 1-3pm
- GSI: Anthony Opiari (topipari)
 - Office hours (Beyster 1637 A)
 - Tuesday 1-3pm, Wednesday 3-5pm

Administrivia

- Lecture time/place: MW 1:30-2:40pm MMT, EECS 1500
 - 367 Lab Section: F 2:30-3:20 MMT, EECS 1500
- Website: <http://autorob.org>
- Discussion channel: <https://autorob.slack.com/>
 - This might switch to discord, mattermost, or IRC
- Office hours queue: <https://oh.eecs.umich.edu/courses/eecs567>

AUTOROB

schedule

kineval

git

assignments: 1 2

AutoRob

Introduction to Autonomous Robotics
Michigan EECS 367

Robot Kinematics and Dynamics
Michigan ME 567 EECS 567 ROB 510

Fall 2019



Course Schedule (tentative and subject to change)					
Note: Assignment descriptions will have updated assignment due dates. Assignment due dates listed in the schedule are merely a guide.					
Date	Topic	Reading	Project		
Sep 4	Initialization : Course overview, Robotics roadmap, Path planning quick start What is a robot? : Brief history and definitions for robotics	Spong Ch.1 Corke Ch.1	Setup git repository	Out: Path Planning	
Sep 6	367 Lab: Git-ing started with git, JavaScript, and KinEval				
Week 2					
Sep 9	Path Planning : DFS, BFS, A-star, Greedy best first Addendum : DFS example	Wikipedia	Crockford, HTML Sandbox , hello.html (source) , JavaScript by Example (source) , hello_anim (source) , hello_anim_text (source)		
Sep 11	JavaScript and git tutorial : Heap sort example Addendum : coding workflow				
Sep 13	367 Lab: search_canvas.html code overview				
Week 3					
Sep 16	Course meeting cancelled - off-site meeting				
Sep 18			Due: Path Planning		

Slack via web

The screenshot shows a web browser window displaying the Slack interface. The URL in the address bar is <https://autorob.slack.com/messages/CCGLB5XHA/>. The left sidebar has a dark theme and lists several channels and direct messages. The channel **# general** is highlighted with a green background, indicating it is the active channel. The main pane shows the **# general** channel page with a heading, purpose, and a recent message from Chad Jenkins.

Secure <https://autorob.slack.com/messages/CCGLB5XHA/>

autorob

Chad Jenkins

Jump to..

All Threads

Channels

advanced-extensions
asgn1-pathplan
asgn2-pendulum
asgn3-fk
asgn4-dance-fsm
asgn5-ik
asgn6-rrt
asgn7-best-use
general

random
staff

Direct Messages

slackbot
Chad Jenkins (you)
Maithili

#general

8 | 8 | 9 | 0 | Company-wide announcements and work-based matters

Search

@

general

You created this channel on August 28th. This is the very beginning of the **# general** channel. Purpose: This channel is for workspace-wide communication and announcements. All members are in this channel. [edit]

+ Add an app [Invite others to this channel](#)

Tuesday, August 28th

Chad Jenkins 3:16 PM
joined #general along with Maithili.

Message #general

Slack
OS X
app

Slack

autorob-w16

CHANNELS (3)

f16

w16

w16_random

DIRECT MESSAGES (52)

slackbot

ocj (you)

R

K1

M

N1

a

364

S

N5

BV

X8

+

EQ

#w16

51 members Compose Search

are treated as vector space. April 11th configurations are 11-dimensional vectors for the mr2 robot, 2-dimensional vectors for the canvas example, and 18-dimensional vectors for the Fetch robot.

ocj 7:14 PM @ [REDACTED] You are correct to be concerned about the relative weighting of dimensions for vectors in configuration space. Each dimension may need to be weighted based on the properties of that degree of freedom, such as its units, extents, scaling, etc. Scaling each dimension $\$i\$$ by a weight $\$w_i\$$ converts your computation of distance between two configurations $\$q\$$ and $\$q' \$$ to this form: $d(q, q') = \sqrt{\sum w_i (q_i - q'_i)^2}$

ocj 7:14 PM uploaded an image: Pasted image at 2016-04-11, 7:22 PM

$$d(q, q') = \sqrt{\sum w_i (q_i - q'_i)^2}$$

[REDACTED] 7:40 PM Okay, thanks

+ Message #w16

All Courses > Robotics 367/510/567 > Office Hours

Robotics 367/510/567

Office Hours (Beyster 3rd floor (3rd floor atrium))



Instructor's message [Edit](#) [Broadcast](#)

Priority given to questions about project concepts. Lower priority given to questions about regrading. (I am working on it.)

Instructor Mode

Student Mode

Instructor Queue Management

Queue Pop

Go Offline

Take All Instructors Offline

Empty Queue

Notifications

eecs.help can notify you when a request comes into an empty queue.

[Get notified](#)

[No thanks](#)

Requests 1

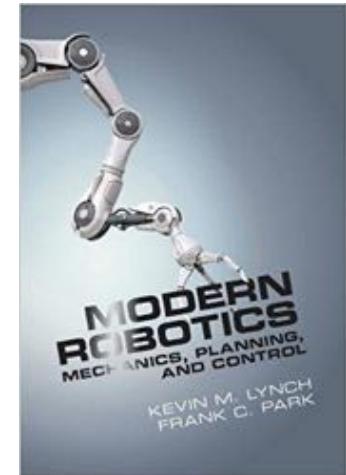
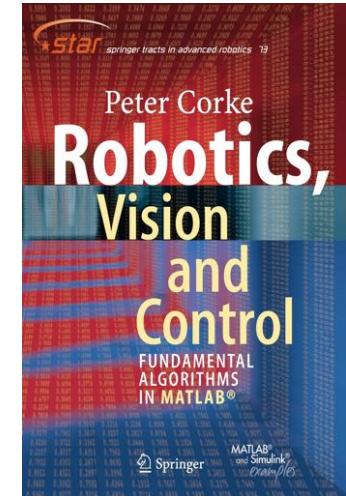


Course Structure

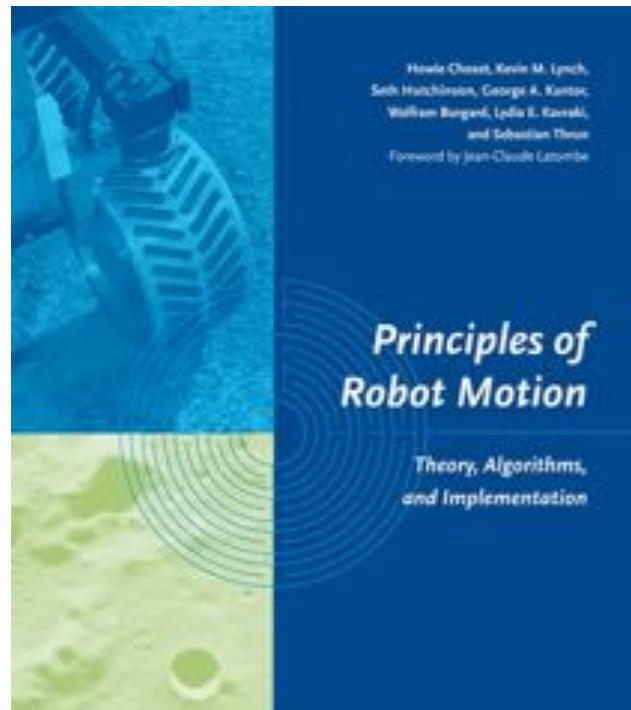
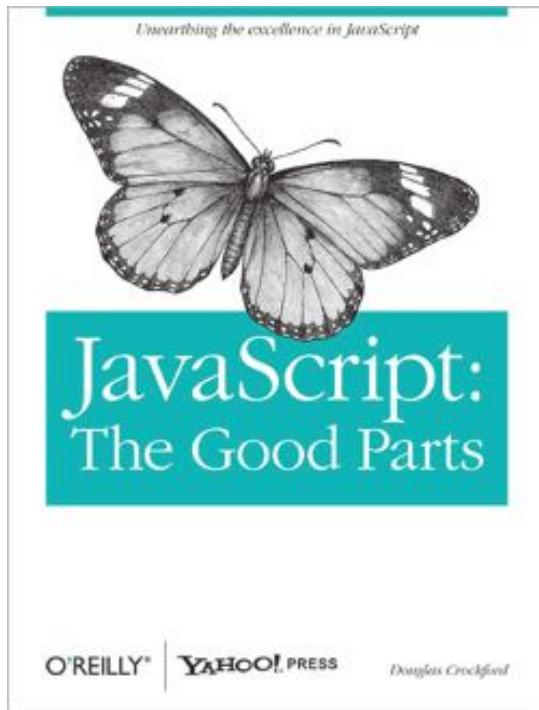
- Autonomous robot modeling and control
 - Objective: Give you the computational skills (and code) to model and control any mobile manipulator
- Project-focused class
 - 7 individual projects: from single joint control up to articulated motion planning
- Computing-friendly introduction to robotics: projects in JavaScript

Course Textbook

- Robot Modeling and Control (Spong, Hutchinson, Vidyasagar)
- Alternative: Robotics, Vision, and Control (Corke)
- Suggested but unsupported: Modern Robotics (Lynch and Park)
- In-depth coverage of concepts and math contained in textbooks
- Additional handouts and links will appear on the course website



Optional reading



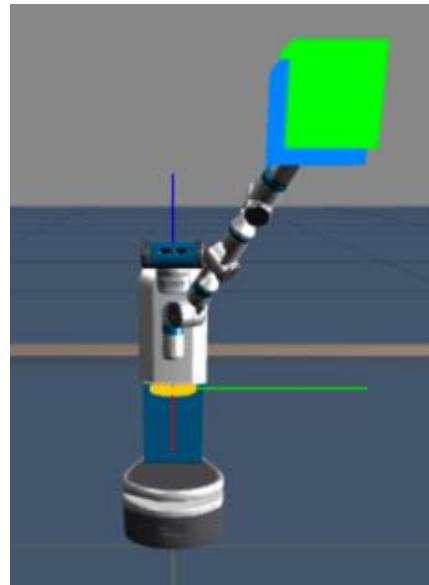
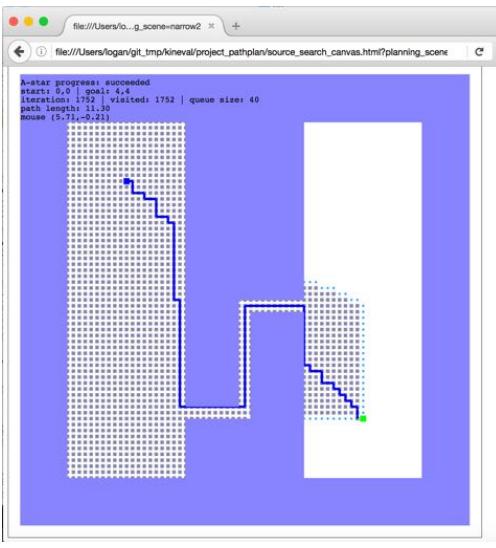
Projects

- Projects implemented in JavaScript/HTML5 using KinEval stencil
 - Projects submitted and tracked through git (gitlab|github|bitbucket)
 - Instructor (ohseejay|ocj) needs admin access
- 7 projects
 - 6 Programming, 1 Written/Oral
- Grading: projects are broken down into features that are “checked”
 - points are earned through successful implementation of features

Projects

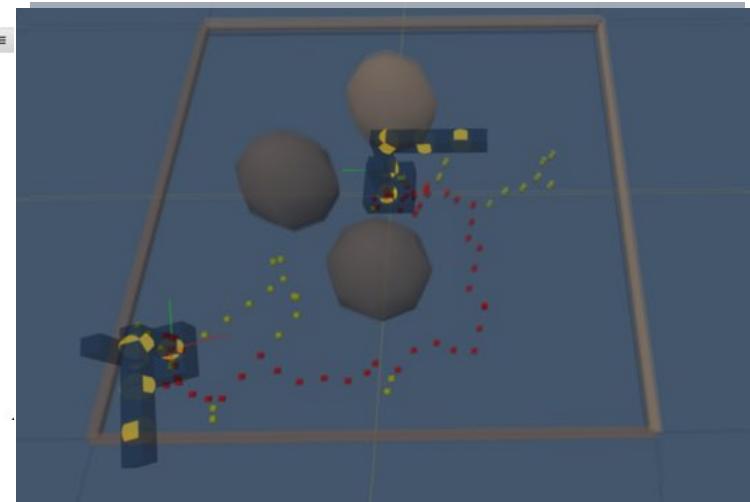
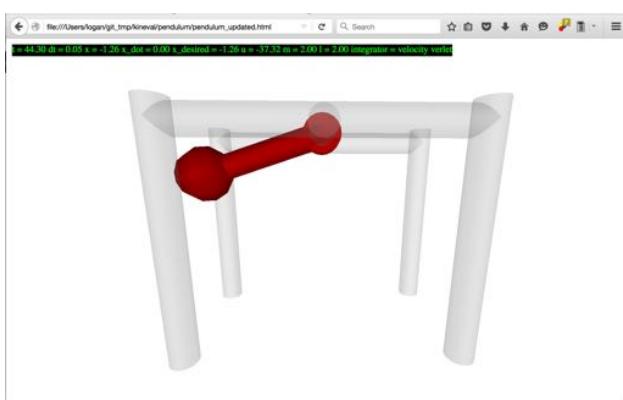
- **Path Planning** A-star search in 2D world
- **Pendulum** physical simulation and PID control of 1 DoF robot
- **Forward Kinematics** convert robot configuration to 3D space
- **Dance Contest** control of robot joints to do a dance
- **Inverse Kinematics** control gripper of a robot to reach a point in 3D
- **Motion Planning** collision-free planning over robot configurations
- **Best Use of Robotics** what will you do with all of this power?

- Path Planning



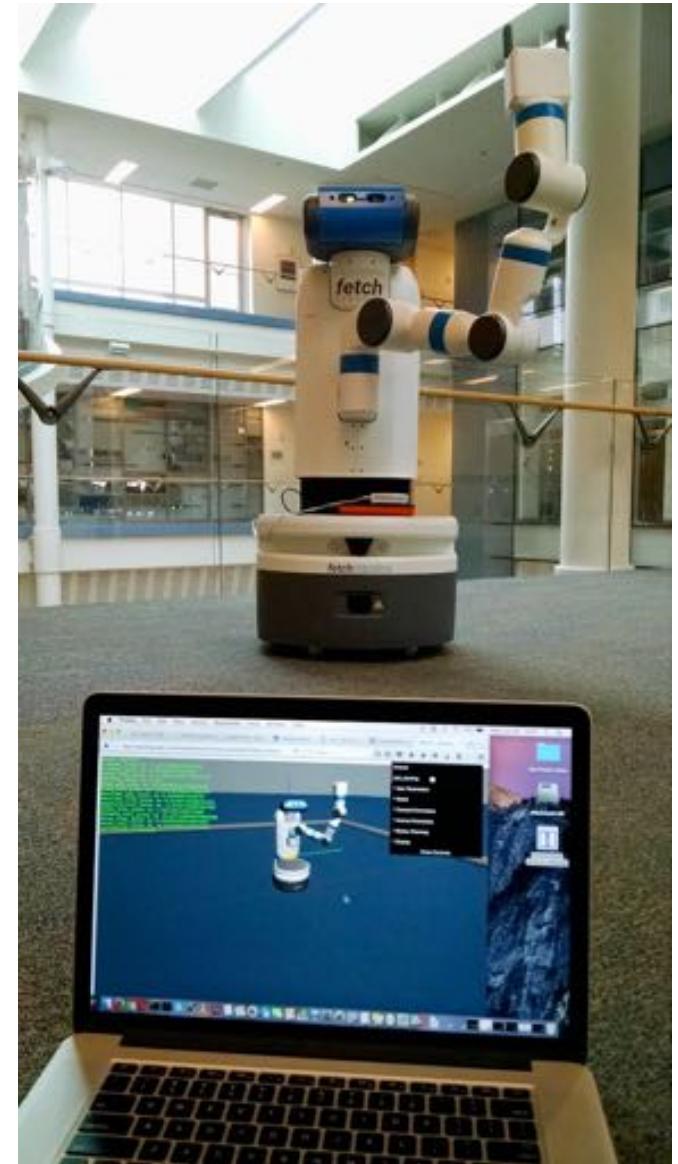
- FK/IK

- Pendularm



- RRT

Will you work with a real robot?



Will you work with
a real robot?

Yes, at least once
using rosbridge/ROS



Grading Summary

EECS 367: Introduction to
Autonomous Robotics

- 7 projects (12 points each)
- 5 quizzes (4 points each)

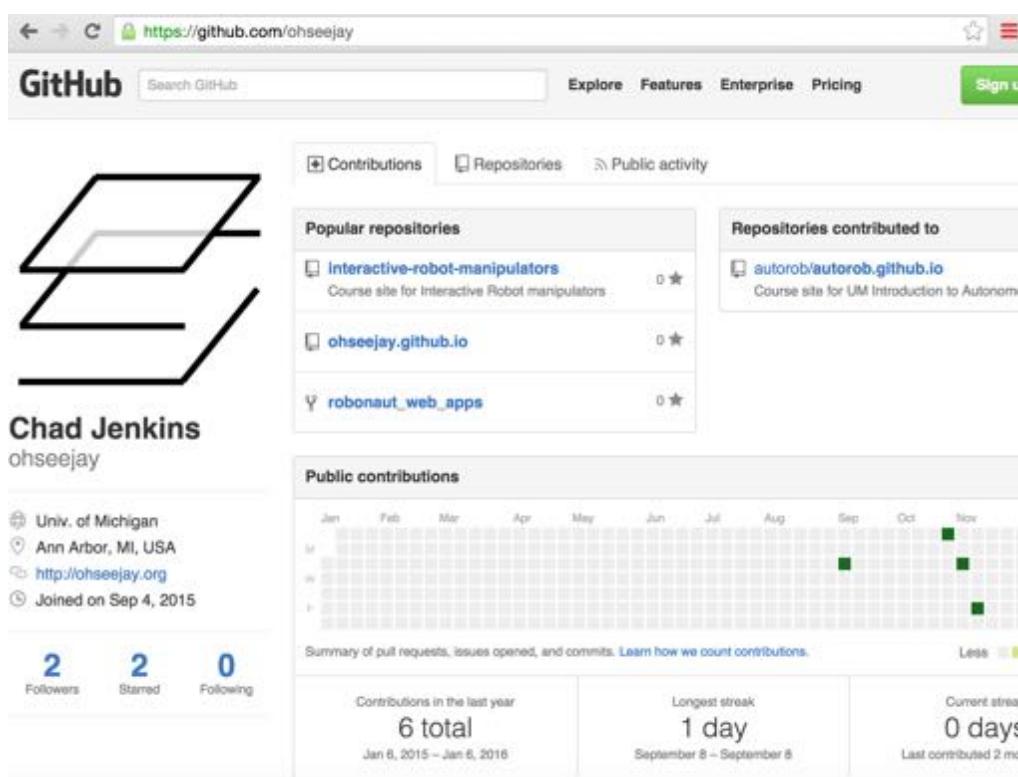
A: 93+ points
B: 83+ points
C: 73+ points

ME/EECS 567 ROB 510:
Robot Kinematics and
Dynamics

- 7 projects (18 points each)
- 5 quizzes (4 points each)
- Advanced features (4 points)

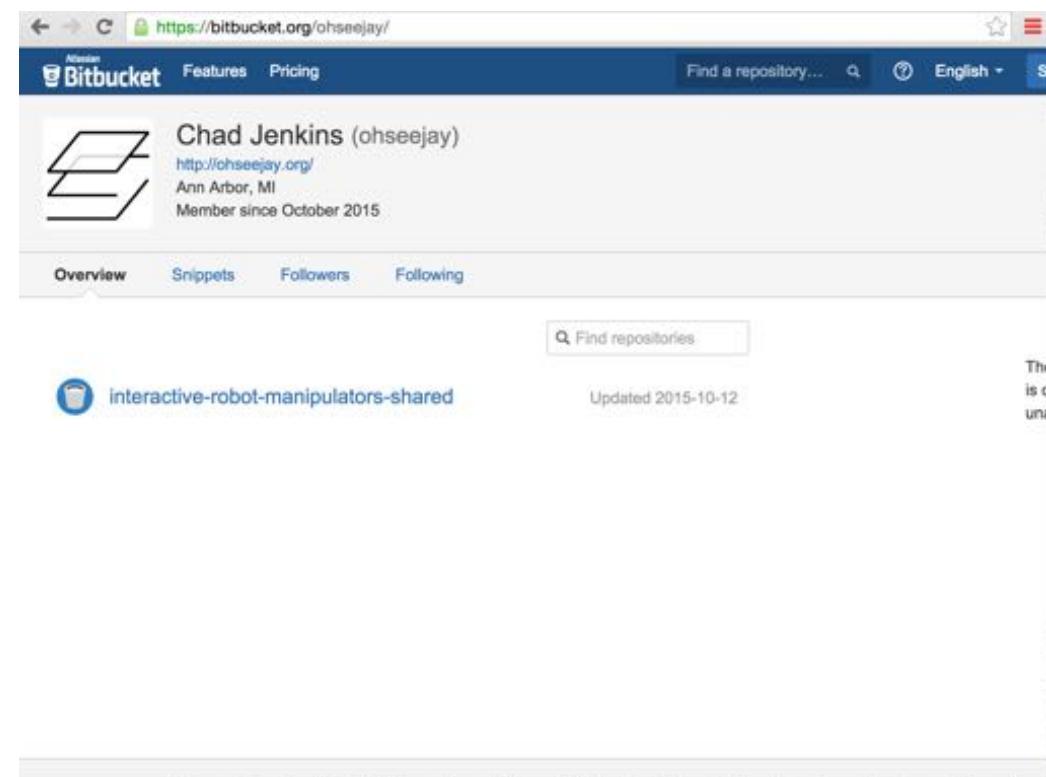
A: 135+ points
B: 120+ points
C: 105+ points

github.com/ohseejay



A screenshot of a GitHub user profile page for 'ohseejay'. The profile picture is a stylized drawing of a robotic arm. The name 'Chad Jenkins' and handle 'ohseejay' are displayed. Below the profile picture, there's a summary of contributions: 2 Followers, 2 Starred, and 0 Following. The main content area shows 'Popular repositories' including 'interactive-robot-manipulators', 'ohseejay.github.io', and 'robonaut_web_apps'. It also displays 'Public contributions' with a heatmap showing activity in September and October. Summary statistics at the bottom show 6 total contributions in the last year, a longest streak of 1 day from September 8 to September 8, and a current streak of 0 days.

bitbucket.org/ohseejay



A screenshot of a Bitbucket user profile page for 'ohseejay'. The profile picture is the same as the GitHub one. The name 'Chad Jenkins (ohseejay)' and handle 'ohseejay' are displayed. It shows 'Member since October 2015'. Below the profile picture, there are tabs for 'Overview', 'Snippets', 'Followers', and 'Following'. A repository named 'interactive-robot-manipulators-shared' is listed, updated on 2015-10-12. At the bottom, there's a navigation bar with links to 'Blog', 'Support', 'Plans & pricing', 'Documentation', 'API', 'Site status', 'Version info', 'Terms of service', and 'Privacy policy'.

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gitlab.eecs.umich.edu/ocj

The screenshot shows a GitLab user profile for a user named 'ocj'. The profile page includes a bio section with a red fox logo, activity feed showing recent pushes to 'ocj / testing' branches, and a summary of issues. The URL in the browser bar is <https://gitlab.eecs.umich.edu/u/ocj>.

Activity

Groups

Contributed projects

Personal projects

Snippets

Summary of Issues, n

about 4 hours ago

about 4 hours ago

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Collaboration Policy

- All work submitted must be your own
 - All code submitted must comply with Michigan Honor License
- No code can be communicated, including verbally
 - Explicit use of external sources must be clearly cited
 - Repositories must be **private** for proper compliance
- Free flow of discussion and ideas is encouraged

Michigan Honor License

- 3-Clause BSD License + Michigan Honor Code + proper citation
- Assert the compliance of your code with the MHL
 - Append your name to the end of LICENSE in your repository
- Submitted code will not be graded without asserting LICENSE

Late Policy

- Projects submitted after deadline may not be graded (zero credit)
- If a late submission is allowed, it can receive at most
 - 80% credit if pushed within 2 weeks of the deadline
 - 60% credit if pushed within 4 weeks of the deadline
 - 50% credit if pushed anytime before final grading

Regrading policy

- Projects features are graded with:
 - “CHECK” (sufficiently completed)
 - “DUE” (insufficiently completed)
 - “PENDING” (not due yet)
- A project feature can be regraded for partial credit for at most
 - 80% credit if pushed within 2 weeks of the last returned grading
 - 60% credit if pushed anytime before final grading

[sdnt / repository name](#) [Private](#)

[Unwatch](#) [2](#) [Star](#) [0](#) [Fork](#) [0](#)

[Code](#) [Issues 0](#) [Pull requests 0](#) [Projects 0](#) [Wiki](#) [Insights](#)

Projects for EECS398 Intro to Autonomous Robotics at the University of Michigan

71 commits 7 branches 0 releases 3 contributors

Branch: master [New pull request](#) [Create new file](#) [Upload files](#) [Find file](#) [Clone or download](#)

	sdnt Updated motion planning to disallow rotations about x-z axis	Latest commit b14c770b Jan 10
	js	Fall 2016 release
	kinerva	Disallow rotations about x-z axis. Fixed return val. Can now trace path
	project_pathplan	2d rrt-connect complete using drawHighlightedPath. Had to change give...
	project_pendulum	pendulum seems complete
	robots	Fall 2016 release
	tutorial_heapsort	Added heap increase key function to heap.js to help with A* algorithm
	tutorial_js	Playing with Javascript samples
	worlds	Deleted all source_*.js files and added honorb.txt
	.gitignore	Implemented and tested matrix multiply and matrix transpose
	README.md	Fall 2016 release
	grading.txt	added grading for Final grading
	home.html	Fall 2016 release

Branch: master ▾

repository name / grading.txt

 odestoj added grading for Final grading

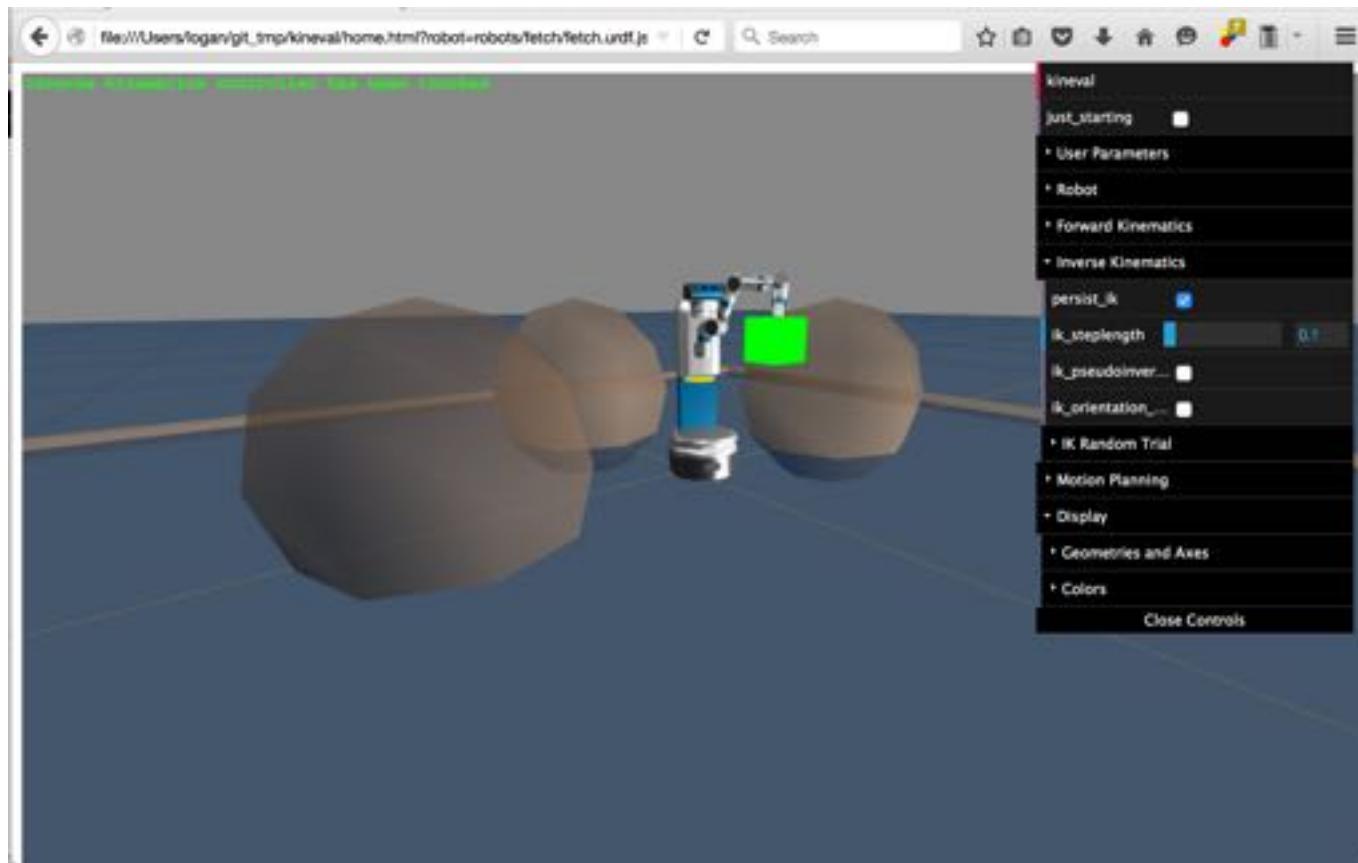
1 contributor

60 lines (58 sloc) 2.26 KB

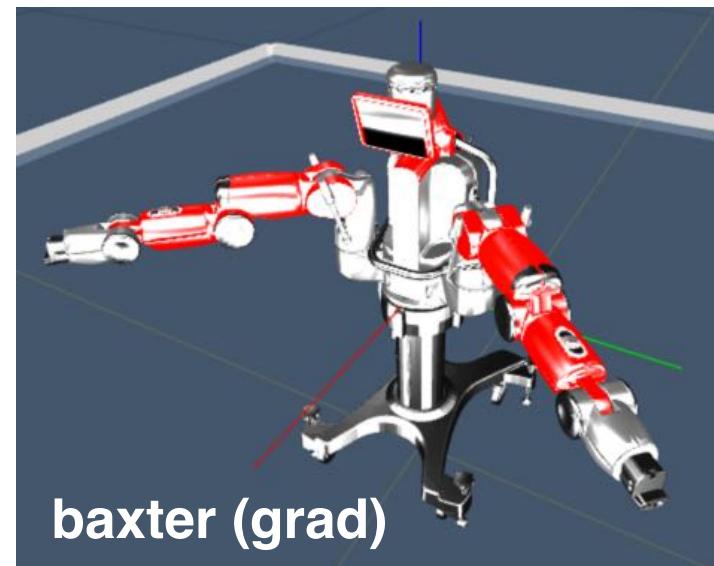
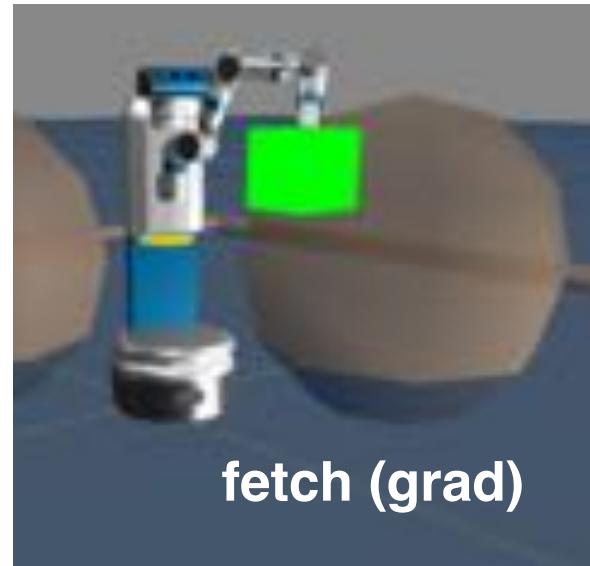
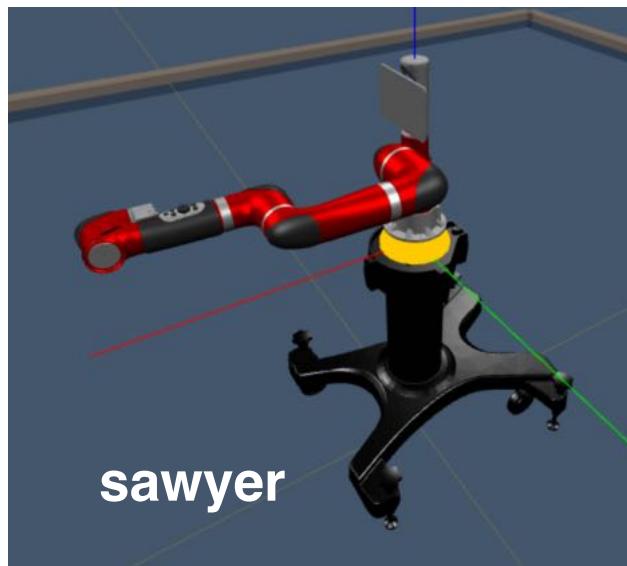
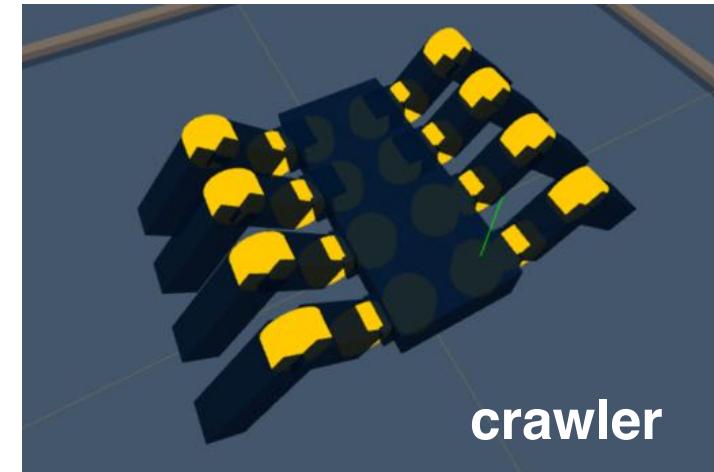
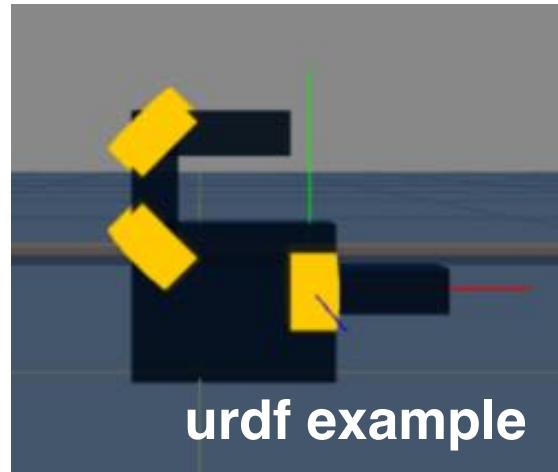
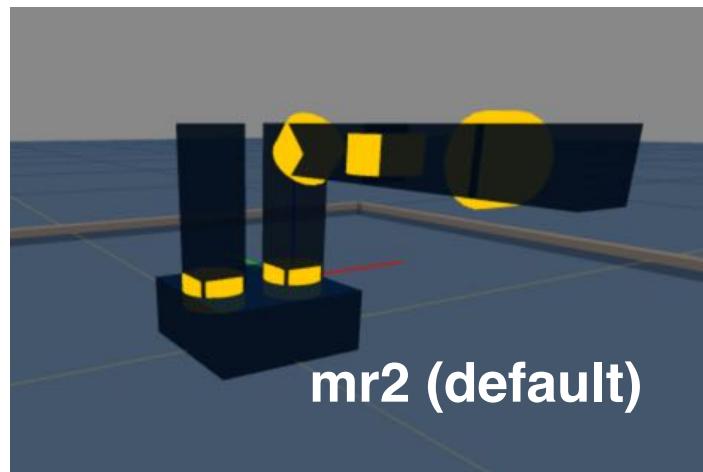
[Raw](#) [Blame](#)

```
1 53: student name
2 EECS 398-004 F16
3 Assignment 1 feature 1 (4.00/4): PathPlan_Heap: CHECK
4   comment: good work
5 Assignment 1 feature 2 (8.00/8): PathPlan_AStar: CHECK
6   comment: good work
7 Assignment 2 feature 3 (4.00/4): Pendularm_Euler: CHECK
8   error: Euler integrator is incorrect
9   comment: why is this integrator stable?
10  error: integration of dynamics is incorrect
11  comment: double check computation of pendulum acceleration
12  regrade: servo converges after several oscillations, borderline control performance
13 Assignment 2 feature 4 (4.00/4): Pendularm_VelocityVerlet: CHECK
14   error: integration of dynamics is incorrect
15   comment: double check computation of pendulum acceleration
16   regrade: working
17 Assignment 2 feature 5 (4.00/4): Pendularm_PID: CHECK
18   error: integration of dynamics is incorrect
19   comment: modulo correction is not needed
20 Assignment 3 feature 6 (2.00/2): FK_MatrixRoutines: CHECK
```

KinEval code stencil



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KINNOVA

MOVO^{BETA}

A MOBILE
MANIPULATOR
PLATFORM

kinovaMOVO.com



Maybe also?



KINNOVA

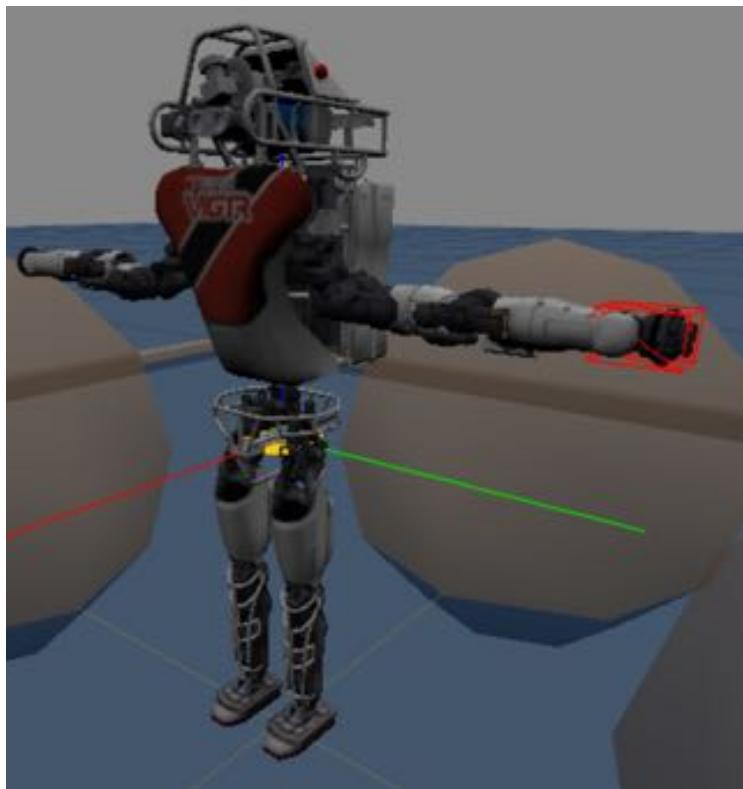
MOVO^{BETA}

A MOBILE
MANIPULATOR
PLATFORM

kinovaMOVO.com



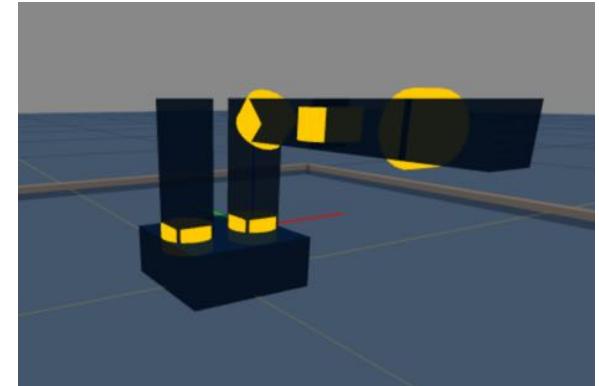
Maybe also?



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KinEval code stencil

- Code stencil for AutoRob projects in 3D
- Uses threejs 3D rendering library and WebGL
- URDF-like robot description
- Usable, but not perfect, camera and UI controls
- AABB collision detection provided for planning
- Warning: professor-level coding



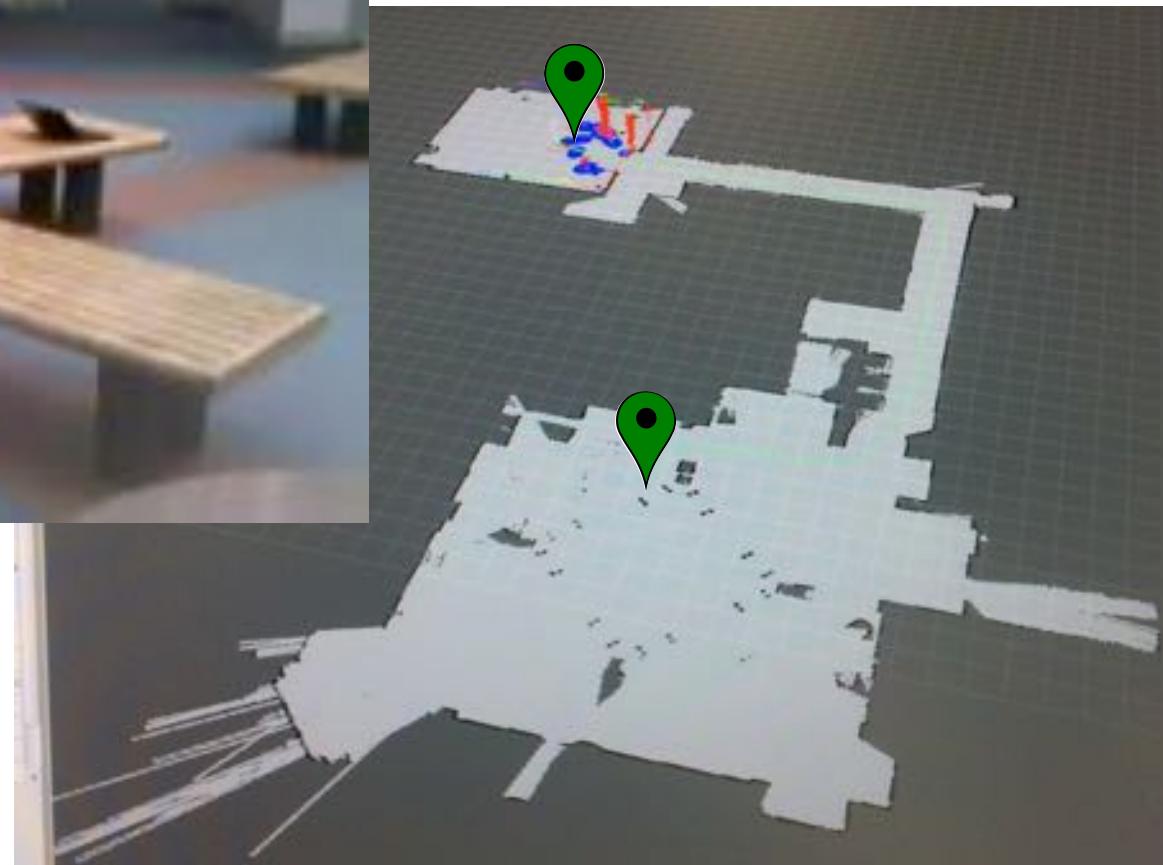
Let's start with base navigation

(Lecture 2 foreshadowing)



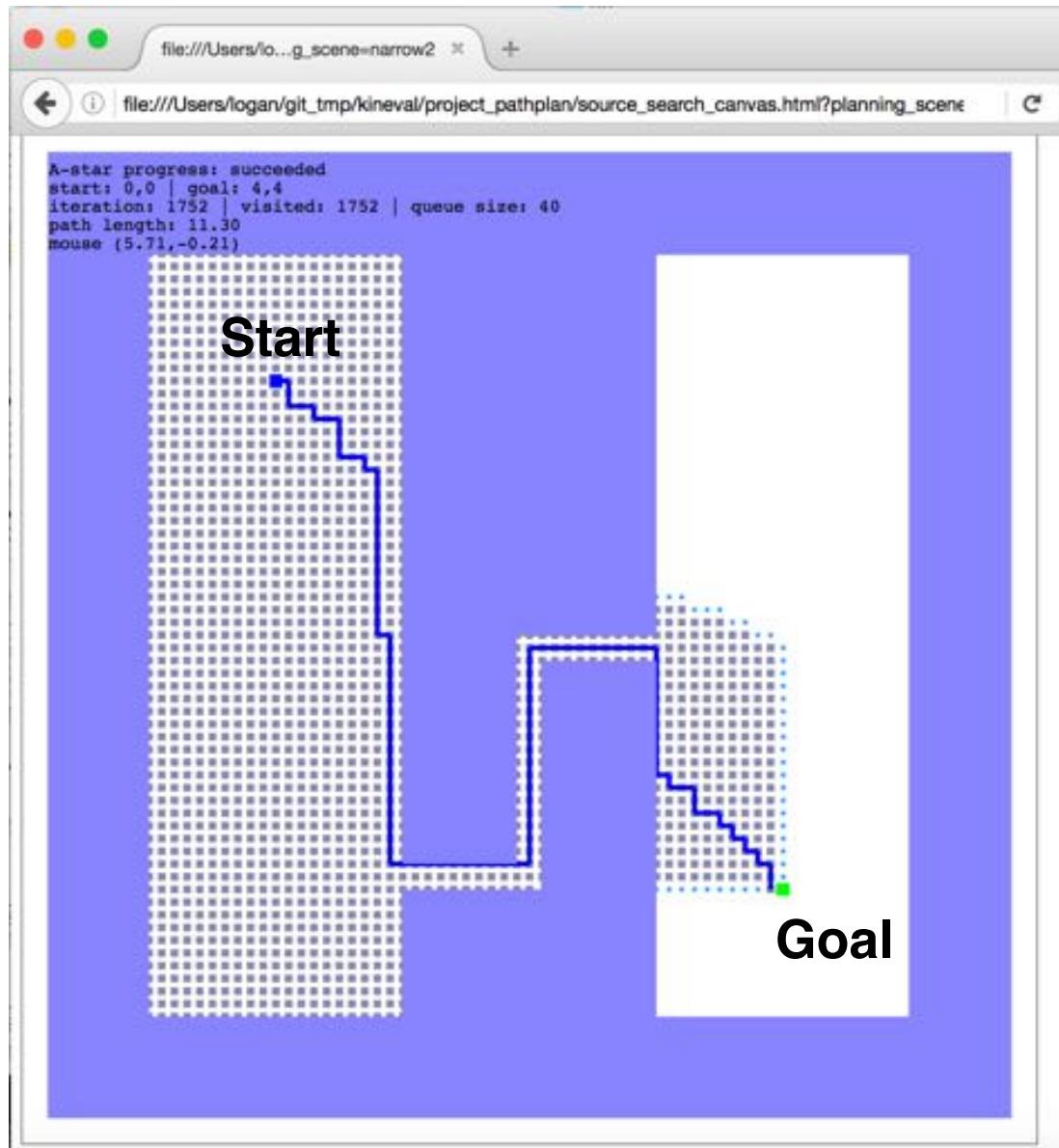
Let's start with base navigation

How to get from Location A to
Location B?



Project 1: 2D Path Planning

- A-star algorithm for search in a given 2D world
- Implement in JavaScript/HTML5
- Heap data structure for priority queue
- Grads: DFS, BFS, Greedy
- Submit through your git repository



Dijkstra shortest path algorithm

```
all nodes  $\leftarrow \{dist_{start} \leftarrow \text{infinity}, parent_{start} \leftarrow \text{none}, visited_{start} \leftarrow \text{false}\}$   
start_node  $\leftarrow \{dist_{start} \leftarrow 0, parent_{start} \leftarrow \text{none}, visited_{start} \leftarrow \text{true}\}$   
visit_queue  $\leftarrow \text{start\_node}$ 
```

```
while visit_queue != empty && current_node != goal
```

```
    cur_node  $\leftarrow \text{min\_distance(visit\_queue)}$ 
```

```
    visitedcur_node  $\leftarrow \text{true}$ 
```

```
    for each nbr in not_visited(adjacent(cur_node))
```

```
        enqueue(nbr to visit_queue)
```

```
        if distnbr > distcur_node + distance(nbr,cur_node)
```

```
            parentnbr  $\leftarrow \text{current\_node}$ 
```

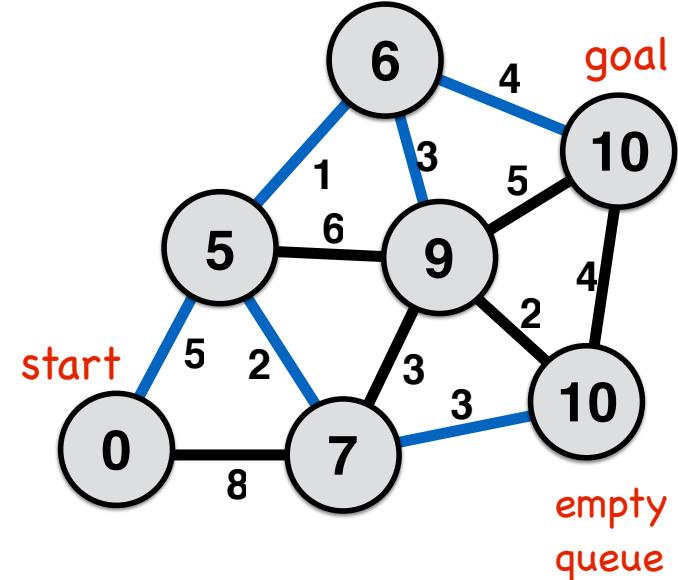
```
            distnbr  $\leftarrow dist_{cur\_node} + distance(nbr,cur\_node)$ 
```

```
        end if
```

```
    end for loop
```

```
    end while loop
```

```
output  $\leftarrow \text{parent, distance}$ 
```



A-star shortest path algorithm

```
all nodes  $\leftarrow \{dist_{start} \leftarrow \text{infinity}, parent_{start} \leftarrow \text{none}, visited_{start} \leftarrow \text{false}\}$ 
```

```
start_node  $\leftarrow \{dist_{start} \leftarrow 0, parent_{start} \leftarrow \text{none}, visited_{start} \leftarrow \text{true}\}$ 
```

```
visit_queue  $\leftarrow \text{start\_node}$ 
```

```
while (visit_queue != empty)  $\&\&$  current_node != goal
```

```
    dequeue: cur_node  $\leftarrow f\_score(\text{visit\_queue})$  ← implement min binary heap for priority queue
```

```
    visitedcur_node  $\leftarrow \text{true}$ 
```

```
    for each nbr in not_visited(adjacent(cur_node))
```

```
        enqueue: nbr to visit_queue
```

```
        if distnbr > distcur_node + distance(nbr,cur_node)
```

```
            parentnbr  $\leftarrow \text{current\_node}$ 
```

```
            distnbr  $\leftarrow dist_{cur\_node} + distance(nbr,cur\_node)$ 
```

```
            f_score  $\leftarrow distance_{nbr} + line\_distance_{nbr,goal}$ 
```

```
        end if
```

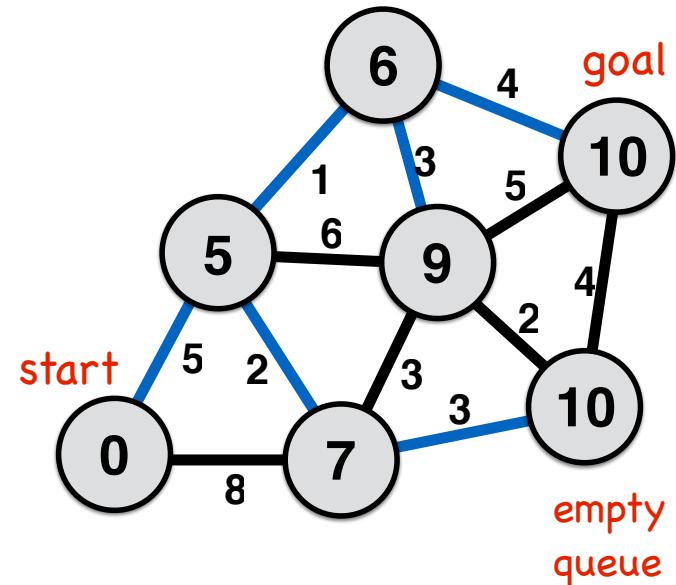
```
    end for loop
```

```
    end while loop
```

```
output  $\leftarrow \text{parent, distance}$ 
```

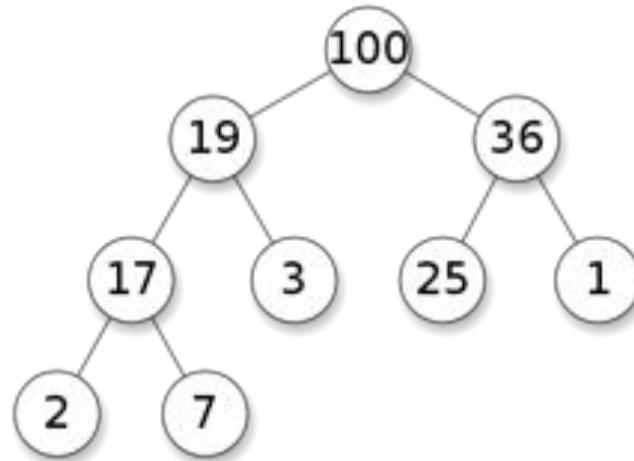
g_score:
distance along path

h_score:
best distance to goal

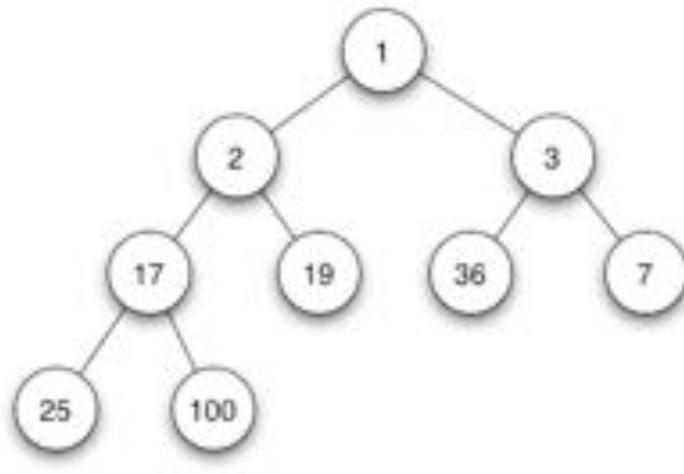


Heaps

A heap is a tree-based data structure satisfying the heap property:
every element is greater (or less) than its children



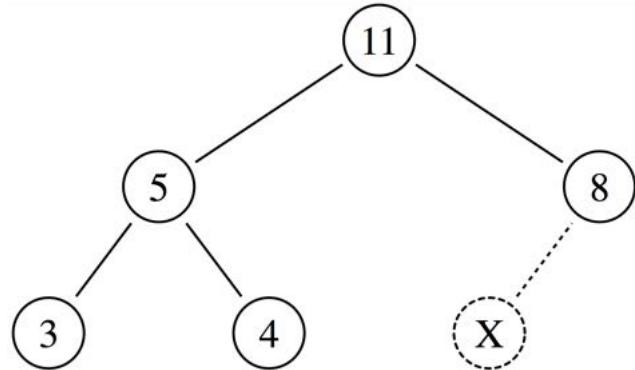
max heap



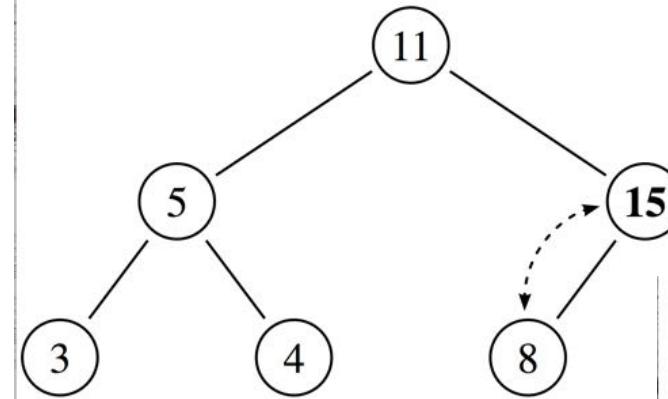
min heap

Heap operations: Insert

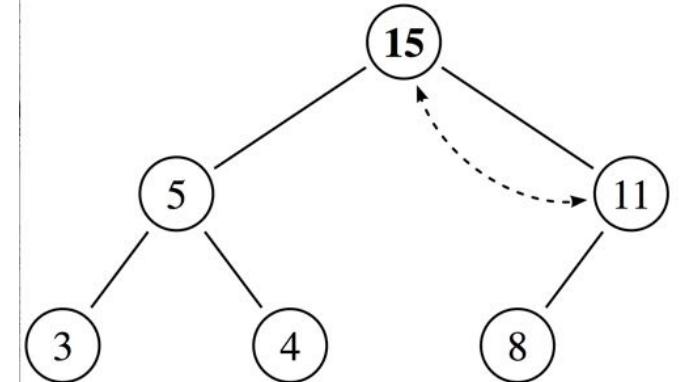
1) add new element to end of tree



2) swap with parent

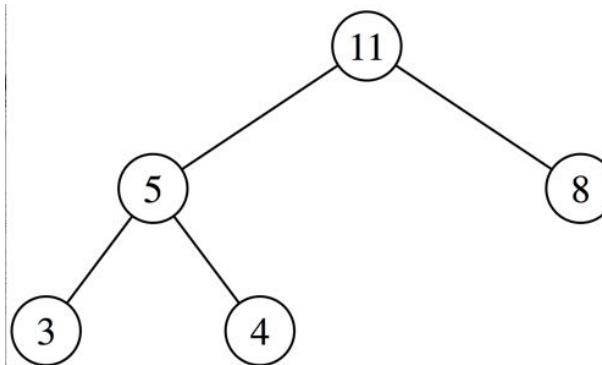


3) until heaped, do (2)

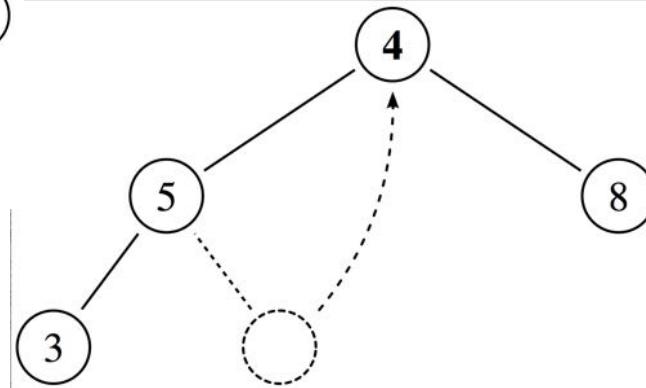


Heap operations: Extract

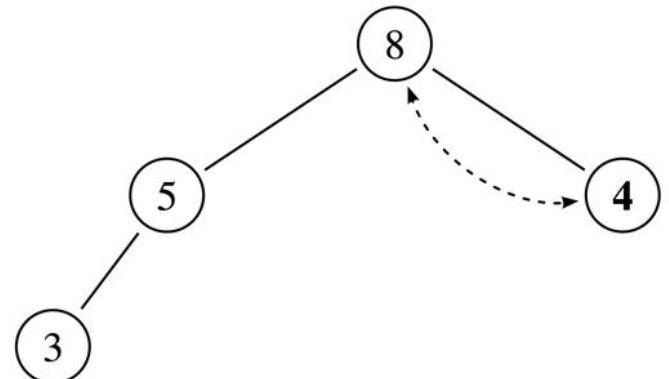
1) extract root element



2) put last element at root



3) swap with smaller child
4) until heaped, do (3)



```
<!DOCTYPE html>                                         heapsort.html
<html>
  <head>
    <title>Heap Sort by Chad Jenkins</title>
  </head>
  <body onload=startMeUp()>                         HTML5 document will invoke  
JavaScript function at start
    <a href="http://ohseejay.org"><h1>My Heap Sort</h1></a>
    <canvas width=900 height=200 id="myCanvas"></canvas>
    <div id="output">hello world</div>
  </body>
</html>

<script>
function startMeUp() {
  .. executable code to perform heapsort; will depend on heap.js ...
}
</script>
```

git basics

- Create a git repository from gitlab, github, or bitbucket website
- Install git on your machine
 - <https://git-scm.com/book/en/v2/Getting-Started-Installing-Git>
 - OSX: <https://code.google.com/p/git-osx-installer/>

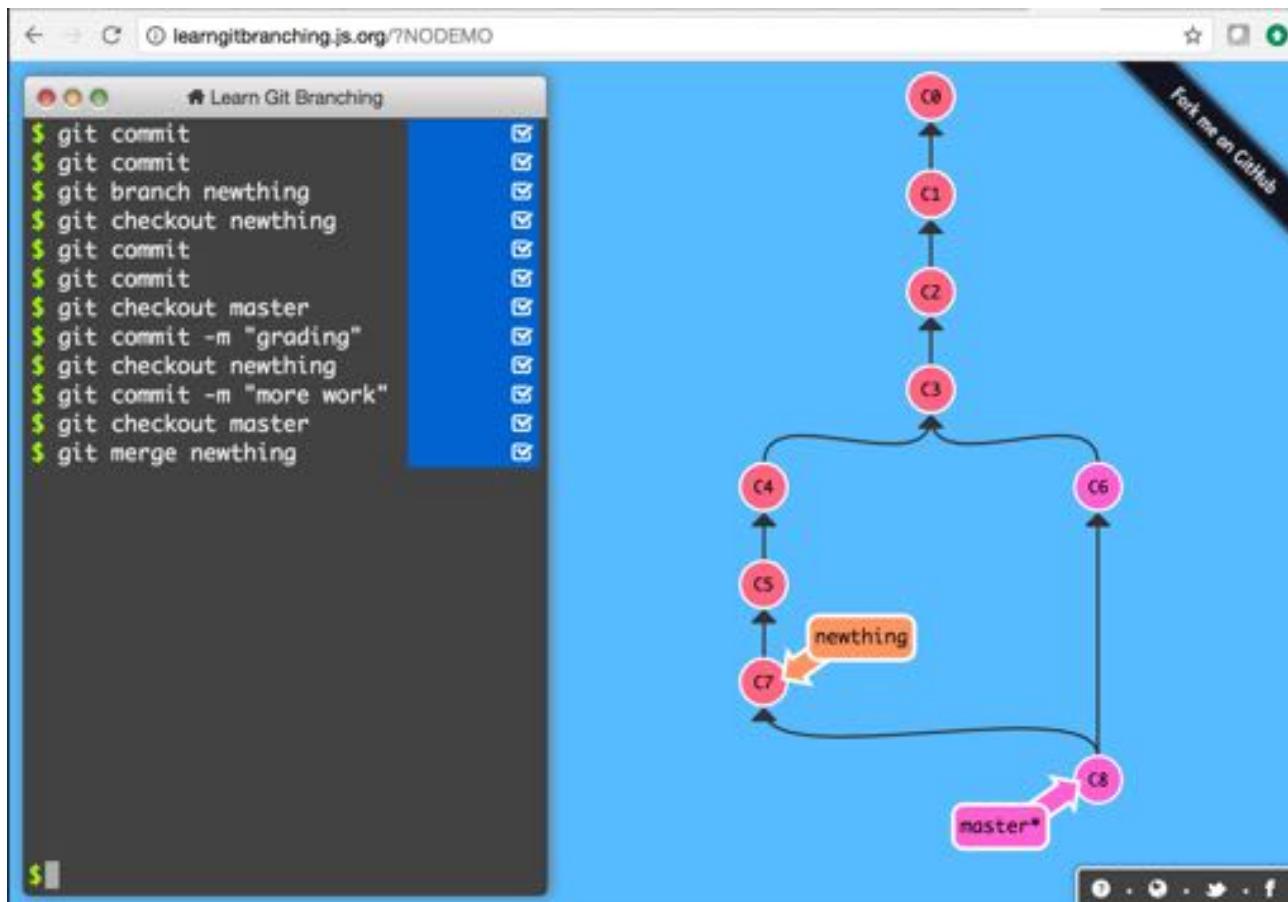
git basics

- create a local copy of a repository: `git clone <repo url>`
- add files to a repository: `git add <file listing>`
- commit changes to local repository: `git commit -a -m "<msg>"`
- push local changes to a remote repository: `git push`
- pull remote changes to a local repository: `git fetch` or `git pull`
- create a code branch in a repository: `git branch <branch name>`
- checkout a code branch from a repository : `git branch <branch name>`
- merge branches in a repository:

```
git checkout <branch name>
```

```
git merge <other branch name>
```

Highly recommended tutorial



<http://learngitbranching.js.org/>

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Can I enroll in this class?

- Most likely! Probably yes!
- We will try to enroll all who want to take the course
- Enrollment issues can be discussed at office hours or lab section
 - Friday 2:30-3:30pm in EECS 1500
 - Monday 3-5pm and Tuesday 1-3pm in Beyster 3644

What I need from you **now**

- Accept invitation to the course discussion channel (coming tonight)
 - <https://autorob.slack.com>
- Install git and setup your working environment
 - create a git repository: <https://gitlab.eecs.umich.edu/>
 - ensure you can clone, commit, and push files to your repository
- Over the discussion channel, send me:
 - informal introduction confirming your name, email, and enrollment
 - pointer to your git repo for the course

What I need from you **soon**

- Get started on Assignment 1 (Path Planning)
 - Clone kineval-stencil repository (release this weekend)
 - Study examples in tutorial_js subdirectory
 - Complete tutorial_heapsort (noted with “STENCIL” in files)
 - Complete project_pathplan (concepts covered next week)

What is a robot?

(be sure to ready over Lecture 0)