

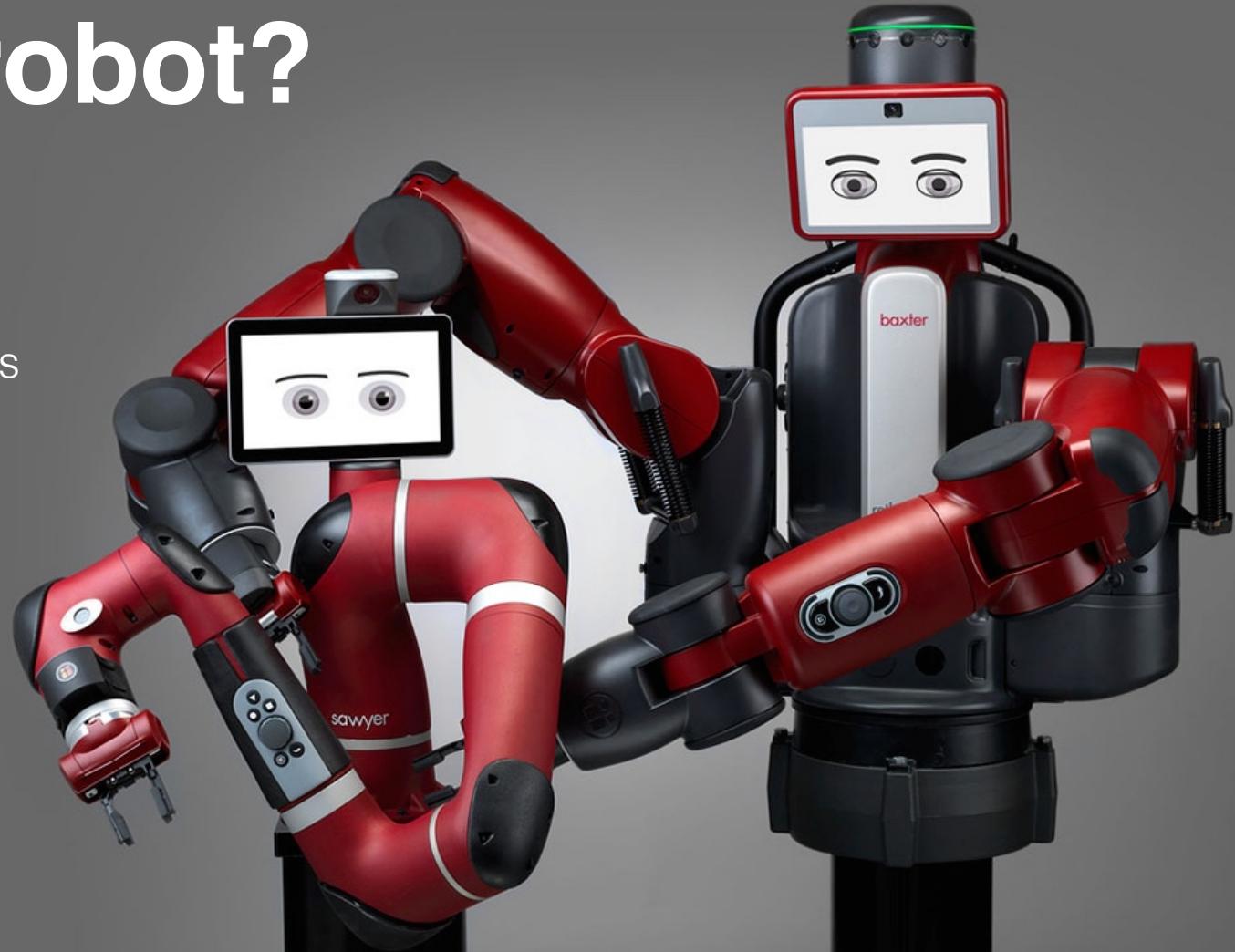
# What is a robot?

EECS 367  
Intro. to Autonomous Robotics

ROB 511  
Robot Operating Systems

Fall 2020

[autorob.org](http://autorob.org)



# What is a robot?

(don't be shy with your answer)



SINCE 1828

JOIN MWU | GAMES | BROWSE THESAURUS | WORD OF THE DAY | VIDEO | WORDS AT PLAY

robot

DICTIONARY

THESSAURUS

1 : a machine that resembles a living creature in being capable of moving independently (as by walking or rolling on wheels) and performing complex actions (such as grasping and moving objects)

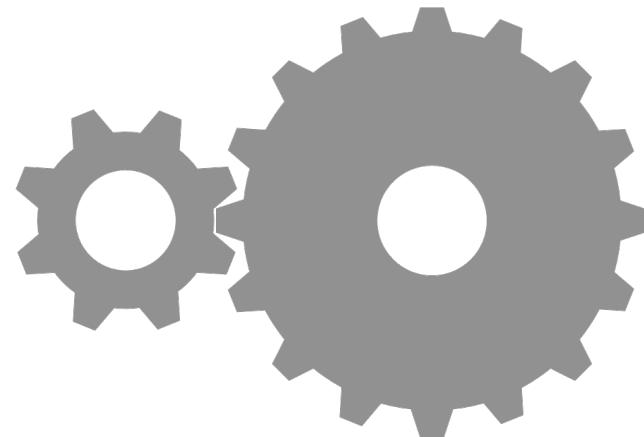
- When the next space lander headed for Mars, on board will be dozens of tiny mobile *robots* that will roll out across the Martian landscape, exploring every nook and cranny. — Michael Bowker

*often* : such a machine as built to resemble a human being or animal in appearance and behavior

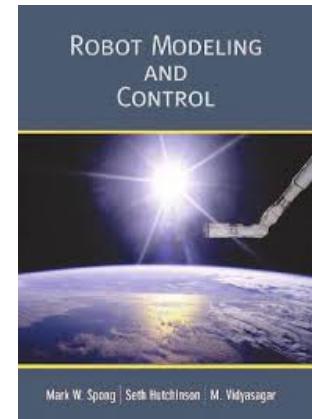
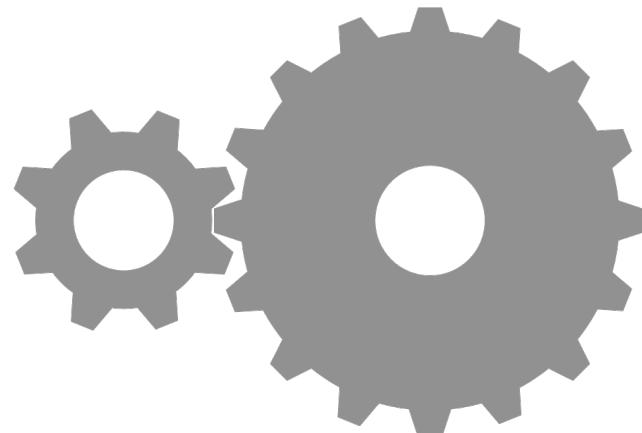
- While science fiction *robots* have been capable of independent thought, emotions, even a little cooking and sewing, scientists are finding that endowing a mechanical being with even the most basic human functions is a monumental



# One possible thought...

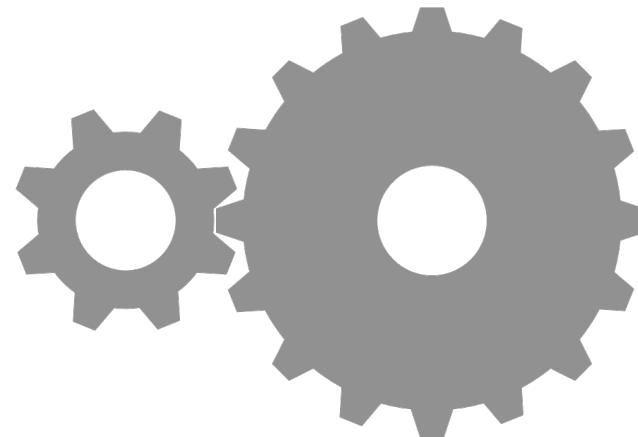


robot (n):  
a machine with actuated joints  
whose motion can be programmed



robot (n):

a machine with actuated joints  
whose motion can be programmed



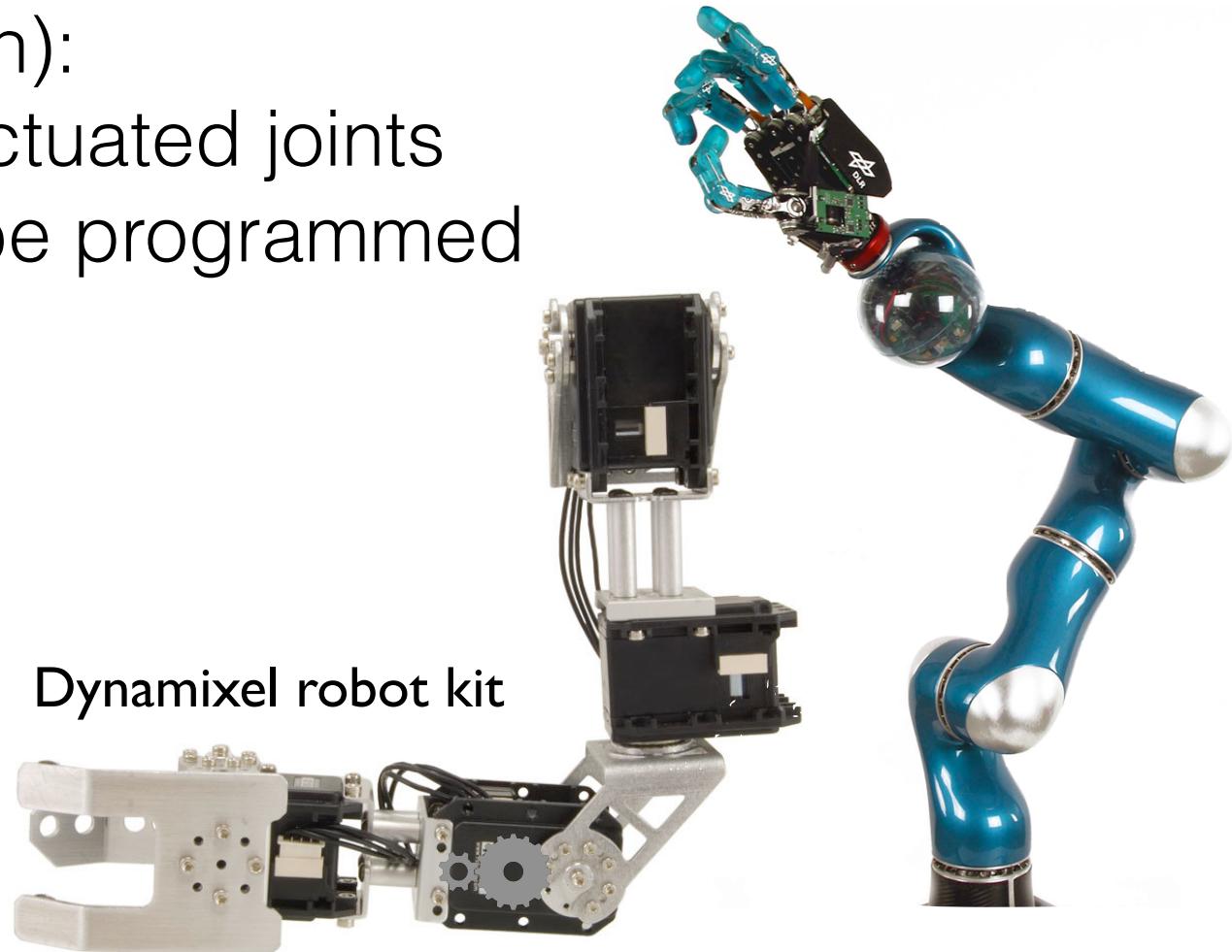
DLR Lightweight arm



DLR Lightweight arm

robot (n):

a machine with actuated joints  
whose motion can be programmed

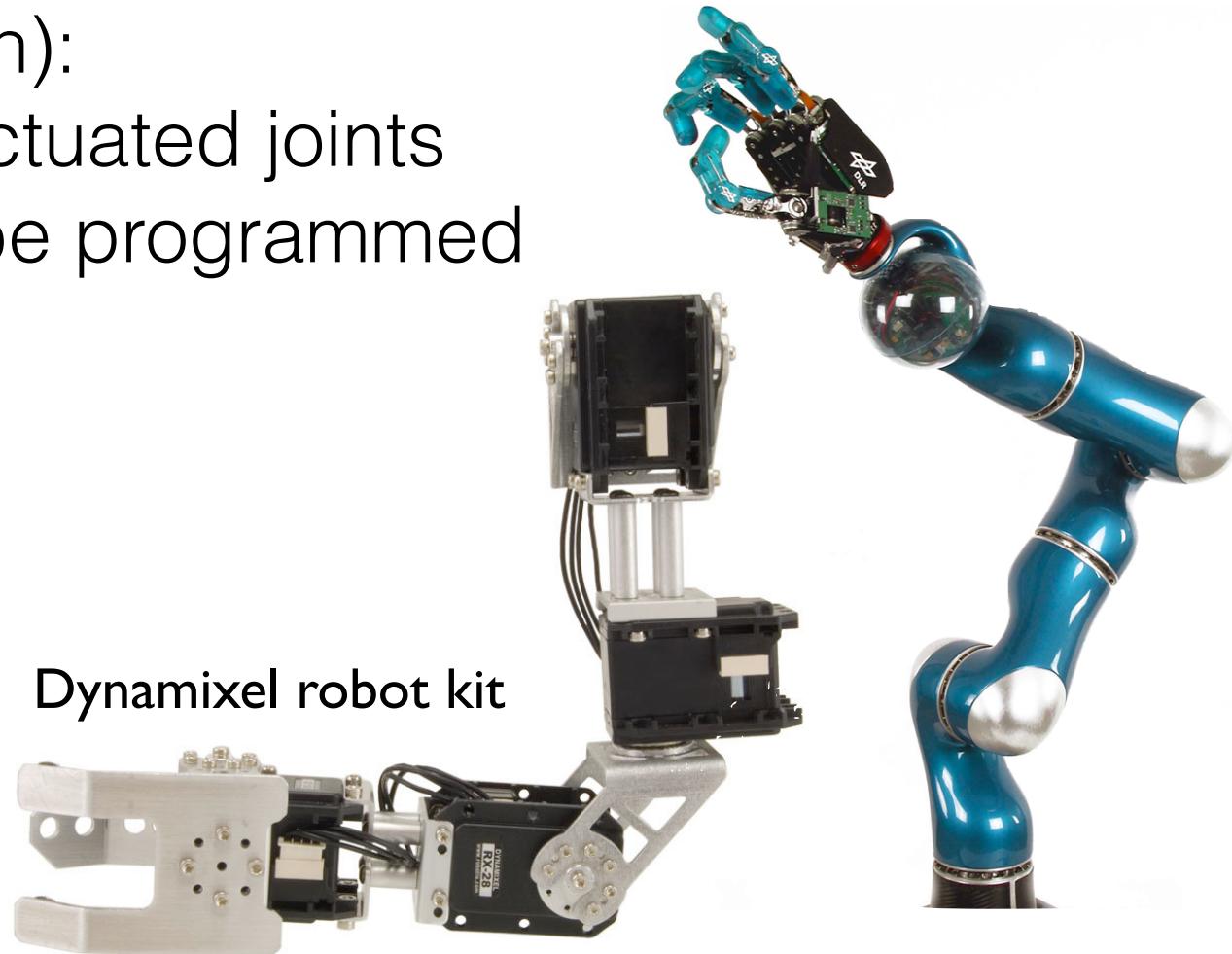


Dynamixel robot kit

DLR Lightweight arm

robot (n):

a machine with actuated joints  
whose motion can be programmed



Dynamixel robot kit

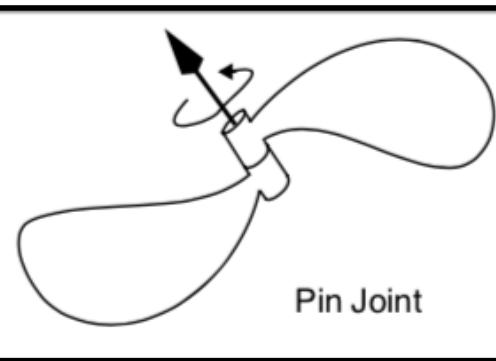
Robotic machines are comprised of joints and links

A link is a rigid part of the robot machine

A joint connects two links

The pose of a joint can be controlled by motor and is called a degree-of-freedom

Connections of joints and links form a hierarchy of articulated motion



DLR Lightweight arm



Dynamixel robot kit



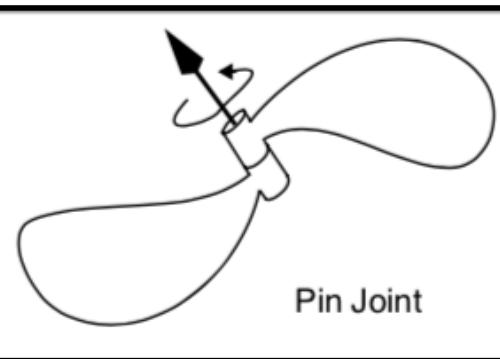
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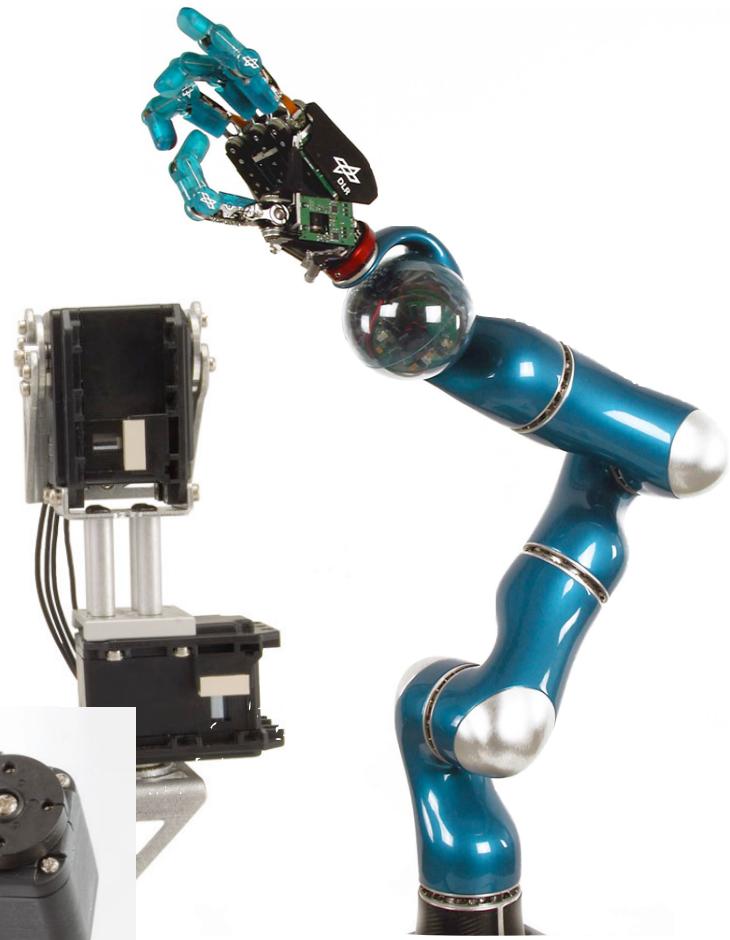
A joint connects two links

The pose of a joint can be controlled by motor and is called a degree-of-freedom

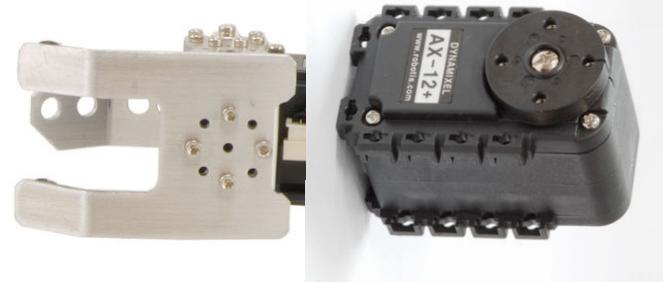
Connections of joints and links form a hierarchy of articulated motion

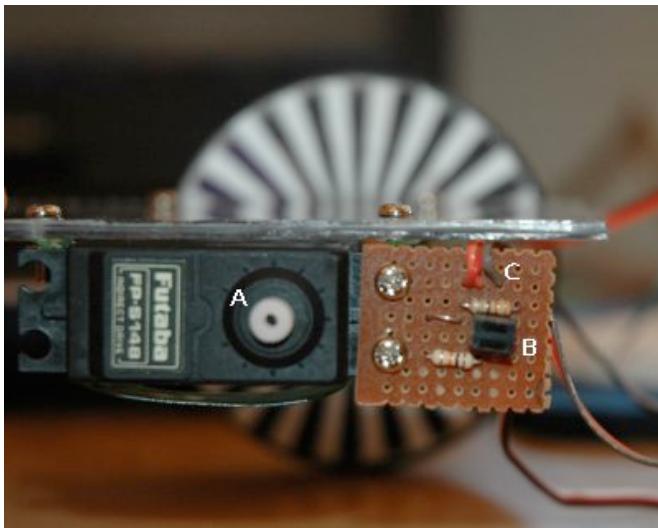


DLR Lightweight arm

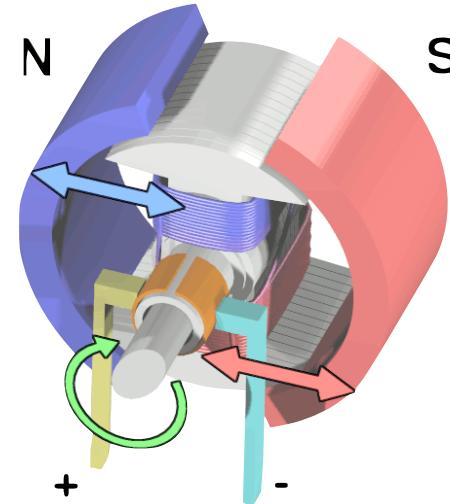


Dynamixel robot kit





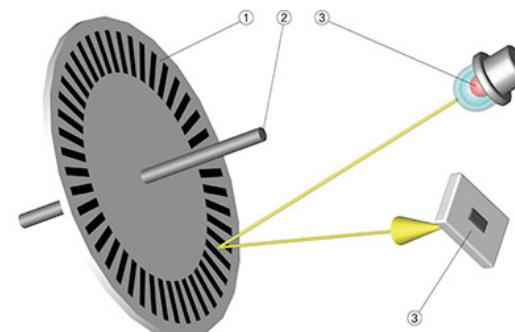
Motors have:



Electromagnetic  
motor

actuators to produce motion

proprioception to sense pose



Optical encoder

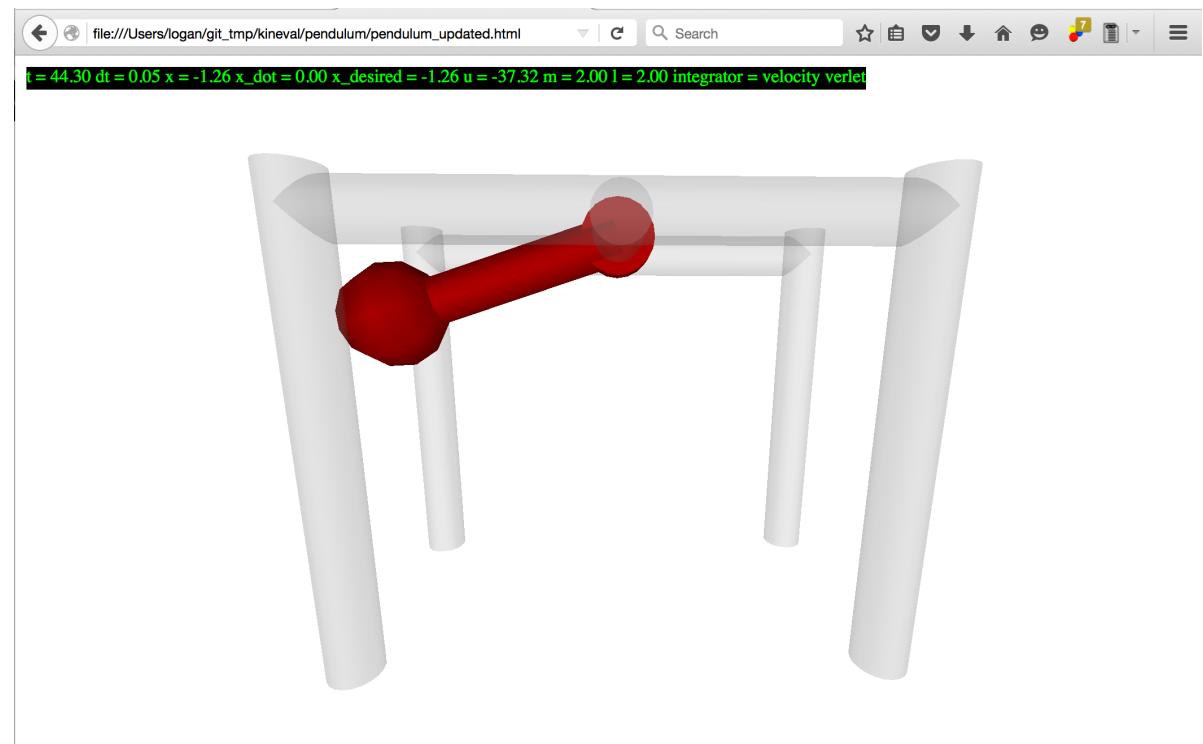
# Project 2: Pendularm

- 1 degree-of-freedom robot arm
- Physically simulate through Lagrangian equations of motion
- Control arm pose with a PID controller



# Project 2: Pendularm

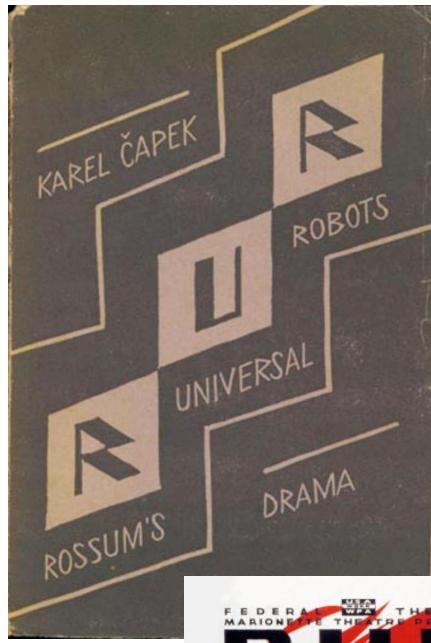
- 1 degree-of-freedom robot arm
- Physically simulate through Lagrangian equations of motion
- Control arm pose with a PID controller



“Robotics” is science fiction

Automation by “robots” is real

# robot



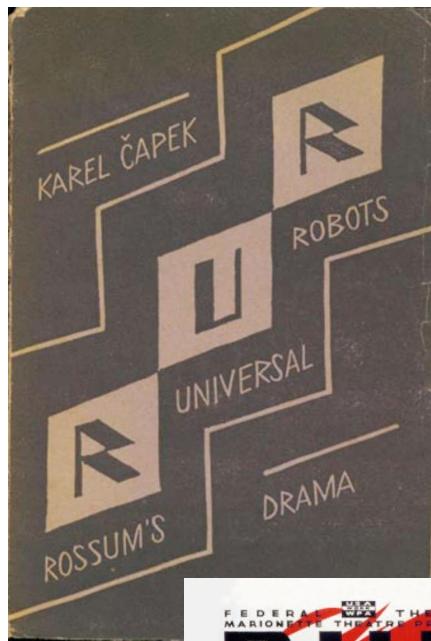
R.U.R.  
(1920)



Karel Čapek  
(1890-1938)



# robot



R.U.R.  
(1920)

Karel Čapek  
(1890-1938)



# robot

Josef Čapek  
(1887-1945)

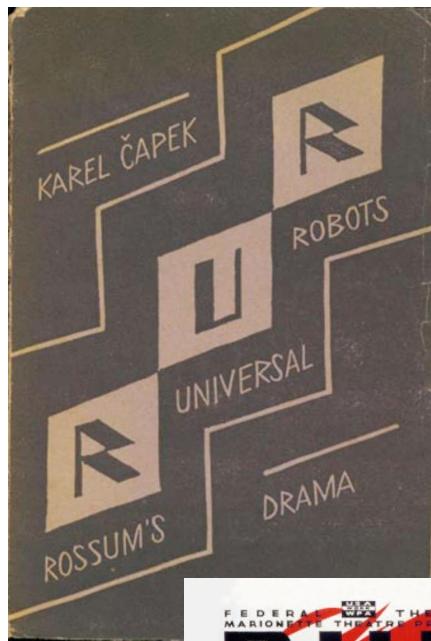


forced labor | serf | slave

# robota

Josef Čapek  
(1887-1945)





R.U.R.  
(1920)

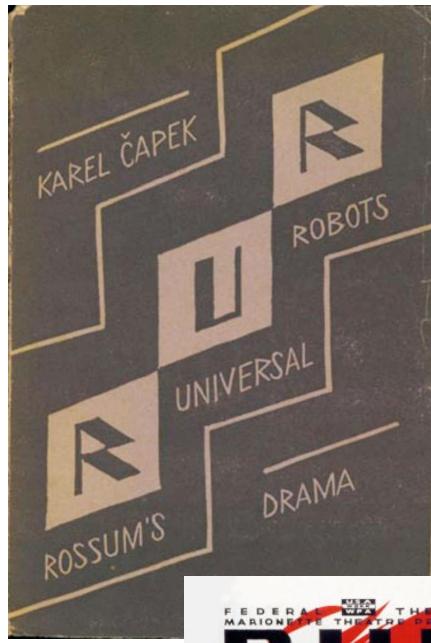
Karel Čapek  
(1890-1938)



# robot

Josef Čapek  
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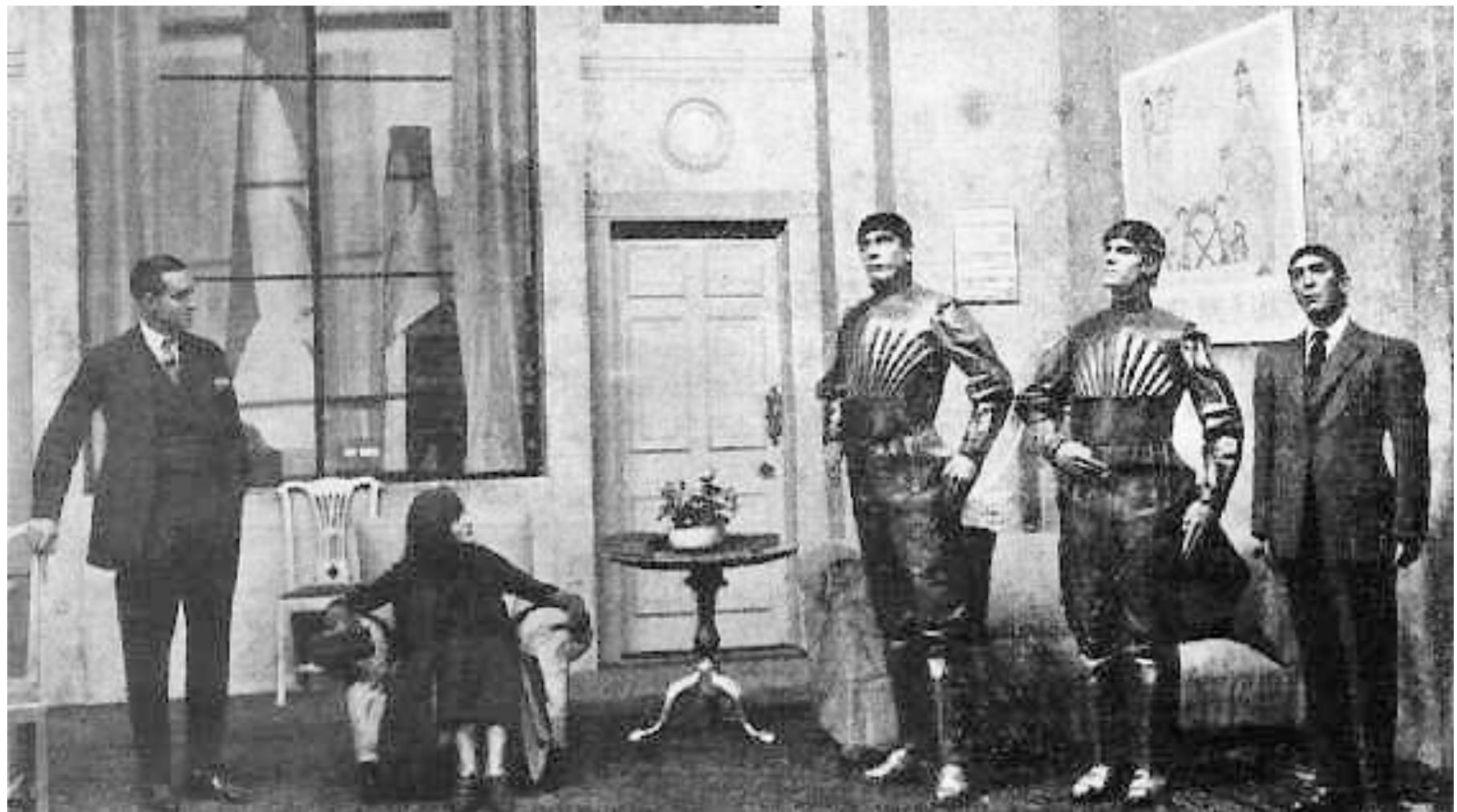
R.U.R.  
(1920)



Karel Čapek  
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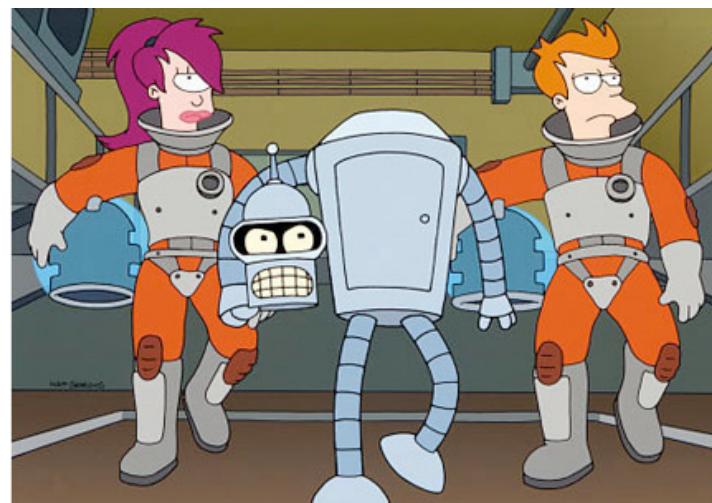
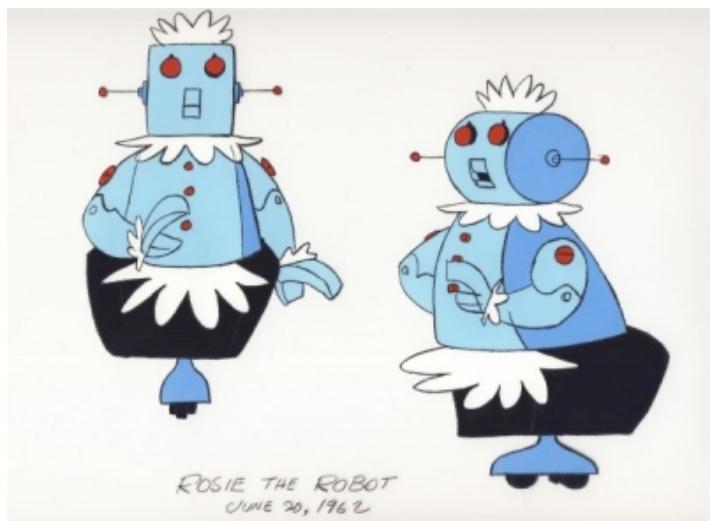
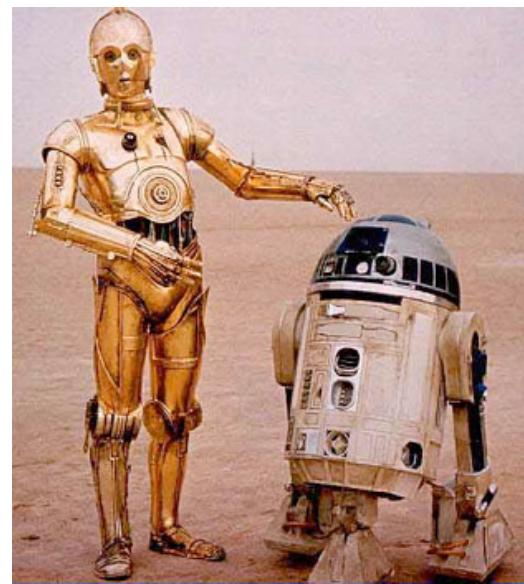
# robot



Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



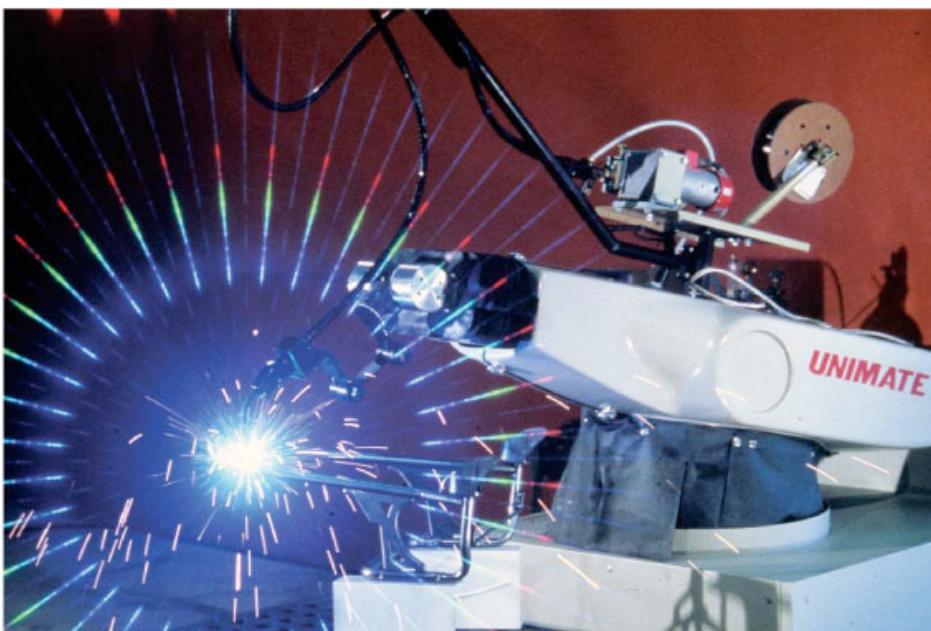
Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

In reality, modern automation  
began in the 1950s

by George E. Munson Condensed and edited by Leslie Ballard

# The Rise and Fall OF UNIMATION INC.

A story of robotics innovation & triumph that changed the world



June 13, 1961

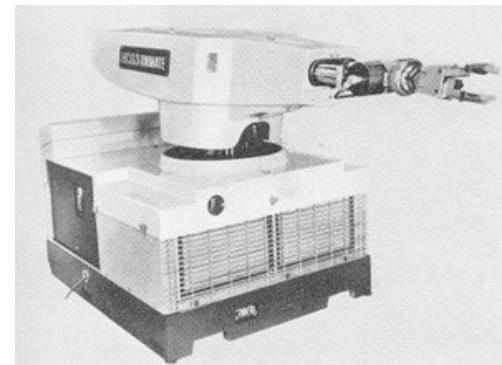
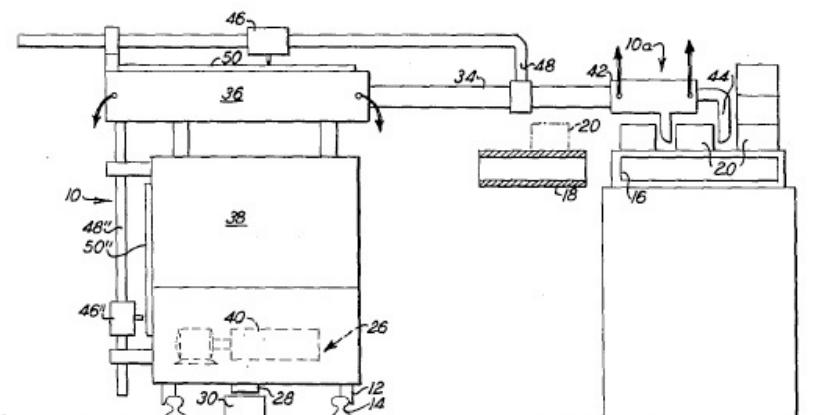
G. C. DEVOL, JR

2,988,237

Filed Dec. 10, 1954

PROGRAMMED ARTICLE TRANSFER

3 Sheets-Sheet 1

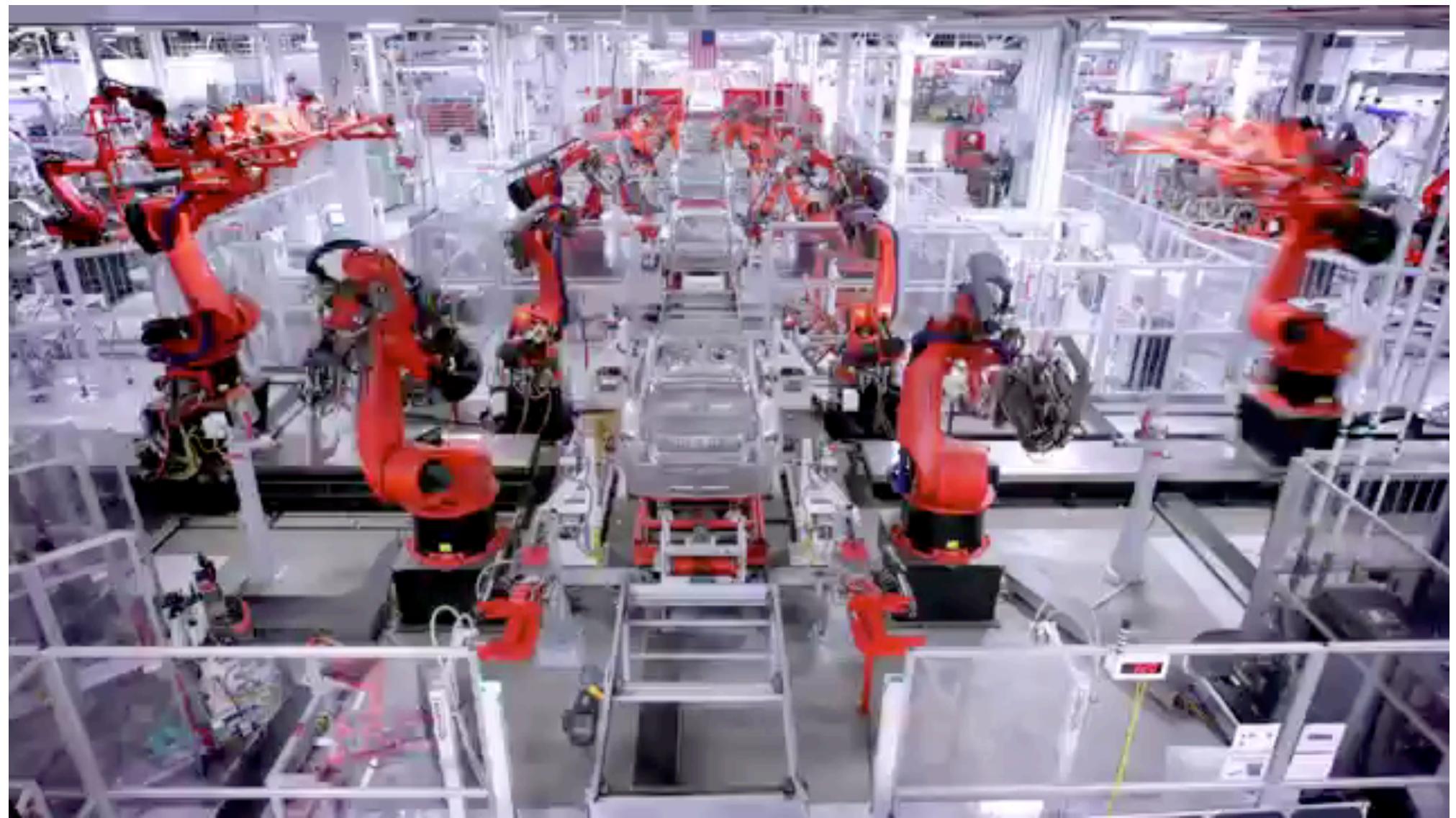




<http://wn.com/unimate>

Industrial One-Arm Bandit AKA Industrial One Armed Bandit (1968) - <https://youtu.be/VdolSBpyCaU>

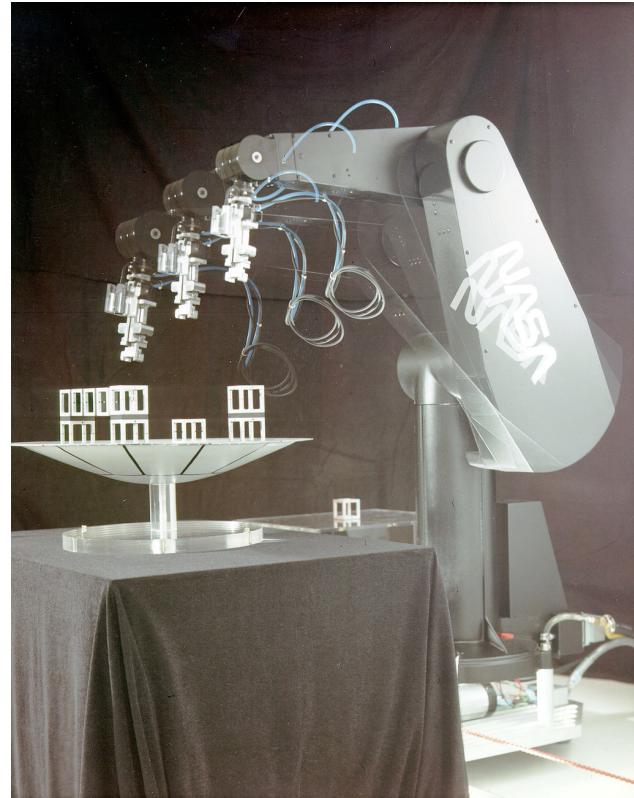
Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



WIRED at Tesla - [https://www.youtube.com/watch?v=8\\_lfxPl5ObM](https://www.youtube.com/watch?v=8_lfxPl5ObM)

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

Industrial robotics has focused mostly on pick-and-place tasks



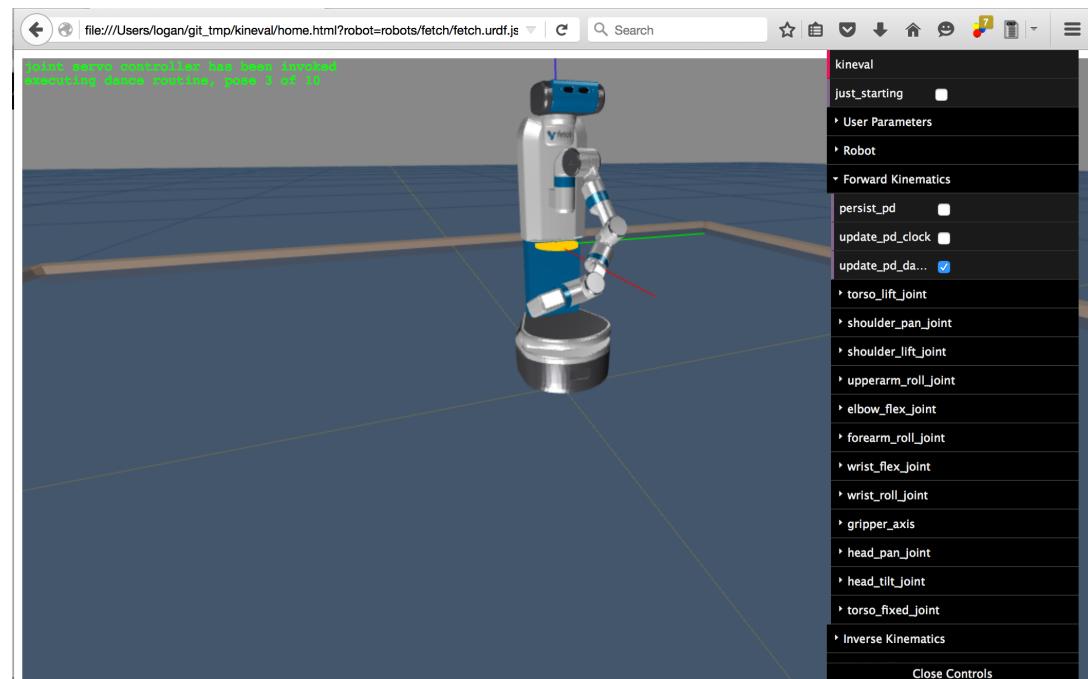
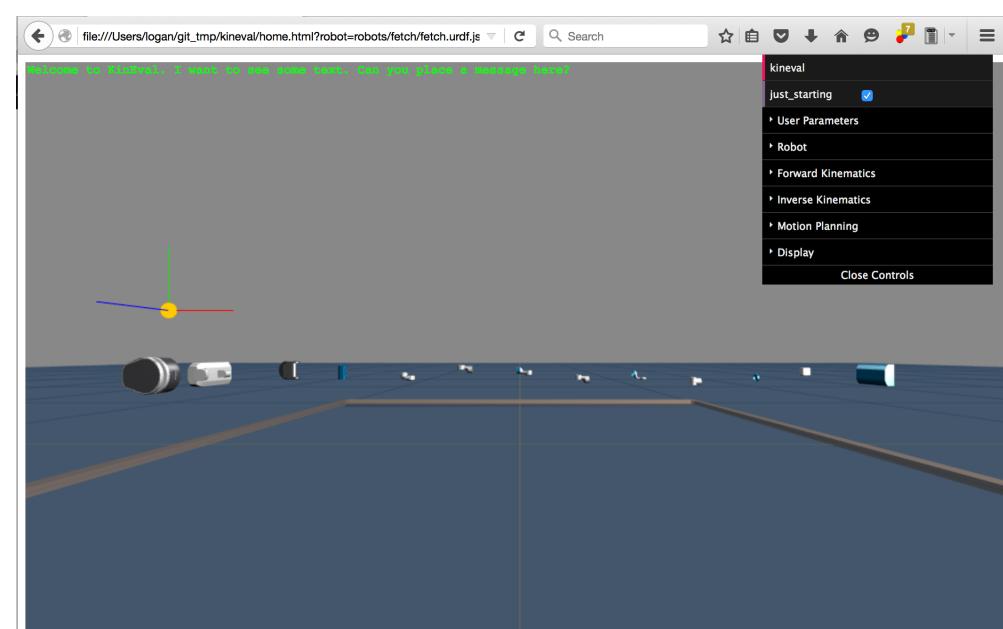
often the 3Ds — “Dirty, Dull, or Dangerous”

Unimate PUMA (*Programmable Universal Machine for Assembly, or Programmable Universal Manipulation Arm*)

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

# Projects 3-4: Forward Kinematics

Assemble individual robot links and joints into a posable robot that can dance



Does perfect sensing with perfect  
motors make a perfect robot?

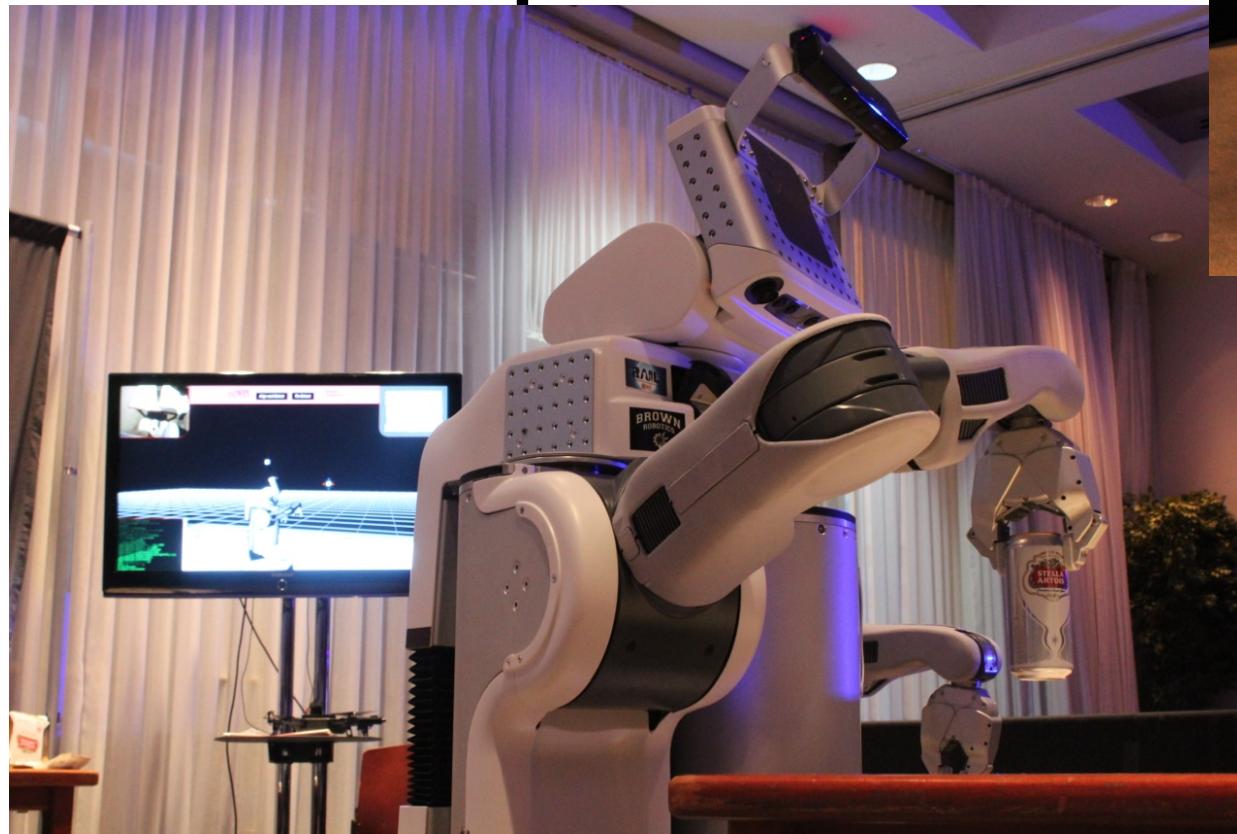
Does perfect sensing with perfect  
motors make a perfect robot?

No

Does perfect sensing with perfect  
motors make a perfect robot?

A robot also needs computation  
to map sensing to action.

# Dexterous Manipulation

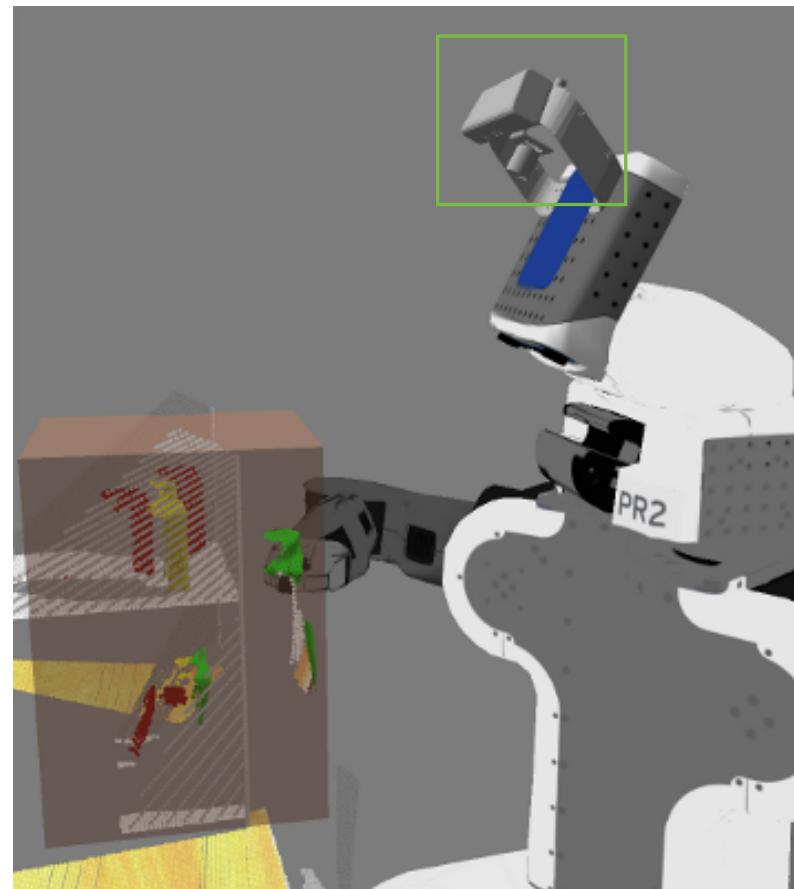
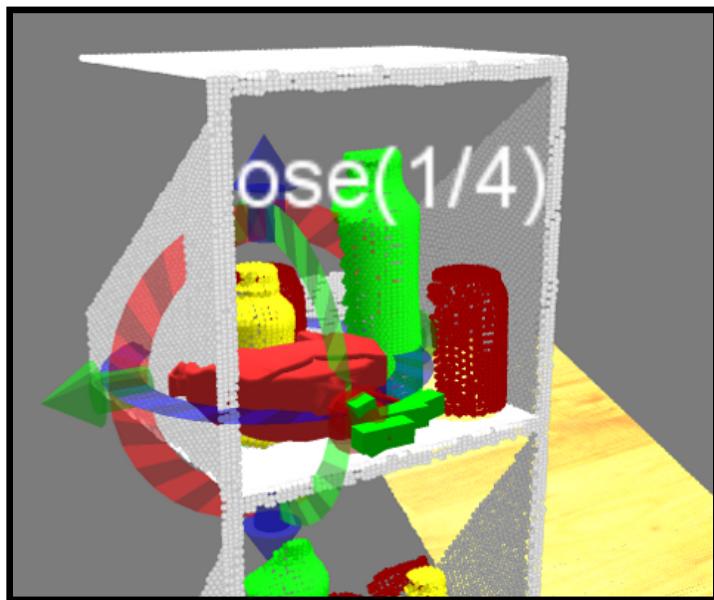




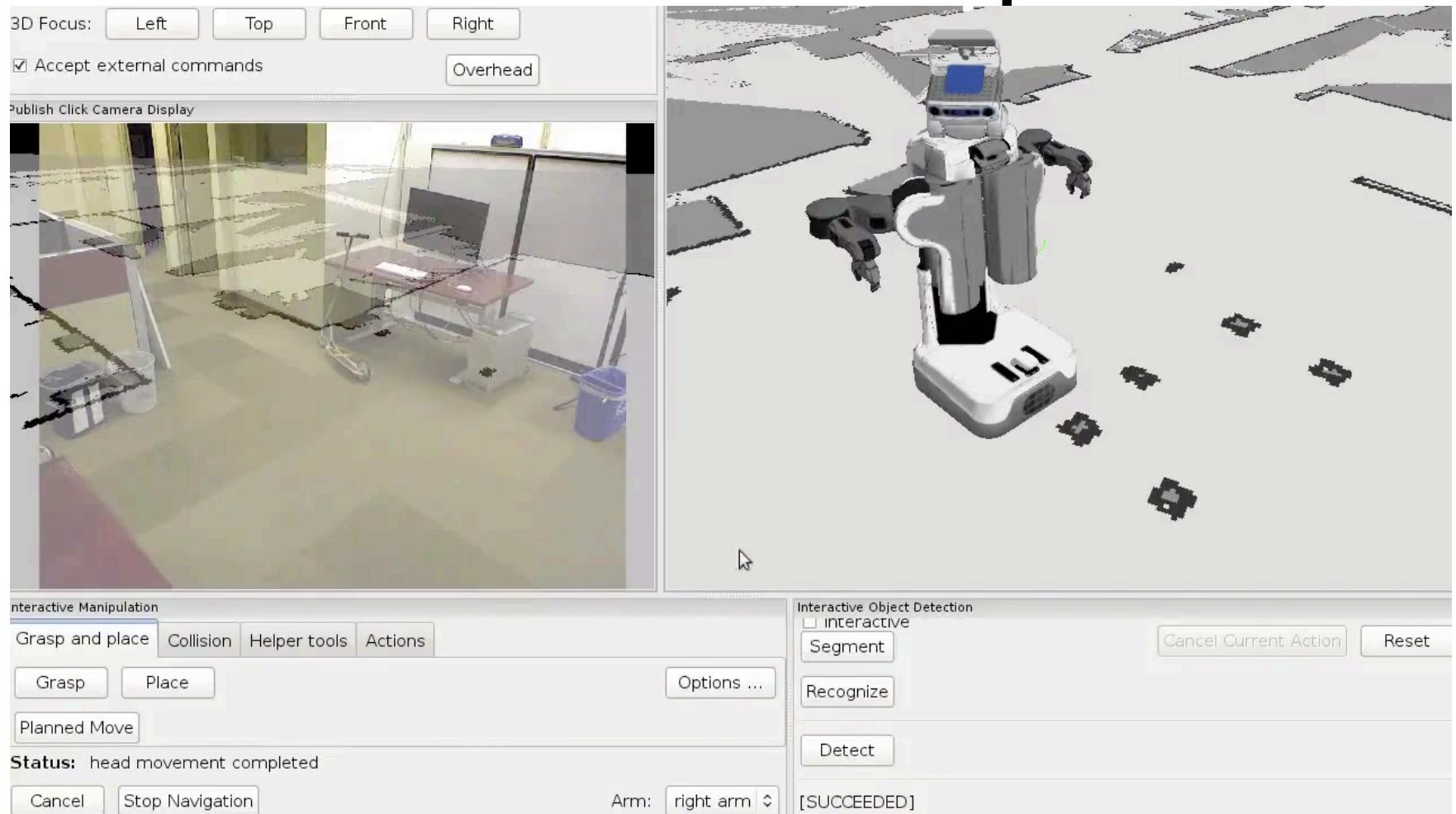
Robotic Roommates Shopping for and Preparing Bavarian Breakfast

TU-Munich - [https://youtu.be/gbIDPqb\\_2iM](https://youtu.be/gbIDPqb_2iM)

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



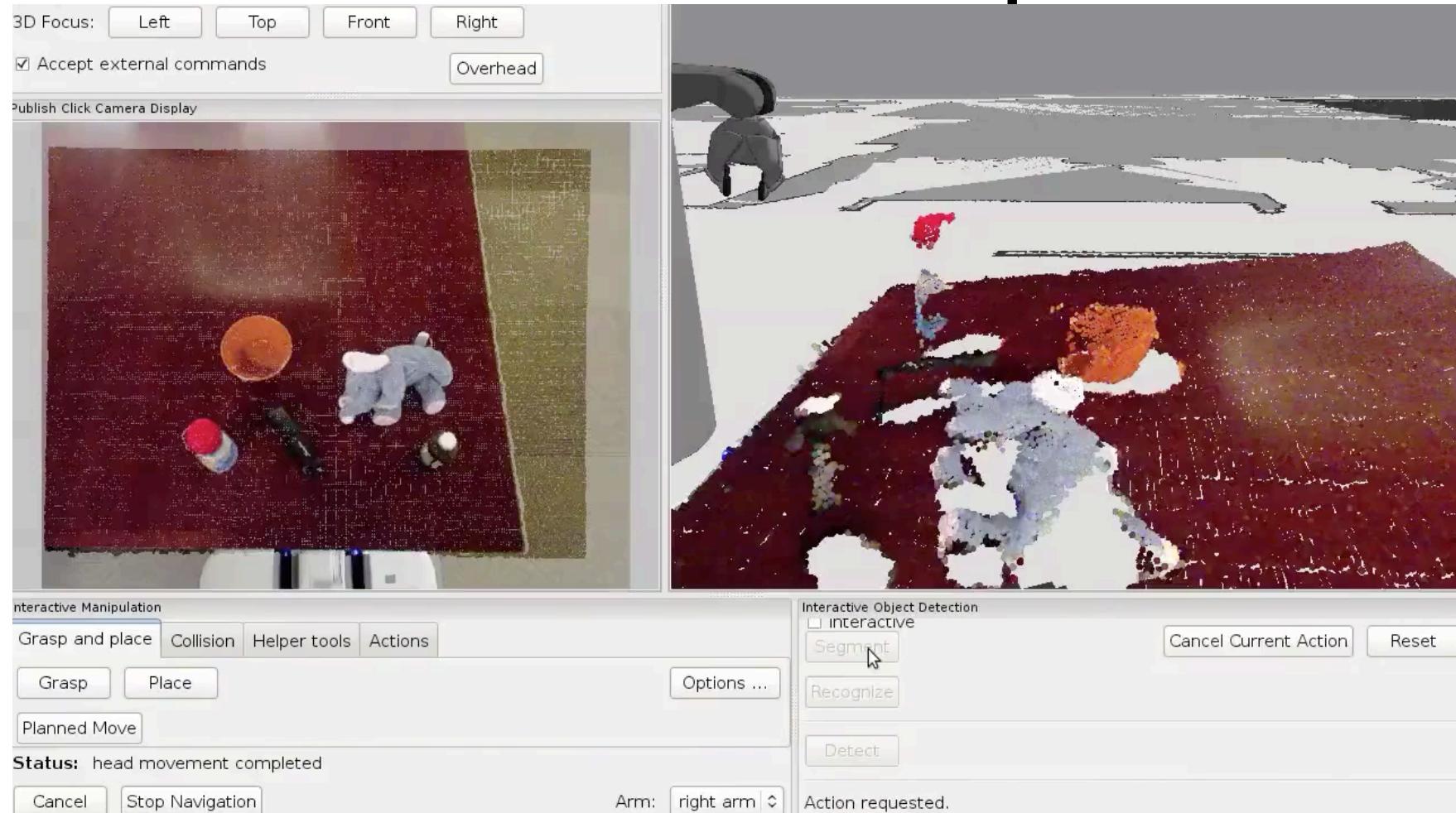
# PR2 Interactive Manipulation



Willow Garage - [https://wiki.ros.org/pr2\\_interactive\\_manipulation/groovy](https://wiki.ros.org/pr2_interactive_manipulation/groovy)

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

# PR2 Interactive Manipulation



Sui, Zhou, Zeng, Jenkins 2017

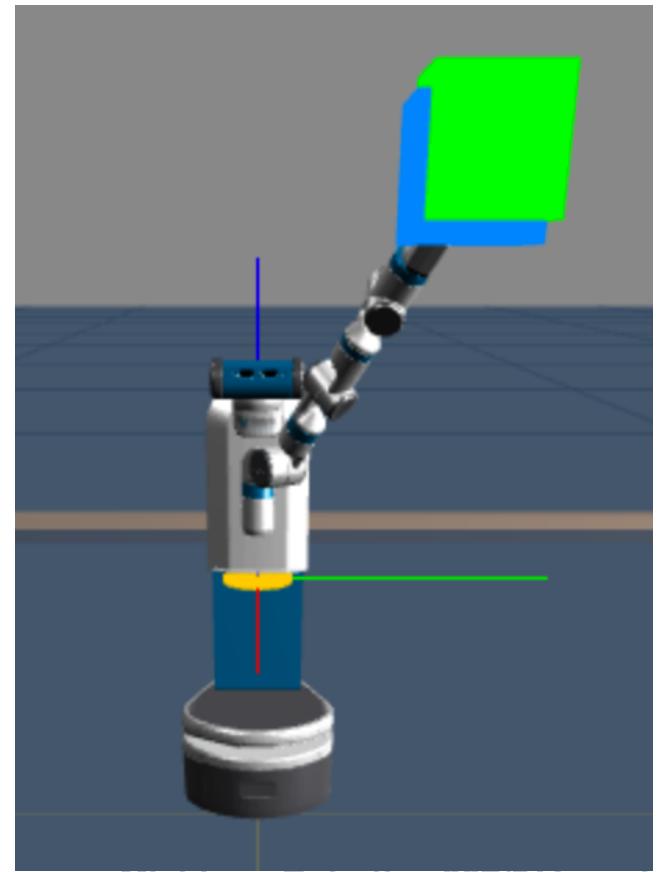


# Project 5: Inverse Kinematics

Given target location for robot gripper,  
compute joint angles to reach location

Compute Manipulator Jacobian

Perform gradient descent optimization



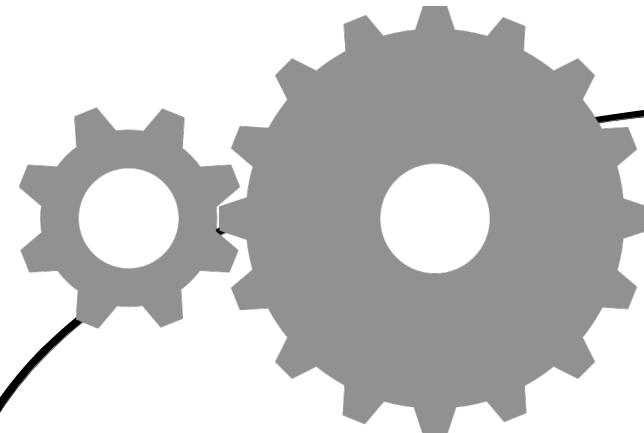
# Another perspective on robot history



Unimate PUMA robot history - <http://vimeo.com/2276417>

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

# Robotics

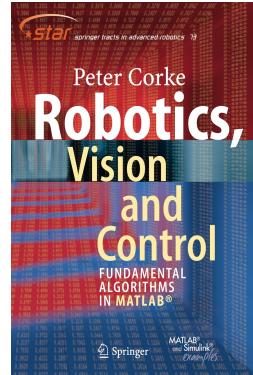


Mechanical Engineering  
Electrical Engineering  
“Mechatronics”



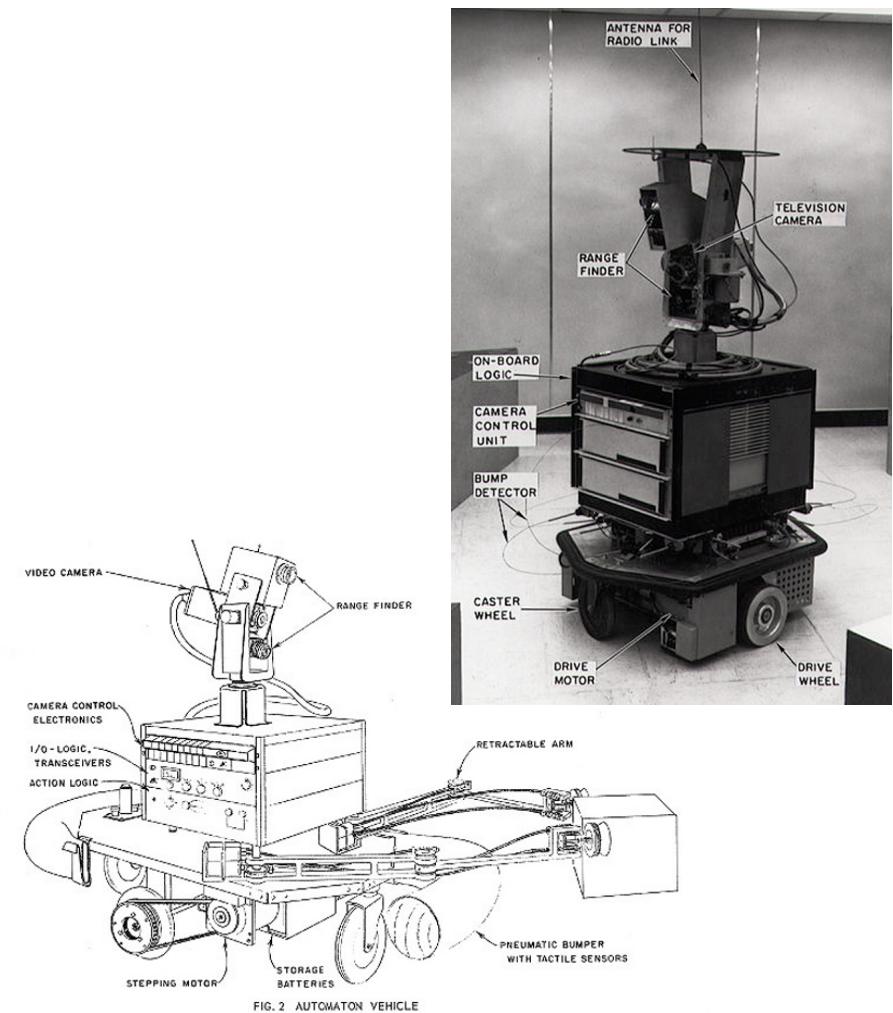
Computer Science  
Artificial Intelligence  
“Autonomy”

robot (n):  
a goal oriented machine  
that can sense, plan, and act



There are many definitions for “robot”.  
AutoRob will use this one.

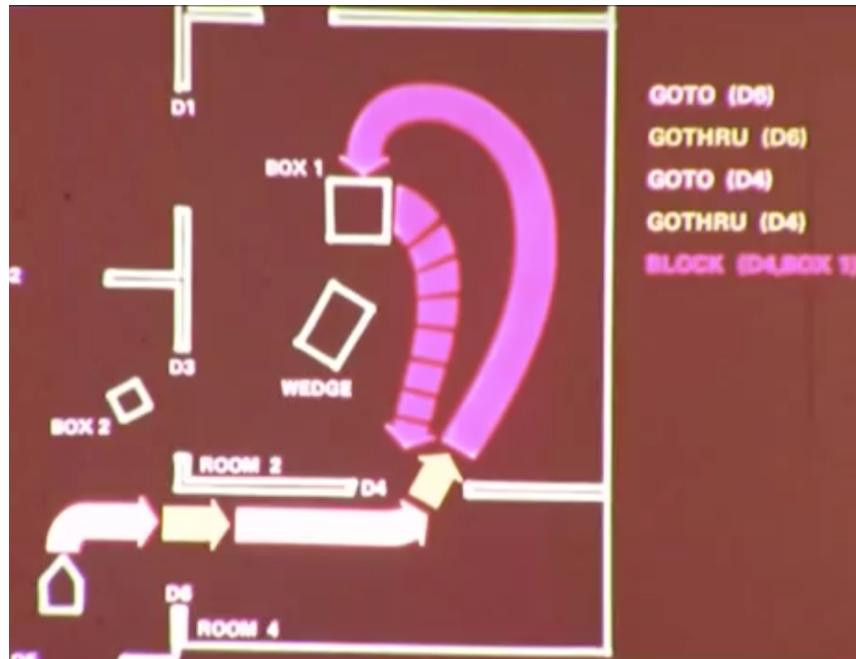
# Mobility/Navigation



Shakey SRI (1969) - <http://www.ai.sri.com/shakey/>

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

"SHAKEY: Experimentation in Robot Learning and Planning" (1972) - <https://youtu.be/GmU7SimFkpU>



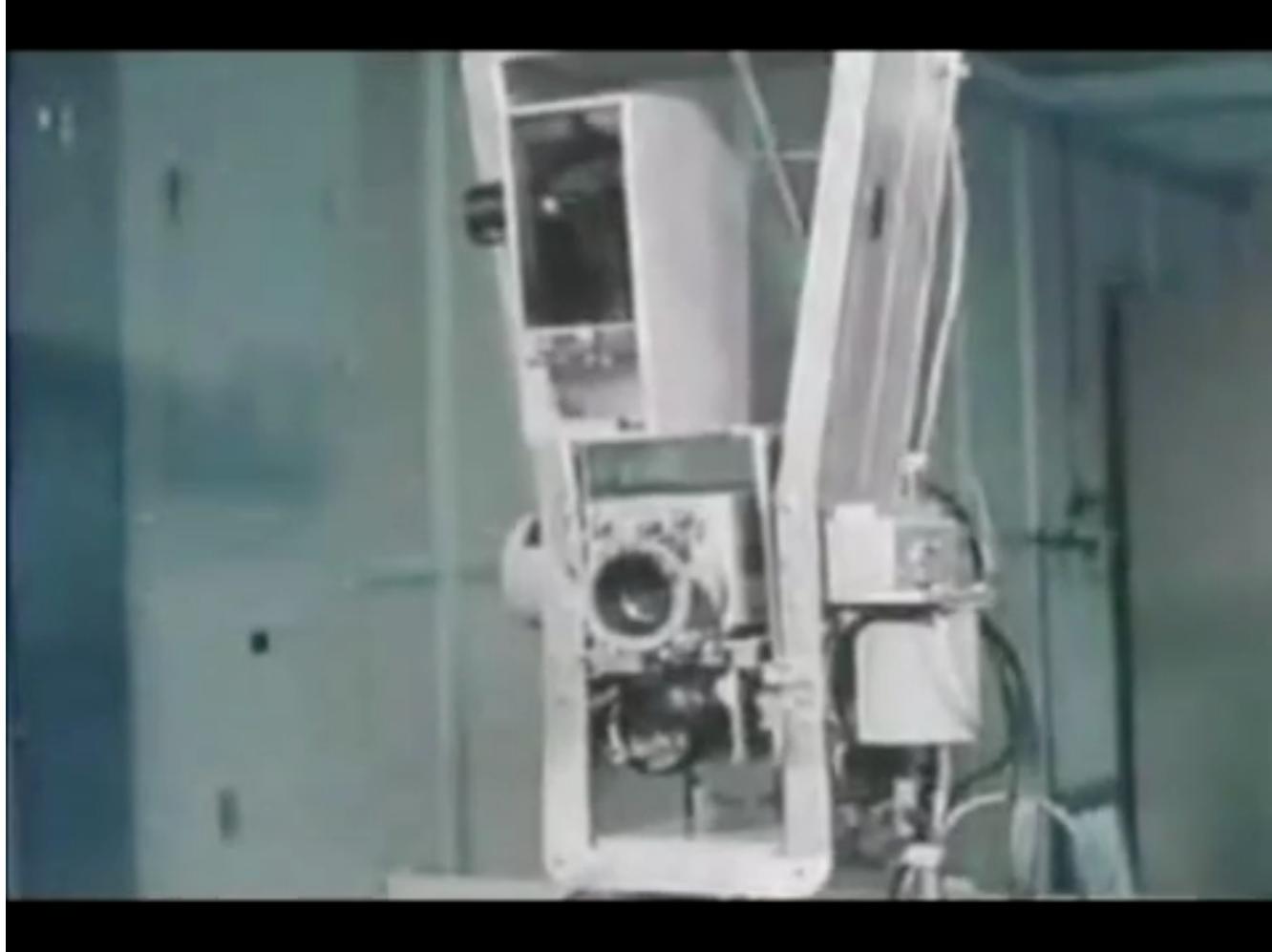
Autonomous robots traditionally use a sense-plan-act loop

Sense: perceive an accurate model of the world

Plan: decide a sequence of actions to reach goal

Act: execute actions to realize goal

# Early(est) computer vision



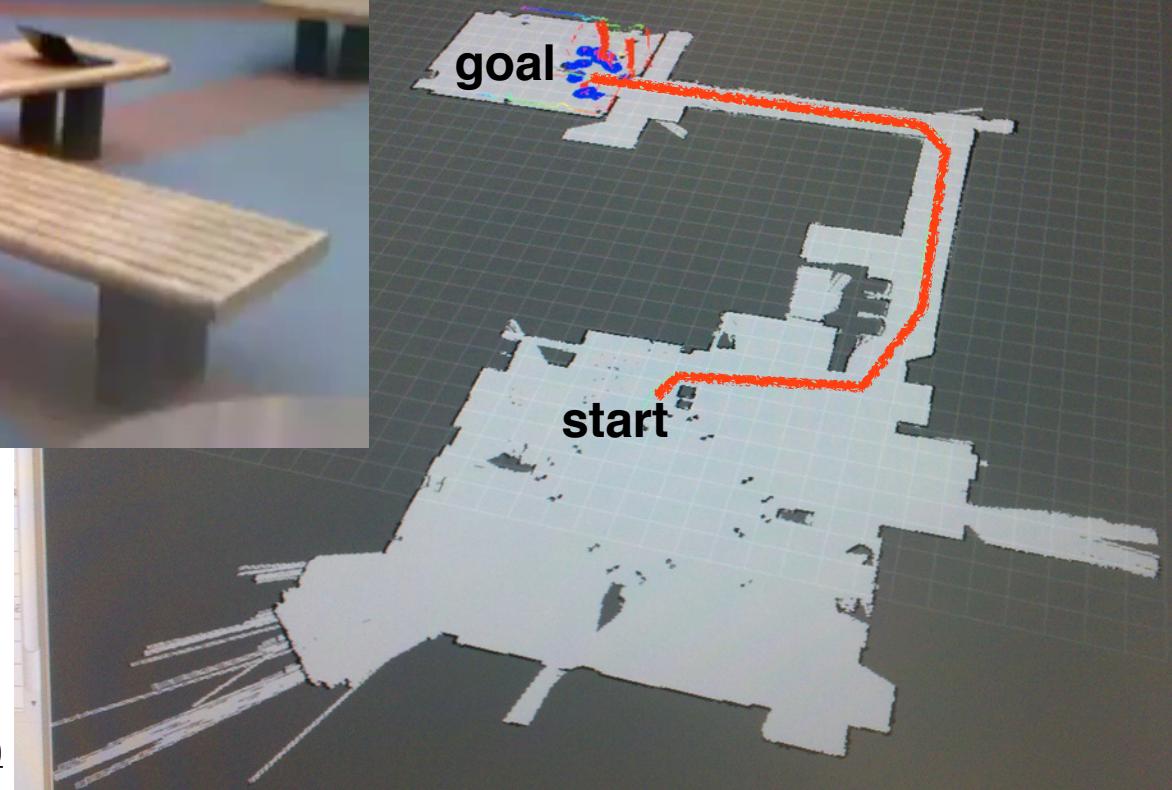
# Modern robot navigation...



PR2 navigation at Brown University  
June 2011

Jenkins Robotics Group - <https://youtu.be/lnt62LmHXg0>

Navigation map and executed path



robot navigation

=

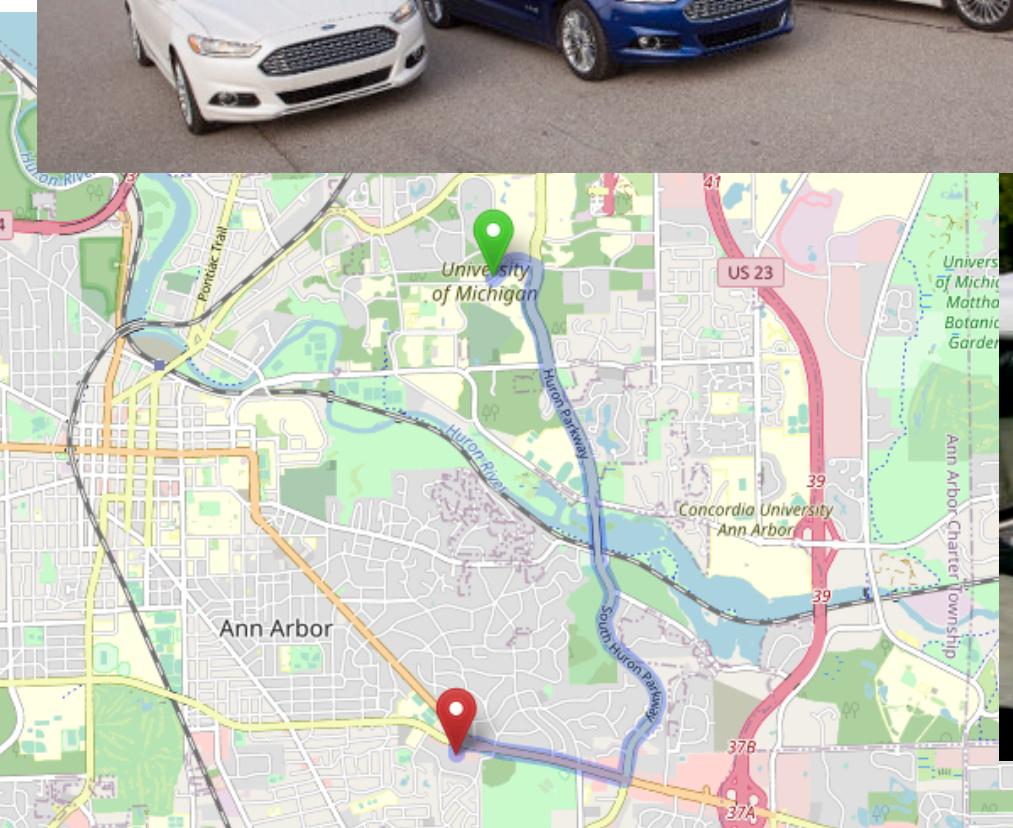
autonomous driving

(to a reasonable approximation)

## UMich/Ford Next Generation Vehicle



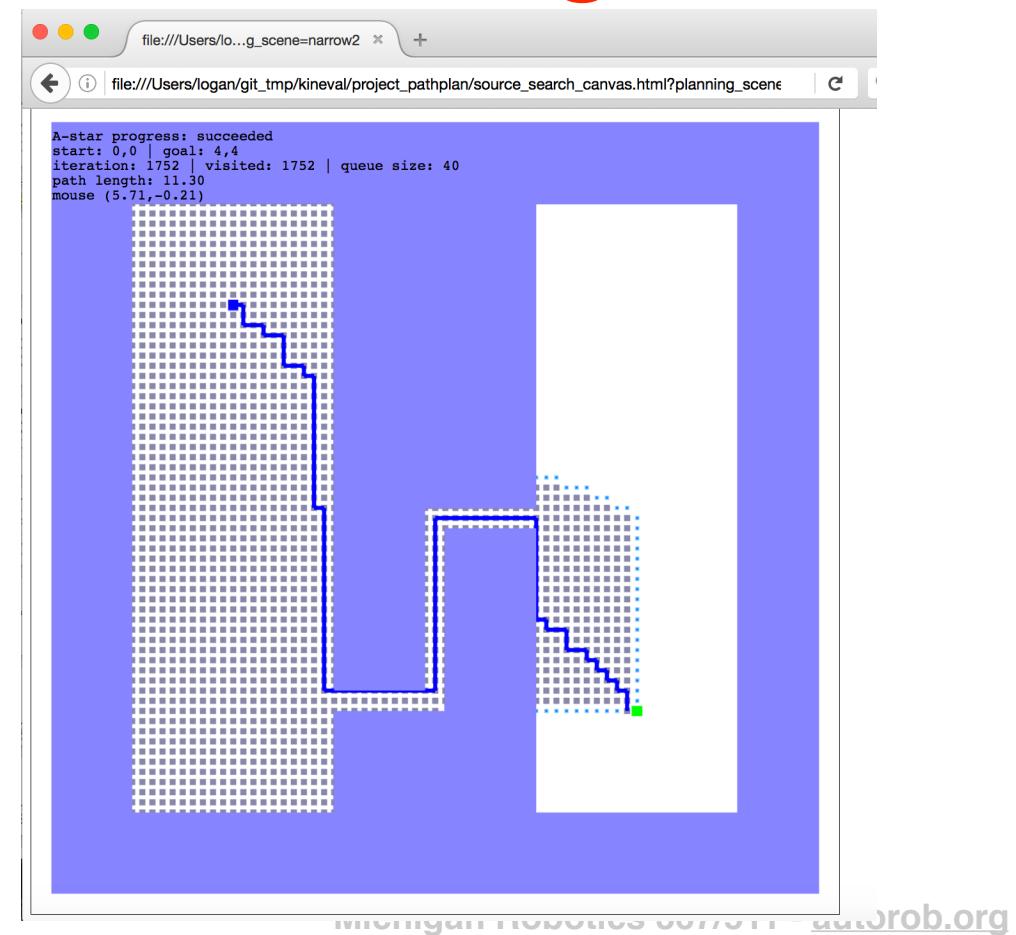
Decision making through  
search-based planning



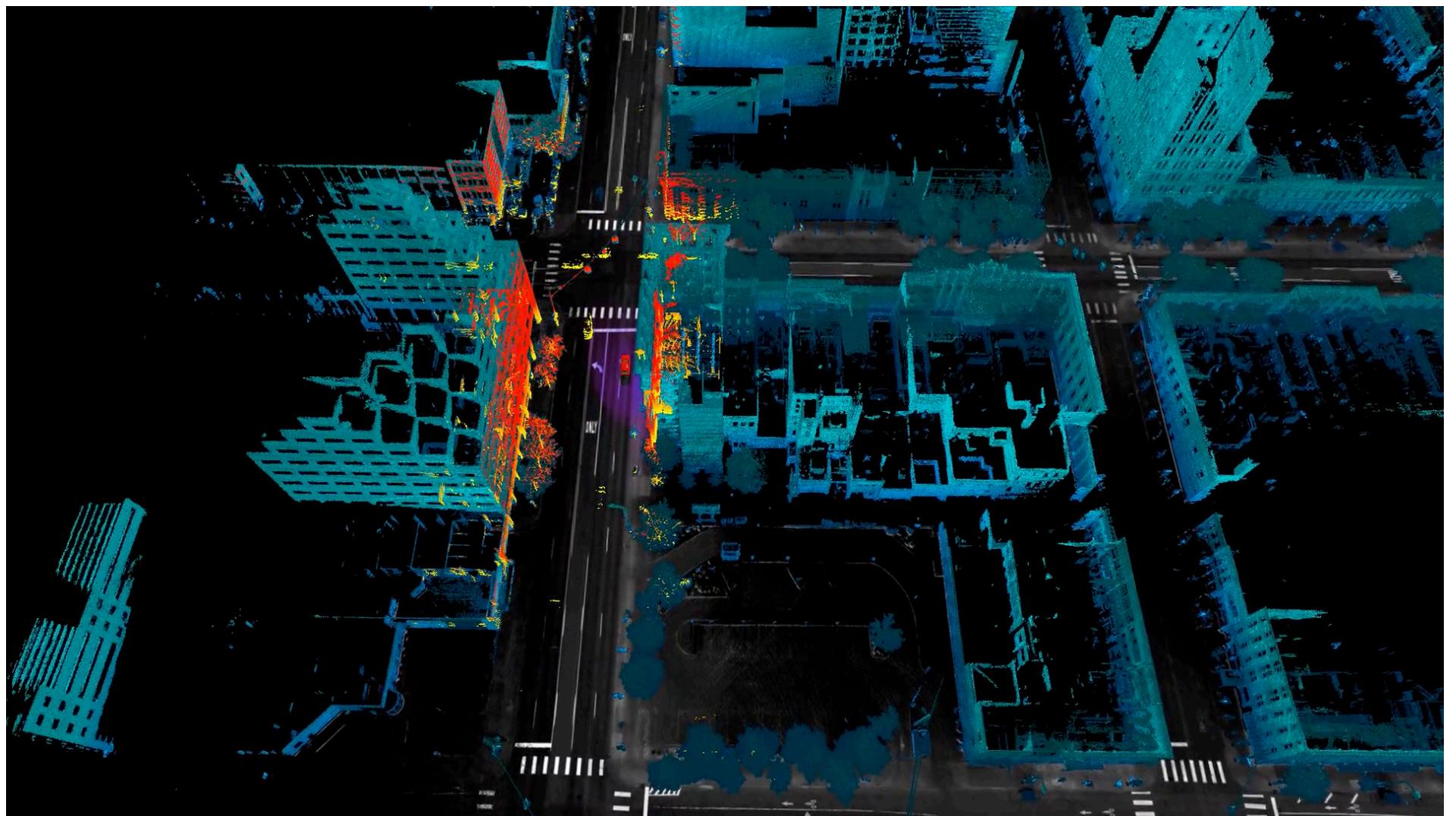
Google Self-driving car  
Michigan Robotics 807/31 autorob.org

# Project 1: Path Planning

Compute collision-free motion path from current 2D location to goal location



# How can we build that map?



Eustice, Olson, et al. - Next Generation Vehicle - <https://youtu.be/G6ARRD60IQk>

Michigan Robotics 807/911 | autobot.org

Do we need to build a map?

# MIT Technology Review



Wealth & Investment  
Management

See how realigning  
can help maximiz

Ghengis hexapod robot



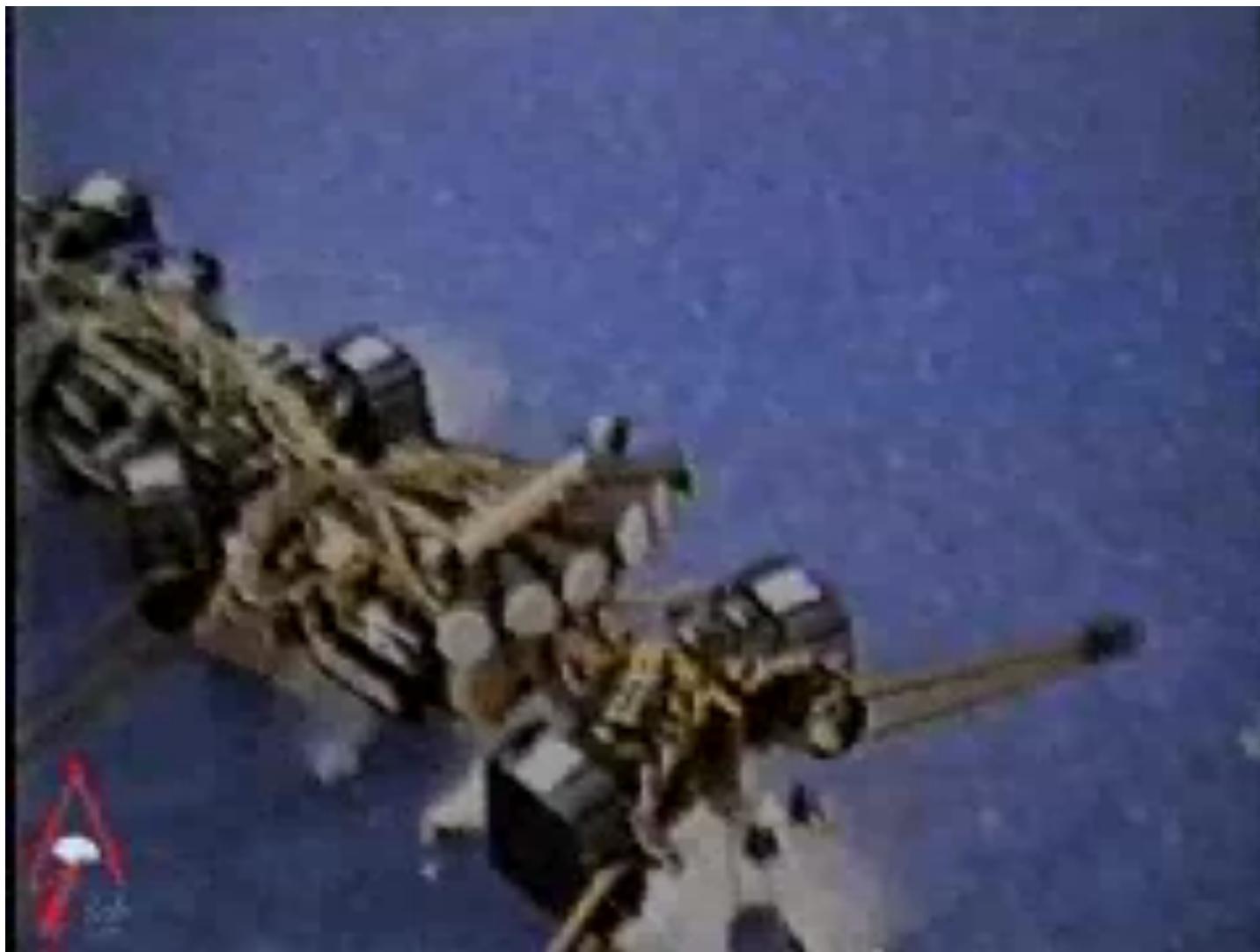
## Intelligent Machines

# Honey, They've Shrunk the Rover

The Sojourner vehicle that trekked across the Martian surface captured the world's fancy last summer, but we haven't seen anything yet. Next will come rovers that can roam miles across Mars and "aerobots" able to survey other planets.

by Eric Scigliano   January 1, 1998

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



Decision through  
FSM-based reaction

MIT Ghengis (1989)

<http://groups.csail.mit.edu/lbr/genghis/>

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



Decision through  
FSM-based reaction

MIT Ghengis (1989)

<http://groups.csail.mit.edu/lbr/genghis/>

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

# What is more difficult than Mars?

# Can today's robot vacuums handle the mess of two toddlers?

By [Ben Popper](#) on December 29, 2015 11:00 am

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Some robots will need to be  
more deliberate...



Amazon - <https://youtu.be/Ox05Bks2Q3s>

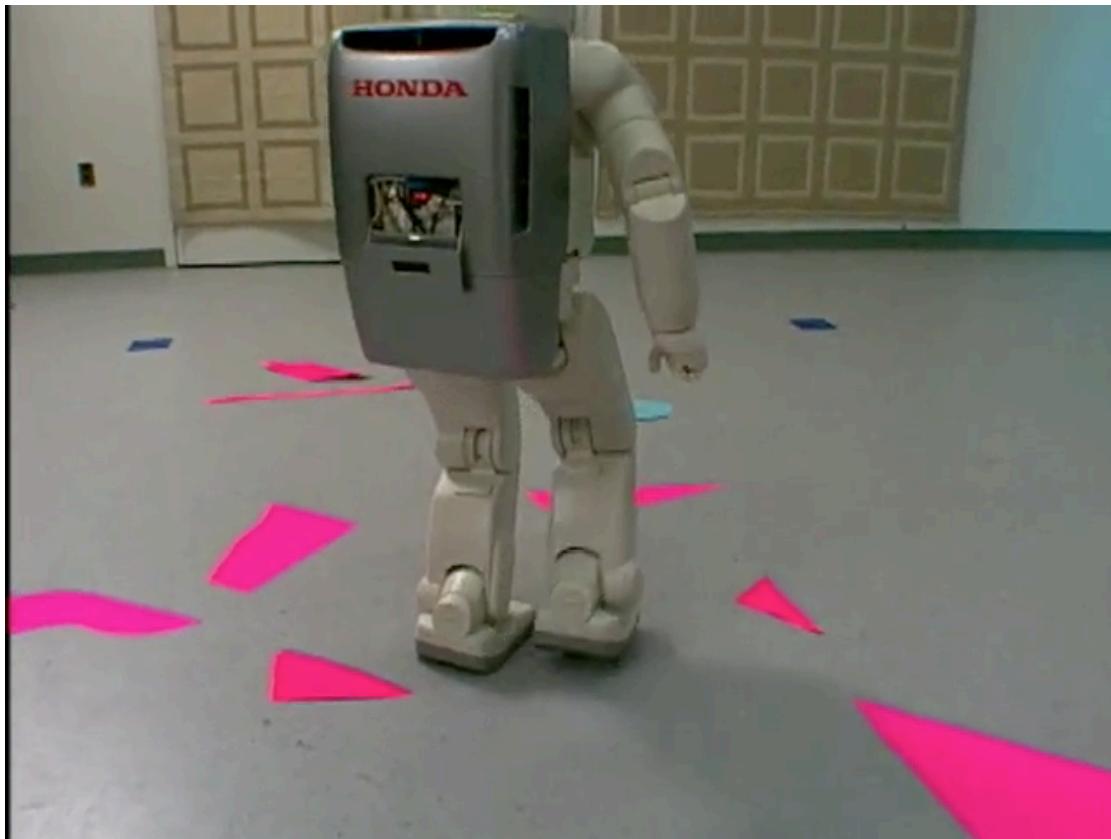
Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



[https://youtu.be/0E4gt54\\_vHo](https://youtu.be/0E4gt54_vHo)

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

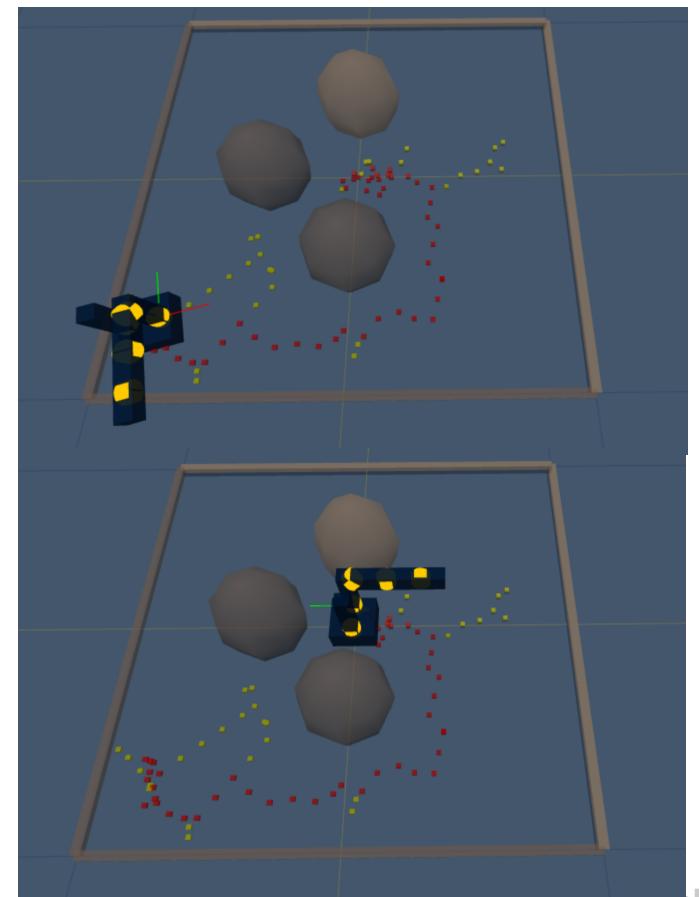
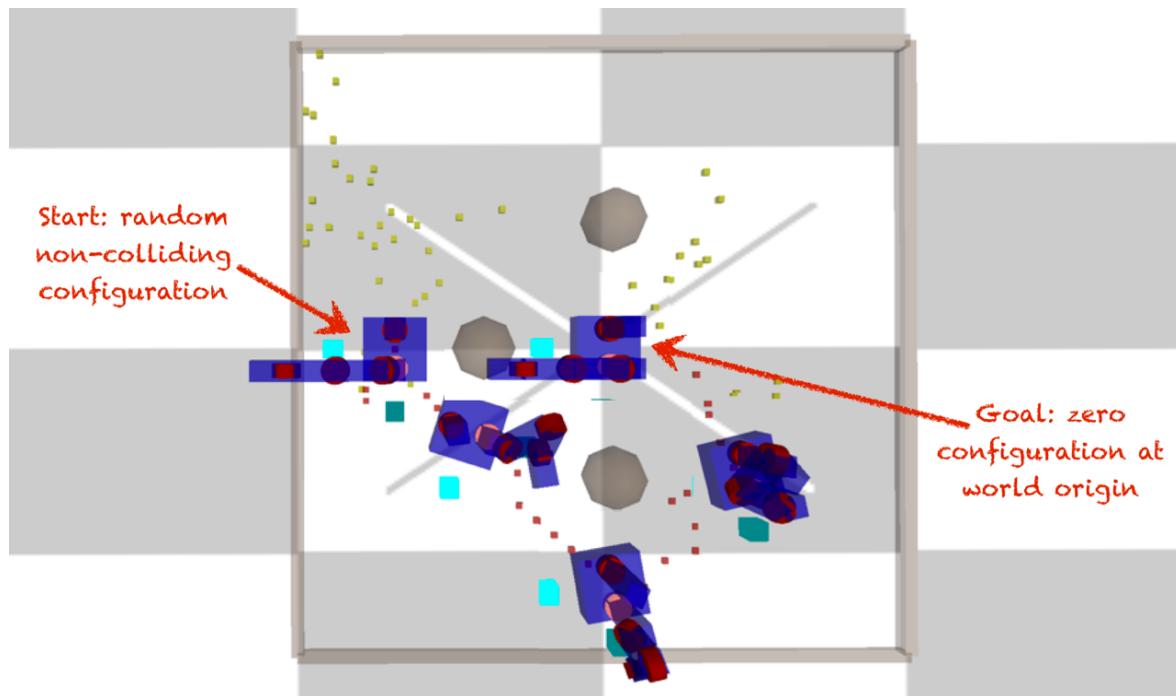
# Rapidly-Exploring Random Trees



for high dimensional  
search over robot  
configurations

# Project 6: RRT Planning

Compute collision-free motion path  
from current pose to goal (start) pose

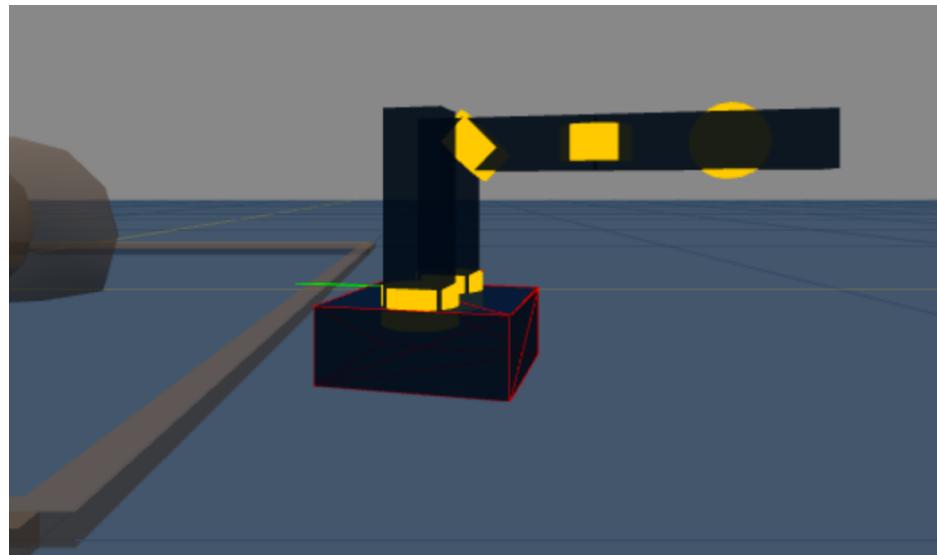


# What about collisions?

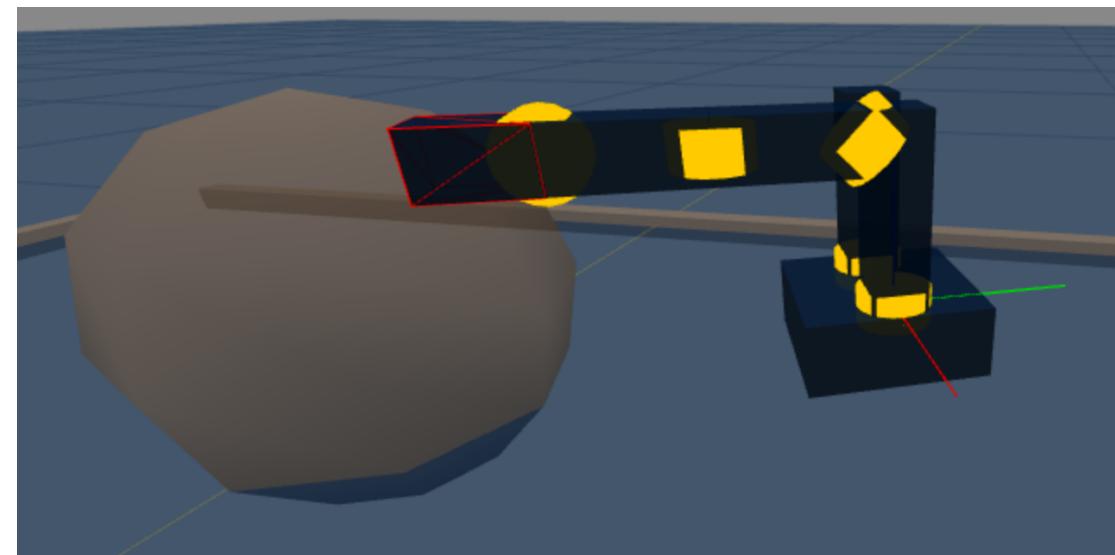
# What about collisions?



# Simple collision detection provided for course projects



“electric fence” on robot base



Axis-aligned bounding box  
collision detection on each link

**Completely autonomous robots  
are a fantasy**

Completely autonomous robots  
are a fantasy

Why?

# Completely autonomous robots are a fantasy

Uncertainty

Why?

Accountability

Perception

Liability

Reliability

Ethics

Adaptability

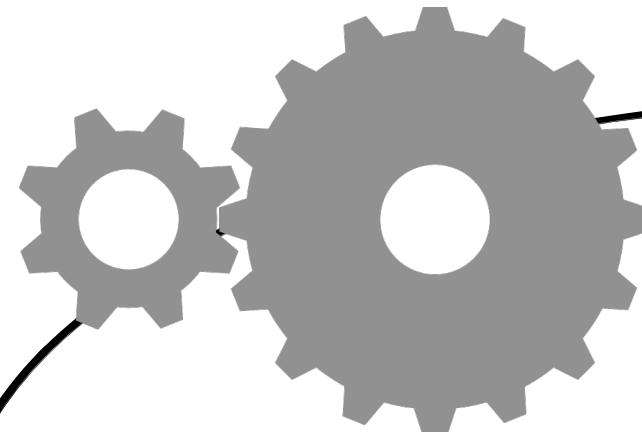
Safety

Social norms

# Always have a human in the loop



# Robotics



Mechanical Engineering  
Electrical Engineering  
“Mechatronics”



Human Factors  
Supervisory Control  
“Usability”



Computer Science  
Artificial Intelligence  
“Autonomy”

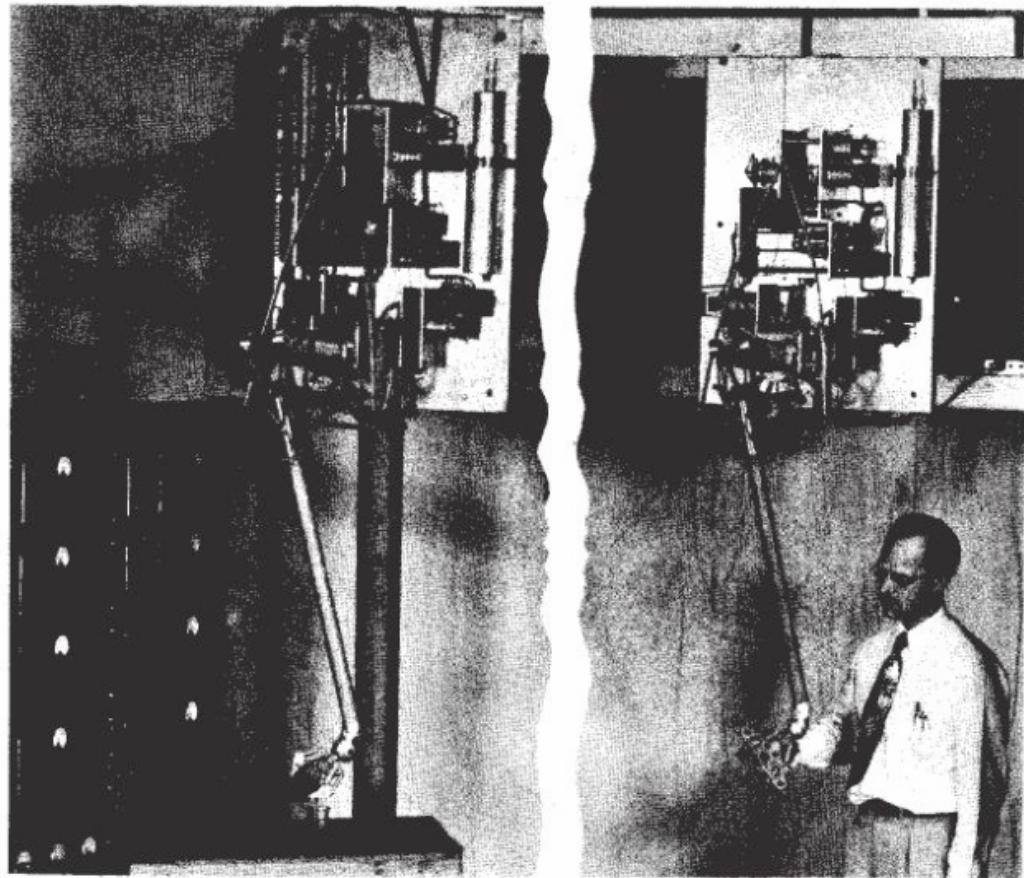


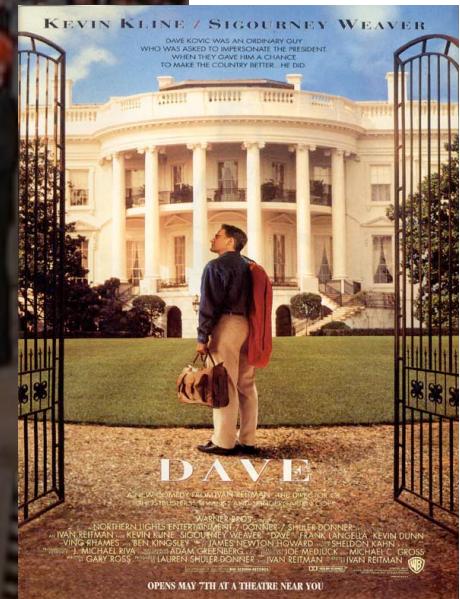
FIGURE 6.—The ANL Model E1 **electric master slave**. Used only for experimental purposes, this bilateral manipulator was developed in 1954. (Courtesy of Argonne National Laboratory.)

R. Goertz - Argonne



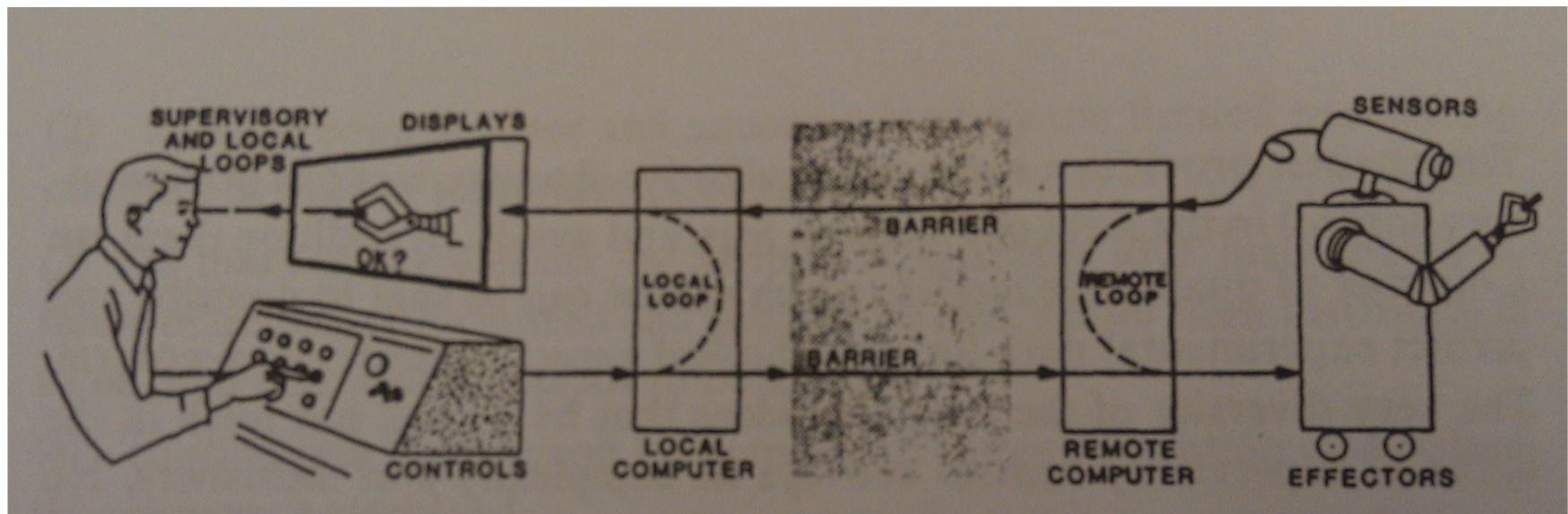
## Teleoperation

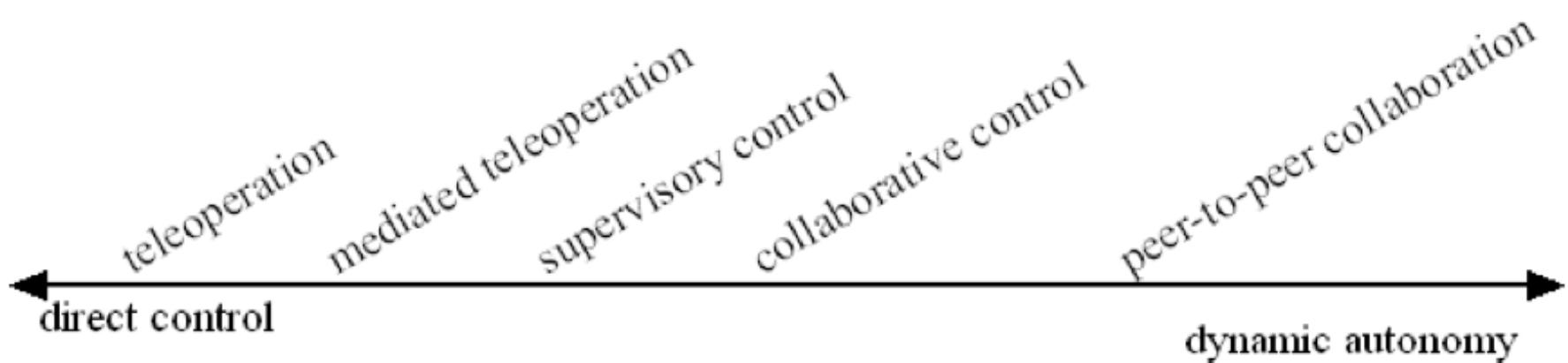
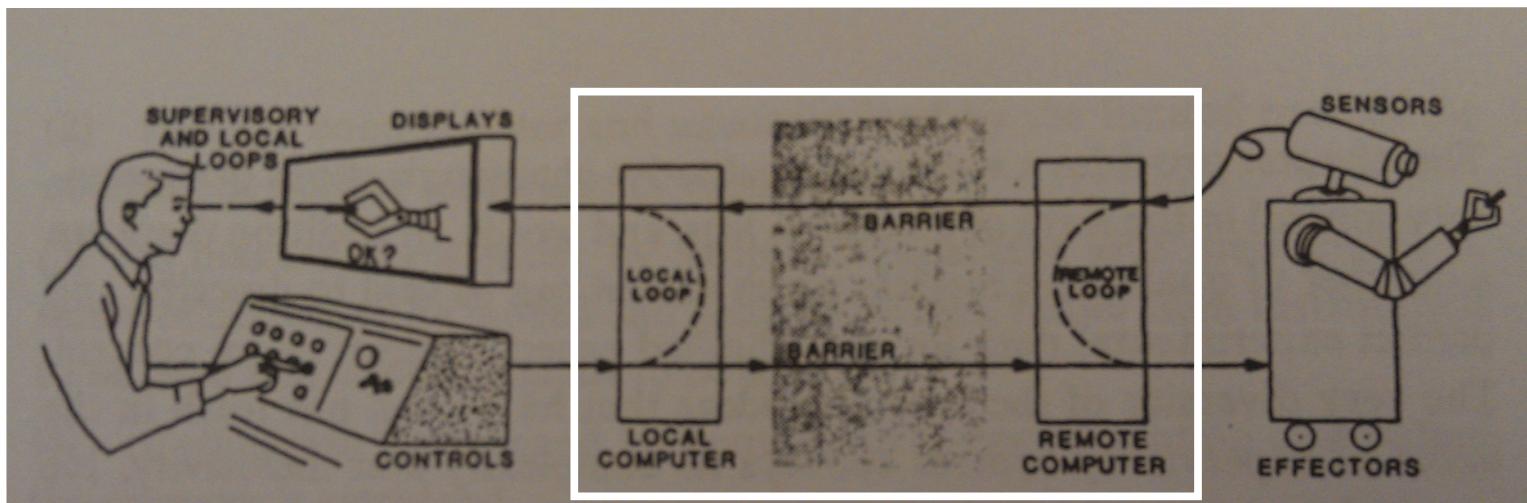
Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

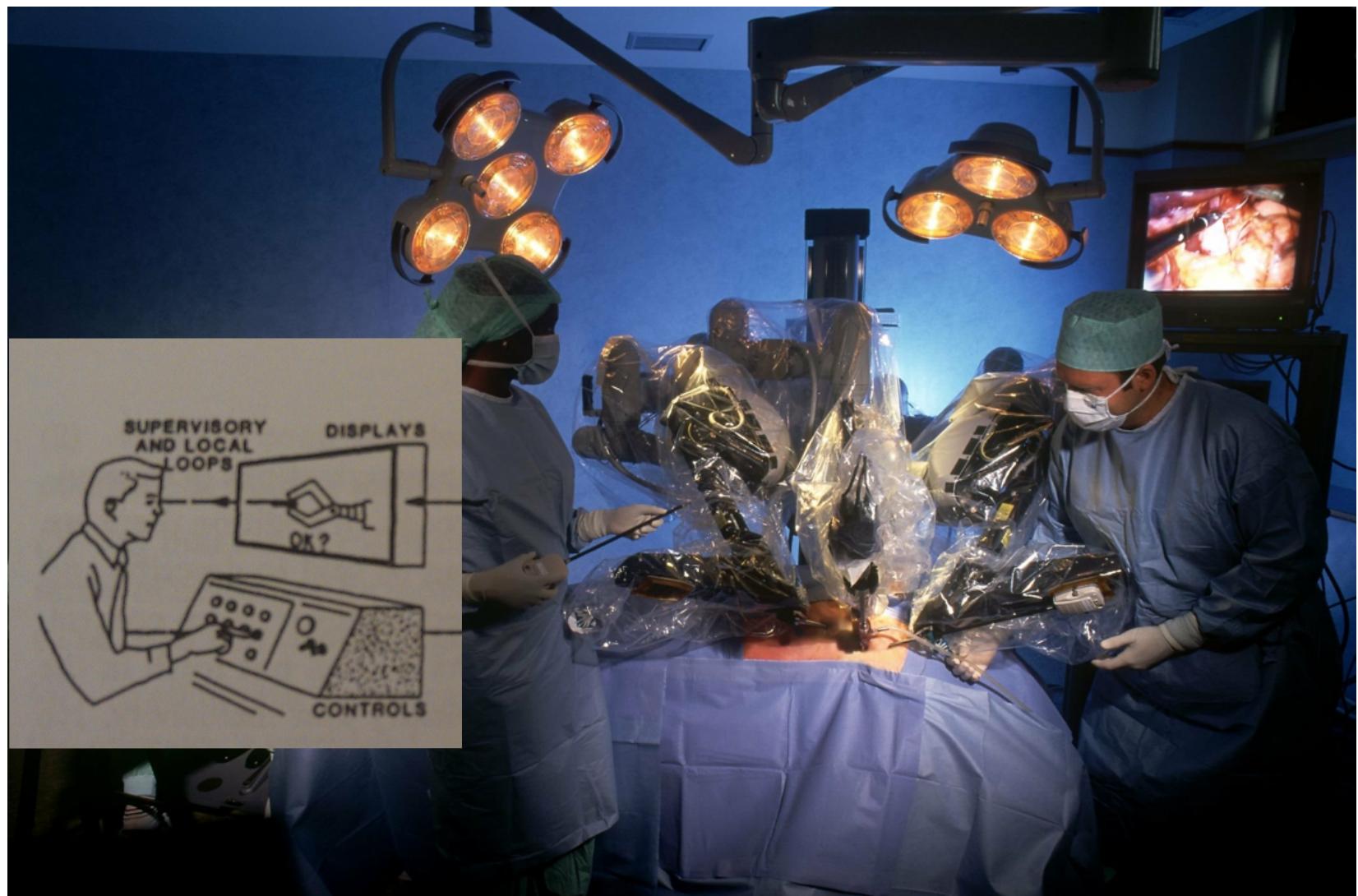


Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

# Supervisory Control







Intuitive Surgical

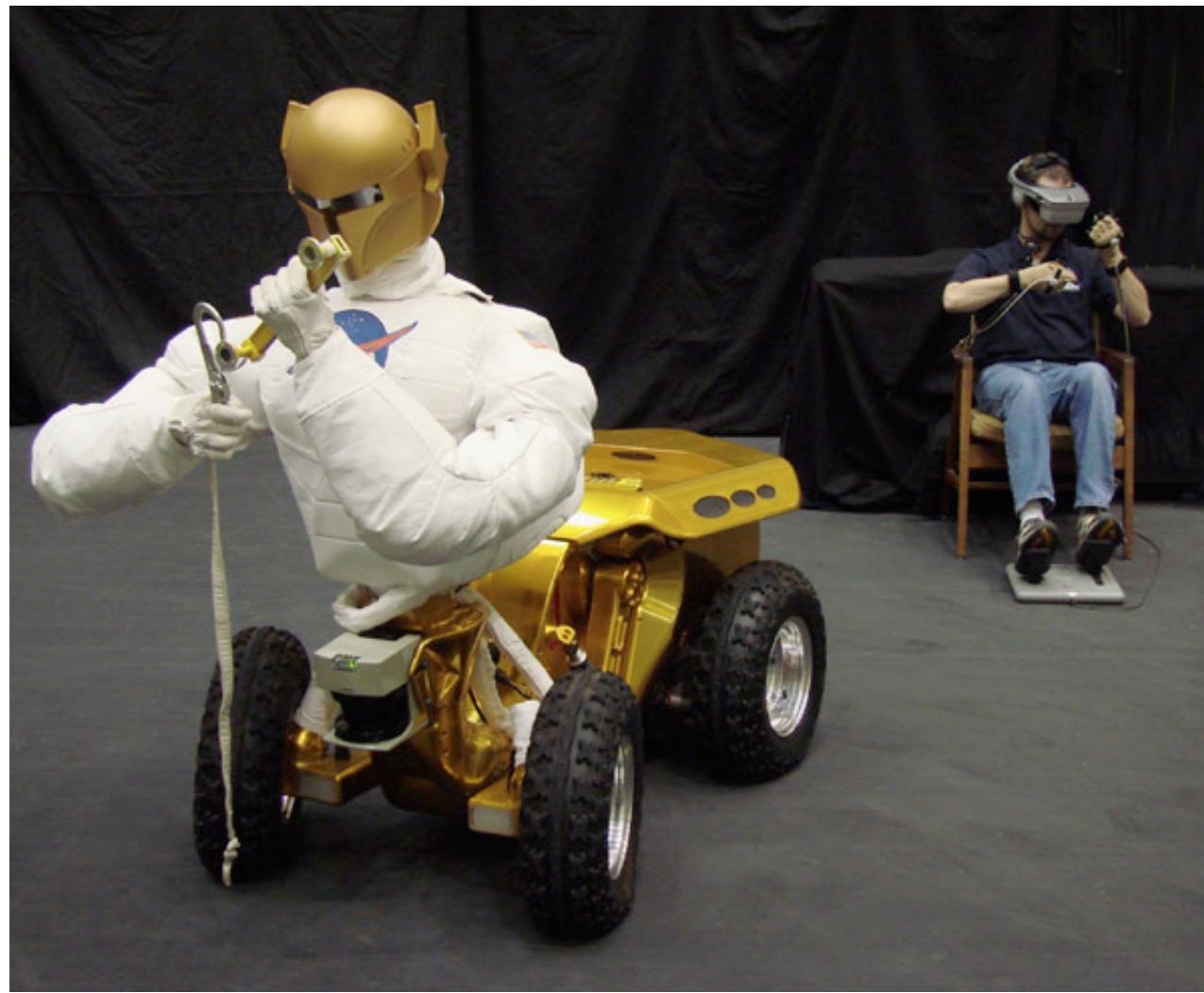
Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



Intuitive Surgical

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)





NASA Robonaut



Michigan Robotics 367/511 - [autorob.org](http://autorob.org)

Making robotics accessible  
for all people

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The rise of personal robots

1.2M views



14:04

Deep sea diving ... in a wheelchair

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9:38

Henry Evans and Chad Jenkins | TEDxMidAtlantic

# Meet the robots for humanity



▶

9:49



### Details

About the talk

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28 languages

### Comments (227)

Join the conversation

Paralyzed by a stroke, Henry Evans uses a telepresence robot to take the stage and show how new robotics, tweaked and personalized by a group called Robots for Humanity, help him live his life to the full. He shows off a nimble little quadrotor drone, created by a team led by

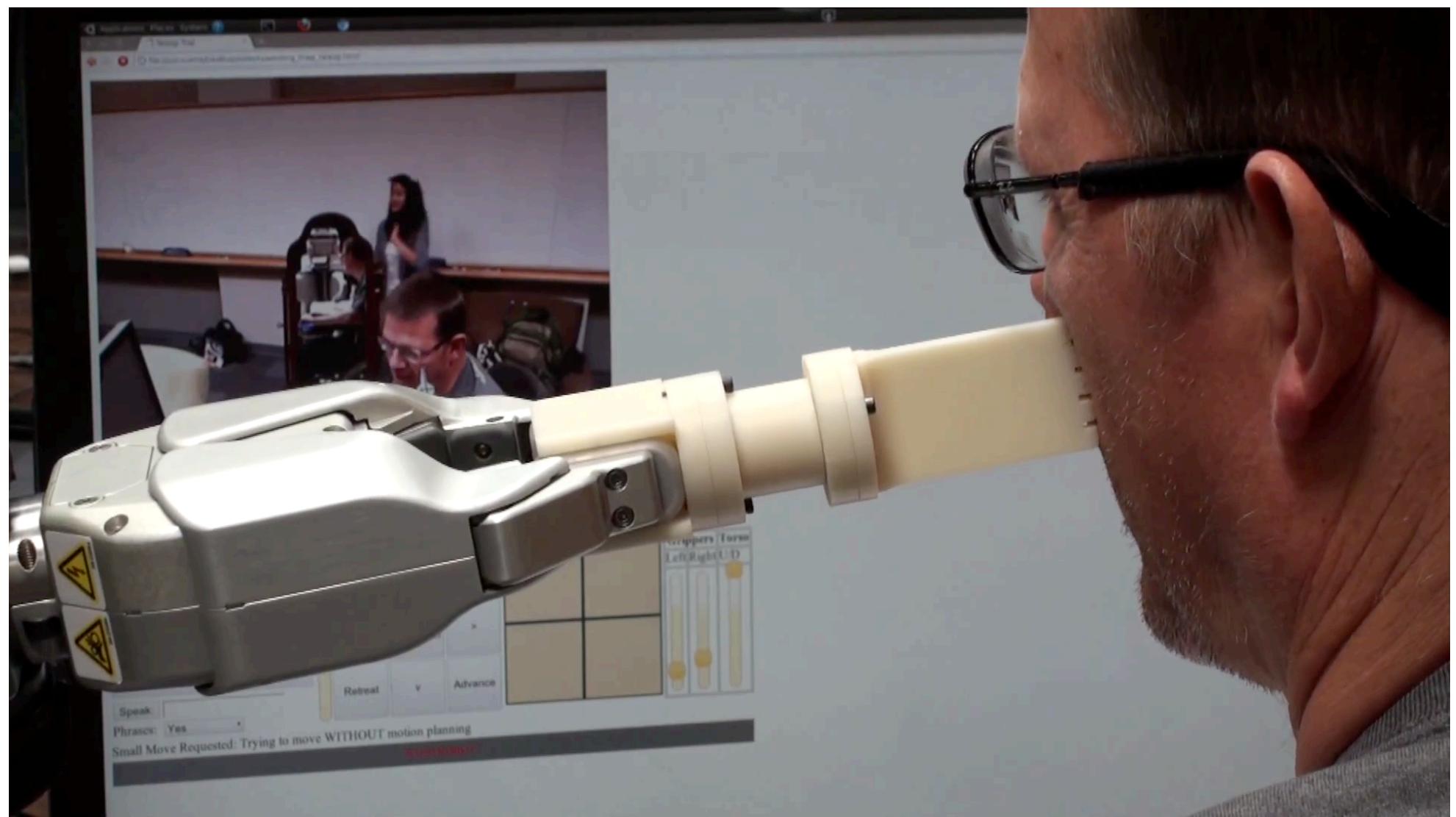
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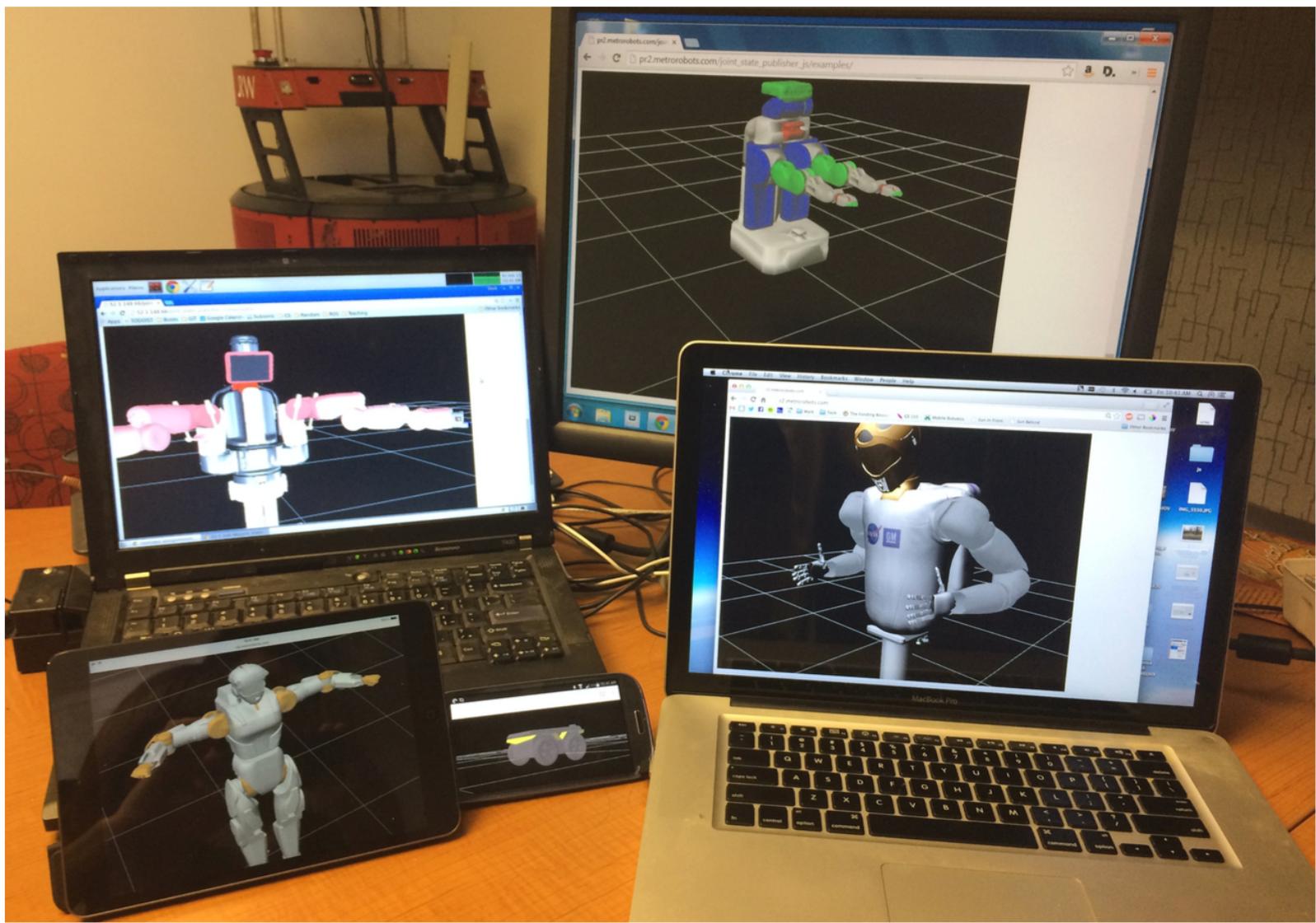


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Courtesy Robots for Humanity

Michigan Robotics 367/511 - [autorob.org](http://autorob.org)



Toris, Jenkins, et al. (2015)

[www.your-new-best.com](http://www.your-new-best.com) - autorob.org

# MAP BUILDER

SPEED: 90%



Michigan Courtesy Russell Toris (WPI) [www.wpi.org](http://www.wpi.org)



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Does a robot have free will?

How will people use your robot?

How well can people use your robot?

Will robots help or harm society?

Who is responsible if a robot causes harm?

Does a robot have free will?

Do you have free will?

# Human-Robot Interaction

# Human-Robot Interaction



Alan Schultz  
(1959-2019)

Foundations and Trends® in  
Human–Computer Interaction  
Vol. 1, No. 3 (2007) 203–275  
© 2007 M. A. Goodrich and A. C. Schultz  
DOI: 10.1561/1100000005

**now**  
the essence of knowledge

## Human–Robot Interaction: A Survey

Michael A. Goodrich<sup>1</sup> and Alan C. Schultz<sup>2</sup>

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<sup>2</sup> US Naval Research Laboratory, Washington, DC 20375, USA,  
schultz@aic.nrl.navy.mil

### Abstract

Human–Robot Interaction (HRI) has recently received considerable attention in the academic community, in labs, in technology companies, and through the media. Because of this attention, it is desirable to present a survey of HRI to serve as a tutorial to people outside the field and to promote discussion of a unified vision of HRI within the field. The goal of this review is to present a unified treatment of HRI-related problems, to identify key themes, and discuss challenge problems that are likely to shape the field in the near future. Although the review follows a survey structure, the goal of presenting a coherent

# Human-Robot Interaction

HRI is a descendent of human factors and supervisory control

Modern HRI is largely regarded as the application of psychological user studies with design, computational, and mechanical considerations

HRI also includes **social robotics** and ethical issues around robotics

Foundations and Trends® in  
Human–Computer Interaction  
Vol. 1, No. 3 (2007) 203–275  
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Autism treatment

# Social Robotics

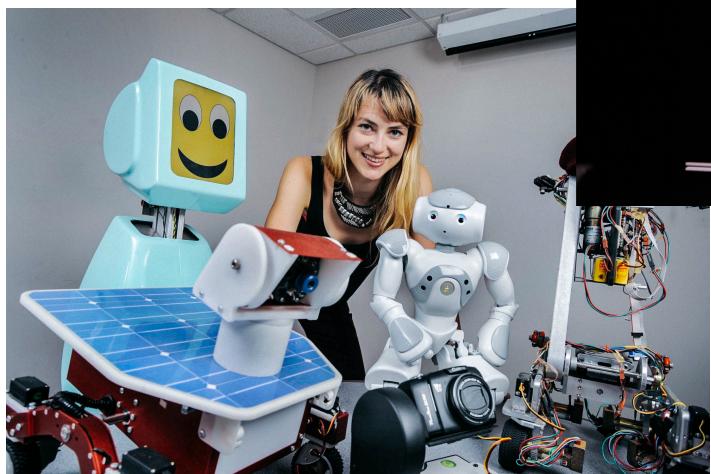


Education

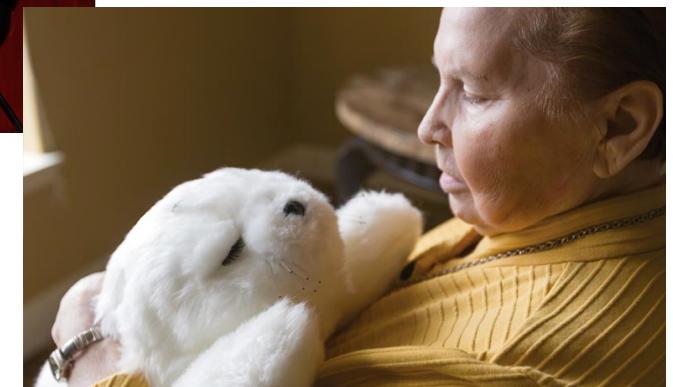
## Rehabilitation



Entertainment



Elder care

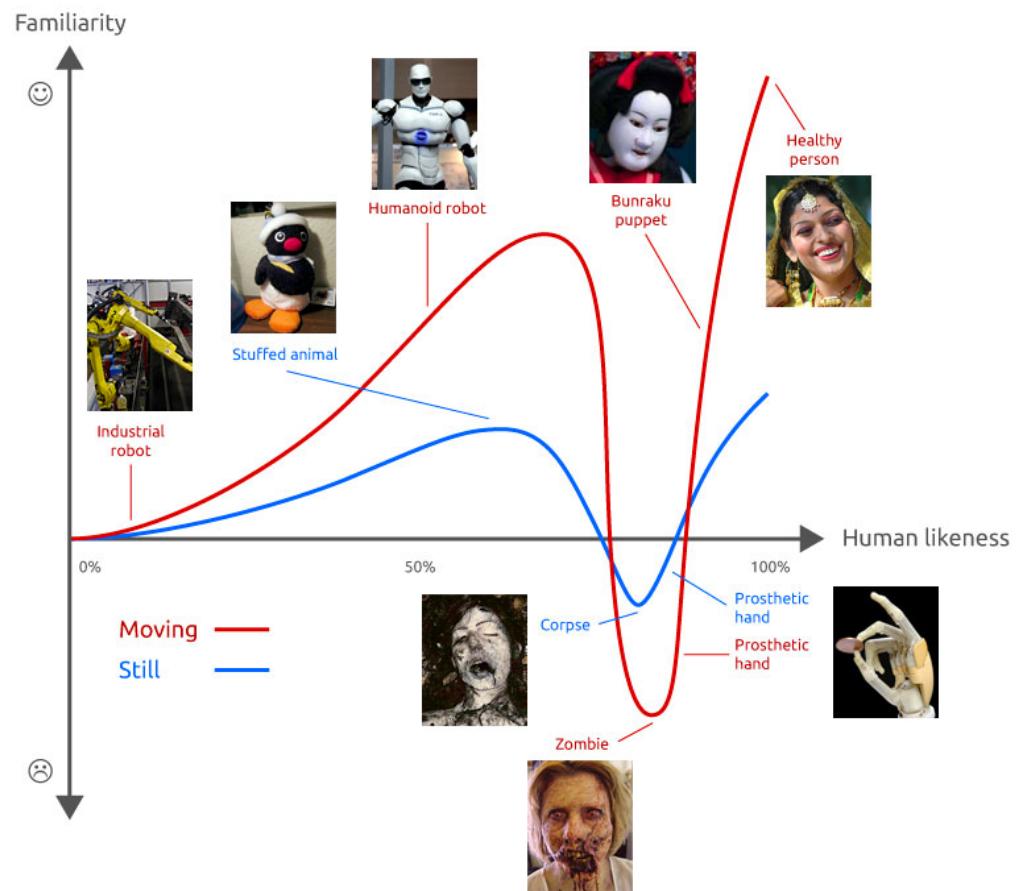


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<https://youtu.be/WijMCSfX0RA>

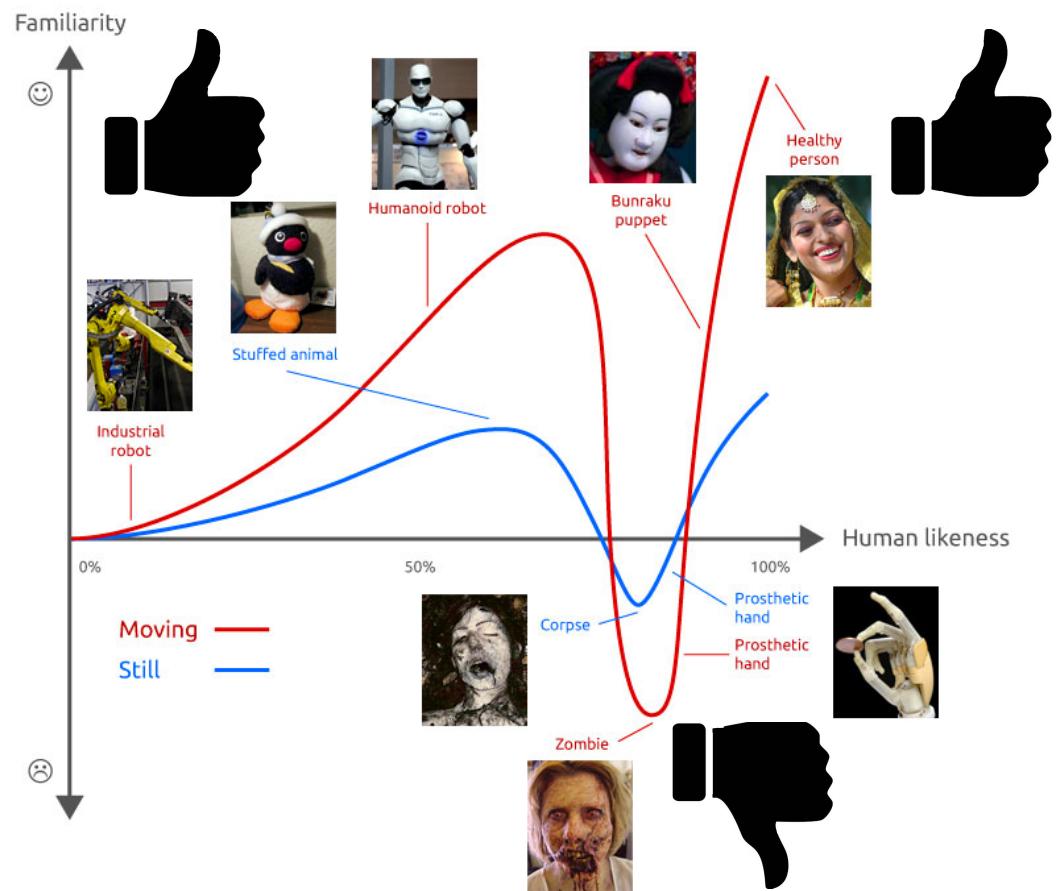
# The Uncanny Valley





<https://youtu.be/WijMCSfX0RA>

# The Uncanny Valley



robot (n):

a machine that resembles a living creature in  
being capable of moving independently and  
performing complex actions



← → C ⓘ <https://www.merriam-webster.com/dictionary/robot>

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robot

DICTIONARY      THESAURUS

**Maybe this is robotics after all...**

1 : a machine that resembles a living creature in being capable of moving independently (as by walking or rolling on wheels) and performing complex actions (such as grasping and moving objects)

- When the next space launch heads for Mars, on board will be dozens of tiny mobile *robots* that will fan out across the Martian landscape, exploring every nook and cranny. —Michael Bowditch

*often* : such a machine built to resemble a human being or animal in appearance and behavior

- While science fiction *robots* might be capable of independent thought, emotions, even a little cooking and sewing, scientists are finding that endowing a mechanical being with even the most basic human functions is a monumental



f

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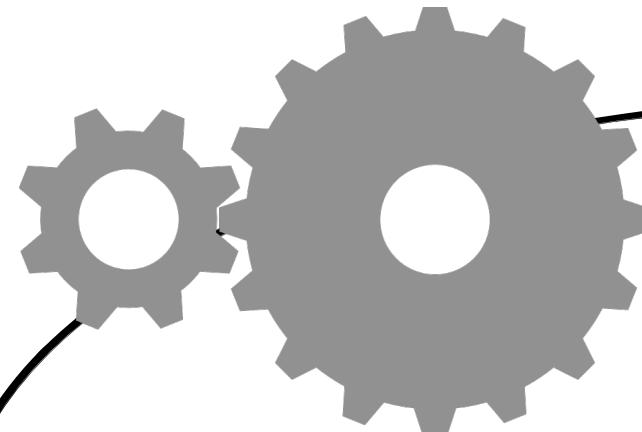
people

heart

CITE

T

# Robotics



Mechanical Engineering  
Electrical Engineering  
“Mechatronics”



Human Factors  
Supervisory Control  
“Usability”



Computer Science  
Artificial Intelligence  
“Autonomy”

Good luck and make progress.