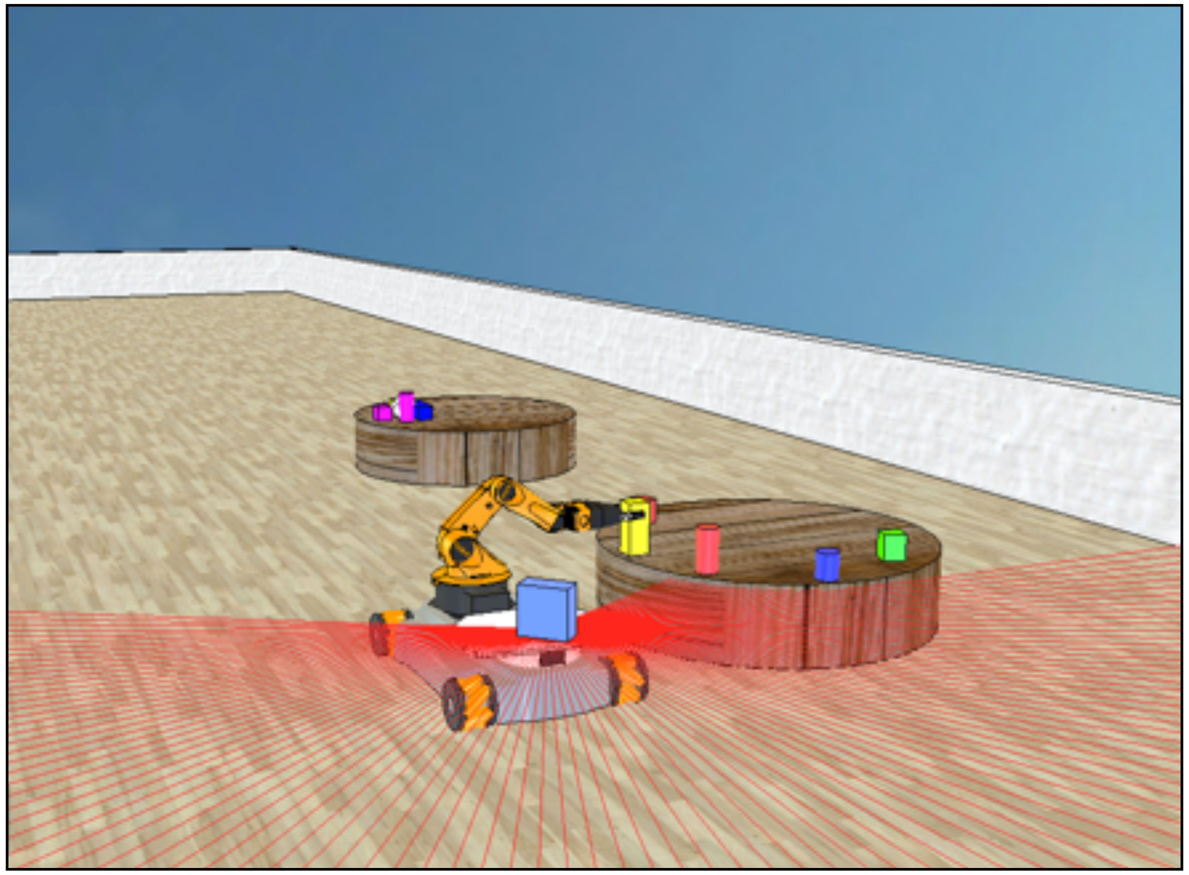
TRS: An Open-source Recipe for Teaching/Learning Robotics with a Simulator.

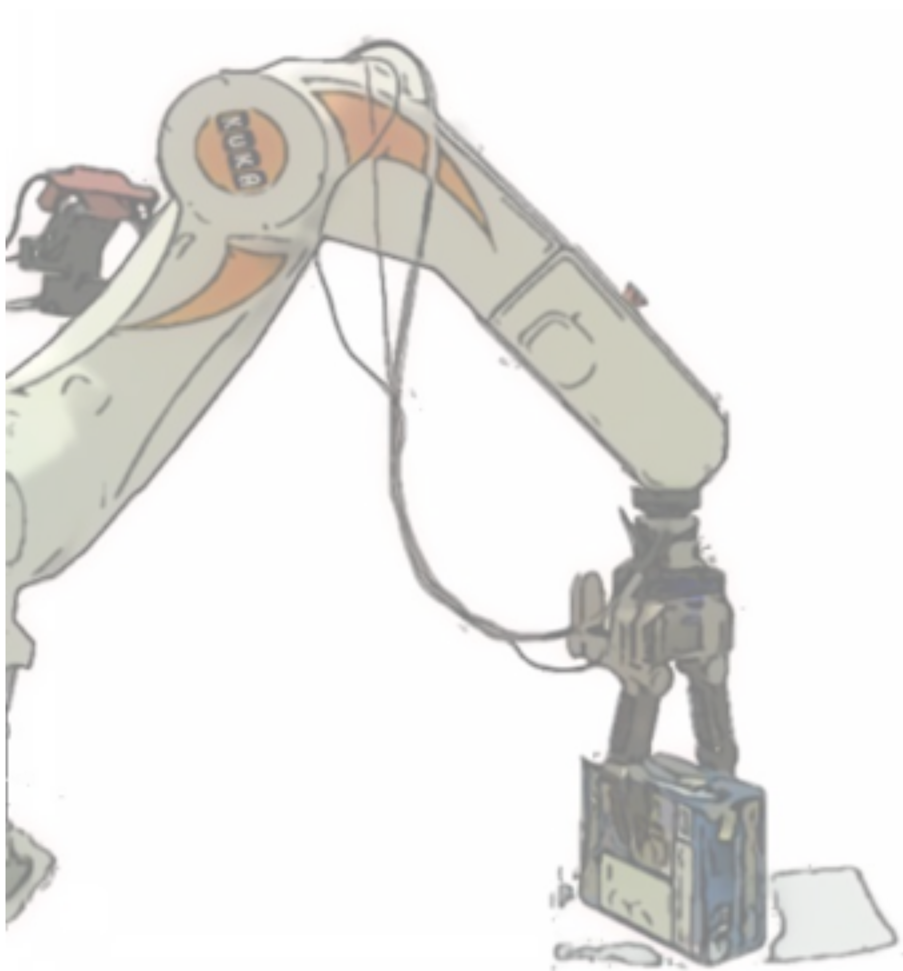
Learning Robotics with a Simulator: Setup Your Laptop in 5 min, Code a Control, Navigation, Vision or Manipulation Project in 100 Lines.

Renaud Detry

Peter Corke

Marc Freese

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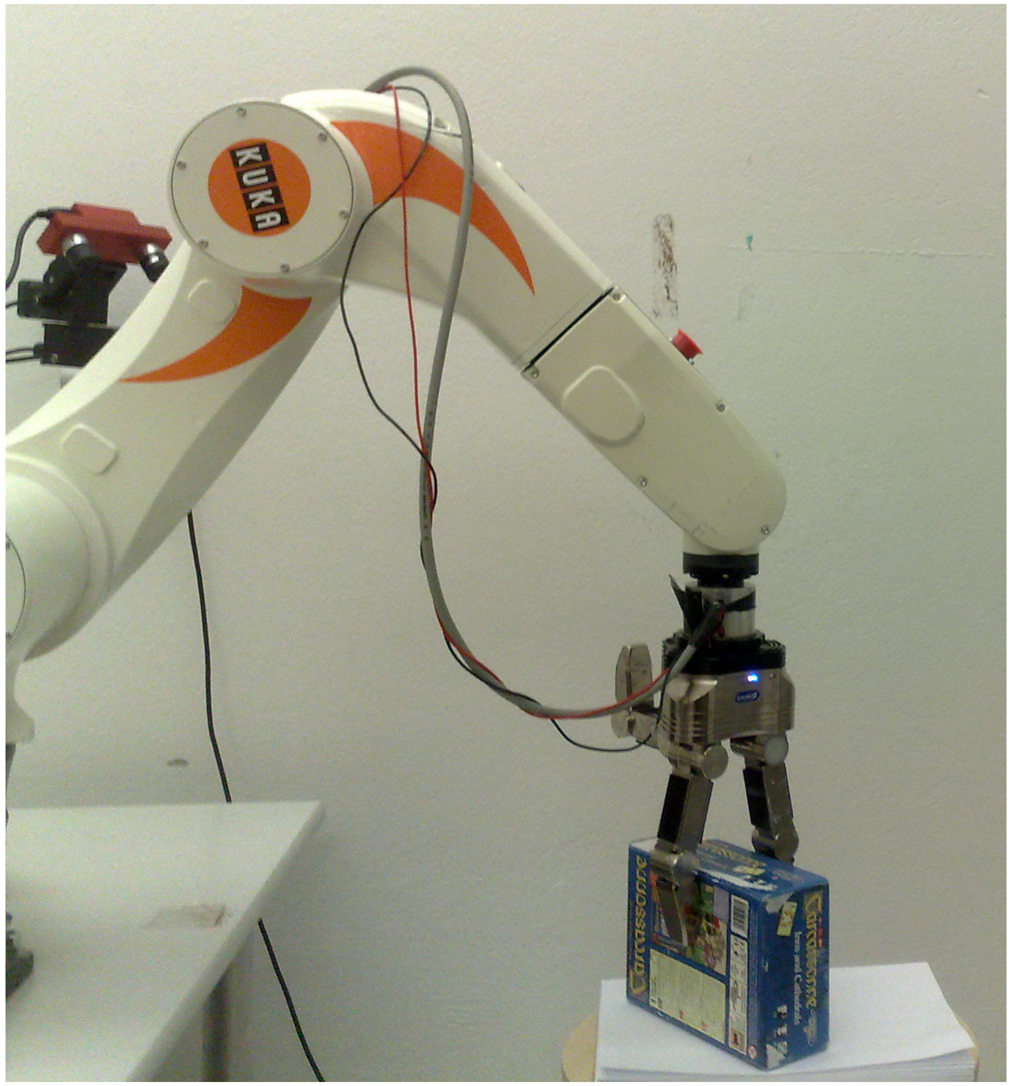

KUKA

TRS: an environment that

- can be setup in a few minutes,
- allows students to code vision, navigation, manipulation in few lines of code

V-REP + Peter Corke's Matlab Robot Toolbox

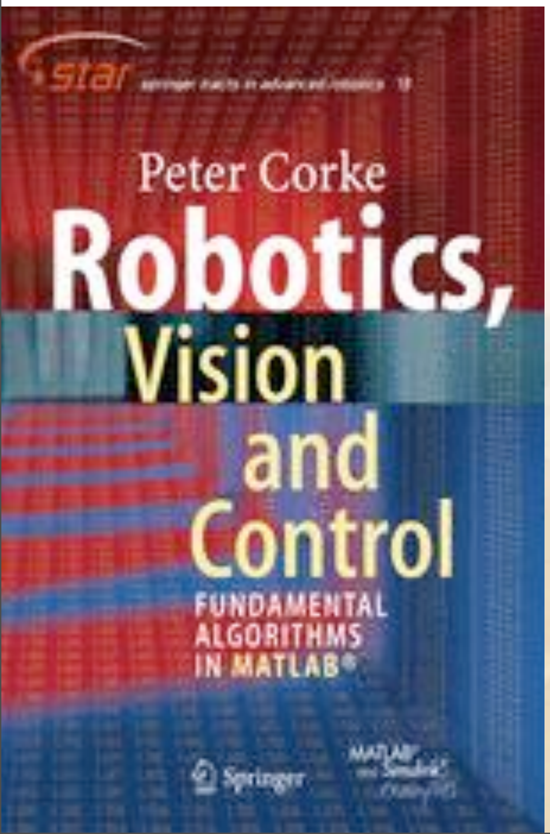
Toolbox: Code

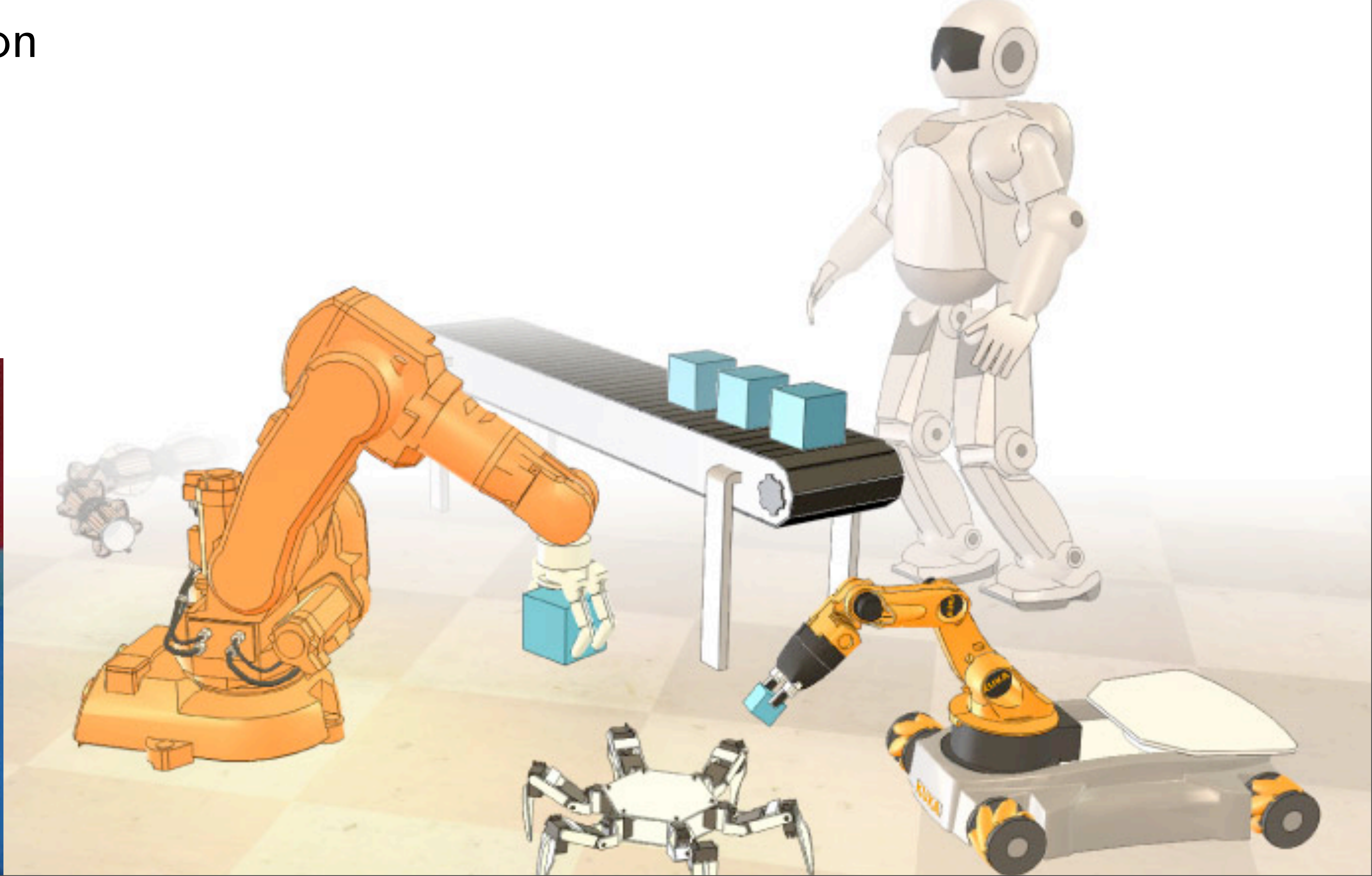
- Control
- Vision
- Navigation

in 100 lines!

VREP:

- Trivial installation — Linux, Mac, Win
- Remote API for C++, Python, Matlab, ROS





Program: http://teaching-robotics.org/trs2014/

Session 1: 8:30–10:00 (1:30 hours)

8:30–8:40: Welcome and Introduction
Renaud Detry (University of Liège, Belgium)
8:40–9:20: Tuto 1
The V-REP Simulator and its Matlab API
Marc Freese (Coppelia Robotics)
9:20–10:00: Tuto 2
The Robotics Toolbox for MATLAB
Peter Corke (Queensland University of Technology, Australia)

COFFEE BREAK

Session 2: 10:30–12:30 (2 hours)

10:30–11:10: Tuto 3
A Robotics Project in Matlab
Renaud Detry (University of Liège, Belgium)
11:10–11:35: Practical Session
Installation on the Participants' Computers
11:35–11:45: Selected Contributions
KUKA LWR4 dynamic modeling in V-REP and remote control via Matlab/Simulink
Marco Cognetti and Massimo Cefalo (Sapienza Universita di Roma)
11:45–12:00: Discussion and Closing

TRS: An Open-source Recipe for Teaching/Learning Robotics with a Simulator.

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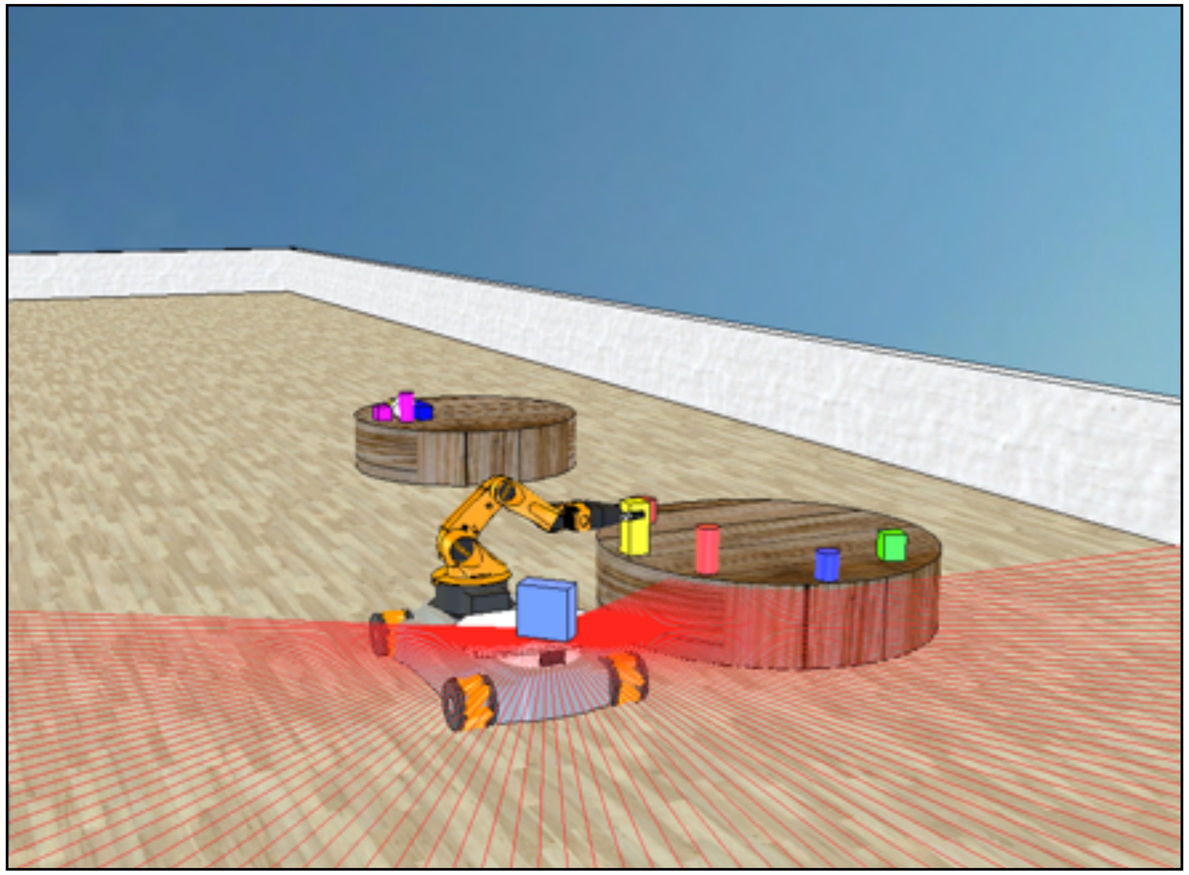
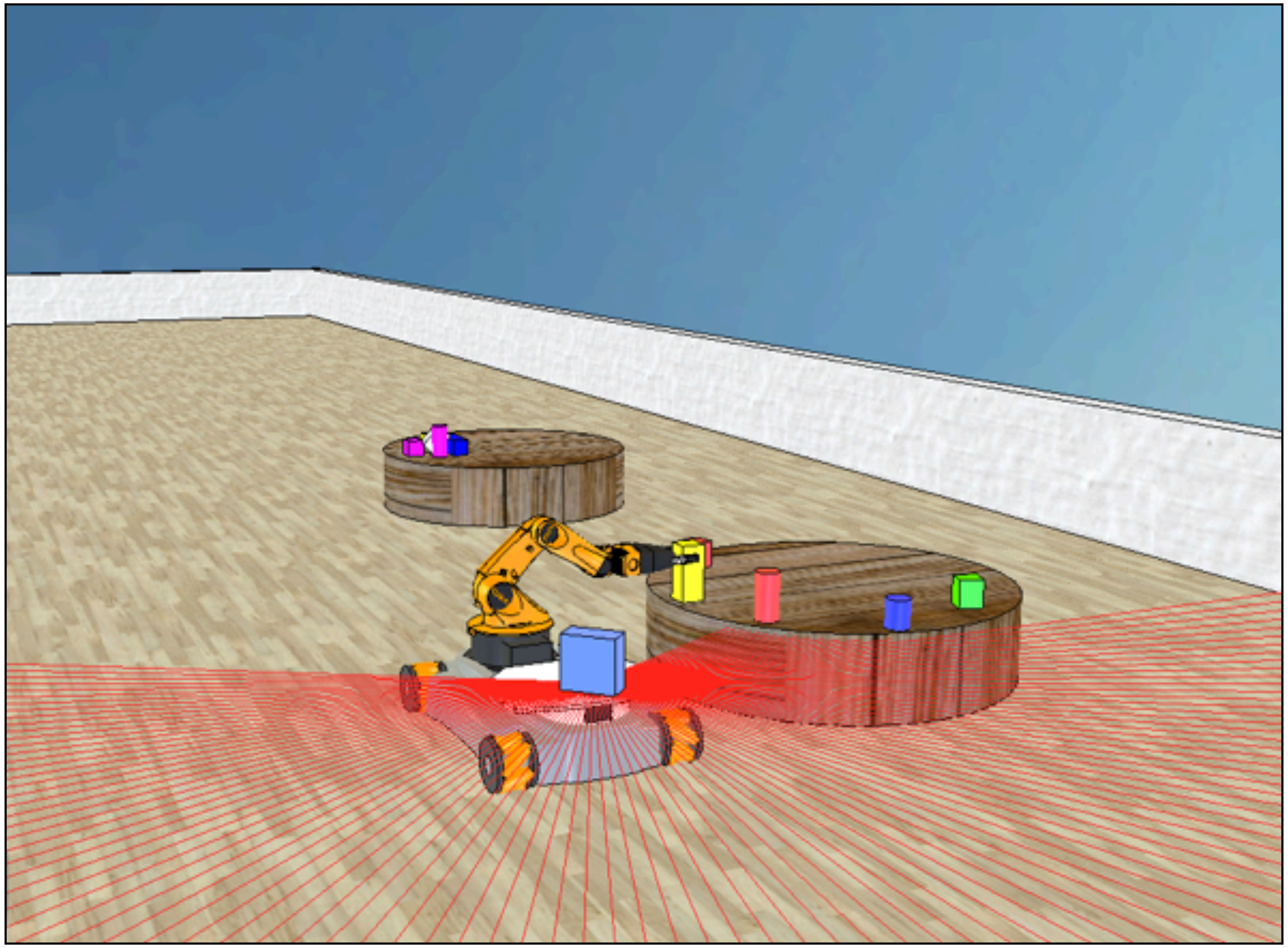
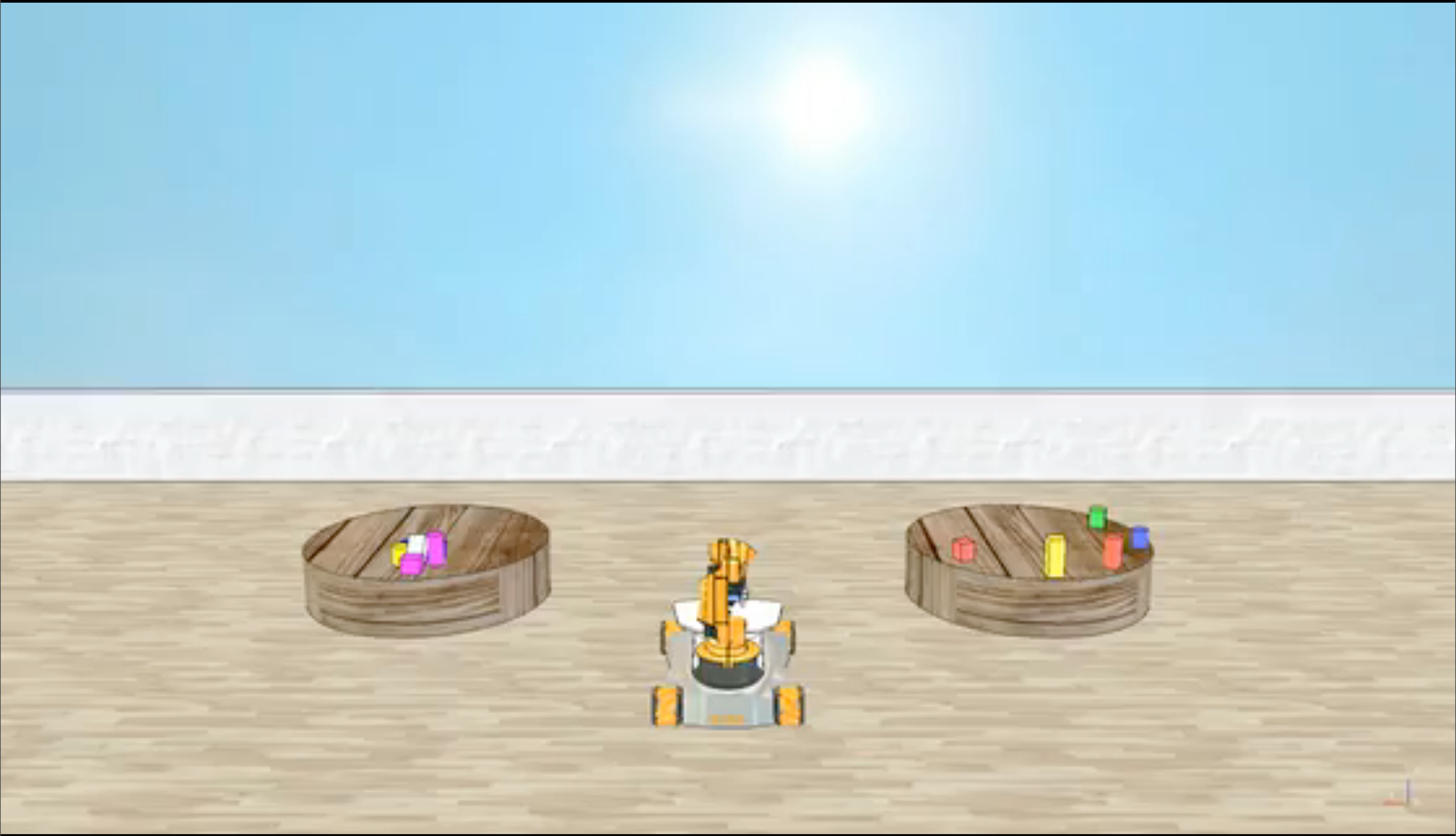


- Involves: control, navigation, mapping, vision and manipulation.
- Goal: pickup groceries from a table and store them in baskets.





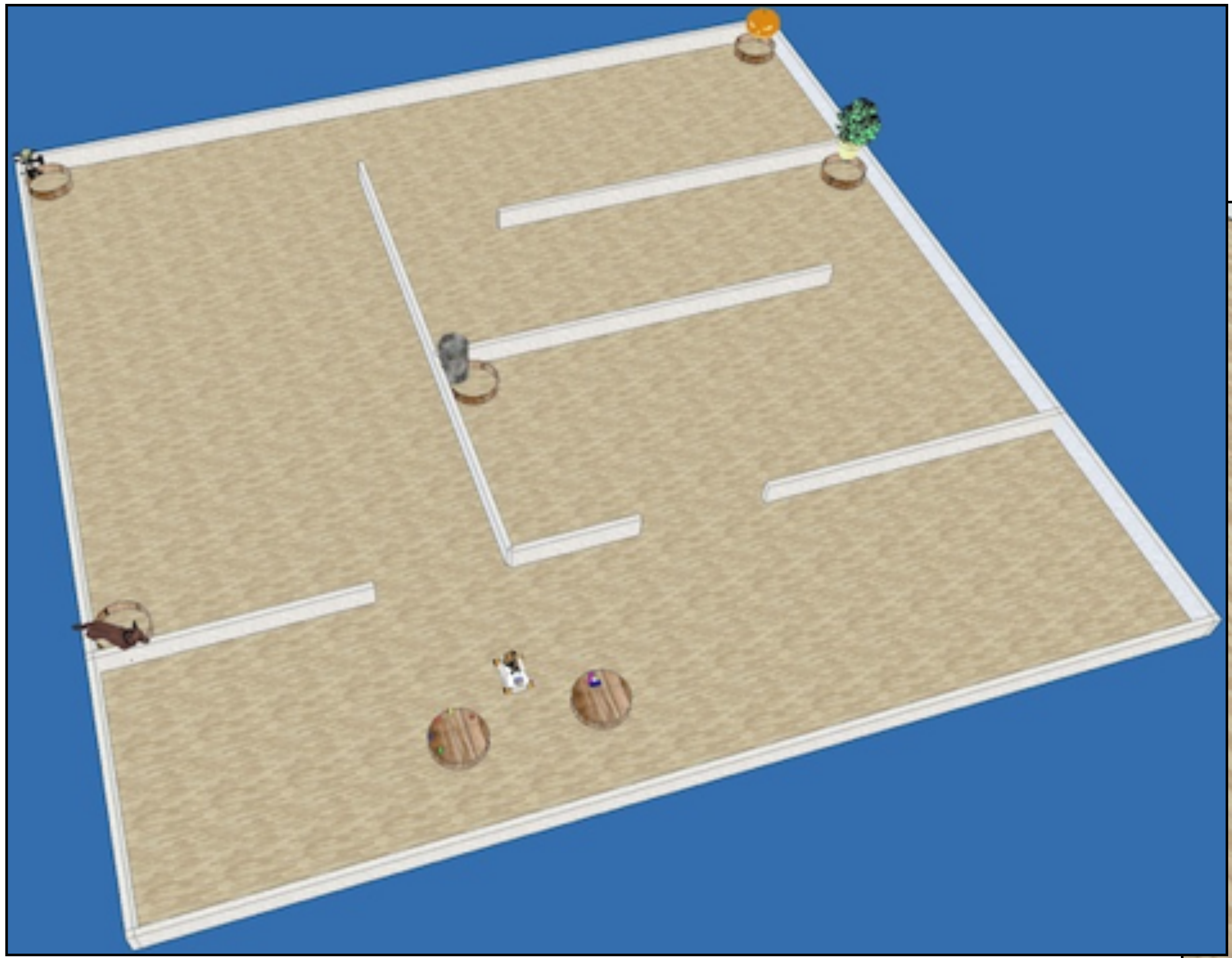
What You Get

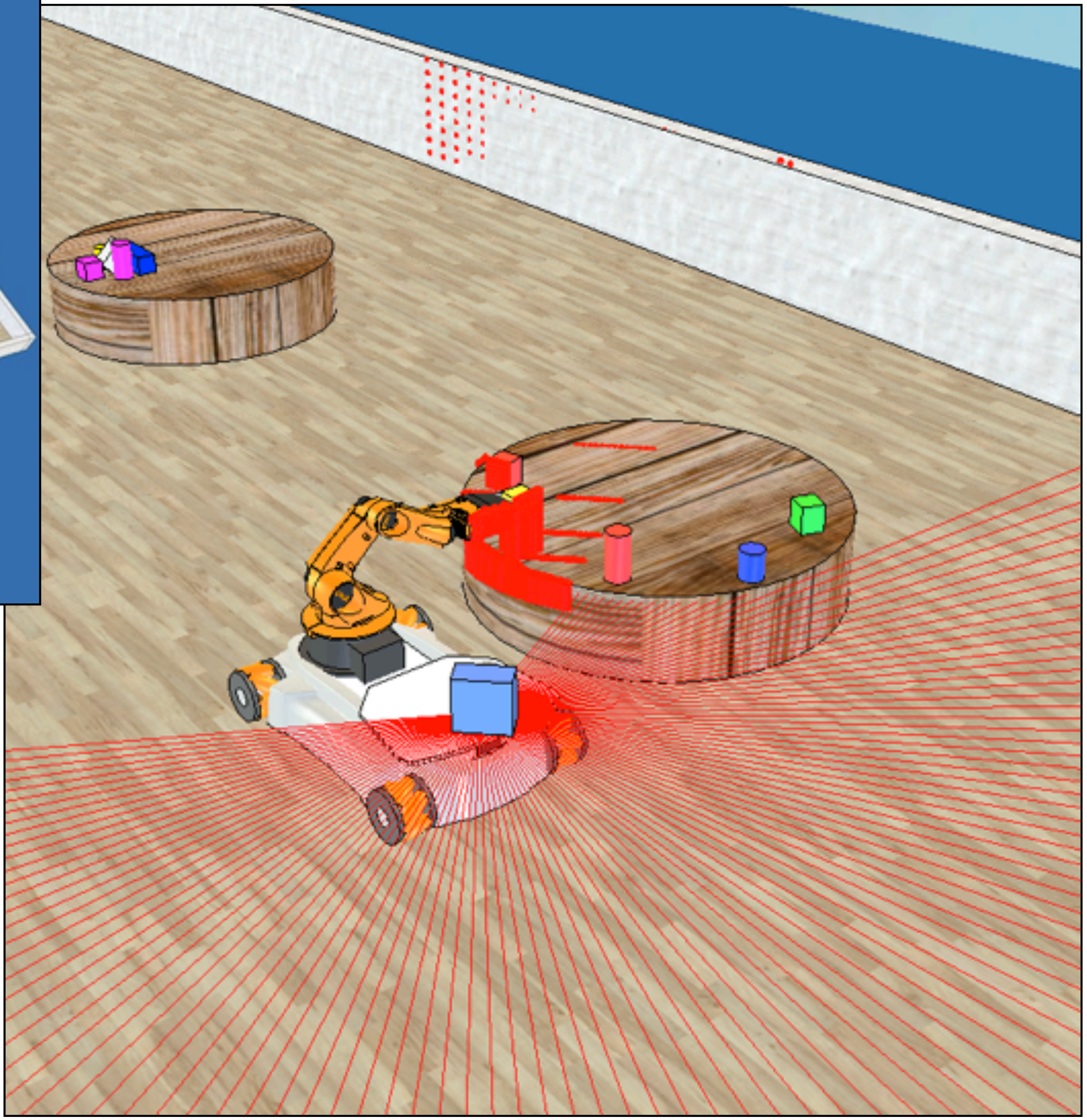
We provide a complete recipe for organizing the project:

- a V-REP model of a house floor and a youBot,
- a Matlab script that illustrates access the robot's sensors and actuators,
- a page that explains how to setup a laptop to work on the project,
- a page that presents the project definition: objectives, milestones, a description of the robot and the documentation of the Matlab functions that access the robot's sensors and actuators.

http://teaching-robotics.org/trs

1) V-REP model of a youBot and a house





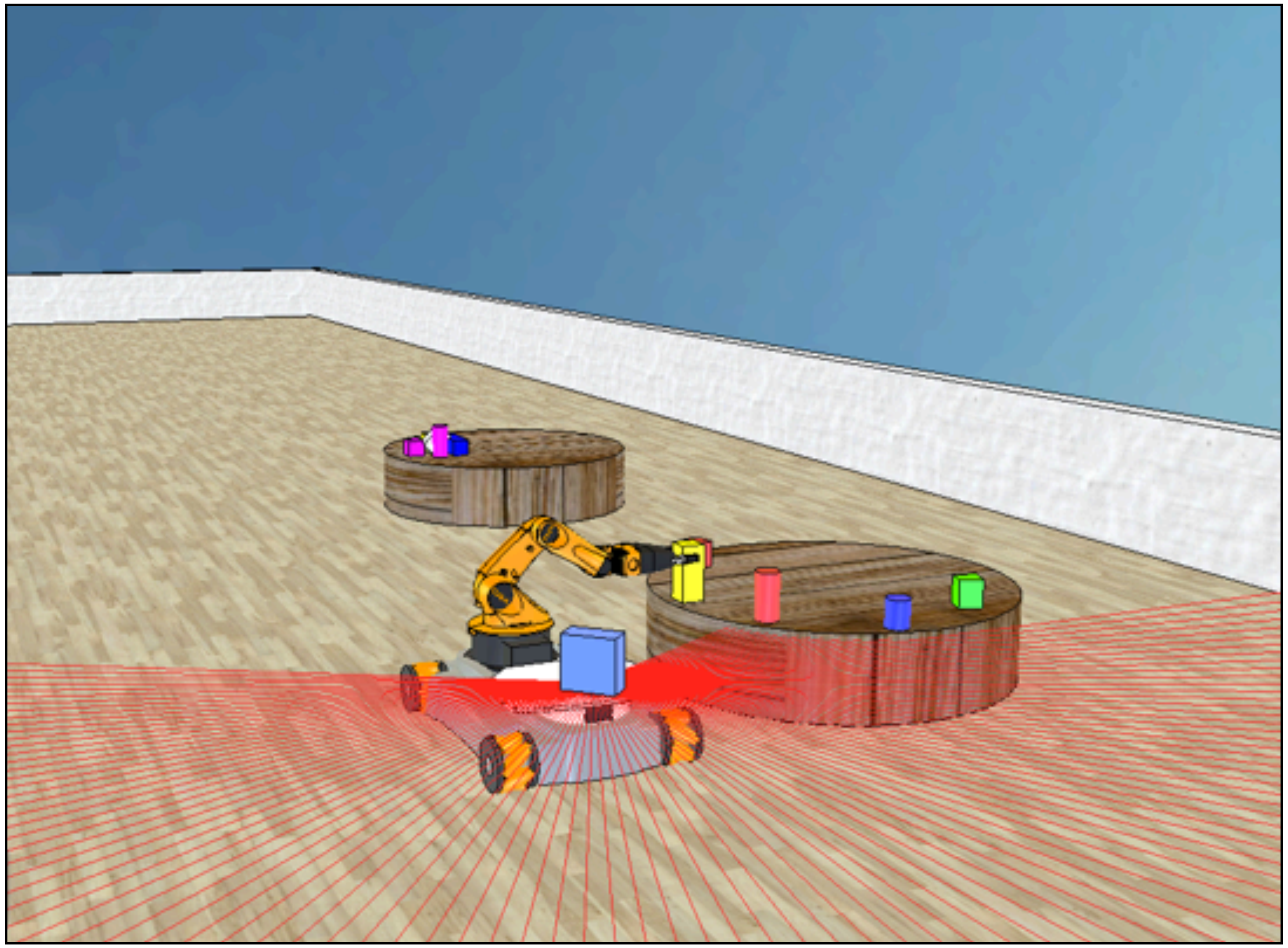
2) Matlab script showing how to access the youBot

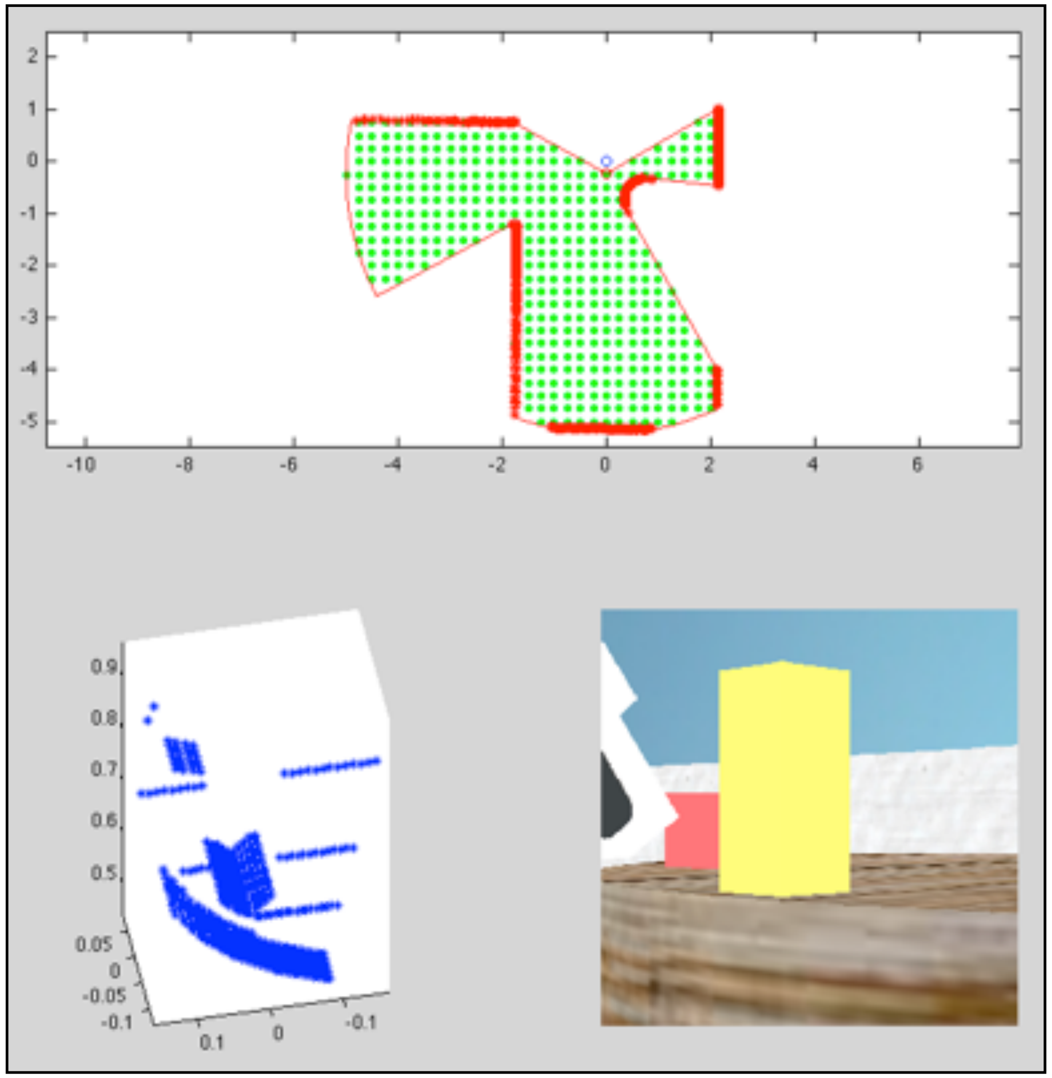
```matlab
function youbot()
% youbot Illustrates the V-REP Matlab bindings.

% (C) Copyright Renaud Detry 2013.
% Distributed under the GNU General Public License.
% (See http://www.gnu.org/copyleft/gpl.html)

   disp('Program started');
   %Use the following line if you had to recompile remoteApi
   %vrep = remApi('remoteApi', 'extApi.h');
   vrep=remApi('remoteApi');
   vrep.simxFinish(-1);
   id = vrep.simxStart('127.0.0.1', 19997, true, true, 2000, 5);

   if id < 0,
   disp('Failed connecting to remote API server. Exiting.');
   vrep.delete();
   return;
   end
   fprintf('Connection %d to remote API server open.\n', id);

   % Make sure we close the connexion whenever the script is interrupted.
   cleanupObj = onCleanup(@() cleanup_vrep(vrep, id));

   % This will only work in "continuous remote API server service"
   % See http://www.v-rep.eu/helpFiles/en/remoteApiServerSide.htm
   res = vrep.simxStartSimulation(id, vrep.simx_opmode_oneshot_wait);
   % We're not checking the error code - if vrep is not run in continuous remote
   % mode, simxStartSimulation could return an error.
   % vrchk(vrep, res);

   % Retrieve all handles, and stream arm and wheel joints, the robot's pose,
   % the Hokuyo, and the arm tip pose.
   h = youbot_init(vrep, id);
   h = youbot_hokuyo_init(vrep, h);

   % Let a few cycles pass to make sure there's a value waiting for us next time
   % we try to get a joint angle or the robot pose with the simx_opmode_buffer
   % option.
   pause(.2);

   % Constants:

   timestep = .05;
   wheelradius = 0.0937/2; % This value may be inaccurate. Check before using.

   % Min max angles for all joints:
   armJointRanges = [-2.9496064186096,2.9496064186096;
                     -1.5707963705063,1.308996796608;
                     -2.2863812446594,2.2863812446594;
                     -1.7802357673645,1.7802357673645;
                     -1.5707963705063,1.5707963705063 ];

   startingJoints = [0,30.91*pi/180,52.42*pi/180,72.68*pi/180,0];

   % In this demo, we move the arm to a preset pose:
   pickupJoints = [90*pi/180, 19.6*pi/180, 113*pi/180, -41*pi/180, 0*pi/180];

   % Tilt of the Rectangle22 box
   r22tilt = -44.56/180*pi;


   % Parameters for controlling the youBot's wheels:
   forwBackVel = 0;
   leftRightVel = 0;
   rotVel = 0;

   disp('Starting robot');

   % Set the arm to its starting configuration:
   res = vrep.simxPauseCommunication(id, true); vrchk(vrep, res);
   for i = 1:5,
   res = vrep.simxSetJointTargetPosition(id, h.armJoints(i),...
                                         startingJoints(i),...
                                         vrep.simx_opmode_oneshot);
   vrchk(vrep, res, true);
   end
   res = vrep.simxPauseCommunication(id, false); vrchk(vrep, res);

   plotData = true;
   if plotData,
   subplot(211)
   drawnow;
   [X,Y] = meshgrid(-5:.25:5,-5.5:.25:2.5);
   X = reshape(X, 1, []);
   Y = reshape(Y, 1, []);
   end

   % Make sure everything is settled before we start
   pause(2);

   [res homeGripperPosition] = ...
     vrep.simxGetObjectPosition(id, h.ptip,...
                                h.armRef,...
                                vrep.simx_opmode_buffer);
   vrchk(vrep, res, true);
   fsm = 'rotate';

   while true,
   tic
   if vrep.simxGetConnectionId(id) == -1,
   error('Lost connection to remote API.');
   end

   [res youbotPos] = vrep.simxGetObjectPosition(id, h.ref, -1,...
                                                 vrep.simx_opmode_buffer);
```

```matlab
vrchk(vrep, res, true);
[res youbotEuler] = vrep.simxGetObjectOrientation(id, h.ref, -1,...
                                                  vrep.simx_opmode_buffer);
vrchk(vrep, res, true);

if plotData,
% Read data from the Hokuyo sensor:
[pts contacts] = youbot_hokuyo(vrep, h, vrep.simx_opmode_buffer);

in = inpolygon(X, Y, [h.hokuyo1Pos(1) pts(1,:) h.hokuyo2Pos(1)],...
               [h.hokuyo1Pos(2) pts(2,:) h.hokuyo2Pos(2)]);

subplot(211)
plot(X(in), Y(in),'.g', pts(1,contacts), pts(2,contacts), '*r',...
     [h.hokuyo1Pos(1) pts(1,:) h.hokuyo2Pos(1)],...
     [h.hokuyo1Pos(2) pts(2,:) h.hokuyo2Pos(2)], 'r',...
     0, 0, 'ob',...
     h.hokuyo1Pos(1), h.hokuyo1Pos(2), 'or',...
     h.hokuyo2Pos(1), h.hokuyo2Pos(2), 'or');
axis([-5.5 5.5 -5.5 2.5]);
axis equal;
drawnow;

end
angl = -pi/2;

if strcmp(fsm, 'rotate'),
rotVel = 10*angdiff(angl, youbotEuler(3));
if abs(angdiff(angl, youbotEuler(3))) < 1/180*pi,
rotVel = 0;
fsm = 'drive';
end
elseif strcmp(fsm, 'drive'),
forwBackVel = -20*(youbotPos(1)+3.167);

if youbotPos(1)+3.167 < .001,
forwBackVel = 0;
vrep.simxSetObjectOrientation(id, h.rgbdCasing, h.ref,...
                              [0 0 pi/4], vrep.simx_opmode_oneshot);
for i = 1:5,
res = vrep.simxSetJointTargetPosition(id, h.armJoints(i), pickupJoints(i),...
                                      vrep.simx_opmode_oneshot);
vrchk(vrep, res, true);
end
if plotData,
fsm = 'snapshot';
else,
fsm = 'extend';
end
end
elseif strcmp(fsm, 'snapshot'),
% Read data from the range camera

% Reading a 3D image costs a lot to VREP (vrep has to simulate the image). It
% also requires a lot of bandwidth, and processing a 3D point cloud (for
% instance, to find one of the boxes or cylinders that the robot has to
% grasp) will take a long time in Matlab. In general, you will only want to
% capture a 3D image at specific times, for instance when you believe you're
% facing one of the tables.

% Reduce the view angle to better see the objects
res = vrep.simxSetFloatSignal(id, 'rgbd_sensor_scan_angle', pi/8,...
                              vrep.simx_opmode_oneshot_wait);
vrchk(vrep, res);
% Ask the sensor to turn itself on, take A SINGLE 3D IMAGE,
% and turn itself off again
res = vrep.simxSetIntegerSignal(id, 'handle_xyz_sensor', 1,...
                                vrep.simx_opmode_oneshot_wait);
vrchk(vrep, res);

fprintf('Capturing point cloud...\n');
pts = youbot_xyz_sensor(vrep, h, vrep.simx_opmode_oneshot_wait);
% Each column of pts has [x;y;z;distancetosensor]
% Here, we only keep points within 1 meter, to focus on the table
pts = pts(1:3,pts(4,:)<1);
subplot(223)
plot3(pts(1,:), pts(2,:), pts(3,:), '*');
axis equal;
view([-169 -46]);

% Save the pointcloud to pc.xyz.
% (pc.xyz can be displayed with meshlab.sf.net).
fileID = fopen('pc.xyz','w');
fprintf(fileID,'%f %f %f\n',pts);
fclose(fileID);
fprintf('Read %i 3D points, saved to pc.xyz.\n', max(size(pts)));

% Read data from the RGB camera

% This is very similar to reading from the 3D camera. The comments in the 3D
% camera section directly apply to this section.

res = vrep.simxSetIntegerSignal(id, 'handle_rgb_sensor', 1,...
                                vrep.simx_opmode_oneshot_wait);
vrchk(vrep, res);
fprintf('Capturing image...\n');
[res resolution image] = ...
  vrep.simxGetVisionSensorImage2(id, h.rgbSensor, 0,...
                                 vrep.simx_opmode_oneshot_wait);
vrchk(vrep, res);
fprintf('Captured %i pixels.\n', resolution(1)*resolution(2));
subplot(224)
imshow(image);
drawnow;
fsm = 'extend';
elseif strcmp(fsm, 'extend'),
```

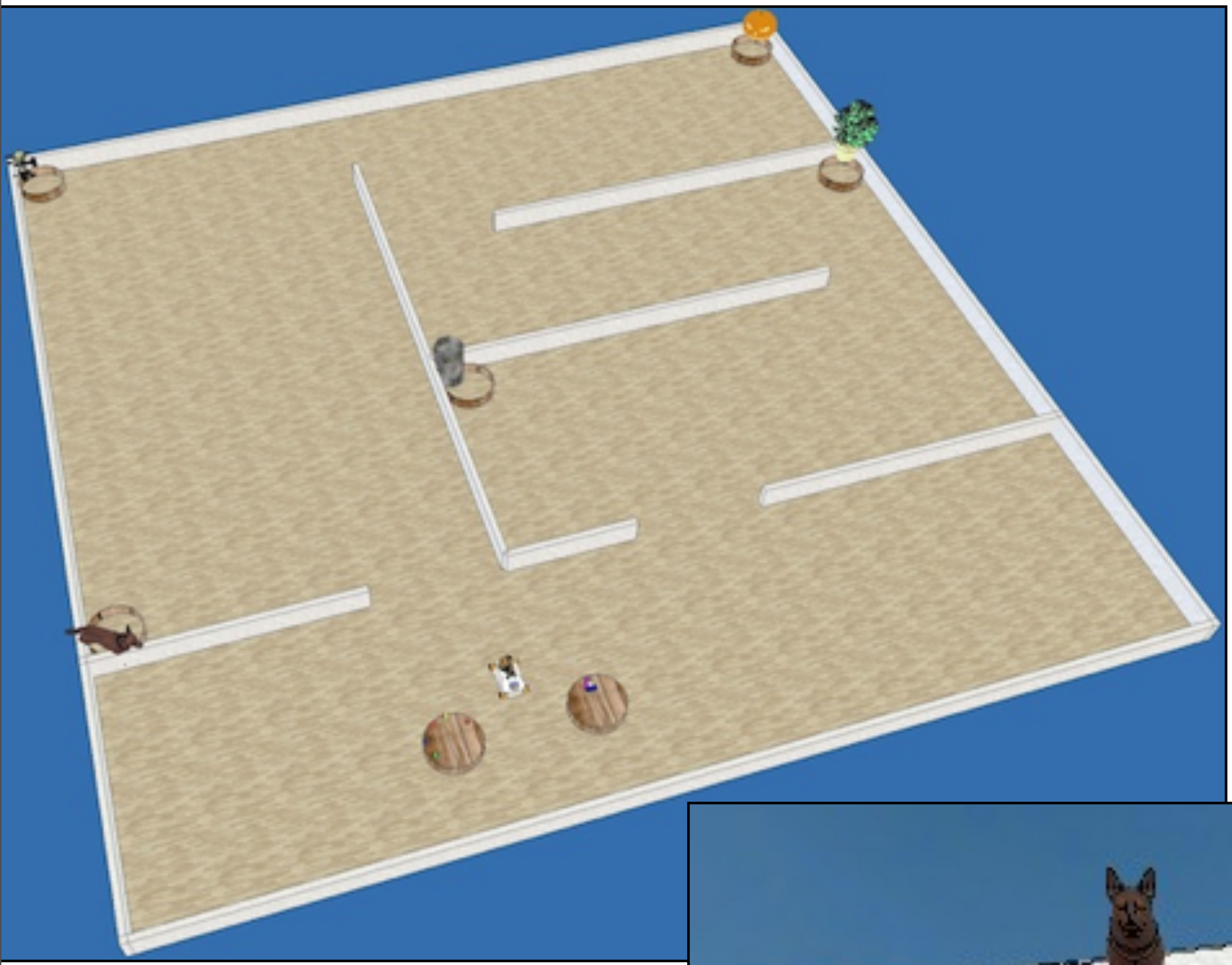
Practice Navigation, Grasping, Vision in 5 Minutes

```
vrep = remApi('remoteApi', 'extApi.h');
id = vrep.simxStart('127.0.0.1', 57689, true, true, 2000, 5);

[res image] = vrep.simxGetVisionSensorImage(id, cam);

vrep.simxSetJointTargetVelocity(id, wheel1, 10);
```





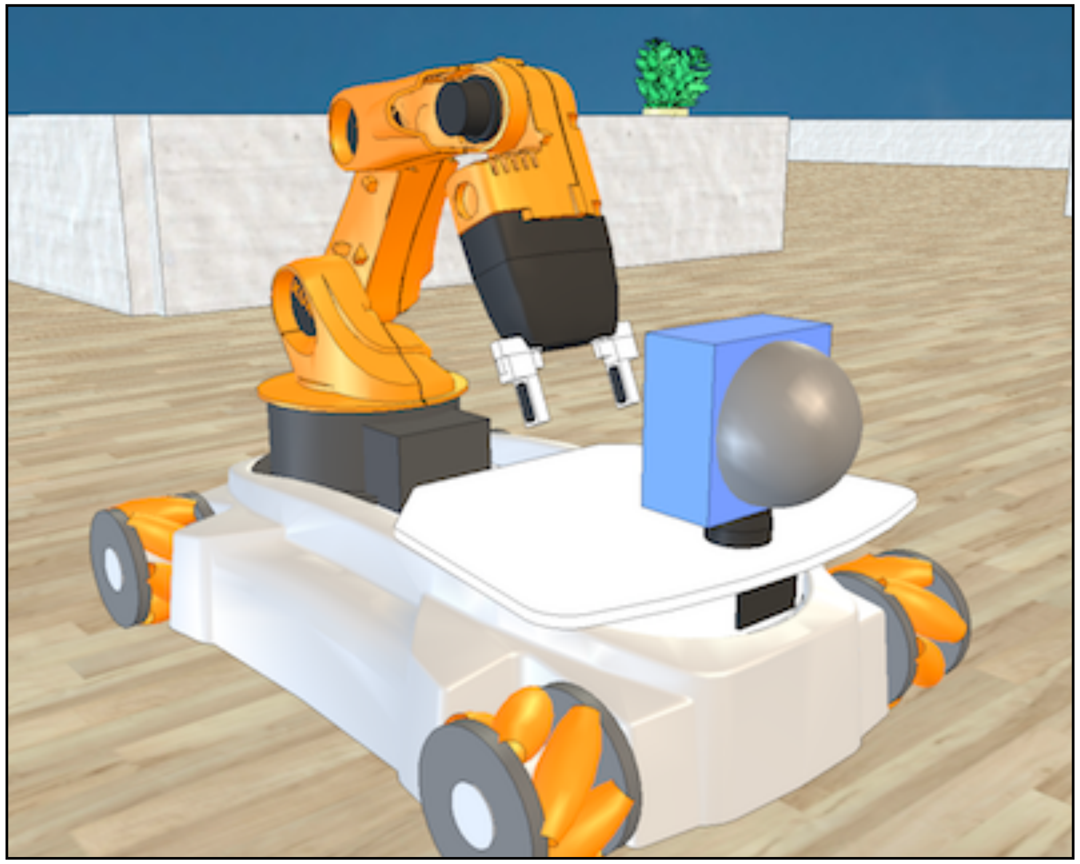
Project Definition

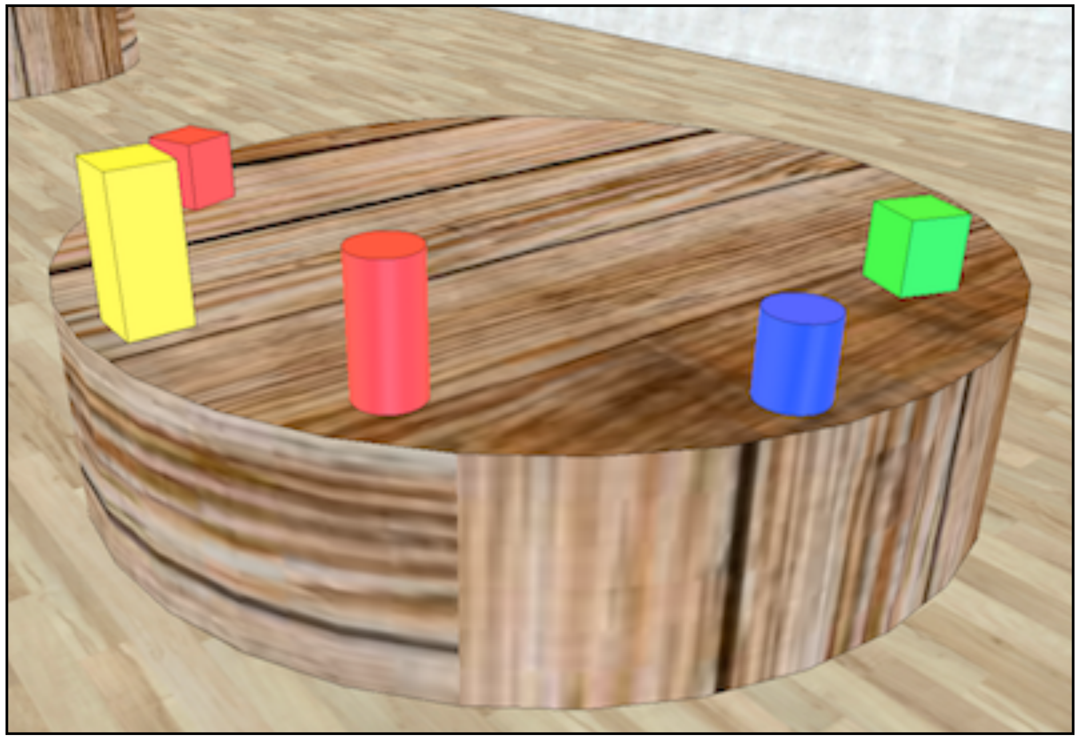


Aim of the project: put the objects five baskets distributed across the house

Project Definition

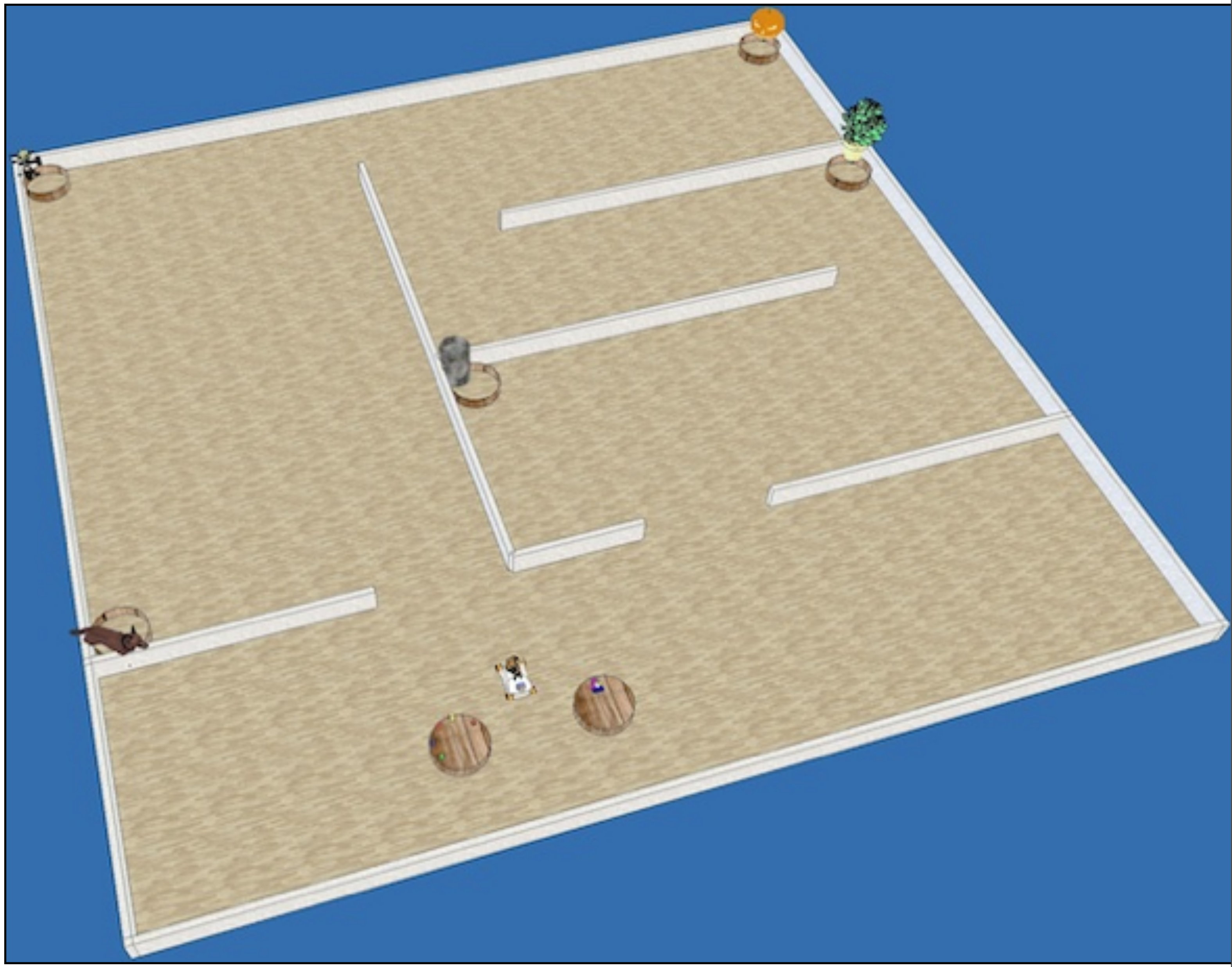
- Object are either cylindrical or box-shaped.
- The bases of boxes and cylinders are fixed
- Objects are initially placed on two tables facing the youBot's starting position.
- One one table, objects are placed upright. On the other table, stacked





Project Definition

- Baskets are distributed around the house.
- There's a landmark object next to each basket.
- The landmark allow the robot to identify the room to which each basket belongs



Project Definition

The robot has access to a list of instructions that tell into which basket each object must go:

- `inst(1).shape`: shape of the first object (either `box` or `cylinder`).
- `inst(1).color`: color of the first object (R, G, B values).
- `inst(1).picture`: path to an image of the landmark next to which is located the basket in which object 1 must go.
- `inst(2).shape`: shape of the second object (either `box` or `cylinder`).
- `inst(2).color`: color of the second object (R, G, B values).
- `inst(2).picture`: path to an image of the landmark next to which is located the basket in which object 2 must go.
- ...

Milestone A: Navigation

Building a map of the house (a map of the walls and other obstacles).

1. Using accurate localization (via `simxGetObjectPosition` on `youBot_ref` or `youBot_center`)
2. Without using `simxGetObjectPosition` on `youBot_ref` or `youBot_center`.

This milestone covers the following topics:

- Navigation and mapping: with the help of RTB, students learn how to manage a map, how to handle exploration, and how to plan trajectories that avoid obstacles
- Control: TRS provides raw access to the youBot's wheels. A students learn to implement a controller that configures the robot's position and orientation in order to follow a trajectory.
- Poses and reference frames: students learn to move points and velocity vectors from the frame of the robot to the world frame and vice verça.

Milestone B: Manipulation

Picking up objects and moving them to any room of the house (except the room where the objects start in) (not necessarily in a basket).

1. Moving only the objects from the first table (where objects stand upright), using V-REP IK. Objects can fall on the floor.
2. Moving all the objects (both tables), using V-REP IK. Objects can fall on the floor.
3. Moving all the objects (both tables), using V-REP IK. Objects *cannot* fall on the floor.
4. Moving all the objects (both tables), *without* using V-REP IK. Objects *cannot* fall on the floor.

This milestone covers the following topics:

- Articulated arms: students learn about forward and inverse kinematics.
- Vision/Fitting: locating objects, deciding where to place the gripper.

Milestone C: Vision

Finding and identifying the baskets.

1. Finding the baskets and the tables.
2. Recognizing the landmark objects accompanying the baskets, based on the data from `instructions.mat`.

This milestone covers the following topics:

- Fitting: RANSAC or Hough, or other, to find the cylindrical baskets with the Hokuyo sensor
- Object recognition

Milestone D: Manipulation+Vision

Manipulation+Vision

1. Placing the objects into arbitrary baskets (as long as there is the same number of objects in each basket). (Requires at least B.1 and C.1.)
2. Placing the objects into the appropriate basket, as indicated by `instructions.mat`. (Requires at least B.1 and C.2.)

This milestone covers the following topics:

- Planning order and shortest paths for brining the objects to the baskets.

Milestone E: Calibration

Computing the transformation between the frame of the vision sensor, and the frame of the robot. (Without `simxGetObjectOrientation` on `rgbdSensor`.)

The Robot: Configuration Signals

Turn vision sensors on/off:

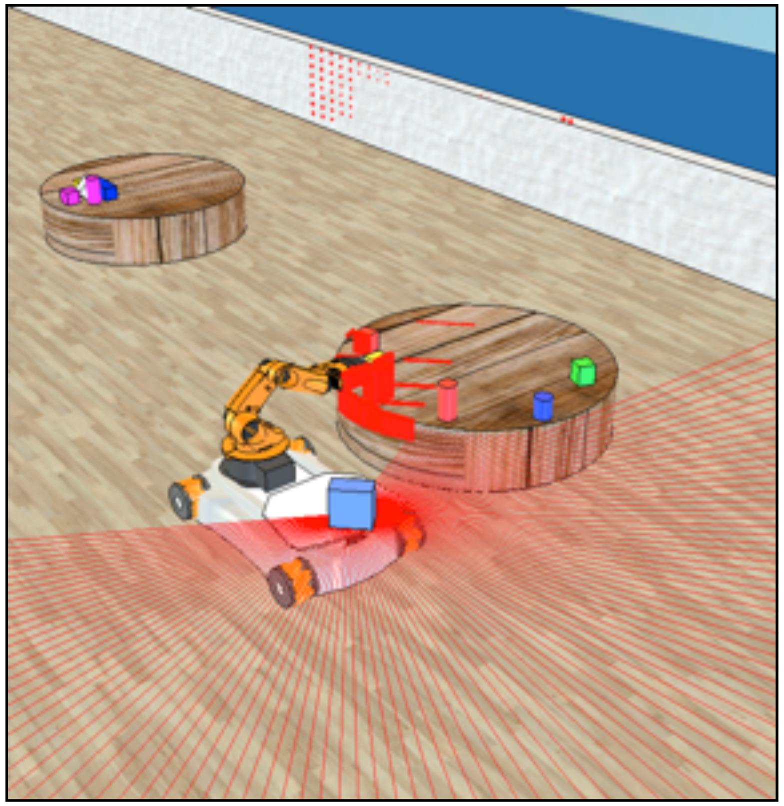
`handle_xyz_sensor`, `handle_xy_sensor`, `handle_rgb_sensor`

```
vrep.simxSetIntegerSignal(id, 'handle_rgb_sensor', 0)
```

The view angle of the depth camera and the RGB camera can be controlled via a signal named `rgbd_sensor_scan_angle`.

The `gripper_open` signal controls the gripper.

The `km_mode` signal turns the robot's inverse kinematics mode on or off.



V-REP API: Authorized Calls

- simxGetLastCmdTime
- simxGetLastErrors
- ~~simxGetModelProperty~~
- ~~simxGetObjectChild~~
- ~~simxGetObjectFloatParameter~~
- ~~simxGetObjectGroupData~~
- simxGetObjectHandle

  Only for objects that are part of the robot.
- ~~simxGetObjectIntParameter~~
- simxGetObjectOrientation

  Only with the following arguments:

objectHandle	relativeToObjectHandle	Milestone
rgbdSensor	youBot_ref, youBot_center	all except E
xyzSensor	rgbdSensor	(any)
rgbSensor	rgbdSensor	(any)
fastHokuyo_sensor1	youBot_ref, youBot_center	(any)
fastHokuyo_sensor1	youBot_ref, youBot_center	(any)
youBot_ref, youBot_center	-1	all except A.2
youBot_gripperPositionTip	youBot_ref	all except B.4
youBot_gripperPositionTarget	youBot_ref	all except B.4
youBot_gripperOrientationTip	Rectangle22	all except B.4
youBot_gripperOrientationTarget	Rectangle22	all except B.4

- ~~simxGetObjectParent~~
- simxGetObjectPosition

  See simxGetObjectOrientation.
- ~~simxGetObjects~~
- ~~simxGetObjectSelection~~

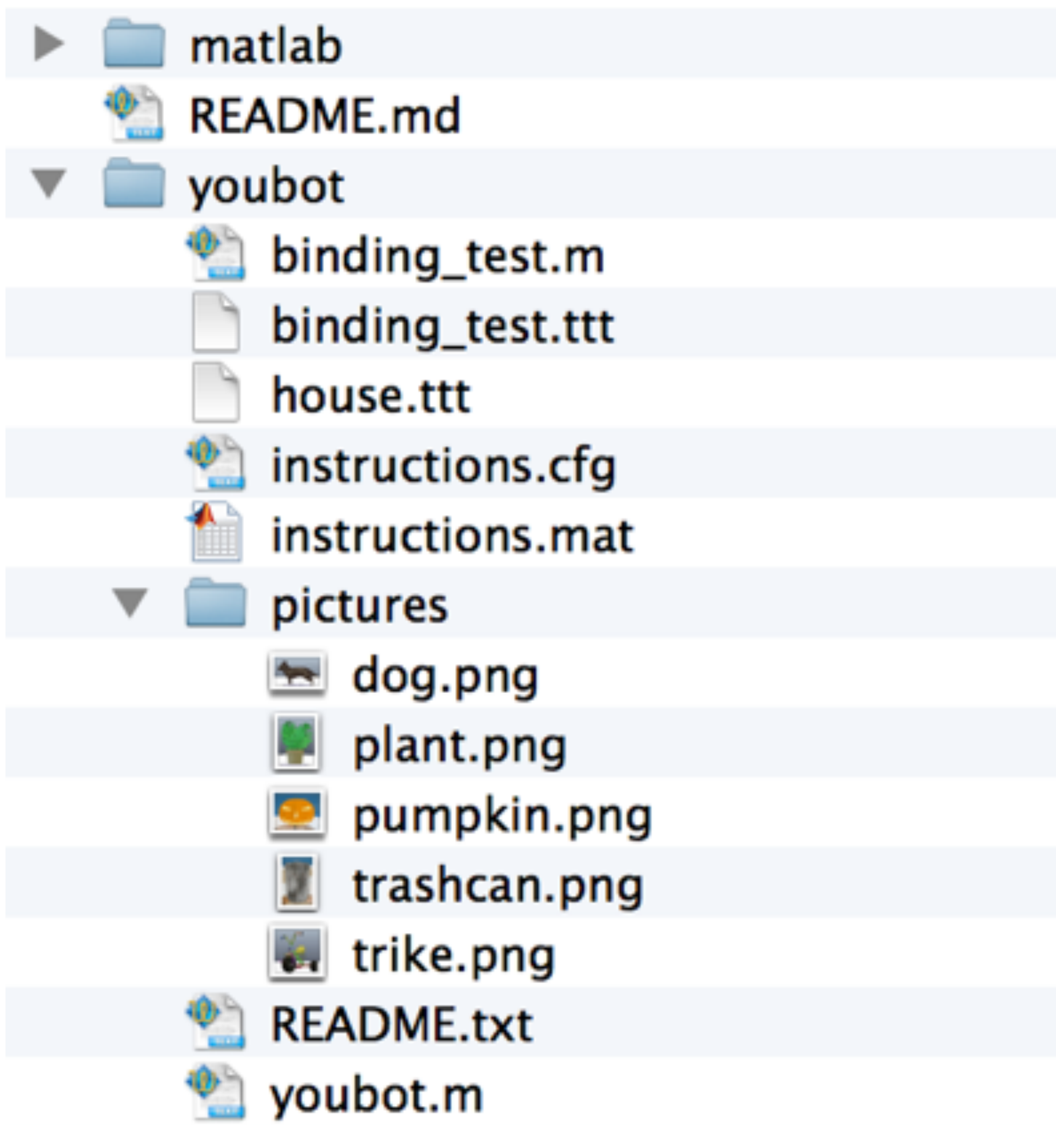
What You Get

- Recipe for organizing a Master-level robotics project
- The project: pickup groceries from a table and store them in baskets.
- Involves: control, navigation, mapping, vision and manipulation.

http://teaching-robotics.org/trs

How To Use

- Freely distributed via GitHub
  https://github.com/ULgRobotics/trs.git
- `master` branch: code & V-REP models (GPL)



- `gh-pages` branch: doc & project details (CC)

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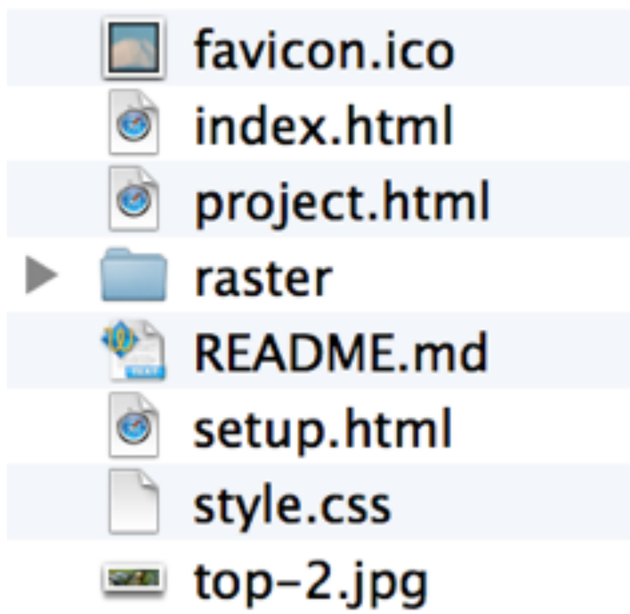

Github serves the gh-pages branch over http via github.io

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http://teaching-robotics.org/trs

Teaching-robotics.org

http://teaching-robotics.org/

http://roboticscourseware.org/

Teaching-Robotics.org: a community-driven website for sharing ressources related to teaching robotics to Master and PhD students.

- **Motivation**
- **Ressources**
- **Events**
- **Contact**

Motivation

This website aims to offer community-driven ressources related to teaching robotics.

Ressources

TRS: An Open-source Recipe for Teaching/Learning Robotics with a Simulator.

Events

Hong Kong, June 5 2014, at ICRA: Workshop on using MATLAB/Simulink for Robotics Education and Research.

Chicago, September 14 2014, at IROS: Tutorial on teaching robotics with a simulator.

Contact

Renaud Detry, *University of Liege, Belgium*

Learning Robotics with a Simulator: Setup Your Laptop in 5 min, Code a Control, Navigation, Vision or Manipulation

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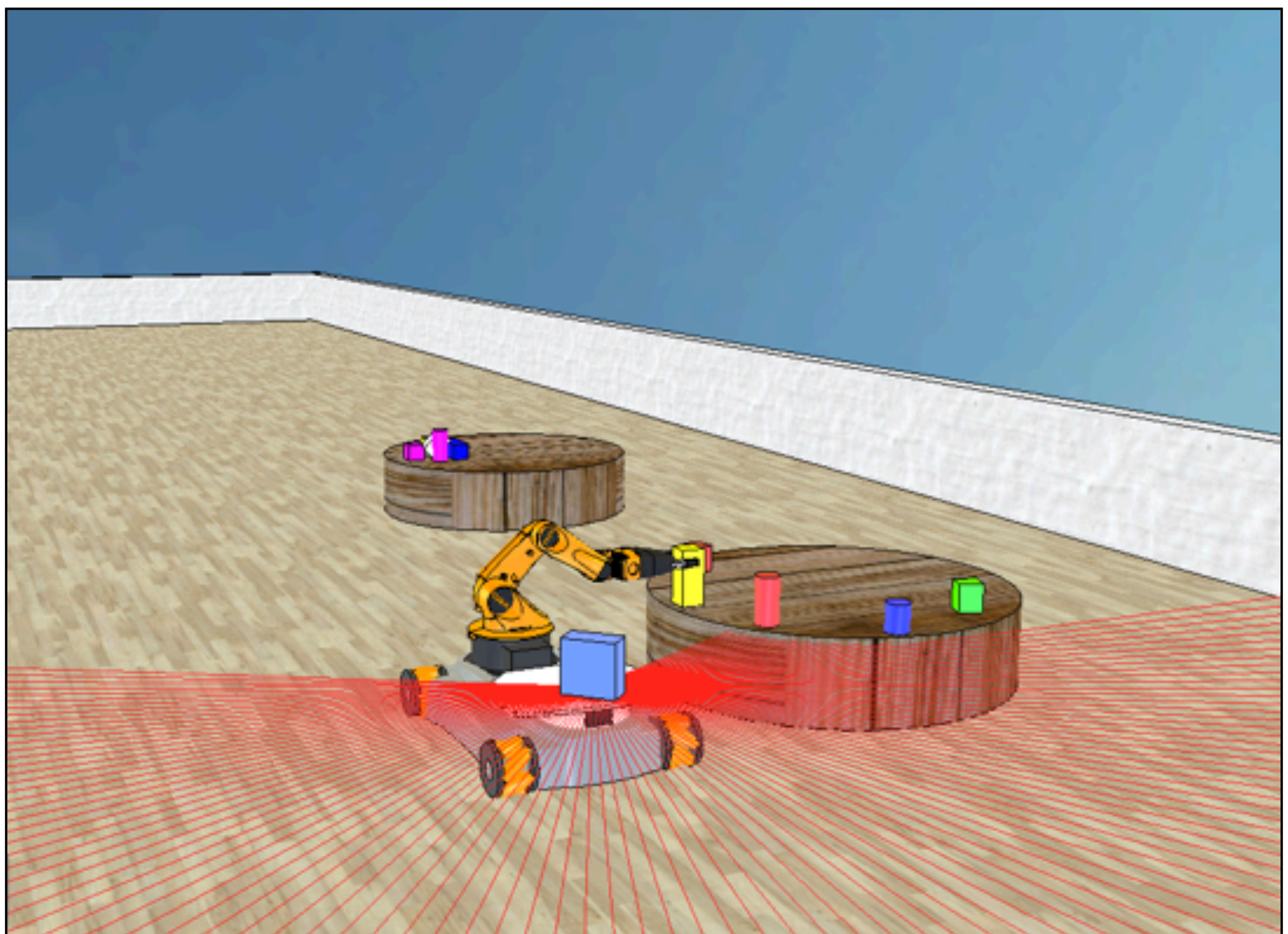

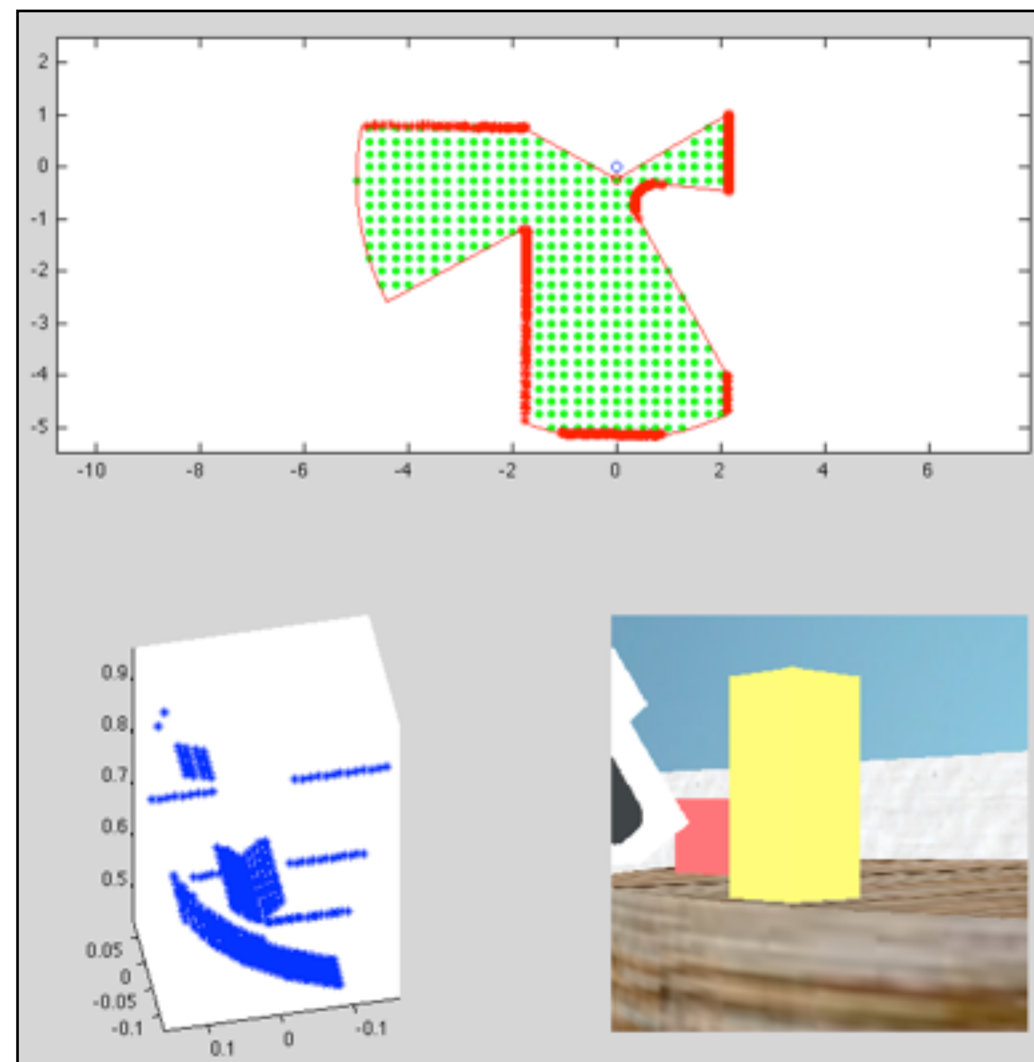

Control Exercise

If you have an internet connexion:

- Go to the bottom of http://teaching-robotics.org/trs2014
- Follow the instructions provided under the heading "Exercise"

If you do not have an internet connexion, or connexion too slow:

- Request one of our USB sticks
- Copy all of its contents to your hard drive
- Install the V-REP copy that corresponds to your system
- Expand the ZIP archive named *trs.zip*
- In the *trs/youbot* directory, you will find a script named *control.m*. Your task is to fill in the blanks in that script to make the robot follow the trajectory stored in the variable *traj*.