Welcome to CS 3630!

Fall 2025:

- *Online Book!*
- *Revamped projects!*

Course Instructors

Frank Dellaert, Professor

School of Interactive Computing

Stints at Skydio, Facebook, Holomatic, Google, Verdant Robotics

TAs:

Robots are useful!

- Manufacturing
- Logistics (inventory, warehouse logistics, packaging)
- Transportation (self-driving cars)
- Consumer and professional services (cleaning, mowing)
- Health, independence and quality of life (exoskeletons, semi-autonomous wheelchairs)
- Agriculture

Robot Taxonomy

- **Industrial Robots**
- Service Robots
- Field Robots
- Humanoid Robots
- Medical Robots
- Self-Driving Cars
- Aerial Vehicles

http://www.kuka.com

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http://www.frc.ri.cmu.edu/robots/

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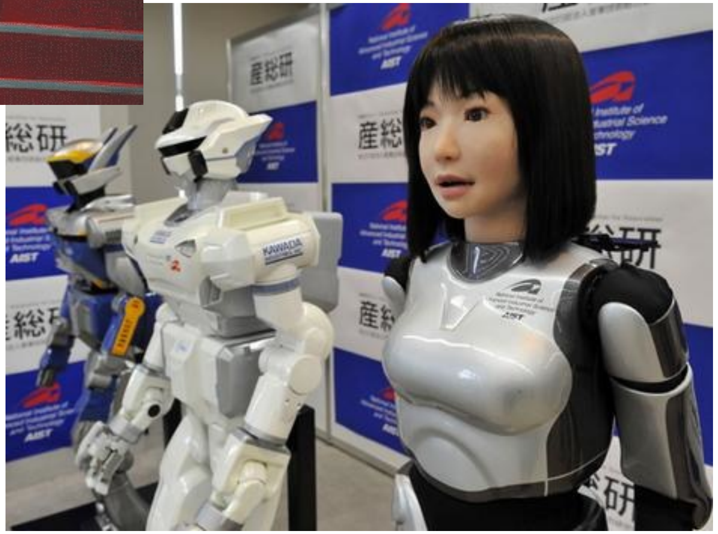

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In this class…

- We will not deal specifically with each of these robots.
- However, the mathematical and computational tools that we introduce can be applied to all the above robots.
- Likewise, the sensors and sensing methods that we will introduce can be applied to all the problems described above.

Class Website

Class Website

https://dellaert.github.io/25F-3630/

- Mostly externally facing
- Communication in class is via
  - Piazza (Q&A)
  - Canvas (esp. grades)
  - Gradescope

The course web site will always have the most up-to-date version of the schedule (next!).

Introduction to Perception and Robotics

Georgia Tech CS 3630 Fall 2022 edition

Home	Book	Resources
Syllabus	Schedule	Projects

Maintained by Frank Dellaert and the TAs of CS 3630

Based on a theme by orderedlist

Instructor: Frank Dellaert in Interactive Computing

TAs: Matthew King-Smith, Isabella Poage, Srihari Subramanian, Abhineet Jain, Allison Fister, Aswin Prakash, Nitin Vegesna, Asha Gutlapalli, John Yi, Meher Nigam, Avinash Prabhu, Adwait Deshpande, Vivek Mallampati, Priyal Chhatrapati, Prannoy Jada

Welcome to the homepage of CS3630, Fall 2022!

Course Description

This course covers fundamental problems and leading solutions to autonomous robot navigation – what and how must a robot perceive the world, and how can it use that information to navigate effectively.

Schedule

Class Schedule

There will almost certainly be changes to precise lecture topics, but quiz and project dates are unlikely to change.

The course web site will always have the most up-to-date version of the schedule.

Week	Mth	Date	Day	Module	Topic	Slides	Reading	Quizzes	Projects
1	Aug	19	Tue		Introduction	L1_Course_Overview	-		Intro to Python
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16	Dec	2	Tue	Drone	Visual SLAM	L28_Drones_4_VisualSLAM	7.4		P6 due, all quizzes graded!

Six Modules

The class is organized into six modules, each of which focuses on a specific robot performing a specific application:

- A Trash Sorting Robot
- A Vacuum Cleaning Robot
- A Robot for Logistics (e.g., warehouse operations)
- The Duckiebot (a simple wheeled mobile robot)
- Autonomous Cars
- Drones

Trash Sorting Robot

- Pieces of trash arrive to a robot work cell.
- The robot's job is to classify each piece of trash and move it to an appropriate bin.
- Simple, deterministic, high-level actions.
- Simple sensors.
- Uncertainty in sensor readings introduces probability into perception.
- Planning is the problem of choosing actions to minimize average costs over a long horizon.

Vacuum Cleaning Robot

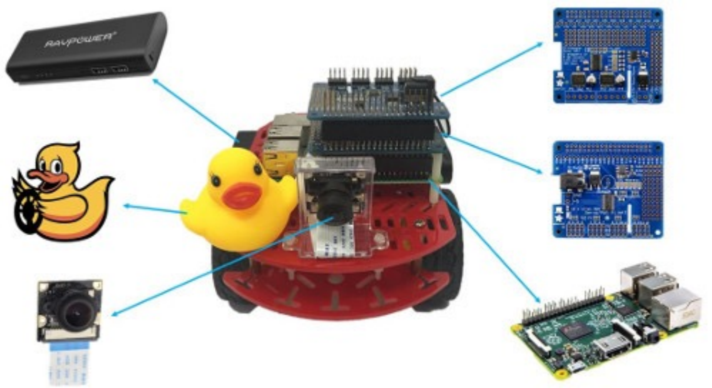
- Robot actions are uncertain: command to move to living room might take the robot to the kitchen.
- Sensing is uncertain.
- Perception is addressed using Hidden Markov Models (HMMs).
- Planning is addressed using Markov Decision Processes (MDPs).

Simple Logistics Robot

- Mobile robot platform that moves in a warehouse.
- Omnidirectional wheels, so the robot can move in any direction at any time (not like a car).
- LIDAR sensing (includes uncertainty)
- Monte Carlo localization to deal with uncertainty when determining the robot’s location.
- Planning is not so difficult, because warehouses are fairly regular and well organized.

Duckiebots

- The Duckiebot has two wheels (differential drive), and can only move “forward/backward” (can change the direction of “forward/ backward” by rotating).
- Rotation complicates the geometry of motion. We’ll introduce the appropriate mathematics to deal with rotations.
- For perception, we’ll introduce deep learning methods (very casual and superficial – not a deep dive into deep learning).
- In a post-pandemic world, with smaller lecture sizes, we hope one day to use the Duckiebots in the lab portion of this course.



Autonomous Cars

- The robot is a fully instrumented autonomous (aka self-driving) car).
- The car has a non-zero turning radius (unlike the Duckiebot), and cannot move sideways.
- We’ll use LIDAR sensors to determine the world state.
- Project will involve a large, real-world data set used for autonomous driving research.

Drones

- Drones fly in 3D.
- Dealing with rotations in 3D is tricky, but we'll introduce the math to deal with this.
- Motion planning is tricky – point the vehicle in the wrong direction, and it will dive and crash. We'll introduce state-of-the-art motion planning methods to deal with this.
- We'll use visual odometry (i.e., using computer vision to measure travelled distances) to determine the drone's position and orientation.
- Planning includes dealing with the dynamics of the drone's motion. We'll deal with this using trajectory optimization methods.

Class Schedule Revisited

Projects will focus on specific aspects of the problems associated to one of the modules.

Each project will be assigned on a Tuesday, and will be due at midnight two weeks later.

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Class Schedule Revisited

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There will be a quiz at the end of each module.

The module ends on a Tuesday, and the quiz will be in class the following Thursday.

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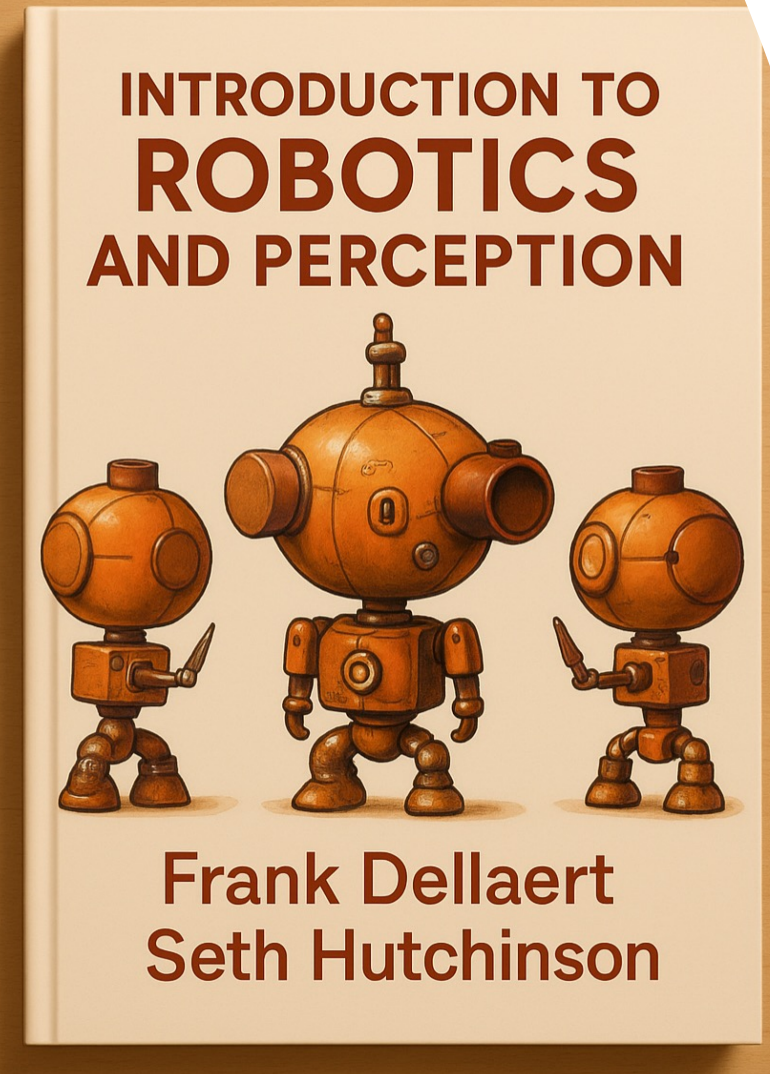
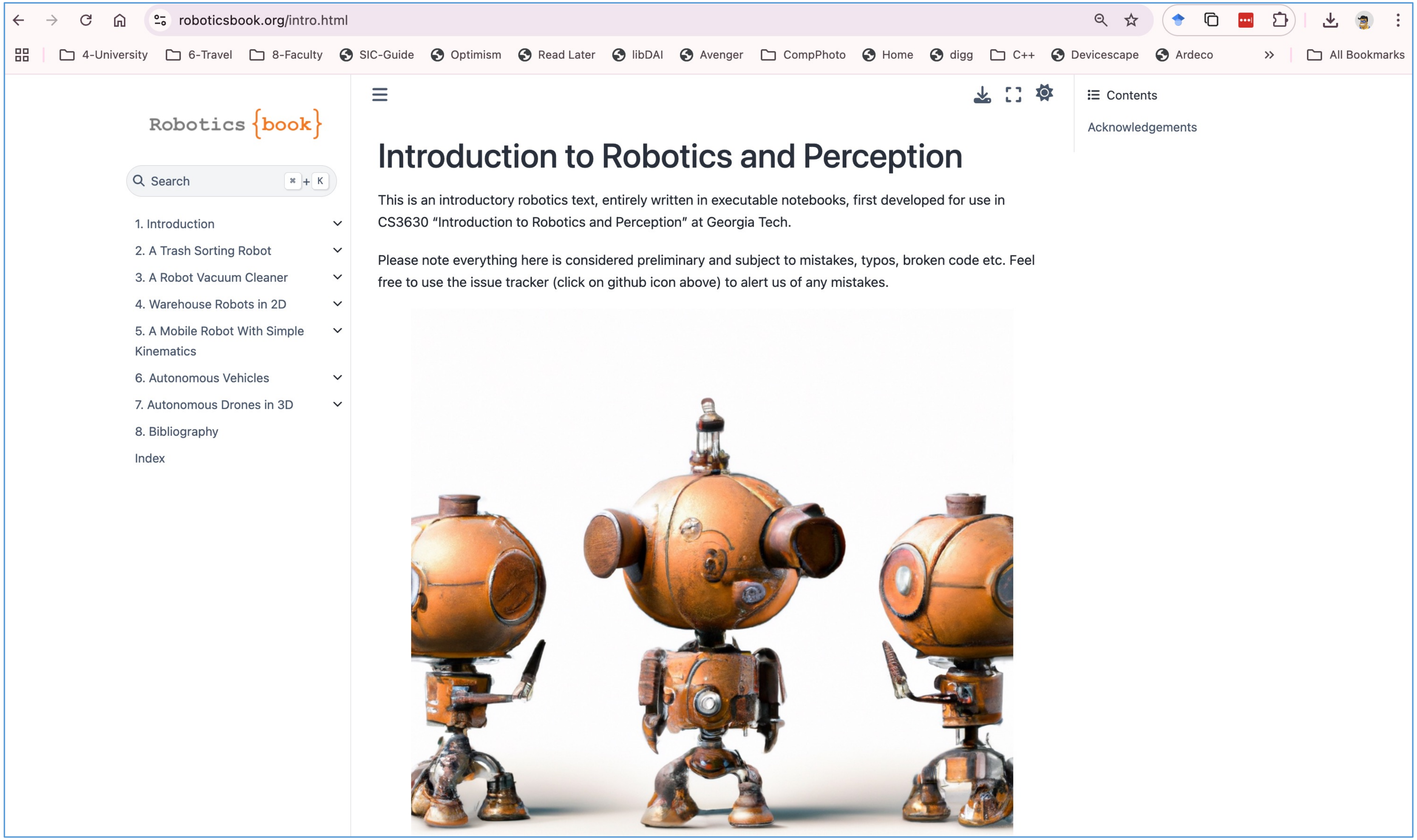
Syllabus
Let’s go to the website


INTRODUCTION TO
ROBOTICS
AND PERCEPTION
Frank Dellaert
Seth Hutchinson

Book

We’ll use the online “textbook” for the course, soon to be in print.



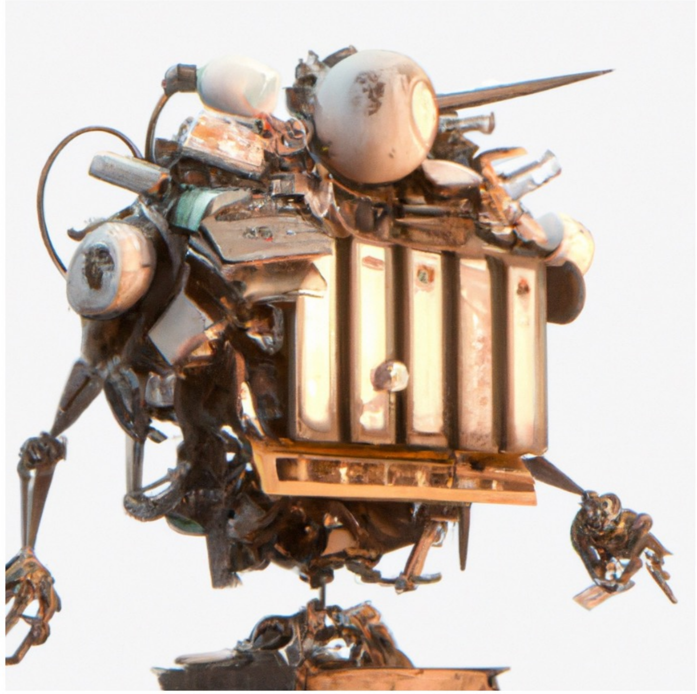
Typical page view for page of text.

Robotics {book}

Search ⌘ + K

2. A Trash Sorting Robot

> A simple robot that sorts trash into appropriate bins can be used to introduce many of the concepts that we will teach in this book.



In this chapter we introduce the main concepts that will be covered in this book using a simple trash sorting robot as an example. Imagine, if you will, a trash sorting facility that has installed a robot at one of its conveyor belts to help out with the sorting of trash, in order to increase the proportion of trash that can be sustainably recycled. Imagine also that you are tasked with creating the software that will govern the robot's actions. How would you go about this? Even this simple robot will be sufficiently rich to tease out the main sense-think-act cycle that governs most, if not all, robot systems.

A typical page might include text and equations.

Robotics {book}

Search ⌘ + K

Book Table of Contents is at the left

2.2.5. Probability Theory vs. Statistics

> Probability theory is the study of certain mathematical functions, while statistics are functions of data. The two are related, but different.

Probability theory and statistics seem to be concerned with the same kinds of ideas, but they are two very different fields of study.

Probability theory is the study of a certain class of mathematical functions (probability distributions). The modern, axiomatic approach to probability theory begins with three axioms, from which all other properties are derived:

- For $A \subseteq \Omega$, $P(A) \geq 0$
- $P(\Omega) = 1$
- For $A_i, A_j \subseteq \Omega$, if $A_i \cap A_j = \emptyset$, then $P(A_i \cup A_j) = P(A_i) + P(A_j)$.

Probability theory does not consider the problem of how one might obtain the probability distribution P. Probability theorists take this as a given, along with the axioms.

Expectation is a property of a probability distribution. For a discrete random variable X with $\Omega = \{x_1 \ldots x_n\}$, $E[X]$ (also called the mean, and often denoted by μ) can be computed as above

$$\mu = E[X] = \sum_{i=1}^{n} x_i p_X(x_i) \tag{2.8}$$

Contents

Section Table of Contents is at the right

The book is a collection of Jupyter Notebooks.

Robotics {book}

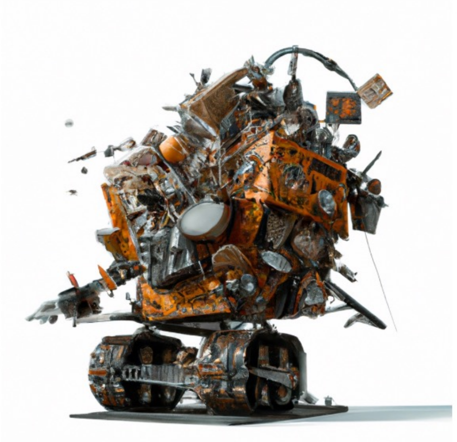
Search ⌘ + K

Open the Notebook in Colab

2.2. Actions for Sorting Trash

Open in Colab

> Robots change the world through their actions. Action models capture their salient aspects.



Robots decide how to act in the world by reasoning about how their actions can be used to achieve their goals, given the current state of the world. At a high level, actions can be represented by symbolic descriptions of their effects (changes that will occur in the world state when the action is executed) and by their preconditions (things that must be true in the current state in order to execute the action). The robot's goals can be encoded as a symbolic description of the desired world state, or, as we will do now, by associating a cost with executing an action in a particular world state. Note that assigning a cost to an action is equivalent to assigning a reward (merely multiply the cost by -1 to obtain a reward). If we use a cost-based approach, we generally frame the planning problem as a decision problem: choose the action that minimizes cost. If we are interested in long time horizons, we would choose the sequence of actions that minimize cost over the chosen time period. If there are uncertainties, either in the world state or in the effects of actions, we would minimize the expected value of the cost.

Contents

The book is a collection of Jupyter Notebooks

jupyter {book}

Introduction to Robotics and Perception

Search this book...

Powered by Jupyter Book

Run code to install libraries

Open in Colab

```
%pip install -q -U gtbook
```

```
Note: you may need to restart the kernel to use updated packages.
```

```
from gtbook.discrete import Variables
from gtbook.display import pretty
import numpy as np
import pandas as pd
import gtsam
import plotly.express as px
import plotly.io as pio
pio.renderers.default = "png"
```

2. Actions for Sorting Trash

2.1. Modeling Actions

> : Robots change the world through their actions. Action models capture the salient aspects of those changes.

Robots decide how to act in the world by reasoning about how their actions can be used to achieve their goals, given the current state of the world. At a high level, actions can be represented by symbolic descriptions of their effects (changes that will occur in the world state when the action is executed) and by their preconditions (things that must be true in the current state in order to execute

Contents

➢ *Edit and run python code inline to illustrate concepts.*

➢ *By hacking the code, you can try out new ideas and improve your understanding.*

jupyter {book}

Introduction to Robotics and Perception

Search this book...

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2.5. Simulation by Sampling

> :It is easy to demonstrate the relationship between expectation and the average over many trials - simply sample and average!

The code below computes the average cost over N samples for a specified action. Try various values for N, and notice that as N increases, the average tends to be an increasingly better approximation of the expected cost.

```
# Sample N times, and evaluate the cost of executing the given action:
total_cost = 0
N = 100
action = 0
for i in range(N):
    category = category_prior.sample()
    total_cost += cost[action, category]
print(total_cost/N)
```

```
3.36
```

For example, one experiment with 100 samples yielded:

```
cost_estimate = [3.14, 0.6, 4.01, 1.0]
```

Questions?