RYERSON UNIVERSITY

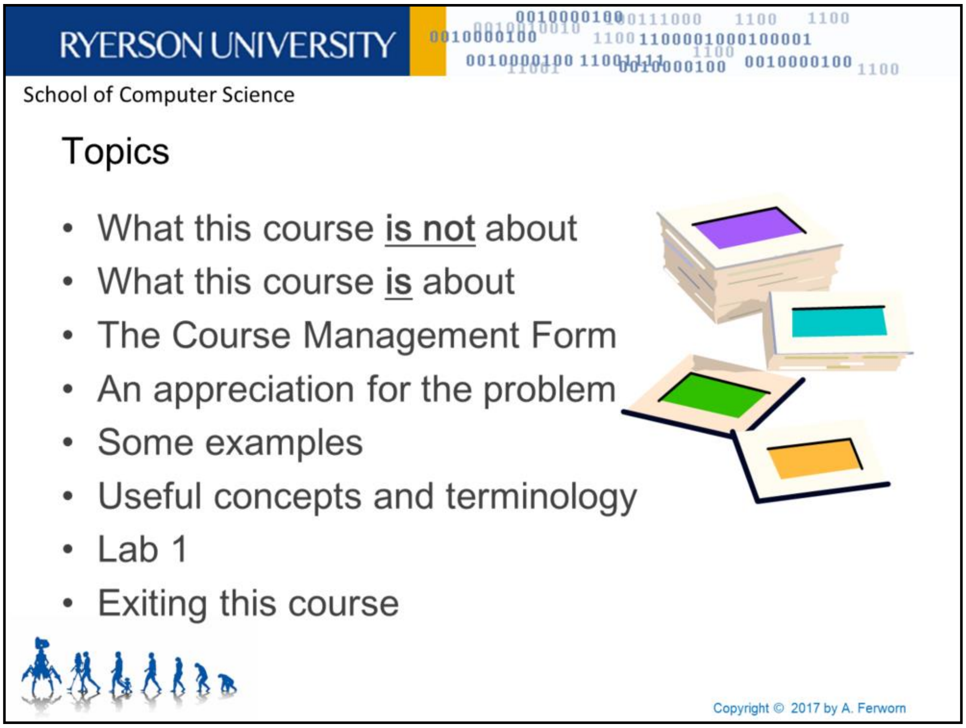
School of Computer Science

CPS607
Autonomous Mobile Robotics

An introductory course in the design and implementation of autonomous vehicles. Topics will include the nature of autonomy and autonomous behaviour. Issues involving sensing and actuation will be discussed. Students will be introduced to the constraints and issues involved in building systems designed to interact with an environment independently. Students will be expected to construct working robots.

Lect: 3 hrs., Lab: 2 hrs

Prof. Alex Ferworn

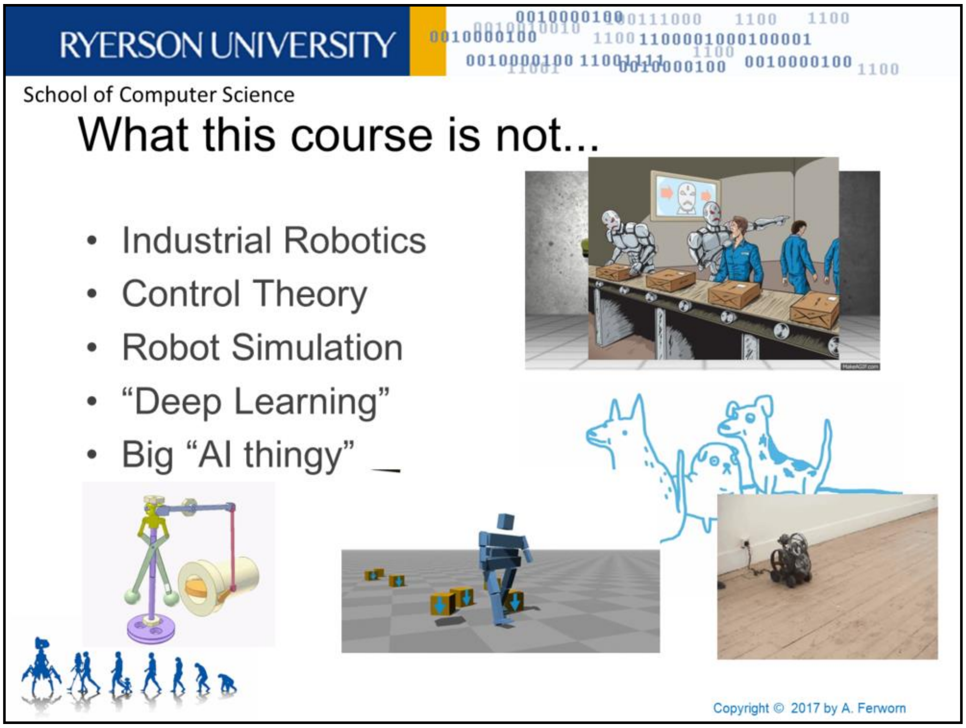


If you are expecting a course on traditional robotics involving industrial arms or carefully constructed physical devices roaming the hallways of some building…you are in the wrong place.

In this course we examine some fairly fundamental issues of self-control of a rather badly constructed piece of junk you optomisticly call a robot. Hopefully--before it falls apart--you learn something about an area that you probably did not think much about in your life as a computer science student.

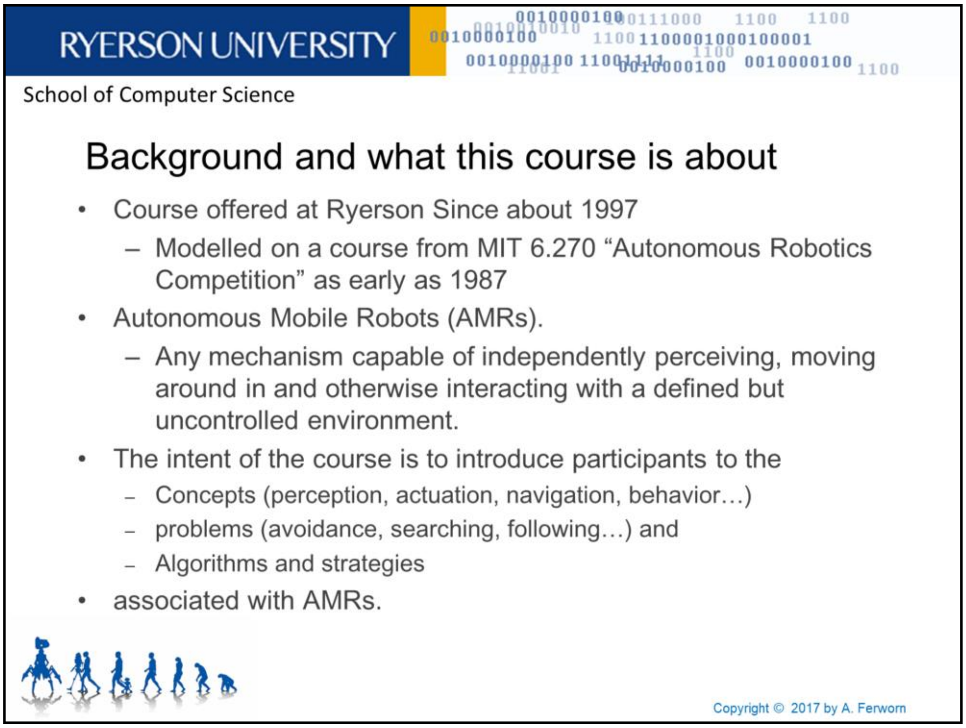
If the notion of endowing a device with autonomy were easy we would see a lot more things that controlled themselves. There have been many attempts and quite a bit of hype in the field of autonomous robotics. We will discuss some of these in this class.

Please read the course management form for reasons to drop this course now before it is too late!



These topics are typically what are discussed in first courses in robotics. My experience has been that students end up in one of two states at the end of a traditional course. 1) The student comes out of the course thinking that the world of robotics is a rather simple one based on mathematics (however complex) and therefore tractable by anyone who sets their minds to work on a problem. Engineers typically approach robotics with this notion, and there have been some very impressive robots purpose-built to solve industrial problems. The car industry is one obvious example where robots have played an impressive role. 2) The student is turned off by the extremely dry way that control theory is taught and loses interest in the problem.

I hope to avoid both these states.



We will spend a lot of time talking about environmental considerations. AMRs a built to exist in a specific environment. This is not particularly hard to understand since you were built to survive in a particular environment as well. If you think about it, we would have a hard time if the Sun suddenly went out or gravity stopped working. We claim we are adaptable (and to a certain extent we are) but by and large we are situated and function best in our situation….so to an AMR.

The course in Guelph is presented at both the undergraduate and graduate masters level and for all intents and purposes is identical to the one at Ryerson.

The History of 6.270

In the Beginning

The origins of this course begin with Woody Flowers in MIT's Mechanical Engineering department. Woody Flowers had the idea that teaching should be interactive and not just lecturing. He developed the famous "Introduction to Design" class (course number 2.70 [now 2.007]). In 2.007, undergraduates use scrap parts---metal, plastic, and wood---to build machines that go on to compete in a head-to-head contest at the end of the course.

Michael B. Parker, an undergraduate in MIT's Electrical Engineering and Computer Science (Course Six) department, had just taken 2.007. Mike liked the course so much that he was jealous: "Why should there be a course like this for Mechanical Engineering students, but not for the students in his department?" he thought.

Course Six's Answer

So in 1987, Mike organized the first 6.270 contest as "Course Six's answer" to the 2.007 course. The contest was a programming competition in which students wrote programs to control computer-simulated robots. In the first two years of the contest, the goal was to design a simulated robot that tried to find and destroy other robots. Unlike the machines that are built in the 2.007 course, there was no human control of the simulated robots (in 2.007 the students control the machines through a joystick and some switches). This was what separated the 2.007 course and the 6.270 contest.

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Course Management Form

- Meeting Times
  - Classes
    - Mon 17-18 EPH225
    - Wed 10-12 ENG101
  - Labs
    - Fridays 1400-1600 and **ENG206**
    - TA: Jimmy Tran
    - No lab in week 1

(default==no class)

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Schedule

Week	Dates	Item
1	4-7 Sept	• Dissuasion and Introduction to Autonomy • Lab 1 assigned—Edge Detection
2	10-14 Sept	• Dealing with Environments: The Tutebot and its brain
3	17-21 Sept	• Robots through history, Sensing 1
4	24-28 Sept	• Introduction to Arduino, Sensing in the natural world • Lab 2 assigned—Obstacle Avoidance • Lab 1 due
5	1-5 Oct	• Mobility Systems 1
Study Week	8-12 Oct	Be Happy!
6	15-19 Oct	• Perspectives on Intelligence: Braitenberg Vehicles • Lab 3 assigned—Acquiring and Tracking Targets. • Lab 2 due • Midterm test assigned
7	22-26 Oct	• Understanding Animal Behaviour 1 • Midterm test due
8	29 Oct – 2 Nov	• Complex Adaptive Behaviour • Lab 4 assigned—Behaviour Generation. • Lab 3 due
9	5-9 Nov	• Motion Planning
10	12-16 Nov	• TBA
11	19-23 Nov	• Mobility Systems 2 • Lab 4 due
12	26-30 Nov	• Understanding animal behaviour 2
	3 Dec	• Exam prep
Exam week	4-15 Dec	• TBA

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References

- There is no compulsory text book
- Notes will be provided on the course web site:
  - http://www.scs.ryerson.ca/~aferworn/courses/CPS607/INDEX.HTML
- Other References
  - Siegwart, Roland. "Introduction to autonomous mobile robots" / Roland Siegwart and Illah Nourbakhsh.
    - This text is available for free download
  - Braitenberg, Valentino. "Vehicles, experiments in synthetic psychology", MIT Press Cambridge, Mass 1984.
    - If you can find this book (which is short) read it and be enlightened

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Evaluation

Item	Explanation	Value
Lab 1	Edge detection	10 %
Lab 2	Obstacle Avoidance	10 %
Lab 3	Acquiring and Tracking Targets	10 %
Lab 4	Behavior Generation	10 %
Midterm Test	Take home	30 %
Final Exercise	Exam week	30 %

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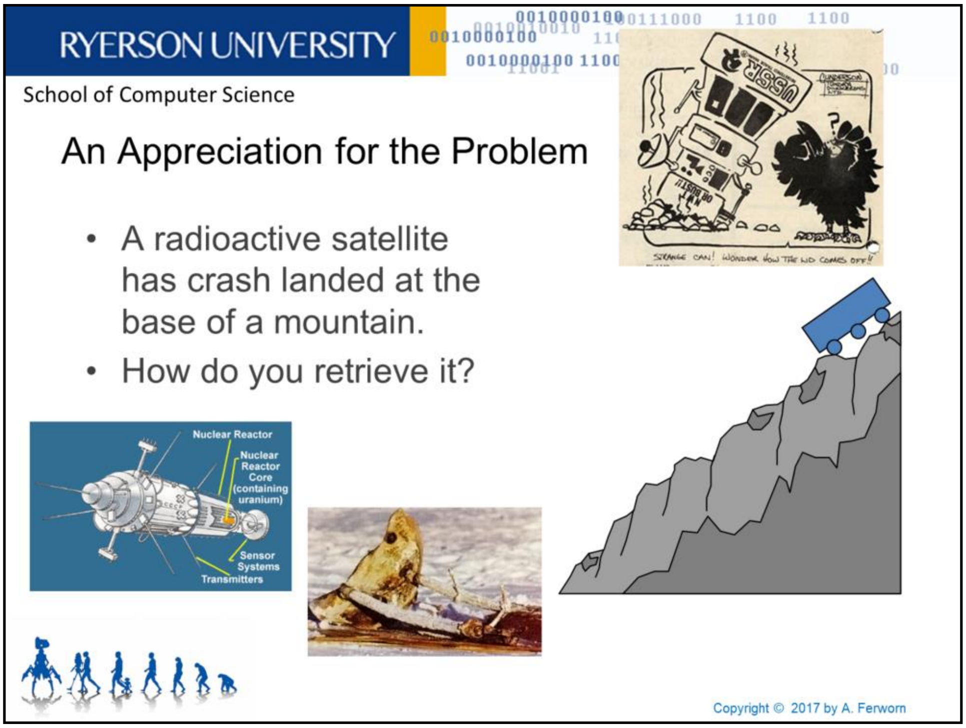
A Note on Labs

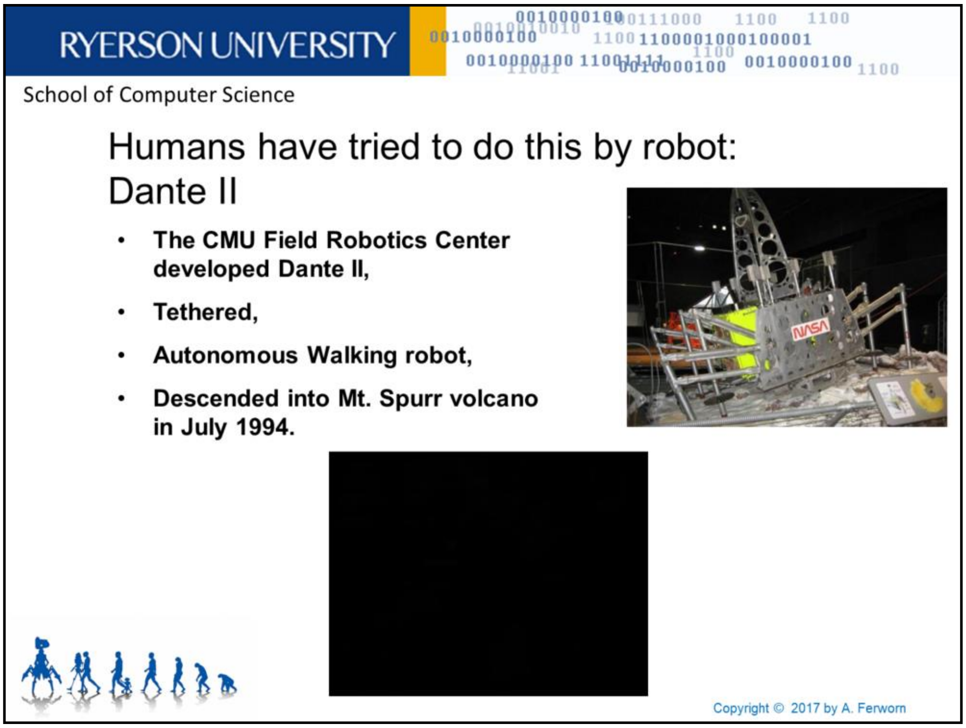
- Go to the labs
  - Labs where nothing is due
    - The TA will give you information about how to complete the lab when something is due (including info about programming micro-controllers).
  - Labs where something is due
    - Your working robot will be marked in the lab performing the task specified in the problem statement.



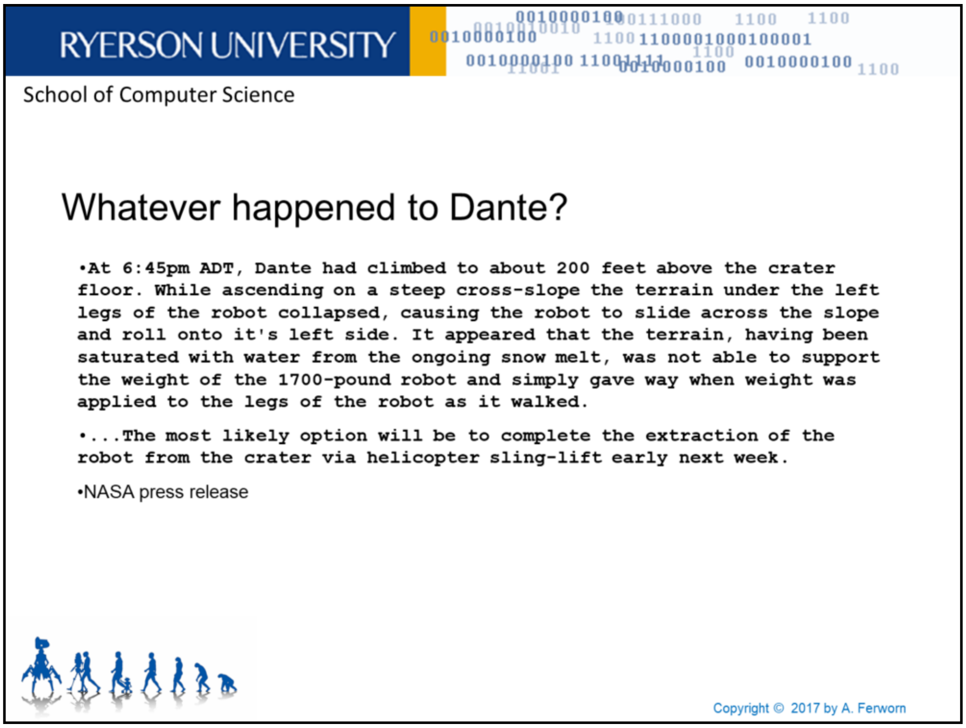
Sending people to retrieve radioactive debris is extremely dangerous and controlling something going down a steep incline with an unprepared surface seems like a difficult problem.

This is not an artificial scenario!

Kosmos 954 (Russian: Космос 954) was a reconnaissance satellite launched by the Soviet Union in 1977. A malfunction prevented safe separation of its onboard nuclear reactor; when the satellite reentered the Earth's atmosphere the following year, it scattered radioactive debris over northern Canada, prompting an extensive cleanup operation known as Operation “Morning Light”.



The CMU Field Robotics Center (FRC) developed Dante II, a tethered walking robot, which explored the Mt. Spurr (Aleutian Range, Alaska) volcano in July 1994. High-temperature, fumarole gas samples are prized by volcanic science, yet their sampling poses significant challenge. In 1993, eight volcanologists were killed in two separate events while sampling and monitoring volcanoes. The use of robotic explorers, such as Dante II, opens a new era in field techniques by enabling scientists to remotely conduct research and exploration. Using its tether cable anchored at the crater rim, Dante II is able to descend down sheer crater walls in a rappelling-like manner to gather and analyze high temperature gasses from the crater floor. In addition to contributing to volcanic science, a primary objective of the Dante II program is to demonstrate robotic exploration of extreme (i.e., harsh, barren, steep) terrains such as those found on planetary surfaces.



The most likely cause for the collapse was a problem with the software used to achieve the autonomous walking behaviour. The algorithm assumed that the foot of the leg being moved would be place in snow. In order to break the crust of the snow the leg was pushed hard and down. This apparently had been simulated unfortunately the sides of the volcano were rather muddy…who would have figured that a volcano would melt the snow?

Men in 20s built tunnel for 'man cave': Cops. Two men in their 20s dug a tunnel near a Toronto Pan Am games venue at York University.

Citation: TORONTO SUN, FIRST POSTED: MONDAY, MARCH 02, 2015 08:10 AM EST

Cross-disciplinary project could advance archaeology research

May 16, 2016

Due to its relatively isolated location, the substantial archaeological preservation of el-Hibeh remained relatively undisturbed for thousands of years. Despite disturbances ancient and modern, el-Hibeh was a site with uniquely and substantially preserved archaeological remains. However, since 2011, the turmoil in Egypt has led to relaxation of the security of the site. While by no means the only victim of cultural heritage destruction in Egypt and around the world, Hibeh has been particularly badly damaged. A partnership between Ryerson's computer sciences, digital media and history departments could help researchers access archeological dig sites that are currently not safe to visit.

On April 26th, students demonstrated their robots designed with the end goal of exploring and mapping archeological dig sites remotely. Students in professor Alexander Ferworn's Computer Science class on Human Robot Interaction as well as Graduate students in the Master of Digital Media program participated in the project.

These robots are the solution to a real world problem currently being experienced in Egypt. Since 2001, with the permission and cooperation of the Egyptian Ministry of State for Antiquities, the University of California, Berkeley has conducted excavations at the site of el-Hibeh, Egypt, directed by professor Carol Redmount. In 2015, Ryerson University entered into collaboration with Berkeley University led by Ryerson history professor Jean Li as an associate director of the el-Hibeh, Egypt project. "Since 2011, accelerated looting activities have made tomb shafts unstable and potentially dangerous for archaeological exploration," said Li, who would like to return for further research. "The goal is to use the robots for damage assessment before returning to traditional archaeological activities."

As part of this research, Li is also eager to explore the general mortuary practices of provincial towns of ancient Egypt. The archeological site in question has both well-preserved urban structures and tombs and burials, which can give information on the mortuary practices in the provincial towns, the funerary practices of women, and by extension their roles and status in society, as well as ancient urbanism.

All of this research hinges on being able to further excavate the site. "However, we can't really begin to dig until we assess the damage caused by sustained looting since 2011," said Li. "This is where Alex's robots came in."

When Li approached Ferworn, he had originally thought search and rescue dogs might be the solution to the problem, but upon further reflection, robots seemed to be the better option. "We had these students building robots," Ferworn said, adding that it seemed like a logical choice to get students to design the robots with the archeological site in mind for their final exam.

Using everything from Raspberry Pi (a low cost, credit card-sized computer) to iPhones, Starbucks coffee cups, duct tape and popsicle sticks, the robots were assembled to do a "BUSA dig", BUSA being the name of the Ikea polyester children's play tunnel used in the simulation. To recreate the environment, a cardboard maze was constructed at the end of the tunnel through which the robots needed to be dropped. The students then had to blindly navigate through the “site” using only the equipment their robots had for visuals. The goal was to navigate the course without bumping into the “artifacts” which were represented by a variety of objects like a doll, tea lights, and other knickknacks, while avoiding the improvised explosive devices (IEDs) like mouse traps and “the squid,” a robot with swirling parts and hooks activated when the students’ robots made contact with it.

Six teams of students made robots, and according to Ferworn, they showed a lot of potential. “They are not field ready, and they aren’t the exact prototypes,” said Ferworn. “But the students get a lot of experience in creating them. Now we have six robots designed with this in mind. No one else is doing this, and we are the only ones with any experience in it. We have six machines that are vastly different from one another that kind of answer the question of how we do this in reality. ”

Li said the project plays to Ryerson’s strengths of inter-disciplinary collaboration. It was through Michael Carter, director of industry relations in Ryerson’s Master of Digital Media program who first introduced her to the robotics component. Carter’s students participated in the teams as well.

“The robots also have potentially far greater application than just scouting and assessing damage,” said Li. “Their function is to retrieve information; information that can help us reconstruct tombs and burials, domestic and monumental architecture, and help compile data for traditional archaeological research as well as for the augmented reality/virtual reality visualization branch of the overall collaborative project.” According to Carter, the project has generated a lot of buzz among his peers in archeology, as he tweeted about the live event. His own work uses virtual reality to recreate archeological sites. He sees potential in these robots to help visualize sites in greater detail.

The visualization project is a marriage of traditional research with new technological methods. The dimensions and locations of the various relief images of the site must be reconstructed first, involving research into old excavation photos and reports and visualizing in 2D the locations of the images. This low tech method will help create a map to assist the creation of a 3D reconstruction of the site.

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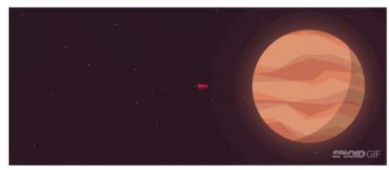
Why Autonomous Robots

- Tasks
  - That are repetitive/boring
    - Cleaning (Roomba)
    - Delivering (Autonomous Vehicles)
  - Where communication is impractical or impossible
    - Space Exploration



Overview of the Mars Pathfinder Mission

The Pathfinder project was one of the first of NASA's Discovery Program missions. These missions are defined as low cost (less than $150 million) and have a three year or shorter development time. Pathfinder is going to land a single vehicle, which we call the Lander, on the surface of Mars on July 4, 1997. Once there it will carry out a number of engineering, technology and science experiments. A primary technology objective for Pathfinder was to demonstrate a low cost cruise stage and the Entry, Descent and Landing (EDL) systems required for putting a payload safely on the Martian surface. The Mars Pathfinder lander was built at a cost of $171 million , this includes the $25 million cost to build the microrover.

Overview of the Mars Microrover

Sojourner is the name given to the first robotic roving vehicle to be sent to the planet Mars. Sojourner weighs 11.0 kg (24.3 lbs.) on earth (about 9 lbs. on Mars) and is about the size of a child's small wagon. The Microrover has six wheels and can move at speeds up to 0.6 meters (1.9 feet) per minute. This isn't very fast, but during the course of a day on Mars the Microrover can cover a lot of territory (perhaps up to 3 meters). However, that speed will be fast enough to accomplish many tasks during a day, since we are not planning on driving the Microrover more than 10 meters (32.8 feet) away from the lander.

The rover's wheels and suspension use a rocker-bogie system that is unique in that it does not use springs. Rather, its joints rotate and conform to the contour of the ground, providing the greatest degree of stability for traversing rocky, uneven surfaces. Asix-wheel chassis was chosen over a four-wheel design because it provides greater stability and obstacle-crossing capability. Six-wheeled vehicles can overcome obstacles three times larger than those crossable by four-wheeled vehicles. For example, one side of Sojourner could tip as much as 45 degrees as it climbed over a rock without tipping over. The wheels are 13 centimeters (5 inches) in diameter and made of aluminum. Stainless steel treads and cleats on the wheels provide traction and each wheel can move up and down independently of all the others. Three motion sensors along Sojourner's frame can detect excessive tilt and stop the rover before it gets dangerously close to tipping over. Sojourner is capable of scaling a boulder on Mars that is more than 20 centimeters (8 inches) high and keep on going. (Ref:JPL 96-207 p.32)

Microrover Mission Objectives and Highlights

The primary function of Sojourner is to demonstrate that small rovers can actually operate on Mars. The Russians placed a remote control vehicle on the moon called Lunakhod 1 (Luna 16). It landed on November 11, 1970 and drove a total of 10.5 Km and covered a visual area of 80,000 square meters during which it took more than 20,000 images. Even though there was only a 3 second signal delay, that rover proved very difficult to drive. Sojourner will be humanities first attempt to operate a remote control vehicle on another planet. After landing, Sojourner will stand up and drive down one of the two ramps mounted to the lander petal. A lander IMP (IMager for Pathfinder) camera mission panoramic image as well as images taken on either side of the rover petal will assist the mission operations engineers in deciding which ramp is safest to drive down. After a successful ramp egress we will begin a nominal 7 sol (1 sol = 1 Martian day) mission to conduct science and technology experiments. This mission is conducted under the constraint of a once-per-sol opportunity for command and telemetry transmissions between the lander and earth operators. Communications with the rover is not done in real-time because of the approximately 11 minute light-time delay in receiving the signals. Sojourner must be able to carry out her mission with a form of supervised autonomous control. This means that goal locations (called waypoints) or move commands must be sent to the rover ahead of time and Sojourner then navigates and safely traverses to these locations on her own.

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What happened to Sojourner?

- **After a near collision of mars rover 'Sojourner' with the rock 'Yogi' on Wednesday 9. due to a false timed signal, Pathfinder`s computer resets itself on Friday 11. and Monday 14., breaking the connection for a while.**
- NASA press release

The problem is clearly difficult even for NASA

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Surprise: Doing Hard things is Still Hard

- Boston Dynamics: Autonomous Shelf Stacking

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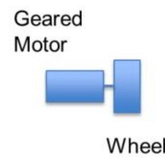
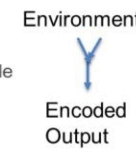
Useful Terminology about Robots

- Propulsion
  - Force from your robot providing movement.
  - Propulsion is often divided into sides (right propulsion, left propulsion)
  - Propulsion occurs when it is activated (through actuation)
- Direction
  - A course along which something moves
- Steering
  - Causing an robot to move in a direction
- Sensors and Sensing
  - A sensor samples a piece of the world and makes the information available
- Controller
  - Takes sensor input, transforms it, provides actuation output
- Autonomous Mobile Robot (AMR)
  - The robot that you will build. Until you know more, “autonomy” refers to its ability to move around on its own.
  - Your AMR will have propulsion controlled by steering to set its direction.





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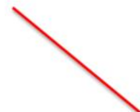
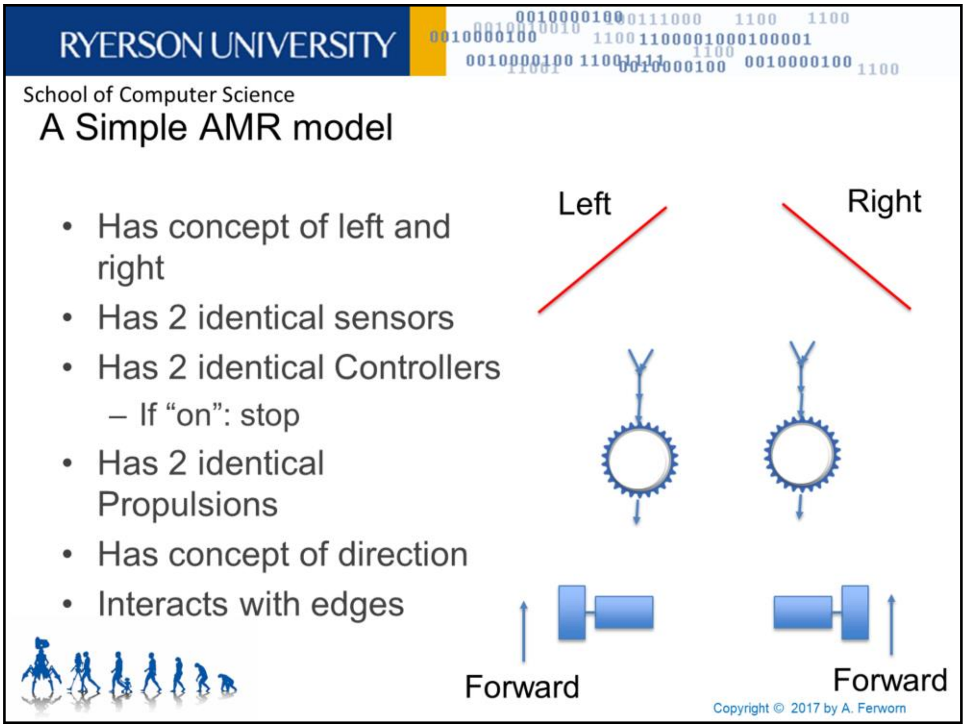
Useful Terminology about the world

- The World
  - The surface (and all it contains) in which your AMR must survive.
  - The world usually has an irregular shape but it is flat
  - It may contain obstacles to avoid and goals to achieve.



- Edge
  - Where the world ends
- Splash
  - This is what happens when your AMR falls off the world



If we have a left and a right side of our problem we can start to reason about our robot that also has a left and right side. Really the only thing that has not been defined is how the controllers are connected to the propulsion. Let us assume that the left controller is attached to the left propulsion (assume the same for the right side) and we will also assume that the direction of motion for the respective propulsions is forward.

Case 1: Direct Connections

Let us assume the robot is travelling straight forward and the left sensor is activated by an edge. This means that the left controller will send a "stop" signal to the left propulsion. As the right sensor has not detected an edge, the right controller will not be activated and the right propulsion will continue forward. This means that the robot will be pushed left as the left propulsion stops and acts as a pivot. The robot will eventually splash as its motion continues toward the left edge.

Case 2: Crossed connections

Let us now assume that everything remains the same as per case 1 except the left controller is connected to the right propulsion (and vice verse for the opposite controller and propulsion). This is called a “cross connection”. In this case when the left sensor signals the presence of the left edge to the left controller, the left controller send a “stop” signal to the right propulsion. This will allow the left propulsion to keep moving forward and pivot on the stopped right propulsion allowing the robot to avoid the edge.

The results of all this is steering.

Note: This works well for round worlds.

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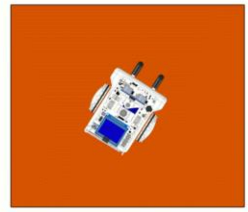
Lab 1 “Hello World” for robots

- Required
  - You are to build an AMR that is capable of
    - Remaining in near-continuous motion in the world for a period of 2 minutes (changing direction does not count as stopping)
    - Avoiding the edge of the world
    - Bonus: Find and push a small object somewhere in the world



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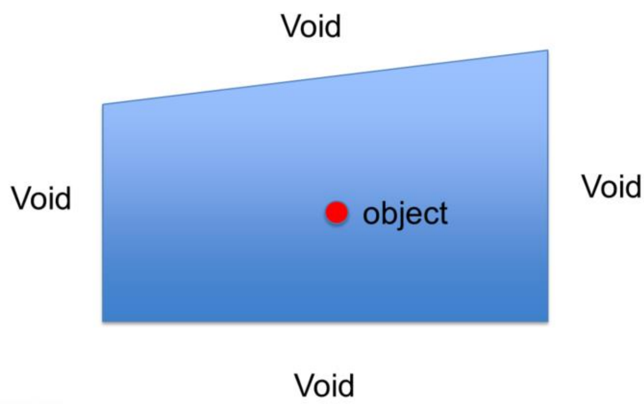

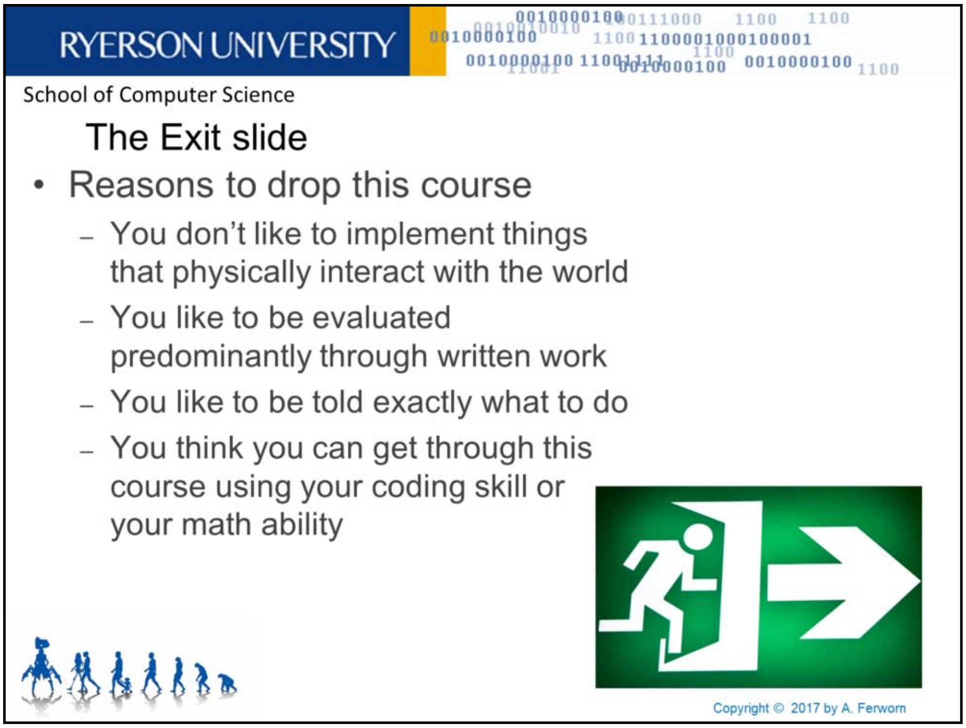

It's not that I really want you to quit! All I want to do is inform you that this course is not for everyone. We have had people with lots of experience building things like this and lots of people with no experience. Both types of people have been able to do well. In fact I get most of my grad students from this course. But, the fact remains that this course is not for everyone and will take up significant amounts of your time.