Beach Cities Robotics

FIRST Team 294

Automation and Robotics

Introductory Robotics Lectures for BCR Summer Camp

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1 What is Automation?

People build automatic devices so that they have less work to do for the same gain, or so that their capabilities are expanded. Automated artifacts are literally labor saving devices.

1.1 Examples of Automation

We can illustrate automation by giving some examples.

1.1.1 Transportation

A wheeled cart is not automation, but the wheel is an important design feature allowing automation.

1.1.1.1 Iron Horses and Horseless Carriages

The steam engine was an important advance in the history of technology. James Watt created a steam engine that produced rotary motion suitable for driving wheels. This enabled transportable steam engines, many of which were put on rails allowing vast improvements in transportation efficiency.

Figure 1: Steam locomotive.

When engines and wheels were freed from the railroad tracks, the machines came to be called "automobiles." These still were not what we would today call "automated" but they were getting closer.

1.1.1.2 Skyscrapers

In the 19th century, a man named Elisha Otis invented a fail-safe device for elevators, which he demonstrated at the 1853 New York World's Fair. Previously, elevator accidents had prevented them from becoming popular; so most buildings were under five or six stories tall. After the Otis elevator was invented, buildings began to be built taller and taller. In the 20th century, buildings over 20 floors high became common.

Figure 2: New York World's Fair, Crystal Palace Exposition. Image by Otis Elevator.

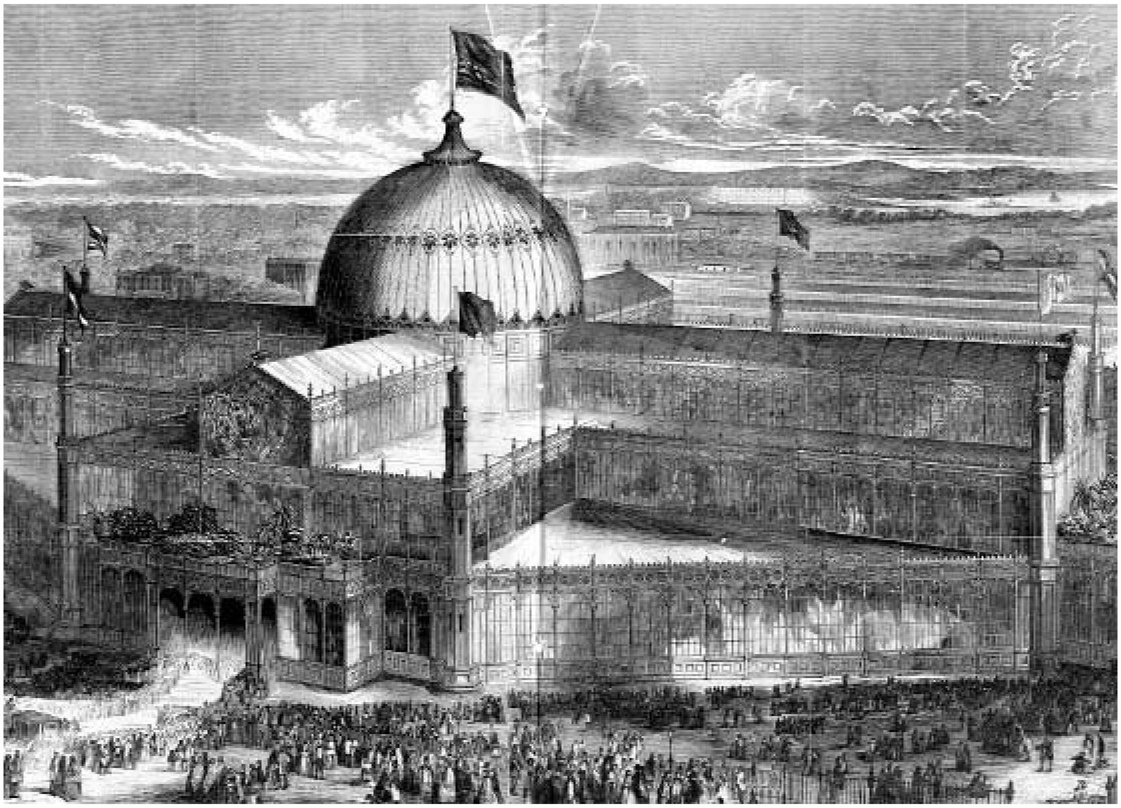

Figure 3: Crystal Palace, New York, 1853.

Figure 4: Otis has himself hauled up in his elevator platform and has an assistant cut the rope in front of the gathered spectators.

With very tall buildings with many occupants and several elevators, automated elevators with scheduling algorithms help to minimize the waiting time for elevator passengers.

Figure 5: The Empire State Building's 73 elevators can move 600 to 1,400 feet (183 to 427 meters) per minute. At the maximum speed, you can travel from the lobby to the 80th floor in 45 seconds. Photo and caption copyright 2001 by HowStuffWorks, fair use for educational purposes.

1.1.2 Manufacturing

Eli Whitney invented interchangeable parts making mass production possible (batch mode). Henry Ford implemented an assembly line (pipeline flow) for even greater efficiency. Manufacturers are replacing human workers with robots in the dirtier and more hazardous jobs such as welding and painting.

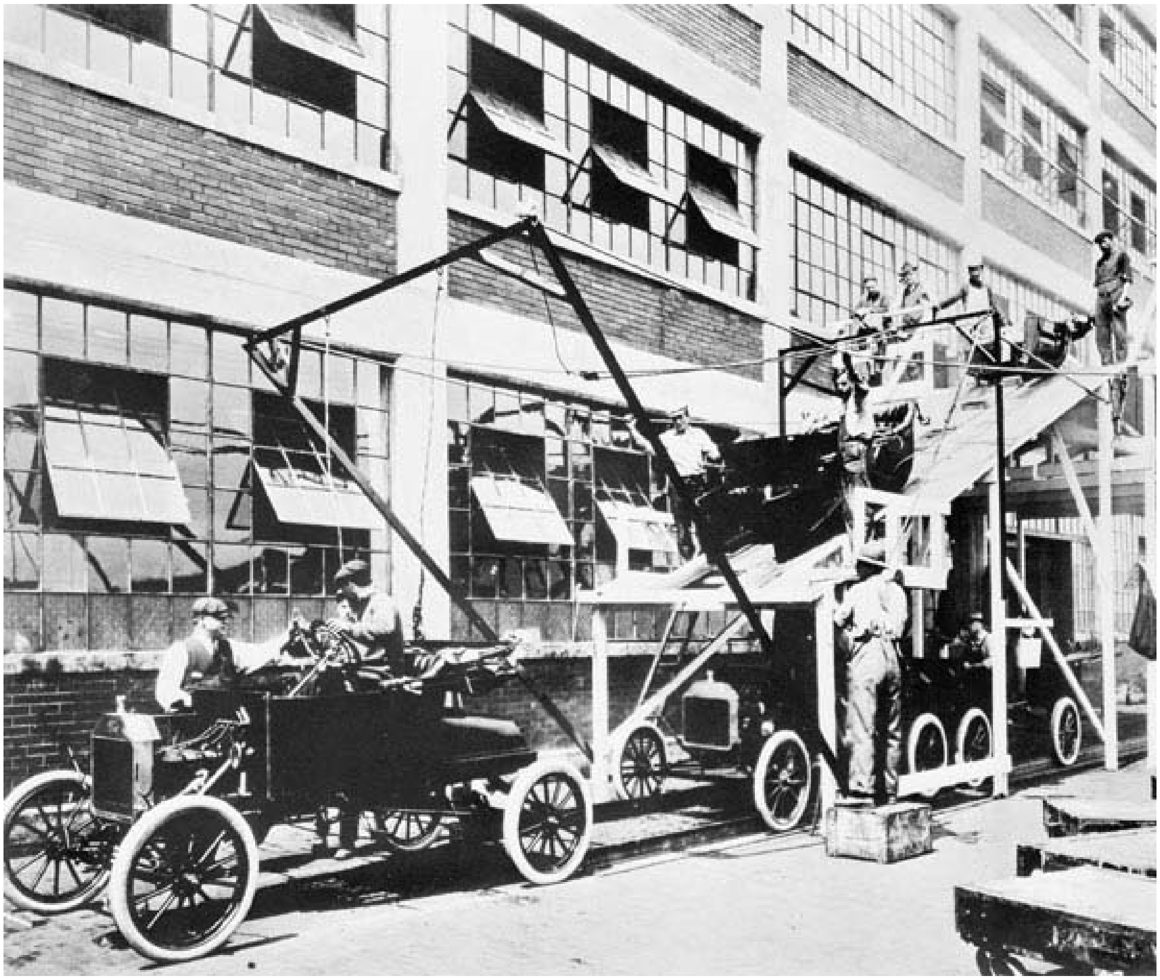

Figure 6: First Ford assembly line, 1913.

2 Robotics: Flexible Automation

Most manufacturing automation is called fixed automation. A stamping machine can stamp only one kind of sheet metal part without being retooled, for example, or a boring machine bores only one kind of hole in one kind of part. When robots are part of an automatic process, the process can be changed by changing the programming of the robots. Robotic automation is called flexible automation.

Figure 7: Welding robots at a Toyota automobile factory.

2.1 Definition of Autonomy

Everyone should be familiar with the automatic toaster, a common home appliance. Bread is put in the toaster, a lever is pushed down, and when the toast is done, it shuts off and pops up automatically. The toaster is automatic, but not autonomous.

Figure 8: Hearth Toaster from the Walter Himmelreicht collection, Pennsylvania, c. 1800. Bread was placed between the arches; when one side was browned, the toaster was rotated to brown the other side. Photo and caption from the Cyber Toaster Museum.

An autonomous toaster would have a more flexible capability. It would have a way of knowing what kind of bread was in it and how well done the user wants the toast, so it could adjust the heat accordingly. It would be able to monitor the toasting process so the toast would always be fully done and never burned. Autonomy is a smarter kind of automation.

Figure 9: Sunbeam, Model T-20, from the late 1940s through the mid 1950s. This was the first "fully automatic" toaster. When bread is placed into this toaster, it is automatically lowered; when the toasting cycle is complete, the unit shuts off and gently raises the toast for removal. Photo and caption from the Cyber Toaster Museum.

Definition: Autonomy is the ability of a system to perform successfully for extended periods without human intervention.

2.2 Examples of Robots

The earliest movie robot was Maria in the 1927 silent film *Metropolis*. Maria's builder, Rotwang, solved the intelligence programming problem by transferring the mind of the human Maria into the robot.

Figure 10: Maria the robot from the 1927 silent film *Metropolis*, with Rotwang, the robot's creator.

Robots remained in the realm of science fiction until the 1960s with Marvin Minsky's Blocks World at MIT and Shakey the robot at Stanford.

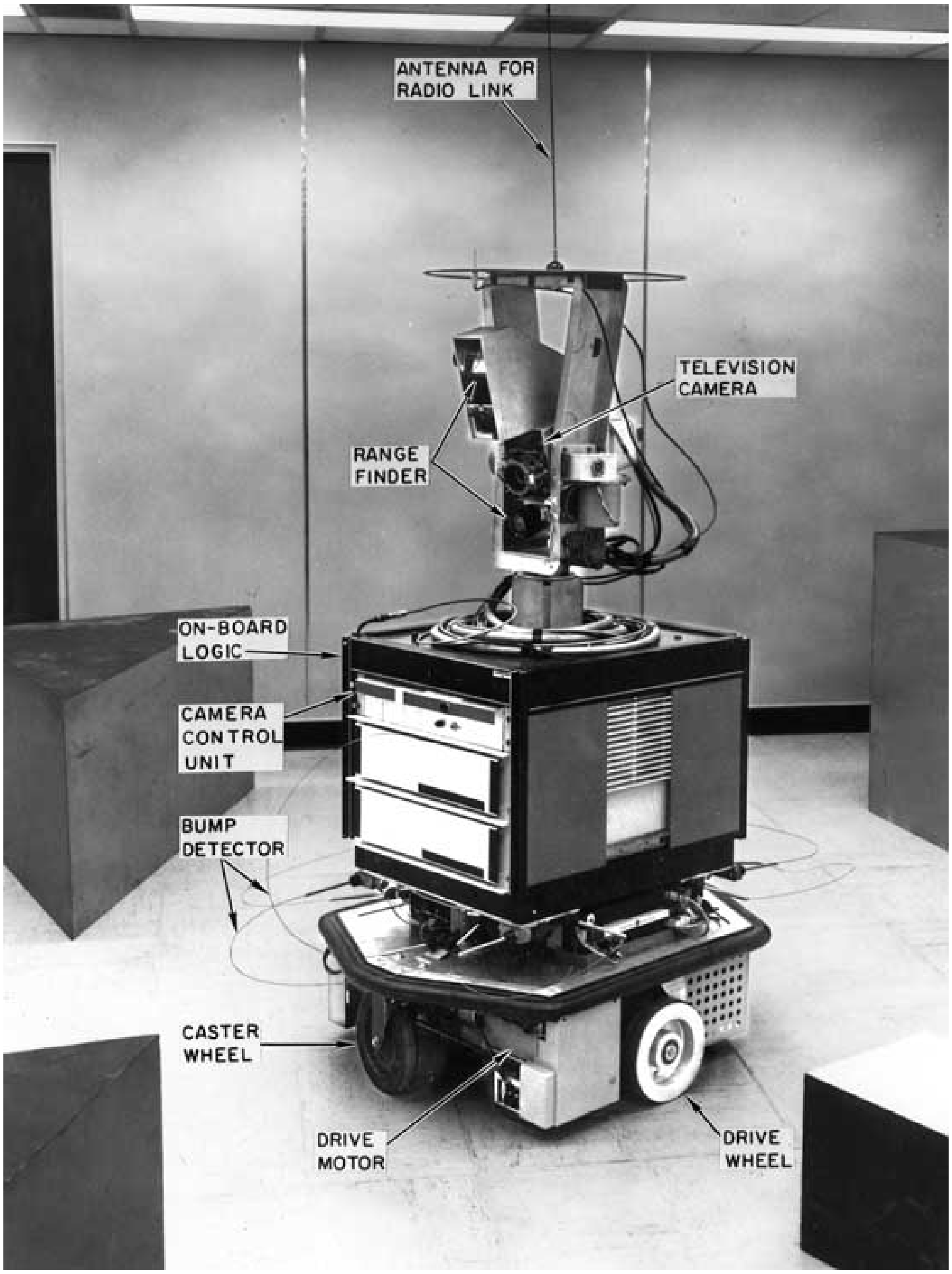

Figure 11: Shakey the robot, Stanford University, 1970.

2.3 Definition of Robot

A robot is an autonomous artifact that obtains information by sensing the world around it and uses the information to manipulate its environment to achieve goals. Robot sensing includes vision, sound, touch, and others. Manipulation includes the use of specialized tools and dexterous manipulation. Robots often have the ability to change their locations in the world (locomotion).

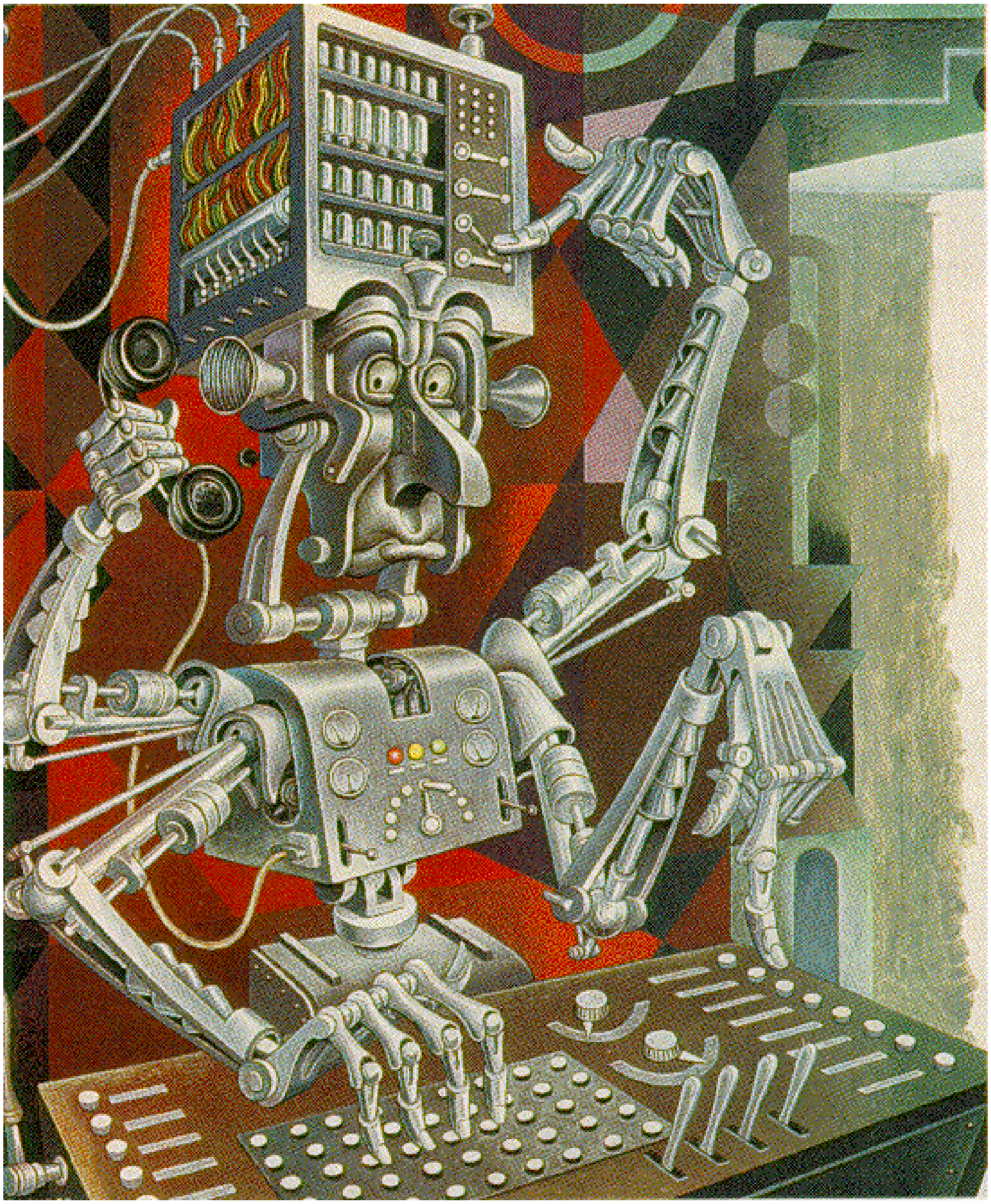

Figure 12: Executive of the Future, Boris Artzybasheff, 1947.

2.3.1 Features of a Robot

Robots are designed to have the features appropriate to their functionality.

Figure 13: Robot for laser cutting, welding, and drilling.

2.3.1.1 Mobility

Not all robots are mobile, but mobility is a very useful feature for many applications. However, mobility imposes mass and power constraints on a robot.

Figure 14: RoboX tour guide robot from BlueBotics, Switzerland.

Wheels provide the easiest form of mobility to implement, but require relatively smooth terrain. Legged robots borrow their solution from nature, and improve capability on rough ground, but are notoriously difficult to implement. Tracks (as on military tanks) are a good compromise.

Mobility might also include the ability to fly or swim, or in the case of space robots to change trajectory or orientation with rocket thrusters.

2.3.1.2 Sensing

Figure 15: Six axis robot arm from Adept Robotics, San Jose, California.

If robots didn't have autonomy, they wouldn't need sensing. They could have all their actions pre-programmed into them, but their capabilities would be considerably limited. With sensing, the robot must use the information acquired from the sensors in deciding what to do next.

The information from the sensors will only make sense if the robot has some way of using the information to create or modify a model of the world. The process of using sensor data is called representation. Representation and decision making require intelligence.

2.3.1.3 Intelligence

One common approach to robotics is to use a sensing-action cycle. The robot takes sensor data to build or modify a model of the world around it. Then it uses its objectives (goals) to decide how to operate on the world model to achieve a particular goal or sub-goal. Then it performs the action and repeats the cycle.

Different robot applications require different intelligence strategies. Some applications require complex planning algorithms. Others where speed is important have simple and fast programs.

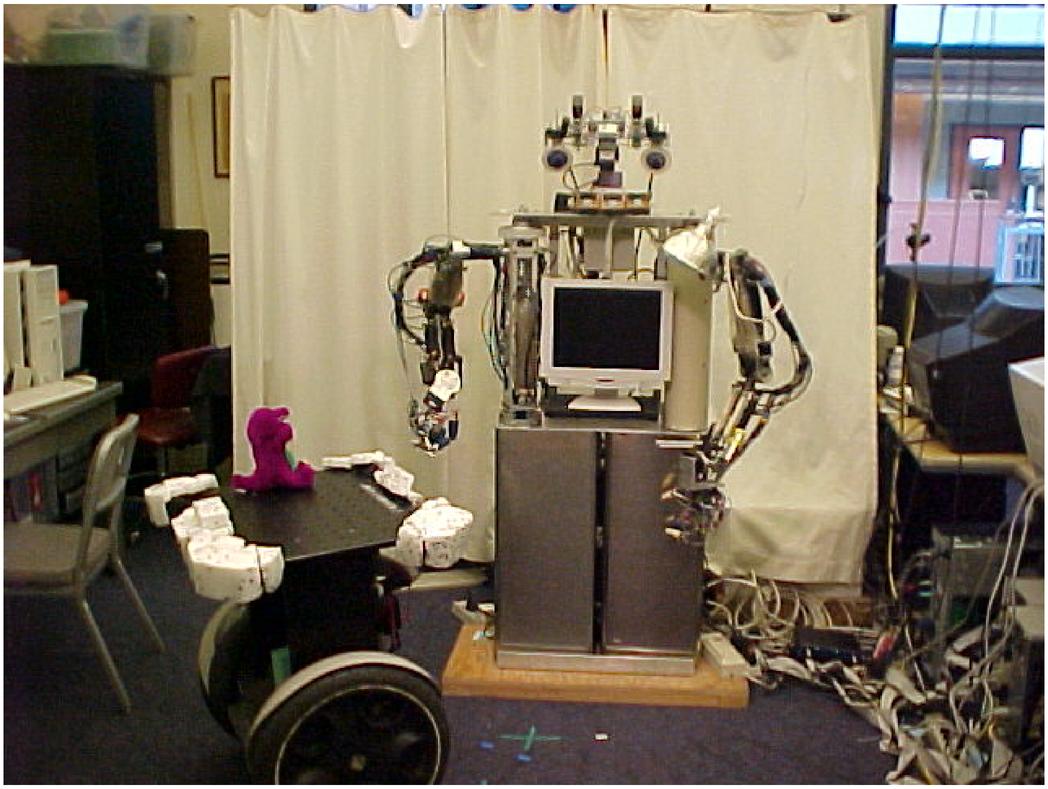

Figure 16: A Segway RMP providing ISAAC with a Barney doll. Vanderbilt University Center for Intelligent Systems.

Anthropomorphic robots have long been a research area in which the application requires sophisticated artificial intelligence (AI) involving binocular image recognition to build 3D models of the world and voice recognition for conversing with humans.

2.4 Robotics Disciplines

Robotics researchers and engineers work in several areas or disciplines within robotics.

2.4.1 Navigation

Navigation algorithms are generally applicable to mobile robots. Robots evaluate their current position from sensor data and construct a plan for moving to a goal or way-point (sub-goal).

Figure 17: Model 912 mobile robot from White Box Robotics.

A classic example of a navigation problem is to cross a parking lot without running into any parked cars. Finding a relatively short path is also an objective of this problem.

One way to do this is to use the “visibility graph” technique. The conventional visibility graph runs in time n^2 where n is the number of obstacles in the workspace. A locality heuristic allows us to reduce the computation time to n for workspaces that are not densely populated in obstacles, which is the general case. An application program has been devised to illustrate this heuristic.

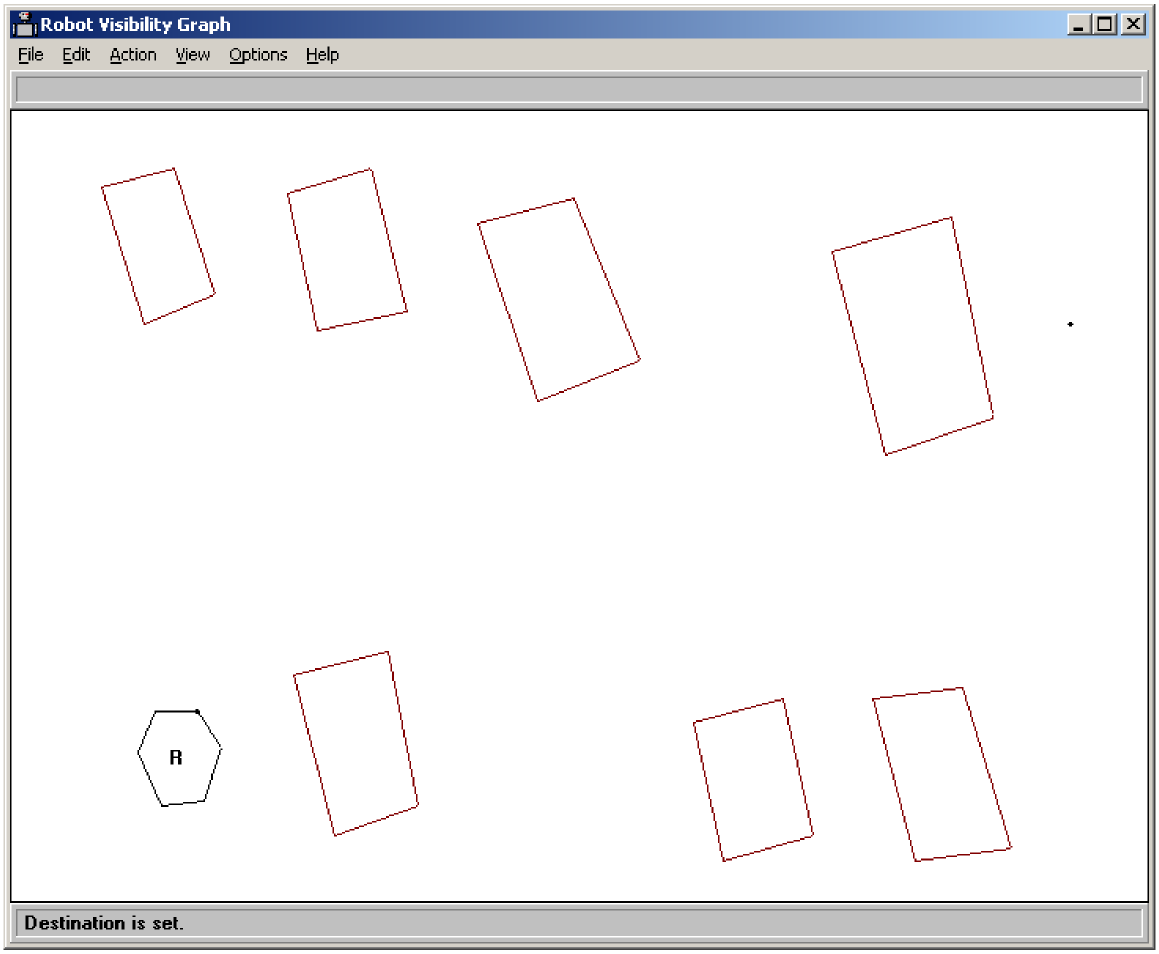

Figure 18: Visibility graph demonstration program. The robot is represented by the hexagon in the lower left corner. The goal point is in the upper right corner. The red rectangular obstacles represent cars in a parking lot.

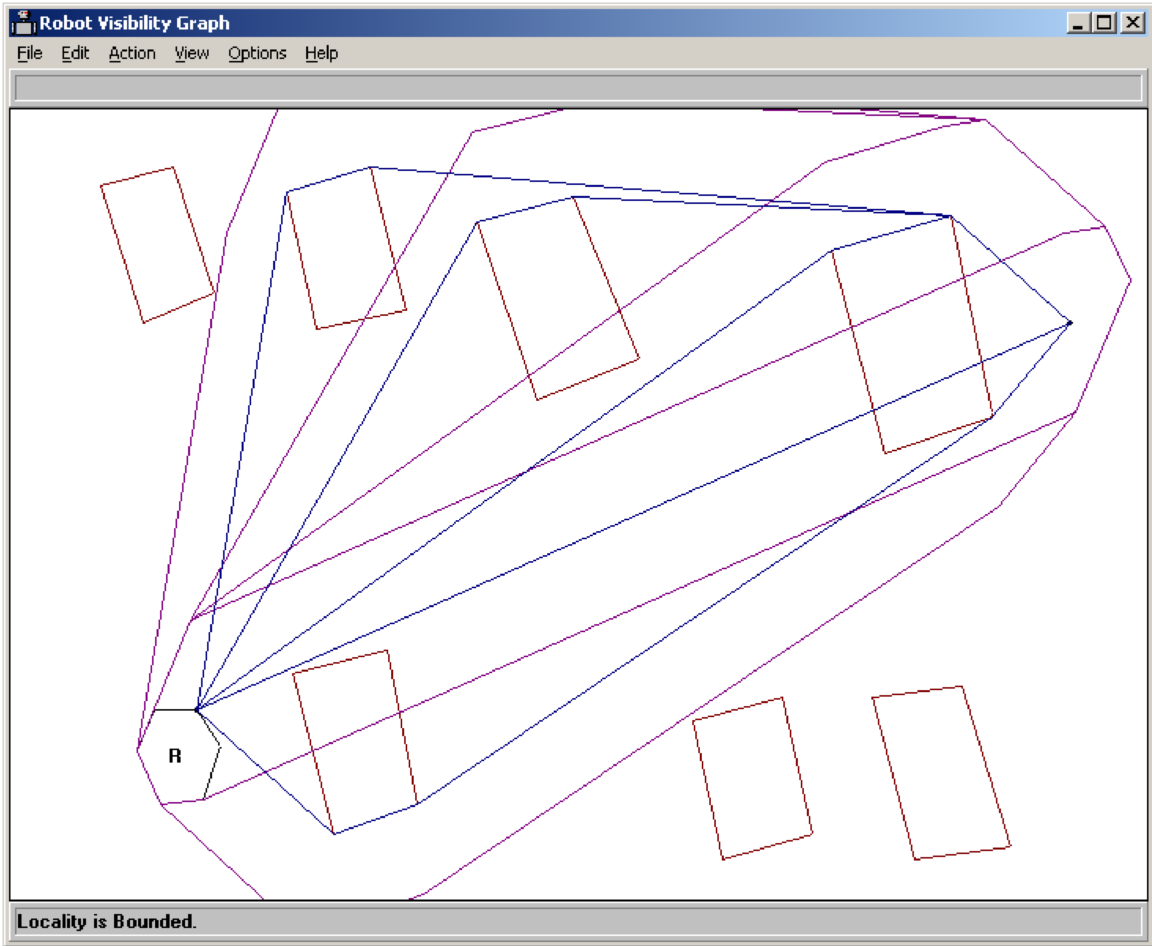

Figure 19: The locality is bounded by drawing a line from the robot to the goal and then "growing" this line by the robot (Minkowski sum). If the grown line contacts any obstacles, those obstacles are included in the locality and the process repeats until no new obstacles are included in the locality. Here, four obstacles are included in the locality.

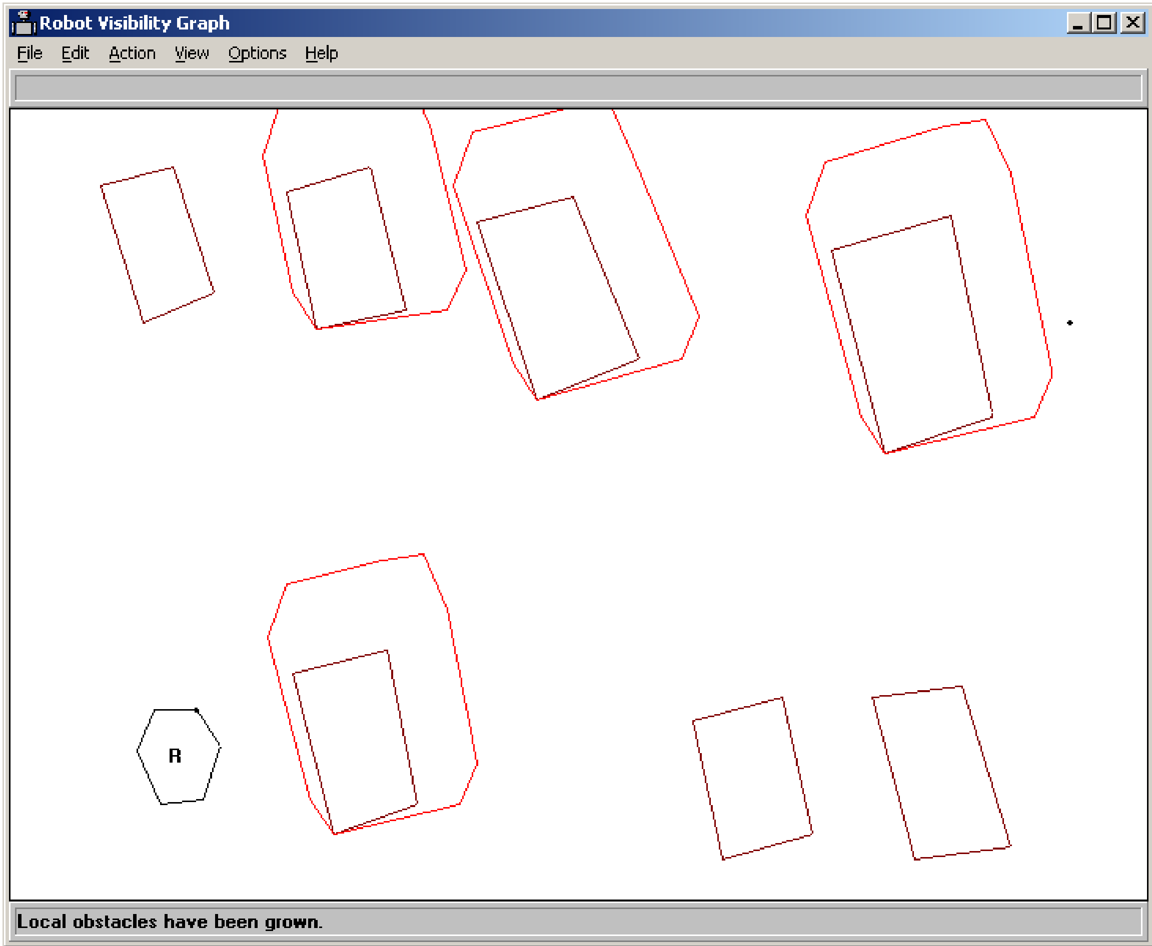

Figure 20: Next, the local obstacles are "grown" by the robot (take the Minkowski sum).

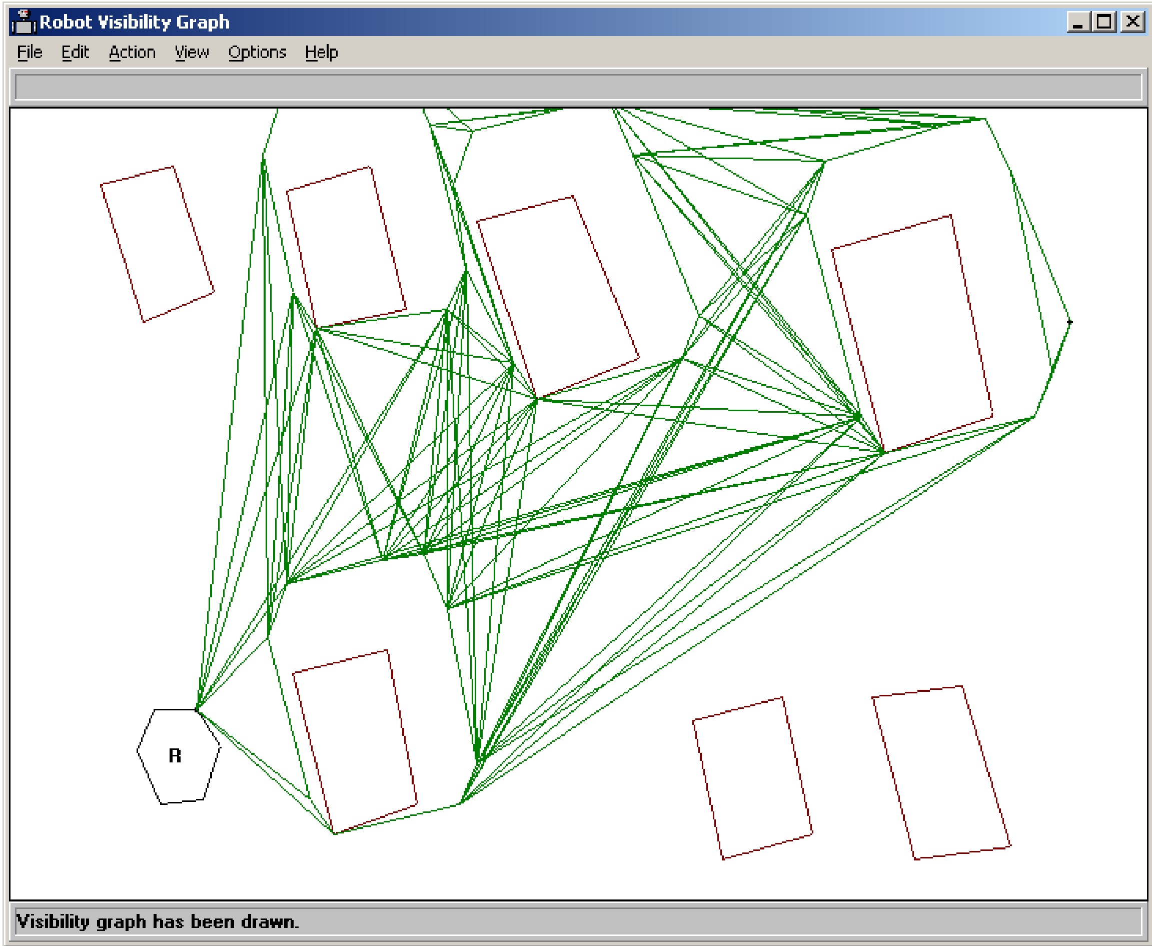

Figure 21: Then we draw the visibility graph of the robot, grown local obstacles, and the goal point.

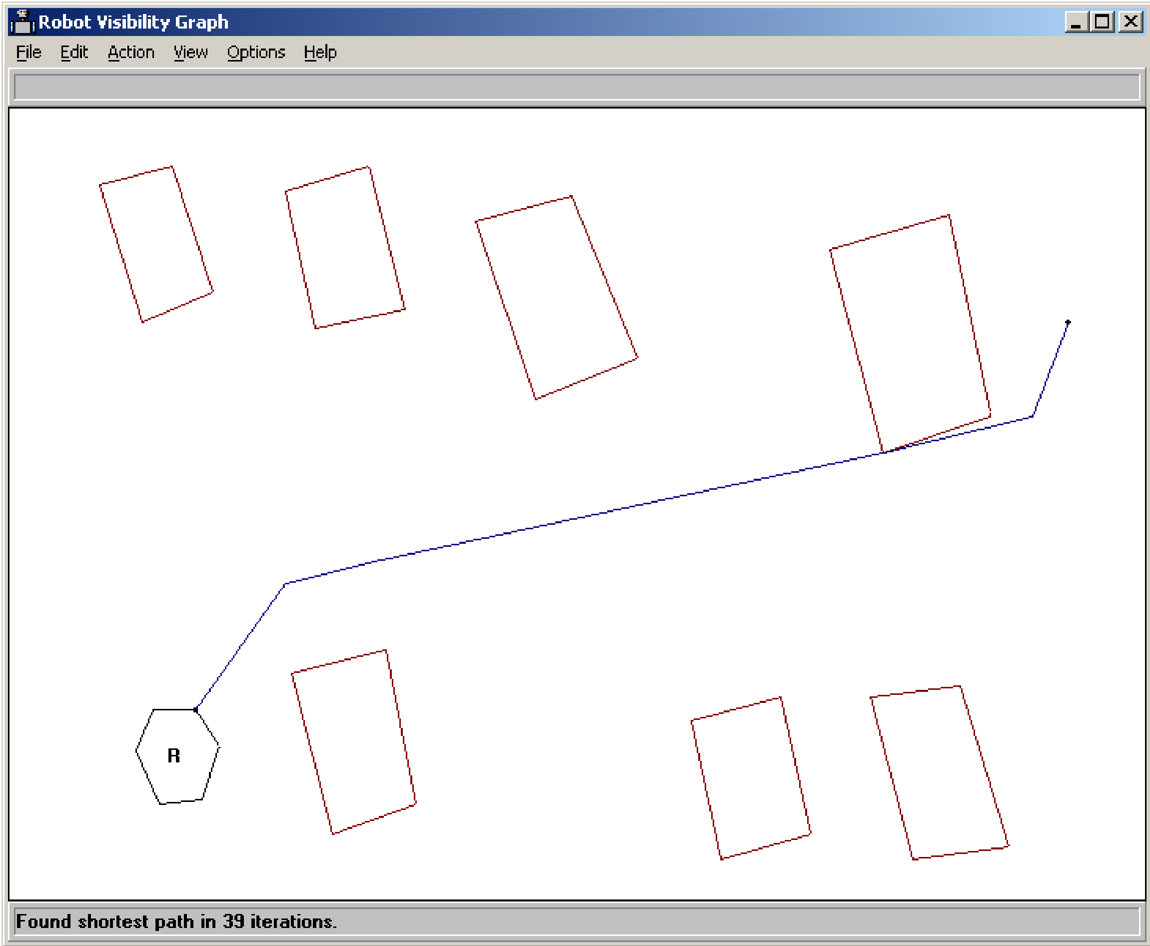

Figure 22: The shortest path in the visibility graph is then found using Djikstra's algorithm.

2.4.2 Manipulation

Manipulation is the area of robotics concerned with finding a good grip (grasping) and then handling objects so that objectives are met.

Figure 23: Commercial dexterous robot hand from the Shadow Robot Company.

In handling an object, there are a large number of "configurations" of the gripper on the object. The robot has to know how to compute an acceptable grip. If there is an error, the robot could drop the object it picks up, or won't be able to properly hand it off or put it where it belongs.

For example, suppose a robot needs to hand a pan of water to a person or another robot. If the first robot's hand completely covers the handle, the person or second robot won't be able to take the pan.

2.4.3 Computer Vision

Another very rich and interesting research area is computer vision. This usually requires constructing a 3D model of the world based on the images from one or more cameras.

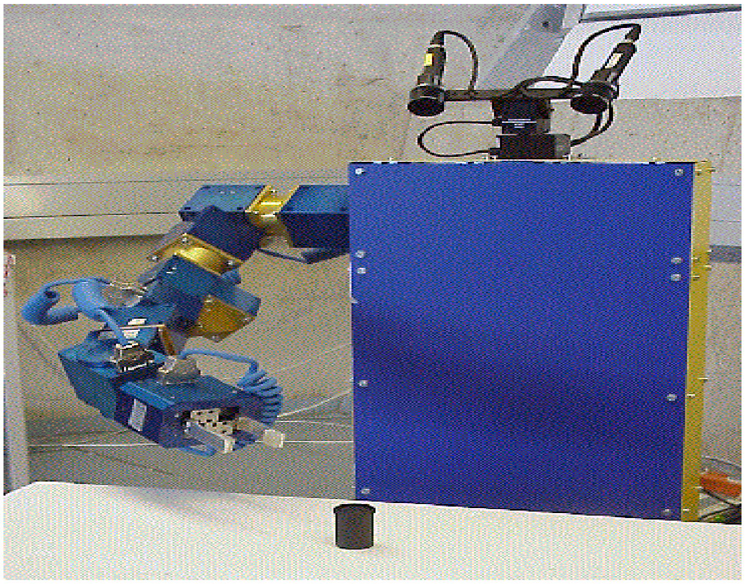

Figure 24: MARVIN, a vision research robot at Munchin Technical University.

Many vision systems use "binocular vision" similar to humans. Others use laser range finders, sonar, or radar. Stereoscopic vision can be constructed using one camera and moving it from place to place in the scene to be modeled.

2.4.4 Artificial Intelligence

Navigation, manipulation, and computer vision all require artificial intelligence. However, artificial intelligence goes beyond those three strictly robotic disciplines. Realizing the fullest capabilities of robots will require speech understanding and common sense reasoning.

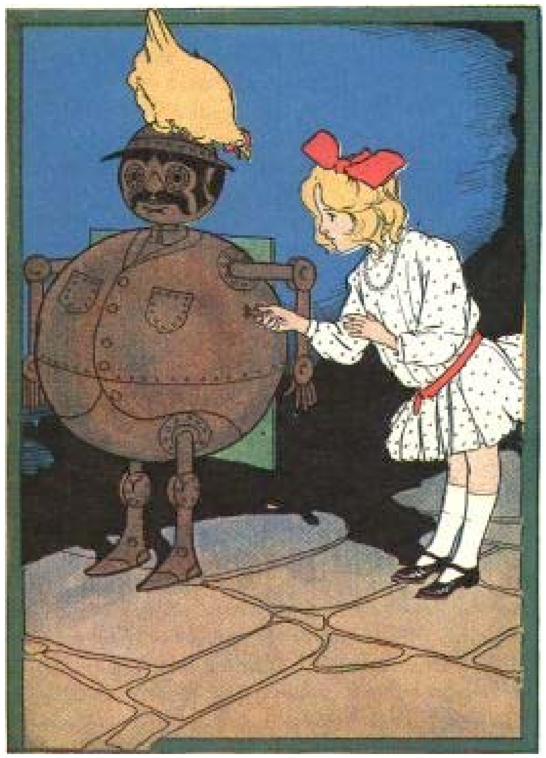

Figure 25: Tiktok, the clockwork man in the children's story *Ozma of Oz*, by L. Frank Baum. Tiktok had to be wound up with a key, one spring was wound for movement, and one spring was wound for thinking.

For a robot to communicate with people will require that it have understanding of the world, or at least understanding of its domain environment. Research projects to achieve this goal have been underway at universities for many years.

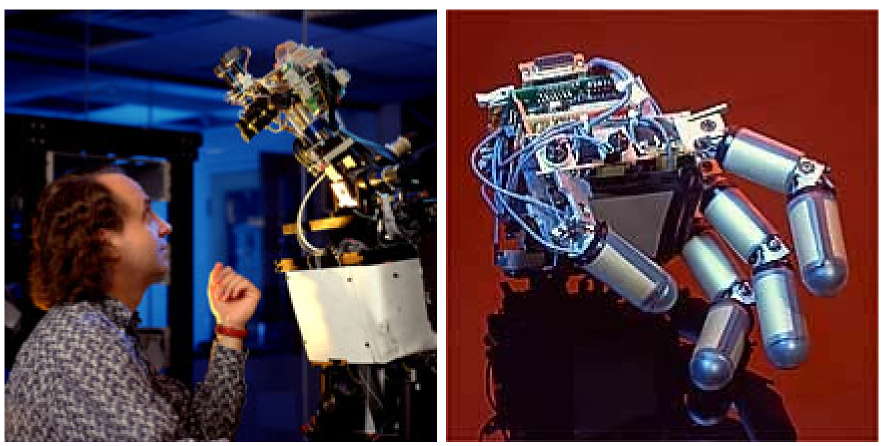

Figure 26: Rodney Brooks poses with Cog (left), Cog's hand.

For example, Rodney Brooks' goal at MIT is to produce a fully capable anthropomorphic robot in his Cog project.

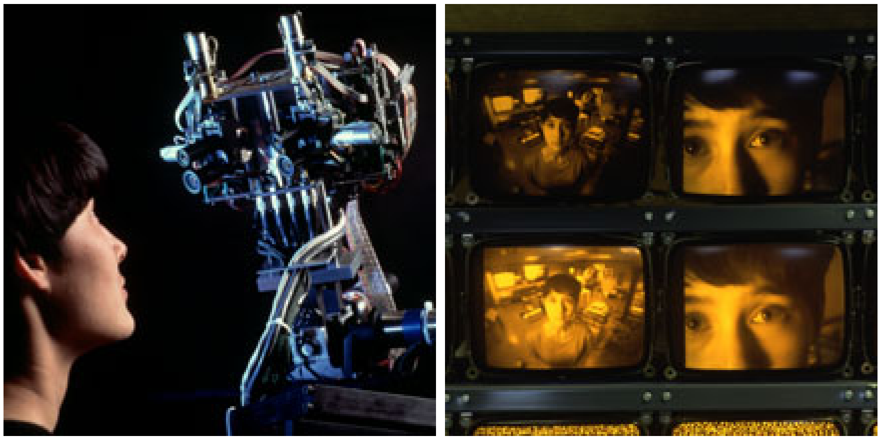

Figure 27: Cynthia Breazeal with Cog (left), what Cog sees.

The Cyc project (http://www.opencyc.org/) has been building a commons sense database for machine intelligence for over 20 years.

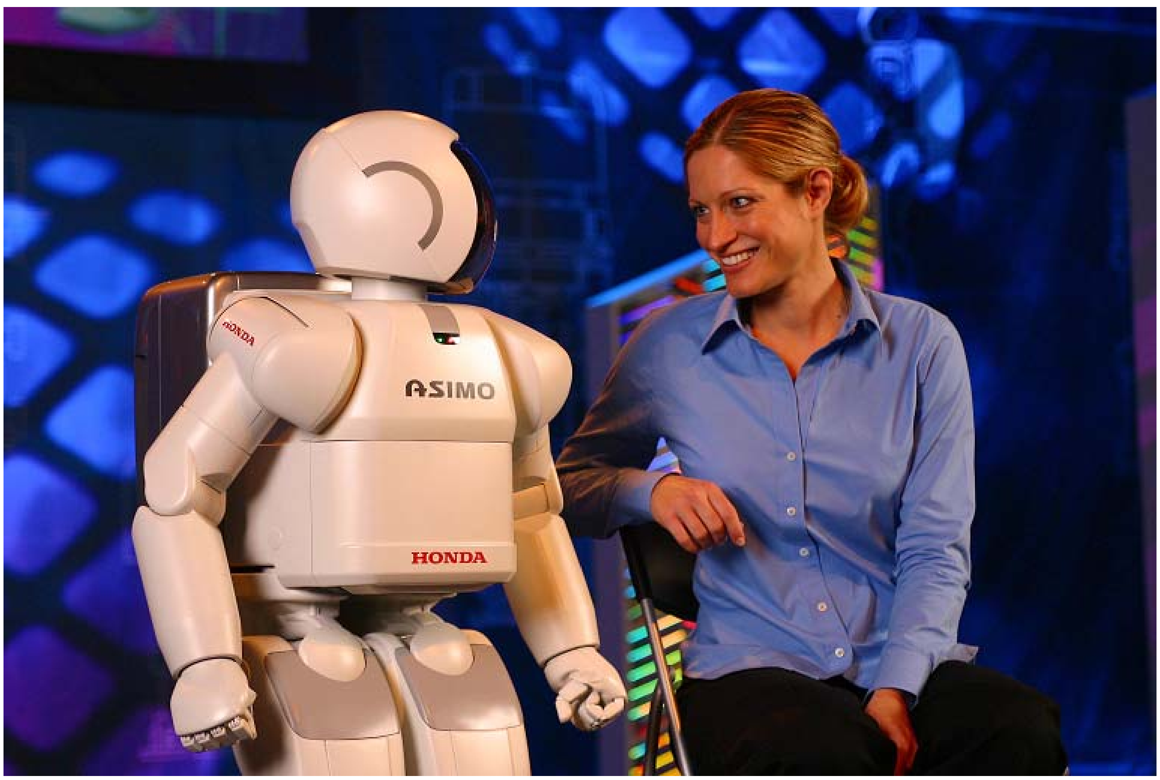

Figure 28: ASIMO, the anthropomorphic robot built by Honda.

The Honda Corporation in Japan has created a walking anthropomorphic robot named ASIMO, which stands for Advanced Step in Innovative Mobility. The name probably also derives from the late Isaac Asimov who wrote *I, Robot* and developed the so-called Three Laws of Robotics, which are actually design guidelines. ASIMO's maximum walking speed is currently 1.6 k/h.

2.4.4.1 Computer Hierarchy

There are two parallel computer hierarchies, a conceptual hierarchy, and a system hierarchy.

2.4.4.1.1 Data

The lowest level of the conceptual hierarchy is data. These are the raw bits, numbers, words, and sequences. Without context, data has little meaning. For example, given the number "74" there is very little meaning to it, except for the fact that it's a relatively small integer in base 10 format.

2.4.4.1.2 Information

The level above data is information, which is data in context. For example, if I say "74 degrees Fahrenheit at 5:00 PM in Baltimore," then you know the context of "74," allowing one to draw inferences.

2.4.4.1.3 Knowledge

Having information about the temperature in Baltimore allows one to infer that one won't need to wear a parka if one travels there today. The inference demonstrates that one has knowledge about temperature, weather, and clothing.

2.4.4.1.4 Intelligence

Intelligence is the next step up in the hierarchy, and is the ability to achieve goals based on knowledge. For example, if I ask a robot to pack my bags for a trip to Baltimore, and the robot looks up the temperature there and doesn't pack my parka, then we might say that the robot exhibits intelligence.

2.4.4.1.5 Wisdom

Wisdom is the ability to set the right goals. If I should ask a robot "where should I go tomorrow?" the robot will have no way to answer that question because wisdom is beyond the capabilities of artificial systems.

2.4.4.1.6 Hardware

Hardware is the lowest level of the system hierarchy. The data are stored in the memory chips and CPU registers.

2.4.4.1.7 Operating System

The operating system is in direct contact with the hardware and mediates application software access to computer resources.

2.4.4.1.8 Application Software

Application software is the middle level in the system hierarchy.

2.4.4.1.9 Network Protocol

The network protocol level regulates communication among computers.

2.4.4.1.10 Policy

Human beings set computer policy. Computer access rights and network security features are examples of policy.

The two computer hierarchies are summarized below in Figure 29.

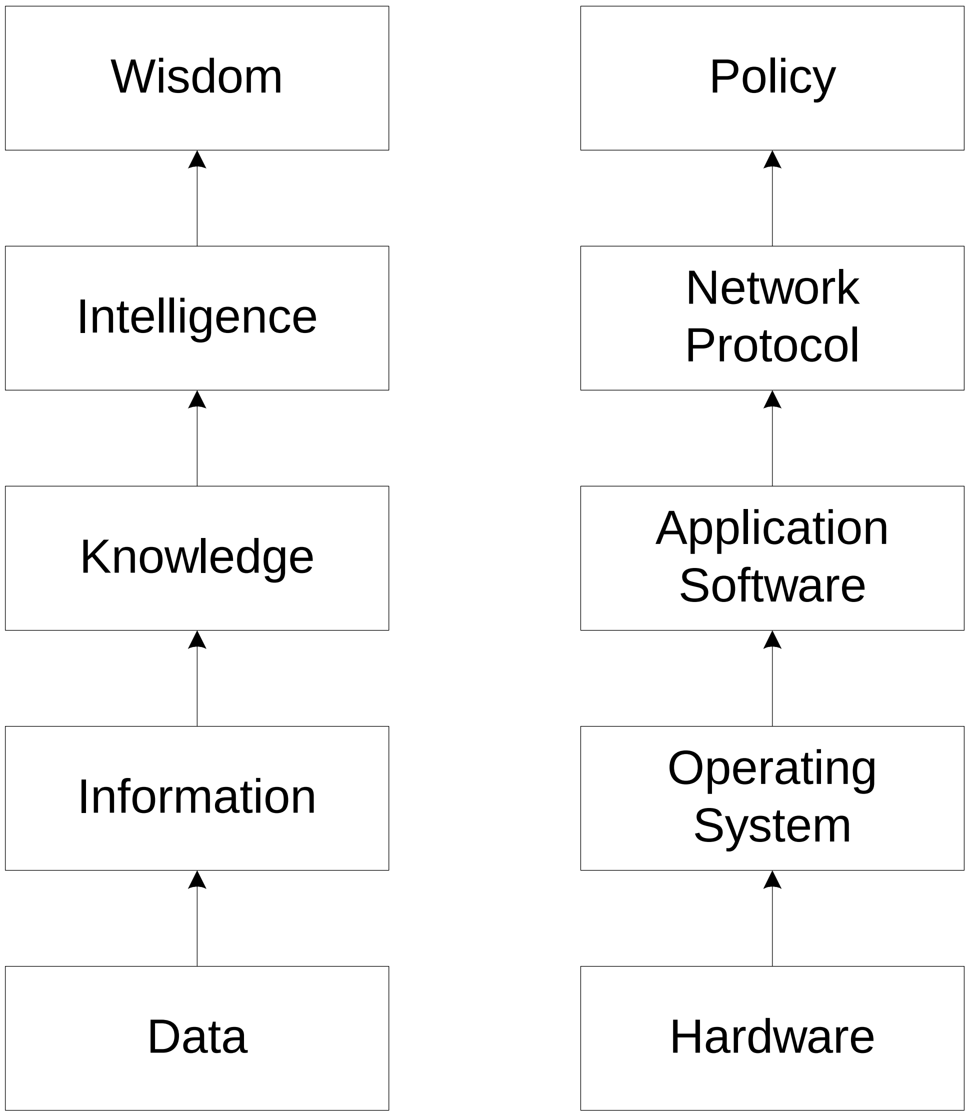

Figure 29: The two somewhat parallel computer hierarchies. The conceptual hierarchy is on the left and the system hierarchy is on the right.

The human user also interfaces directly with the hardware layer via the keyboard and mouse, so the system “hierarchy” is actually a circle. This is shown below in Figure 30.

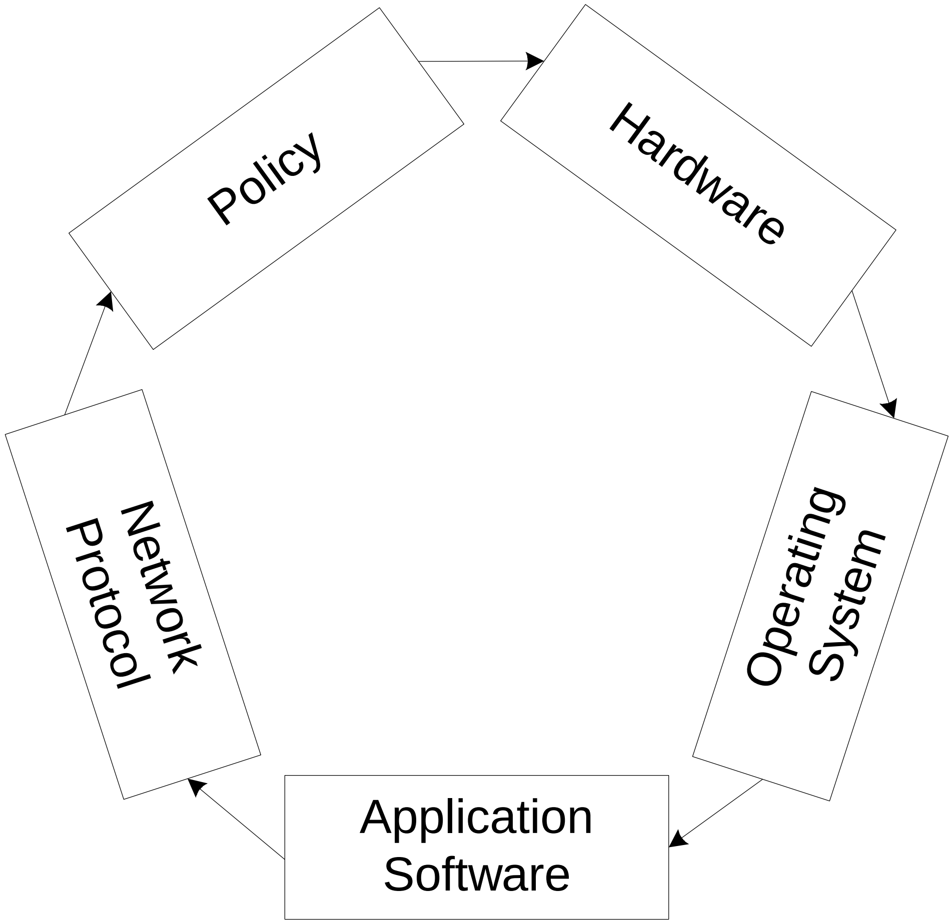

Figure 30: The circular nature of the computer system relation. Human beings at the policy level interface with the hardware to complete the cycle.

Asimov's three laws of robotics are an example of policy implementation. In writing robotic software, the human designer types code on the keyboard. The keystrokes are interpreted by the operating system and passed to the editing and compiling applications.