AI Magazine Volume 19 Number 3 (1998) (© AAAI)

Profile of a Winner: Georgia Tech

The Georgia Institute of Technology earned three first-place finishes in the Find-Life-on-Mars event at the 1997 American Association for Artificial Intelligence (AAAI) Mobile Robot Competition and Exhibition. Its two robots, LEWIS and CLARK, won the multiagent challenge and finals rounds for robots with manipulators. The student team of robot builders chose a multiagent approach for the reliability and efficiency it offers over single-agent solutions. The advantage of teamwork was demonstrated in competition when CLARK's arm was ripped off midway through the challenge round in an engagement with one of the rock hazards. Fortunately, LEWIS survived and collected enough "life forms" to win the round.

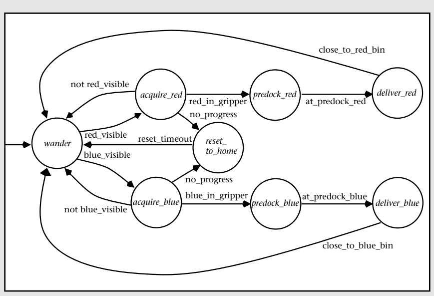
LEWIS and CLARK with Several Members of the Georgia Tech Robot-Building Team.

From left to right: Tucker Balch, Juan Carlos Santamaria, and Tom Collins. (*Photo courtesy of Stanley Leary, Georgia Institute of Technology.*)

LEWIS and CLARK are Nomadic Technologies NOMAD 150 robots (shown in the photograph). The NOMAD 150 is a 3-wheeled kinematically holonomic vehicle equipped with a separately steerable turret, 16 ultrasonic range sensors, and a ring of rubber bump sensors. Georgia Tech modified the robots to add servodriven grippers and real-time vision. The vision system reports the location of colored life forms, rock hazards, and delivery bins at as much as 30 Hertz. A JAVA-based control system running on a laptop computer communicates with the vision and mechanical control systems using serial protocols.

Control systems for the robots were coded using CLAY, a set of JAVA classes that support sequenced behavior-based control (Balch 1997). Complex behaviors are developed using behavioral primitives called *motor schemas,* independent processes that combine to generate an overall behavior (Arkin 1989). Motor schemas take input from specialized perceptual schemas and generate a movement vector representing the desired direction of travel. The relative importance of each schema is encoded with a gain value. The vectors of active motor schemas are multiplied by their gain values, summed, then normalized and transmitted to the hardware for execution.

As an example of how behaviors were developed for the Find-Life-on-Mars event, the robots activate the move_to_red_bin, avoid_obstacle, and noise motor schemas for navigation to a red bin. This assemblage of primitive behaviors moves the robot toward the bin but keeps it from colliding with obstacle hazards. Noise helps move the robot out of any local minima it encounters. In this manner, behaviors were developed for each stage of the task, for example, wander, acquire_red, acquire_blue, predock_red, predock_blue, deliver_red, and deliver_blue. The control systems sequence from one behavior to another based on perceptual cues provided by the sensors. The robots begin their search for Martians using the wander behavior. When a red life form is detected, the robots transition to the acquire_red behavior and, after grasping the object, switch to predock_red. The predock behavior draws the robot to a position in front of the delivery bin, and deliver is used to finally place the object in the bin. A similar sequence is provided for blue life forms. The overall sequence of behaviors is illustrated in the figure that follows.



Behavioral Sequence Used by LEWIS and CLARK for Collecting and Delivering Objects in the Find-Life-on-Mars Event.

The behaviors were tested in simulation, then on robots in the Mobile Robot Laboratory. At the AAAI competition, the Georgia Tech team planned to use the laboratory-developed behaviors as is, but lighting, floor coloring, and the paint used on the rock hazards caused unexpected perceptual difficulties. The floor of the arena included black splotches that were sometimes confused with rocks. The spectrum of light in the arena, in combination with the paint used on the rocks, caused the robots to occasionally mistake rocks for blue Martians. The perceptual difficulties were compounded by the fact that the hazards were too low to be detected by the robots' sonar-ranging sensors. These perceptual difficulties led CLARK to scrape a rock hazard, causing it to lose its arm in the challenge round. Between the challenge and the finals rounds, the hazard-detection problem was solved: The ultrasonic sensors were reaimed downward at a 45-degree angle. Hazards could then be detected reliably.

A change in the task for the final round presented a new challenge. The robots had to collect and deliver Martians painted six different colors instead of only two, but the robots' vision systems can only track three colors at a time. The use of multiple robots enabled a workaround: Each robot was programmed to specialize in the collection of three of the six types of Martian. The improved hazard sensing and refined vision strategy enabled the robots to collect 10 attractors and place 9 of them in the correct delivery bin.

Acknowledgments

Georgia Tech's team was led by Tucker Balch. Darrin Bentivegna and David Huggins programmed the vision hardware, and Harold Forbes built the grippers. Erwin Oei helped with the construction of the grippers and their repair at the contest. Tom Collins served as the team's faculty adviser. We thank Ron Arkin (director of Georgia Tech's Mobile Robot Laboratory) for use of the robot hardware and Nomadic Technologies for providing servocontrol software.

– Tucker Balch