The ARTSI Alliance: Using Robotics and AI to Recruit African-Americans to Computer Science Research

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Abstract

The mission of the ARTSI (Advancing Robotics Technology for Societal Impact) Alliance, a consortium of 19 Historically Black Colleges and Universities (HBCUs) and 9 major research universities (R1s), is to enlarge the nation's engineering and science talent pool by increasing the number of students from underrepresented groups who pursue advanced training in computer science. ARTSI is one of several alliances funded by the National Science Foundation's Broadening Participation in Computing Program. ARTSI focuses specifically on institutions serving African Americans and uses robotics education to attract and engage students. In this paper we describe the activities comprising ARTSI, our vision of a robotics curriculum for CS undergraduates, and ways to integrate robotics modules into existing CS courses.

Overview of ARTSI

The ARTSI Alliance (Advancing Robotics Technology for Societal Impact) grew out of an earlier NSF-funded collaboration between Andrew Williams of Spelman College and David Touretzky of Carnegie Mellon called CARE: Computer and Robotics Education for African-American Students (Williams et al., 2008a). CARE set up robotics labs at three other HBCUs: Hampton University, Florida A&M University, and the University of the District of Columbia, providing each school with four Sony AIBO robots, four iMac workstations, and hands-on training for faculty and selected students. The success of CARE in introducing new robotics courses using high-tech robots at HBCUs led to the formation of the ARTSI Alliance in 2007, again under the direction of Williams and Touretzky. ARTSI added four more HBCUs and six research universities (Williams et al., 2008b). Like CARE, ARTSI is funded by NSF's Broadening Participation in Computing program (Chubin and Johnson, 2010). Now led by Chutima Bonthum-Denecke of Hampton University, Touretzky, and Elva Jones of Winston-Salem State University, the Alliance recently received a two year extension award from NSF. Currently ARTSI comprises 19 HBCUs and 9 research universities, listed in Table 1.

The mission of the ARTSI Alliance is to provide education and research opportunities to engage undergraduate students from non-traditional backgrounds in the study of robotics in areas that are relevant to society. ARTSI has the following goals:

1. Increase the number of underrepresented (primarily African American) students who pursue advanced training in computer science or robotics.

Table 1 ARTSI HBCU and R1, schools and corporate partners

Type	Members
HBCU	Spelman College, Florida A&M Univ., Hampton Univ., Univ. of District of Columbia, Norfolk State Univ., Univ. of Arkansas – Pine Bluff, Morgan State Univ., Winston-Salem State Univ., Elizabeth City State Univ., Jackson State Univ., Tennessee State Univ., North Carolina A&T Univ., Howard Univ., Fort Valley State Univ., Virginia State Univ., Univ. of Maryland Eastern Shore, and Bowie State Univ.
R1	Carnegie Mellon Univ., Georgia Tech., Brown Univ., Duke Univ., Univ. of Alabama, George Institute of Technology, Rice Univ., Univ. of Pennsylvania, Univ. of Michigan.
Industry	Apple Inc., Google., Intel Corporation, iRobot, Seagate Technology, Motorola, Boeing

2. Increase the institutional capacity of HBCUs to offer educational experiences in robotics.
3. Build an active community of HBCU faculty and students who collaborate with each other and with R1 faculty on robotics teaching and research.
4. Conduct outreach activities for the broader public to increase awareness of and interest in African American achievement in robotics, and recruit new students to the pipeline.

Common Hardware/Software Platforms

Although the CARE HBCUs had success with the sophisticated Sony AIBO robot dog, when Sony exited the robotics market in 2006, we were forced to seek other platforms for ARTSI. After roboticists from the University of Alabama and Duke University demonstrated the use of the Create/ASUS robot, the Alliance adopted the Create/ASUS as a common platform. All 19 HBCUs now have at least 2 of these robots; some have as many as 8. It consists of an iRobot Create mobile base on which is mounted an ASUS Eee PC netbook running Ubuntu Linux (see Figure 1). The netbook provides ample computing power, an on-board webcam, speakers for audio output, and both WiFi and ethernet connectivity. It controls the Create via a USB-to-serial cable.

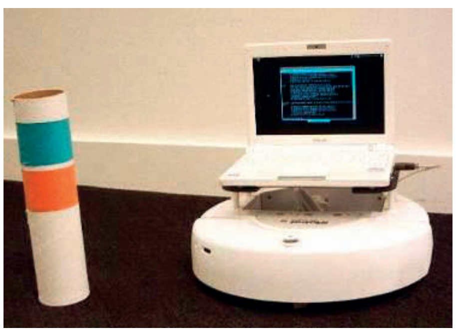

Figure 1. Create/ASUS robot and a navigation marker.

Carnegie Mellon and Florida A&M University, in collaboration with RoPro Design, Inc., are presently developing a successor to this platform, called Calliope, that adds a separate camera on a pan/tilt mount and an arm with a gripper (Figure 2). This may become the new standard platform for ARTSI. For software, most schools are using the Tekkotsu robotics framework developed at Carnegie Mellon (Tira-Thompson and Touretzky, in press; see also Tekkotsu.org), but some are also using Player/Stage, another popular open source platform (playerstage.sourceforge.net).

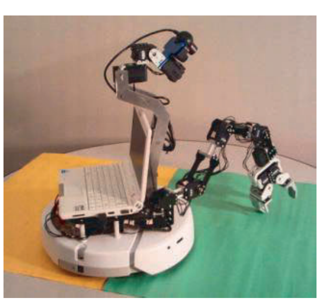

Figure 2: Calliope prototype with pan/tilt and gripper.

LEGO Mindstorms is used in K-12 outreach activities, or to give students a first taste of robotics before moving on to the more advanced platforms.

The Pipeline to Graduate School

Educators concerned with increasing the number of students from underrepresented groups who pursue careers in science must deal with the "leaky pipeline" problem: how to get students into the pipeline to graduate school, and how to keep them there until they reach their goal. Recruitment into the pipeline should start by fostering children's interest in science and engineering, ideally in middle school. By high school students must be taking the correct science and math courses to prepare themselves for college. In college, students must remain motivated and successful in order to be accepted into a graduate program. And in graduate school they must complete coursework and research leading to their successfully defending a doctoral dissertation. Students can "leak out" anywhere along this pipeline due to loss of motivation, insufficient academic skills, difficulty adjusting to a new environment, financial hardship, family responsibilities, or other reasons.

ARTSI works to fill the pipeline primarily by recruiting at the undergraduate level, although there is also a K-12 outreach component. ARTSI works to keep students in the pipeline by building their skills and confidence through a series of activities described in the next section, ultimately preparing them to pursue graduate work in robotics or computer science.

Robotics is attractive and exciting to most young people, who have grown up on a steady diet of fictional robots on TV and in the movies. For many students, interacting with a physical machine is more rewarding than just seeing symbols on a computer screen, although we have also seen some students become frustrated or discouraged by the challenges posed by trying to get relatively unsophisticated machines to behave reliably. Improving the quality of our robots should help address that problem.

Undergraduate Activities

ARTSI has initiated several activities to attract students to robotics and motivate them. A subset of these activities is used by each ARTSI school. With time we hope to see most of these implemented at all our member institutions. A complete set of activities is described below.

Rising sophomores program: This is a four week summer program where participants learn the Linux operating system (shell commands, file system organization, job control, networking, and package management), text editing, basic electronics (soldering; use of a multimeter), simple hardware (servos, switches), and elementary robot programming (LEGO Mindstorms). This program has been piloted at Winston-Salem State University and all six students from the first cohort (Summer 2009) secured REU positions (see below for REU program).

Skills certificate program: This proposed program will make students Linux proficient (a lower-cost alternative to the rising sophomores program) and teach them debugging and web research skills, to better prepare them for summer research internships in R1 labs. Students who complete the training will receive an ARTSI certificate.

Robotics course: This is one of the two primary components of the ARTSI program. Students spend one or two semesters learning to program sophisticated robots in C++. Some schools use this course (or course sequence) as preparation for the ARTSI robotics competition. More details are given in the *Robotics Curriculum* section below.

Summer REU (Research Experiences for Undergraduates) program: This is the second key component of the ARTSI intervention. Students are matched with robotics faculty at major research universities and spend 8-10 weeks working in their labs. For many students, this is their first exposure to a large university environment and their first opportunity to interact closely with nationally recognized robotics researchers and their graduate students. Working in a lab gives students a taste of what research is like and helps build confidence that they too can become graduate students and pursue a career as a researcher or faculty member.

Robotics clubs: A club is established and students and a faculty advisor have weekly, informal meetings that may include discussion of the latest robotics news and videos, experimentation with ARTSI-provided robots, or preparation for an upcoming competition event.

Service learning through K-12 outreach: Many of our HBCUs visit local middle schools and high schools that serve large minority populations to talk about robotics and encourage these students to prepare themselves so that they are eligible to study science or engineering in college. These visits include robot demonstrations and presentations by undergraduate students as well as faculty. Some schools also run after-school enrichment programs or robotics summer camps for K-12 students. Contributing to these events helps undergraduates build confidence in their own abilities and provides experience in public speaking and teaching.

Robotics competitions: Students are given tasks for their robots to perform and have roughly six weeks to develop a solution. The tasks involve a combination of computer vision and robot navigation; a manipulation component is planned for the future. The competition allows students to exercise the skills they acquired in their robotics courses and REU internships, to experience teamwork, and to show off their inventiveness and programming prowess. The tasks from the previous year's competition are used as projects for some robotics courses in subsequent semesters. Unlike other robotics competitions (e.g., VEX or US FIRST) which focus mainly on the mechanical engineering aspects of robotics, in the ARTSI competition students focus exclusively on the computer science component: how to program a robot to exhibit intelligent autonomous behavior.

Computer Science Olympiad: This competition tests general computer science skills and knowledge. It consists of five challenges: programming, web page design, cryptography, hardware/software integration, and LEGO robot building/programming. Students will need to apply what they have learned in their coursework and independent studying to prepare for these problem solving challenges.

In-house research: Students may engage in small research projects at their home institutions. These activities not only attract students to robotics research, but also allow them to acquire enough experience to apply for summer REU positions at R1 schools.

Annual student research conference: At the ARTSI Student Research Conference, held at a different HBCU each year, students exhibit their work in oral and poster sessions, with prizes awarded for the best presentations. The conference also includes talks by leading research figures on robotics technology and its societal impacts.

DARPA SMART Scholarship Program: The Science, Mathematics, and Research for Transformation (SMART) Defense Scholarship-for-Service Program, part of the National Defense Education Program, provides scholarships for both undergraduate and graduate study in STEM fields. NDEP has committed to helping ARTSI students form relationships with Department of Defense (DoD) agencies involved in robotics research who can sponsor their SMART scholarships. The scholarships include opportunities for summer internships with the sponsoring agency. After graduation, scholarship recipients fulfill their service requirement by working as civilian researchers in agency laboratories for a comparable number of years. We are working with staff in the SMART Program Office to familiarize ARTSI students with the program and help interested students prepare their applications.

Faculty Development

ARTSI also includes activities to support HBCU faculty and develop a community of African American robotics researchers. (Several of our R1 faculty are also African Americans.)

Robotics laboratory setup: HBCUs new to ARTSI that do not already have a robotics course receive robots and technical assistance to set up their robotics lab.

Annual summer faculty workshop: This workshop serves several purposes. One is to introduce participating faculty to new hardware, software, and curriculum materials that they can incorporate into their teaching and research. Another is to share experiences and best practices, and give the R1 faculty a chance to learn more about what goes on in the HBCU labs. A third purpose is self-governance: decisions about spending priorities, new initiatives, and the addition of new members to the Alliance are made at these meetings.

Spring faculty workshop: This workshop is held during the annual ARTSI student research conference. It serves a similar purpose as the summer workshop, but is shorter in duration: only 2-3 sessions lasting 60-90 minutes each.

Participation in curriculum development: We have launched a new curriculum module initiative to develop comprehensive modules on several topics (see *Robotics Curriculum* section below). These modules will be jointly developed by R1 and HBCU faculty to assure that they properly fit in the CS curriculum at HBCUs and can be refined over time based on feedback from the classroom.

Research collaborations with R1 faculty: R1 and HBCU faculty are encouraged to collaborate on research, and modest funding is available to facilitate this, e.g., travel funds to visit another school or small equipment purchases for HBCUs. Collaborations often occur through a jointly advised student.

Robotics Curriculum

Robotics is an interdisciplinary subject that should be introduced differently to computer science students than to mechanical or electrical engineers. Much attention has been paid to the use of real or simulated simple robots in introductory computer science courses, but serious robotics, taught as an upper-level elective, has been largely neglected by computer science departments (Touretzky, 2010). In fact, many universities are still relying exclusively on LEGO Mindstorms, which some of their students first encountered in middle school. ARTSI is committed to improving the quality of robotics instruction in computer science departments by training faculty and equipping them with appropriate hardware and software.

Table 2 CMU Cognitive Robotics Lab Assignments

Lab	Assignments
1	Compiling and running Tekkotsu programs
2	Motion commands: moving the body
3	Visual routines and the SketchGUI tool
4	Using the map builder; camera vs. body coordinates
5	State machines and the Storyboard tool
6	Navigation with the Pilot
7	Gestalt perception for robots
8	Kinematics: body representation; using the inverse kinematics solver
9	Human-robot interaction and the Looking Glass display tool
10	Manipulation: grasping and transporting objects

In the process of studying robotics, we find that CS students also gain:

- An appreciation of how mathematics is used in computer science, particularly linear algebra, geometry, and trigonometry.
- Improvement in C++ programming and debugging skills.
- A better understanding of advanced abstraction concepts such as templates, multiple inheritance, and polymorphism.
- Experience working with large software systems, e.g. , the need for coding standards, and how to navigate complex online documentation. Others have also observed robotics to be a good vehicle for teaching software engineering (Baltes and Anderson, 2010).

In this section we describe our vision of a robotics elective for upper level CS students, and an introduction to robotics course for lower level students, both of which have been implemented at many of our HBCUs. An example of the inclusion of robotics modules in an artificial intelligent course is also provided.

Upper-Level CS Undergraduate Robotics Course

A CS undergraduate robotics course should include topics such as machine vision, localization and navigation, kinematics, path planning, control architectures, and human-robot interaction. Such courses are mainly found today at elite universities, taught by faculty who are actively involved in robotics research and employing their own specialized curriculum materials. While there are some good generic introductory texts, e.g., (Mataric, 2007) or (Murphy, 2000), the lack of a capable standard academic platform has made it difficult to provide a turnkey course that can be taught by non-experts.

The adoption of a standard platform for ARTSI is a first step towards this goal. We are continuing this work by developing curriculum modules for the Create/ASUS platform on subjects such as machine vision, navigation, kinematics/manipulation, and robot control architectures. Each module will include ready-to-use lecture notes (slides), demonstration software that can be run on the Create/ASUS or Calliope robots, suggested readings, laboratory exercises (shown in Table 2) and problem sets, and videos that can be shown in class. Some precursor materials can be seen online at the Tekkotsu wiki (wiki.Tekkotsu.org) and the "TekkotsuRobotics" YouTube channel.

An example of a syllabus from a CS upper-level course at an HBCU is shown in Table 3. These courses have adopted some content from the CMU Cognitive Robotics Course. They include topics in vision, localization, path

Table 3. Sample Cognitive Robotics Syllabus at HBCU

Week	Topics
1	Introduction to Robotics
2	Robotics and Society / C++ Review
3	C++ Review, Tekkotsu Introduction, and Robot Safety
4	Tekkotsu Behaviors
5	Behaviors and Events
6	Midterm Exam / Motion Commands
7	Motion Commands
8-10	Vision and Shape Representation / Simulator
11-12	State Machines
13-16	Class Project

Table 4. Sample Low-Level Robotics Course Syllabus

Week	Topics
1	Challenge Program # 1 ~ Vehicle-Bot / Exploer-Bot ⇒ Focus on robot construction and navigation using only ultra-sonic sensor
2-3	Introduction to Robotics & Lego Mindstorms NXT Program # 2 ~ Rescuer-Bot ⇒ Add touch sensor and ability to maneuver motors to grab objects in line of sight
4-5	Program #3 ~ Freestyle Robot construction and program ⇒ Utilize all sensors
6-7	leJOS firmware and its API Program # 4 ~ R2Me2 ⇒ Only navigation with ultra-sonic sensor, but focus is on firmware comparison: NXT-G LabView vs. leJos (Java)
8	Handy-Cricket Board Controller and Logo software
9-11	Sensors, Motors, Digital Display ⇒ Utilize these sensors and motors to build a robot beyond building blocks
12-15	Class Project (using Handy-Cricket Board Controller) ⇒ A robot that will benefit societal need

planning and control. Since there is no standard platform, the HBCU schools vary in the level of use the materials from the CMU Cognitive Robotics Course.

Low-Level CS Robotics Courses

Although our major focus is the development of an upper-level CS robotics course, it is sometimes necessary to introduce the subject matter at a lower level to attract students and build necessary skills. The goal of this type of course is to introduce robotics in a non-threatening manner. Many schools use common robotics hardware such as the LEGO Mindstorms NXT or Handy Cricket controller.

Table 4 shows a sample syllabus of how LEGO Mindstorms NXT was used with two different sets of firmware: NXT-G LabView software (a GUI interface) and leJos (an API for robot programming using Java). This curriculum allows students to apply their existing C++ or Java programming skills and gives them the ability to maneuver their robots. The original curriculum covered only LEGO Mindstorms NXT with two different firmware setups (Boonthum, 2009).

This curriculum was later modified to include two different robot controllers (LEGO NXT and Handy Cricket). The Handy Cricket is a microcontroller that allows students to experience building and programming robots, reinforcing some basic electronics skills: soldering and wiring. Although we are computer science focused and want to emphasize software programming, we find it beneficial to provide students with some hands-on experience in putting sensors and motors together, which gives them some familiarity with electronic components related to robotics.

Table 5. Sample Robotics Modules in Artificial Intelligence Course

Week	Topics
1-3	Introduction to AI, Predicate Calculus Structured and strategies for state space search
4	*Introduction to Cognitive Robotics* Heuristics search
5-6	*Behaviors, Events, Motions* *Sounds, Robot Safety*
9-10	AI representational scheme *State Machines*
11-13	Rule-based, case-based, and model-based systems
14-15	Class Project

Robotics Modules in An Existing CS Course

A few ARTSI schools have integrated robotics modules into their existing CS courses. Table 5 shows an example syllabus, where *italicized topics* indicate robotics content. In this curriculum, the Sony AIBO robot with the Tekkotsu framework was used. Student projects could focus on robot programming: some combination of navigation, playing sounds, and constructing robot behaviors as finite state machines.

It is impossible to provide a single robotics curriculum appropriate for all HBCUs. The same robotics topics can be taught using different robot controllers and different programming languages. Our goal is to provide various robotics modules and a basic robotics curriculum, which each HBCU can customize to fit within its CS curriculum and the needs of its students.

Results

TheARTSI Alliance has served over 300 HBCU students (including providing 51 REU internships), 23 HBCU faculty, and over 1,450 K-12 students. In some instances, our numbers have doubled from year 1 to year 3 (5 robotics courses to 11 robotics courses at HBCUs; from 248 to 639 middle and high school students reached). At least 10 ARTSI students have gone on to continue their education in graduate school. Although this number seems insignificant, it is really not when comparing it to the numbers reported by the Taulbee Survey on African Americans pursuing graduate degrees in computer science.

During the 2010 ARTSI conference, an interview with ARTSI students was conducted. Students reported significant mentoring by their ARTSI faculty, especially toward participation in REU. The experience inspired students and gave them confidence. All of students who participated in ARTSI REU plan to continue graduate school. Most students saw the value of deepening their specialty knowledge with a Master's degree, while some considered their path to Ph.D. ARTSI activities also provide opportunity for peer support and mentoring other students in computer science. Many of ARTSI students are active community builders: ACM student clubs, robotics clubs, or even Women in Computing clubs. Students often educate their peers about opportunities that involve computer science and robotics.

In addition to the interview, a survey for Olympiad competition was collected. Students said that the Computer Science Olympiad increased their interest in computer science (71%) and was relevant to their classroom learning and knowledge (84%). Both interview and survey results are significant evidences that HBCU students truly benefited from participation in ARTSI, which inspired them to go to graduate school.

Ten robotics courses have been incorporated into computer science curriculums at HBCUs, where there were none prior to the ARTSI Alliance. With the development of a central repository, the modules being created with be helpful not only to ARTSI schools but also to other schools that have computer science programs and want to incorporate a robotics course into their curriculum.

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