CUR Focus

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Smartphone Sensor Mining Research: Successes and Lessons

Mobile technology is having a tremendous impact on our society, and no one is more aware of this, or more excited by it, than undergraduate students. Mobile computing is also having a dramatic effect on computing, although the advances in mobile computing have still not been fully reflected in most computer-science curricula. Yet an ambitious research program in the Department of Computer and Information Science at Fordham University has thrust undergraduates into the mobile computing arena and enabled them to make original research contributions through the development of innovative smartphone applications. In doing so, these students have gained knowledge about mobile computing, the research process, and what it takes to build high-quality commercial applications.

Wireless Sensor Data Mining Lab

These successes have grown out of the projects undertaken by the Wireless Sensor Data Mining (WISDM) Lab at Fordham, which grew out of an undergraduate honors thesis that demonstrated that a single wireless device, containing an accelerometer sensor, was capable of identifying the physical activity that a user carrying the device was performing (e.g., walking, jogging, standing, etc.). The initial research into *activity recognition* was quite successful and, given the rapidly growing popularity of smartphones, we soon decided to move our research platform to Android smartphones. We collected accelerometer data from these smartphones, manually labeled the data with the activity the user was performing, and then used data-mining methods to build a "predictive activity recognition model." This work, which was published with undergraduate Jennifer R. Kwapisz as its first author (Kwapisz, Weiss and Moore 2010a), is a heavily cited paper in the area of activity recognition.

WISDM students presenting results during a weekly project meeting.

The decision to move our research platform to smartphones led to increased student interest and the rapid expansion of the WISDM Lab, as the number of student researchers grew from three to more than a dozen. Our second research effort involved *biometric identification*, a project in which we demonstrated that data-mining methods could be used to identify a user from a sample of the user's accelerometer data. The initial results allowed researchers to correctly identify any one user from a pool of thirty-six users (Kwapisz, Weiss, and Moore 2010b), and more recent results extend that level of performance to several hundred users. We were also able to identify user characteristics—such as height, weight, and gender—using predictive models induced from the accelerometer data (Weiss and Lockhart 2011). Thus, we were able to show that we can identify a user's activity, identity, and physical characteristics just by having them carry a smartphone in their pocket.

Our initial work was geared primarily toward research and did not include stand-alone smartphone apps. However, we realized that our work was well suited to the burgeoning area of *mobile health monitoring*. Our activity-recognition work could be used to improve people's health by measuring how much, or little, physical activity they engaged in each day. Based on the strength of the existing undergraduate research, a grant proposal, "Cell Phone-Based Activity Monitoring for Telehealth," was submitted to the National Science Foundation's Smart Health and Well-Being program. The proposal was funded in September 2011, receiving $420,000. These funds, supplemented by other funds from our university, enabled undergraduate research in the WISDM Lab to flourish.

With the additional support from the National Science Foundation, our focus shifted to incorporating our research into an easy-to-use smartphone app, which could be employed by a large numbers of users. This necessitated a vast increase in time and effort because of the substantial development effort that was required. My students and I had to build a polished smartphone app and automate our data-mining algorithms so they could be applied, in real time, to data that streamed into our server. We spent two full years on this developmental effort. The resulting app, called *Actitracker,* is now available free from the Google Play store

CUR Sidebar

"Crowdfunding" for Undergraduate Research

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College students, especially those from lower-income families, too often lack the funds to participate in transformative educational experiences such as undergraduate research, international study, and internships. And with declining state funding, there is an increasing need to look to private support to fund students' research projects.

An increasingly popular method of fundraising is through "crowdfunding"—using online platforms to share projects and pool small donations from many people. Several crowdfunding platforms have developed in the past five years, such as Kickstarter.com, Indiegogo.com, and Gofundme.com. They have processed well over a billion dollars annually in donations and contributions. Recently, the platforms Microryza (microryza.com) and Start Up Scholar (startupscholar.org) have developed specifically for users in higher education, including undergraduate researchers. Universities including Florida State University and the University of Washington are beginning to develop arrangements to use these platforms.

Microryza.com is specifically targeted toward funding scientific research by faculty and students. Start Up Scholar has a wider aim, hoping to broaden access to educational experiences by connecting donors directly to college students in need of project funding. Instead of donating to anonymous foundation funds, crowdfunding platforms allow a donor to invest in a particular student's project. The platform advertises these projects to alumni and other potential donors, processes donations, and facilitates student updates and engagement with donors. Donations can be sent to student bank accounts or, if arranged beforehand, to university foundation accounts. Students update donors during the project and share final reflections or products when the research is complete.

In effect, crowdfunding platforms like Start Up Scholar and Microryza advance a new model for funding and alumni engagement for higher education. As crowdfunding expands with in higher education, we have the potential to increase participation in undergraduate research experiences that improve students' lives and society at large.

to anyone who has an Android phone. More information on the app is available from actitracker.com.

Projects with Partners

Our research has received quite a bit of attention, and as a result we are currently engaged in collaborations with several partners. We are working with a company to implement activity recognition for dogs, via a specialized device that clips onto a dog collar (Weiss et al. 2013). This will help a dog owner ensure that his or her dog is receiving sufficient exercise. We are also engaged in a project with the Albert Einstein College of Medicine in which a variation of our smartphone app is used to collect accelerometer data from patients as they walk in a gait lab. The medical practitioners provide us with diagnoses of any gait abnormalities and we then use this data, along with data-mining methods, to generate a predictive model. When completed, this model will then be embedded in a smartphone app so that the app can identify gait abnormalities.

Our last major project involves developing a GPS-based navigation app for a major New York City Zoo. Aside from helping the visitors move around the zoo more efficiently, the app will also aid the zoo staff by providing useful information that can be derived from the GPS traces. For example, we will be able to determine how much time each visitor spends at each exhibit, how different categories of visitors utilize the zoo, and how weather impacts a person's visit. Ultimately, these *visitor analytics* can be used to improve the design of the zoo.

Structure of the WISDM Lab

The WISDM Lab has involved 42 undergraduate researchers since 2009. Of these, fourteen can be considered core researchers—those who have participated in the lab for between two and four years and who work in the lab an average of 15 to 20 hours per week. The majority of these students have also worked in the lab full-time for at least one summer. There are 11 students who have not been quite as involved, but who have participated in the lab for at least six months, consistently attended our weekly meetings, and made contributions to our projects. Several of these students are relatively new to the lab and will eventually be considered core members. Of these 25 students, 18 are male and 7 are female, yielding a much higher ratio of female to male students in our lab than in our department (roughly 10 percent to 15 percent of computer-science majors are female). Four of our female members have received support from the Clare Booth Luce Scholarship fund, which supports women in science and has specific provisions for supporting under-

graduate research, so this may be a factor. Finally, 17 of the 42 students attended our meetings for several months, but never spent a substantial amount of time working in the lab or working on our projects. Our lab also includes six students who have participated solely as master's students.

Benefits for Undergraduates

Undergraduates have received many benefits from participating in the WISDM Lab, including:

- ***A better understanding of the research process and what is involved in research.*** They also learn that undergraduate computer-science students can perform original research and make substantial contributions. Undergraduates have been first authors or coauthors on all eight papers published on WISDM research.
- ***An increased sense of being part of the academic and research community as highly motivated students interact in an environment of their own—our lab.*** Some students have also developed a connection to the larger research and industry communities by participating in workshops and conferences and in collaborations with our research and industry partners.
- ***Reinforcement of academic skills and the development of real-world skills and experiences rarely attained in an academic setting.*** The real-world skills and experiences arise from working on a complex project with many interdependent parts that require collaboration among many people. For computer-science students, this may also involve producing and maintaining thousands of lines of computer code, whereas typical class projects involve at most a few hundred lines of code. At least one recent graduate was hired specifically because of the specialized skills that he acquired in the WISDM Lab.
- ***An increased knowledge of mobile technology.*** This is especially important because this technology has not yet had a big impact on our curriculum or the curricula at many colleges and universities. Many of the lab's undergraduate researchers learn how to program apps for Android smartphones.
- ***Improved writing and communication skills.*** Students write and modify research papers, which are carefully scrutinized by external reviewers. Students also are required to give oral presentations, either within the university (this is required for those who receive direct funding from Fordham) or at international workshops and conferences.
- ***Payment for their services.*** While this benefit is easy to overlook, it can be quite important, especially for those students who need to earn extra money and who would otherwise not be able to participate in research. Undergraduates involved in the WISDM Lab earn on average $12 per hour, and have collectively earned more than $150,000. A complete list of our funding sources is available from http://www.cis.fordham.edu/wisdm/funding.php.
- ***An increased interest in graduate study.*** Over the past two years, five undergraduates from the WISDM Lab have entered our accelerated five-year BS/MS degree program, and another has pursued graduate studies in computer science at another university. The most active members of the lab are especially likely to participate in the accelerated MS program.

Lessons Learned Concerning Undergraduate Research

There are several reasons for the success of the WISDM Lab, and the lessons that can be learned from its success certainly are applicable to other institutions and to other disciplines.

Lesson 1: Pick a research topic that is of great interest to students and will lead to results that are meaningful to students. Before starting the lab, my research group focused on foundational issues related to data mining. This research was important, but from the perspective of a typical student, it was abstract and the results were not something from which they or their peers would immediately benefit. The work done in the WISDM Lab, however, is very different. First, it involves smartphone technology, and students are familiar with and interested in these phones. Second, the research is directly tied to the development of new smartphone-based applications, which students can appreciate and use. Student interest in the topic is a key reason for the success of the lab.

Lesson 2: Pick a research topic that will ensure that students develop useful, real-world skills from which they will benefit even if they choose not to pursue a career in research. One of the reasons that students join the WISDM Lab is that they know that the skills they acquire there will aid them in their future careers. For example, many of the students working in the lab learn how to program mobile applications, which is a very marketable skill as computing continues to migrate from the desktop to mobile devices (smartphones, tablets, etc). In addition, most students also obtain experience in collaborative software development, as they work in teams to develop large pro-

grams. These skills are highly valued by employers and are not commonly acquired by undergraduate students.

Lesson 3: Build an environment that leads to a sense of camaraderie and team identity. Prior to the establishment of the WISDM Lab my research group included no more than three students at a time. With such a small group, it was difficult to form a team identity or exhibit true group dynamics. However, once the research group grew to include five or six students, this changed. Now, with more than a dozen members, our research group has a well-defined identity, and the students have a strong sense of community. The students work well together and assist each other when necessary, with many of the more senior students assuming leadership roles and taking on more responsibility. Having adequate, and dedicated, lab space is also critical to establishing this sense of community.

WISDM students started spending a lot of time working together only after we acquired our own lab. Previously we only had lab space to accommodate two students at a time, but our dedicated WISDM Lab can accommodate a dozen students. Most of the more experienced WISDM members, as noted earlier, spend an average of 15 to 20 hours in the lab each week. This may include some non-research activities, such as homework, but this is encouraged since it further fosters a sense of community. The commitment that the students feel to the lab also leads them to recruit new members, which further advances undergraduate research.

Lesson 4: Institutional support is essential and one should take maximum advantage of any support that is available. Such institutional support for undergraduate research has been critical to the success of the WISDM Lab. Michael Latham, dean of Fordham College at Rose Hill, one of Fordham's undergraduate colleges, has listed undergraduate research as one of his three top priorities for the college and has provided several kinds of support. Over the past few years his office has provided our undergraduate lab members with ten paid Summer Science Research Internships. This summer support is critical because it is the only time that undergraduates can focus exclusively on research. The dean's office has also provided six undergraduate research assistantships to lab members during the academic year, as well as travel funds so that students can present their work at international workshops and conferences. Student members of the lab have received more than $75,000 in direct funding from the undergraduate college. They have also been indirectly funded via three Faculty Research Grants provided by Nancy Busch, Fordham University's chief research officer and dean of the Graduate School of Arts & Sciences. This internal funding was essential in enabling us to subsequently acquire external funding from the National Science Foundation. Institutional support does not have to be monetary, and students have also benefited by receiving academic credit for their research by enrolling in our department's Projects and Internships course.

Challenges for Supporting Undergraduate Research

Despite our successes, it is important for faculty to recognize that there are many challenges associated with fostering and maintaining undergraduate research, even when substantial funding is available. The most significant challenge involves finding adequate faculty time to run a predominately undergraduate research lab. Undergraduates tend to have much steeper learning curves than do graduate students (especially Ph.D. students), and even when they do become productive researchers, their coursework tends to greatly limit the time they have available for research. These factors also tend to limit the research productivity of the faculty members involved. In addition, the faculty members must also balance undergraduate research with their teaching and service responsibilities.

Further compounding the time problem is the fact that supervising undergraduates, at least at institutions that have graduate programs, does not typically yield the same institutional recognition that accrues when faculty supervise graduate students. For example, faculty members at Fordham are allocated credits that can lead to course reductions for supervising master's and Ph.D. theses, and also for serving as readers of graduate theses, but they generally receive no such credit for supervising undergraduate research. Finally, supervising undergraduate research may not officially be acknowledged in tenure, merit, and promotion procedures. All of these considerations can make it difficult to build and sustain undergraduate research, especially at institutions that also offer graduate programs. However, the tide may be turning in this regard, as the value of undergraduate research becomes more recognized.

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