IMPLEMENTING A TRUE UNDERGRADUATE RESEARCH EXPERIMENT

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ABSTRACT

Innovative areas of Computer Science such as artificial intelligence and massive parallel processing are almost becoming extinct. Industry research focuses on very short-term goals that do not allow the freedom of long-term scientific research. Consequently, Computer Science professionals are not motivated to create optimized solutions or to search for more advanced and efficient techniques. This paper describes a research methodology that improves the motivational aspect of participation of undergraduate students in new discoveries. Such methodology is now being applied in a study focused in developing new computer architecture features and supporting theory. This creative experience aims to the preparation of future Computer Science professionals for a more innovative and successful career in the industry or on pursuit of an advanced degree. This paper reports a successful experience in this area, with a promising future, showing how the students were selected, motivated and coached to achieve the research goals.

1. INTRODUCTION

The field of Computer Science is in a constant evolution. New microprocessor technologies are transforming the computational environment in all industry segments. However, this fast movement is bringing back old problems. Operating systems that occupy any free memory available, programming environments that consume high amounts of disk space, poor performance applications, and other slow moving dinosaurs are becoming common market products. At the same time, innovative areas from the past such as artificial intelligence and massive parallel processing are almost becoming extinct. Industry research looks at very short-term goals that do not allow the freedom of scientific research [6]. These are clear symptoms of a low interest of the Computer Science professionals on creating optimized solutions or searching for more advanced and efficient techniques. In this paper we describe a research methodology that improves the motivational aspect of participation of undergraduate students in new discoveries. Such methodology is now being applied to a study focused in developing new computer architecture features and supporting theory. This creative experience aims the preparation of future Computer Science professionals for a more innovative and successful career in industry or in the pursuit of an advanced degree.

The computer industry still considers those with advanced degrees the sole source of research efforts [4]. A brief survey of research grants awarded by the National Science Foundation to institutions proposing some sort of undergraduate research goal shows that most of these projects are focused in educational infrastructure or in practical training [11,
By educational infrastructure one must understand the establishment of laboratories for class support or just the development of new courses. In any of these two cases, the undergraduate student involvement is purely passive as a future beneficiary of the work being done by faculty or graduate students. In the second group of funded projects, those mentioned as practical training experiences, faculty and graduate students conduct the actual research, transferring to the undergraduate students the required experimental tasks. Such tasks usually involve programming, measurements, and simulations, which can be considered activities that do not require any extraordinary creativity but just a reasonable knowledge in their field or the study of existing results [3, 9, 10, 15].

While the current research funding efforts seem not to provide the appropriate environment for active undergraduate research, the job market in Computer Science is in a constant expansion, immediately absorbing the more recent graduates [5]. The lack of basic motivation for future research and the exciting idea of a rewarding job position keeps moving the young students away from graduate programs, reducing the possibilities of new discoveries in an unstoppable cycle. Since it is almost impossible to slow down the job market, our project focuses on the motivational aspect of the undergraduate research. By focusing on the undergraduate motivation, this project also tries to increase the proportion of American citizens entering graduate programs. Such a number has been decreasing in recent years as verified by the National Science Foundation [12]. Recent studies point to the fact that students learn too many concepts and do not experience the practical aspects of their profession [1, 2]. This assumption reinforces the idea that the practical aspects of the curriculum must be emphasized. The result is a set of well elaborated study programs that are supposed to attend the immediate needs of the industry, generating a new batch of computer scientists that are focused on the engineering segment of the field and not in the science. A good example of a successful program following this concept is the research project in robotics reported by Koelzer [7]. However, the theoretical research, which can lead to new discoveries in a long-term effort, is not seen as a productive investment and it is losing its funding sources.

In this paper, we present a first report on a research initiative that focuses on theoretical results, while preparing the students with the “on-the-job” training required by the industry. The motivational aspects of this research are also discussed in order to extrapolate future results. The next section briefly describes the history of the project. Section 3 presents the actual implementation and the tasks assigned to the students, showing also the expected results and the current trends, while Section 4 concludes the paper.

2. BACKGROUND

In the Fall of 1996, an interesting experiment was conducted in a Software Engineering class in order to provide the students with some experience in teamwork while emphasizing the requirement analysis phase of a large software project [14]. Projects were assigned to the students requiring them to read scientific journal articles in order to obtain the basic information on the system to be developed. The creativity and motivation of the students reported in that project was so significant that a decision was made on the inclusion of undergraduate students in a NSF grant proposal. The research topic involved study of loop transformations and parallel processing which comprised the main area of research of the
faculty designated as principal investigators. Such a proposal, entitled “Architecture support and code generation for general nested loops with fine-grain parallelism,” was accepted and awarded US $ 240,000.00 for a 3-years period. This research is motivated by the fact that most of the optimized solutions applicable to multi-dimensional systems such as image processing, geophysical signal processing, and fluid dynamics, require the problem space to be traversed according to a wavefront movement. Existing hardware description languages, as well as general purpose programming languages, focus in row-wise and/or column-wise execution of the problem space. If a wavefront direction is required by the optimized system and it is not parallel to the horizontal or vertical axis of the vector basis defining such a space, then complex transformations on the source code are required in order to emulate the wavefront characteristic. In the proposed study, a compromise between hardware features and compiling techniques is pursued in order to reduce the programming effort required to obtain the optimized performance.

The project consists of two distinct phases aimed to progressively achieve the balance between hardware and software necessary to support the desired optimization. Initially, optimization techniques for uniform loops requiring execution similar to a wavefront processing are analyzed. Such analysis will allow the identification of which new features should be implemented at the programming language level to support the fine grain parallelism. Such new features will provide the necessary information for a new hardware design able to support them.

A potential hazard in pipelined architectures will exist if the loops being investigated contained any conditional branch statement. A second phase of the project will allow the generalization of the problem by including the study of such loops, named conditional loops. Existing studies present solutions for the branch problem by using historical data, execution profiles and even speculative execution of future instructions. More recently, some research has been done in modifying instruction sets and hardware features to try to solve this problem. In those results there was no guarantee of eliminating 100% of the hazard occurrences by correctly anticipating the branch decision. This phase will present new hardware features required to support such a guarantee.

The proposed study is being conducted with an emphasis on preparing undergraduate students for advanced degrees. This goal will be accomplished by requiring the students to focus on theoretical details of the project, elaborating their own conclusions and observations, participating in the implementation of tools and simulators and presenting their partial results in the appropriate conferences. The NSF grant was budgeted in such a way to provide stipend to one graduate and five undergraduate students for a period of three years. Therefore, one might infer that the most significant factor in motivating the students’ participation was the possibility of improving their financial earnings. Moreover, as stated in [8], the future of a doctorate student is not so brilliant (50% of recent graduates surveyed in that study reported working in temporary positions). In the next section, we will show how these factors can be considered meaningless when the students are really motivated for participating in a research project.

3. PROJECT IMPLEMENTATION

After obtaining the NSF award, the first task of the principal investigators (PIs) was to
assemble the future research team. It was important at this point to invite students for an informative meeting, which would allow those interested in the project to understand its objectives and the lack of “industry oriented experience.” The work was to be done towards theoretical research. Some of the invited students were already recipients of some sort of assistantships and were informed that they would need to exchange their current award for the new one in order to avoid accumulative awards. This would make the decision in participating on the project almost independent of a financial decision. The number of work hours associated with the project was limited to ten hours per week, preventing conflicts or significant impact in the students academic performance, while keeping the stipend in a low range such that it could not be looked at as the motivational aspect of the project.

The interest in participating in the project was extraordinary. The six supported students were selected. This selection, initially, focused on juniors who could work in the project for at least two years. Two seniors were also included to provide maturity for the group and a graduate student was selected among recently admitted students for the graduate program. However, the team was not limited to that group of six individuals. Other students volunteered to participate in the project, increasing the team size to four graduate students and eight undergraduates, twice the budgeted numbers. Later, in a departmental decision, a financial award was made to the volunteers as a reward for their interest. This team was divided into 3 major groups: compiler, architecture and simulation, according to the students’ interest and a balanced distribution among the three areas. After the first year, a new adjustment was made. The students supported by the department had their activities redirected towards other goals due to their low involvement in the main research studies. One of them, however, was called to substitute for one of the graduating seniors.

Motivational aspects

In order to give the students a flavor of industry experience, they were also assigned to six service tasks: Unix system administration, Windows NT/95 administration, Latex programming, Web development, Assembler language support, and Windows programming support. Figure 1 shows such a distribution and its relation to the main research areas.

Three faculty members were assigned to conduct the research, each one responsible for one of the three main areas. The most significant and motivational aspect explained to the students was that in a theoretical research nobody knows the answer. This was equivalent to placing them at the same level as the faculty. This approach introduced the student to the real research activity: search for the answer and disseminate the information among their peers. The project focus was to find a solution to a problem that was not described in books. Such a task would require the analysis of a large amount of information before achieving any conclusion. To make the task a little more difficult, the source of such information consists basically of scientific papers published in journals or conference proceedings. Such material is usually considered hard to read and understand in a short time.

The students’ feedback was surprising. During the first three weeks they were submitted to presentation sessions about the fundamentals of the research proposal and assigned to readings that supported those concepts. The number of questions, comments and suggestions made by the students during those three weeks were of exceptional quality. Some of them were able to provide intuitive solutions for the problems described, before knowing
that those solutions were already recently published.

Research meetings

After this first period of adjustment, the students were asked to volunteer to study a specific topic, such as branch prediction techniques, instruction level parallelism and architectural implementation of such concepts. They should later present those concepts to the other elements of the team. Again, the number of volunteers exceeded the number of topics. Three students were selected for reading papers in those areas and making the presentations. Two other students were assigned to participate in a Conference in Computer Design and report the last advances in the field of branch prediction.

The students had two to three weeks to get prepared and they could request any support from the faculty. By their own initiative, the students browsed through books and sometimes they read through five to seven other papers to improve their grasp on the topic. The result was a very participative sequence of meetings with undergraduate students answering faculty questions in a natural, informal manner, with a very good knowledge of the topic. Unfortunately, this is the kind of situation that normally does not occur in a presentation of a homework or class project where the students are more interested in their final grade than in the material they are presenting.

The completion of the first year of research came with a positive balance. Some of the students were able to demonstrate their research potential by submitting and publishing their results in traditional conferences. Half of the group, however, assumed supporting roles, limiting themselves to activities such as program analysis, development and simulations. These students decision did not impact the outcome of the experiment with undergraduate research, since those activities also produced significant results. However, knowing that all of them are looking for an advanced degree as their next step, it is almost certain, that these students working in the supporting roles will experience a slight delay in their adaptation to graduate studies.

Algorithm
The common question at this point becomes how to design an algorithm to implement a successful undergraduate research. Our proposed algorithm is described in the following steps:

1. Make the topic of the project a theoretical one.
2. Propose and if possible obtain an initial funding for the project.
3. Invite a group of good students to participate. Allow other students to join the team.
4. Place the faculty members participating in the project in a double position: supervisors and at the same time researchers with as much knowledge as the students.
5. Present the problem and give everybody a chance for creative solutions and research initiative.
6. In every meeting, remind the students about conference deadlines and the chances of participating in one.

The explanation for such an algorithm is simple. In step one we guarantee that the project will not become just one more programming assignment or homework since the theory is not yet developed. Step two gives soundness to the project: “someone out there has interest in its realization.” If the funding is not granted and the faculty still has interest in conducting the research, then a motivational speech can accomplish the same goal. One may say that without the funding, the stipend will not exist and there will be no interest. This can be partially true, however, at least three of the students working in this research were already working with the PI before there was any positive signal that the award was going to be granted. Also, a second experiment in Software Engineering with two students not involved in the grant project has resulted in one publication. Step three is also easy to explain. Combining good students with motivated or interested ones, the research is guaranteed to survive any difficult obstacle such as a paper rejected in a conference or a group solution that is found in the literature. Step four provides the extra motivation to the students, just like any faculty vs. students’ softball game. Students will perform beyond their class ability to show that they can get an answer before the faculty has a chance. Step five is now in progress. The problem was conceptually developed and needs solution. The students work consisted of doing literature survey, presenting current trends and existing results to their peers, and developing new solutions and algorithms, including implementations when appropriate. Possible alternatives are discussed in the research meetings and new developments bring new challenges. The research team expected to unveil at least one significant contribution in each of the main areas by the end of the first year. The actual result was the publication of nine papers and the expectation of five new ones before the end of the second year.

Finally, step six keeps the students thinking about achieving some deadline, which would allow them to participate in a conference. However, never allow them to assume that such date is a hard deadline. They must have the freedom to work at their own pace and get the results that are really significant before being exposed to critics’ audiences. This paper can not yet report the full success of the method, however it showed the implementation of a true research environment, not just a programming task. In the last 18 months, 7 undergraduate students have participated in the NSF project. Three of them already graduate, two are now enrolled in Ph.D. programs at Notre Dame and Central Florida and the third one is working in
his Master’s Degree. Three others plan to graduate in the Spring of 1999 and have already sent applications for admission to Ph.D. programs. The last one is a junior and will be working in the research for one more year. Three students worked in the Software Engineering research and two of them already graduated and are working towards their Master’s degree.

4. CONCLUSION

The research departments in industry are working with short-term goals and profitable targets. Research funding agencies are following the same trend by being pressured with small budgets and technology transfer requirements. New discoveries are being sidelined by lack of resources or interest. In order to build a new generation of scientists, it is important to submit undergraduate students to real, long range, theoretical research. This experience can provide the students the necessary skills to excel in industry or in advanced studies. The use of short term research and implementation projects do not satisfy the basic condition of inciting the students imagination, abstraction and creativity required in a true research environment. The paper has shown that a good research team can be assembled by putting together students with good academic records and those interested in research. Also, the use of theoretical resources and the challenge of discovering the unknown are high motivational factors for successful undergraduate research. This is an on-going research effort and not all the answers are available, however they will be in a short time frame.

5. REFERENCES


