NSF CAREER: Symbolic-Numeric Constraint-Based Solutions for Real-World Scientific Problems

REPORT for Year 1 (2010) of the project Activities and Findings

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1 Summary of context and expected activities

Numerical constraint solving (NCS) techniques have proven to be efficient to solve real problems ranging from electronic circuit to aircraft design. Yet they are under-utilized. The lack of user support of the solvers can partly explain this, but most importantly NCS techniques have iso- lated themselves into a jargon (constraints) and a schema (propagation/reduction) that disconnect them, respectively, from real problems and real needs (e.g., scalability, flexibility, and distribu- tivity). The goal of this career plan is to make NCS better adapted to real-world needs while making it more accessible. In order to achieve the goal, this project will concentrate on theory and algorithms at the crux of the efficiency, adaptability, and distributivity aspects of problem- solving techniques.

During Year 1 of this project, the following research objective was to be pursued: **RO1: To open NCS to novel techniques, improving scalability**. The research was planned to be oriented towards designing new algorithms that lie between local consistency techniques and global constraints: symbolic-numeric approaches would be studied from the theoretical point of view, and algorithms would be developed and embedded in a new solving toolbox;

As a constant "parallel" thread over the whole duration of the project, the results of the research objectives are planned to be fed into the work carried out to pursue our education objectives: **EO1: to enhance the problem-solving skills** and interest in advanced studies for middle-school to undergraduate students; and **EO2: to enhance the participation of women** and Hispanics in computing.

This document reports the activities and findings of Dr. Ceberio's team during Year 1 of her NSF CAREER project, titled: Symbolic-Numeric Constraint-Based Solutions for Real-World Scientific Problems.

In the rest of this report, we will start by presenting Dr. Ceberio's team over Year 1 in Section 2. The research activities and findings will be reported in Section 3 and we

will draw plans for Year 2. Section 4 reports on the education / outreach activities carried out during Year 1, discusses how they align with the objectives of this project, and presents the forecoming activities planned for Year 2.

2 Presentation of the team working on this project

Over the course of Year 1, several students, at the undergraduate and graduate levels, were involved at different levels of commitment in the project. Only two of them were involved all year. They are listed hereafter:

- George Moreno, undergraduate student: part of the team until July 2010;
- Luis Carlos Gutierrez, undergraduate student: part of the team since March 2010;
- Mario Bencomo, undergraduate student: part of the team in spring and fall semesters;
- Luis Martinez, undergraduate student: part of the team since June 2010;
- Marisol Chacon, undergraduate student: part of the team in September 2010;
- Paden Portillo, undergraduate student (spring) and graduate student (fall): part of the team in spring and fall semesters;
- Xiaojing Wang, graduate student: part of the team all year;
- Shubhra Datta, graduate student: part of the team all year;
- Christian Del Hoyo, graduate student: part of the team since September 2010;
- Jeremy Cummins, undergraduate student / REU student supported by the REU site summer program of Dr. Fuentes at UTEP: part of the team in summer 2010.

3 Research activities and directions

Objective RO1 was pursued during the first year of the project. The team mostly focused on ways to speed up the solving process of constraint problems. We were also interested in and driven by the objective of scaling solvers, making larger problems solvable using interval constraint solving techniques / new techniques for that matter.

We explored different venues to reach this goal.

- Interval arithmetic
- Towards global constraints
- Hybrid solvers

It is to be noted that although our main target was purely about solving constraints, over the course of Year 1, we also considered continuous optimization problems for which we were looking for a global solution. The way we addressed this problem was so close to solving constraints that it made sense, when optimization problems came our way, to address them as well.

Lastly, it is to be mentioned that most of the time spent this year was on training the involved students to the NCS area of research. While the training was mostly successful, it is to be noted that some students had to leave the project and the training could not be completed, and even if it had been, their expertise in the group was lost. The main reason for students to drop out of the team was that they were otherwise overcommitted to jobs or many other courses (often both) and could not attend to all of their commitments.

Hereafter is a summary of our research activities, directions, and findings.

3.1 Interval arithmetic

Our original idea was to address the dependency problem of interval arithmetic. There are several ways of doing so, most of which are symbolic-numeric approaches. In this project, we decided to explore the possibility of using an arithmetic different from the usual one: circular interval arithmetic (as opposed to box interval arithmetic).

We spent a good part of the year studying the practicality of using it and then designed ways of doing it. The major problems we faced were: how to partition the search space? (disks are not as trivial as boxes and will create redundancies or an incomplete search); how to even just evaluate a constraint on a disk? (for now, we kept our research in 2D mostly).

Our work led to some results in how to bisect ellipsoids. This work was first submitted to CoProD'10 (and has been submitted to the post-proceedings issue of Springer's Advances in Soft and Intelligent Computing), and is also part of the student competition conference of the International Test and Evaluation Association.

We believe researching in this direction is promising but might not be integrated directly in constraint solvers as it is. We are going to pursue in 2011 the idea that disks could be used to grasp basin of attractions of optimization problems, hence helping (with additional information) converge faster to minima. This is our claim and we will work on showing it is true or understanding its limitations.

3.2 Towards global constraints

In this project, we aim at exploring and designing global continuous constraints. Our starting point is the idea of breaking away from the locality of reasoning of most traditional constraint solvers.

A reasonable first attempt consisted in looking at linear systems, hoping to be able to extend this to non-linear systems (based on an earlier work of the PI). We were lucky enough that we cam across a tensor decomposition set of constraints that was linear and rectangular. We have been working on this problem since summer 2010 and

making progress in ways to 1) reduce redundancies in an efficient manner (we wrote an article on a modified Fourier Motzkin technique); 2) design appropriate guidance for solvers to tackle such problems (although large).

Directions for work in 2011 include finalizing our corresponding global constraint by integrating it in a solver and benchmarking its effect when compared to a traditional local approach, and quantifying the scalability of this approach.

3.3 Hybrid solvers

In the same attempt as making solvers scalable, we have been working on studying the improvement brought by hybridizing solvers (local/global). We did it in the context of a very specific problem: fuzzy measure extraction in the area of multi-criteria decision making. However, the framework that was developed is flexible enough that we will later be able to apply it to just about any type of continuous constrained optimization.

After solving this problem with a local algorithm only (in this case, the modified Bees algorithm; we wrote an article on our results), we made it interact with a global constraint solver (in this case, RealPaver), and quantify the improvement (we have a journal article almost ready for submission).

Directions for work in 2011 include applying our hybrid solver to software quality assessment (we have started already but will need some time to refine the approach: e.g., determining a reasonable objective function), and studying the scalability of the approach as well as extending our framework to support an adaptive interaction.

3.4 Other topics for 2011

During Year 2 of the project, we will continue working on the above-mentioned topics, but we will also start considering soft constraints. Although we do not expect to make much contribution in this area next year, it is necessary for the team to start getting familiar with this topic. Introducing this new topic to the team will also coincide with the arrival of a new PhD student in the team: she will take over this new topic as the lead and can therefore start studying it while getting adjusted to her new environment (new university, new country: she comes from Morroco).

4 Education and outreach activities

In this section, the major education activities of the PI's team are reported, as well as other major outreach / synergistic activities.

4.1 Education

I seek as much as possible ways to infuse course work or any students' experience with results / topics considered in my research work. This means for instance, and as far as

the first year of this project went, proposing lab/project topics, giving guest lectures, hosting interns.

4.1.1 Course lectures / lab and project topics

In the spring, I was invited to teach constraints in the AI course taught by Tanja Magoc at UTEP. For her course, I also provided her with some AI projects related to constraints and optimization.

In my classes (I usually teach logical foundations of computer science and advanced algorithms), I also provided project topics related to constraints and optimization.

4.1.2 Interventions in high-school classes

One of the educational objectives of this project is to enhance women's and minorities' participation in computing disciplines. The other one is to enhance the problem-solving skills and interest in computing of the next generation of potential computer scientists. To this end, our team and I have been in contact with two schools in particular, with which we are planning to start collaborating: we are working on developing material that would be relevant to the topics taught in class (we are targeting math and science departments). We have already designed small projects, using matlab and scratch, but we are now working more closely with the heads of the departments directly in the schools to be sure to provide material that is completely relevant to the topics taught and that suit the needs of the instructors. We expect to have our first presentation at Loretto Academy by the end of 2010 or early 2011.

4.1.3 Summer research project for high school students

Before summer 2010, as a result of giving an invited lecture to early college high school students at El Paso Community College, I was offered the possibility to propose and coordinate a summer research project for these students. With the help of two of my undergraduate students, we participated in this program, proposed two projects, had two students work on one of them, and they even ranked second in the end-of-summer student project competition.

The experience benefited both the early college high school students as well as my students who were given the opportunity to mentor them.

We are planning on renewing this experience next summer, 2011.

4.1.4 Host for high-school interns

Through our collaboration with Harmony Science Academy, we had the opportunity of hosting two female junior high school students. We made this internship official for the students to get full credit, via the NEXUS program at UTEP. Since summer 2010, these two students have been part of our team.

We were able to teach them some programming (mainly robot-C since both work on robotics projects with us) and some calculus material (for the purpose of the kinematics project of one of the students).

This experience has benefited both the intern students, because they have been exposed to a research environment and have learned a lot, and my students, because they have been thriving as mentors and themselves learning a lot to be ahead of the curve when mentoring the interns. Part of their experience is available online: we gave them access to part of our website: cr2g.constraintsolving.com so that they can report on their activities (and through this, they have also learned how to use a Content Management System, in this case, WordPress).

We expect to be welcoming a new student in spring 2011.

4.1.5 Plans for 2011

Besides what was already mentioned, we plan to better structure the group, as students become more mature, so as to optimize mentoring from interns to PhD students. We also plan to seek the organization of an event that would focus on women in computing. We are thinking about organizing a series of events arount the time of the NCWIT awards for aspirations in computing deadline: we are so far involved in recruiting participants for this award competition and in reviewing applications (as the advisor of the ACM chapter at UTEP, I coordinate these efforts) but we are aiming at some more visible and centralized (across high schools of El Paso) event next year.

4.2 Outreach / synergistic activities

4.2.1 Outreach activities

All year round, we seek opportunities to showcase our work and/or to be present at events that involve younger or broader audience. As a result, this year, we have participated in the following events:

- UTEP's open house in April: we prepared posters to present to prospective students and their family. Part of our posters were also showcasing projects designed especially for high-school students, integrating constraints in a subtle manner, but yet with topics that might seem more appealing to students (posters will be available on the webpage of the project).
- Once a year, we participate in the career fair of an elementary school of El Paso. Such activities do not have a direct impact on the demographics of computing disciplines but we believe that we have to be part of the community and that our presence will eventually have an impact: not documented yet by us though.
- We also take part in judging events, such as robotics events that Harmony Science Academy organizes, or engineering magnet school project evaluations organized by schools like Chapin high school with which we have close contact.

4.2.2 Synergistic activities

The major synergistic activities undertaken by the team are in organizing workshops and conferences, as well as in maintaining a community website, http://constraintsolving.com.

- Conferences: Every year, the team organizes a workshop dedicated to constraint solving and other decision-making techniques (optimization for instance), and their applications. This workshop (see coprod.constraintsolving.com) aims at gathering a community of domain scientists along with researchers who "have solutions" (algorithms and solvers to address the domain scientists' problems). CoProD'08 and '09 were supported by NSF. A proposal is underway to seek funding for CoProD'11.

  Besides CoProD, I also seek opportunities to both contribute to the community and get visibility for my research through the organization and chairing of events. Upcoming is NAFIPS'11, http://nafips.cs.utep.edu, which I co-chair and for which I am also co-program chair. Having events in El Paso is always a way to bring in people and introduce them to my students, which helps my students getting exposed, offers them more opportunities to present their work, and for outside researchers to get to know my lab and work. After NAFIPS, no major such conference is on my list to organize: I would usually prefer not to do this every year as it entails a significant amount of service work.

- Website: constraintsolving.com aims at gathering information about constraints, recent development, solvers, applications. Since it first appeared online, in July 2007, this website has had a little under 20 hits a day, consistently. We keep updating it, both for content and ease of access. A link to the research performed by Dr. Ceberio's team is also available from constraintsolving.com.