Sabbatical Activity Report

Marc Moreno Maza

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Contents

1 Brief CV

1.1 Position

Associate Professor
Department of Computer Science
University of Western Ontario (UWO)

1.2 Contact information

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1.3 Degrees

Degree	**University**	**Department**	**Year**
Doctorate	Paris 6, France	Computer Science	1997
Master's	Paris 6, France	Computer Science	1992
Master's	Paris 6, France	Pure Mathematics	1991
Bachelor's	Paris 6, France	Applied Mathematics	1990

1.4 Employment history

Date	**Rank & Position**	**Department**	**Institution**
2008/09 - date	Visiting Scientist	Computer Science and Artificial Intelligence (CSAIL)	Massachusetts Institute of Technology (MIT)
2008/07 - date	Associate Professor	Computer Science	Univ. of Western Ontario
2003/07- date	Assistant Professor (cross-appointed)	Applied Mathematics	Univ. of Western Ontario
2002/08 - 2008/07	Assistant Professor	Computer Science	Univ. of Western Ontario
2000/09 - date	Maître de Conférences (with tenure)	Computer Science	Univ. of Lille 1, France
1997/07-2002/09	Computational Mathematician	Computational Mathematics Group	NAG, Oxford, UK
1995/09-1997/07	Lecturer	Computer Science	Univ. of Paris 6, France
1992/09-1997/09	Doctoral Student	Computer Science	Univ. of Paris 6, France
1992/09-1997/09	Teaching Assistant	Computer Science	Univ. of Paris 7, France

2 Publications and other scholarly works from July 2008 to June 2009

This section lists my publications, including research articles and software packages, written during my sabbatical leave. Authors of each paper are ordered as they appear on the publication, that is, in alphabetical order, since this is the norm in the area of symbolic computation. Moreover, names of students are in bold.

2.1 Refereed articles

Journal articles:

[**1**] F. Lemaire, ***M. Moreno Maza***, **W. Pan** and Y. Xie. When does $\langle T \rangle$ equal Sat(T)? Submitted to *J. of Symbolic Computation.* (Submitted October 2008.)

[**2**] **X. Li**, ***M. Moreno Maza***, **R. Rasheed** and É. Schost. The Modpn ibrary: Bringing Fast Polynomial Arithmetic into Maple. Submitted to *J. of Symbolic Computation.* (Submitted November 2008.)

[**3**] **C. Chen**, F. Lemaire, **L. Liyun**, ***M. Moreno Maza***, **W. Pan** and Y. Xie. Computing with Constructible Sets in Maple. Submitted to *J. of Symbolic Computation.* (Submitted November 2008.)

Conference articles:

[4] **C. Chen**, ***M. Moreno Maza***, B. Xia, L. Yang. Computing Cylindrical Algebraic Decomposition via Triangular Decomposition. Published in *Proc. of ISSAC 2009*, ACM Press, 8 pages, 2009.

[**5**] **X. Li**, ***M. Moreno Maza***, **W. Pan** Computations modulo regular chains. Published in *Proc. of ISSAC 2009*, ACM Press, 8 pages, 2009.

[**6**] ***M. Moreno Maza***, Y. Xie. Balanced Dense Polynomial Multiplication on Multi-cores. To appear in *Proc. of Parallel and Distributed Computing, Applications and Technologies (PDCAT)*, IEEE Computer Society, 10 pages, 2009.

[**7**] ***M. Moreno Maza***, Y. Xie. FFT-based Dense Polynomial Arithmetic on Multi-cores. Presented at *High Performance Computing Symposium (HPCS) 2009.* (Submitted to the HPCS 2009 post-conference proceedings), 22 pages, 2009.

[**8**] **C. Chen**, J H. Davenport, J. May, ***M. Moreno Maza***, B. Xia, R. Xiao and Y. Xie. User Interface Design for Geometrical Decomposition Algorithms in Maple Published in *Proc. Mathematical User-Interface 2009*, 12 pages, 2009.

[**9**] F. Boulier, **C. Chen**, F. Lemaire, ***M. Moreno Maza***. Real Root Isolation of Regular Chains To be submitted to *Asian Symposium on Computer Mathematics*, 10 pages, 2009.

2.2 Other scholarly or artistic works

2.2.1 Software packages

My software contributions listed below are accessible from the following URLs or shipped within the computer algebra system MAPLE.

[**10**] **X. Li**, ***M. Moreno Maza*** and **W. Pan**. The `Modpn` library. Published in *Maple 13*, Maplesoft, Canada, April 2009.

[11] **X. Li**, ***M. Moreno Maza*** and **W. Pan**. The `FastArithmeticTools` module of the `RegularChains` library. Published in *Maple 13*, Maplesoft, Canada, April 2009.

[12] **C. Chen**, F. Lemaire, ***M. Moreno Maza***, B. Xia, R. Xiao and **Y. Xie**. The `SemiAlgebraicSetTools` module of the `RegularChains` library. Published in *Maple 13*, Maplesoft, Canada, April 2009.

2.2.2 Academic honors

- September 2008: *Visiting Scientist* position at the Massachusetts Institute of Technology (MIT).
- March 2009: *Best Novel Use of Mathematics in Technology Transfer*, MITACS Award, for my PhD students Mr Xin Li and Mr Wei Pan.
- July 2009: *Best Poster Award* at the international Symposium on Symbolic and Algebraic Computation, for the poster *Balanced Dense Polynomial Multiplication on Multi-cores* by Yuzhen and myself.

3 Achievements during sabbatical leave

3.1 Background

My research is in the area of symbolic computation and it is devoted to solving systems of algebraic and differential nonlinear equations. More precisely, I am interested in a class of methods called *triangular decompositions*. They generalize the natural idea of case discussion when solving a system of equations and inequations. I share my efforts among theory, algorithms, implementation and applications.

The results that I have obtained during the lest 6 years indicate that we are close to obtain software solvers, based on triangular decompositions, that can provide high performance computation (HPC). In particular, these new solvers will be able to exploit the computing power offered by the emerging parallel architectures, including symmetric multiprocessing (SMP), graphical processor units (GPU) and multi-cores. The international workshop *PASCO'2007* on Parallel Symbolic Computation that I have organized in July 2007 at UWO has demonstrated the need for developing parallel algorithms and software for achieving high performance in symbolic computation from grids to home computers.

`http://www.orcca.on.ca/conferences/pasco2007/site/index.html`

Matteo Frigo (MIT, CilkArts) was one of the invited speakers of *PASCO'2007*. This turned out to be the beginning of the cooperation between my research group and the one of Charles E. Leiserson (MIT, CilkArts). Prof. Leiserson is well-known for his work on high-performance computing, in particular for his contributions to *multi-threaded parallelism* and *cache-oblivious algorithms*, two subjects that he has in fact formalized before leading the development of recognized software packages such as the `FFTW` library and the `Cilk/Cilk++` concurrency platform. Prof. Leiserson is also famous for his textbook *Introduction to Algorithms*.

My former PhD student, Dr Yuzhen Xie, who owns a NSERC post-doctoral fellowship, has joined the research group of Prof. Leiserson in August 2008. When I was visiting them in September

2009, Prof. Leiserson offered me a *Visiting Scientist* position at MIT, which I accepted. The Computer Science and Artificial Intelligence Laboratory (CSAIL) of MIT is indeed a very attractive place for learning about the latest technologies and developing new collaboration.

The expertise of Prof. Leiserson and his group members, in particular Dr Xie, was a unique opportunity to attack one of the fundamental aspects of polynomial system solving: *high-performance for polynomial arithmetic*. In the last decade, significant efforts have been deployed by different groups of researchers for delivering highly efficient software packages for computing symbolically with polynomials. However, most of these works are dedicated to serial implementation. None of the computer algebra software packages available today offers parallel implementation of asymptotically fast algorithms for polynomial arithmetic. Our goal was then to fill this gap. More precisely, we decided to design and develop what would play the role for polynomial systems that the *Basic Linear Algebra Subroutines* (BLAS) plays for linear systems. Naturally, we call this new project *Basic Polynomial Algebra Subroutines* (BPAS).

3.2 Research results obtained during my sabbatical at MIT

Efficient implementation of algorithms on parallel architectures makes necessary to consider non-standard complexity measures such as *parallel speed-up* and *cache complexity* (memory traffic). Dr Xie and I have analyzed the performances of dense polynomial multiplication, based on multi-dimensional FFT computations, for these complexity measures. We have shown that the best configuration was when the input polynomials are *bivariate* and *balanced*. This latter term means that the partial degrees of their product are equal. Our experimentation study has confirmed this prediction on multi-core architectures and on a large variety of test problems. This is an amazing discovery since many algorithms on polynomial tend to reduce to the univariate case, not to the bivariate one. Our poster presented these results at the *International Symposium on Symbolic and Algebraic Computation (ISSAC) 09* received a *Best Poster Award*.

Figures 1 and 2 give running time and speed-up factor of 4-variate multiplication on unbalanced input computed via balanced bivariate multiplication. On both figures, the black and red curves illustrate the performances of our new and previous approaches, respectively. On Figure 2, “net speed-up” is the total gain from 4-D FFT multiplication to multiplication via balanced bivariate multiplication, that is, from our previous to our new approach. On our test, this net speed-up is 31 on 16 cores, due to the good cache performance of our balanced bivariate multiplication.

Motivated by these theoretical and experimental results, we have shown how multivariate (and univariate!) multiplication could be efficiently reduced to *balanced bivariate multiplication*. In practice, we reach speed-up factors of 15 on 16 cores, for sufficiently large input data. This works is reported in [**6**].

Equipped with this efficient kernel (balanced bivariate multiplication) we have investigated how higher-level algorithms could be developed on top of it. Composing parallel applications is not an easy task due to memory traffic issues. In [**7**] we have shown that parallel normal form computations could in fact greatly benefit from parallel polynomial multiplication. Once again we achieve speed-up factors close to 15 on 16 cores, which improves on previous work in a significant manner.

Today, we have a complete set of arithmetic operations (multiplication, division, normal form computation) for dense multivariate polynomials over finite fields. Our work has gained the interest of other software projects in high-performance scientific computing, namely the `LinBox` (for

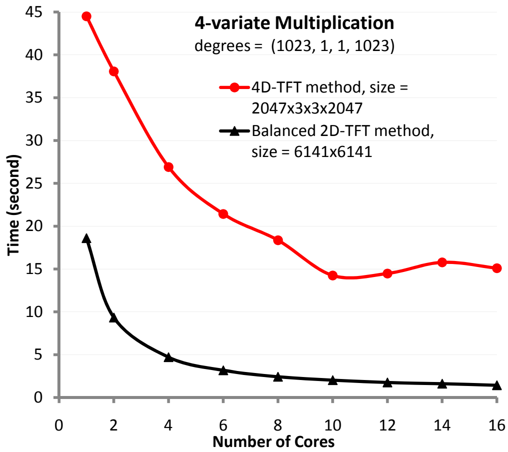

Figure 1: Timing (s) of 4-variate multiplication on unbalanced input via balanced bivariate multiplication.

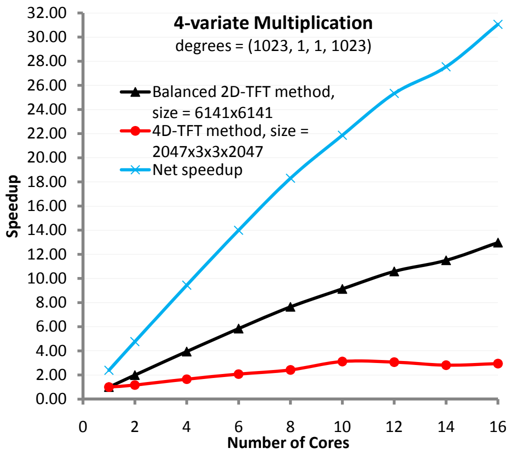

Figure 2: Speed-up factors of 4-variate multiplication on unbalanced input via balanced bivariate multiplication.

symbolic linear algebra) and `SPIRAL` (for Digital Signal Processing). Meetings with the leaders of these projects will take place later this summer.

3.3 Research results obtained with my graduate students

During this academic year at MIT, I visited my graduate students at UWO five times (October, November, January, March, April) for a total period of 9 weeks. They all have made excellent progress on their theses. They form a strong team with three senior graduate students (Xin Li, Wei Pan, Changbo Chen) and new members (Liyun Li, Sardar Haque and Paul Vrbik). Their research projects are complementary and part of the Canada-wide MITACS project *Mathematics for Computer Algebra and Analysis* (MOCAA). Their work leads to mathematical software, most of which is integrated in the computer algebra system MAPLE, distributed by Waterloo Maple Inc. The software packages **[10, 11, 12]** are our contributions to the latest release of MAPLE. This amounts to 36,00 lines of C language code and 70,000 of MAPLE code providing *state of the art* algorithms.

3.3.1 Xin Li and Wei Pan

My PhD student, Xin Li has successfully defended his thesis in April and he is working today at IBM in Toronto. Together with Wei Pan (who is another of my PhD student) Xin Li obtained the 2009 MITACS award

Best Novel Use of Mathematics in Technology Transfer

for integrating [**10, 11**] fast polynomial arithmetic into MAPLE. Xin's thesis is dedicated to implementation techniques and new algorithms for polynomial arithmetic. Wei, Xin and I have solved an important algorithmic problem in [**5**]: We have obtained the first algorithm based on modular techniques and fast arithmetic for computing polynomial GCDs over any tower of simple extensions, including non-separable ones. All previous algorithms assume that extensions are separable. Moreover, our implementation outperforms previous ones by several orders of magnitude.

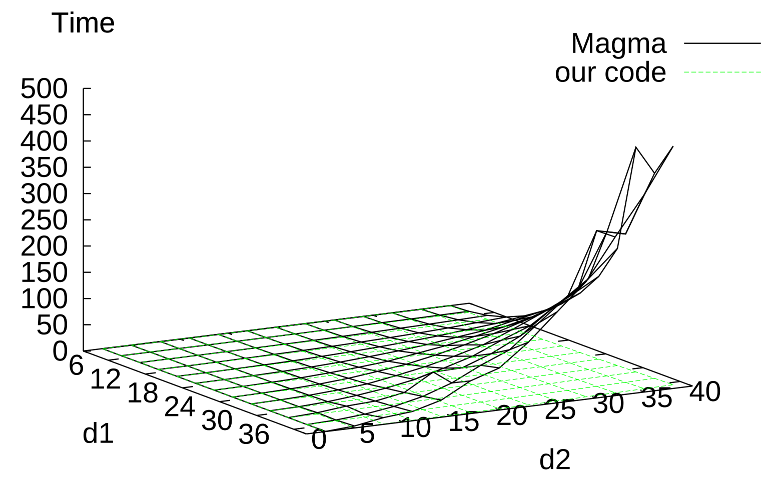

Figure 3: Generic bivariate systems: MAGMA vs. our code.

Figure 3 illustrates the performances of our MODPN library in MAPLE: we consider here the running times for solving systems of bivariate polynomials, on generic input systems with partial degrees d_1 and d_2 and with finite field coefficients. It is clear that, when the input data are large enough, our code outperforms the computer algebra MAGMA (our strongest competitor on such problems).

Today, Wei Pan is adapting our algorithms and code to the hardware acceleration technologies such as GPUs.

3.3.2 Changbo Chen

My PhD student, Mr Changbo Chen, has developed a new approach for computing the real solutions of parametric polynomial systems. One of our motivations in the design is to take advantage of the efficient polynomial arithmetic developed in our research group. This work, reported in [**5**] and extended in [**4**], has gained the interest of Prof. J. H. Davenport (from the University of Bath and currently on sabbatical at the University of Waterloo) who is one of the top experts in the real solutions of parametric polynomial systems. One of the well-known challenges is this subject is how to present the results of such computation to a user, in particular a non-expert one. We have been investigating this question with Prof. Davenport, Dr Xie (MIT), Dr John May (Maplesoft) and my collaborators at Peking University, Prof. Bican Xia and his PhD student, Mr Rong Xiao. Our new approach (based on piece-wise functions and lazy evaluation) has led to [**8**] and will be submitted to the next release of MAPLE.

3.3.3 Liyun Li, Sardar Haque and Paul Vrbik

Liyun Li, Sardar Haque and Paul Vrbik have started their theses during the academic year 2008-2009. Sardar and Paul were awarded at *UWORCS'09* (the annual conference to showcase computer science research at the University of Western Ontario).

Sardar won this year's Biocomputing award which is presented by the Biocomputing Laboratory. The award is in recognition of his research paper proposing an ingenious and novel DNA Computing algorithm for solving the 3-Satisfiability Problem, that avoided an exponential blow-up of the search space.

This summer, Liyun, Sardar, Paul are already engaged in research works part of the MOCAA project. When I am not in London, I have at least one hour (often two) of individual tele-conference with each of my graduate students (Changbo, Wei, Liyun, Sardar, Paul). They also receive support from Prof. François Lemaire (Université de Lille 1) Dr Yuhen Xie and Rong Xiao. Prof. François Lemaire was my post-doctoral fellow in 2003-2004 and he is actively participating in our collaboration with MAPLE (through a French research project). Mr Rong Xiao (Peking University) will become my post-doctoral fellow at UWO starting September 2009.

3.4 Other scholarly activity during my sabbatical

Prof. Jeremy Johnson (team leader of the `SPIRAL` project and I have co-organized a session on *High-Performance Computer Algebra* at *Applications of Computer Algebra (ACA)'09.* This successful meeting will be followed by a special issue of the Journal of Symbolic Computation that Prof. Jeremy Johnson and I will be co-editing.