Anno: 2019 - prot. BIRD192932

Richiesta di finanziamento per Progetto/Assegno di Ricerca

Progetto

1.0 Macroarea di Afferenza del Responsabile Scientifico del Programma di Ricerca
Principal Investigator's macroarea

1 - Matematica, scienze fisiche, dell'informazione e della comunicazione, ingegneria e scienze della Terra

1.1 Area Scientifica del Responsabile Scientifico del Programma di Ricerca
Principal Investigator's scientific area

01 - Scienze Matematiche

1.2 Responsabile Scientifico del Programma di Ricerca
Principal Investigator (PI)

VIANELLO	Marco	M
(Cognome/Surname)	(Nome/Name)	(sesso/gender)
PROFESSORE ASSOCIATO	MAT/08	26/10/1961
(Qualifica/Category)	(Settore Scientifico Disciplinare/ Scientific Disciplinary Sector)	(Data di Nascita/Date of Birth)
VNLMRC61R26L736G		DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM
(Codice fiscale/Tax code)		(Dipartimento/Department)
0498271370	0498271499	marcov@math.unipd.it
(Prefisso e Telefono/ Code and Phone Number)	(Numero Fax)	(Indirizzo di Posta Elettronica/E-mail Address)

Lingua di compilazione del progetto
Language

English

1.3 Area Scientifica del Programma di Ricerca
Scientific area of the research program

Area Scientifica Prevalente /Main scientific Area	**Scienze Matematiche**	(% di afferenza) 100
Area Scientifica/Scientific Area		(% di afferenza)
Area Scientifica/Scientific Area		(% di afferenza)

1.4 Titolo del Programma di Ricerca
Title

Numerical Modelling by Tchakaloff-like Cubature

1.5 Abstract del Programma di Ricerca
Abstract

We have been developing since 2015 numerical techniques for the compression of multivariate discrete measures, based on a discrete version of Tchakaloff Theorem on the existence of positive cubature formulas, that can be proved by Caratheodory Lemma on conical combinations of finite-dimensional vectors. Such a "Tchakaloff-like Cubature Compression", that can be implemented by standard algorithms of Linear or Quadratic Programming, solves a sparsity problem that could not be treated by the most popular Compressed Sensing approaches (l^1-minimization), since by construction the l^1-norm of the weights is constant.
The present research program is aimed at developing some emerging applications of Sparse Approximation by Tchakaloff-like Cubature Compression, for example in the fields of numerical modelling by PDEs (cubature optimization on curved elements within the emerging Virtual Element Method), computational statistics (near-optimal regression designs for geo-spatial analysis), computational optics (numerical ray tracing for optical design with nonstandard pupils arising within Large Synoptic Space Telescope simulations), polynomial optimization (implementation by algebraic cubature of Lasserre's measure-based optimization hierarchies).

1.6 Settori scientifico-disciplinari interessati dal Programma di Ricerca
Scientific Disciplinary Sectors

MAT/08

1.7 Parole chiave
Keywords

1. AREA 01 - Mathematics - Numerical Analysis - Numerical Approximation And Computational Geometry (Primarily Algorithms) - QUADRATURE AND CUBATURE FORMULAS
2. AREA 01 - Mathematics - Numerical Analysis - Partial Differential Equations, Boundary Value Problems - FINITE ELEMENTS, RAYLEIGH-RITZ AND GALERKIN METHODS, FINITE METHODS
3. AREA 01 - Mathematics - Numerical Analysis - Numerical Approximation And Computational Geometry (Primarily Algorithms) - SMOOTHING, CURVE FITTING
4. AREA 01 - MSC - Optics - EXPLICIT MACHINE COMPUTATION AND PROGRAMS

1.8 Curriculum del Responsabile Scientifico del programma di ricerca
Principal Investigator's curriculum

MARCO VIANELLO: SCIENTIFIC CURRICULUM

* Born in Venice on October 26, 1961
* 1st Degree in Mathematics, Univ. of Padova, 1987
* Ph.D. in Computational Mathematics, 1992 (consortium: BO-PD-TS-UD), supervisor Prof. R. Spigler
* INdAM fellowship (1991-1993)
* Ricercatore (Lecturer) of Numerical Analysis at the Faculty of Science, Univ. of Padova (1993-2000)
* Associate Professor of Numerical Analysis at the Dept. of Mathematics of the Univ. of Padova (October 2000-present)
* National scientific qualification (Abilitazione Scientifica Nazionale) as full professor of Numerical Analysis, Dec. 2013-Dec. 2019
* National scientific qualification (Abilitazione Scientifica Nazionale) as full professor of Numerical Analysis, May 2019-May 2025
* personal web page: http://www.math.unipd.it/~marcov

Research results

Author of

* 130 mathematical papers in the fields of:
Multivariate Approximation Theory and Algorithms - Numerical Quadrature and Cubature - Numerical Methods for Differential and Integral Equations - Asymptotic Approximations
with 27 co-authors, published in 57 journals/books
* several software packages

Coordination and supervision activity

* Co-founder of the CAA: Padova-Verona Research Group on Constr. Approx. and Appl. (http://www.math.unipd.it/~marcov/CAA.html)
* Advisor of 3 Ph.D.s in Mathematical Sciences - Univ. of Padova: A. Sommariva 1999, M. Caliari 2002, F. Piazzon 2016
* Supervisor of 4 post-docs: A. Sommariva 2000-2004, A. Martinez 2005-2006, M. Caliari 2006-2007, F. Piazzon 2017-2019
* Coordinator of 14 local annual projects (years 2005-2018, about 3 kEuros and 3 components per year)
* Coordinator of a University Biennial Project (Padova) (2003-2004, funding: 35 kEuro, people: 8)
* Local coordinator of a PRIN 2003 (2004-05, national coord. L. Lopez, Bari; funding: 20 kEuro, people: 4)
* Coordinator of a national INdAM-GNCS project (2012, funding: 5 kEuro, people: 5)
* Scientific Area Committee (2004-2005) and Board of the Doctoral School in Mathematical Sciences (2005-2010 and 2019-) Univ. of Padova
* Organizer of 4 international conferences and 9 workshops on Approximation Theory (Canazei, 2006-2018)
* Managing Editor of the journal Dolomites Res. Notes on Approx., published by Padova Univ. Press and indexed on: ISI, MATHSCINET, SCOPUS

Evaluation activity

* Referee selected by 39 international journals
* Reviewer for the European Commission FP7 Marie Curie program (2012)
* Reviewer for the FWO Research Foundation - Flanders, Belgium (2013-2015)
* Reviewer for the NRDI National Research Office of Hungary (2018)
* Reviewer for the Austrian Science Fund (FWF) (2018)

1.9 Pubblicazioni scientifiche più significative del Responsabile Scientifico del Programma di Ricerca
Principal Investigator's publications

nº	Pubblicazione
1.	Martinez, Angeles, Piazzon, Federico, Sommariva, Alvise, Vianello, Marco (2019). Quadrature-based polynomial optimization. OPTIMIZATION LETTERS, ISSN: 1862-4472, doi: 10.1007/s11590-019-01416-x -Impact Factor 1.013
2.	Sommariva Alvise, Vianello Marco (2018). Nearly optimal nested sensors location for polynomial regression on complex geometries. SAMPLING THEORY IN SIGNAL AND IMAGE PROCESSING, vol. 17, p. 95-101, ISSN: 1530-6429
3.	Sudhakar, Y, SOMMARIVA, ALVISE, VIANELLO, MARCO, Wall, W. A. (2017). On the Use of Compressed Polyhedral Quadrature Formulas in Embedded Interface Methods. SIAM JOURNAL ON SCIENTIFIC COMPUTING, vol. 39, p. 571-587, ISSN: 1064-8275, doi: 10.1137/16M1085206 -Impact Factor 2.046
4.	Gentile M., Sommariva A., Vianello M (2017). Polynomial approximation and quadrature on geographic rectangles. APPLIED MATHEMATICS AND COMPUTATION, vol. 297, p. 159-179, ISSN: 0096-3003, doi: 10.1016/j.amc.2016.08.014 -Impact Factor 2.3
5.	PIAZZON, FEDERICO, SOMMARIVA, ALVISE, VIANELLO, MARCO (2017). Caratheodory-Tchakaloff Subsampling. DOLOMITES

RESEARCH NOTES ON APPROXIMATION, vol. 10, p. 5-14, ISSN: 2035-6803, doi: 10.14658/pupj-drna-2017-1-2

6. Piazzon Federico, Sommariva Alvise, Vianello Marco (2017). Caratheodory-Tchakaloff Least Squares. In: 2017 International Conference on Sampling Theory and Applications (SampTA). p. 672-676, IEEE, ISBN: 978-1-5386-1565-2, Tallinn, Estonia., July 3 - 7, 2017, doi: 10.1109/SAMPTA.2017.8024337

7. VIANELLO, MARCO (2016). Compressed sampling inequalities by Tchakaloff's theorem. MATHEMATICAL INEQUALITIES & APPLICATIONS, vol. 19, p. 395-400, ISSN: 1331-4343, doi: 10.7153/mia-19-31 -Impact Factor .603

8. SOMMARIVA, ALVISE, VIANELLO, MARCO (2015). Compression of multivariate discrete measures and applications. NUMERICAL FUNCTIONAL ANALYSIS AND OPTIMIZATION, vol. 36, p. 1198-1223, ISSN: 0163-0563, doi: 10.1080/01630563.2015.1062394 -Impact Factor .649

9. Da Fies G., Vianello M. (2014). Product Gaussian quadrature on circular lunes. NUMERICAL MATHEMATICS, vol. 7, p. 251-264, ISSN: 1004-8979, doi: 10.4208/nmtma.2014.1319nm -Impact Factor .71

10. Gaspare Da Fies, SOMMARIVA, ALVISE, VIANELLO, MARCO (2013). Algebraic cubature by linear blending of elliptical arcs. APPLIED NUMERICAL MATHEMATICS, vol. 74, p. 49-61, ISSN: 0168-9274, doi: 10.1016/j.apnum.2013.08.003 -Impact Factor 1.036

11. G. Da Fies, M. Vianello (2012). Algebraic cubature on planar lenses and bubbles. DOLOMITES RESEARCH NOTES ON APPROXIMATION, vol. 5, p. 7-12, ISSN: 2035-6803

12. G. Da Fies, M. Vianello (2012). Trigonometric Gaussian quadrature on subintervals of the period. ELECTRONIC TRANSACTIONS ON NUMERICAL ANALYSIS, vol. 39, p. 102-112, ISSN: 1068-9613 -Impact Factor 1.261

13. L. Bos, M. Vianello (2012). Subperiodic trigonometric interpolation and quadrature. APPLIED MATHEMATICS AND COMPUTATION, vol. 218, p. 10630-10638, ISSN: 0096-3003, doi: 10.1016/j.amc.2012.04.024 -Impact Factor 1.349

14. M. GENTILE, A. SOMMARIVA, M. VIANELLO (2011). Polynomial interpolation and cubature over polygons. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 235, p. 5232-5239, ISSN: 0377-0427, doi: 10.1016/j.cam.2011.05.013 -Impact Factor 1.112

15. CALIARI, MARCO, DE MARCHI, STEFANO, SOMMARIVA, ALVISE, VIANELLO, MARCO (2011). Padua2DM: fast interpolation and cubature at the Padua points in Matlab/Octave. NUMERICAL ALGORITHMS, vol. 56, p. 45-60, ISSN: 1017-1398, doi: 10.1007/s11075-010-9373-1 -Impact Factor 1.042

16. SANTIN G, SOMMARIVA A, M. VIANELLO (2011). An algebraic cubature formula on curvilinear polygons. APPLIED MATHEMATICS AND COMPUTATION, vol. 217, p. 10003-10015, ISSN: 0096-3003, doi: 10.1016/j.amc.2011.04.071 -Impact Factor 1.317

17. DE MARCHI S, VIANELLO M., XU Y (2009). New cubature formulae and hyperinterpolation in three variables. BIT, vol. 49, p. 55-73, ISSN: 0006-3835, doi: 10.1007/s10543-009-0210-7 -Impact Factor .648

18. SOMMARIVA A., VIANELLO M (2009). Gauss-Green cubature and moment computation over arbitrary geometries. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 231, p. 886-896, ISSN: 0377-0427, doi: 10.1016/j.cam.2009.05.014 -Impact Factor 1.292

19. SOMMARIVA A., VIANELLO. M, ZANOVELLO R (2008). Nontensorial Clenshaw-Curtis cubature. NUMERICAL ALGORITHMS, vol. 49, p. 409-427, ISSN: 1017-1398, doi: 10.1007/s11075-008-9203-x -Impact Factor .61

20. A. SOMMARIVA, M. VIANELLO (2007). Product Gauss cubature over polygons based on Green's integration formula. BIT, vol. 47, p. 441-453, ISSN: 0006-3835, doi: 10.1007/s10543-007-0131-2 -Impact Factor .695

21. SOMMARIVA A, VIANELLO M. (2006). Numerical cubature on scattered data by radial basis functions. COMPUTING, vol. 76, p. 295-310, ISSN: 0010-485X, doi: 10.1007/s00607-005-0142-2 -Impact Factor .881

22. SOMMARIVA A., VIANELLO M (2006). Meshless cubature by Green's formula. APPLIED MATHEMATICS AND COMPUTATION, vol. 183, p. 1098-1107, ISSN: 0096-3003, doi: 10.1016/j.amc.2006.05.211 -Impact Factor .816

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1.10 Componenti il Gruppo di Ricerca
Research-Unit Participants

1.10.0 Professori e ricercatori anche a tempo determinato dell'Università di Padova
University of Padua Researchers

nº	Cognome	Nome	Dipartimento	Area scientifica di ateneo	Qualifica	Settore	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno	Stato della risposta
1.	MARCUZZI	Fabio	DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM	01 - Mathematics	Ricercatore confermato	MAT/08	6	6	
2.	MARTINEZ	Angeles	DIP. MATEMATICA	01 -	Ricercatore a t.d. -	MAT/08	3	3	

	CALOMARDO		"TULLIO LEVI-CIVITA" - DM	Mathematics	t.pieno (art. 24 c.3-a L. 240/10)				
3.	SOMMARIVA	Alvise	DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM	01 - Mathematics	Professore Associato (L. 240/10)	MAT/08	6	6	
4.	VIANELLO	Marco	DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM	01 - Mathematics	Professore Associato confermato	MAT/08	8	8	

1.10.1 Professori a contratto di cui all'art. 23 della legge 240/2010, altro Personale dell'Università di Padova anche a tempo determinato (personale tecnico-amministrativo, Dirigenti e CEL)
Other University of Padua Staff

nº	Nome	Dipartimento	Qualifica	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno

1.10.2 Titolari di assegni di ricerca dell'Università di Padova
University of Padua Research Grants

nº	Cognome	Nome	Dipartimento	Area scientifica di ateneo	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno
1.	PIAZZON	Federico	DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM	01 - Scienze Matematiche	3	

1.10.3 Studenti di Dottorato di Ricerca dell'Università di Padova
University of Padua Students phD Students

nº	Cognome	Nome	Dipartimento	Area scientifica di ateneo	Qualifica	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno
1.	DESSOLE	Monica	DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM	01 - Scienze Matematiche	Dottorando	3	3
2.	GATTO	Marta	DIP. MATEMATICA "TULLIO LEVI-CIVITA" - DM	01 - Scienze Matematiche	Dottorando	3	3

1.10.4 Professori, ricercatori anche a tempo determinato di altre Università
Other Universities Researchers

nº	Cognome	Nome	Università	Area scientifica di ateneo	Dipartimento	Qualifica	Settore	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno
1.	ARTIOLI	Edoardo	Università degli Studi di ROMA "Tor Vergata"	09 - Ingegneria Civile e Architettura	DIP. Ingegneria Civile e Ingegneria Informatica	Prof. Associato	ICAR/08	3	3
2.	BOS	Leonard Peter	Università degli Studi di VERONA	01 - Scienze Matematiche	DIP. Informatica	Prof. Ordinario	MAT/08	3	3

1.10.5 Dipendenti di altre amministrazioni pubbliche, di enti pubblici o privati, di imprese, di istituzioni straniere, soggetti esterni in possesso di specifiche competenze nel campo della ricerca
Other Personnel

nº	Cognome	Nome	Ente	Qualifica	Mesi/Persona(*) Primo anno	Mesi/Persona(*) Secondo anno
1.	FACCIO	CHIARA	graduate student, University of Padova	MSc in Mathematics	6	6

2.1.0 Pubblicazioni scientifiche più significative dei componenti il gruppo di ricerca (docenti dell'ateneo di Padova)
Relevant publications of the Research Group (University of Padua Researchers)

nº	Pubblicazioni
1.	**MARCUZZI F., MARINETTI S (2008). Efficient reconstruction of corrosion profiles by infrared thermography. JOURNAL OF PHYSICS. CONFERENCE SERIES, vol. 124, p. 1-11, ISSN: 1742-6596, doi: 10.1088/1742-6596/124/1/012033**
2.	**MARCUZZI, FABIO (2009). Space and time localization for the estimation of distributed parametersin a finite element model. COMPUTER METHODS IN APPLIED MECHANICS AND ENGINEERING, vol. 198, p. 3020-3025, ISSN: 0045-7825, doi: 10.1016/j.cma.2009.05.007 Impact factor 1.806**
3.	**DEOLMI G, MARCUZZI, FABIO, MORANDI CECCHI M. (2011). The Best-Approximation Weighted-Residuals Method for the steady convection diffusion reaction problem. MATHEMATICS AND COMPUTERS IN SIMULATION, vol. 82 n.1, p. 144-162, ISSN: 0378-4754, doi: 10.1016/j.matcom.2010.11.009 Impact factor .738**

4.	**MARINETTI S, MARCUZZI F. (2007). Experimental assessment of hidden corrosion profile by FEM processing applied to thermographic data. In: Proceedings of Advanced Infrared Technology and Applications 9. Leon (Mexico), Ottobre 2007**
5.	**MARCUZZI, FABIO, MORANDI CECCHI M, VENTURIN M. (2008). An anisotropic unstructured triangular adaptive mesh algorithm based on error and error gradient information. MATHEMATICS AND COMPUTERS IN SIMULATION, vol. 78, p. 645-652, ISSN: 0378-4754, doi: 10.1016/j.matcom.2008.04.006 Impact factor .93**
6.	**MARCUZZI F., MORANDI CECCHI M (2008). Least squares FEM approximation and subgrid extraction for convection dominated problems. In: -. Proceedings MASCOT 07. IMACS SERIES COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 13, p. 131-140, IMACS Series in Computational and Applied Mathemat, ISSN: 1098-870X, Rome, Italy, Ottobre 2007**
7.	**G. Deolmi, F. Marcuzzi (2013). A parabolic inverse convection-diffusion-reaction problem solved using space-time localization and adaptivity. APPLIED MATHEMATICS AND COMPUTATION, vol. 219, p. 8435-8454, ISSN: 0096-3003, doi: 10.1016/j.amc.2013.02.040 Impact factor 1.6**
8.	**VIRGULIN, MARCO, CASTELLARO, MARCO, MARCUZZI, FABIO, GRISAN, ENRICO (2014). Analytic heuristics for a fast DSC-MRI. In: Proc. SPIE 9034, Medical Imaging 2014: Image Processing, 903424 (March 21, 2014). ISBN: 9780819498274, San Diego, CA, FEB 16-18, 2014, doi: 10.1117/12.2042835**
9.	**Marcuzzi, Fabio (2018). Linear estimation of physical parameters with subsampled and delayed data. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 331, p. 11-22, ISSN: 0377-0427, doi: 10.1016/j.cam.2017.09.036**
10.	**DESSOLE, MONICA, Fabio Marcuzzi (2019). Fully iterative ILU preconditioning of the unsteady Navier-Stokes equations for GPGPU. COMPUTERS & MATHEMATICS WITH APPLICATIONS, vol. 77, p. 907-927, ISSN: 0898-1221, doi: 10.1016/j.camwa.2018.10.037**
11.	**L. Bergamaschi, A. Martínez (2015). Efficiently preconditioned inexact Newton methods for large symmetric eigenvalue problems. OPTIMIZATION METHODS & SOFTWARE, vol. 30, p. 301-322, ISSN: 1055-6788, doi: 10.1080/10556788.2014.908878 Impact factor .841**
12.	**BERGAMASCHI, LUCA, MARTINEZ CALOMARDO, ANGELES (2017). Two-stage spectral preconditioners for iterative eigensolvers. NUMERICAL LINEAR ALGEBRA WITH APPLICATIONS, vol. 24, p. 1-14, ISSN: 1099-1506, doi: 10.1002/nla.2084**
13.	**MARTINEZ CALOMARDO, ANGELES (2016). Tuned preconditioners for the eigensolution of large SPD matrices arising in engineering problems. NUMERICAL LINEAR ALGEBRA WITH APPLICATIONS, vol. 23, p. 427-443, ISSN: 1070-5325, doi: 10.1002/nla.2032 Impact factor 1.303**
14.	**Valentina De Simone, Luca Bergamaschi, Daniela Di Serafino, Angeles Martinez Calomardo (2018). BFGS-like updates of constraint preconditioners for sequences of KKT linear systems in quadratic programming. NUMERICAL LINEAR ALGEBRA WITH APPLICATIONS, vol. 25, p. 1-19, ISSN: 1099-1506, doi: 10.1002/nla.2144**
15.	**Bergamaschi, L., Facca, E., Martínez, Á., Putti, M. (2019). Spectral preconditioners for the efficient numerical solution of a continuous branched transport model. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 354, p. 259-270, ISSN: 0377-0427, doi: 10.1016/j.cam.2018.01.022**
16.	**Bergamaschi, Luca, Martínez, Ángeles (2018). Spectral acceleration of parallel iterative eigensolvers for large scale scientific computing. In: Parallel Computing is Everywhere. ADVANCES IN PARALLEL COMPUTING, vol. 32, p. 107-116, IOS Press BV, ISBN: 9781614998426, ISSN: 0927-5452, doi: 10.3233/978-1-61499-843-3-107**
17.	**De Marchi, S., Martínez, A., PERRACCHIONE, EMMA (2019). Fast and stable rational RBF-based partition of unity interpolation. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 349, p. 331-343, ISSN: 0377-0427, doi: 10.1016/j.cam.2018.07.020**
18.	**Martinez, Angeles, Piazzon, Federico, Sommariva, Alvise, Vianello, Marco (2019). Quadrature-based polynomial optimization. OPTIMIZATION LETTERS, ISSN: 1862-4472, doi: 10.1007/s11590-019-01416-x**
19.	**Carreño, Amanda, Bergamaschi, Luca, Martinez, Angeles, Vidal-Ferrándiz, Antoni, Ginestar, Damian, Verdú, Gumersindo (2019). Block Preconditioning Matrices for the Newton Method to Compute the Dominant ?-Modes Associated with the Neutron Diffusion Equation. MATHEMATICAL AND COMPUTATIONAL APPLICATIONS, vol. 24, p. 1-14, ISSN: 2297-8747, doi: 10.3390/mca24010009**
20.	**M. GENTILE, A. SOMMARIVA, M. VIANELLO (2011). Polynomial interpolation and cubature over polygons. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 235, p. 5232-5239, ISSN: 0377-0427, doi: 10.1016/j.cam.2011.05.013 Impact factor 1.112**
21.	**ATKINSON K, SOMMARIVA A. (2005). Quadrature over the sphere. ELECTRONIC TRANSACTIONS ON NUMERICAL ANALYSIS, vol. 20, p. 104-118, ISSN: 1068-9613**
22.	**SLOAN I.H, SOMMARIVA A. (2008). Approximation on the sphere using radial basis functions plus polynomials. ADVANCES IN COMPUTATIONAL MATHEMATICS, vol. 29, p. 147-177, ISSN: 1019-7168, doi: 10.1007/s10444-007-9048-1 Impact factor 1.148**
23.	**CALIARI, MARCO, DE MARCHI, STEFANO, SOMMARIVA, ALVISE, VIANELLO, MARCO (2011). Padua2DM: fast interpolation and cubature at the Padua points in Matlab/Octave. NUMERICAL ALGORITHMS, vol. 56, p. 45-60, ISSN: 1017-1398, doi: 10.1007/s11075-010-9373-1 Impact factor 1.042**
24.	**SOMMARIVA A., VIANELLO M (2009). Gauss-Green cubature and moment computation over arbitrary geometries. JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS, vol. 231, p. 886-896, ISSN: 0377-0427, doi: 10.1016/j.cam.2009.05.014 Impact factor 1.292**
25.	**Alvise Sommariva (2013). Fast construction of Fejér and Clenshaw-Curtis rules for general weight functions. COMPUTERS & MATHEMATICS WITH APPLICATIONS, vol. 65, p. 682-693, ISSN: 0898-1221, doi: 10.1016/j.camwa.2012.12.004 Impact factor 1.996**
26.	**Gerard Meurant, Alvise Sommariva (2014). Fast variants of the Golub and Welsch algorithm for symmetric weight functions in Matlab.**

	NUMERICAL ALGORITHMS, vol. 67, p. 491-506, ISSN: 1017-1398, doi: 10.1007/s11075-013-9804-x **Impact factor 1.417**
27.	**SOMMARIVA, ALVISE, VIANELLO, MARCO (2015). Compression of multivariate discrete measures and applications. NUMERICAL FUNCTIONAL ANALYSIS AND OPTIMIZATION, vol. 36, p. 1198-1223, ISSN: 0163-0563, doi: 10.1080/01630563.2015.1062394** **Impact factor .649**
28.	**Gentile M., Sommariva A., Vianello M (2017). Polynomial approximation and quadrature on geographic rectangles. APPLIED MATHEMATICS AND COMPUTATION, vol. 297, p. 159-179, ISSN: 0096-3003, doi: 10.1016/j.amc.2016.08.014**
29.	**Sudhakar, Y, SOMMARIVA, ALVISE, VIANELLO, MARCO, Wall, W. A. (2017). On the Use of Compressed Polyhedral Quadrature Formulas in Embedded Interface Methods. SIAM JOURNAL ON SCIENTIFIC COMPUTING, vol. 39, p. 571-587, ISSN: 1064-8275, doi: 10.1137/16M1085206** **Impact factor 2.195**
30.	**S. De Marchi, A. Martínez, E. Perracchione, M. Rossini (2019). RBF-Based Partition of Unity Methods for Elliptic PDEs: Adaptivity and Stability Issues Via Variably Scaled Kernels. JOURNAL OF SCIENTIFIC COMPUTING, vol. 79, p. 321-344, ISSN: 0885-7474, doi: 10.1007/s10915-018-0851-2**

2.1.1 Pubblicazioni scientifiche più significative dei componenti il gruppo di ricerca (altri partecipanti al progetto) Relevant publications of the Research Group (Other participants)

****
EDOARDO ARTIOLI (associate professor, University of Rome 2)

Artioli E, de Miranda S, Lovadina C, Patruno L (2019). An equilibrium-based stress recovery procedure for the VEM. INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGINEERING, vol. 117, p. 885-900, ISSN: 0029-5981, doi: 10.1002/nme.5983.

Artioli E, de Miranda S, Lovadina C, Patruno L (2018). A family of virtual element methods for plane elasticity problems based on the Hellinger-Reissner principle. COMPUTER METHODS IN APPLIED MECHANICS AND ENGINEERING, vol. 340, p. 978-999, ISSN: 0045-7825.

ARTIOLI E (2018). Asymptotic homogenization of fibre-reinforced composites: a virtual element method approach. MECCANICA, vol. 53, p. 1187-1201, ISSN: 1572-9648, doi: https://doi.org/10.1007/s11012-018-0818-2.

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LEN BOS (full professor, University of Verona)

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FEDERICO PIAZZON (post-doc, mathematics, University of Padova)

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Piazzon, F.; Vianello, M. Suboptimal polynomial meshes on planar Lipschitz domains. Numer. Funct. Anal. Optim. 35 (2014), no. 11, 1467-1475.

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MONICA DESSOLE (Ph.D. student in mathematics, University of Padova)

MSc Dissertation: "An hybrid model for solving the variable density incompressible Navier-Stokes equations on GPUs", University of Padova, 2017.

M. Dessole, F. Marcuzzi, Fully iterative ILU preconditioning of the unsteady Navier-Stokes equations for GPGPU, Comput. Math. Appl. 77 (2019), 907-927.

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CHIARA FACCIO (MSc in mathematics, University of Padova)

MSc Dissertation: "Proximal algorithms for nuclear norm system identification", University of Padova, 2019 (http://tesi.cab.unipd.it/62447/1/tesi_chiara_FaccioDef.pdf).

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MARTA GATTO (Ph.D. student in mathematics, University of Padova)

MSc Dissertation: "Numerical methods for discontinuous differential equations and applications to computational termofluid-dynamics", Univ. of Padova, 2015.

M. Gatto, F. Marcuzzi, DLTI model-based denoising of input-output data, 2019, submitted.

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2.2 Curriculum scientifico dei Componenti il Gruppo di Ricerca
Participants' curriculum

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FABIO MARCUZZI

- Laurea degree (MSc) in Electronics Engineering at Padova University, 1991, with a thesis on Adaptive Control of Electromechanical Systems.
- Master in Mathematics and Informatics at Padova University, 1996.
- PhD degree in Computational Mathematics Padova University, 1999, with a thesis on Adaptivity in the Finite Element Method

Now: Assistant Professor of Numerical Analysis at the Department Mathematics, University of Padova.

Partecipant to research projects: MURST Cofin1998, EU project CRAFT-CONTRACT G3ST-CT-2000-50046 "ROLLING" (2001), MURST Cofin2003, "Progetto di Ateneo", University of Padova (2006), MIUR PRIN 2009, "Progetto di Ateneo", University of Padova (2010), "Progetto di Ateneo", University of Padova (2015).

Visiting Researcher at Stanford University (USA) and invited professor at the University of Lille (France).

Scientific coordinator of a research program for graduate students and research grants on inverse problems in industry. In 2006 founded the Laboratory for Numerical Applications at the Department of Mathematics, University of Padova. In 2008 founded a University spin-off. In 2017 and 2018 received fundings from private industries for two doctoral grants.

Author of papers and presentations at international conferences: https://www.research.unipd.it/cris/rp/rp24577#.XM1IKiNab-Y

Has refereed several papers on numerical algorithms, for international conferences and journals.

Has taught courses on Numerical Analysis, Numerical Methods for PDE Problems and Numerical Methods for Data Analysis at the school of Science and at the PhD School of Information Engineering, University of Padova.

Advisor of 50 theses for the laurea (MsC) in Mathematics and in Engineering, and supervisor of four PhD students.

He has patented an algorithm: European Patent 95112646.5-2314 "Improvement in a washing machine with automatic determination of the weight of the washload", 1998 (dept. in 1995).

Homepage: http://www.math.unipd.it/~marcuzzi/

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ANGELES MARTINEZ CALOMARDO

Angeles Martinez Calomardo was born in Villena (Spain) in 1968.
She is married with two children.

She earned an MsC degree in Computer Science at the Politechnical University of Valencia (Spain) in 1993, and PhD in Mathematics at the same university in 1998.

She has been assistant professor at the Department of Mathematics of the Politechnical University of Valencia from 1996 to 1999.

Since September 1999 she lives in Padova.
She is currently research assistant (RTD-A) at the Department of Mathematics of the University of Padova.
From May 31 2019 she will start working at the Dept. of Mathematics and Geosciences of the University of Trieste, where she has won a tenure-track position as RTD-B.

She has had visiting positions at the School of Maths of the University of Edimburgh (UK) and at the Department of Mathematics of the Polytechnical University of Valencia.

Her scientific interests lie in the field of Numerical Linear Algebra and Parallel Scientific computing. More specifically she works on Sparse Matrix Computations, Iterative Methods, Preconditioning Techniques and Parallel Computing. She has worked mostly on iterative methods for sparse linear systems arising from the discretization of PDEs or constrained convex optimization problems solved by the Interior Point Method. In the last years she has started working on approximation of multivariate functions and applications, specifically, on polynomial approximation and optimization and radial basis functions.

She is a member of the GNCS-INDAM research unit.
She has been involved in several research projects and has been the Principal investigator of the ISCRA (Italian Supercomputing Resource Allocation) project PRECISO: Parallel Preconditioners for Iterative Solver.

She has coauthored about 30 papers on international journals and on refereed volumes with several collaborators.

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ALVISE SOMMARIVA

Personal data
* Born in Venice on October 11, 1968
* B.Sc in "Mathematics", 1993, University of Padua
* Ph.D. in "Computational Mathematics", 1999, University of Padua
* Research Fellowship, Univ. of Padua, 1999-2002
* Post-Doc Fellowship, Univ. of Padua, 2002-2004
* Research Associate, Univ. of New South Wales (Australia), 2004-2005
* Assistant Professor in Numerical Analysis, Univ. of Padua, 2006-2014
* Associate Professor in Numerical Analysis, Univ. of Padua, 2014-
* National scientific qualification (Abilitazione Scientifica Nazionale) as full professor of Numerical Analysis, 2018-2024
* Personal web page: http://www.math.unipd.it/~alvise

Referee Activity
Referee selected by 17 international journals

Research results
* Author of 60 papers in Numerical Analysis (Approximation Theory, Numerical Integration and Integral Equations)
* Several software packages

Scientific participation to national and internationals research projects
* Conditioning issues in multivariate approximation and image reconstruction, 24m, coordinator
* Member of 7 national/international projects

Other activities
* Advisor/coadvisor of 26 degree thesis
* PhD jury: 2012, at KU Leuven (B); 2017, at Univ. of Padua
* Member of two research fellowship committees at Univ. of Padua and one at ISMAR, Venice
* Member of Scientific Area Committee, Univ. of Padua, 2019-
* Member of PhD Committee, Univ. of Padua, 2019-
* Member of Padova-Verona research group on Constructive Approximation and Applications
* Member of Research ITalian network on Approximation, 2016-
* Responsible of Numerical Analysis Lab., Univ. of Padua, 2014-2019
* Editor of Dolomites Research Notes on Approximation, 2017-

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EDOARDO ARTIOLI

Edoardo Artioli graduated in Civil Engineering in 2002 from the University of Bologna, where he got his PhD in Structural Mechanics in 2006.
He was postdoctoral researcher at the Institute for Applied Mathematics and Computer Science of the Italian Research Council in Pavia, in 2006/07.
In March 2008, Dr. Artioli joined the faculty of the Department of Civil Engineering and Computer Science at the University of Rome - Tor Vergata where he is associate professor of solid and structural mechanics.

His research activity is in computational mechanics, with special interest on the development of numerical tools for modeling and simulation of nonlinear inelastic structures.
He has developed state update algorithms for nonlinear inelastic constitutive models and nonlinear 3D finite element methods for continua and structures.
Recently, he has been mainly working on the development of innovative virtual element methods (VEM).
He has been PI of the research unit 'Tor Vergata' in the PRIN Project "Advanced modeling of shape memory alloys for civil, industrial and biomedical engineering applications", 2010-12.

He has co-authored 31 papers on international journals, 27 papers in international conferences, and 3 book chapters with international relevance and diffusion.
His teaching activity spans over fifteen years already, starting as a PhD student, at either contract professor level, in Civil Engineering programs at the universities of Bologna, Pavia, and Ferrara.
He now teaches solid mechanics in the Civil Engineering program as well as strength of materials in the Biomedical Engineering program at University of Rome, Tor Vergata.
Edoardo Artioli is on the R&D staff of the research oriented Finite Element Analysis Program - FEAP.
In the past ten years, he has been visiting scholar on various occasions at the Civil Engineering Department of the University of California at Berkeley, where he is currently holds the status of J1-visiting professor.

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LEN BOS

Ph.D. 1981, University of Toronto.
Assistant Professor, University of Calgary, 1982-1987.
Associate Professor, University of Calgary, 1987-1995.
Full Professor, University of Calgary, 1995-2009.
Professore Ordinario, Universita' di Verona, 2009-present. SSD Mat/08.

During the period 1983-present he has published 103 peer reviewed papers, has 6 others accepted for publication and 5 others submitted for publication. On Mathscinet he has 699 citations.

He has also published 9 articles for the Italian highschool magazine Matematicamente, written two book reviews and translated two books (from German into English).

He has supervised 3 Ph.D. students and many undergraduate and masters level theses.

He has frequently been an invited conference/seminar speaker, including 20 times since 2010.

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FEDERICO PIAZZON

Personal info

Birth: May 24th 1981
Current position: Post-doc (12 months), University of Padova, Supervisor: Prof. Marco Vianello.
Previous positions
Post-doc (24 months), University of Padova, Supervisor: Prof. Marco Vianello.
Research fellowship (18 months) NEM Numerical methods for Environmental Modelling, University of Padova, Supervisor: Prof. Mario Putti.

Education

2016 Ph.D degree, Department of Mathematics, University of Padova, Doctoral dissertation: Bernstein Markov Properties and Applications.
Supervisor: Prof. Norm Levenberg (Indiana University, Bloomington).
2012 Master (Laurea Magistrale), University of Padova, thesis: Recent Results in the Theory of Polynomial Weakly Admissible Meshes.
Supervisor: Prof. Marco Vianello, Counter-Supervisor: Prof Len Bos (Verona).
2010 Bachelor (Laurea Triennale), University of Padova, Supervisor: Prof. Marco Vianello.

Research

I am author of 21 papers in the field of multivariate approximation theory.
I attended to several international conferences where I presented my results either by talks, poster-sessions or giving two mini-courses.
In two occasions I was an invited speaker.

Visiting periods

In 2015 I visited Norm Levenberg at Indiana University, Bloomington IN, for one month working on my doctoral dissertation.
In 2014 I spent five months at LATP Universite Aix-Marseille, Marseille FR, working withNorm Levenberg and Frank Wielonsky.

Organizing activities

Organizer of Dolomites Research Week on Approximation, September 2018, Canazei (TN).
Organizer of the conference SPAN2018 (Seminari Padovani di analisi Numerica), 3-4thMay 2018, University of Padova.
Organizer of Dolomites Research Week on Approximation, September 2017, Canazei (TN).

Editorial activities

I have been guest editor of two special issues of Dolomites Research Notes on Approximation.
I reviewed papers for-Journal of Approximation Theory-Computational Methods and Function Theory-Dolomites Research Notes on Approximation.

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MONICA DESSOLE

Research
Ongoing: Ph.D. student in Mathematics at University of Padova
Project: GPU computing for modelling, nonlinear optimization and machine learning.
Keywords: parallel algorithms, numerical linear and multilinear algebra.
Supervisor: Prof. Fabio Marcuzzi

2017-2018: Research Fellow at University of Padova
Project: Massively parallel numerical methods for the iterative solution of time-dependent Navier-Stokes equations, application to dual-fluid flowsimulation in a large range of Reynolds number.
Keywords: variable-density fluids; ILU preconditioning; GPU computing.
Supervisor: Prof. Fabio Marcuzzi
Scientific Director: Prof. Alessandro Beghi

Education
2017: Master's Degree in Mathematics at University of Padova
Thesis: "An hybrid model for solving the variable density incompressible Navier-Stokes equations on GPUs"
Supervisor: Prof. Fabio Marcuzzi
Co-Supervisor: Prof. Caterina Calgaro, Universite' Lille 1

2014: Bachelor's Degree in Mathematics at University of Padova
Thesis "The inverse shortest path problem"
Supervisor: Prof. Marco Di Summa

Abroad experience
Sep 2015 - Jan 2016: ERASMUS+ Programme at Universite' Lille 1 - Sciences et Technologies, Master 2 Calcul Scientifique - UFR de Mathematiques

Publications
[1] M. Dessole, F. Marcuzzi, Fully iterative ILU preconditioning of the unsteady Navier-Stokes equations for GPGPU. Computers & Mathematics with Applications, Volume 77, Issue 4, 2019, Pages 907-927, ISSN 0898-1221, doi:https://doi.org/10.1016/j.camwa.2018.10.037

Teaching and Tutoring
Ongoing: Teaching for "Scientific Computing with Python", Massive Online Open Course on EduOpen Platform at University of Padova
Oct 2017 - Jan 2018: Teaching assistant for "Computer Programming",

Bachelor's Degree in Mathematics at University of Padova, course held by Prof. Fabio Aiolli

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CHIARA FACCIO

Date of birth: 19/07/1993

Education

2019: Master's Degree in Mathematics at the University of Padova, with evaluation 108/110
Thesis: "Proximal algorithms for nuclear norm system identification"
Supervisor: Prof. Fabio Marcuzzi
Abstract: In this thesis, we present four proximal algorithms for the solution of a nuclear norm optimization problem.
Respect to other papers, we solve a more generic version of this problem.
Another contribution is related in particular to the model order selection, in fact, we propose to use the parsimony principle.
Experimentally with this method, we obtain a better fit with a lower model order.

2014: Bachelor's Degree in Mathematics at the University of Padova
Thesis: "Lissajous points for polynomial interpolation on various domains"
Supervisor: Prof. Stefano De Marchi
Abstract: In this thesis, we study the bivariate polynomial interpolation on node sets related to Lissajous curves on the square Q = [-1,1]x[-1,1].
The Lissajous points are the self-intersection and boundary contact of the curve on Q and they depend on a parameter p.
We notice an interesting behavior: they lie on concentric squares and circles. We analyze the distribution of the Lissajous points and curves on different domains and we study the effect of different values of the parameter p on the convergence behavior of polynomial interpolation.

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MARTA GATTO

Marta Gatto graduated in Computational Mathematics in 2015 at the University of Padova with a thesis on "Numerical methods for discontinuous differential equations with applications to computational thermo-fluid dynamics".

In the two following years she worked in the field of mathematical modelling on the development of time varying analytical models for thermo-fluid dynamics, within an FSE project, and as teaching assistant for the course of Computer Programming in Python of the Degree Course in Mathematics.

She is currently a Ph.D. student of the Doctoral School in Computational Mathematics at the University of Padova, under the supervision of Prof. Fabio Marcuzzi. Her scholarship is funded by Electrolux Italia spa, and her research project is entitled "High Performance Calculation for Model Based Design applied to home appliances design".

She collaborated at the creation of the online course "Scientific Computing in Python" on the platform Eduopen.

Her research focuses on Numerical methods for Signals and Systems and on Mathematical System Modelling from Data.

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2.3 Stato dell'Arte: base di partenza scientifica nazionale ed internazionale
State of the Art

Tchakaloff theorem, a cornerstone of quadrature theory, essentially asserts that for every compactly supported measure there exists a positive algebraic quadrature formula with cardinality not exceeding the dimension of the exactness polynomial space. Originally proved by V. Tchakaloff in 1957 for absolutely continuous measures, it has then be extended to any measure with finite polynomial moments, cf. e.g. [4].

The idea of reduction/compression of a finite measure by Tchakaloff theorem recently arose in different contexts, for example in a probabilistic setting [2,7], as well as in univariate [1] and multivariate [5,6] numerical quadrature, with applications to multivariate polynomial inequalities and least squares approximation [3,8]. When the measure is discrete itself (e.g., a cubature formula with a large number of nodes and a positive weight vector u), the problem consists in finding a sparse nonnegative solution w to the

(2.3.1) underdetermined MOMENT SYSTEM: V' w = moms = V' u

where V' is the transposed Vandermonde matrix at the discrete measure support in a chosen polynomial basis, moms the vector of moments of the basis, u and w the original and the sparse weight vector, respectively. Existence of a solution is ensured (even constructively) by the well-known Caratheodory theorem on finite-dimensional conic combinations, applied to the columns of V'. Now, such a proof does not give directly an efficient implementation. Nevertheless, there are at least two reasonably efficient approaches to solve the problem.

The first rests on Quadratic Programming, namely on the classical Lawson-Hanson active-set method for NonNegative Least Squares (NLLS); cf. e.g. [1,3,6]. Indeed, one can solve the quadratic minimum problem (||.|| being the 2-norm)

(2.3.2) NNLS: MIN { ||V' w - moms||^2 , w >= 0 }

by the classical Lawson-Hanson active-set method, which seeks a sparse solution. Then, the nonvanishing components of such a solution determine the compressed formula.

The second approach is based instead on Linear Programming (LP); cf. e.g. [3,5,7]. Namely, one can solve the linear minimum problem

(2.3.3) LP: MIN { c'w , V' w = moms , w >= 0 }

where the constraints identify a polytope (the feasible region) and the vector c is chosen to be linearly independent from the rows of V', so that the objective functional is not constant on the polytope. Observe that in our setting the feasible region is nonempty, since moms = V' u, and we are interested in any basic feasible solution, i.e., in any vertex of the polytope, that has at least ncols(V')?nrows(V') vanishing components. As is well-known, the solution of the LP problem is a vertex of the polytope that can be computed by the Simplex Method; again, the nonvanishing components of such a solution determine the compressed formula.

Our limited numerical experience with moderate size problems (2D instances and low polynomial degrees, say deg<20) has shown that NNLS via Lawson-Hanson algorithm is a robust method, easy to implement by standard Matlab routines and more efficient in these cases than LP.

REFS (very limited due to stringent textlength restrictions)

[1] D. Huybrechs, Stable high-order quadrature rules with equidistant points,J. Comput. Appl. Math. 231 (2009).

[2] C. Litterer, T. Lyons, High order recombination and an application to cubature on Wiener space, Ann. Appl. Probab. 22 (2012).

[3] F. Piazzon, A. Sommariva, M. Vianello, Caratheodory-Tchakaloff Least Squares, SampTA 2017, IEEE Xplore Digital Lib. (2017).

[4] M. Putinar, A note on Tchakaloff's theorem, Proc. Amer. Math. Soc. 125 (1997).

[5] E.K. Ryu, S.P. Boyd, Extensions of Gauss quadrature via linear programming, Found. Comput. Math. 15 (2015).

[6] A. Sommariva, M. Vianello, Compression of multivariate discrete measures and applications, Numer. Funct. Anal. Optim. 36 (2015).

[7] M. Tchernychova, “Caratheodory” cubature measures, Ph.D. dissertat. in Mathematics (superv. T. Lyons), Oxford, 2015.

2.4 Descrizione del Programma di Ricerca
Description of the research program

This biennial project is articulated into 4 main research lines, concerning multidisciplinary applications of the Caratheodory-Tchakaloff cubature compression method described in Section 2.3, to different fields such as numerical modelling by PDEs, optimal regression designs and geo-spatial analysis, computational optics, polynomial optimization. We stress that the bibliography is only indicative and very limited, due to textlength system restrictions.

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Line 1: EFFICIENT CUBATURE METHODS ON CURVED ELEMENTS

The problem of efficient numerical integration over polygons has been object of great interest during the last fifteen years, mainly due to the development and expansion of polygonal/polyhedral finite element models and methods; cf. e.g. [1,8] and the references therein. On the other hand, the case of polygons with possible curved edges has also recently emerged, for example in connection with the VEM (Virtual Element Method), cf. e.g. [2,3,4,5].

In the recent paper [3] we considered a particular situation of interest for the VEM in computational mechanics problems, namely the construction of algebraic cubature formulas, i.e. exact formulas on bivariate polynomials up to a given total degree, with low cardinality on polygonal elements with a circular edge. Convex as well as concave elements of this kind may appear by polygonal discretization, the concave ones typically in the presence of circular holes, and both kinds for example with a fibre-reinforced composite material. The method relies on splitting of the element into "circular" trapezoids, where a Gaussian product-like formula can be obtained by "subperiodic" Gaussian quadrature and blending [6], followed by a compression stage as described in Section 2.3 of the project.

In this project we plan to implement algebraic cubature formulas of PI-type (Positive weights, Interior nodes), that are exact on much more general curvilinear polygons, in view of application to the VEM but also for their independent interest. In principle, all the edges could be curved. The main ideas are the following:
1) representing the boundary by (e.g. cubic) splines;
2) computing the moments of a fixed polynomial basis by Green's formula and exact piecewise Gaussian integration on the spline boundary;
3) computing Tchakaloff-like nodes and positive weights by solving an underdetermined moment system like (2.3.1) in Section 2.3 on a suitable discrete subset (Tchakaloff set).

The key step here, as well as the main difference with respect to the approach sketched in Section 2.3, is that we do not start from a known high-cardinality cubature formula to be compressed, but we rely on the concept of "Tchakaloff sets" (suitably large subsets of everywhere dense sets that support Tchakaloff-like formulas) introduced in the classical but overlooked paper [9].

The approach works for Jordan integration sets, but can be easily adapted to sets with holes. In order to generate Tchakaloff sets (e.g. via domain intersection with sufficiently dense uniform grids), it is essential to implement an efficient "inpolygon" routine for spline curvilinear polygons (the indicator function), by winding or crossing number computation. We stress that the method is similar to that adopted in [7], with the main relevant difference that the resulting cubature formula is here guaranteed to be low-cardinality and Positive Interior.

This section of the project is a collaboration with Edoardo Artioli of the Dept. of Civil Eng. at the Univ. of Rome 2.

REFS

[1] P.F. Antonietti, P. Houston, G. Pennesi, Fast Numerical Integration on Polytopic Meshes with Applications to Discontinuous Galerkin Finite Element Methods, J. Sci. Comput. 77 (2018).

[2] E. Artioli, L. Beirao da Veiga, C. Lovadina, E. Sacco, Arbitrary order 2D virtual elements for polygonal meshes: Part I, elastic problem, Comput. Mech. 60 (2017).

[3] E. Artioli, A. Sommariva, M. Vianello, Algebraic cubature on polygonal elements with a circular edge, preprint, 2019 (www.researchgate.net/profile/Edoardo_Artioli).

[4] L. Beirao da Veiga, F. Brezzi, A. Cangiani, G. Manzini, L.D. Marini, A. Russo, Basic principles of virtual element methods, Math. Models Methods Appl. Sci. 23 (2013).

[5] L. Beirao da Veiga, A. Russo, G. Vacca, The Virtual Element Method with curved edges, ESAIM: Math. Model. Numer. Anal. 53 (2019).

[6] G. Da Fies, A. Sommariva, M. Vianello, Algebraic cubature by linear blending of elliptical arcs, Appl. Num.Math. 74 (2013).

[7] A. Sommariva, M. Vianello, Gauss-Green cubature and moment computation over arbitrary geometries, J. Comput. Appl. Math. 231 (2009).

[8] Y. Sudhakar, A. Sommariva, M. Vianello, W.A. Wall, On the use of compressed polyhedral quadrature formulas in embedded interface methods, SIAM J. Sci. Comput. 39 (2017).

[9] D.R. Wilhelmsen, A nearest point algorithm for convex polyhedral cones and applications to positive linear approximation, Math. Comp. 30 (1976).

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Line 2: NEAR-OPTIMAL REGRESSION DESIGNS

The purpose of this research line of the project is to find efficient algorithms for the computation of near-optimal multivariate sampling sets for polynomial regression. This topic has strong connections with computational statistics and approximation theory. Here, optimality has two aspects to be treated together: cardinality of the sampling set (see [7]), and norm of the least-square regression operator.

We recall that in statistics, a design is a probability measure supported on a continuous or discrete compact set X (the design space). There are several notions of design optimality, we are here mainly interested in G-optimality, that is the Christoffel polynomial (the reproducing kernel diagonal,) has the min max-norm among all designs, which essentially entails that the design minimizes both, the maximum prediction variance by n-th degree regression (statistical interpret.), and the uniform norm of the corresponding weighted least-square operator (approximation theory interpret.). In approximation theory, this is usually called an optimal measure [1].

The min-max problem above is hard to solve, but by the celebrated Kiefer-Wolfowitz equivalence theorem the notion is equivalent to D-optimality, that is the determinant of the Gram-matrix in a fixed polynomial basis is maximum among all designs. The computational literature on D-optimal designs is vast and ramified [6]; a typical approach in the continuous case consists in the discretization of the compact set and then iterative D-optimization over the discrete set. We stress that in the discrete case D-optimization is ultimately a convex programming problem, being equivalent to minimizing -log(det(V'D(w)V)) with the constraints w>=0, sum(w_i)=1 (where V is a Vandermonde-like matrix at X and D(w) the diagonal weight matrix), due to convexity of -log(det( )).

Being interested in G-optimality, a good measure is the so-called G-efficiency (the percentage of G-optimality reached). A possible approach could then be the following (see [2,3] for 2D instances):
1) applying a standard multiplicative algorithm (cf. [6]) to reach a good G-efficiency, say e.g. 90%;

2) computing a Tchakaloff-like compression of the resulting design, keeping the same G-efficiency with a much smaller support.

Since the convergence of standard algorithms is typically sublinear and a huge number of iterations would be needed to concentrate the measure on the optimal support, this approach could give a reasonably efficient method to near-minimize both, the regression operator norm and the regression sampling cardinality. As a relevant application we may quote geo-spatial analysis, where one is interested in reconstructing/modelling a scalar or vector field (such as the magnetic field) on a region with a possibly complex shape, by the placement of a relatively small sensor network.

On the other hand, it would be important to try different methods such as those proposed in [4,5], to speed-up convergence. Indeed, efficient computation of the "real" optimal design support could be extremely interesting from the approximation theory point of view, also by the the fact that optimal designs converge (weakly) to the pluripotential theoretic equilibrium measure of the underlying compact set [1]. This could give a new insight into optimal distributions of points for polynomial fitting and interpolation, which is a substantially open problem even on standard compact sets such as the simplex and the ball.

We stress that this research line is at the computational core of the project. In particular, it might be important to investigate whether parallel/GPU computing could give a substantial acceleration to Tchakaloff-like discrete measure compression on large-scale applications (high polynomial degree and/or 3D and higher-dimensional instances).

In this section of the project we plan to carry on a collaboration with Len Bos of the Dept. of Computer Science at the Univ. of Verona.

REFS

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Line 3: OPTICAL DESIGN WITH NONSTANDARD PUPILS

The role of efficient numerical cubature within optical design was recognized since the seminal paper [5] by Forbes in the '80s, who suggested to adopt product Gaussian quadrature for efficient numerical ray tracing on circular or elliptical apertures (pupils), to compute the Root-Mean-Square (RMS) Spot Size. Significant advancements concerning noncircular pupil configurations arising in optical astronomy were made by Bauman and Xiao in 2010 [2], by means of cubature formulas based on prolate spheroidal wave functions. Nowadays Gaussian-like cubature is adopted within the most popular optical design packages like e.g. Zemax OpticsStudio [7], at least for the most common pupil configurations.

In [2] the authors considered a 3-disks model for a LSST-like (Large Synoptic Survey Telescope [6]) aperture, where the main circular pupil has a large central obscuration (about 60% obscuration by diameter) as well as a considerable vignetting (of up to 10% by area), by two co-axial disks. The same model was then treated in [3] by "subperiodic" trigonometric Gaussian quadrature, via domain splitting into circular sections. Nevertheless, some specific pupil configurations arising in LSST simulations are not effectively treatable by the available optical design tools.

In this section of the project, we consider the problem of computing efficiently the RMS Wavefront Error on a more complex 5-disks model of the LSST pupil. In this model obscuration and vignetting are made by four co-axial disks. The relevant integration region is obtained by intersection with two larger external disks and subtraction of two internal disks. There are several configurations, depending on the mutual position of the co-axial disks centers and on the disk radii [1].

A first approach is being pursued in [1], approximating the disks by regular polygons with hundreds of sides and using the Matlab "polyshape" package to determine the (polygonal) integration region. Cubature is then constructed by triangulation elements and Tchakaloff-like compression of the resulting high-cardinality formula, and numerical test are provided concerning the main classical Zernike aberrations.

Another approach that should be explored is determining the integration region by subtraction of integrals on "lunes" (set difference of disks) and resorting to product Gaussian formulas for circular lunes obtained in [4] by "subperiodic" trigonometric Gaussian quadrature. The final compression stage can be here implemented simply by QR factorization with column pivoting. Though more efficient, this method considered as a unique cubature formula would however present some negative weights and non-interior points (being thus suitable only for simulations and not for physical ray tracing). On the other hand, it is worth observing that the first approach, based on polygonal boundary approximation, can be applied to much more complicated pupil masking configurations of interest in astronomical optics and deserves further development.

This section of the project is a collaboration with Brian Bauman of the Optical Eng. team at LLNL (Lawrence Livermore National Lab. - USA), who is directly involved in the LSST project [6].

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Line 4: CUBATURE-BASED POLYNOMIAL OPTIMIZATION

The description of this research line is brief, since it is in some sense the most challenging where only essentially open problems can be formulated.

In the seminal paper [4], Lasserre proposed a new paradigm for the computation of the minimum of a polynomial on a multidimensional compact set, based on minimizing the expectation with respect to sets of probability measures whose densities are SOS (Sum of Squares) polynomials; see also [3] for a convergence analysis. As recently shown in [2,5], Lasserre measure-based optimization hierarchies can be implemented by discrete minimization at the nodes of positive algebraic cubature formulas, with a sampling cardinality that can be lower than in other grid-based approaches [1,6]. All the vast literature on algebraic cubature becomes in such a way relevant to polynomial optimization, especially "sparse" formulas.

Positivity of the weights, though not known to be necessary, is however essential in the proofs. A first natural question arises, whether positivity could be relaxed in some way, e.g. by cubature formulas that satisfy the Polya-Steklov convergence condition (boundedness of the weights 1-norm). For example, as known sparse-grid cubature typically has some negative weights. On the other hand, when seeking positivity and sparsity at the same time, the main problem is whether Tchakaloff-like cubature could be implemented efficiently in high or at least moderate dimension (for example, on product-like sets by successive tensor-product and compression).

REFS

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2.5 Obiettivo del Programma di Ricerca e, nel caso di assegni di ricerca, indicazione dei risultati attesi dall'attività dell'assegnista/assegnisti previsti alla fine del primo anno e a conclusione della ricerca
Short-term and long-term goals and expected results

This is a multidisciplinary research project, with a new research group.

The project aims at integrating for the first time different complementary competences at the Dept. of Mathematics of the University of Padova: Vianello, Sommariva and the post-doc Piazzon work in multivariate approximation theory and algorithms (especially multivariate polynomial fitting and numerical cubature), Marcuzzi and the graduate students Dessole, Faccio and Gatto work mainly in regression analysis applied to signals and systems and computational inverse problems, with strong competences in GPU programming, Martinez works in numerical linear algebra and numerical optimization and has strong competences in parallel computing. Martinez who is presently Research Assistant (RTD-A) at the Dept. of Mathematics in Padova, from May 31 2019 will start working at the Dept. of Mathematics and Geosciences of the University of Trieste, where she has won a tenure-track position as RTD-B, but will carry on the collaboration with this project.

The interaction of these researchers will concern the computational core of the project, that is the study and implementation of effective large-scale optimization algorithms (possibly on GPUs), for the computation of near-optimal cubature formulas and regression designs on multivariate domains with various geometries, with a broad application spectrum including computational mechanics, geo-spatial analysis, optical design.

There is an external collaboration with Bos (Verona), a leading expert in multivariate approximation theory, who has been already working for many years with some of the participants within the Padova-Verona Research Group on Constructive Approximation and Applications (https://www.math.unipd.it/~marcov/CAA.html).

The other two external collaborations concern the application core of the project. The collaboration with Artioli (Civil Engineering, Rome 2) will concentrate on numerical modelling and computational mechanics by the VEM method, where we plan to implement efficient algebraic cubature formulas on curvilinear polygonal elements. The collaboration with Bauman (Optical Engineering team, Lawrence Livermore National Lab. - USA) will concentrate on optical design applied to astronomical adaptive optics, in particular on the implementation of efficient cubature methods for the computation of the RMSWE (Root-Mean-Square Wavefront Error) on obscured and vignetted pupils, a problem arising within simulations for the LSST (Large Synoptic Space Telescope).

One of the main goals of the project is the implementation of the methods by the production of numerical software made available to the interested communities (numerical modelling by PDEs, computational statistics, optical design, numerical optimization). In particular, we plan to write codes for the computation of near-optimal regression designs on 2D and 3D regions, for the construction of Positive Interior algebraic cubature formulas with low cardinality on curvilinear polygonal elements, for the efficient computation of the RMSWE on nonstandard pupils of interest within the Large Synoptic Space Telescope project.

2.6 Elementi e modalità per la valutazione dei risultati finali
Criteria for final evaluation

Besides traditional evaluation elements of the research results, such as presentation at international workshops/conferences and publication in specialized journals or conference proceedings, an essential role will be played in this project by the implementation and dissemination/publication of numerical codes and packages in online repositories devoted e.g. to computational statistics and computational physics/optics, or general purpose collections of numerical software like the Netlib.

2.7 Informazioni aggiuntive
More informations

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3.0 Costo del Programma
Program Cost
3.1 Assegni di ricerca da attivare in questo Programma di Ricerca
Research Grants

nº	Attività specifica nel progetto e competenze	Durata complessiva (mesi)	Costo complessivo assegno (1) (euro)	Quota cofin disponibile (2) (max 50%)	Tipologia dei fondi utilizzati a cofin (3)	Quota cofin chiesta al dipartimento
	TOTALE		**0.000**	**0.000**		**0.000**

3.2 Richiesta di attrezzature di importo superiore a 5.000 Euro
Equipments (> Eur 5.000)

n°	Descrizione attrezzatura da acquistare	Costo previsto (euro)
	TOTALE	0.000

3.3 Eventuale cofinanziamento del progetto

n°		Tipologia dei fondi utilizzati a cofin	Quota cofin disponibile
1.	Cofinanziamento del progetto		0
	TOTALE		0

3.4 Costo complessivo del Programma di Ricerca
Overall budget and breakdown of costs

	Descrizione	Costo complessivo assegno [(1)] (euro)
Materiale inventariabile/Durables		
Materiale di consumo e funzionamento/ Consumables/Running costs		
Congressi e missioni/ Conferences and University business trips	Missions (workshops, conferences, schools, visiting periods) of the local participants. Reciprocal visits with the non-local participants.	18.000
Servizi esterni/External services		
Assegni di ricerca/Research Grants	(vedi punto 3.1)	
Attrezzature scientifiche di importo superiore a 5.000 Euro / Equipments (> EUR 5000)	(vedi punto 3.2)	
TOTALE		**18.000**

Dichiarazione / Declaration

Il presente progetto NON prevede sperimentazione animale

Il Responsabile della Ricerca: ....

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