Eurographics Course Proposal

1 Title of the Course

An Introduction to Optimization Techniques in Computer Graphics

2 Presenters

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3 Format

We propose to hold a half-day course (180 min). After the conference, a course website will make the materials available to a wider audience.

4 Motivation and Definition of Scope

Background Many students in Computer Science do not have a sufficient background in applied mathematics to employ state-of-the-art optimization techniques and to judge the outcome of such techniques critically (e.g. regarding the stability/quality/accuracy of their output). At the same time, the use of optimization techniques in computer graphics is becoming ubiquitous.

Treating optimization algorithms as a black box yields sub-optimal results at best. At worst, stability issues and convergence problems may prevent the solution of a problem or impede the general application of a method to a wide range of input, i.e. beyond the set of examples shown in a paper. The course will draw attention to these aspects and to current best practices. This will enable participants to judge articles that use optimization schemes critically and improve their own skill set.

Scope and Intended Audience For this purpose, we propose an introductory course on optimization techniques in computer graphics. We aim at thoroughly covering the basic techniques in optimization, only requiring a good working knowledge of the mathematical foundations in a standard CS curriculum, in particular, multi-dimensional analysis and linear algebra. Part of the course will be suitable for a starting PhD student. On the other end, our goal is to lead up to current research including modern ideas such as compressed sensing, convex variational formulations, and sparsity-inducing norms. We aim at exposing the major underlying ideas, exposing the working principles and giving hints for a successful implementation. The course thus also caters to the experienced researcher that seeks to utilize these modern techniques.

We approach these goals by discussing a mixture of classic and more modern optimization approaches. Each section is presented by an expert in the area. Further, each section is comprised of two major parts: 1.) a condensed introduction of the necessary background and 2.) its application in particular graphics problems. We aim at giving implementation hints and the exposure of current-best-practices.

Dissemination of Materials We will set up a course web page where associated material will be available after the conference.

5 Intended Structure

This section outlines the topics and general the structure of the course. Each section

1. Introduction (Ivo Ihrke (5 min))

    - Motivation and Overview

2. Least Squares Fitting in Finite-Dimensional Vector Spaces (Xavier Granier - 35 min)

   - linear least squares
     - the normal equations
     - sum-of-basis-functions approximation
   - non-linear least squares
     - gradient descent
     - Newton-Raphson method
     - Levenberg-Marquardt method
   - constrained optimization
     - soft constraints: the modified objective function
     - hard constraints: Lagrange multipliers
   - robust optimization
     - sampling-based techniques (e.g. RANSAC)
     - robust norms (e.g. M-estimators, L_1, ...)
   - estimation variance and bias
   - Applications
     - curve fitting
     - fitting of scattering profiles (BRDF/BTDF)
     - rational function fitting for specular BRDFs

3. Numerical Linear Algebra with Applications in Geometry Processing (Gaël Guennebaud - 35 min)

   - A zoo of linear solvers: which one shall I use? (20 min)
     - Why you should never invert a matrix?
     - Dense problems: being smarter than the black-box backslash and SVD
       - many small problems (never say never)
       - few but large problems
     - Sparse problems
       - direct methods (ordering and pre-factorization)
       - iterative methods (preconditioning)
       - how to get the best of each?
     - GPU or not GPU?
     - Symmetry: why shall I care?
       - example: linear equality constraints
     - Still lost: online-benchmarking
   - Optimization Techniques on Surfaces (15 min)

  - Laplacian operator on meshes
    * Polyharmonic interpolation
    * Going higher order with non-conformal elements
  - Linear least squares with quadratic constraints
    * algebraic distances and unsigned fields
    * generalized eigenvalues
  - Application examples of non-linear methods
    * deformation
    * mappings

4. Inverse Problems (Ivo Ihrke)

   - What is an Inverse Problem ?
     - examples deconvolution and tomography
   - conditioning, ill-posedness and well-posedness
     - condition number
     - the null-space vs. the numerical null-space
   - introduction to regularization
     - data fit vs. prior knowledge
     - the regularized normal equations
     - how to encode prior knowledge ?
     - how to choose the regularization parameter (automatically) ?
   - numerical solution
     - link to sparse matrices and iterative solvers (see Gaël Guennebaud)
     - operator implementation of iterative solvers
     - the linear operator, its adjoint, and their interpretation
     - GPU implementations
   - Applications
     - tomographic view synthesis for glasses-free displays
     - tomographic measurement of fluid flows
     - coded aperture deblurring / aperture shaping to improve conditioning

5. Variational Methods (Bastian Goldlücke - 35 min)

   - Introduction to Variational Methods
     - the continuous world view - why is it beneficial ?
     - variational models, priors, regularizers and data terms
     - convex vs. non-convex
   - Applications and Classes of Functionals

  - Bayesian modeling, MAP estimate and image processing (denoising, inpainting, deblurring ...)
  - Matching problems (stereo, flow)
  - Discrete labeling (segmentation), functional lifting and global optimality
- Optimization
  - Notes on operator discretization
  - Differentiable functionals, explicit and implicit descent
  - Convex functionals, subgradient descent
  - Some state-of-the-art methods (Bregman, FISTA, Chambolle-Pock)

6. Compressive sensing, or how to sample data from what you know! (Laurent Jacques - 35 min)

- General Introduction to Compressive Sensing (15 min):
  - Low complexity models for general data representation
    * sparsity in bases and dictionaries
    * lowrank data models for high dimensional geometries
  - Incoherent sensing and nonadaptive sensing through randomness
  - Nonlinear data reconstruction procedures in a nutshell:
    * global optimization and local greedy methods
    * stability and sensing requirements.
  - CS, what is it good for?
    * pushing the analog frontiers
    * very high dimensional data sensing
- Compressive Imaging Applications (15 min):
  - Compressive imaging appetizer: Rice single pixel camera
  - A few advanced case studies:
    * Radiointerferometry and aperture synthesis
    * Hyperspectral imaging and CASSI systems
    * Compressive Lightfield imaging
    * Coded Strobing Photography for Highspeed imaging
- Conclusions and further readings (5 min)

6 Authors' Biographical Sketches

Ivo Ihrke is a permanent researcher at Inria Bordeaux Sud-Ouest where he leads the research group "Generalized Image Acquisition and Analysis" which is supported by an Emmy-Noether fellowship of the German Research Foundation (DFG). Prior to that he was heading a research group within the Cluster of Excellence "Multimodal Computing and Interaction" at Saarland University. He was an Associate Senior Researcher at the MPI Informatik, and associated with the Max-Planck Center for Visual Computing and Communications. Before joining Saarland University he was a postdoctoral research fellow at the University of British Columbia, Vancouver, Canada, supported by the Alexander von Humboldt-Foundation. He received a MS degree in Scientific Computing from the Royal Institute of Technology (KTH), Stockholm, Sweden (2002) and a PhD (summa cum laude) in Computer Science from Saarland University (2007). His main research interest are the modeling of forward and inverse light transport processes and computational algorithms for solving these large scale problems in the context of computational imaging, measurement, and display.

Experience and Expertise
Ivo's early education is in Scientific Computing with a strong emphasis on numerical linear algebra, iterative sparse solvers, PDE discretization, stability conditions, etc. During his PhD studies he has extensively applied his knowledge, introducing tomographic methods to the computer graphics literature. He has since refined his methods, in particular regarding operator implementations of linear system solvers and the properties of different regularizers.
He has been teaching on these and related topics since 2007.

Most Relevant Papers

Ivo Ihrke and Marcus Magnor: "Image-Based Tomographic Reconstruction of Flames". Proc. of SCA (2004), 367–375

Ivo Ihrke and Marcus Magnor: "Adaptive Grid Optical Tomography". Graphical Models 68 (2006), 484–495

Bradley Atcheson,Ivo Ihrke, Wolfgang Heidrich, Art Tevs, Derek Bradley, Marcus Magnor, and Hans-Peter Seidel. "Time-Resolved 3D Capture of Non-Stationary Gas Flows". ACM Transactions on Graphics (TOG), 27(5), 132 (2008)

Oliver Klehm, Ivo Ihrke, Hans-Peter Seidel, and Elmar Eisemann, "Volume Stylizer: Tomography-based Volume Painting", Proc. I3D, pp. 161–168, 2013

Xavier Granier is head of the manao team at INRIA and professor at the Institut d'Optique Graduate School. His main research background is realistic rendering and global illumination. He has extended his interest from rendering to acquisition and modeling of material properties and light sources (at University of British Columbia - Vancouver - Canada), sketching interactions (with Zheijiang University - Hangzhou - China) and expressive rendering (previously called non-photorealistic rendering). Currently, the main focus of his research is the accurate simulation of optical phenomena and the creation of new technologies that combine the strengths of optics and computer graphics.

Experience and Expertise
Xavier has a background in applied mathematics. In his research career, he has applied this knowledge mostly to global illumination problems, but also to data acquisition, in particular light source measurements performed in basis expansions and reflectance modeling by rational BRDF fitting.
He is teaching at the Institute d'Optique where he is creating (amongst other courses) a background course on numerical techniques for optics students.

Most Relevant Papers

Michael Goesele, Xavier Granier, Wolfgang Heidrich, and Hans-Peter Seidel. 2003. "Accurate light source acquisition and rendering". In ACM SIGGRAPH 2003 Papers (SIGGRAPH '03)

Xavier Granier and Wolfgang Heidrich, "A simple layered RGB BRDF model", Graphical Models, Volume 65, Issue 4, 2003, Pages 171–184

Romain Pacanowski, Oliver Salazar Celis, Christophe Schlick, Xavier Granier, Pierre Poulin, and Annie Cuyt, "Rational BRDF," Visualization and Computer Graphics, IEEE Transactions on , vol.18, no.11, pp. 1824–1835, Nov. 2012

Gaël Guennebaud is a permanent researcher at Inria Bordeaux since 2008. Before that, he obtained an ERCIM fellowship to work as a post-doctoral research associate at the Computer Graphics Laboratory of ETH-Zurich with Prof. Markus Gross and at the Visual Computing Lab of CNR Pisa, working with Prof. Roberto Scopigno. He obtained a MS degree and PhD in Computer Science from the University Paul Sabatier and the Research Institute for Computer Science of Toulouse (France).
His main research interest include both real-time rendering and geometry processing in general, and surface reconstruction, point-based graphics, complex appearance, and soft-shadows rendering in particular.

Experience and Expertise
Gaël's background is in geometry processing techniques. He is founder and main developer of the Eigen linear algebra library and involved in the development of MeshLab. He has extensive experience in optimization techniques applied to geometry processing.
He is regulary teaching on these and related aspects in the department of Computer Science/Bordeaux University and at the Institute d'Optique.

Most Relevant Papers

Simon Boye, Pascal Barla, Gael Guennebaud. "A Vectorial Solver for Free-form Vector Gradient". In ACM Transaction on Graphics (Siggraph Asia 2012).
Cengiz Oztireli, Gaël Guennebaud, Markus Gross. "Feature Preserving Point Set Surfaces based on Non-Linear Kernel Regression." In Computer Graphics Forum (Eurographics 2009).
Gaël Guennebaud, Markus Gross. "Algebraic Point Set Surfaces". Siggraph 2007
Jiazhou Chen, Gael Guennebaud, Pascal Barla, Xavier Granier. "Non-oriented MLS Gradient Fields". Computer Graphics Forum 2013.

Laurent Jacques received the B.Sc. in Physics, the M.Sc. in Mathematical Physics and the PhD in Mathematical Physics from the Université catholique de Louvain (UCL), Belgium. He was a Postdoctoral Researcher with the Communications and Remote Sensing Laboratory of UCL in 2005–2006. He obtained in Oct. 2006 a four-year (3+1) Postdoctoral funding from the Belgian FRS-FNRS in the same lab. He was a visiting Postdoctoral Researcher, in spring 2007, at Rice University (DSP/ECE, Houston, TX, USA), and from Sep. 2007 to Jul. 2009, at the Swiss Federal Institute of Technology (LTS2/EPFL, Switzerland). Formerly funded by Belgian Science Policy (Return Grant, BELSPO, 2010-2011), and as a F.R.S.-FNRS Scientific Research Worker (2011-2012) in the ICTEAM institute of UCL, he is a FNRS Research Associate since Oct. 2012. His research focuses on Sparse Representations of signals (1-D, 2-D, sphere), Compressed Sensing theory (reconstruction, quantization) and applications, Inverse Problems in general, and Computer Vision. Since 1999, Laurent Jacques has co-authored 20 papers in international journals, 38 conference proceedings and presentations in signal and image processing conferences, and three book chapters.

Experience and Expertise
During his PhD studies, Laurent Jacques' initial interests were focused on processing methods for 1D, 2D, and spherical data, e.g., using specialized wavelet transforms and greedy signal decomposition methods. Later, from 2004 and during two postdoctoral stays (at Rice University, USA, and at EPFL, Switzerland), he specialized in Compressed Sensing (CS) theory and in its application to imaging sciences. Since 2012, Laurent is professor and FNRS Research Associate at UCLouvain (Belgium) and his main research covers:

- sparse and low-rank data models for general inverse problem solving (e.g., tomographic problems, data restoration techniques)
- quantization of compressive measurements, e.g., targeting extreme 1bit or high rate quantization for reconstruction of general signals
- direct applications of the CS paradigm, e.g., in optics for hyper-spectral and light-field imaging.

Most Relevant Papers

L. Jacques, J. N. Laska, P. T. Boufounos, and R. G. Baraniuk, "Robust 1Bit Compressive Sensing via Binary Stable Embeddings of Sparse Vectors" IEEE Transactions on Information Theory, Vol. 59(4), pp. 2082–2102, 2013.

L. Jacques, P. Vandergheynst, A. Bibet, V. Majidzadeh, A. Schmid, and Y. Leblebici. "CMOS Compressed Imaging by Random Convolution" Proc. of ICASSP'09, pp. 1113–1116, 2009, Taipei, Taiwan.

L. Jacques, D. K Hammond, J. M. Fadili, "Dequantizing compressed sensing: When oversampling and nongaussian constraints combine", IEEE Transactions on Information Theory, Vol. 57(1), pp. 559–571, 2011.

Y. Wiaux, L. Jacques, G. Puy, A. M. M. Scaife, P. Vandergheynst, "Compressed sensing imaging techniques for radio interferometry", Monthly Notices of the Royal Astronomical Society 395 (3), 1733–1742

Bastian Goldluecke received a PhD on “Multi-Camera Reconstruction and Rendering for Free-viewpoint Video” from the MPI for computer science in Saarbruecken in 2005. Subsequently, he held PostDoc positions at the University of Bonn and TU Munich, where he worked on variational methods and convex optimization techniques, in particular for high-accuracy geometry and texture reconstruction. In 2012, he joined the Heidelberg Collaboratory for Image Processing as an assistant professor and head of the junior research group Variational Light Field Analysis. In 2013, he was awarded an ERC Starting Grant on the topic of “Light Field Imaging and Analysis”.

Experience and Expertise

Bastian has a background in mathematics and computer science. During his PhD studies he concentrated on minimal surface problems for multi-view reconstruction, in particular on level set methods for their solution. He has since moved to convex variational optimization techniques to avoid the commonly occurring local minima that riddled previous techniques. Bastian develops and maintains a popular open source library (cocolib) for GPU-based optimization methods for variational inverse and multi-label problems. He is regularly teaching on these subjects since 2010 and has given tutorials at ECCV 2010 and ICCV 2011.

Most Relevant Papers

B. Goldluecke, I. Ihrke, C. Linz and M. Magnor, “Weighted Minimal Hypersurface Reconstruction”, IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 29(7), pp. 1194–1208, 2007.

B. Goldluecke, E. Strekalovskiy and D. Cremers, “The Natural Vectorial Total Variation which Arises from Geometric Measure Theory”, SIAM Journal in Imaging Sciences, Vol. 5(2), pp. 537–563, 2012.

B. Goldluecke, E. Strekalovskiy and D. Cremers, “Tight Convex Relaxations for Vector-Valued Labeling”, SIAM Journal in Imaging Sciences, Vol. 6(3), pp. 1626–1664, 2013.

B. Goldluecke and M. Aubry and K. Kolev and D. Cremers, “A Super-resolution Framework for High-Accuracy Multiview Reconstruction”, Springer International Journal on Computer Vision, to appear, 2013
