Directional Field Synthesis, Design, and Processing

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ACM Reference format:
Amir Vaxman, Marcel Campen, Olga Diamanti, David Bommes, Klaus Hildebrandt, Mirela Ben-Chen, and Daniele Panozzo. 2017. Directional Field Synthesis, Design, and Processing. In *Proceedings of SIGGRAPH '17 Courses, Los Angeles, CA, USA, July 30 - August 03, 2017,* 3 pages.
DOI: http://dx.doi.org/10.1145/3084873.3084921

SUMMARY

Direction fields and vector fields play an increasingly important role in computer graphics and geometry processing. The synthesis of directional fields on surfaces, or other spatial domains, is a fundamental step in numerous applications, such as mesh generation, deformation, texture mapping, and many more. The wide range of applications resulted in definitions for many types of directional fields: from vector and tensor fields, over line and cross fields, to frame and vector-set fields. Depending on the application at hand, researchers have used various notions of objectives and constraints to synthesize such fields. These notions are defined in terms of fairness, feature alignment, symmetry, or field topology, to mention just a few. To facilitate these objectives, various representations, discretizations, and optimization strategies have been developed. These choices come with varying strengths and weaknesses. This course provides a systematic overview of directional field synthesis for graphics applications, the challenges it poses, and the methods developed in recent years to address these challenges.

PREREQUISITES

The audience should have some prior experience with triangle mesh representation of geometric models, and a working knowledge of calculus, linear algebra, and computer graphics fundamentals. Some familiarity with the basics of differential geometry and numerical optimization are helpful, but not required.

INTENDED AUDIENCE

The course targets researchers and developers who seek to understand the concepts and technologies used in direction field and vector field synthesis, learn about the most recent developments, and discern how this powerful tool, which has had impact in a variety of research and application areas, might benefit their area of work. Participants will get a broad overview, and obtain the knowledge on how to choose the proper combination of techniques for many relevant tasks.

SOURCES

These notes are largely based on the following state-of-the-art report by the lecturers. It has been extended to include updates on the most recent developments.

- A. Vaxman, M. Campen, O. Diamanti, D. Panozzo, D. Bommes, K. Hildebrandt, M. Ben-Chen. *Directional Field Synthesis, Design, and Processing*. Computer Graphics Forum 35 (2), 2016.

An earlier version of this course was held by the authors at SIGGRAPH Asia 2016. Notes, slides, demos, and code are available in this repository: https://github.com/avaxman/DirectionalFieldSynthesis

FURTHER READING

Being a relatively young and developing topic, no textbooks covering the various aspects of directional field synthesis in the context of computer graphics and geometry processing are available. The notes of a recent course on vector field processing offer another perspective on parts of the topic, with a focus on the discrete differential geometry aspects:

- F. de Goes, M. Desbrun, Y. Tong. *Vector Field Processing On Triangle Meshes.* SIGGRAPH Courses, 2016.

By contrast, we treat directional fields in a broader sense, focusing on the theoretical and practical aspects related to their geometrical, topological, and representational properties which are crucial for the efficient use of field synthesis in applications and research.

ORGANIZERS & LECTURERS

Amir Vaxman Utrecht University, The Netherlands

Amir Vaxman is an assistant professor in the division Virtual Worlds at Utrecht University, The Netherlands. He was a postdoctoral fellow at TU Vienna, working with Helmut Pottmann in the Geometric Modeling and Industrial Geometry group. He received his PhD from the Technion-IIT under the supervision of Gill Barequet. His research focuses on vector-field design and architectural geometry, with an emphasis on polyhedral meshes.

SIGGRAPH '17 Courses, Los Angeles, CA, USA

DOI: http://dx.doi.org/10.1145/3084873.3084921

Marcel Campen New York University, USA

Marcel Campen is a postdoctoral researcher at the Courant Institute of Mathematical Sciences (New York University), working with Denis Zorin and Claudio Silva. He received his PhD in 2014 from RWTH Aachen University, where he worked with Leif Kobbelt. Marcel was awarded the EUROGRAPHICS Best PhD Thesis Award for his work on quad layouts. A large number of his projects include various forms of directional field synthesis, for applications such as quadrangular remeshing, quad layouting, parametrization, procedural modeling, or metric manipulation.

Olga Diamanti Stanford University, USA

Olga Diamanti is a postdoctoral researcher at Stanford, working with Leo Guibas. She received her PhD in 2015 from ETH Zurich, where she worked with Olga Sorkine-Hornung at the Interactive Geometry Lab. She obtained a Master's Degree in Computer Science with an Excellency Scholarship from ETH Zurich, and a Dipl.Ing. degree in Electrical Engineering from the National Technical University of Athens, Greece. Her current interests are in geometry processing and modeling, specifically on vector field design, surface parametrizations, and inter-surface mappings.

David Bommes RWTH Aachen, Germany

David Bommes is an assistant professor in the Computer Science department at RWTH Aachen University (Germany). His PhD thesis from 2012 (RWTH Aachen University) is on Quadrilateral Surface Mesh Generation for Animation and Simulation and was awarded the EUROGRAPHICS Best PhD Thesis Award. Furthermore, David was awarded the EUROGRAPHICS Young Researcher Award in 2016. Currently he is leading the Mesh Generation and Optimization group, which scientifically contributes to the areas of geometry processing, in particular direction fields, parametrization and quad/hex mesh generation, and nonlinear/mixed-integer optimization.

Klaus Hildebrandt TU Delft, The Netherlands

Klaus Hildebrandt is an assistant professor in the Computer Graphics and Visualization group at Delft University of Technology, The Netherlands. He was a Senior Researcher at the Max Planck Institute for Informatics in Saarbrücken, Germany, where he headed the Applied Geometry group. He received his PhD from Freie University Berlin. His research interests are in geometric modeling and geometry processing, computational and discrete differential geometry and physically-based computer animation.

Mirela Ben-Chen Technion, Israel

Mirela Ben-Chen is an assistant professor in the Computer Graphics and Geometric Computing group at the Computer Science department at the Technion, Israel. She was a Fullbright postdoctoral scholar at Stanford University, and received her PhD from the Technion. Her research interests are computer graphics, geometry processing, discrete differential geometry, conformal geometry, and shape analysis and understanding.

Daniele Panozzo New York University, USA

Daniele Panozzo is an assistant professor at the Courant Institute of Mathematical Sciences in New York University. Before joining NYU, he was a senior postdoctoral researcher at ETH Zurich. He obtained his PhD from the University of Genova in 2012. He has been a visiting researcher at the University of Maryland, the Courant Institute of Mathematical Sciences (NYU), and ETH Zurich. His research interests are in digital fabrication, geometry processing, architectural geometry, and discrete differential geometry. Daniele's doctoral thesis was awarded the EUROGRAPHICS Award for Best PhD Thesis and his work has been covered by Swiss National Television and various national and international print media. Daniele was awarded the EUROGRAPHICS Young Researcher Award in May 2015 and the NSF CAREER Award in 2017. He is leading the development of libigl, an open-source geometry processing library that supports academic and industrial research and practice. Libigl was awarded the EUROGRAPHICS Symposium of Geometry Processing Software Award in July 2015.

COURSE OVERVIEW

The course will start with an overview over the broad variety of types of direction fields and vector fields that have found use in applications. We establish a concise taxonomy for these directional fields, and briefly introduce the necessary differential geometry background.

After discussing the concepts of discretization and their specific pitfalls in the context of directional fields, we focus on the most important representations used for these fields in geometry processing. It will become clear that every choice of discretization and representation comes with different advantages and shortcomings; we provide a guide to making the proper choice, depending on the concrete requirements of the application. We illustrate the importance of these choices by comparing results from various field synthesis and optimization methods and demonstrate the algorithms to clarify the crucial differences.

After introducing the most common synthesis objectives and constraints, such as smoothness and alignment, we also discuss advanced and specialized ones, pertaining to symmetry, conjugacy, holonomy, or based on differential operators.

While directional fields are used as an abstract mathematical tool in many applications, it can be extremely helpful to actually visualize them—for purposes of understanding, debugging, and assessment. We explain efficient means of visualization suited for specific types of fields. The course will conclude with a demonstration of how directional field synthesis provides benefits in important application scenarios, and a discussion of the major open problems in this area of research.

SYLLABUS

- Introduction
- Applications
- Taxonomy
- Discretization
- Representation
  – Break –
- Objectives, Constraints, Operators
- Visualization
- Live coding demo
- Open Problems
- Q&A