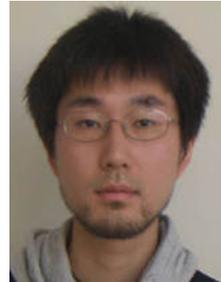## Computer Graphics Laboratory

Shigeo Takahashi
Professor

Pierre-Alain Fayolle
Associate Professor

Yohei Nishidate
Associate Professor

Laboratory information:

Members of the Computer Graphics Laboratory conduct research into physics-based modeling of different phenomena, visualization and shape modeling. Innovative approaches to graphical user interfaces and direct interaction methods, modeling, rendering, simulation and visualization are under development. Created mathematical models are used for graphical representation of natural and complex phenomena.

Research areas include:

- Visualization of surface and volume data, which results from finite element, boundary element and finite difference modeling.

- Nanomechanics modeling. Finite element and molecular mechanics modeling of micro- and nanostructures.

- Ray-tracing simulation for lens design.

- Augmented reality interface for different fields of human activity.

- Using graphics processing units for physics-based modeling and animation.

- Development of algorithms for shape modeling, analysis and understanding (operations on shape, segmentation and reconstruction).

- Topological data mining/representation for scientific/mathematical visualization.

- Visual representation of texts and networks for information visualization.

- Map schematization including 2D railway maps, 3D urban maps, map annotations, aesthetic designs, etc.

- Modeling human visual perception and its application to visual analytics.

Professors of the Computer Graphics Laboratory deliver courses in Computer Graphics, Numerical Analysis, Modeling and Visualization. Graduation projects are related to computer graphics, human-computer interaction, physics-based modeling, shape modeling and processing, visualization, and animation.

Refereed academic journal

[fayolle-305-013-01:2015] Mathieu Sanchez, Oleg Fryazinov, Pierre-Alain Fayolle, and Alexander Pasko. Convolution Filtering of Continuous Signed Distance Fields for Polygonal Meshes. *Computer Graphics Forum*, 34(6):277–288, 2015.

> Signed distance fields obtained from polygonal meshes are commonly used in various applications. However, they can have C1 discontinuities causing creases to appear when applying operations such as blending or metamorphosis. The focus of this work is to efficiently evaluate the signed distance function and to apply a smoothing filter to it while preserving the shape of the initial mesh. The resulting function is smooth almost everywhere, while preserving the exact shape of the polygonal mesh. Due to its low complexity, the proposed filtering technique remains fast compared to its main alternatives providing C1-continuous distance field approximation. Several applications are presented such as blending, metamorphosis and heterogeneous modelling with polygonal meshes.

[fayolle-305-013-02:2015] Alexander G Belyaev and Pierre-Alain Fayolle. On transfinite Gordon–Wixom interpolation schemes and their extensions. *Computers & Graphics*, 51:74–80, 2015.

> Among various barycentric coordinates and their extensions, the linear and cubic (Hermite) Gordon-Wixom transfinite interpolation schemes deliver the most accurate approximations of the harmonic and biharmonic functions, respectively. However interpolation properties of the original Gordon-Wixom interpolations are studied for convex domains only and, therefore, their current practical importance is limited. In this paper, we propose simple modifications of the Gordon-Wixom interpolation schemes, study their properties, and show how they can be used for approximating solutions to the Poisson and inhomogeneous biharmonic equations. Our modified Gordon-Wixom interpolations are easily extended to non-convex domains and, according to our experiments, deliver more accurate approximations of the harmonic and biharmonic functions compared with the original Gordon-Wixom schemes. We also demonstrate how our approach can be used for approximating the distance function.

[fayolle-305-013-03:2015] Alexander G Belyaev and Pierre-Alain Fayolle. On Variational and PDE-Based Distance Function Approximations. *Computer Graphics Forum*, 34(8):104–118, 2015.

In this paper, we deal with the problem of computing the distance to a surface (a curve in two dimensional) and consider several distance function approximation methods which are based on solving partial differential equations (PDEs) and finding solutions to variational problems. In particular, we deal with distance function estimation methods related to the Poisson-like equations and generalized double-layer potentials. Our numerical experiments are backed by novel theoretical results and demonstrate efficiency of the considered PDE-based distance function approximations.

[shigeo-305-013-01:2015] Koto Nohno, Hsiang-Yun Wu, Kazuho Watanabe, Shigeo Takahashi, and Issei Fujishiro. Axis Contraction of Parallel Coordinates Using Spectral Graph Analysis. *Journal of the Institute of Image Electronics Engineers of Japan*, 44(3):447–456, 2015.

(written in Japanese) Parallel coordinates is well-known as a popular tool for visualizing the underlying relationships among variables in high-dimensional datasets. This visualization technique is useful for visually understanding the degree of correlation between data samples in terms of two adjacent axes. However, this representation still suffers from distracting visual clutter especially when the numbers of data samples and their associated dimension become high, because the associated polyline samples intricately overlap with each other within the limited screen space. This paper presents a method of alleviating such visual clutter by contracting multiple axes through the analysis of correlation between every pair of variables. In this method, we first define the similarity between a pair of dimensions as the value of the correlation coefficient, and construct a subgraph from the complete graph through eliminating all the edges in that their absolute correlation coefficients are less than some threshold, and then reorder the multiple axes by projecting the nodes onto the primary axis obtained using the spectral graph analysis. This allows us to compose a dendrogram tree by recursively managing a pair of the closest axes one by one. Smooth animation of the associated axis contraction and expansion has also been implemented to enhance the visual readability of behavior inherent in the given high-dimensional datasets. We also conducted a user study to investigate how the correlations among coordinate axes are better visualized using our approach.

[shigeo-305-013-02:2015] Daisuke Sakurai, Osamu Saeki, Hamish Carr, Hsiang-Yun Wu, Takahiro Yamamoto, David J. Duke, and Shigeo Takahashi. Interactive Visualization for Singular Fibers of Functions f: R3 →

R2. *IEEE Transactions on Visualization and Computer Graphics*, 22(1):945–954, 2016.

Scalar topology in the form of Morse theory has provided computational tools that analyze and visualize data from scientific and engineering tasks. Contracting isocontours to single points encapsulates variations in isocontour connectivity in the Reeb graph. For multivariate data, isocontours generalize to fibers-inverse images of points in the range, and this area is therefore known as fiber topology. However, fiber topology is less fully developed than Morse theory, and current efforts rely on manual visualizations. This paper presents how to accelerate and semi-automate this task through an interface for visualizing fiber singularities of multivariate functions R3 → R2. This interface exploits existing conventions of fiber topology, but also introduces a 3D view based on the extension of Reeb graphs to Reeb spaces. Using the Joint Contour Net, a quantized approximation of the Reeb space, this accelerates topological visualization and permits online perturbation to reduce or remove degeneracies in functions under study. Validation of the interface is performed by assessing whether the interface supports the mathematical workflow both of experts and of less experienced mathematicians.

Unrefereed academic journal

[shigeo-305-013-03:2015] Ulrik Brandes, Hans Hagen, Shigeo Takahashi, and Xiaoru Yuan. Guest Editors' Introduction. Special Section on the IEEE Pacific Visualization Symposium 2014. *IEEE Transactions on Visualization and Computer Graphics*, 21(8):887–888, 2015.

The papers in this special section present extended versions of four selected papers from the 2014 IEEE Pacific Visualization Symposium (PacificVis2014).

Refereed proceedings of an academic conference

[fayolle-305-013-04:2015] Pierre-Alain Fayolle and Alexander Pasko. User-assisted reverse modeling with evolutionary algorithms. In *Evolutionary Computation (CEC), 2015 IEEE Congress on*, pages 2176–2183, 2015.

This paper presents a system for user-assisted reverse modeling: from digitized point-cloud to solid models ready to be used in a CAD modeling system. Our

approach consists in the following steps: segmentation, fitting, and constructive model discovery. Each of these steps are based on evolutionary algorithms. The obtained objects can then be further edited or parameterized by users and fitted to adapt their shape to different point-clouds.

[nisidate-305-013-01:2015] Y. Nishidate, I. Khmyrova, J. Kholopova, E. Polushkin, V. Zemlyakov, and S. Shapoval. Computational Modeling of Planar Light-emmiting Diode with Mesh-like Electrode. In et al. M. Gholami, editor, *International Conference on Modeling, Simulation and Applied Mathematics(MSAM2015)*, volume 122 of *Advances in Intelligent Systems Research*, pages 237–241, Phuket, Thailand, Aug. 23-24 2015. Atlantis Press.

Numerical procedure is developed for modeling of a planar light-emitting diode (LED) with top metal electrode patterned like a mesh with square cross sectional strips. The procedure is applied for modeling LED output performance at different parameters of the mesh-like electrode. Our numerical analysis predicts that the maximum output can be achieved at the mesh opening size around 600 nm.

[nisidate-305-013-02:2015] Y. Nishidate, J. Kholopova, E. Polushkin, I. Khmyrova, and S. Shapoval. Impact of Mesh-Like Top p-Electrode on Output Performance of Light-Emitting Diode: Numerical Study. In *15th International Conference on Numerical Simulation of Optoelectronic Devices(NUSOD2015)*, pages 13–14, Taipei, Taiwan, Sep. 7-11 2015. IEEE.

Numerical model and procedure for the lightemitting diode (LED) with realistic mesh strips having square cross-section are developed and used for simulation of electrical and output optical characteristics at different dimensions of the mesh and bias voltages. Performances simulated for realistic square cross-section strips and analytical model based on the finite-radius wire approximation were compared. Comparison demonstrates the advantages of realistic model, in particular, for extraction of the mesh-like electrode parameters resulting in maximum optical output.

[nisidate-305-013-03:2015] Y. Nishidate. Precision Ray-tracing Procedure for Inhomogeneous Refractive-index Media with Discrete Input Data. In *10th International Conference on Optics-photonics Design and Fabrication(ODF16)*, pages 29S1–04, Weingarten, Germany, Feb. 28-Mar. 2 2016.

A procedure is developed for precise ray-tracing simulation in inhomogeneous refractive-index media. The Nagata patch is applied for reproducing the lens surface to achieve a satisfactory precision. Inhomogeneous distribution of refractive index is reconstructed by the moving least squares method, and the ray equation of geometric optics is integrated with automatic step size adjustment. Furthermore, an iterative procedure is proposed to maintain precision near the exit of inhomogeneous media. The developed procedure is applied for ray-tracing in axial and radial gradient optical fibres, and precision verified through comparisons with analytical solutions.

[nisidate-305-013-04:2015] Y. Nishidate, I. Khmyrova, J. Kholopova, E. Polushkin, and S. Shapoval. Numerical Study of Light-Emitting Diode with Injected Current Modulated by Designed Electrode. In *10th International Conference on Optics-photonics Design and Fabrication(ODF16)*, pages 1S2–09, Weingarten, Germany, Feb. 28-Mar. 2 2016.

Numerical model and procedure are developed to study the output optical performance of light-emitting diode (LED) in which injected current is spatially modulated by mesh-like top metal electrode. Modeling results demonstrate the effect of mesh pitch variation on the output optical power. In particular, at a certain value of the mesh pitch maximum total output optical power is revealed. The present model can be used in optimization of the LEDs with designed metal electrodes.

[shigeo-305-013-04:2015] Kazuho Watanabe, Hsiang-Yun Wu, Yusuke Niibe, Shigeo Takahashi, and Issei Fujishiro. Biclustering Multivariate Data for Correlated Subspace Mining. In *Proceedings of the 8th IEEE Pacific Visualization Symposium (PacificVis 2015)*, pages 287–294, April 2015.

Exploring feature subspaces is one of promising approaches to analyzing and understanding the important patterns in multivariate data. If relying too much on effective enhancements in manual interventions, the associated results depend heavily on the knowledge and skills of users performing the data analysis. This paper presents a novel approach to extracting feature subspaces from multivariate data by incorporating biclustering techniques. The approach has been maximally automated in the sense that highly-correlated dimensions are automatically grouped to form subspaces, which effectively supports further exploration of them. A key idea behind our approach lies in a new mathematical formulation of asymmetric biclustering, by combining spherical k-means clustering for grouping highly-correlated dimensions, together with ordinary

k-means clustering for identifying subsets of data samples. Lower-dimensional representations of data in feature subspaces are successfully visualized by parallel coordinate plot, where we project the data samples of correlated dimensions to one composite axis through dimensionality reduction schemes. Several experimental results of our data analysis together with discussions will be provided to assess the capability of our approach.

[shigeo-305-013-05:2015] Rie Ishida, Shigeo Takahashi, and Hsiang-Yun Wu. Interactively Uncluttering Node Overlaps for Network Visualization. In *Proceedings of the 19th International Conference on Information Visualization (IV 2015)*, pages 200–205, July 2015.

Visual interaction with networks have been promising in the sense that we can successfully elucidate underlying relationships hidden behind complicated mutual relationships such as co-authorship networks, product co purchasing networks, and scale-free social networks. However, it is still burdensome to alleviate visual clutter arising from overlaps among node labels especially in such interactive environments as the networks become dense in terms of the topological connectivity. This paper presents a novel approach for dynamically rearranging the network layouts by incorporating centroidal Voronoi tessellation for better readability of node labels. Our idea is to smoothly transform the network layouts obtained through the conventional force-directed algorithm to that produced by the centroidal Voronoi tessellation to seek a plausible compromise between them. We also incorporated the Chebyshev distance metric into the centroidal Voronoi tessellation while adaptively adjusting the aspect ratios of the Voronoi cells so that we can place rectangular labels compactly over the network nodes. Finally, we applied the proposed approach to relatively large networks to demonstrate the feasibility of our formulation especially in interactive environments.

[shigeo-305-013-06:2015] Hsiang-Yun Wu, Sheung-Hung Poon, Shigeo Takahashi, Masatoshi Arikawa, Chun-Cheng Lin, and Hsu-Chun Yen. Designing and Annotating Metro Maps with Loop Lines. pages 9–14, 2015.

Schematic metro maps provide an effective means of simplifying the geographical configuration of public rapid transportation systems. Nonetheless, travelers still find it difficult to identify routes of a specific topology on the maps because it is usually hidden behind the conventional octilinear layout of the entire map. In this paper, we present an approach to designing schematic maps with loop lines, which are drawn as circles together with annotation labels for

guiding different traveling purposes. Our idea here is to formulate the aesthetic criteria as mathematical constraints in the mixed-integer programming model, which allows us to either align stations on the loop line at a grid if they are interchange stations or noninterchange stations on a circle otherwise. We then distribute the annotation labels associated with stations on the loop line evenly to the four side boundary of the map domain in order to make full use of the annotation space, while maximally avoiding intersections between leader lines and the metro network by employing a flow network algorithm. Finally, we present several experimental results generated by our prototype system to demonstrate the feasibility of the proposed approach.

Writing a textbook or technical book

[shigeo-305-013-07:2015] Shixia Liu, Gerik Scheuermann, and Shigeo Takahashi. *Proceedings of 8th IEEE Pacific Visualization Symposium (PacificVis 2015).* IEEE Computer Society Press, 2015.

ISBN 978-1-4673-6879-7

[shigeo-305-013-08:2015] Takayuki Itoh, Paolo Bottoni, and Shigeo Takahashi. *Proceedings of the 8th International Symposium on Visual Information Communication and Interaction (VINCI 2015).* 2015, OPTaddress =.

Academic society activities

[fayolle-305-013-05:2015] Pierre-Alain Fayolle, 2015.

Program Committee member, Shape Modeling International 2015

[fayolle-305-013-06:2015] Pierre-Alain Fayolle, 2015.

Reviewer, Journal of Computational Design and Engineering

[fayolle-305-013-07:2015] Pierre-Alain Fayolle, 2015.

Reviewer, Computer & Graphics

[nisidate-305-013-05:2015] Y. Nishidate, Oct. 2015.

Reviewer, Optical and Quantum Electronics

[nisidate-305-013-06:2015] Y. Nishidate, Jan. 2016.

> Reviewer, Optical and Quantum Electronics

[nisidate-305-013-07:2015] Y. Nishidate, Mar. 2016.

> Reviewer, Optical and Quantum Electronics

Advisor for undergraduate research and graduate research

[fayolle-305-013-08:2015] Keiya Wachi. Hand controlled scene manipulation, The University of Aizu, 2015.

[fayolle-305-013-09:2015] Shingo Ito. A simple approach to mesh deformation, The University of Aizu, 2015.

[nisidate-305-013-08:2015] Fumiya Tajima. Master thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

[nisidate-305-013-09:2015] Hikaru Abe. Master thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

[nisidate-305-013-10:2015] Takuya Saito. Master thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

[nisidate-305-013-11:2015] Yusuke Ito. Graduation thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

[nisidate-305-013-12:2015] Joji Ikarashi. Graduation thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

[nisidate-305-013-13:2015] Keishi Chida. Graduation thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

[nisidate-305-013-14:2015] Tatsumi Nitsuma. Graduation thesis, University of Aizu, 2016.

> Thesis Advisor: Y. Nishidate

Summary of Achievement

Contributions related to syllabus preparation

[nisidate-305-013-15:2015] Numerical Analysis (role: Course Coordinator)

[nisidate-305-013-16:2015] Finite Element Modeling and Visualization (role: Master course instructor)

Other significant contribution toward university planning, management, or administration

[nisidate-305-013-17:2015] PC-Koshien Programming Section (role: Problem Preparation Committee)

[nisidate-305-013-18:2015] PC-Koshien Programming Section, Preliminaly and Final Contests (role: Judge)

[nisidate-305-013-19:2015] Entrance Exam (role: Problem Proposals, Problem Creation, and Marking)

[nisidate-305-013-20:2015] Entrance Exam by Commendation(role: Problem Proposals, Problem Creation, and Marking)

Contributions related to regional education

[nisidate-305-013-21:2015] Computer Science Summer Camp (role: Executive Committee)

[nisidate-305-013-22:2015] Computer Science Summer Camp (role: Computer Graphics Course Coordinator)

Did you participate in Public Lectures, and/or Open Campus? (Yes or No) If yes, please describe what you did.

[nisidate-305-013-23:2015] organized place to exhibit, recruited students to explain, provided materials to exhibit.

[shigeo-305-013-09:2015] Open campus (FY2015)