IN PARTNERSHIP WITH:
CNRS
Institut polytechnique de Grenoble
Université de Grenoble Alpes

Activity Report 2018

Project-Team MAVERICK

Models and Algorithms for Visualization and Rendering

IN COLLABORATION WITH: Laboratoire Jean Kuntzmann (LJK)

RESEARCH CENTER
Grenoble - Rhône-Alpes

THEME
Interaction and visualization

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Project-Team MAVERICK

Creation of the Team: 2012 January 01, updated into Project-Team: 2014 January 01

Keywords:

Computer Science and Digital Science:

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A5.5.1. - Geometrical modeling
A5.5.2. - Rendering
A5.5.3. - Computational photography
A5.5.4. - Animation

Other Research Topics and Application Domains:

B5.5. - Materials
B5.7. - 3D printing
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B9.2.3. - Video games
B9.2.4. - Theater
B9.6.6. - Archeology, History

1. Team, Visitors, External Collaborators

Research Scientists

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Joëlle Thollot [Institut polytechnique de Grenoble, Associate Professor, HDR]
Romain Vergne [Univ Grenoble Alpes, Associate Professor]

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Alban Fichet [Inria]
Morgane Gerardin [Univ Grenoble Alpes, from Oct 2018]
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Visiting Scientist

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2. Overall Objectives

2.1. Overall Objectives

Computer-generated pictures and videos are now ubiquitous: both for leisure activities, such as special effects in motion pictures, feature movies and video games, or for more serious activities, such as visualization and simulation.

Maverick was created as a research team in January 2012 and upgraded as a research project in January 2014. We deal with image synthesis methods. We place ourselves at the end of the image production pipeline, when the pictures are generated and displayed (see figure 1). We take many possible inputs: datasets, video flows, pictures and photographs, (animated) geometry from a virtual world... We produce as output pictures and videos.

These pictures will be viewed by humans, and we consider this fact as an important point of our research strategy, as it provides the benchmarks for evaluating our results: the pictures and animations produced must be able to convey the message to the viewer. The actual message depends on the specific application: data visualization, exploring virtual worlds, designing paintings and drawings... Our vision is that all these applications share common research problems: ensuring that the important features are perceived, avoiding cluttering or aliasing, efficient internal data representation, etc.

Computer Graphics, and especially Maverick is at the crossroad between fundamental research and industrial applications. We are both looking at the constraints and needs of applicative users and targeting long term research issues such as sampling and filtering.

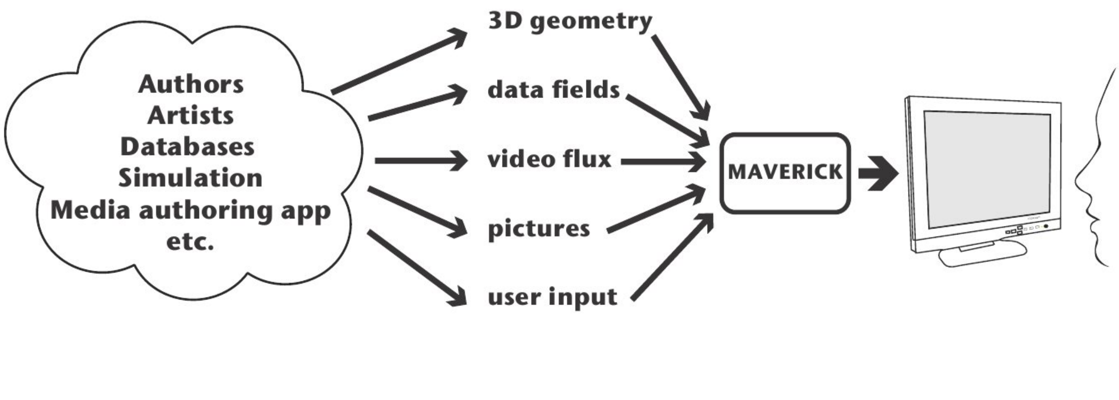


Figure 1. Position of the Maverick research team inside the graphics pipeline.

The Maverick project-team aims at producing representations and algorithms for efficient, high-quality computer generation of pictures and animations through the study of four *Research problems*:

- *Computer Visualization*, where we take as input a large localized dataset and represent it in a way that will let an observer understand its key properties,
- *Expressive Rendering*, where we create an artistic representation of a virtual world,
- *Illumination Simulation*, where our focus is modelling the interaction of light with the objects in the scene.
- *Complex Scenes*, where our focus is rendering and modelling highly complex scenes.

The heart of Maverick is *understanding* what makes a picture useful, powerful and interesting for the user, and designing algorithms to create these pictures.

We will address these research problems through three interconnected approaches:

- working on the *impact* of pictures, by conducting perceptual studies, measuring and removing artefacts and discontinuities, evaluating the user response to pictures and algorithms,
- developing *representations* for data, through abstraction, stylization and simplification,
- developing new methods for *predicting* the properties of a picture (*e.g.* frequency content, variations) and adapting our image-generation algorithm to these properties.

A fundamental element of the Maverick project-team is that the research problems and the scientific approaches are all cross-connected. Research on the *impact* of pictures is of interest in three different research problems: *Computer Visualization*, *Expressive rendering* and *Illumination Simulation*. Similarly, our research on *Illumination simulation* will gather contributions from all three scientific approaches: impact, representations and prediction.

3. Research Program

3.1. Introduction

The Maverick project-team aims at producing representations and algorithms for efficient, high-quality computer generation of pictures and animations through the study of four **research problems**:

- *Computer Visualization* where we take as input a large localized dataset and represent it in a way that will let an observer understand its key properties. Visualization can be used for data analysis, for the results of a simulation, for medical imaging data...
- *Expressive Rendering*, where we create an artistic representation of a virtual world. Expressive rendering corresponds to the generation of drawings or paintings of a virtual scene, but also to some areas of computational photography, where the picture is simplified in specific areas to focus the attention.
- *Illumination Simulation*, where we model the interaction of light with the objects in the scene, resulting in a photorealistic picture of the scene. Research include improving the quality and photorealism of pictures, including more complex effects such as depth-of-field or motion-blur. We are also working on accelerating the computations, both for real-time photorealistic rendering and offline, high-quality rendering.
- *Complex Scenes*, where we generate, manage, animate and render highly complex scenes, such as natural scenes with forests, rivers and oceans, but also large datasets for visualization. We are especially interested in interactive visualization of complex scenes, with all the associated challenges in terms of processing and memory bandwidth.

The fundamental research interest of Maverick is first, *understanding* what makes a picture useful, powerful and interesting for the user, and second *designing* algorithms to create and improve these pictures.

3.2. Research approaches

We will address these research problems through three interconnected research approaches:

3.2.1. Picture Impact

Our first research axis deals with the *impact* pictures have on the viewer, and how we can improve this impact. Our research here will target:

- *evaluating user response:* we need to evaluate how the viewers respond to the pictures and animations generated by our algorithms, through user studies, either asking the viewer about what he perceives in a picture or measuring how his body reacts (eye tracking, position tracking).
- *removing artefacts and discontinuities:* temporal and spatial discontinuities perturb viewer attention, distracting the viewer from the main message. These discontinuities occur during the picture creation process; finding and removing them is a difficult process.

3.2.2. Data Representation

The data we receive as input for picture generation is often unsuitable for interactive high-quality rendering: too many details, no spatial organisation... Similarly the pictures we produce or get as input for other algorithms can contain superfluous details.

One of our goals is to develop new data representations, adapted to our requirements for rendering. This includes fast access to the relevant information, but also access to the specific hierarchical level of information needed: we want to organize the data in hierarchical levels, pre-filter it so that sampling at a given level also gives information about the underlying levels. Our research for this axis include filtering, data abstraction, simplification and stylization.

The input data can be of any kind: geometric data, such as the model of an object, scientific data before visualization, pictures and photographs. It can be time-dependent or not; time-dependent data bring an additional level of challenge on the algorithm for fast updates.

3.2.3. Prediction and simulation

Our algorithms for generating pictures require computations: sampling, integration, simulation... These computations can be optimized if we already know the characteristics of the final picture. Our recent research has shown that it is possible to predict the local characteristics of a picture by studying the phenomena involved: the local complexity, the spatial variations, their direction...

Our goal is to develop new techniques for predicting the properties of a picture, and to adapt our image-generation algorithms to these properties, for example by sampling less in areas of low variation.

Our research problems and approaches are all cross-connected. Research on the *impact* of pictures is of interest in three different research problems: *Computer Visualization*, *Expressive rendering* and *Illumination Simulation*. Similarly, our research on *Illumination simulation* will use all three research approaches: impact, representations and prediction.

3.3. Cross-cutting research issues

Beyond the connections between our problems and research approaches, we are interested in several issues, which are present throughout all our research:

sampling is an ubiquitous process occurring in all our application domains, whether photorealistic rendering (*e.g.* photon mapping), expressive rendering (*e.g.* brush strokes), texturing, fluid simulation (Lagrangian methods), etc. When sampling and reconstructing a signal for picture generation, we have to ensure both coherence and homogeneity. By *coherence*, we mean not introducing spatial or temporal discontinuities in the reconstructed signal. By *homogeneity*, we mean that samples should be placed regularly in space and time. For a time-dependent signal, these requirements are conflicting with each other, opening new areas of research.

filtering is another ubiquitous process, occuring in all our application domains, whether in realistic rendering (*e.g.* for integrating height fields, normals, material properties), expressive rendering (*e.g.* for simplifying strokes), textures (through non-linearity and discontinuities). It is especially relevant when we are replacing a signal or data with a lower resolution (for hierarchical representation); this involves filtering the data with a reconstruction kernel, representing the transition between levels.

performance and scalability are also a common requirement for all our applications. We want our algorithms to be usable, which implies that they can be used on large and complex scenes, placing a great importance on scalability. For some applications, we target interactive and real-time applications, with an update frequency between 10 Hz and 120 Hz.

coherence and continuity in space and time is also a common requirement of realistic as well as expressive models which must be ensured despite contradictory requirements. We want to avoid flickering and aliasing.

animation: our input data is likely to be time-varying (*e.g.* animated geometry, physical simulation, time-dependent dataset). A common requirement for all our algorithms and data representation is that they must be compatible with animated data (fast updates for data structures, low latency algorithms...).

3.4. Methodology

Our research is guided by several methodological principles:

Experimentation: to find solutions and phenomenological models, we use experimentation, performing statistical measurements of how a system behaves. We then extract a model from the experimental data.

Validation: for each algorithm we develop, we look for experimental validation: measuring the behavior of the algorithm, how it scales, how it improves over the state-of-the-art... We also compare our algorithms to the exact solution. Validation is harder for some of our research domains, but it remains a key principle for us.

Reducing the complexity of the problem: the equations describing certain behaviors in image synthesis can have a large degree of complexity, precluding computations, especially in real time. This is true for physical simulation of fluids, tree growth, illumination simulation... We are looking for *emerging phenomena* and *phenomenological models* to describe them (see framed box "Emerging phenomena"). Using these, we simplify the theoretical models in a controlled way, to improve user interaction and accelerate the computations.

Transferring ideas from other domains: Computer Graphics is, by nature, at the interface of many research domains: physics for the behavior of light, applied mathematics for numerical simulation, biology, algorithmics... We import tools from all these domains, and keep looking for new tools and ideas.

Develop new fondamental tools: In situations where specific tools are required for a problem, we will proceed from a theoretical framework to develop them. These tools may in return have applications in other domains, and we are ready to disseminate them.

Collaborate with industrial partners: we have a long experiment of collaboration with industrial partners. These collaborations bring us new problems to solve, with short-term or medium-term transfert opportunities. When we cooperate with these partners, we have to find *what they need*, which can be very different from *what they want*, their expressed need.

4. Application Domains

4.1. Application Domains

The natural application domain for our research is the production of digital images, for example for movies and special effects, virtual prototyping, video games... Our research have also been applied to tools for generating and editing images and textures, for example generating textures for maps. Our current application domains are:

- Offline and real-time rendering in movie special effects and video games;
- Virtual prototyping;
- Scientific visualization;
- Content modeling and generation (e.g. generating texture for video games, capturing reflectance properties, etc);
- Image creation and manipulation.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

- the paper "MNPR: A Framework for Real-Time Expressive Non-Photorealistic Rendering of 3D Computer Graphics" [13], co-authored by Santiago Montesdeoca, Hock Soon Seah, Amir Semmo, Pierre Bénard, Romain Vergne, Joëlle Thollot and Davide Benvenuti, has received the "Best Paper Award" during the conference Expressive 2018.
- the paper "High-performance By-Example Noise using a Histogram-Preserving Blending Operator" [4], co-authored by Eric Heitz and Fabrice Neyret, has received the "Best Paper Award" during the conference High-performance Graphics 2018.
- the paper "A New Microflake Model with Microscopic Self-Shadowing for Accurate Volume Downsampling" [5], co-authored by Guillaume Loubet and Fabrice Neyret, has received the "Best Paper Award" during the conference Eurographics 2018.

6. New Software and Platforms

6.1. Diffusion curves

KEYWORDS: Vector-based drawing - Shading
FUNCTIONAL DESCRIPTION: Diffusion Curves is a vector-based design tool for creating complex shaded images. This prototype is composed of the Windows binary, along with the required shader programs (ie. in source code).

- Participants: Adrien Bousseau, Alexandrina Orzan, David Salesin, Holger Winnemoeller, Joëlle Thollot and Pascal Barla
- Partners: CNRS - LJK - INP Grenoble - Université Joseph-Fourier
- Contact: Joëlle Thollot
- URL: http://maverick.inria.fr/Publications/2008/OBWBTS08/index.php

6.2. GigaVoxels

FUNCTIONAL DESCRIPTION: Gigavoxel is a software platform which goal is the real-time quality rendering of very large and very detailed scenes which couldn't fit memory. Performances permit showing details over deep zooms and walk through very crowdy scenes (which are rigid, for the moment). The principle is to represent data on the GPU as a Sparse Voxel Octree which multiscale voxels bricks are produced on demand only when necessary and only at the required resolution, and kept in a LRU cache. User defined producer lays accross CPU and GPU and can load, transform, or procedurally create the data. Another user defined function is called to shade each voxel according to the user-defined voxel content, so that it is user choice to distribute the appearance-making at creation (for faster rendering) or on the fly (for storageless thin procedural details). The efficient rendering is done using a GPU differential cone-tracing using the scale corresponding to the 3D-MIPmapping LOD, allowing quality rendering with one single ray per pixel. Data is produced in case of cache miss, and thus only whenever visible (accounting for view frustum and occlusion). Soft-shadows and depth-of-field is easily obtained using larger cones, and are indeed cheaper than unblurred rendering. Beside the representation, data management and base rendering algorithm themself, we also worked on realtime light transport, and on quality prefiltering of complex data. Ongoing researches are addressing animation. GigaVoxels is currently used for the quality real-time exploration of the detailed galaxy in ANR RTIGE. Most of the work published by Cyril Crassin (and al.) during his PhD (see http://maverick.inria.fr/Members/Cyril.Crassin/) is related to GigaVoxels. GigaVoxels is available for Windows and Linux under the BSD-3 licence.

- Participants: Cyril Crassin, Eric Heitz, Fabrice Neyret, Jérémy Sinoir, Pascal Guehl and Prashant Goswami
- Contact: Fabrice Neyret
- URL: http://gigavoxels.inrialpes.fr

6.3. GRATIN

FUNCTIONAL DESCRIPTION: Gratin is a node-based compositing software for creating, manipulating and animating 2D and 3D data. It uses an internal direct acyclic multi-graph and provides an intuitive user interface that allows to quickly design complex prototypes. Gratin has several properties that make it useful for researchers and students. (1) it works in real-time: everything is executed on the GPU, using OpenGL, GLSL and/or Cuda. (2) it is easily programmable: users can directly write GLSL scripts inside the interface, or create new C++ plugins that will be loaded as new nodes in the software. (3) all the parameters can be animated using keyframe curves to generate videos and demos. (4) the system allows to easily exchange nodes, group of nodes or full pipelines between people.

- Participants: Pascal Barla and Romain Vergne
- Partner: UJF
- Contact: Romain Vergne
- URL: http://gratin.gforge.inria.fr/

6.4. HQR

High Quality Renderer

KEYWORDS: Lighting simulation - Materials - Plug-in

FUNCTIONAL DESCRIPTION: HQR is a global lighting simulation platform. HQR software is based on the photon mapping method which is capable of solving the light balance equation and of giving a high quality solution. Through a graphical user interface, it reads X3D scenes using the X3DToolKit package developed at Maverick, it allows the user to tune several parameters, computes photon maps, and reconstructs information to obtain a high quality solution. HQR also accepts plugins which considerably eases the developpement of new algorithms for global illumination, those benefiting from the existing algorithms for handling materials, geometry and light sources.

- Participant: Cyril Soler
- Contact: Cyril Soler
- URL: http://artis.imag.fr/~Cyril.Soler/HQR

6.5. libylm

LibYLM
KEYWORD: Spherical harmonics
FUNCTIONAL DESCRIPTION: This library implements spherical and zonal harmonics. It provides the means to perform decompositions, manipulate spherical harmonic distributions and provides its own viewer to visualize spherical harmonic distributions.

- Author: Cyril Soler
- Contact: Cyril Soler
- URL: https://launchpad.net/~csoler-users/+archive/ubuntu/ylm

6.6. MobiNet

KEYWORDS: Co-simulation - Education - Programmation
FUNCTIONAL DESCRIPTION: The MobiNet software allows for the creation of simple applications such as video games, virtual physics experiments or pedagogical math illustrations. It relies on an intuitive graphical interface and language which allows the user to program a set of mobile objects (possibly through a network). It is available in public domain for Linux,Windows and MacOS.

- Participants: Fabrice Neyret, Franck Hétroy-Wheeler, Joëlle Thollot, Samuel Hornus and Sylvain Lefebvre
- Partners: CNRS - LJK - INP Grenoble - Inria - IREM - Cies - GRAVIR
- Contact: Fabrice Neyret
- URL: http://mobinet.imag.fr/index.en.html

6.7. PLANTRAD

KEYWORDS: Bioinformatics - Biology
FUNCTIONAL DESCRIPTION: PlantRad is a software program for computing solutions to the equation of light equilibrium in a complex scene including vegetation. The technology used is hierarchical radiosity with clustering and instantiation. Thanks to the latter, PlantRad is capable of treating scenes with a very high geometric complexity (up to millions of polygons) such as plants or any kind of vegetation scene where a high degree of approximate self-similarity permits a significant gain in memory requirements.

- Participants: Cyril Soler, François Sillion and George Drettakis
- Contact: Cyril Soler

6.8. PROLAND

PROcedural LANDscape
KEYWORDS: Real time - 3D - Realistic rendering - Masses of data - Atmosphere - Ocean
FUNCTIONAL DESCRIPTION: The goal of this platform is the real-time quality rendering and editing of large landscapes. All features can work with planet-sized terrains, for all viewpoints from ground to space. Most of the work published by Eric Bruneton and Fabrice Neyret (see http://evasion.inrialpes.fr/Membres/Eric.Bruneton/) has been done within Proland and integrated in the main branch. Proland is available under the BSD-3 licence.

- Participants: Antoine Begault, Eric Bruneton, Fabrice Neyret and Guillaume Piolet
- Contact: Fabrice Neyret
- URL: https://proland.inrialpes.fr/

6.9. ShwarpIt

KEYWORD: Warping

FUNCTIONAL DESCRIPTION: ShwarpIt is a simple mobile app that allows you to manipulate the perception of shapes in images. Slide the ShwarpIt slider to the right to make shapes appear rounder. Slide it to the left to make shapes appear more flat. The Scale slider gives you control on the scale of the warping deformation.

- Contact: Georges-Pierre Bonneau
- URL: http://bonneau.meylan.free.fr/ShwarpIt/ShwarpIt.html

6.10. Vrender

FUNCTIONAL DESCRIPTION: The VRender library is a simple tool to render the content of an OpenGL window to a vectorial device such as Postscript, XFig, and soon SVG. The main usage of such a library is to make clean vectorial drawings for publications, books, etc.

In practice, VRender replaces the z-buffer based hidden surface removal of OpenGL by sorting the geometric primitives so that they can be rendered in a back-to-front order, possibly cutting them into pieces to solve cycles.

VRender is also responsible for the vectorial snapshot feature of the QGLViewer library.

- Participant: Cyril Soler
- Contact: Cyril Soler
- URL: http://artis.imag.fr/Software/VRender/

6.11. X3D TOOLKIT

X3D Development pateform
FUNCTIONAL DESCRIPTION: X3DToolkit is a library to parse and write X3D files, that supports plugins and extensions.

- Participants: Gilles Debunne and Yannick Le Goc
- Contact: Cyril Soler
- URL: http://artis.imag.fr/Software/X3D/

7. New Results

7.1. Expressive Rendering

7.1.1. A workflow for designing stylized shading effects

Participants: Alexandre Bléron, Romain Vergne, Thomas Hurtut, Joëlle Thollot.

In this report [18], we describe a workflow for designing stylized shading effects on a 3D object, targeted at technical artists. Shading design, the process of making the illumination of an object in a 3D scene match an artist vision, is usually a time-consuming task because of the complex interactions between materials, geometry, and lighting environment. Physically based methods tend to provide an intuitive and coherent workflow for artists, but they are of limited use in the context of non-photorealistic shading styles. On the other hand, existing stylized shading techniques are either too specialized or require considerable hand-tuning of unintuitive parameters to give a satisfactory result. Our contribution is to separate the design process of individual shading effects in three independent stages: control of its global behavior on the object, addition of procedural details, and colorization. Inspired by the formulation of existing shading models, we expose different shading behaviors to the artist through parametrizations, which have a meaningful visual interpretation. Multiple shading effects can then be composited to obtain complex dynamic appearances. The proposed workflow is fully interactive, with real-time feedback, and allows the intuitive exploration of stylized shading effects, while keeping coherence under varying viewpoints and light configurations (see Fig. 2). Furthermore, our method makes use of the deferred shading technique, making it easily integrable in existing rendering pipelines.

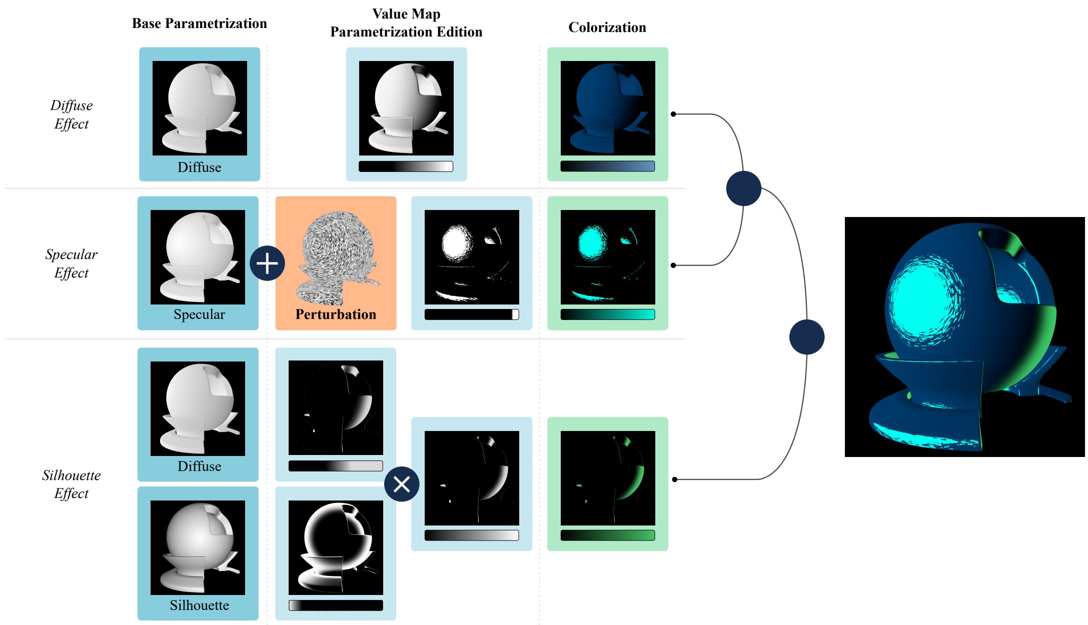


Figure 2. Illustration of our workflow showing an example with three appearance effects. A user can modify and combine base parametrizations to design the shading behavior (blue nodes) of an appearance effect, using value maps and combination operations. A color map (green nodes) is then applied on the designed behavior to colorize the effect. Output effects are then composited to obtain the final appearance. Perturbations (orange nodes) can be attached to every operation in order to add procedural details to an effect. The orientation of the perturbation can be controlled by the gradient of a shading behavior (as shown here), or by an external vector field, such as a tangent map.

7.1.2. MNPR: A framework for real-time expressive non-photorealistic rendering of 3D computer graphics

Participants: Santiago Montesdeoca, Hock Soon Seah, Amir Semmo, Pierre Bénard, Romain Vergne, Joëlle Thollot, Davide Benvenuti.

We propose a framework for expressive non-photorealistic rendering of 3D computer graphics: MNPR. Our work focuses on enabling stylization pipelines with a wide range of control, thereby covering the interaction spectrum with real-time feedback. In addition, we introduce control semantics that allow cross-stylistic art-direction, which is demonstrated through our implemented watercolor, oil and charcoal stylizations (see Fig. 3). Our generalized control semantics and their style-specific mappings are designed to be extrapolated to other styles, by adhering to the same control scheme. We then share our implementation details by breaking down our framework and elaborating on its inner workings. Finally, we evaluate the usefulness of each level of control through a user study involving 20 experienced artists and engineers in the industry, who have collectively spent over 245 hours using our system. MNPR is implemented in Autodesk Maya and open-sourced through this publication, to facilitate adoption by artists and further development by the expressive research and development community. This paper was presented at Expressive [13] and received the best paper award.

Figure 3. A scene rendered through MNPR in different styles. Baba Yaga's hut model, © Inuciian.

7.1.3. Motion-coherent stylization with screen-space image filters

Participants: Alexandre Bléron, Romain Vergne, Thomas Hurtut, Joëlle Thollot.

One of the qualities sought in expressive rendering is the 2D impression of the resulting style, called flatness. In the context of 3D scenes, screen-space stylization techniques are good candidates for flatness as they operate in the 2D image plane, after the scene has been rendered into G-buffers. Various stylization filters can be applied in screen-space while making use of the geometrical information contained in G-buffers to ensure motion coherence. However, this means that filtering can only be done inside the rasterized surface of the object. This can be detrimental to some styles that require irregular silhouettes to be convincing. In this paper, we describe a post-processing pipeline that allows stylization filters to extend outside the rasterized footprint of the object by locally *inflating* the data contained in G-buffers (see Fig. 4). This pipeline is fully implemented on the GPU and can be evaluated at interactive rates. We show how common image filtering techniques, when integrated in our pipeline and in combination with G-buffer data, can be used to reproduce a wide range of *digitally-painted* appearances, such as directed brush strokes with irregular silhouettes, while keeping enough motion coherence. This paper was presented at Expressive [11].

7.2. Illumination simulation and materials

7.2.1. Rendering homogeneous participating media

Participants: Beibei Wang, Nicolas Holzschuch, Liangsheng Ge, Lu Wang.

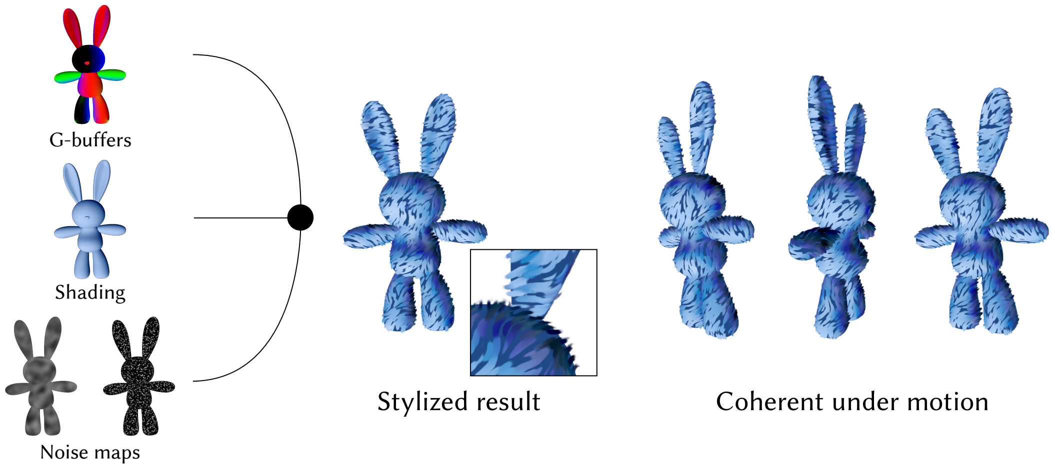


Figure 4. Using standard G-buffers and auxiliary buffers (noise, shading) as input, our pipeline can reproduce stylization effects that extend outside the original rasterized footprint of the object. Visual features produced by the filters stay coherent under motion or viewpoint changes.

Illumination effects in translucent materials are a combination of several physical phenomena: refraction at the surface, absorption and scattering inside the material. Because refraction can focus light deep inside the material, where it will be scattered, practical illumination simulation inside translucent materials is difficult. We have worked on a Point-Based Global Illumination method for light transport on homogeneous translucent materials with refractive boundaries. We start by placing light samples inside the translucent material and organizing them into a spatial hierarchy. At rendering, we gather light from these samples for each camera ray. We compute separately the sample contributions for single, double and multiple scattering, and add them. Multiple scattering effects are precomputed and stores in a table, accessed at runtime. An illustration of our approach is given in Fig 5. We present two implementations of our algorithm: an offline version for high-quality rendering and an interactive GPU implementation. The offline version provides significant speed-ups and reduced memory footprints compared to state-of-the-art algorithms, with no visible impact on quality. The GPU version yields interactive frame rates: 30 fps when moving the viewpoint, 25 fps when editing the light position or the material parameters. This work was published in IEEE Transactions on Visualization and Computer Graphics [9].

Storing the precomputed table for these multiple scattering effects is the largest memory cost for this algorithm. In a separate work, we used a neural network to encode these effects. We replaced the precomputed multiple scattering table with a trained neural network, with a cost of 6490 bytes (1623 floats). At runtime, the neural network is used to generate multiple scattering. The approach can be combined with many rendering algorithms, as illustrated in Fig. 6. This work was published as a Siggraph Talk [12].

7.2.2. Fast global illumination with discrete stochastic microfacets using a filterable model

Participants: Beibei Wang, Lu Wang, Nicolas Holzschuch.

Many real-life materials have a sparkling appearance, whether by design or by nature. Examples include metallic paints, sparkling varnish but also snow. These sparkles correspond to small, isolated, shiny particles reflecting light in a specific direction, on the surface or embedded inside the material. The particles responsible for these sparkles are usually small and discontinuous. These characteristics make it difficult to integrate them efficiently in a standard rendering pipeline, especially for indirect illumination. Existing approaches use a 4-dimensional hierarchy, searching for light-reflecting particles simultaneously in space and direction. The

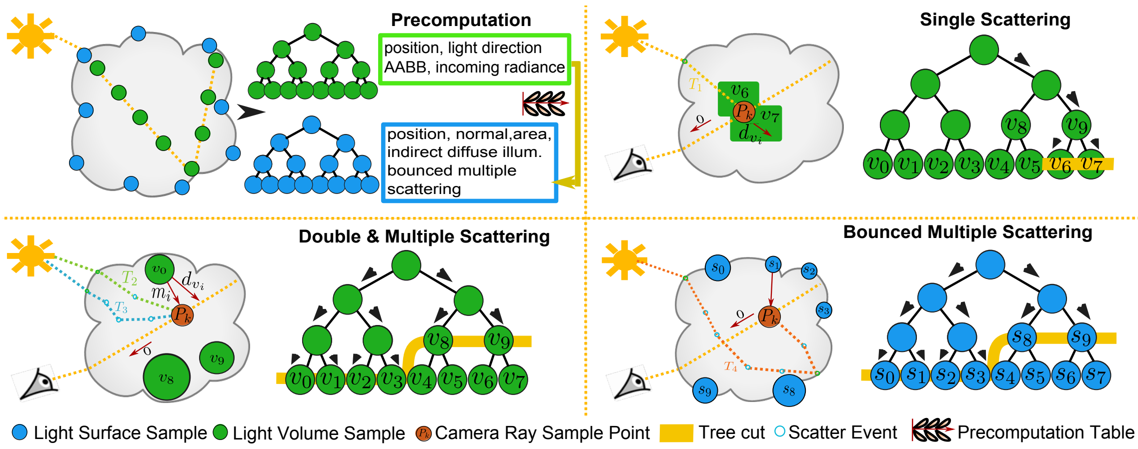


Figure 5. Our algorithm: we begin by computing incoming light at volume and surface samples. We then compute Single-, Double- and Multiple scattering effects for each camera ray using these volume and surface samples.

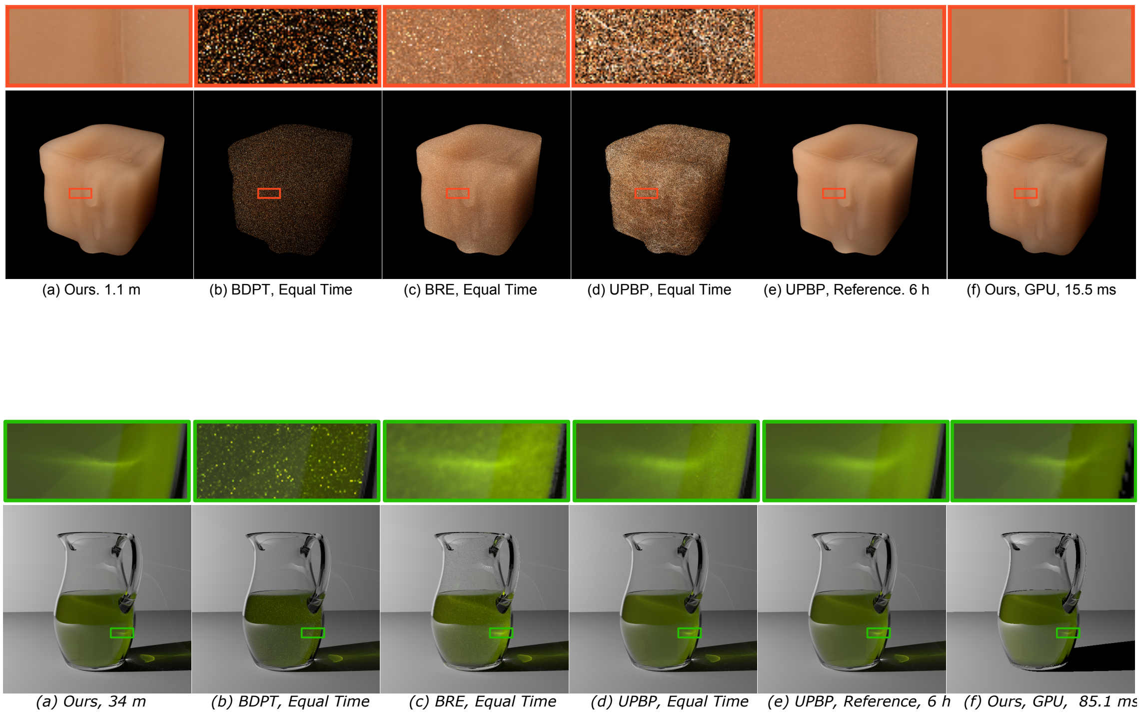


Figure 6. comparison between our algorithm, other algorithms with equal time or equal quality and reference images. Top row: wax. For this material, with a large albedo and a small mean free path, multiple scattering effects dominate. Bottom row: olive oil. For this material with low albedo and large mean-free-path, low-order scattering effects dominate.

approach is accurate, but still expensive. We have shown that this 4-dimensional search can be approximated using separate 2-dimensional steps. This approximation allows fast integration of glint contributions for large footprints, reducing the extra cost associated with glints be an order of magnitude, as illustrated in Fig. 7. This work was published in Computer Graphics Forum and presented at the Pacific Graphics conference [10].

Figure 7. Our algorithm, compared to the original Discrete Stochastic Microfacets model (c). Converting the 4D search to a product of 2D searches (b) produces almost identical results. This is the basis for our filterable model (a), which allows fast global illumination with negligible cost..

7.2.3. Handling fluorescence in a uni-directional spectral path tracer

Participants: Michal Mojzík, Alban Fichet, Alexander Wilkie

We present two separate improvements to the handling of fluorescence effects in modern uni-directional spectral rendering systems.

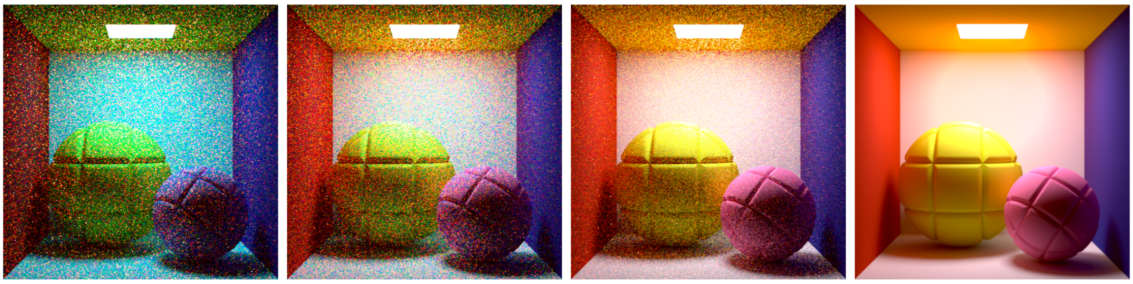
The first is the formulation of a new distance tracking scheme for fluorescent volume materials which exhibit a pronounced wavelength asymmetry. Such volumetric materials are an important and not uncommon corner case of wavelength-shifting media behaviour, and have not been addressed so far in rendering literature. This new tracking scheme (figure 8(b)) converges faster than a simple modification that can be added to the traditional exponential tracking (figure 8(a)).

The second one is that we introduce an extension of Hero wavelength sampling which can handle fluorescence events, both on surfaces, and in volumes. Both improvements are useful by themselves, and can be used separately: when used together, they enable the robust inclusion of arbitrary fluorescence effects in modern uni-directional spectral MIS path tracers (figure 8(c)). Our extension of Hero wavelength sampling is generally useful, while our proposed technique for distance tracking in strongly asymmetric media is admittedly not very efficient. However, it makes the most of a rather difficult situation, and at least allows the inclusion of such media in uni-directional path tracers, albeit at comparatively high cost. Which is still an improvement since up to now, their inclusion was not really possible at all, due to the inability of conventional tracking schemes to generate sampling points in such volume materials. This work was published in the journal Computer Graphics Forum [6].

7.2.4. A versatile parameterization for measured material manifolds

Participants: Cyril Soler, Kartic Subr, Derek Nowrouzezahrai.

A popular approach for computing photorealistic images of virtual objects requires applying reflectance profiles measured from real surfaces, introducing several challenges: the memory needed to faithfully capture realistic material reflectance is large, the choice of materials is limited to the set of measurements, and image synthesis using the measured data is costly. Typically, this data is either compressed by projecting it onto a subset of its linear principal components or by applying non-linear methods. The former requires many components to faithfully represent the input reflectance, whereas the latter necessitates costly extrapolation



(a) $\max(\sigma_t, \sigma_s$, 16 spp, mono
(b) Fluorescent-aware, 16 spp, mono
(c) Fluo-aware, 16spp, HWSS
(d) Fluo-aware, 65000 spp, HWSS

Figure 8. Comparison of proposed techniques to improve rendering of fluorescence.

algorithms. We learn an underlying, low-dimensional non-linear reflectance manifold amenable to rapid exploration and rendering of real-world materials. We can express interpolated materials as linear combinations of the measured data, despite them lying on an inherently non-linear manifold. This allows us to efficiently interpolate and extrapolate measured BRDFs, and to render directly from the manifold representation. We exploit properties of Gaussian process latent variable models and use our representation for high-performance and offline rendering with interpolated real-world materials. This work has been published in the journal Computer Graphics Forum [7], and presented at Eurographics 2018.

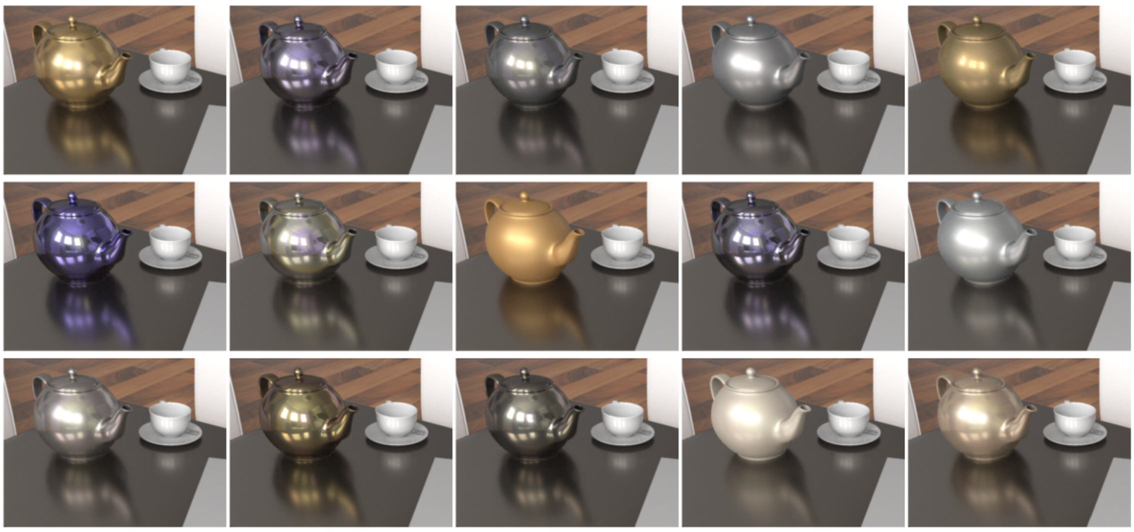


Figure 9. Four of the images above (Number 2, 4, 6 and 12 in reading order) are rendered with measured BRDFs from the MERL dataset, the remaining 11 being rendered with BRDFs randomly picked from our parameterization of the non-linear manifold containing MERL materials. We explore this manifold interactively to produce high-quality BRDFs which retain the physical properties and perceptual aspect of real materials.

7.3. Complex scenes

7.3.1. A new microflake model with microscopic self-shadowing for accurate volume downsampling

Participants: Guillaume Loubet, Fabrice Neyret.

In this work, we addressed the problem of representing the effect of internal self-shadowing in elements about to be filtered out at a given LOD, in the scope of volume of voxels containing density and phase-function (represented by a microflakes).

Naïve linear methods for downsampling high resolution microflake volumes often produce inaccurate results, especially when input voxels are very opaque. Preserving correct appearance at all resolutions requires taking into account inter- and intravoxel self-shadowing effects (see Figure 10). We introduce a new microflake model whose parameters characterize self-shadowing effects at the microscopic scale. We provide an anisotropic self-shadowing function and a microflake distribution for which scattering coefficients and phase functions of our model have closed-form expressions. We use this model in a new downsampling approach in which scattering parameters are computed from local estimations of self-shadowing in the input volume. Unlike previous work, our method handles datasets with spatially varying scattering parameters, semi-transparent volumes and datasets with intricate silhouettes. We show that our method generates LoDs with correct transparency and consistent appearance through scales for a wide range of challenging datasets, allowing for huge memory savings and efficient distant rendering without loss of quality. This work received the Best Paper Award at Eurographics 2018 and was published in the journal Computer Graphics Forum [5].

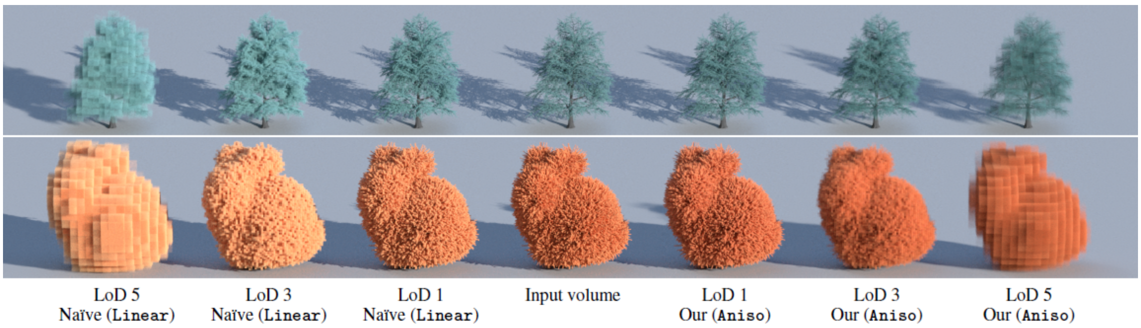


Figure 10. Comparison between naïve downsampling of microflake volumes and our method ("Aniso"). Naïve dowsampling of volumes with dense voxels often lead to inaccurate results due to the loss of inter- and intra-voxel self-shadowing effects. Our method is based on a new participating medium model and on local estimations of self-shadowing. It generates LoDs with correct transparency and consistent appearance through scales. Rendered with volume path tracing in Mitsuba (http://www.mitsuba-renderer.org/): the trunk of the cedar is a mesh.

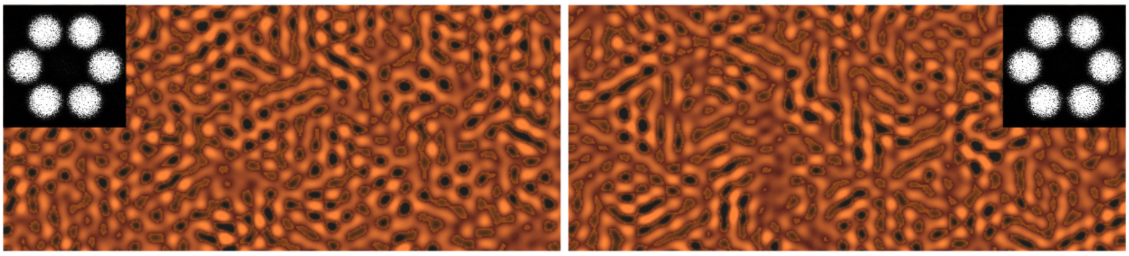
7.4. Texture synthesis

7.4.1. Gabor noise revisited

Participants: Vincent Tavernier, Fabrice Neyret, Romain Vergne, Joëlle Thollot.

Gabor Noise is a powerful procedural texture synthesis technique, but has two major drawbacks: It is costly due to the high required splat density and not always predictable because properties of instances can differ from those of the process. We bench performance and quality using alternatives for each Gabor Noise ingredient: point distribution, kernel weighting and kernel shape. For this, we introduce 3 objective criteria to measure process convergence, process stationarity, and instance stationarity. We show that minor implementation changes allow for $17-24\times$ speed-up with same or better quality (see Fig. 11).

This paper was presented at AFIG [17] and received the best paper award. An article has been submitted to Eurographics-short 2019.



(a) Seminal Gabor, $N = 45$ (b) Bernoulli+strat.+sin, $N = 3$

Figure 11. Real case with complex power spectrum (3 kernels, cf. inset) and non-linear post-treatment. Our optimized set of ingredients achieves the same visual quality in $1/17^{th}$ of the time required by the seminal method.

7.4.2. High-performance by-example noise using a histogram-preserving blending operator

Participants: Eric Heitz, Fabrice Neyret.

We propose a new by-example noise algorithm that takes as input a small example of a stochastic texture and synthesizes an infinite output with the same appearance. It works on any kind of random-phase inputs as well as on many non-random-phase inputs that are stochastic and non-periodic, typically natural textures such as moss, granite, sand, bark, etc. Our algorithm achieves high-quality results comparable to state-of-the-art procedural-noise techniques but is more than 20 times faster. Our approach is conceptually simple: we partition the output texture space on a triangle grid and associate each vertex with a random patch from the input such that the evaluation inside a triangle is done by blending 3 patches. The key to this approach is the blending operation that usually produces visual artifacts such as ghosting, softened discontinuities and reduced contrast, or introduces new colors not present in the input. We analyze these problems by showing how linear blending impacts the histogram and show that a blending operator that preserves the histogram prevents these problems. The main requirement for a rendering application is to implement such an operator in a fragment shader without further post-processing, i.e. we need a histogram-preserving blending operator that operates only at the pixel level. Our insight for the design of this operator is that, with Gaussian inputs, histogram-preserving blending boils down to mean and variance preservation, which is simple to obtain analytically. We extend this idea to non-Gaussian inputs by "Gaussianizing" them with a histogram transformation and "de-Gaussianizing" them with the inverse transformation after the blending operation. We show how to precompute and store these histogram transformations such that our algorithm can be implemented in a fragment shader, as illustrated in Fig. 12. This work received the Best Paper Award at High Performance Graphics 2018 [4].

7.5. Visualization

7.5.1. A "What if" approach for eco-feedback

Participants: Jérémy Wambecke, Georges-Pierre Bonneau, Romain Vergne, Renaud Blanch.

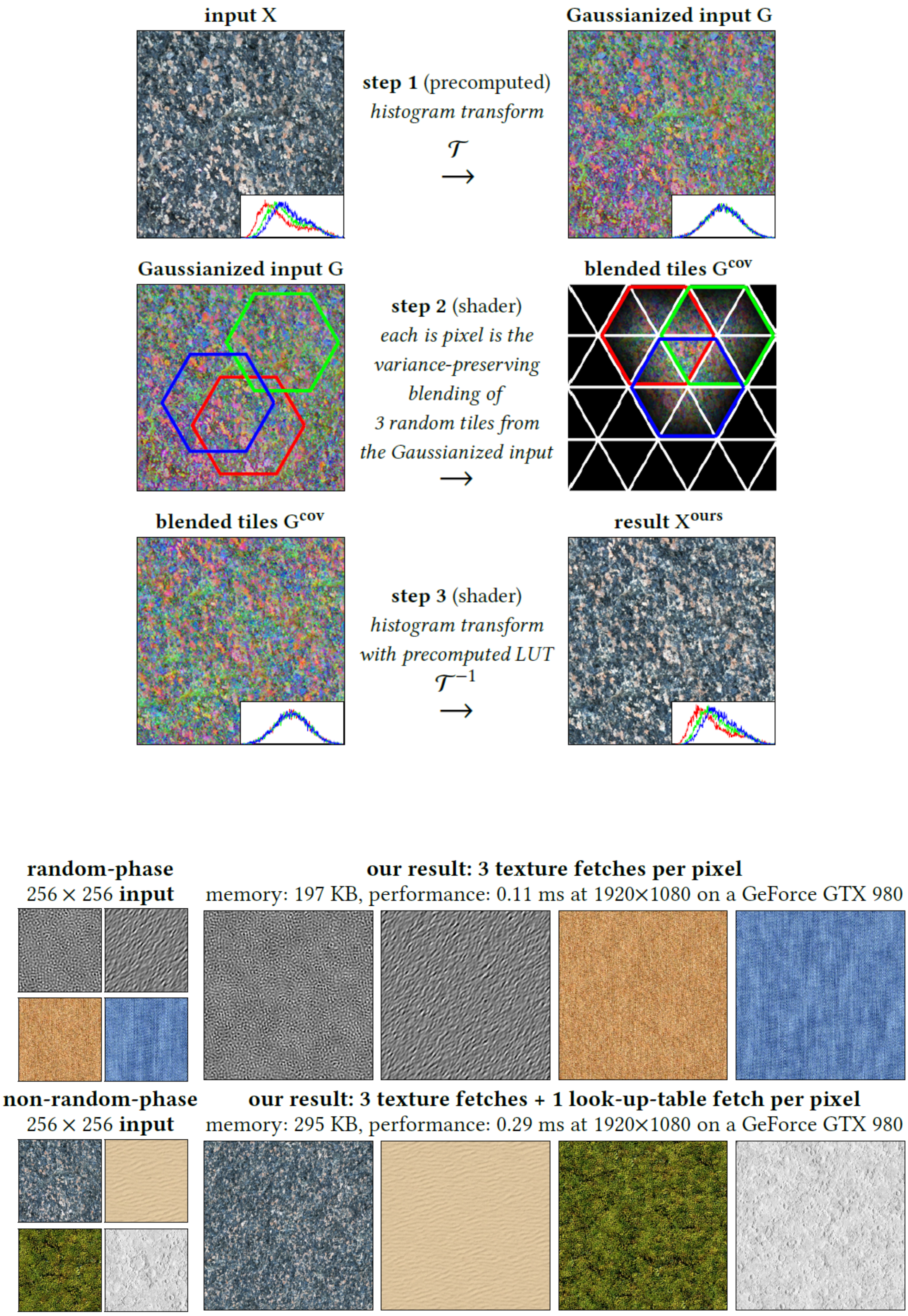


Figure 12. Top: method overview. Bottom: results and performances.

Many households share the objective of reducing electricity consumption for either economic or ecological motivations. Eco-feedback technologies support this objective by providing users with a visualization of their consumption. However as pointed out by several studies, users encounter difficulties in finding concrete actions to reduce their consumption. To overcome this limitation, we introduce and evaluate Activelec, a system based on the visualization and interaction with user's behavior rather than raw consumption data. The user's behavior is modeled as the set of actions modifying the state of appliances over time. A key novelty of our solution is its focus on the What if approach applied to eco-feedback. Users can analyze and experiment scenarios by selecting and modifying their usage of electrical appliances over time and visualize the impact on the consumption, as illustrated in Fig. 13. In [16] we conducted two laboratory user studies that evaluate the usability of Activelec and the relevance of the What if approach for electricity consumption. Our results show that users understand the interaction paradigm and can easily find relevant modifications in their usage of appliances. Moreover participants judge these changes of behavior would require little effort to be adopted. In [15] we conducted an in-situ evaluation of Activelec, confirming these results in a real setting.

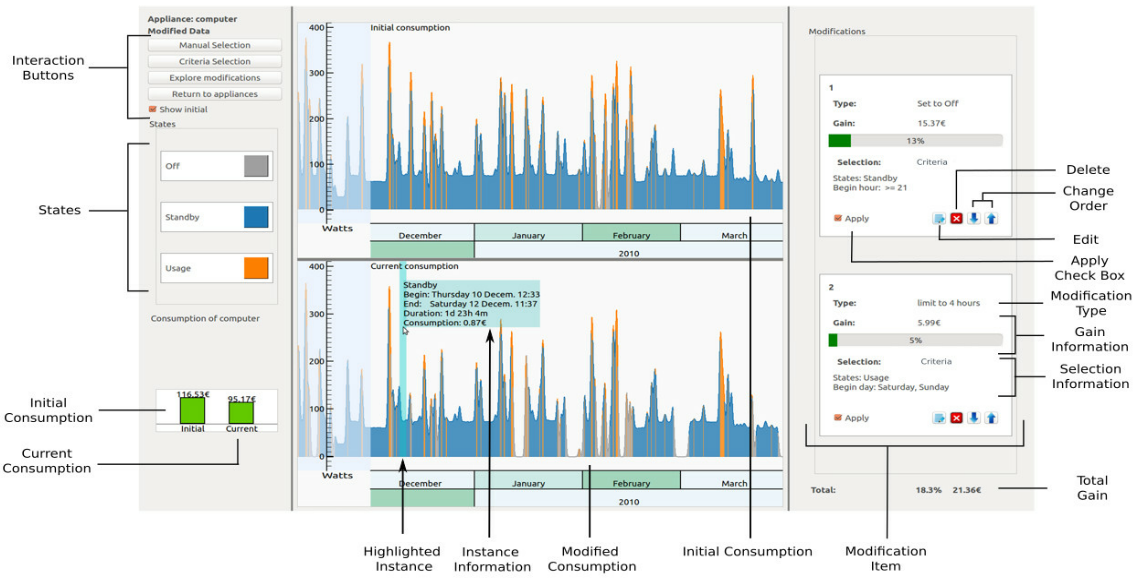


Figure 13. Interface of our system. A computer has been chosen by the user, whose states are Usage (orange) and Standby (blue). At the right, we can see that the user has applied two modifications, the first one to remove instances of Standby after 9 P.M, and the second one to limit the instances of On to 4 hours during the weekend. When the user is selecting instances, this panel displays information about the selection.

7.5.2. Morphorider: a new way for Structural Monitoring via Shape Acquisition

Participants: Tibor Stanko, Laurent Jouanet, Nathalie Saguin-Sprynski, Georges-Pierre Bonneau, Stefanie Hahmann.

In collaboration with CEA-Leti we introduce a new kind of monitoring device, illustrated in Fig. 14, allowing the shape acquisition of a structure via a single mobile node of inertial sensors and an odometer. Previous approaches used devices placed along a network with fixed connectivity between the sensor nodes (lines, grid). When placed onto a shape, this sensor network provides local surface orientations along a curve network on the shape, but its absolute position in the world space is unknown. The new mobile device provides a novel way of structures monitoring: the shape can be scanned regularly, and following the shape or some specific parameters along time may afford the detection of early signs of failure. Here, we present a complete framework for 3D shape reconstruction. To compute the shape, our main insight is to formulate the reconstruction as a set of optimization problems. Using discrete representations, these optimization problems are resolved efficiently and at interactive time rates. We present two main contributions. First, we introduce a novel method for creating well-connected networks with cell-complex topology using only orientation and distance measurements and a set of user-defined constraints. Second, we address the problem of surfacing a closed 3D curve network with given surface normals. The normal input increases shape fidelity and allows to achieve globally smooth and visually pleasing shapes. The proposed framework was tested on experimental data sets acquired using our device. A quantitative evaluation was performed by computing the error of reconstruction for our own designed surfaces, thus with known ground truth. Even for complex shapes, the mean error remains around 1%. This work was published at the 9th European Workshop on Structural Health Monitoring [14].

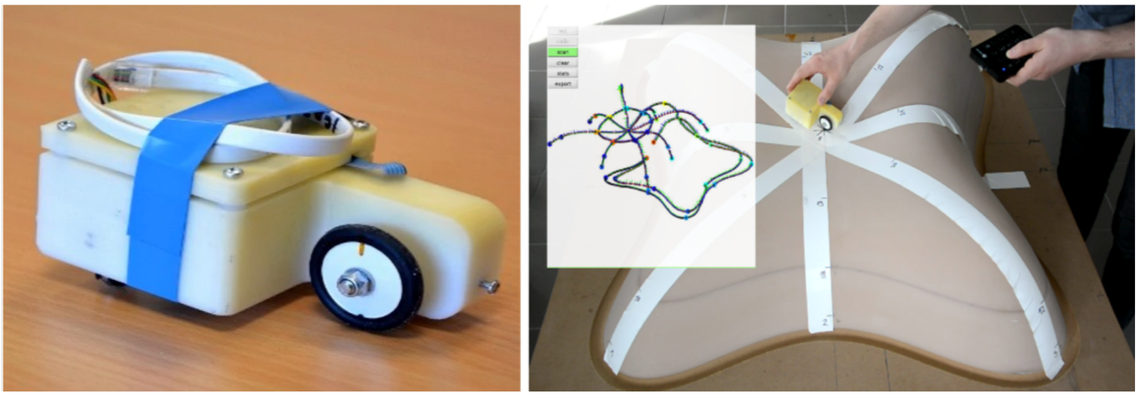


Figure 14. Morphorider: Structural Monitoring via Shape Acquisition (right) with a mobile device (left) equipped with an inertial node of sensors and an odometer.

8. Partnerships and Cooperations

8.1. Regional Initiatives

We have frequent exchanges and on-going collaborations with Cyril Crassin from nVIDIA-Research, and Eric Heitz, Laurent Belcour, Jonathan Dupuy and Kenneth Vanhoey from Unity-Research. Maverick is part of the GPU Research Center labeled by nVIDIA at Inria Grenoble. Team contact: Fabrice Neyret.

8.2. National Initiatives

8.2.1. ANR: Materials

Participants: Nicolas Holzschuch [contact], Romain Vergne.

We are funded by the ANR for a joint research project on acquisition and restitution of micro-facet based materials. This project is in cooperation with Océ Print Logic technologies, the Museum of Ethnography at the University of Bordeaux and the Manao team at Inria Bordeaux. The grant started in October 2015, for 48 months.

8.2.2. CDP: Patrimalp 2.0

Participants: Nicolas Holzschuch [contact], Romain Vergne.

The main objective and challenge of Patrimalp 2.0 is to develop a cross-disciplinary approach in order to get a better knowledge of the material cultural heritage in order to ensure its sustainability, valorization and diffusion in society. Carried out by members of UGA laboratories, combining skills in human sciences, geosciences, digital engineering, material sciences, in close connection with stakeholders of heritage and cultural life, curators and restorers, Patrimalp 2.0 intends to develop of a new interdisciplinary science: Cultural Heritage Science. The grant starts in January 2018, for a period of 48 months.

8.2.3. ANR: CaLiTrOp

Participant: Cyril Soler [contact].

Computing photorealistic images relies on the simulation of light transfer in a 3D scene, typically modeled using geometric primitives and a collection of reflectance properties that represent the way objects interact with light. Estimating the color of a pixel traditionally consists in integrating contributions from light paths connecting the light sources to the camera sensor at that pixel.

In this ANR we explore a transversal view of examining light transport operators from the point of view of infinite dimensional function spaces of light fields (imagine, e.g., reflectance as an operator that transforms a distribution of incident light into a distribution of reflected light). Not only are these operators all linear in these spaces but they are also very sparse. As a side effect, the sub-spaces of light distributions that are actually relevant during the computation of a solution always boil down to a low dimensional manifold embedded in the full space of light distributions.

Studying the structure of high dimensional objects from a low dimensional set of observables is a problem that becomes ubiquitous nowadays: Compressive sensing, Gaussian processes, harmonic analysis and differential analysis, are typical examples of mathematical tools which will be of great relevance to study the light transport operators.

Expected results of the fundamental-research project CALiTrOp, are a theoretical understanding of the dimensionality and structure of light transport operators, bringing new efficient lighting simulation methods, and efficient approximations of light transport with applications to real time global illumination for video games.

8.3. International Initiatives

8.3.1. Inria International Partners

8.3.1.1. Declared Inria International Partners

Title: “MAIS”: Mathematical Analysis of Image SynthesisInternational Partner (Institution - Laboratory - Researcher):

University of Montreal (Canada) - Département d’Informatique et Recherche Opérationnelle - Derek Nowrouzezahrai
Duration: 2015 - 2019

8.4. International Research Visitors

8.4.1. Visits to International Teams

8.4.1.1. Research Stays Abroad

Alban Fichet has returned in October 2018 from a 12 months research stay at Charles University in Prague, to work with Alexander Wilkie and Jaroslav Krivanek on material models.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

- Nicolas Holzschuch is a member of the steering committee for the Eurographics Working Group on Rendering.

9.1.2. Scientific Events Selection

9.1.2.1. Member of the Conference Program Committees

- Georges-Pierre Bonneau: *Solid and Physical Modeling* 2018, *Shape Modeling International* 2018, *EnvirVis* 2018, Short paper track for *Eurographics Visualization Symposium* 2018,
- Joëlle Thollot: *Expressive* 2018.

9.1.3. Journal

9.1.3.1. Reviewer - Reviewing Activities

All members of the Maverick team work as reviewers for the most prestigious journals, including ACM TOG, IEEE TVCG, etc.

9.1.4. Research Administration

- Georges-Pierre Bonneau is member of the “conseil du Laboratoire Jean Kuntzmann”.
- Romain Vergne is member of the “conseil du Laboratoire Jean Kuntzmann”.
- Romain Vergne is co-responsible of the GT Rendu.
- Romain Vergne is co-responsible of the PhD students of the Laboratoire Jean Kuntzmann.
- Nicolas Holzschuch is an elected member of Inria Evaluation Committee (CE), an elected member of Inria Comité Technique (CTI) and a reserve member of Inria Scientific Council (CS).
- Nicolas Holzschuch is responsible for the department "Geometry and Images" of the Laboratoire Jean Kuntzmann.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Joëlle Thollot and Georges-Pierre Bonneau are both full Professor of Computer Science. Romain Vergne is an associate professor in Computer Science. They teach general computer science topics at basic and intermediate levels, and advanced courses in computer graphics and visualization at the master levels. Nicolas Holzschuch teaches advanced courses in computer graphics at the Master level.

Licence: Joëlle Thollot, Théorie des langages, 27h, L3, ENSIMAG, France

Licence: Joëlle Thollot, Séminaire d’innovation, 10h, L3, ENSE3, France

Master: Joëlle Thollot, Responsable de la flière MMIS (Modélisation mathématique, image, simulation) 24h, M1-M2, ENSIMAG, France

Master: Joëlle Thollot, Tutorat d’apprentis, 10h, M1-M2, ENSIMAG, France

Licence : Romain Vergne, Introduction to algorithms, 64h, L1, UGA, France.

Licence : Romain Vergne, WebGL, 29h, L3, IUT2 Grenoble, France.

Master : Romain Vergne, Geometric modeling, 18h, M1, UGA, France.

Master : Romain Vergne, Image synthesis, 27h, M1, UGA, France.

Master : Romain Vergne, Image synthesis, 15h, M1, Polytech, France.

Master : Romain Vergne, 3D graphics, 15h, M1, UGA, France.

Master : Nicolas Holzschuch, Computer Graphics II, 18h, M2 MoSIG, France.

Master : Nicolas Holzschuch, Synthèse d'Images et Animation, 32h, M2, ENSIMAG, France.

Licence: Georges-Pierre Bonneau, Algorithmique et Programmation Impérative, 23h, L3, Polytech-Grenoble, France.

Master: Georges-Pierre Bonneau, responsable de la 4ième année du département INFO, 32h, M1, Polytech-Grenoble, France

Master: Georges-Pierre Bonneau, Image Synthesis, 23h, M1, Polytech-Grenoble, France

Master: Georges-Pierre Bonneau, Data Visualization, 40h, M2, Polytech-Grenoble, France

Master: Georges-Pierre Bonneau, Digital Geometry, 23h, M1, UGA

Master: Georges-Pierre Bonneau, Information Visualization, 22h, Mastere, ENSIMAG, France.

Master: Georges-Pierre Bonneau, Scientific Visualization, M2, ENSIMAG, France.

Master: Georges-Pierre Bonneau, Computer Graphics II, 18h, M2 MoSiG, UGA, France.

9.2.2. Supervision

PhD: Guillaume Loubet, Efficient representations for sub-pixel appearence, 25/06/2018, Fabrice Neyret

PhD: Jérémy Wambecke, Visualisation de Données Temporelles Personnelles, 22/10/2018, Georges-Pierre Bonneau, Romain Vergne, Renaud Blanch

PhD: Alexandre Bléron, Stylization of animated 3D scenes in a painterly style, 8/11/2018, Joëlle Thollot, Romain Vergne

PhD in progress: Alban Fichet, Efficient representation for measured reflectance, 1/10/2015 Nicolas Holzschuch.

PhD in progress: Vincent Tavernier, Procedural stochastic textures, 1/10/2017, Fabrice Neyret, Joëlle Thollot, Romain Vergne.

PhD in progress: Sunrise Wang, Light transport operators simplification using neural networks, 1/9/2018, Nicolas Holzschuch

PhD in progress: Morgane Gérardin, Connecting physical and chemical properties with material appearance, 1/10/2018, Nicolas Holzschuch

PhD in progress: Ronak Molazem, Dimensional Analysis of Light Transport, 1/09/2018, Cyril Soler

9.2.3. Juries

Nicolas Holzschuch, member of the jury and referee, PhD of Laurent Gilles, Telecom Paristech, 12/11/2018

Nicolas Holzschuch, member of the jury and referee, PhD of Hélène Perrier, University of Lyon, 7/3/2018

Joëlle Thollot, member of the jury and referee, PhD of Jean-Dominique Favreau (Inria Sophia-Antipolis) 15/03/2018,

Joëlle Thollot, member of the jury, HdR of Aurélie BUGEAU, University of Bordeaux, 30/05/2018

Georges-Pierre Bonneau, president of the jury, PhD of Ali Jabbari, University of Grenoble, 4/07/2018

Georges-Pierre Bonneau, member of the jury, HdR of Basile Sauvage, University of Strasbourg, 16/07/2018

Georges-Pierre Bonneau, president of the jury, PhD of Even Enthem, University of Grenoble, 26/10/2018

9.3. Popularization

Every year, “MobiNet” (see section 6.7) classes are conducted with high school pupils of the large Grenoble area to practice initiation and intuition on Computer Science, Maths and Physics. Depending on the year, we have 2 to 4 groups in the scope of INP-Grenoble “Enginneering weeks”, and 0 to 2 groups in the scope of Math-C2+ operations.

Fabrice Neyret published a popularization article "Le mouvement sous toutes ses coutures" [19] in the booklet "Maths Mouvement Express 2018".

Fabrice Neyret maintains the blog shadertoyunofficial (https://shadertoyunofficial.wordpress.com/) and various shaders examples on Shadertoy site (https://www.shadertoy.com/) to popularize GPU technologies as well as disseminates academic models within computer graphics, computer science, applied math and physics fields.

Cyril Soler presented at FOSDEM2018 his work on privacy preserving data distribution over decentralized mesh networks ([https://www.youtube.com/watch?v=FR9SSdGN0K8]).

10. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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[2] G. LOUBET. *Efficient models for representing sub-pixel appearances*, Université Grenoble Alpes, June 2018, https://tel.archives-ouvertes.fr/tel-01849666

[3] J. WAMBECKE. *Visualization of personal time-dependent data*, Université Grenoble Alpes, October 2018, https://tel.archives-ouvertes.fr/tel-02007675

Articles in International Peer-Reviewed Journals

[4] E. HEITZ, F. NEYRET. *High-Performance By-Example Noise using a Histogram-Preserving Blending Operator*, in "Proceedings of the ACM on Computer Graphics and Interactive Techniques", August 2018, vol. 1, n^{o} 2, Article No. 31:1-25 [*DOI :* 10.1145/3233304], https://hal.inria.fr/hal-01824773

[5] G. LOUBET, F. NEYRET. *A new microflake model with microscopic self-shadowing for accurate volume downsampling*, in "Computer Graphics Forum", May 2018, vol. 37, n^{o} 2, pp. 111-121 [*DOI :* 10.1111/CGF.13346], https://hal.archives-ouvertes.fr/hal-01702000

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[7] C. SOLER, K. SUBR, D. NOWROUZEZAHRAI. *A Versatile Parameterization for Measured Material Manifolds*, in "Computer Graphics Forum", April 2018, vol. 37, n^{o} 2, pp. 135-144 [*DOI :* 10.1111/CGF.13348], https://hal.inria.fr/hal-01702722

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[11] A. BLÉRON, R. VERGNE, T. HURTUT, J. THOLLOT. *Motion-coherent stylization with screen-space image filters*, in "Expressive '18 - The Joint Symposium on Computational Aesthetics and Sketch Based Interfaces and Modeling and Non-Photorealistic Animation and Rendering", Victoria, Canada, ACM, August 2018, pp. 1-13 [*DOI :* 10.1145/3229147.3229163], https://hal.inria.fr/hal-01826558

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