Activity Report 2015

Project-Team GRAPHDECO

GRAPHics and DEsign with hEterogeneous COntent

RESEARCH CENTER
Sophia Antipolis - Méditerranée

THEME
Interaction and visualization

Table of contents

Project-Team GRAPHDECO

Creation of the Team: 2015 January 01, updated into Project-Team: 2015 July 01

Keywords:

Computer Science and Digital Science:

3.1.4. - Uncertain data
5. - Interaction, multimedia and robotics
5.1. - Human-Computer Interaction
5.1.1. - Engineering of interactive systems
5.3.5. - Computational photography
5.5. - Computer graphics
5.5.2. - Rendering
5.5.3. - Computational photography
5.6. - Virtual reality, augmented reality

Other Research Topics and Application Domains:

5. - Industry of the future
5.2. - Design and manufacturing
5.7. - 3D printing
8. - Smart Cities and Territories
8.3. - Urbanism and urban planning
9. - Society and Knowledge
9.1.2. - Serious games
9.2. - Art
9.2.2. - Cinema, Television
9.2.3. - Video games
9.5. - Humanities
9.5.6. - Archeology, History

1. Members

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2. Overall Objectives

2.1. General Presentation

In traditional Computer Graphics (CG) input is *accurately modeled* by hand by artists. The artists first create the 3D geometry – i.e., the polygons and surfaces used to represent the 3D scene. They then need to assign colors, textures and more generally material properties to each piece of geometry in the scene. Finally they also define the position, type and intensity of the lights. This modeling process is illustrated schematically in Fig. 1(left)). Creating all this 3D content involves a high level of training and skills, and is reserved to a small minority of expert modelers. This tedious process is a significant distraction for creative exploration, during which artists and designers are primarily interested in obtaining compelling imagery and prototypes rather than in accurately specifying all the ingredients listed above. Designers also often want to explore many variations of a concept, which requires them to repeat the above steps multiple times.

Once the 3D elements are in place, a *rendering* algorithm is employed to generate a shaded, realistic image (Fig. 1(right)). Costly rendering algorithms are then required to simulate light transport (or *global illumination*) from the light sources to the camera, accounting for the complex interactions between light and materials and the visibility between objects. Such rendering algorithms only provide meaningful results if the input has been *accurately* modeled and is *complete*, which is prohibitive as discussed above.

A major recent development is that many alternative sources of 3D content are becoming available. Cheap depth sensors allow anyone to capture real objects but the resulting 3D models are often *uncertain*, since the reconstruction can be inaccurate and is most often incomplete. There have also been significant advances in casual content creation, e.g., sketch-based modeling tools. The resulting models are often approximate since people rarely draw accurate perspective and proportions. These models also often lack details, which can be seen as a form of uncertainty since a variety of refined models could correspond to the rough one. Finally, in recent years we have witnessed the emergence of new usage of 3D content for rapid prototyping, which aims at accelerating the transition from rough ideas to physical artifacts.

The inability to handle *uncertainty* in the data is a major shortcoming of CG today as it prevents the direct use of cheap and casual sources of 3D content for the design and rendering of high-quality images. The abundance and ease of access to *inaccurate*, *incomplete* and *heterogeneous* 3D content imposes the need to *rethink the foundations of 3D computer graphics* to allow *uncertainty* to be treated in inherent manner in Computer Graphics, from design all the way to rendering and prototyping.

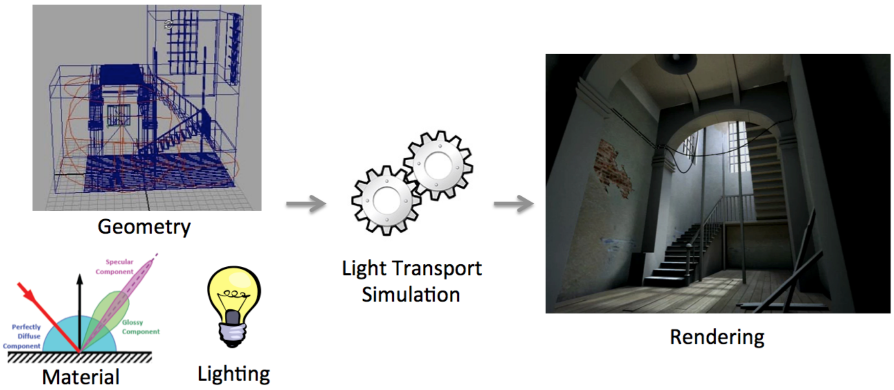


Figure 1. Traditional computer graphics pipeline. Rendering from www.thegnomonworkshop.com

The technological shifts we mention above, together with developments in computer vision, user-friendly sketch-based modeling, online tutorials, but also image, video and 3D model repositories and 3D printing represent a great opportunity for new imaging methods. There are several significant challenges to overcome before such visual content can become widely accessible.

In GraphDeco, we have identified two major scientific challenges of our field which we will address:

- First, the design pipeline needs to be revisited to **explicitly account for the variability and uncertainty of a concept and its representations**, from early sketches to 3D models and prototypes. Professional practice also needs to be adapted and facilitated to be accessible to all.
- Second, a new approach is required to **develop computer graphics models and algorithms capable of handling uncertain and heterogeneous data** as well as traditional synthetic content.

We next describe the context of our proposed research for these two challenges. Both directions address hetereogeneous and uncertain input and (in some cases) output, and build on a set of common methodological tools.

3. Research Program

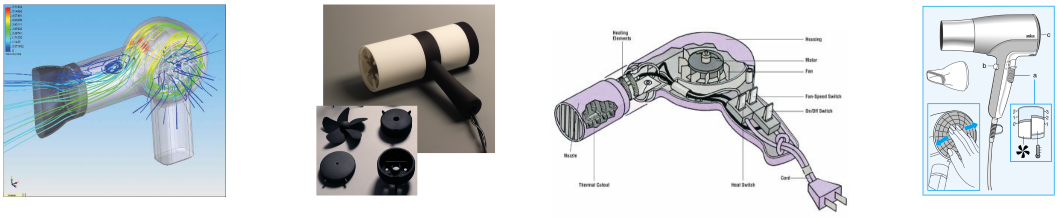
3.1. Introduction

Our research program is oriented around two main axes: 1) Computer-Assisted Design with Heterogeneous Representations and 2) Graphics with Uncertainty and Heterogeneous Content. These two axes are governed by a set of common fundamental goals, share many common methodological tools and are deeply intertwined in the development of applications.

3.1.1. Computer-Assisted Design with Heterogeneous Representations

Designers use a variety of visual representations to explore and communicate about a concept. Figure 2 illustrates some typical representations, including sketches, hand-made prototypes, 3D models, 3D printed prototypes or instructions.

(a) Ideation sketch (b) Presentation sketch (c) Coarse prototype (d) 3D model



(f) Simulation (e) 3D Printing (g) Technical diagram (h) Instructions

Figure 2. Various representations of a hair dryer at different stages of the design process. Image source, in order: c-maeng on deviantart.com, shauntur on deviantart.com, "Prototyping and Modelmaking for Product Design" Hallgrimsson, B., Laurence King Publishers, 2012, samsher511 on turbosquid.com, my.solidworks.com, weilung tseng on cargocollective.com, howstuffworks.com, u-manual.com

The early representations of a concept, such as rough sketches and hand-made prototypes, help designers formulate their ideas and test the form and function of multiple design alternatives. These low-fidelity representations are meant to be cheap and fast to produce, to allow quick exploration of the *design space* of the concept. These representations are also often approximate to leave room for subjective interpretation and to stimulate imagination; in this sense, these representations can be considered *uncertain*. As the concept gets more finalized, time and effort are invested in the production of more detailed and accurate representations, such as high-fidelity 3D models suitable for simulation and fabrication. These detailed models can also be used to create didactic instructions for assembly and usage.

Producing these different representations of a concept requires specific skills in sketching, modeling, manufacturing and visual communication. For these reasons, professional studios often employ different experts to produce the different representations of the same concept, at the cost of extensive discussions and numerous iterations between the actors of this process. The complexity of the multi-disciplinary skills involved in the design process also hinders their adoption by laymen.

Existing solutions to facilitate design have focused on a subset of the representations used by designers. However, no solution considers all representations at once, for instance to directly convert a series of sketches into a set of physical prototypes. In addition, all existing methods assume that the concept is unique rather than ambiguous. As a result, rich information about the variability of the concept is lost during each conversion step.

We plan to facilitate design for professionals and laymen by adressing the following objectives:

- We want to assist designers in the exploration of the *design space* that captures the possible variations of a concept. By considering a concept as a *distribution* of shapes and functionalities rather than a single object, our goal is to help designers consider multiple design alternatives more quickly and effectively. Such a representation should also allow designers to preserve multiple alternatives along all steps of the design process rather than committing to a single solution early on and pay the price of this decision for all subsequent steps. We expect that preserving alternatives will facilitate communication with engineers, managers and clients, accelerate design iterations and even allow mass personalization by the end consumers.
- We want to support the various representations used by designers during concept development. While drawings and 3D models have received significant attention in past Computer Graphics research, we will also account for the various forms of rough physical prototypes made to evaluate the shape and functionality of a concept. Depending on the task at hand, our algorithms will either analyse these prototypes to generate a virtual concept, or assist the creation of these prototypes from a virtual model. We also want to develop methods capable of adapting to the different drawing and manufacturing techniques used to create sketches and prototypes. We envision design tools that conform to the habits of users rather than impose specific techniques to them.
- We want to make professional design techniques available to novices. Affordable software, hardware and online instructions are democratizing technology and design, allowing small businesses and individuals to compete with large companies. New manufacturing processes and online interfaces also allow customers to participate in the design of an object via mass personalization. However, similarly to what happened for desktop publishing thirty years ago, desktop manufacturing tools need to be simplified to account for the needs and skills of novice designers. We hope to support this trend by adapting the techniques of professionals and by automating the tasks that require significant expertise.

3.1.2. Graphics with Uncertainty and Heterogeneous Content

Our research is motivated by the observation that traditional CG algorithms have not been designed to account for uncertain data. For example, global illumination rendering assumes accurate virtual models of geometry, light and materials to simulate light transport. While these algorithms produce images of high realism, capturing effects such as shadows, reflections and interreflections, they are not applicable to the growing mass of uncertain data available nowadays.

The need to handle uncertainty in CG is timely and pressing, given the large number of *heterogeneous sources of 3D content* that have become available in recent years. These include data from cheap depth+image sensors (e.g., Kinect or the Tango), 3D reconstructions from image/video data, but also data from large 3D geometry databases, or casual 3D models created using simplified sketch-based modeling tools. Such alternate content has varying levels of *uncertainty* about the scene or objects being modelled. This includes uncertainty in geometry, but also in materials and/or lights – which are often not even available with such content. Since CG algorithms cannot be applied directly, visual effects artists spend hundreds of hours correcting inaccuracies and completing the captured data to make them useable in film and advertising.

Figure 3. Image-Based Rendering (IBR) techniques use input photographs and approximate 3D to produce new synthetic views.

We identify a major scientific bottleneck which is the need to treat *heterogeneous* content, i.e., containing both (mostly captured) uncertain and perfect, traditional content. Our goal is to provide solutions to this bottleneck, by explicitly and formally modeling uncertainty in CG, and to develop new algorithms that are capable of mixed rendering for this content.

We strive to develop methods in which heterogeneous – and often uncertain – data can be handled automatically in CG with a principled methodology. Our main focus is on *rendering* in CG, including dynamic scenes (video/animations).

Given the above, we need to address the following challenges:

- Develop a theoretical model to handle uncertainty in computer graphics. We must define a new formalism that inherently incorporates uncertainty, and must be able to express traditional CG rendering, both physically accurate and approximate approaches. Most importantly, the new formulation must elegantly handle mixed rendering of perfect synthetic data and captured uncertain content. An important element of this goal is to incorporate *cost* in the choice of algorithm and the optimizations used to obtain results, e.g., preferring solutions which may be slightly less accurate, but cheaper in computation or memory.
- The development of rendering algorithms for heterogeneous content often requires preprocessing of image and video data, which sometimes also includes depth information. An example is the decomposition of images into intrinsic layers of reflectance and lighting, which is required to perform relighting. Such solutions are also useful as image-manipulation or computational photography techniques. The challenge will be to develop such "intermediate" algorithms for the uncertain and heterogeneous data we target.
- Develop efficient rendering algorithms for uncertain and heterogeneous content, reformulating rendering in a probabilistic setting where appropriate. Such methods should allow us to develop approximate rendering algorithms using our formulation in a well-grounded manner. The formalism should include probabilistic models of how the scene, the image and the data interact. These models should be data-driven, e.g., building on the abundance of online geometry and image databases, domain-driven, e.g., based on requirements of the rendering algorithms or perceptually guided, leading to plausible solutions based on limitations of perception.

4. Application Domains

4.1. Application Domains

Our research on design and computer graphics with heterogeneous data has the potential to change many different application domains. Such applications include:

Product design will be significantly accelerated and facilitated. Our interviews with car designers illustrate how the separate working practices of 2D illustrators, 3D modelers and artists who create physical prototypes results in a slow and complex process with frequent misunderstandings and corrective iterations between different people and different media. This could significantly accelerate the design process (from months to weeks), result in much better communication between the different experts, or even create new types of experts who cross boundaries of disciplines today.

Mass customization will allow end customers to participate in the design of a product before buying it. In this context of “cloud-based design”, users of an e-commerce website will be provided with controls on the main variations of a product created by a professional designer. Intuitive modeling tools will also allow users to personalize the shape and appearance of the object while remaining within the bounds of the pre-defined design space.

Digital instructions for creating and repairing objects, in collaboration with other groups working in 3D fabrication could have significant impact in sustainable development and allow anyone to be a creator of things, not just consumers, the motto of the *makers* movement.

Gaming experience individualization is an important emerging trend; using our results players will also be able to integrate personal objects or environments (e.g., their homes, neighborhoods) into any realistic 3D game. The success of creative games where the player constructs their world illustrates the potential of such solutions. This approach also applies to serious gaming, with applications in medicine, education/learning, training etc. Such interactive experiences with high-quality images of heterogeneous 3D content will be also applicable to archeology (e.g., realistic presentation of different reconstruction hypotheses), urban planning and renovation where new elements can be realistically used with captured imagery. Other applications could include *enhanced personal photography/videography*, or interactive experiences to enhance news reports.

Virtual training, which today is restricted to pre-defined virtual environment(s) that are expensive and hard to create; with our solutions we open the possiblity to seamlessly and realistically use on-site data together with the actual virtual training environment. As an example, virtual reality has been used for training locomotive drivers for manual intervention on railway tracks; the environment used is a simplistic synthetic scene. With our results, any *real* site can be captured, and the synthetic elements for the interventions rendered with high levels of realism, thus greatly enhancing the quality of the training experience.

Other applications may include scientific domains which use photogrammetric data (captured with various 3D scanners), such as geophysics and seismology. Note however that our goal is not to produce 3D data suitable for numerical simulations; our approaches can help however in combining captured data with presentations and visualization of scientific information (involving a collaboration with other groups with experts in Visualization.)

5. Highlights of the Year

5.1. Highlights of the Year

This was the first year of existence of GRAPHDECO, which was officially created in July 2015. The group has advanced on its main research axes, that of Computer-Assisted Design with Heterogeneous Representations and Graphics with Uncertainty and Heterogeneous Content. Our most notable results are our ACM Transactions on Graphics papers on regularized curvature fields [7], multi-view intrinsic images and relighting [6] and finally computer-assisted crafting on wire-wrapping [8]. The ANR DRAO was completed in December with an excellent review result, and the EU project CR-PLAY was also evaluated with excellent results for it's 2nd year. Two Ph.D. students graduated this year (S. Duchêne [2] and E. Iarussi [3]) and A. Bousseau defended his Habilitation [1].

5.1.1. Awards

Kenneth Vanhoey received a thesis award from the University of Strasbourg, from which he graduated in 2014. Johanna Delanoy and Adrien Bousseau won second best paper award in the AFIG [5].

6. New Software and Platforms

6.1. SWARPI

SWARPI (for Superpixel Warp for Image-based rendering)
FUNCTIONAL DESCRIPTION

This software package is the implementation of the publication and it was developed previously at REVES and now maintained by GRAPHDECO with public funding. The LINUX main software consists of two components: the depth synthesis step and the image-based runtime rendering step : a. depth synthesis step reads 3D points coming from the automated 3D reconstruction pipeline, together with images and calibrated cameras, and produces the superpixel decomposition and the depth synthesis algorithm. This package is provided as a set of C++ sources (for superpixel and depth) and matlab sources for depthSynth. b. The runtime rendering step is a C++ program (sources provided) which takes the result of the first step as input to allow interactive 3D navigation from pictures. The code uses multi-pass deferred shading with pixel and fragment shaders to perform the rendering.

- Participants: George Drettakis, Gaurav Chaurasia, Sylvain François Duchene and Olga Sorkine-Hornung
- Contact: George Drettakis

6.2. SWARPI-Unity

SWARPI-Unity (for Superpixel Warp for Image-based rendering for Unity)
This software package is the Unity port of the SWARPI used in the context of the CR-PLAY project.

- Participants: Jérôme Esnault, George Drettakis and Gaurav Chaurasia
- Contact: George Drettakis

6.3. SWARPI2-IBR-COMMON

SWARPI2-IBR-COMMON (for Superpixel Warp for Image-based rendering and common Image Based Rendering features)
This is the second version of SWARPI which is used internally for the research projects developed for Image-Based Rendering ([15]).

- Participants: George Drettakis, Gaurav Chaurasia, Jérôme Esnault and Sylvain François Duchene
- Contact: George Drettakis

6.4. CrossShade

CrossShade is an algorithm to estimate surface normals over a design sketch composed of vector curves representing silhouettes, boundaries and cross-sections. This algorithm has been developed in collaboration with U. of Toronto (Karan Singh) and U. British Columbia (A. Sheffer). We filed a patent on this technology and we have contacts with several companies about a potential transfer.

- Participants: Adrien Bousseau
- Contact: Adrien Bousseau

6.5. True2Form

True2Form is a sketch-based modeling system that reconstructs 3D curves from typical design sketches. This algorithm has been developed in collaboration with U. of Toronto (Karan Singh) and U. British Columbia (A. Sheffer). We filed a patent on this technology and we have contacts with several companies about a potential transfer.

- Participants: Adrien Bousseau
- Contact: Adrien Bousseau

7. New Results

7.1. Computer-Assisted Design with Heterogeneous Representations

7.1.1. BendFields: Regularized Curvature Fields from Rough Concept Sketches

Participants: Adrien Bousseau, Emmanuel Iarussi.

Designers frequently draw curvature lines to convey bending of smooth surfaces in concept sketches. We present a method to extrapolate curvature lines in a rough concept sketch, recovering the intended 3D curvature field and surface normal at each pixel of the sketch (Fig. 4). This 3D information allows us to enrich the sketch with 3D-looking shading and texturing. We first introduce the concept of *regularized curvature lines* that model the lines designers draw over curved surfaces, encompassing curvature lines and their extension as geodesics over flat or umbilical regions. We build on this concept to define the orthogonal cross field that assigns two regularized curvature lines to each point of a 3D surface. Our algorithm first estimates the projection of this cross field in the drawing, which is non-orthogonal due to foreshortening. We formulate this estimation as a scattered interpolation of the strokes drawn in the sketch, which makes our method robust to sketchy lines that are typical for design sketches. Our interpolation relies on a novel smoothness energy that we derive from our definition of regularized curvature lines. Optimizing this energy subject to the stroke constraints produces a dense non-orthogonal 2D cross field, which we then lift to 3D by imposing orthogonality. Thus, one central concept of our approach is the generalization of existing cross field algorithms to the non-orthogonal case. We demonstrate our algorithm on a variety of concept sketches with various levels of sketchiness. We also compare our approach with existing work that takes clean vector drawings as input.

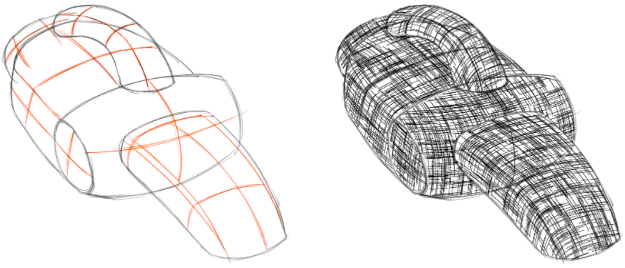
This work is a collaboration with David Bommes from Titane project team at Inria Sophia-Antipolis, now at RWTH Aachen University. It has been published at ACM Transactions on Graphics (TOG) [7].

7.1.2. Line Drawing Interpretation in a Multi-View Context

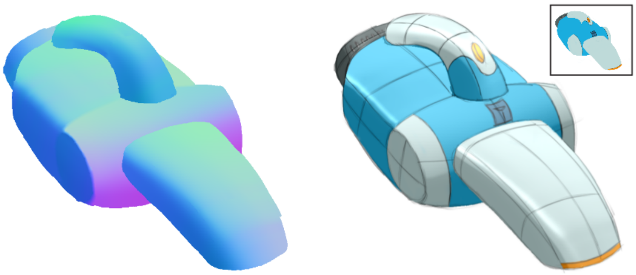
Participant: Adrien Bousseau.

Many design tasks involve the creation of new objects in the context of an existing scene. Existing work in computer vision only provides partial support for such tasks. On the one hand, multi-view stereo algorithms allow the reconstruction of real-world scenes, while on the other hand algorithms for line-drawing interpretation do not take context into account. Our work combines the strength of these two domains to interpret line drawings of imaginary objects drawn over photographs of an existing scene (Fig. 5). The main challenge we face is to identify the existing 3D structure that correlates with the line drawing while also allowing the creation of new structure that is not present in the real world. We propose a labeling algorithm to tackle this problem, where some of the labels capture dominant orientations of the real scene while a free label allows the discovery of new orientations in the imaginary scene. We illustrate our algorithm by interpreting line drawings for urban planing, home remodeling, furniture design and cultural heritage.

This work is a collaboration with Jean-Dominique Favreau and Florent Lafarge from Titane project team, Inria Sophia-Antipolis. It has been published at the Conference on Computer Vision and Pattern Recognition (CVPR) [14].



(a) Input sketch (b) Estimated curvature lines



(c) Estimated normals (d) Shaded sketch

Figure 4. Our method [7] takes as input a rough design sketch with annotated curvature lines (a). We propose a novel smoothness energy to propagate the curvature information to all pixels (b), which allows us to recover surface normals (c) and compute shading (d).

Figure 5. Our method [14] takes as input several photographs of a scene, along with a line drawing of a new object (left). We exploit the dominant orientations of the existing scene to reconstruct the line drawing in 3D (right).

7.1.3. WrapIt: Computer-Assisted Crafting of Wire Wrapped Jewelry

Participants: Adrien Bousseau, Emmanuel Iarussi.

Wire wrapping is a traditional form of handmade jewelry that involves bending metal wire to create intricate shapes. The technique appeals to novices and casual crafters because of its low cost, accessibility and unique aesthetic. We present a computational design tool that addresses the two main challenges of creating 2D wire-wrapped jewelry: decomposing an input drawing into a set of wires, and bending the wires to give them shape (Fig. 6). Our main contribution is an automatic wire decomposition algorithm that segments a drawing into a small number of wires based on aesthetic and fabrication principles. We formulate the task as a constrained graph labeling problem and present a stochastic optimization approach that produces good results for a variety of inputs. Given a decomposition, our system generates a 3D-printed custom support structure, or *jig*, that helps users bend the wire into the appropriate shape. We validated our wire decomposition algorithm against existing wire-wrapped designs, and used our end-to-end system to create new jewelry from clipart drawings. We also evaluated our approach with novice users, who were able to create various pieces of jewelry in less than half an hour.

This work is a collaboration with Wilmot Li from Adobe, San Francisco. The project was initiated by a 3-months visit of Emmanuel Iarussi at Adobe. It has been published at ACM Transactions on Graphics (Proc. SIGGRAPH Asia) [8].

Figure 6. Our system [8] helps novices convert a line drawing (left) into a real piece of jewelry (right).

7.1.4. How Novices Sketch and Prototype Hand-Fabricated Objects

Participant: Adrien Bousseau.

We are interested in how to create digital tools to support informal sketching and prototyping of objects by *novices*. Achieving this goal first requires a deeper understanding of how novices currently generate, explore, and communicate design ideas with traditional tools, i.e., sketches on paper and hands-on prototyping materials. We describe a study framed around two all-day design charrettes where participants perform a complete design process including ideation sketching, concept development and presentation, fabrication planning documentation and collaborative fabrication of hand-crafted prototypes. This structure allows us to control key aspects of the design process while collecting rich data about creative tasks, including sketches on paper, physical models, and videos of collaboration discussions. We observed that while participants had no formal training in design, they made use of advanced visualization techniques to convey 3D concepts. Participants also extensively used physical materials (paper, foam, cardboard) both to support concept exploration and to communicate their ideas to collaborators. We deduce from these observations recommendations for the conception of design tools adapted to the needs and skills of novices.

This work is a collaboration with Wendy McKay, Theophanis Tsandilas and Lora Oehlberg from the InSitu project team - Inria Saclay, in the context of the ANR DRAO project. It is conditionally accepted to ACM CHI 2016.

7.1.5. Vectorizing Rough Line Drawings

Participant: Adrien Bousseau.

Our goal in this project is to convert rough, freehand bitmap sketches to clean vector drawings, keeping three main objectives in mind: (i) the vectorial curves should approximate well the input drawing, (ii) the drawing should be composed of a small number of curves with few control points to preserve the compactness and editability of vector graphics, and (iii) the algorithm should support user guidance to disambiguate the multiple interpretations inherent to artistic inputs. Unfortunately, existing vectorization algorithms only partly satisfy these requirements. In particular, while most methods employ curve fitting to satisfy the first objective of data fidelity, this fitting is performed locally and is often sub-optimal with respect to our second objective of *low complexity*. To achieve our objectives, we propose to cast line drawing vectorization as a global optimization that balances data fidelity with model complexity. We express data fidelity as the goodness of fit of Bézier curve segments, and we express model complexity as the number and degree of curve segments that compose the output drawing. Our algorithm produces clean, compact and editable vector drawings from bitmap sketches.

This ongoing work is a collaboration with Jean-Dominique Favreau and Florent Lafarge from Titane project team, Inria Sophia-Antipolis.

7.1.6. Exploring Design Spaces with Sketch-Based Rendering

Participant: Adrien Bousseau.

Designers often start product design by drawing many quick and imperfect sketches. These sketches typically capture shape variations of a concept from different viewpoints. We introduce *sketch-based rendering* as a way to help designers explore the design space induced by such sketches. Our interactive tool allows designers to interpolate between the sketches, providing a continuous, 3D-like visualization of the concept and its variations without requiring explicit 3D information.

We propose an iterative algorithm to match and warp between sketches using little user interaction. We designed this algorithm to address the specific challenges inherent to concept sketches, in particular the fact that they are dominated by contours rather than color or texture, and that these contours should not distort during interpolation. We also describe how to approximate the relative camera positions of different sketches from the magnitude of their 2D motion fields. This approach allows plausible 3D-like camera movements despite the presence of sketch distortions and variations that prevent standard camera calibration. Our tool, thus, fills a gap in the initial stage of the product design pipeline by allowing designers and their patrons to make better informed choices before proceeding to more expensive 3D modeling and prototyping.

This ongoing work is a collaboration with Ishan Darolia and Vinay Namboodiri from IIT Kampur and Rahul Arora and Karan Singh from University of Toronto.

7.1.7. Sketch-Based Inverse Procedural Modeling

Participant: Adrien Bousseau.

Designing and modeling 3D objects is a crucial skill in various areas of entertainment, science, and engineering. However, this task is notoriously hard and unintuitive, especially for novices. Prior work has addressed the modeling problem from many different directions. Sketch-based modeling exploits human intuition and experience in drawing objects. Nevertheless, the quality of the final 3D model depends on the sketching skills of the user, the amount of details added to the drawing, and ability to resolve inherent ambiguities of the sketching process. Another popular direction is procedural modeling, which has been successfully used to create detailed and complex cities, realistic and growing vegetation, and other man-made objects. But procedural modeling is difficult to control and thus hard to use as an exploratory design tool making it accessible only to experts. Our goal in this project is to leverage both the intuitiveness, freedom and flexibility of sketching and the precision, exactness, and detail amplification of procedural modeling. Users of our system begin to sketch a 3D model using a mouse or a digital pen on a tablet. After only a few strokes, our algorithm finds a compact 3D procedural representation that matches the sketch while augmented it with geometric details.

This ongoing work is a collaboration with Gen Nishida, Bedrich Benes, Ignacio Garcia Dorado and Daniel Aliaga from Purdue University.

7.1.8. A data-based approach to retrieve the viewpoint of a design sketch

Participants: Johanna Delanoy, Adrien Bousseau.

Designing objects requires frequent transitions from a 2D representation, the sketch, to a 3D one. Because 3D modeling is time consuming, it is made only during late phases of the design process. Our long term goal is to allow designers to automatically generate 3D models from their sketches. In this work, we address the preliminary step of recovering the viewpoint under which the object is drawn. We adopt a data-driven approach where we build correspondences between the sketch and 3D objects of the same class from a database. In particular, we relate the curvature lines and contours of the 3D objects to similar lines commonly drawn by designers using histograms of orientation. The 3D objects from the database are then used to vote for the viewpoints and the more probable ones are chosen. Our results on design sketches suggest that using both contours and curvature lines give higher precision than using either one. In particular, curvature information improves viewpoint retrieval when details of the objects are different from the sketch.

The work has been published in the journal Revue Française d'Informatique Graphique and presented at the 28th Journées de l'Association Française d'Informatique Graphique [5].

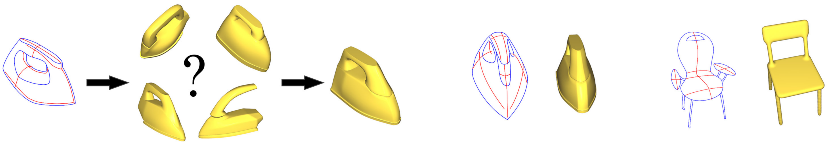


Figure 7. Our method [5] allows to retrieve the viewpoint of a design sketch, using a collection of 3D objects.

7.2. Graphics with Uncertainty and Heterogeneous Content

7.2.1. Multi-View Intrinsic Images for Outdoors Scenes with an Application to Relighting

Participants: Sylvain Duchêne, Clement Riant, Gaurav Chaurasia, Stefan Popov, Adrien Bousseau, George Drettakis.

We introduce a method to compute intrinsic images for a multi-view set of outdoor photos with cast shadows, taken under the same lighting (Fig. 8). We use an automatic 3D reconstruction from these photos and the sun direction as input and decompose each image into reflectance and shading layers, despite the inaccuracies and missing data of the 3D model. Our approach is based on two key ideas. First, we progressively improve the accuracy of the parameters of our image formation model by performing iterative estimation and combining 3D lighting simulation with 2D image optimization methods. Second we use the image formation model to express reflectance as a function of discrete visibility values for shadow and light, which allows us to introduce a robust visibility classifier for pairs of points in a scene. This classifier is used for shadow labelling, allowing us to compute high quality reflectance and shading layers. Our multi-view intrinsic decomposition is of sufficient quality to allow relighting of the input images. We create shadow-caster geometry which preserves shadow silhouettes and using the intrinsic layers, we can perform multi-view relighting with moving cast shadows. We present results on several multi-view datasets, and show how it is now possible to perform image-based rendering with changing illumination conditions.

Figure 8. Our algorithm [2] decomposes outdoor images (a) into reflectance (c) and shading (d). This decomposition enables relighting of photographs by rendering new shadows in the shading layer (b).

This work was published in ACM Transactions on Graphics [2].

This work is part of an industrial partnership with Autodesk and has been published in ACM Transactions on Graphics [2].

7.2.2. A Bayesian Approach for Selective Image-Based Rendering using Superpixels

Participants: Rodrigo Ortiz Cayon, Abdelaziz Djelouah, George Drettakis.

Many recent Image-Based Rendering (IBR) algorithms have been proposed each having different strengths and weaknesses, depending on 3D reconstruction quality and scene content. Each algorithm operates with a set of hypotheses about the scene and the novel views, resulting in different quality/speed trade-offs in different image regions. We developed a principled approach to select the algorithm with the best quality/speed trade-off in each region. To do this, we propose a Bayesian approach, modeling the rendering quality, the rendering process and the validity of the assumptions of each algorithm. We then choose the algorithm to use with Maximum a Posteriori estimation. We demonstrate the utility of our approach on recent IBR algorithms which use oversegmentation and are based on planar reprojection and shape-preserving warps respectively. Our algorithm selects the best rendering algorithm for each superpixel in a preprocessing step; at runtime our selective IBR uses this choice to achieve significant speedup at equivalent or better quality compared to previous algorithms. The work has been published in the International Conference on 3D Vision (3DV) - 2015 [15].

7.2.3. Uncertainty Modeling for Principled Interactive Image-Based Rendering

Participants: Rodrigo Ortiz Cayon, George Drettakis.

Despite recent advances in IBR methods, they are limited in regions of the scene which are badly or completely unreconstructed. Such regions have varying degrees of uncertainty, which previous solutions treat with heuristic methods. Currently we attempt to develop a comprehensive model of uncertainty for interactive IBR. Regions with high uncertainty would feed an iterative multi-view depth synthesis algorithm. For the rendering

Figure 9. In top-left, we use planes fronto-parallel to the input view which fail for trees and slanted planes. Using local plane estimation top-right the result is improved, especially for slanted planes (blue box). Using the shape preserving warp bottom-left of the warping method we previously developed, better results are achieved for the tree (red box), but the quality of the slanted planes is worse. Our algorithm [15] bottom-right makes the correct choice locally, giving the best solution in each case.

we will formalize an unified IBR algorithm, which provides a good quality/speed tradeoff by combining the advantages of forward warping and depth-based backprojection algorithms and includes plausible stereoscopic rendering for unreconstructed volumetric regions.

7.2.4. *Multi-view Inpainting*

Participants: Theo Thonat, George Drettakis.

We are developing a new approach for removing objects in multi-view image datasets. For a given target image from which we remove objects, we use Image-Based Rendering for reprojecting the other images into the target and for regions not visible in any other image we use inpainting techniques. The difficulties reside in formalizing the unified algorithm and enforcing multi-view consistency. This is an ongoing project in collaboration with Adobe Research (E. Shechtman and S. Paris).

7.2.5. *Beyond Gaussian Noise-Based Texture Synthesis*

Participants: Kenneth Vanhoey, Georgios Kopanas, George Drettakis.

Texture synthesis methods based on noise functions have many nice properties: they are continuous (thus resolution-independent), infinite (can be evaluated at any point) and compact (only functional parameters need to be stored). A good method is also non-repetitive and aperiodic. Current techniques, like Gabor Noise, fail to produce structured content. They are limited to so-called “Gaussian textures”, characterized by second-order statistics like mean and variance only. This is suitable for noise-like patterns (e.g., marble, wood veins, sand) but not for structured ones (e.g., brick wall, mountain rocks, woven yarn). Other techniques, like Local Random-Phase noise, leverage some structure but as a trade-off with repetitiveness and periodicity.

In this project, we model higher-order statistics produced by noise functions. Then we define an algorithm for maximal-entropy sampling of the parameters of the noise functions so as to meet prescribed statistics to reproduce. This sampling ensures both the reproduction of higher-order visual features with high probability, like edges and ridges, and non-repetitiveness plus aperiodicity thanks to the stochastic sampling method. We are currently investigating a learning method so as to inject into the model the appropriate prescribed statistics deduced from an input exemplar image.

This ongoing work is a collaboration with Ian Jermyn from Durham University and will be submitted for publication in 2016.

7.2.6. *Unifying Color and Texture Transfer for Predictive Appearance Manipulation*

Participants: Fumio Okura, Kenneth Vanhoey, Adrien Bousseau, George Drettakis.

Recent color transfer methods use local information to learn the transformation from a Source to an Exemplar image, and then transfer this appearance change to a Target image (figure 10 (a) to (d)). These solutions achieve successful results for general mood changes, e.g., changing the appearance of an image from “sunny” to “overcast”. However, they fail to create new image content, such as leaves on a bare tree (figure 10 (d)). Texture transfer, on the other hand, can synthesize such content but tends to destroy image structure (figure 10 (e)). We propose the first algorithm that unifies color and texture transfer, outperforming both by automatically leveraging their respective strengths (figure 10 (f)). A key novelty in our approach resides in teasing apart appearance changes that can be modeled simply as changes in color versus those that require new image content to be generated. Our method starts with an analysis phase which evaluates the success of color transfer on the Source/Exemplar scene. To do so, color transfer parameters are learned on this pair, and applied on the Source. The color transferred Source image is then evaluated against the Exemplar which serves as a ground truth, using texture distance metrics (textons in our case). This provides information on the localization of success and failure of color transfer on this scene. This analysis then drives the synthesis: a selective, iterative texture transfer algorithm that simultaneously predicts the success of color transfer on the Target and synthesizes new content using texture transfer where needed. Synthesis exploits a dense pixel matching between the Source/Exemplar scene, on which information is learned, and the Target/Output scene, on which we want to synthesize. The algorithm iterates between synthesizing the new scene by locally using either color or texture transfer, and improving the dense matching on the scene being synthesized. As a result, it leverages the best of both techniques on a variety of scenes by transferring large temporal changes between photographs, such as change of season and flooding. We demonstrate this with seasonal changes on vegetation (e.g., trees) and snow, and on examples involving flooding.

This work is a collaboration with Alexei Efros from UC Berkeley in the context of the associate team CRISP. It has been published in Computer Graphics Forum [9] and was accepted and presented at the Eurographics symposium on Rendering.

Figure 10. Illustration of our appearance prediction method [9]. The future appearance of a target image (c) is predicted (f) based on the knowledge learned from a quasi-aligned source-exemplar pair ((a) and (b)) which characterizes an analogous transformation. The key insight is to selectively operate color transfer ((d): only operate rigid local color histogram transformations, i.e., change the background's overall mood) or texture transfer ((e): copying pixels or patches from the exemplar, i.e. synthesize the three's leaves) where suitable, so as to obtain an improved result (f).

7.2.7. Simplification of Triangle Meshes with Digitized Radiance

Participant: Kenneth Vanhoey.

Very accurate view-dependent surface color of virtual objects can be represented by outgoing radiance of the surface. This data forms a surface light field, which is inherently 4-dimensional, as the color is varying both spatially and directionally. Acquiring this data and reconstructing a surface light field of a real-world object can result in very large datasets, which are very realistic, but tedious to store and render. In this project, we consider the processing of outgoing radiance stored as a vertex attribute of triangle meshes, and especially propose a principled simplification technique. We show that when reducing the global memory footprint of such acquired objects, smartly reducing the spatial resolution, as opposed to the directional resolution, is an effective strategy for overall appearance preservation. To define such simplification, we define a new metric to guide an iterative edge collapse algorithm. Its purpose is to measure the visual damage introduced when operating a local simplification. Therefore, we first derive mathematical tools to calculate with radiance functions on the surface: interpolation, gradient computation and distance measurements. Then we derive a metric using these tools. We particularly ensure that the mathematical interpolation used in the metric is coherent with the non-linear interpolation we use for rendering, which makes the math coherent with the rendered object. As a result we show that both synthetic and acquired objects benefit from our radiance-aware simplification process: at equal memory footprint, visual quality is improved compared to state of the art alternatives.

This work is a collaboration with the ICube laboratory, Strasbourg, France. It was published in the Computer Graphics Journal [11] and was accepted and presented at Computer Graphics International 2015 in Strasbourg, France.

7.2.8. Video based rendering for vehicles

Participants: Abdelaziz Djelouah, Georgios Koulieris, George Drettakis.

The main objective of image based rendering methods is to provide high quality free-view point navigation in 3D scenes using only a limited set of pictures. Despite the good visual quality achieved by most recent methods, the results still look unrealistic because of the static nature of the rendered scenes. This project is in the general context of enriching image based rendering experience by adding dynamic elements and we are particularly interested by adding vehicles.

Vehicles represent an important proportion of the dynamic elements in any urban scene and adding an object with such a complex appearance model has many challenges. First, contrary to classic IBR the number of viewpoints is limited because all input videos must be recorded at the same time. Also, because of this limited number of viewpoints, using classic multi-view reconstruction methods does not produce good results. Instead we use 3D stock models as proxy for the cars. The first step is the registration of the 3D model with the input videos. Then, using the 3D model, the input videos are processed to extract the different visual layers (base color, reflections, transparency, etc.). Finally, the objective is to find the appropriate way to combine the 3D model and the extracted layers to provide the most realistic image from any viewpoint.

This ongoing work is a collaboration with Gabriel Brostow from University College London in the context of the CR-PLAY EU project and with Alexei Efros from UC Berkeley.

7.2.9. Finger-Based Manipulation in Immersive Spaces and the Real World

Immersive environments that approximate natural interaction with physical 3D objects are designed to increase the user's sense of presence and improve performance by allowing users to transfer existing skills and expertise from real to virtual environments. However, limitations of current Virtual Reality technologies, e.g., low-fidelity real-time physics simulations and tracking problems, make it difficult to ascertain the full potential of finger-based 3D manipulation techniques. This project decomposes 3D object manipulation into the component movements, taking into account both physical constraints and mechanics. We fabricate five physical devices that simulate these movements in a measurable way under experimental conditions. We then implement the devices in an immersive environment and conduct an experiment to evaluate direct finger-based against ray-based object manipulation. The key contribution of this work is the careful design and creation of physical and virtual devices to study physics-based 3D object manipulation in a rigorous manner in both real and virtual setups.

This work was presented at IEEE Symposium on 3D User Interfaces [12], and is in collaboration with the EXSITU Inria group in Paris (T. Tsandilas, W. Mackay, L. Oehlberg).

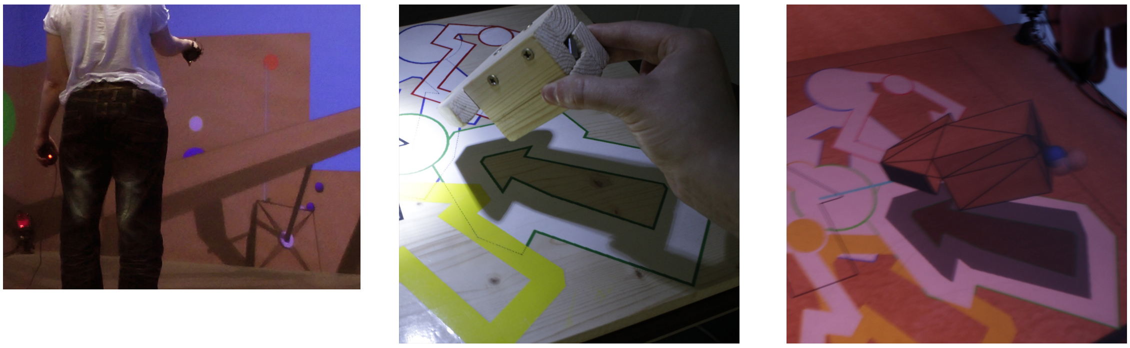


Figure 11. A user in our immersive environment (left) for finger-based manipulation [12]. Completing a 6 DoF manipulation task in real (center) and virtual (right) settings.

7.2.10. Gaze Prediction using Machine Learning for Dynamic Stereo Manipulation

Participants: Georgios Koulieris, George Drettakis.

Comfortable, high-quality 3D stereo viewing is becoming a requirement for interactive applications today. The main challenge of this project is to develop a gaze predictor in the demanding context of real-time, heavily task-oriented applications such as games. Our key observation is that player actions are highly correlated with the present state of a game, encoded by game variables. Based on this, we train a classifier to learn these correlations using an eye-tracker which provides the ground-truth object being looked at. The classifer is used at runtime to predict object category – and thus gaze – during game play, based on the current state of game variables. We use this prediction to propose a dynamic disparity manipulation method, which provides rich and comfortable depth. We evaluate the quality of our gaze predictor numerically and experimentally, showing that it predicts gaze more accurately than previous approaches. A subjective rating study demonstrates that our localized disparity manipulation is preferred over previous methods.

This is a collaboration with the Technical University of Crete (K. Mania) and Cottbuss University (D. Cunningham), and will be presented at IEEE VR 2016.

7.2.11. Compiling High Performance Recursive Filters

Infinite impulse response (IIR) or recursive filters, are essential for image processing because they turn expensive large-footprint convolutions into operations that have a constant cost per pixel regardless of kernel size. However, their recursive nature constrains the order in which pixels can be computed, severely limiting both parallelism within a filter and memory locality across multiple filters. Prior research has developed algorithms that can compute IIR filters with image tiles. Using a divide-and-recombine strategy inspired by parallel prefix sum, they expose greater parallelism and exploit producer-consumer locality in pipelines of IIR filters over multi-dimensional images. While the principles are simple, it is hard, given a recursive filter, to derive a corresponding tile-parallel algorithm, and even harder to implement and debug it. We show that parallel and locality-aware implementations of IIR filter pipelines can be obtained through program transformations , which we mechanize through a domain-specific compiler. We show that the composition of a small set of transformations suffices to cover the space of possible strategies. We also demonstrate that the tiled implementations can be automatically scheduled in hardware-specific manners using a small set of generic heuristics. The programmer specifies the basic recursive filters, and the choice of transformation requires only a few lines of code. Our compiler then generates high-performance implementations that are an order of magnitude faster than standard GPU implementations, and outperform hand tuned tiled implementations of specialized algorithms which require orders of magnitude more programming effort – a few lines of code instead of a few thousand lines per pipeline. This work was presented the High Performance Computing conference and is a collaboration with F. Durand, J. Ragan-Kelley and G. Chaurasia of MIT and S. Paris of Adobe [13].

7.2.12. Probabilistic Connections for Bidirectional Path Tracing

Participants: Sefan Popov, George Drettakis.

Bidirectional path tracing (BDPT) with Multiple Importance Sampling is one of the most versatile unbiased rendering algorithms today. BDPT repeatedly generates sub-paths from the eye and the lights, which are connected for each pixel and then discarded. Unfortunately, many such bidirectional connections turn out to have low contribution to the solution. The key observation in this projects is that we can importance sample connections to an eye sub-path by considering multiple light sub-paths at once and creating connections probabilistically. We do this by storing light paths, and estimating probability mass functions of the discrete set of possible connections to all light paths. This has two key advantages: we efficiently create connections with low variance by Monte Carlo sampling, and we reuse light paths across different eye paths. We also introduce a caching scheme by deriving an approximation to sub-path contribution which avoids high-dimensional path distance computations. Our approach builds on caching methods developed in the different context of VPLs. Our Probabilistic Connections for Bidirectional Path Tracing approach raises a major challenge, since reuse results in high variance due to correlation between paths. We analyze the problem of path correlation and derive a conservative upper bound of the variance, with computationally tractable sample weights. We present results of our method which shows significant improvement over previous unbiased global illumination methods, and evaluate our algorithmic choices.

This work was in collaboration with R. Ramamoorthi (UCSD) and F. Durand (MIT) and appeared in the Eurographics Symposium on Rendering [10].

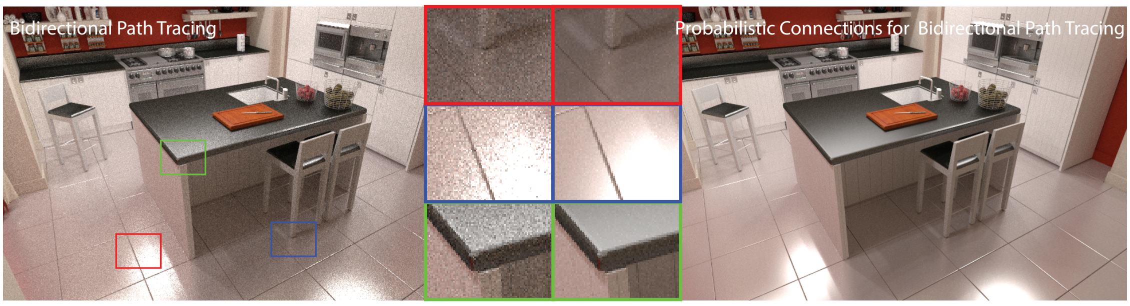


Figure 12. Our Probabilistic Connections for Bidirectional Path Tracing [10] approach importance samples connections to an eye sub-path, and greatly reduces variance, by considering and reusing multiple light sub-paths at once. Our approach (right) achieves much higher quality than bidirectional path-tracing on the left for the same computation time.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

We received a donation from Adobe research in the context of the collaboration with W. Li and a donation from Technicolor for a new collaboration which will start in 2016 on image manipulation.

We collaborate extensively with Testaluna SA, and other game companies in the context of the CR-PLAY EU project.

We have started a Regional Ph.D. these with the local company Kaleidoscope (Toulon).

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. Regional Ph.D. Scholarship

The thesis of T. Thonat is financed in part by a Région Provence Alpes-Côte d’Azur Ph.D. scholarship, with the industrial support of Kaleidoscope (Toulon).

9.2. National Initiatives

9.2.1. ANR

9.2.1.1. ANR ALTA

Participants: Emmanuelle Chapoulie, Stefan Popov, George Drettakis.

The ANR ALTA project started in October 2011, and focuses on the development of novel algorithms for realistic and efficient global illumination. The project is coordinated by the Grenoble Inria group ARTIS (N.Holzschuch), and the Bordeaux Inria group MANAO (X. Granier) is also a partner. Our participation is the study of error bounds for these algorithms and the development of interactive global illumination. This year we developed a new global illumination algorithm described in Sec. 7.2.12 which was published at EGSR [10].

9.2.1.2. ANR DRAO

Participants: Emmanuel Iarussi, Adrien Bousseau.

https://www-sop.inria.fr/members/Adrien.Bousseau/drao/

The ANR DRAO is a young researcher project coordinated by Adrien Bousseau, in collaboration with the InSitu project team at Inria Saclay - Ile de France (W. Mackay and T. Tsandilas) and the MANAO project team (P. Barla and G. Guennebaud) and POTIOC project team (M. Hachet) at Inria Bordeaux - Sud Ouest. The goal of this collaboration is to develop novel drawing tools for amateurs as well as for expert designers and illustrators, combining expertise in Computer Graphics (REVES and MANAO) and Human-Computer Interaction (InSitu, POTIOC). This ANR project funds the PhD of Emmanuel Iarussi.

The first part of the project involved the observation of how people draw with existing tools. To do so we conducted observational studies where we will interview designers and illustrators and collect data by videotaping drawing sessions and by recording drawings with digital pens. In the second part of the project we deduced from our observations new user interfaces and rendering algorithms that automate part of the drawing process and enrich 2D drawings with realistic rendering capabilities. We combined computer vision and computer graphics techniques to estimate geometric information from sketches and then used this information to guide rendering algorithms that generate plausible depictions of material and lighting over the drawing. We also developed computer-assisted drawing lessons to help amateurs draw from photographs and 3D models, using image analysis algorithms to estimate the structure of a photograph and use that structure as guidance for drawing. To summarize, the goal of the ANR DRAO project was to make amateurs more confident in their drawing skills and to allow expert designers to produce complex illustrations more effectively.

The ANR DRAO has resulted in three publications this year on normal field estimation from rough sketches [7], 3D interpretation of line drawings [14] and jewelry design [8].

9.2.1.3. ANR SEMAPOLIS

Participant: George Drettakis.

This ANR project started in October 2013. The goal is to use semantic information to improve urban reconstruction and rendering. The consortium is led by ENPC (R. Marlet) and includes the Inria Willow team and the GREY-C laboratory on image processing. Our contribution will be in the rendering part.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. CR-PLAY – Capture Reconstruct Play

http://www.cr-play.eu

Type: COOPERATION (ICT)

Instrument: Specific Targeted Research Project

Objectif: Creativity

Duration: November 2013 - October 2016

Coordinator: Testaluna SA (IT)

Partner: TU Darmstadt (DE), UC London (UK), U. Patras (GR), Miniclip UK, Cursor Oy (FI)

Inria contact: George Drettakis

Abstract: The goal of this project is to use image- and video-based rendering and relighting techniques in the context of games and in particular mobile or casual games. The computer graphics and vision partners (UCL, TUD) are leaders in their fields, and have developed algorithms allowing easy capture of scenes using images and video, and reconstruction using vision algorithms. UCL and Inria have developed image- and video-based rendering algorithms which can be useful for games. These tools need to be perfected, reducing artifacts and difficulty of use so that they can be useful and productive for games companies. For evaluation, the HCI lab of the University of Patras will provide cutting-edge methodologies to make the resulting systems useable. The consortium is led by the games company Testaluna, based in Genova Italy. Other industrial partners include Cursor Oy (a regional group of games companies in Finland, which is a leader in Europe in Casual games) and Miniclip, which is one of the major players in the online game market.

We have started specific scientific collaborations with TUD on capture guidance and IBR and with UCL on video-based rendering.

9.4. International Initiatives

Inria@SiliconValley
Associate Team involved in the International Lab:

9.4.1. CRISP2

Title: Creating and Rendering Images based on the Study of Perception

International Partner (Institution - Laboratory - Researcher):

University of California Berkeley (United States) - Electrical Engineering and Computer Science Department (EECS) - Maneesh Agrawala

Start year: 2014

See also: http://www-sop.inria.fr/reves/crisp/

The CRISP collaboration aims at developing novel techniques to create and manipulate effective numerical imagery. We adopt a multidisciplinary approach, focusing on understanding how people create and perceive images, on developing new rendering algorithms based on this understanding, and on building interactive tools that enable users to efficiently produce the images they have in mind. The participants of CRISP share complementary expertise in computer graphics, human computer interaction and human visual perception.

In 2015 we published two papers in the Computer Graphics Forum journal, which were presented at the Eurographics Symposium on Rendering (EGSR). In the first paper we used a model of texture similarity to transfer seasons between photographs . Our algorithm predicts how to change colors and textures in an image to give it the seasonal appearance of another image. In particular, our method captures season-related effects such as leaves on trees, snow and flooding. This work was done in collaboration with Alexei Efros who is an expert in data-driven image manipulation.

The second paper contributes to more traditional, physically-based rendering using bidirectional path tracing . The key idea behind our approach is to exploit combinatorial explosion to cheaply construct a set of light paths as the Cartesian product of the eye and light sub-paths. The novelty of our work is to approximate the contribution of these paths in a probabilistic manner, without constructing each path in the set explicitly. This work results from collaboration with Ravi Ramamoorthi.

We are currently focusing our efforts on two core topics of the CRISP collaboration: perceptual rendering and plausible image-based rendering. In particular, we plan to explore several projects related to the perception and rendering of stereo images. This research will greatly benefit from an Inria postdoc, George Koulieris, who will share his time between Inria and UC Berkeley. In addition, Martin S. Banks from UC Berkeley plans to spend part of his sabbatical at Inria.

CRISP has resulted in two publications this year with Aloyha Efros [9] and R. Ramammoorthi [10].

9.4.2. *Inria International Partners*

9.4.2.1. Declared Inria International Partners

Canada. A. Bousseau collaborates regularly with the University of Toronto (K. Singh) and the University of British Columbia (A. Sheffer).

United Kingdom. In the context of the postdoctoral fellowship of K. Vanhoey, we collaborate with I. Jermyn from Durham University.

India. A. Bousseau collaborates with Vinay Namboodiri from IIT Kanpur. They co-advised two master students, one came for an internship at Inria (Rahul Arora).

United States. We have several collaborations with Adobe Research. We worked on jewelry design [8] with Wilmot Li, who hosted Emmanuel Iarussi for an 3-months internship. We also work with Eli Shechtman and Sylvain Paris in the context of the multi-view inpainting project of T. Thonat. We collaborate with F. Durand from MIT in the context of the global illumination project [10]. We collaborate with Daniel Aliaga from Purdue University on sketch-based procedural modeling.

Greece. We collaborate with the Technical University of Crete in the context of the project on attention and Virtual Reality (G. Koulieris).

9.5. International Research Visitors

9.5.1. *Visits of International Scientists*

Prof. D. Aliaga from Purdue (US) visited in June for two weeks, Prof. K. Bala (Cornell, US), A. Shamir (IDC, IS), D. Salesin (Adobe, US) visited early September and participated in a workshop after the HDR defense of A. Bousseau. Prof. N. Mitra (UCL, UK), M. Alexa (TU Berlin, D) visited end September and participated in a scientific workshop after the defense of E. Iarussi.

9.5.1.1. Internships

Rahul Arora, was a Masters Intern, until Apr 2015 from IIT Kampur. Vivien Cabannes was a 3rd year intern from ENS Ulm from June 2015 until July 2015. Lorenzo Caroggio and Huayi Huang were last year engineering student interns from Univ. Genova in teh context of an ERASMUS exchange. Ayush Tewari was a Masters II intern from MOSIG Grenoble Feb. -Jul. 2015. Georgios Kopanas, was an ERASMUS intern from the Tech. Un. Thessaly, Sep.-Dec. 2015.

9.5.2. *Visits to International Teams*

G. Drettakis visited Berkeley in the context of the CRISP Associate team in August.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. *Scientific events selection*

10.1.1.1. Member of the conference program committees

A. Bousseau served on the Eurographics 2015 international program committee and on the SIGGRAPH 2015 program committee. G. Drettakis served on the SIGGRAPH 2015, Eurographics Symposium on Rendering and Eurographics 2015 program committees.

10.1.2. *Journal*

10.1.2.1. Member of the editorial boards

G. Drettakis is an associate editor of the ACM Transactions on Graphics and the Computational Visual Media journal.

10.1.3. Invited talks

K. Vanhoey gave invited talks at Technische Universität Darmstadt (Darmstadt, Germany), Karsruhe Institut für Technologie (Karsruhe, Germany), laboratoire LIRIS (Lyon, France), and laboratoire I3S (Sophia-Antipolis, France). K. Vanhoey presented the project "Unifying Color and Texture Transfer for Predictive Appearance Manipulation" at the French workshop on Rendering (GT Rendu) in Paris.

10.1.4. Leadership within the scientific community

G. Drettakis chairs the Eurographics working group on Rendering and chairs the local "Jacques Morgenstern" Colloquium organizing committee.

10.1.5. Research administration

10.1.5.1. Reviewer - Reviewing activities

A. Bousseau and G. Drettakis were reviewers for several major conferences (Eurographics, SIGGRAPH Asia etc.). K. Vanhoey is a regular reviewer for the Computer and Graphics Journal.

10.1.5.2. Research Evaluation

G. Drettakis served as an evaluator for the KAUST Visual Computing Center and the EC Fet Open Call in November-December.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Masters II: G. Drettakis, A. Bousseau: Foundations of Image Synthesis, CentralSupelec, Paris, 28h.

Masters I: A. Bousseau, G. Drettakis: Image Synthesis International Masters I, University of Nice Sophia-Antipolis, 12h.

Masters I: G. Drettakis, A. Bousseau: Image Synthesis, Masters MAPI Cannes, University of Nice Sophia-Antipolis, 12h.

Bachelors (Licence): A. Djelouah; Teaching assistant for the course of computer science at the university of Nice.

Bachelors (Licence): J. Delanoy; Teaching assistant for the course of databases and supervisor of student projects at IUT - University Nice Sophia-Antipolis.

Bachelors (Licence) K. Vanhoey teaches the Programming course (C language) in 3rd year of the "Electronics" department of Polytech Nice Sophia-Antipolis (32h).

10.2.2. Supervision

- PhD defended: Sylvain Duchêne, Computer Drawing Tools for Assisting Learners, Hobbyists, and Professionals , University Nice Sophia Antipolis, since October 2012 (defended May 2015), Advisor: George Drettakis, Co-advisor: A. Bousseau.
- PhD defended: Emmanuel Iarussi, Computer Drawing Tools for Assisting Learners, Hobbyists, and Professionals , University Nice Sophia Antipolis, since October 2012 (defended September 2015), Advisor: George Drettakis, Co-advisor: A. Bousseau
- PhD in progress: Rodrigo Ortiz-Cayon, Advisor: G. Drettakis. Started December 2013 (CR-PLAY)
- PhD in progress: Johanna Delanoy, Advisor: A. Bousseau. Started October 2015 (Inria)
- PhD in progress: Théo Thonat, Advisor: G. Drettakis. Started October 2015 (Region and SEMAPOLIS)
- HDR defended: Adrien Bousseau, Depicting shape, materials and lighting: observation, formulation and implementation of artistic principles , University Nice Sophia Antipolis, defended September 2015

10.2.3. Juries

G. Drettakis was a member of the thesis committee for A. Djelouah (Inria Grenoble) in March, for S. Pujades (Inria Grenoble) in September, and external examiner for the Ph.D. of J. Imber (Surrey) in November.

10.3. Popularization

Adrien Bousseau presented his work on sketch-based modeling as an invited seminar in the course of Marie-Paule Cani at Collège de France. Our work with the Institut Claude Pompidou was featured in a news article in the eldiario.es online magazine. GRAPHDECO was presented in the Inria Sophia-Antipolis internal letter in November.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

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