Flexible Rendering

Generic Methods for Real-Time and Non-Photorealistic Rendering:

INRIA, Projet Artis – MIT Laboratory for Computer Science

1. Identification du partenaire étranger.

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2. Historique de la collaboration.

The collaboration between the INRIA Artis project (formerly part of iMAGIS) and the MIT Computer Graphics Group has a successful history in the domain of high-performance computer graphics. Supported in part by an NSF-INRIA grant (INT-9724005), the collaboration has led to major breakthroughs in the domain of real-time graphics. The following participants have been involved since 1997:

IMAGIS / INRIA	MIT
François Sillion (DR2)	Julie Dorsey (professor)
Claude Puech (professeur)	Frédo Durand (assistant professor)
George Drettakis (CR1)	Gernot Schaufler (post doc)
Joëlle Thollot (MCF)	Byong Mok Oh (PhD)
Xavier Décoret (doctorant)	Sami Shalabi (Masters)
Stéphane Grabli (doctorant)	Max Chen (Masters)
Yann Argotti (ingénieur puis DEA)	

Prof. Julie Dorsey paid extended visits to the iMAGIS project in 1998 and 1999. Sami Shalabi has visited iMAGIS in 1997 and 1998, working with Yann Argotti on the classification and encoding of urban structure, which laid out the basis of the data structure used in all the subsequent work of the two teams [Shalabi 1998]. Byong Mok Oh spent 10 days in France in 1998 to work on lighting simulation in cities. Frédo Durand received his PhD from University Joseph Fourier before he joined MIT as a post-doc in 1999, and as a faculty since September 2002.

The iMAGIS team has been a pioneer of image-based acceleration [Sillion 1997]. Working together, we have performed a rigorous analysis of the potential errors induced by this approach, and have developed specific techniques to treat these (Fig 1). This joint work started with a one-week visit to MIT by Xavier Décoret in 1998, and has been published in the selective Eurographics conference [Décoret et al. 1999].

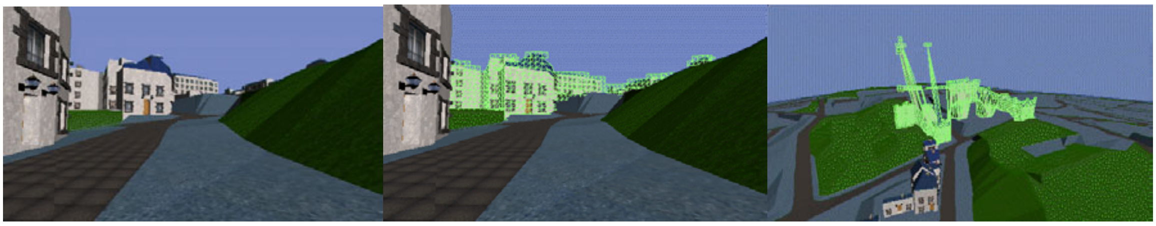

Fig. 1: (a) Rendering of a street using image-based acceleration. (b) Emphasized image-based impostor used to render the distant geometry. (c) Birds-eye view showing the emphasized impostor. Invisible parts have been culled.

In order to exploit the specificities of urban scenes, we have developed two visibility acceleration techniques that alleviate the long-lasting limitations of previous methods. These approaches result in generic solutions to the problem of visibility preprocessing (Fig. 2). For the first project, Gernot Schaufler visited iMAGIS twice in 1999, and Xavier Décoret went to MIT for two weeks in 1999, and one week in 2000. The second project was made possible by a one-week trip by Joëlle Thollot to MIT in 2000 and three one-week visits by Frédo Durand to iMAGIS in 2000 and 2001. These results have been acknowledged by two joint publications at the prestigious SIGGRAPH conference [Schaufler et al. 2000, Durand et al. 2000].

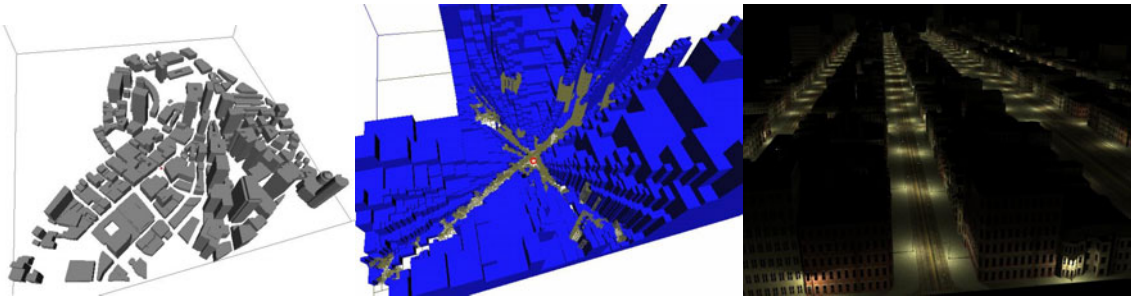

Fig. 2: (a) Part of a city model. (b) The hidden parts from the current street are highlighted in blue. (c) Lighting simulation of a city district using our visibility acceleration technique.

In addition to these already published results, the two teams are working on a number of common projects. Xavier Décoret, Frédo Durand and François Sillion work on model simplification using a new primitive combining geometry and image-based rendering. This has involved two trips by Xavier Décoret to MIT, and two visits by Frédo Durand to iMAGIS. Samuel Hornus works on 3D visibility, including practical real-time techniques and analytical solutions. He has spent a week in 2002 at MIT to work with Frédo Durand. Stéphane Grabli is informally co-supervised by Frédo Durand and Francois Sillion. He works on style capture for line drawing, and he has spent the Summer of 2002 at Boston.

These successful results would not have been possible without the aforementioned numerous exchanges of researchers and graduate students. In addition, weekly conference calls have allowed us to work as a team across the Atlantic.

References

References in bold are co-signed by researchers from the two teams.

[Cunzi et al. 2003] Cunzi, M., Thollot, J., Gascuel, J.D., Paris, S., Debunne, G., Drettakis, G., Durand, F. *Zoomable paper for immersive NPR Walkthroughs*, submitted to the ACM Symposium on Interactive 3D graphics '2003.

[Décoret et al. 1999] Decoret, X., Schaufler G., Sillion F, and Dorsey J. *Multi-layered impostors for accelerated rendering*. Computer Graphics Forum 18:3 (Proceedings of Eurographics '99), pp. 61-73.

[Durand et al. 2000] Durand, F., Drettakis G., Thollot J., and Puech C. *Conservative Visibility Preprocessing using Extended Projections*. Proceedings of ACM SIGGRAPH 2000, Computer Graphics Proceedings, Annual Conference Series, July 2000, pp. 239-248.

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[Durand et al. 2002] Durand, F., Drettakis, G. and Puech, C. *The 3D Visibility Complex* . ACM Transactions on Graphics, 21(2), 2002.

[Durand 2002] Durand F. An Invitation to Discuss Computer Depiction. Proceedings of the ACM/Eurographics Symposium on Non-Photorealistic Animation and Rendering (NPAR), June 2002.

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[Shalabi 1998] Shalabi S. *Analysis of Urban Morphology for Real Time Visualization of Urban Scenes*. Master of Engineering Thesis, Massachusetts Institute of Technology, 1998.

[Sillion 1997] Sillion F., Drettakis G. and Bodelet B. *Efficient Impostor Manipulation for Real-Time Visualization of Urban Scenery*. Proceedings of Eurographics'97, Budapest, Hungary, September 4-8, 1997.

3. Relations existantes entre l'INRIA et l'organisme partenaire

The MIT Computer Graphics Group also has an informal relationship with the REVES project-team from INRIA Sophia in the area of visibility computation and non-photorealistic rendering. Reference [Cunzi et al. 2003] is co-authored with George Drettakis from REVES.

4. Programme de travail prévisionnel

4.1. Description scientifique de ce programme de travail

Our research addresses two important challenges of computer graphics: generic and adaptive real-time systems, and the intricate notion of pictorial style. These research objectives naturally fall in INRIA's strategic objectives concerning the development of new applications based on multimedia techniques, and the combination of simulation and virtual reality.

The ever-increasing size of 3D models makes display acceleration a crucial issue. Applications of real-time 3D graphics include e.g. simulation, training, games, virtual tourism, scientific visualization, all areas where the interactive display of complex 3D model is paramount. Hardware improvement alone cannot respond to the exponential increase in scene complexity, and acceleration algorithms are necessary to decrease the load of the graphics cards. Efficient acceleration techniques have been developed that work well in specific cases, but in practice, user intervention is still heavily required and some common scene configurations remain challenging. In addition, the development of a real-time display system remains an elusive craft where the programmers have to use intuition and spend a large amount of time optimizing for a specific hardware configuration.

The recent field of non-photorealistic rendering aims at the production of pictures that are inspired by traditional media such as pencil drawing or painting. It is motivated by the effectiveness of such styles to convey information, and also by the aesthetic and expressive quality of such rendering. Most of the pictures that surround us are usually not photorealistic: think of educational diagrams, technical illustration, repair manuals, maps, and artistic pictures… Non-photorealistic styles can make a picture more readable by abstracting the information, they can focus the attention on the most relevant parts, and they often have a pleasing aesthetic quality. With the Internet and PC revolution, most graphical content becomes dynamic, images are generated on-the-fly depending on the user's needs, expertise, clearance, etc. It therefore becomes increasingly important to be able to generate compelling non-photorealistic renderings automatically. Other applications of non-photorealistic rendering include games with cartoon or other pictorial styles, animation movies, digital photography processing, and even artistic creation.

Generic and Adaptive Real-Time Display

Our research on real-time rendering focuses on generic and robust acceleration techniques. This will then allow us to tackle the crucial goal of systems that can automatically adapt to the hardware resources and to scene characteristics. In particular, ensuring real-time (in the strong sense of the term, with a time budget) is a crucial issue, since psychophysical studies have shown that a steady frame-rate is more important than a fast frame-rate for immersive graphics.

Display acceleration can be addressed through two complementary approaches: fast culling of invisible portions of the scene (occlusion culling), and model simplification (LOD). We are working on these two categories of techniques and on their integration. Visibility can be computed with respect to the current viewpoint, or with respect to a volumetric region of space. The latter solution permit better prediction and an amortization of the calculation, but is typically more involved and often raises robustness issues. In order to get the best of both approaches, we are developing robust techniques that reduce the visibility with respect to a region containing the viewpoint to a calculation with respect to a single point.

Current model simplification techniques focus either on finely tessellated, connected and topologically simple meshes using geometric mesh simplification, or on distant geometry using image-based billboards and impostors. As a result, seamlessly merging multiple parts or objects for aggressive acceleration is hardly feasible. Mesh simplification is, for example, currently of little use for objects such as trees, and image-based acceleration exhibits disocclusion and sampling artifacts for close and complex objects. We propose to tackle the simplification of complex geometry by alleviating the connectivity constraint and by using a view-dependent strategy. A longer-term goal is the development of a hybrid technique bridging the gap between mesh simplification and image-based acceleration, hence offering a continuum of simplification strategies optimized for each configuration and rendering power.

Rendering "on a budget" requires reliable metrics to predict the impact of simplification techniques, in order to optimize the use of the available graphics power. It also implies a careful integration of visibility and simplification techniques. Most current approaches rely on geometric criteria, and fail to take advantage of the specificities and "flaws" of the human visual system. We propose to develop psychophysical metrics, taking into account perceptual masking effect due to occlusion, and apply them to level of detail selection.

Nowadays, adapting a real-time system to a particular hardware configuration or to a given kind of scene is a tedious process that involves algorithmic choices, and fine parameter tuning. This is made even more difficult with the range of devices spanning PCs, game consoles, multiprocessor high-end systems, or PDAs. We believe that a large part of this effort can be automated in order to always get the best of a hardware configuration for a given application. This involves the development of a flexible system, and the careful study of metrics that predict the efficiency of a method. The main difference between computer graphics and traditional compilation and optimization is the possibility to decrease image quality to reach a particular frame rate. As special intermediate project, we plan to work on the compilation and targeting of real-time shaders. These small programs take advantage of the recent programmability of the graphics hardware to render complex material appearance. Their use currently relies on low level programming, and the set of instructions and capabilities highly depends on the particular graphics hardware. In the longer term, adaptive real-time rendering algorithms are a necessary step towards flexible graphics system for pervasive computing, where rendering has to be dynamically distributed among very different devices.

Non-Photorealistic Rendering and Style

As initiated in our study of computer depiction [Durand 2002], we believe that a comprehensive framework taking into account the perception and visual art literature is necessary to organize non-photorealistic rendering (NPR) and to develop techniques that are more interoperable. In addition, we believe that many important stylistic and pictorial issues are common to realistic and non-realistic pictures. Our work focuses on temporal issues for NPR walkthroughs and on the development of a principled framework, both at the theoretical and practical level. This is a necessary step towards a longer-term goal: the study, parameterization, and capture of the elusive notion of style.

Current techniques in NPR focus on particular styles of rendering and usually present a completely integrated system. In order to reach maturity, the field needs to be grounded on a clearly defined set of modular basic techniques and on a clear understanding of their articulation. We are working on modular methods for the creation of non-photorealistic images both from 3D models and from real images. Our current work focuses on systematic approaches to the generation of line drawing from 3D models, and on a modular system for the generation of non-photorealistic pictures from a set of photographs.

Computer-generated non-photorealistic pictures permit the animation of static traditional pictorial styles. A user can walk through the 3D scene depicted by pencil drawing, engraving or oil painting. This raises the challenge of *temporal coherence*. The random flickering of strokes must be avoided, and a tradeoff must be found between the shower-door effect caused by static strokes in 2D and strokes that look mapped on 3D models. We are particularly interested in temporal coherence for line drawing. We believe that to solve this problem, we need to track the silhouette and to compute differential properties such as the local 2D motion vectors and the longitudinal expansion along the silhouette. Again, our focus is developing generic mechanisms that can be used for a large variety of coherence strategies in line drawing. Related issues arise for the paper texture used in as a background. We are developing paper animation techniques that convey the observer's motion while preserving the 2D rigid quality of paper.

We propose to address the challenge of style via two complementary strategies: procedural exploration, and example-based analysis and capture. Our procedural approach to style will be based on the modular studies mentioned above, and on the study of depiction from the visual arts and perception communities. Our goal is to develop systems where a large variety of styles can be implemented based on a set of generic mechanisms. This contrasts with current approaches of NPR that usually propose a system for a given style. The systems we are developing will then be used to explore depiction styles. We will borrow inspiration from the visual art, and we will implement in our systems procedures that imitate given example images.

In contrast, in our second strategy we will develop systems that directly take example pictures of a given style and apply this style to new inputs. We plan to use tools from statistics and machine learning, and in particular tools used to study the statistics of natural images in ecological optics. The expertise gained using the procedural approach will be crucial to select the relevant learning spaces and style dimensions. We plan to use this approach first with controlled conditions, where the 3D model is known and where an artist uses a tablet to depict it. This will provide us more information on the strategy used by the artist. Our long-term goal is to extract non-photorealistic styles from images alone and to apply them to new scenes.

4.2. Echanges de chercheurs.

We plan to organize regular short visits (one or two weeks) for synchronization on the various projects, and longer stays for faculty and PhD students, according to the following indicative list:

4.2.1. Accueil de chercheurs de votre partenaire

	Year 1	Year 2	Year 3
Frédo Durand (professor)	2 x 1 week	1-2 month	2 x 1 week
Sara Su (PhD)	1 month	2 x 1 week	1week
Eric Chan (PhD)	2 x 1 week	1 month	1 week

4.2.2. Missions INRIA vers votre partenaire

	Year 1	Year 2	Year 3
Joëlle Thollot (MCF)	2-3 months	1 week	2 weeks
François Sillion	1 week	1 week	1week
Stéphane Grabli (doctorant)	1-2 month	1-2 month	

4.3. Réunions, workshops, ...etc

In addition to the above, we plan to organize a 1-week workshop gathering the participants of the collaboration in the summer of 2004, in Cambridge, USA.

5. Budget

5.1. Estimation du coût des échanges et des réunions mentionnés en 4.

The cost of the above mentioned stays (14 one-week trips + 1 two-week trip + 6 extended stays) is about 65,000 € for the three-year period.

5.2. Cette coopération bénéficie-t-elle déjà d'un soutien financier de la part de l'INRIA, de l'organisme étranger partenaire ou d'un organisme tiers (projet européen, NSF, ...) ?

The collaboration is not funded by any other institution at this point. The NSF-INRIA Grant expired in 2000.

5.3. Dans le cas où votre projet d'équipe associée serait retenu, vous parait-il probable d'obtenir de l'organisme étranger partenaire un soutien financier symétrique ?

We are hopeful that the MIT-France program at MIT can match some of the INRIA funding.

6. Formation

Graduate students will be the cornerstones of this collaboration, and both short-term and longer-term exchanges are planned. Long-term visits (1 or 2-month) will permit the bootstrapping of research projects, and shorter visit will be used to synchronize on ongoing projects and to finalize publications. The rest of the time, phone meetings will allow us to collaborate across the Atlantic.

The model we want to follow for this collaboration is the example of Stéphane Grabli, a PhD student in the Artis team. He is co-advised by Francois Sillion on the French side, and Frédo Durand on the US side. He spent 2 months in the summer 2003 to start a project on Non-photorealistic rendering. Weekly phone meeting are now used effectively to discuss the various aspects of the project. We are hopeful that the "equipe associee" funding will permit shorter visit of faculty.

Symmetrically, MIT grad students will greatly benefit from stays at INRIA. The past examples of Byong Mok Oh and Sami Shalabi, supported by the former NSF-INRIA grant, has shown that even 2-week stays are tremendously stimulating and can foster a strong scientific collaboration. We plan that MIT grad students will spend a 1-month period in Grenoble, which will be followed by 1-week visit for follows-up on the scientific joint project.

We also envision possible participation in each other's teaching roles, with the planned exchange of university professors (e.g. F. Durand and Joëlle Thollot) who may propose invited lectures in graduate-level courses (such as the DEA IVR in Grenoble).

7. Impact

7.1. Sur la collaboration que vous avez déjà avec votre partenaire

As explained above, the collaboration has been active for five years now. We expect the "équipe associée" to strengthen it significantly, by allowing a continued exchange of researchers and effective cooperation. It has been our experience that actual visits are indispensable to the success of any joint project, and these involve a significant cost, which is no longer financed at this stage.

7.2. Sur la collaboration avec d'autres projets INRIA

The existing relationship between the REVES project team at INRIA Sophia and both Artis and the MIT Computer Graphics group will help in tightening the cooperation of the entire group in the areas of real-time rendering and non-photorealistic rendering.

7.3. Sur la collaboration avec d'autres équipes de l'organisme étranger partenaire.

Research at the interface between computer graphics and computer vision is becoming increasingly important, due to the crucial need for the acquisition of complex 3D model and the extension of image-processing techniques to the 3D domain. The exchanges with the MIT computer graphics group will undoubtedly favor informal discussions with MIT researchers from the computer vision group at the MIT AI lab, such as Bill Freeman or Trevor Darrell. In particular, the work by Bill Freeman on style capture is of high importance for our joint research on non-photorealistic rendering.