Masse de Données et Connaissances - Appel à projets 2007 (ANR-07-MDCO) **Fiche B : Description technique détaillée du projet**	
Acronyme du projet :	**ATROCO**

1 Résumé du projet en français

<u>1 page au maximum</u>. Sauf exigence particulière de confidentialité à mentionner dans le formulaire excel, le résumé ci-dessous pourra être diffusé par l'ANR ou par l'Unité Support.

Les algorithmes permettant le rendu réaliste d'images de synthèse ont de nombreuses applications, telles que la re-création d'héritages culturels disparus, la création d'effets spéciaux pour le cinéma, ou bien le prototypage virtuel pour les jeus vidéo. Le point commun de toutes ces applications est la nécessité d'obtenir des images de plus en plus réalistes, à l'aide de modèles aux aussi de plus en plus réalistes. Cependant, ces modèles sont excessivement complexes car ils sont définis par un maillage polygonal basé sur un très grand nombre de polygones. En conséquence, ils sont difficiles à représenter, et il faut à un créateur professionnel plusieurs jours ou semaines de travail pour créer le modèle 3D d'un objet complexe tel qu'une statue. En plus de cette complexité géométrique, le champ de réflectance de l'objet doit aussi être précisément représenté. Des textures sont généralement utilisées à cette fin, mais des textures réalistes tendent à être très complexes car elles définissent une fonction à six dimensions représentant les propriétés de réflectance de chaque point de la surface. Ensemble, la géométrie et la réflectance posent donc des problèmes significatifs en termes de stockage et de traitement en temps réel.

L'idée principale de ce projet de recherche est de révolutionner la chaîne de traitements classique de la synthèse d'images réalistes : plutôt que devoir construire un modèle polygonal d'un objet existant, nous souhaitons que le modèle soit créé directement et automatiquement à partir de l'objet. De nombreux outils existent pour créer des modèles numériques d'objets existants, mais ils requièrent des interventions fréquentes d'un utilisateur expert contrôlant attentivement l'éclairage et effectuant un long post-traitement. Les modèles créés sont généralement des surfaces polygonales de très haute définition, inutilisables pour des affichages en temps réel sur des cartes graphiques standards. De plus, l'apparence, les couleurs, matériaux et textures des objets doivent être acquis par d'autres processus. Notre but est de simplifier la chaîne complète des traitements, de l'acquisition au rendu :

- Développer de méthodes d'acquisition qui nécessitent peu d'interventions humaines, et qui peuvent être mises en œuvre aisément par des utilisateurs novices. Ces méthodes doivent permettre d'acquérir simultanément la géométrie et l'apparence des objets.
- Effectuer un post-traitement sur les données créées lors de la première étape afin de rendre ces données utilisables pour un affichage en temps réel, avec une combinaison de représentations géométriques et basées image.
- Réaliser un rendu réaliste de ces modèles, et une incrustation dans un monde réel. Cette étape nécessite de simuler l'éclairage de scènes complexes. La seule complexité des modèles rendrait leur rendu très difficile, et la simulation de la propagation de la lumière à l'intérieur ainsi que leur interaction avec l'environnement la rend encore plus difficile.

Ces trois tâches sont plus interdépendantes qu'elles ne le semblent au premier abord. Par exemple, l'acquisition de la géométrie d'un modèle suppose des hypothèses fortes sur le matériau qui le compose et sur l'éclairage auquel il est soumis. La possibilité d'effectuer une simulation de l'illumination de ce modèle permettra de valider ces hypothèses et permettra ainsi la création d'un modèle plus fidèle à la réalité.

Notre projet de recherche possède plusieurs applications. Celles que nous envisageons en premier lieu et liée à l'héritage culturel, à la fois à des fins d'archivage digital et de mise à disposition au public. Mais notre projet présente aussi des utilisations potentielles dans toutes les applications qui nécessitent la présence d'un objet réel dans un monde virtuel,

telles que la réalité augmentée et les jeux vidéo.

2 Summary in English

<u>1 page au maximum</u>. Sauf exigence particulière de confidentialité à mentionner dans le formulaire excel, le résumé ci-dessous pourra être diffusé par l'ANR ou par l'Unité Support.

Algorithms for realistic image synthesis have numerous applications, for example in cultural heritage, special effects for movies, virtual prototyping and video games. A common theme for all these applications is that they require more and more realistic images, with more realistic models. But these realistic models carry a high complexity, as they are usually defined by a polygonal mesh with a very large number of polygons. A consequence of this complexity is that they are hard to represent: it takes a professional modeller several days or weeks to create a 3D model of an existing complex object such as a statue. In addition to the geometric model complexity, the reflectance field of the object also needs to be precisely represented. Generally, textures are used to this end. However, realistic textures turn out to be extremely complex, as they define a six-dimensional function, representing a bi-direction reflectance property on each individual surface point. Together, geometry and reflectance raise significant problems in terms of storage and real time processing.

Our key idea in this research project is to revolutionize the classical modelling pipeline for realistic image synthesis: instead of having a person create a polygonal model of an existing object, we want to create the model directly from the object. Although several tools exist for creating digital models of existing objects, they currently require constant input from expert users, carefully controlled lighting and a long post-processing step. The models created are high-definition polygonal models, unsuitable for real-time display on standard graphics cards, and the appearance of the object, its colours, materials and textures must be captured separately by another process. Our goal is therefore to simplify the whole process of model acquisition and rendering:

- Develop an **acquisition** method that requires little user input, and can therefore be used by novice users. This acquisition method must capture both the geometry and the appearance of objects.
- **Post-process** the models created by the first step to make them suitable for real-time display, using a combination of geometric and image-based representation.
- **Render** these models and **integrate** them into virtual worlds. This requires illumination simulation on these complex models. The sheer complexity of the models makes rendering them a very difficult task. Simulating the propagation of light inside these models and their interaction with a virtual environment is even more difficult.

These three tasks are more inter-dependent than they appear at first sight: for example, the acquisition of the geometry of the models makes assumptions on the material of the model and on the lighting. Being able to conduct an illumination simulation on the model will validate these assumptions and help in creating a more accurate model.

Our research project has several applications. The main application we envision is with cultural heritage: both for digital archival of items and for displaying these items with the public. But our project also has potential uses with all the applications that require the presence of a real object inside a virtual world, such as augmented reality, special effects and video games.

3 Introduction

<u>2 pages au maximum</u>. On décrira brièvement le projet, les enjeux scientifiques - techniques - économiques associés, les verrous à lever, les résultats attendus et les perspectives ouvertes sur le plan scientifique et/ou en termes d'applications. On discutera la pertinence par rapport à l'appel à projets.

Algorithms for realistic image synthesis have numerous applications, for example in cultural heritage, special effects for movies, virtual prototyping and video games. A common theme for all these applications is that they require more and more realistic images, with more realistic models. But these realistic models carry a high complexity, as they’re usually defined by a polygonal mesh with a very large number of polygons. These polygons must be created by hand, one by one. This long and tedious process often requires several weeks for a professional modeller. Worse, the model created is often not as realistic as the original.

Our key idea in this research project is to revolutionize the classical modelling pipeline for realistic image synthesis: instead of having a person create a polygonal model of an existing object, we want to acquire the model directly from the object. Currently, several tools (such as 3D scanners) exist for creating a digital model of an existing object. But these tools have important limitations: they require careful input from expert users, controlled lighting, and several steps of post-processing to re-align the data. All these limitations make it impossible to digitalize a large library of items, or large elements. Furthermore, the models created are high-definition polygonal models, unsuitable for real-time display and analysis. Finally, these tools only capture the geometry of the object, and its appearance (colours, materials, textures, normals) must be captured in a different step; results from both step have to be reconciled together, a complex process.

Our goal is therefore to simplify the whole process of model acquisition, treatment and rendering:

- For **Acquisition**, we want to create a method that runs largely automatically, and can be used by novice users. This acquisition method must capture simultaneously the geometry and appearance of the objects. The models created will be high-definition representations of both the geometry and appearance of the objects.
- For **Treatment**, we mean a post-processing step, converting these high-definition representations into a form suitable for further computations and display. This form will be neither a complete geometrical model nor a completely image-based model, but rather a combination of both representations, to get the best compacity and ease of use.
- For **Rendering**, our primary goal is the real-time rendering of our complex, highly realistic models. But rendering a single object in isolation is not very useful: objects only exist inside a world, and receive and reflect illumination from this world. So for in order to get a realistic rendering of our complex objects, we must develop methods for simulating the propagation of light inside these models, and their interaction with the virtual environment.

The main difficulty in this project is the size of the data required for an accurate representation of a single object: assuming we want an accuracy of one-tenth of a millimeter, for an object of approximately 40 cm in diameter, this is equivalent to 100 millions of sample points, each sample point including its position, orientation, and illumination. The real-time display of such a complex model is beyond the capacities of standard graphics cards. Actually, even storing the model on the graphics card is going to be an issue. Yet we need this accuracy for some applications, and so we must treat the data in order to convert the high-definition representation into a more compact form, suitable for display and illumination simulation.

Similarly, acquiring the reflectance properties of an object requires sampling its bi-directional reflection function (BRDF). The BRDF is a 4D function expressing the ratio between the incoming light flux and the reflected light. As this 4D function is not constant over the surface of the object, we actually have a 6D function. The acquisition of this 6D function is usually done by taking several pictures of the object under different lighting conditions and different viewing orientations, then filtering the data to create a model of the BRDF.

Our three tasks (acquisition, treatment and rendering) are more inter-dependent than they appear at first sight. Naturally, there is a top-down dependency between them, in the sense that it is necessary to first *acquire* the model, then *treat* it, in order to be able to *render* it. But there is also a bottom-up dependency: for example, the acquisition of the geometry or of the reflectance properties makes several assumption of the material of the model, and on its reaction to direct lighting. Being able to conduct an illumination simulation on the model will be used to validate these assumptions, and will result in a more accurate geometry and BRDF for the model.

Our research project has several applications. The main application we envision is with cultural heritage: our research project will be used, first, for the digital archival of large libraries of items such as statues or archaeological artefacts. But it will be also used for real-time display of these items with the public, for example for the study of fragile objects. Here, especially, it will be really interesting to give the user the possibility to change the environment and lighting around the object, observing the changes in aspect it creates. Our project also has strong potential uses for all the applications that require the presence of a real object inside a virtual world, such as special effects for motion pictures, video games and simulation.

4 Contexte et état de l'art / Context and state-of-the art

4.1 Acquisition of complex objects

4.1.1 Image-based methods

The problems raised by digitization of real objects and materials are numerous. A digital copy should make it possible to retrieve with high fidelity the appearance of an object or of its material whatever are the lighting conditions of the environment (be it virtual or real). The use of pure image-based techniques such as (Gortler *et al.*,2006), (Hawkins *et al.*, 2001), (Levoy *et al.*, 1996) guarantees, by definition, high fidelity. However, the degrees of liberty are strongly restricted with these methods, which makes them completely inappropriate with respect to many applications. In order to guarantee a high degree of freedom, it is necessary to capture a good approximation of the shape, further used as underlying geometric support for applying the data relative to the appearance.

4.1.2 3D scanners

Concerning shape acquisition, a lot of commercial tools exist (scanners), all of them allowing to capture more or less precisely a 3D geometry. Such tools may be considered as 3D cameras. However, these techniques all require to acquire an object from different viewpoints. This raises problems concerning the accurate registration of individual object parts. There exist a lot of work attempting to fix this issue (Matabosch *et al.*, 2004), (Pingi *et al.*, 2005), (Zagorchev *et al.* 2005), (Zhang *et al.* 2004), but nearly never in a very general and totally automatic way. Fully automatic registration remains a difficult problem. Scanners are also not always able to scan all kinds of materials, which further increases the difficulty for some types of objects.

4.1.3 Acquisition of the appearance (material, BRDF)

As for geometry, it is important to perform an accurate registration between images and 3D geometry in order to acquire the appearance of an object. The use of targets (Chen *et al.* 2002) is frequent but very constraining for the operator because of visibility issues. Image-based methods (Matsushita *et al.* 1999) often fail in general cases and others are only assisting manual a procedure (Franken *et al.* 2005). Digitising the appearance and more generally a given material infers cumbersome and painstaking manipulations that can last several hours. In addition, lighting conditions need to be controlled very precisely (using for instance a gonioreflectometer). The amount of images that need to be captured is extremely high, further raising important problems of data storage and massive processing. A good representation that is both accurate and compact is not easy to determine and still represents an open problem and active research area.

4.2 Treatment of complex objects

4.2.1 Shape simplification (levels of detail, alternate representations)

The graphics cards used inside standard PCs have a limited capacity for the raw rendering of polygons, which places a limit on the complexity of the scene they can render in real time (more than 30 Hz). On the other hand, modern graphics cards are programmable. Several algorithms exploit this capacity to render really complex objects, by converting them into a simpler polygonal representation, with the complexity of the shape being moved to displacement maps (or *relief textures*) (Oliveira *et al.*, 2000). These relief textures are part of a large set of methods that combine image-based and geometry-based representations for complex models (Jeschke *et al.*, 2005).

4.2.2 Appearance simplification

Once the appearance of an object or a material is acquired, it must be represented in a way compatible with GPUs. The amount of data however often exceeds by far the local graphics cards memory (Dana *et al.*, 1999). Two approaches are then possible: the first one consists in applying brute force compression (spherical harmonics, wavelets, principal components analysis, and so forth) like in (Vasilescu *et al.,* 2004), (Mueller *et al.* 2003), the second one consists in using a mathematical description of reflectance (like Lafortune's generalized Phong model, Lafortune *et al.,* 1997) and make its parameters fit into the measurements as in (McAllister *et al.*, 2002). While the former are hard to use in everyday applications (because the required memory still remains huge), the latter raise visual errors that can be more or less important depending on the model. The acquired and represented appearance must then be further processed in order to be applied on other surfaces (example-based texturing) or to be rendered at real-time rates.

4.3 Rendering of complex objects

4.3.1 Illumination simulation on complex objects

Graphic cards can not process very large databases since they have limited capacity for rendering polygons. They have also a limited capacity at simulating global effects, such as visibility and global illumination. However, as demonstrated by Wald *et al.* (2004), it is possible to implement efficient ray tracing for real-time rendering of complex models by exploiting ray coherence. Global illumination is also demonstrated within this framework (Benthin *et al.* 2003, Koellig *et al.* 2004).

4.3.3 Integrating complex objects into virtual environments

Compositing objects into a new environment is a two stage process. We first have to estimate an the camera pose in the environment and then illumination effects have to be simulated. Camera pose estimation is a well studied domain (analysing optical flow or using specific markers (Kato *et al.* 2004)). Relighting a static object and a static background is also a known process (Debevec *et al.* 1998, 2005). Compositing onto a live background is still an open problem.

4.4 Bibliography

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5 Partenaires / Partnership

<u>2 pages au maximum</u>. On présentera les partenaires et on décrira aussi les compétences et savoir-faire des équipes impliquées vis-à-vis de l'état de l'art au niveau national et international. On mentionnera ici, pour chacune des équipes, son implication éventuelle dans d'autres projets. Les indications fournies serviront à apprécier la qualité du partenariat.

ARTIS : Acquisition, Representation and Transformations for Image Synthesis

ARTIS is both a research team of INRIA Rhône-Alpes and a team of the LJK laboratory, a joint research unit of CNRS, INRIA, INPG and UJF. It is located at INRIA Rhône-Alpes in Montbonnot, France.

The project was created in January 2003, based on the observation that classical image synthesis methods appear limited with respect to the variety of current applications. In particular, the typical approach consisting in separately modelling a 3D geometry and a set of photometric properties (reflectance, lighting conditions), then in computing their interaction to produce a picture, is too restrictive. First, this approach severely limits the adaptability to particular constraints or freedom allowed in each application (such as precision, real-time, interactivity, uncertainty about input data...); second, it restricts the possible image classes and does not easily lend itself to new uses in a more "expressive" way, such as for illustration, where a form of hierarchy on image constituents must be constructed.

One of the goals of the project is the definition of a more generic framework for the creation of synthetic images, integrating elements of 3D geometry, of 2D geometry (built from these), of appearance (photometry, textures...), of rendering style, and of importance or relevance for a given application. The ARTIS project therefore deals with multiple aspects of image synthesis: model creation from various sources of data, transformations between these models, rendering and imaging algorithms, and the adaptation of the models and algorithms to various constraints or application contexts.

Projects:
The ARTIS research team is currently working within three industrial projects:

- **GraphAnim**: A project for transferring Non-Photorealistic and Artistic Rendering methods to a movie studio in Paris, Broceliande. The goal of the project is writing a software for easy watercolor rendering, integrated inside Maya. GraphAnim lasts for one year, from May 2006 to May 2007.
- **GVTR**: A project for the maturation of several research algorithms used for the real-time display of geographical scenes (relief, mountains, trees, rivers, buildings). GVTR is financed by the GRAVIT consortium, and will last for one year, from April 2007 to April 2008.
- **GENAC**: A joint research project with two research teams: EVASION (INRIA Rhône-Alpes) and GeoMod (LIRIS) and two video-games companies in Lyon: Eden Games and WideScreen Games. In this project, ARTIS will develop algorithms for the real-time simulation of global illumination in video games. GENAC will start in September 2007, and will last for two years.

The ARTIS research team is also involved inside two ANR “Blanc” projects, submitted in March 2007 and currently under review:

- **STYLE:** A joint research project with the research team iPARLA (INRIA Futurs and LABRI). Our goal is to offer efficient tools for artistic rendering of images and animations in various styles: line-drawing, pen-and-ink (hatching or stippling), painting (watercolor, oil)....

- **HFIBMR:** A joint research project with the research teams WILLOW (ENS, ENPC and INRIA Rocquencourt) and LASMEA (UMR 6602, UBP and CNRS). Our common goal is the acquisition, treatment and rendering of High-Fidelity Image-Based Models.

LIRIS : Lyon Research Center for Images and Intelligent Information Systems

LIRIS was born at the beginning of year 2003, following the clustering of several computer science laboratories from Lyon (LIGIM, LISI, RFV). It has been associated to the French research institution CNRS under the label UMR 5205. Grouping around 280 people, with near to 110 searching and teaching people with a faculty position, LIRIS has four administrative supervisions: INSA-Lyon, The Claude Bernard Lyon 1 University, Ecole Centrale of Lyon and University Lumière Lyon 2, and three sites: Villeurbanne, Ecully, Bron and Lyon, all in Lyon suburbs, France.

Presentation :

LIRIS has two main research topics: image and information systems, topics which are turned down in four scientific axis:

Axis 1: knowledge and complex system

Axis 2: Image and video: segmentation and extraction

Axis 3: Modeling and augmented reality

Axis 4: Communicating information system

and two transversal actions:

- Action A - Culture et patrimoine
- Action B - Computer science and health

R3AM team (realistic rendering for mobile augmented reality), part of Axis 3, is the one which is particularly involved in this project. Its historic speciality is realistic rendering, but it recently evolved by starting to explore augmented reality and computer vision.

Projects :

R3AM is currently involved in the following project :

It has also submitted a CIBLE (région rhone-alpes) project about mobile augmented museum visit named **MuMads** and a “pole de compétitivité” project on video-games named **PlayAll.**

LSIIT : Laboratory of Image sciences, Computer science and remote detection
IGG Team (Computer Graphics and Modelling team)

During the last years the IGG team of the LSIIT has acquired a serious knowledge around digitisation of real objects using structured light, the representation and the modelling of objects including their appearance as well as their texturing. We have recently proposed a contribution **[LARUE06]** in the field of cultural heritage by developing a robust fully automatic registration method designed for structured light acquisitions. The initial processing that follows any acquisition mainly consists in removing noise and artefacts in acquired point clouds. Denoising is an important step in geometry acquisition. We have proposed a new representation of geometry **[FOURNIER07]**, which allows us to improve the quality of denoising compared to existing techniques.

Concerning more generally the representation and modelling of 3D objects the IGG team can resort on a long-standing experience. Recently, we are investigating hierarchical and multi-scale representations to deal with very large geometric datasets. This activity is supported by a new researcher in the team, Basile Sauvage, who co-authored a book chapter in this field **[SAUVAGE07]**.

The IGG team has also a long-standing experience in material representation, with a special focus on texturing. In the past, we have developed numerous methods for representing surface imperfections, textures and realistic bi-directional effects. More recently we developed a new method for synthesizing new textures from images **[DISCHLER06]** in a user controlled way as well as a method for encoding refraction fields on GPUs using spherical harmonics for real-time rendering **[GENEVAUX06]**.

Projects (in acquisition and appearance modelling and rendering):

The IGG team is / has been working on two industrial projects:

- **AMI3D:** This project ended in February 2007 (supported by RIAM). It concerned the acquisition of art pieces in the field of cultural heritage. The project involved geometry acquisition as well as appearance acquisition.
- **REVETIR:** A project for the modelling and rendering of translucent material in a medical simulation context. This work is done in collaboration with the IRCAD.

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6 Organisation et management du projet / Project organization and management

<u>2 pages au maximum</u>. On décrira l'organisation mise en place pour le projet et la manière dont sera assurée la coordination de celui-ci. Le mode de pilotage du projet sera décrit en tenant compte des aléas susceptibles d'être rencontrés.

The project will be managed globally by the Nicolas Holzschuch, of the ARTIS team.

Each of the three teams will have the responsibility of one of the work packages: WP 7.1 (Model acquisition) for IGG, WP 7.2 (Model treatment) for ARTIS and WP 7.3 (Model rendering) for R3AM. This responsibility does not mean that the research team is in charge of all the work in this work-package (even if, each time, it corresponds to its area of excellence) but rather that it is in charge of coordinating the efforts by the other teams, ensuring that they stay on schedule, and of ensuring transfers of data and knowledge between the other two teams.

Similarly, each of the sub-packages has been placed under the responsibility of a specific team. Again, it does not mean that the team is solely in charge of doing all the work in the sub package, even if this time the team in charge corresponds to the team that will carry most of the research work and has the strongest experience.

The three work packages in this project are strongly inter-dependent: it is necessary to have completed the model acquisition in order to start the model treatment, and it is necessary to have completed the model treatment to start the model rendering. This could create the potential for several bottlenecks. We have identified this problem, and we have the following work-around: IGG already has several highly complex models (acquired using preliminary versions of this work) that they will release to the other teams at the start of the project. These models will allow the work-packages on treatment and rendering to start immediately. The result of the work on rendering will also help the work on treatment.

7 Structure du projet – Description des sous-projets / Structure of the project – Work-packages

<u>10 pages au maximum</u>. On décrira le programme de travail en identifiant pour chaque étape, les objectifs poursuivis, le rôle de chaque partenaire et les moyens mis en œuvre. La valeur ajoutée des coopérations entre les différentes équipes sera argumentée. Si des doctorants sont présents dans le projet, on explicitera leur sujet de thèse et les conditions de leur encadrement.

7.1 *<u>Acquisition of complex objects</u>*

7.1.1 Shape acquisition

This work-package will be managed by LSIIT, with input and collaboration from ARTIS and LIRIS.

Despite the automatic technique for registration that we have developed at LSIIT, the manipulations during acquisition remain completely free from the operator point of view, like the placement of the different devices for instance. This work has been done by a PhD student (Frédéric Larue), who is now being involved in this project for the next two years. In the framework of this PhD, we wish to improve the planification of acquisition. The motivation is to minimize efforts and thus the global time for acquiring an object. Yet the sampling of the information must be sufficiently dense to guarantee complete results. We further want to extend our acquisition protocols to large-scale environments. Therefore, we plan to acquire a laser scanner which has a larger scanning area. We then have to transpose our system to this new technology.

Since the surfaces acquired by this system result in huge amounts of data we have to process hierarchically the scenes in a second step. We plan to use multi-resolution methods for representing the data. We also want to develop alternate representation techniques in collaboration with ARTIS in order to improve rendering speed of our digitised models. Finally, we want to collaborate with LIRIS in order to improve our environment acquisition techniques. The latter works will be done by two researchers at LSIIT (B. Sauvage and S. Brandel).

7.1.2 Acquisition of the appearance

This work-package will be managed by LSIIT, with input and collaboration from ARTIS and LIRIS.

The acquisition of appearance has also already been studied in our previous research projects (by the PhD Student, F. Larue). Chromatic variations resulting from changing the observer position are currently being acquired as well as rendered in real-time on screens using simple analytical models. The more complex case of bi-directional acquisition is also being studied with a constraint lighting system. We dispose of a semi-gonioreflectometer (semi- in the sense that one degree of freedom is missing). Such measurements are extremely painstaking. We plan to improve the acquisition protocol by further analysing images and reflectance functions to significantly reduce the number of images. Therefore, we first need to complete our gonioreflectometer tool by adding an additional moving arm. Our approach consists in decoupling texture meso-geometry (using the scanner) from its reflectance following the strategy of (Kautz et al. “Decoupling BRDFs from Surface Mesostructures”, Proceedings of Graphics Interface 2004). The reflectance can also be further separated into different major components: diffuse, specular and inter-reflections including sub-surface scattering. By separating these components and approximating them, simpler expressions of texture models can be proposed. We furthermore intend to tackle the difficult problem of light source registration (position estimation). By knowing the meso-geometry of acquired textures and by applying shape from shading-similar vision techniques, one can estimate the position of a light source. The result of our study, which will be done by a research engineer of LSIIT, should lead us towards both, a simpler acquisition protocol and a more compact representation of surface textures suitable for real-time rendering applications.

7.1.3 Acquisition of the environment

This work-package will be managed by LIRIS, in collaboration with ARTIS and LSIIT.

Our overall goal is to render complex objects inside a realistic environment. One of our aims is to place the complex objects acquired using work-packages 7.1.1 and 7.1.2 inside a real environment, and to model the interaction of light between the object and its environment. This complex task requires us to acquire the geometry and lighting characteristics of the environment. This is the goal of this work-package. We plan to work on three tasks:

Firstly, for the local geometry, we plan to use several cameras and use the same techniques described in work-package 7.1.2: by using image-based data, we should be able to approximate local geometry. To do this in real-time, one may use the graphics processors (GPUs) as they are particularly suited for linear algebra computations. To process video in real-time on GPU, we may use the pixel buffer objects which allows asynchronous transfers between central and video memory.

Secondly, for local illumination, we plan to build one special device acting like a “kaleidoscope” with partially darkened parts. By placing this device in front of the lens of our camera, we will obtain multiple copies of the scene with different simulated expositions in one shot. These views will be combined into a single high dynamic range image. Of course, the resolution will be greatly reduced, but we think this is not that important since it is only used to relight a virtual object.

Thirdly, when we capture the incident light with the gaze-ball, the camera reflect image is present in our high dynamic range data, as well as the environment surrounding the sphere. To date, there is no automatic method to remove these two artefacts. We plan to do this by segmenting the camera image using shape recognition algorithms and replacing it with surrounding values or data from another point of view. We may also use the fact that the camera and environment will roughly always be at the same place in the image.

As mentioned previously, the LSIIT plans to acquire a laser scanner in order to be able to digitise precisely more complete environments. The precise geometry will also help us in collaboration with LIRIS to evaluate the accuracy of the aforementioned image-based vision methods, which do not use measurement devices but only camera systems. Concretely, LSIIT wants to conduct series of tests with LIRIS in order to evaluate vision methods as well as their efficiency and accuracy. That is, we want to scan one or two environments (geometry and reflectance) and then apply the vision system to the same environment. A straight comparison of graphical results will allow us to quantify the committed errors when using only camera systems.

7.1.4 Using illumination simulation for better acquisition

This work-package will be managed by LSIIT, with input and collaboration from ARTIS and LIRIS.

Acquiring geometry and basic reflectance properties from images relies on several assumptions, namely that incoming lighting is known, and that the influence of indirect lighting is negligible. It also necessary to make several assumptions on the nature of the reflectance properties of the object (for example, that it is a diffuse object). By conducting an illumination simulation on the acquired geometry and reflectance properties, we plan to validate the results of the first phase. We will use the difference between the illumination simulation on the acquired model and the original pictures to further enhance the quality of the acquisition process, getting more accuracy on the geometry of the object or on its reflectance properties. This work will be done using the results of work-packages 7.3 (rendering complex objects), thus creating a feedback loop in the research project.

To help the process, the LSIIT plans to use simple systems for acquiring basic Phong-like reflectance properties in complex environments, where the lighting conditions cannot be constrained or controlled.

7.2 Treatment of complex objects

This work-package will be managed by ARTIS, in collaboration with LSIIT.

7.2.1 Shape simplification and combined representations

Team responsible: ARTIS (in collaboration with LSIIT)

Our primary goal is to work with complex models, acquired from real world objects. The polygonal models that are generated by direct acquisition from the shape geometry are too complex to be manageable (several hundreds of millions of polygons). This complexity is beyond the memory capacities of either the computers themselves or their graphics cards. In order to use such models, we need to simplify them. This is the *treatment* phase. We want to keep all the complexity of the original shape, including small geometrical details that contribute to the shape appearance, but organize this complexity in such a way that it is manageable by standard personal computers.

To reach this goal, we will use a combined representation, using geometrical and image-based representations. This work is an extension of the relief textures and other impostor methods.

The specificity of this project is the tight integration between the three phases (acquisition, treatment and rendering). Specifically, the two research teams ARTIS and LIRIS will work together in order to use the maximum information from the acquisition phase, to get the most accurate representation combined with the fastest rendering.

In a first step, we will create combined representations from the raw results of the acquisition phase. This first step will use the most accurate geometric representation created from the acquisition phase and will simplify it by converting it into a combined representation (geometry/image). The choice of the optimal representation is still an open problem, requiring lots of user input and knowledge. Our goal is to make this process automatic.

In a second step, we will use the knowledge accumulated from the first step to explore the possibility of generating the combined representation directly from the acquisition setup.

7.2.2 Appearance simplification

Team responsible: LSIIT (in cooperation with ARTIS)

The association of appearance information with geometric information is a difficult problem, which creates huge data structures because of the high dimensionality. Furthermore, the smooth transition between different appearance representation techniques (BTF, displacement map, triangles-based explicit geometry) is still an open and difficult problem that we want to tackle. A naïve solution, would consist in computing mip-maps of bi-directional texture functions mapped on object surfaces. Such BTF mip-maps do, however, not take into account masking and shadowing effects due to object geometry and texture meso-geometry, so they would not only lead to enormous memory requirements but also to inaccurate visual results. We want to develop a hierarchical object representation which also takes into account its appearance, thus maintaining an accurate visual consistency at all levels of scale. We therefore, need to mix different representation techniques and provide a consistent transition between these.

7.3 Rendering of complex objects

This work-package will be managed by LIRIS, in collaboration with ARTIS.

7.3.1 Real-time display of complex objects

Team responsible: ARTIS

The highly complex models that are generated from the acquisition phase are too complex for real-time display. In the second phase, we have converted these complex models into combined representations, using image-based data attached to a crude geometric representation of the object. Our goal is now to display these combined representations in real-time. We will use the programmability of the modern graphics cards to display these combined representations. The strong advantage of these methods is that the rendering time is proportional to the number of pixels occupied by the object on the screen, and not to its number of polygons. Our methods are therefore naturally output-sensitive.

We will place a strong emphasis on the most accurate representation of our complex objects. Specifically, we will use the image-based data to represent a displacement map with respect to the geometry stored. We want the most accurate rendering of this displacement map, including object masking and un-masking. This accuracy will allow us to further simplify the underlying geometry, resulting in faster rendering times.

As our applications include data exploration, we want the user to be able to turn around the object in real-time, in order to explore it under all its faces and get a good knowledge of the object. We therefore place a strong emphasis on the user experience, and require that our methods render the object in real-time (at more than 30 Hz).

7.3.2 Illumination simulation on complex objects

Team responsible: LIRIS, in cooperation with ARTIS

The models we have acquired in the first step (section 7.1) and treated in the second step (section 7.2) only carry information about their geometry and material information. Our goal is to get a photorealistic rendering of these objects. This photorealistic rendering will serve two purposes: first, to allow the users to visualize the acquired objects and to manipulate them, second as a way to refine the analysis of reflectance and illumination, used in work-package 7.1.4. For both goals, we must take into account the high geometric and appearance complexity of our models. This high complexity means that most existing methods will be unable to process the models.

We will explore two different avenues for this work: real-time display of the complex object by simulating lighting effects on the GPU, and parallel ray-tracing for interactive display of the complex models. Both methods aim at producing photo-realistic pictures, but using different methods. The former will be explored by the ARTIS research team, and the latter by the R3AM team.

Both methods will rely on the results of the previous phase (treatment of complex models), using the combined representations created in work-package 7.2 for faster treatment and rendering.

Both methods will also rely on a frequency analysis of light transport, published by the ARTIS team: Specular reflections and shadow boundaries, for example, are high-frequency effects, requiring accurate sampling on the spatial direction. On the other hand, diffuse reflections are low-frequency effects, requiring fewer samples. The frequency content of illumination depends on many factors, including the distance between objects and the BRDF of the receiver. Knowing this frequency content makes a very powerful tool for both high-fidelity and interactive rendering. ARTIS and R3AM will work together on adapting this framework for both illumination simulation methods.

Moreover, we will combine the knowledge of the frequency content with a model of human vision, in order to sample more accurately in place of high saliency.

Interactive parallel ray-tracing:

There are two ways to tackle the large amount of data to be handled for global illumination: build an efficient out of core architecture or reduce the number of computations. One solution of both problems lies in coherent computations. This class of solutions explore only a sub-domain of the simulation at a time, thus allowing fetching a relatively small amount of data into main memory. “Coherent” ray tracing of huge CAD models has been demonstrated with the OpenRT implementation of Wald *et al.* (2004). “Coherent” simulation of global illumination is also known as Metropolis Light Transport (Veach 1997).

The R3AM team has written “YACORT” a competitive implementation the OpenRT API (Segovia et al. 2006a) and has also published work on sampling strategies to reduce computational load (Segovia et al. 2006b). Work on Metropolis Light Transport and its coherent implementation is currently submitted. Handling huge models and distributed rendering have to be developed further.

Global illumination on the GPU:

The frequency analysis carried by the ARTIS team has shown that most high-frequency effects happening in global illumination simulations are *local* effects (specular reflections, shadow boundaries) that can be computed with a limited knowledge of the scene. On the other hand, truly global effects, that require a complete knowledge of the scene, such as diffuse interreflections, are low frequency effects, and can be carried on the CPU.

We have also observed that GPUs are highly powerful machines, that can render many illumination effects, but have a memory problem. In short, they are better suited for local effects.

Our idea is to use the framework developed in the frequency analysis of light transport to automatically separate illumination components into low-frequency and high-frequency effects, and to give each component to the part of the computer that will be best fitted to solve it: high frequency effects for the GPU, low frequency effects for the CPU.

7.3.3 Integrating complex objects into real environments

This work-package will be managed by LIRIS, in cooperation with ARTIS.

To insert a massive virtual object into a real environment, we need to synchronize virtual and real cameras. We have seen that the usual algorithm for this involves a marker detection in the video. Unfortunately, this greatly decrease the moving margin of the camera because the marker should always be entirely in sight and should always be perfectly visible. To improve this, we plan to work on three tasks:

1- Robust markers. By “robust markers”, we mean markers that will be detected in the worst possible configurations: blurry images, rapid camera movement, partially occluded marker... This may be achieved by changing the type of the marker: code encryption (like a bar code for example), noise with special colour properties or scale-invariant pattern. Once the marker has been detected and isolated, it is easy to compute the camera location.

2 - Ego motion. To compensate the lack of markers on wide camera movements, we may use an analysis of the video flow to determine where the user is heading. We plan to do this by using one or several reference frame with a marker, searching differences from one frame to another and computing the global movement direction. By using this technique, only a small numbers of markers needs to be scattered in the environment.

3 - Interest points. Locating markers in a video flow is good, but no marker at all is better. By matching interest points from one frame to another, we may use the environment as one giant marker. Of course, this assumes that we know the geometry of the environment, which is the objective of work-package 7.1.3.

8 Liste des livrables / List of deliverable

Un tableau de l'ensemble des livrables du projet sera inclus sous la forme indiquée ci-après. Les dates sont à exprimées sous forme T0+x [mois].

	Libellé du livrable	Type[1]	Responsable	Partenaires participants	Date
0	Site web du projet – Mise en place au plus tard 6 mois après le démarrage du projet et mise à jour au moins semestrielle	web	Coordonnateur	Tous	T0+6
1	Database of complex objects, to be used as inputs for the other partners, with regular updates and new objects added.	Web (access restricted to project members)	IGG	IGG	T0+6
2	Interactive display of complex objects using parallel ray-tracing (YACORT)	Software	R3AM	R3AM ARTIS	T0+9
3	Outil de numérisation de l'environnement géométrique et photométrique	Software	R3AM	R3AM IGG	T0+12
4	Simplification of complex models	Software	ARTIS	ARTIS IGG	T0+12
5	Small-scale user-assisting structured light scanning system	Software	IGG	IGG	T0+12
6	Bi-directional texture scanning, processing and representation	Software	IGG	IGG ARTIS	T0+18
7	Interactive rendering of complex models using combined representations, including direct lighting and shadows.	Software	ARTIS	ARTIS IGG	T0+18
8	Outil de rendu unifiée permettant d'intégrer des objets virtuels dans une scène réelle de manière simple	Software	R3AM	R3AM ARTIS IGG	T0+24
9	Light simulation on complex models using combined representations	Software	ARTIS	ARTIS IGG	T0+24
10	Hierachical object + appearance representation	Software	IGG	IGG ARTIS R3AM	T0+24
11	Laser-scanner-based Environment scanning system	Software	IGG	IGG R3AM ARTIS	T0+36
12	Using light simulation for better model and appearance acquisition	Software	IGG	ARTIS IGG	T0+36

9 Résultats escomptés – perspectives / Expected results and perspectives

2 pages au maximum.

9.1 Retombées scientifiques et techniques

On résumera les objectifs du projet et les résultats escomptés, en proposant des critères de réussite et d'évaluation. On décrira également les perspectives scientifiques et/techniques ouvertes au-delà de la durée du

1 Logiciel, Publication, Site web, Communication, …

projet. Préciser les impacts escomptés concernant les retombées scientifiques et techniques directes et expliquer comment la pérennité des retombées scientifiques et techniques sera assurée.
Dans le cas de projets prévoyant l'exploitation des outils, codes ou méthodes dans la communauté scientifique, expliciter la communauté concernée, les modalités prévues pour l'impliquer et/ou lui permettre d'exploiter les résultats. Présenter les objectifs par rapport aux projets similaires ou concurrents.
D'une manière plus générale, expliquer comment les retombées scientifiques et techniques seront diffusées au sein de la communauté scientifique.

We expect this project to lead to a unified rendering pipeline using simultaneously 2D and 3D data, breaking the barrier between video and computer graphics. By doing so, a great number of well-known methods in computer vision may be applied to computer graphics problems, eventually solving them in a totally unusual new way. The Impact of our project In the computer graphics community Is potentially high, since we tackle ground truth scientific problems: realistic texture acquisition and representation, accurate object visualization using alternate representations, fast global Illumination computations by using new approaches.
We plan to release several software packages as well as object and material databases with a free license during this project that will help moving our community in this direction.

9.2 Retombées industrielles et économiques escomptées (le cas échéant)

On présentera les retombées industrielles et économiques liées au projet. Si la mise au point d'un nouveau produit, procédé ou service est visée, on traitera également le problème des réglementations et des normes, existantes ou à venir. Présenter la situation actuelle du marché qui pourrait bénéficier des retombées du projet en termes de pertinence et portée possible par rapport à la demande économique et situer la place du projet dans la stratégie industrielle de (ou des) l'entreprise(s) impliquée(s) dans le projet et notamment l'évaluation du risque et de la faisabilité industrielle.

The expected goal described in the previous section may greatly interest the special effects community, as all integration work is, at present time, done by hand. It could also interest architects, who have to deal with very large databases and complex illumination problems. Scanning technology has a very broad use in many additional Industrial fields. Our results in this project will allow us to improve, in terms of automatism, the acquisition of objects with their appearance and the acquisition of textures. Such technologies have many applications in the field of Industrial prototyping as well as in the field of quality control (for instance in automotive Industry).

10 Propriété intellectuelle / Intellectual property

On présentera une analyse des questions de propriété intellectuelle et industrielle identifiés ou susceptibles de se poser, en termes de brevets existants, de licences à obtenir. Les principes de l'accord de propriété intellectuelle qui sera mis en œuvre entre les partenaires du consortium doivent être explicités. En cas de publication de logiciel libre, des indications sur les types de licences utilisées devront être fournies.

Il est rappelé que le règlement relatif à l'attribution des aides de l'ANR prévoit que : "A la demande du chef de projet, la confidentialité des résultats est de droit. La propriété de ces résultats appartient aux bénéficiaires de l'aide, qui en disposent selon les modalités convenues à leur niveau et sous réserve des droits à intéressement des inventeurs. Sous réserve de la nécessité de prévoir une période de confidentialité, dans les cas où des résultats sont à protéger, le bénéficiaire doit s'assurer par toute mesure appropriée de la diffusion publique des comptes rendus scientifiques ou de leurs résumés."

This work relies solely on software and algorithms developed or to be developed by the partners. As such, there are no licences to acquire. We have not identified any issues with respect to intellectual property from other research institutes or private companies.

For the duration of this project, the partners have agreed to share all the algorithms and software related to this work and developed within this research project.

Our general goal is to release as much as possible of this work into open source software, using the GPL licence.

11 Moyens financiers demandés / Financial resources

On précisera les moyens mis en œuvre par chacune des équipes tels que décrits lors de soumission en ligne (équipement, fonctionnement, main d'œuvre, déplacements, prestations) et on en présentera ici brièvement une justification. On précisera également si certains de ces postes feront ou pourraient faire l'objet de cofinancements.

ARTIS/LJK INRIA:
Travel expenses:

The money set aside for travel expenses will be used, first, for cooperation with the other two scientific teams. Given the distance between Grenoble and Strasbourg, the price of a mission for cooperation is estimated at 200 € per person. We will need at least three of these missions each year, for a total cost of 1200 € for the duration of the project (two for scientific cooperation, and one for management issues). Travelling to Lyon from Grenoble is much easier and cheaper, and we intend to do it regularly, approximately every two months. The estimated cost of one travel to Lyon is 40 € per person. If we expect two persons for each trip, the total cost for these exchanges will be 1440 €. Second, we will need to present the scientific results at scientific conferences and congresses. As the main conferences and congresses in computer graphics are located in the United States, the cost of travelling to the United States must be taken into account. We estimate the total cost for a congress in the United States (registration, travel and other expenses) to be 2000 €. A congress in Europe is slightly less expensive, approximately 1600 €. As we estimate our needs at approximately one conference in the US and one in Europe for each year of the project, we reach a total sum of 15000 €.

R3AM/LIRIS:
Travel expenses:
The money set aside for travel expenses will be used, first, for cooperation with the other two scientific teams. Given the distance between Lyon and Strasbourg, the price of a mission for cooperation is estimated at 200 € per person. We will need at least two of these missions each year, for a total cost of 1200 € for the duration of the project. Travelling from Lyon to Grenoble is much easier and cheaper, and we intend to do it regularly, approximately every two months. The estimated cost of one travel to Lyon is 40 € per person. If we expect two persons for each trip, the total cost for these exchanges will be 1440 €.
Second, we will need to present the scientific results at scientific conferences and congresses. As the main conferences and congresses in computer graphics are located in the United States, the cost of travelling to the United States must be taken into account. We estimate the total cost for a congress in the United States (registration, travel and other expenses) to be 2000 €. A congress in Europe is slightly less expensive, approximately 1600 €. As we estimate our needs at approximately one conference in the US and one in Europe for each year of the project, we reach a total sum of 12000 €.

IGG/LSIIT:
Material:

For precise environment acquisition, the IGG – LSIIT team needs a laser scanner. The structured light scanner we currently have can only acquire objects of moderate size (1 m3). The laser scanner has a double function. Firstly, it is used to acquire real environments to be able to perform precise lighting simulations. Secondly, it will be used to evaluate the accuracy of vision and image-based methods, which use only camera systems for acquisition.

We further plan to improve our gonioreflectometer, which is currently lacking in one degree of freedom. We need to add a mobile articulation, capable of supporting a light source or camera, with a precise control of the position. This system is necessary to be able to deal with anisotropic materials.

Travel expenses:

The money set aside for travel expenses will be used, first, for cooperation with the other two scientific teams. Given the distance between Strasbourg and Lyon and Grenoble, the price of a mission for cooperation is estimated at 200 € per person. We will need at least two of these missions each year, for a total cost of 1200 € for the duration of the project. Second, we will need to present the scientific results at scientific conferences and congresses. As the main conferences and congresses in this field are located in the United States, the cost of travelling to the United States must be taken into account. We estimate the total cost for a congress in the United States (registration, travel and other expenses) to be 2000 €. A congress in Europe is slightly less expensive, approximately 1600 €. As we estimate our needs at approximately one conference in the US and one in Europe for each year of the project, we reach a total sum of 12000 €.

12 Experts / Experts

Le projet pourra indiquer dans le tableau ci-dessous une liste d'expert susceptibles d'expertiser le projet et n'étant pas, à la connaissance du coordonnateur du projet, en situation de conflit d'intérêt par rapport au projet. L'Unité Support CEA et l'ANR se réservent le droit de solliciter ces experts pour ce projet ou pour tout autre projet. Le projet pourra aussi indiquer sous le tableau une liste d'expert ou d'entités qui ne doivent pas être sollicités pour expertiser ce projet, en indiquant, le cas échéant, le motif.

Suggestion d'expert pour l'évaluation[2]				
Prénom	Nom	Courriel	Affiliation (labo/entreprise/..)	Domaine(s) d'expertise
Christophe	Schlick	schlick@labri.fr	LABRI	Image synthesis
Kadi	Bouatouch	Kadi@irisa.fr	SIAMES/IRISA	Image synthesis
Reinhard	Klein	rk@cs.uni-bonn.de	CS Dept., U. Bonn	Material acquisition
Chalmers	Alan	alan.chalmers@warwick.ac.uk	Warwick Digital Lab., U. of Warwick	Cultural heritage, Image synthesis

2 *Si possible prévoir des experts étrangers.*