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ASILAN: Interfaces gráficas y algoritmos para aplicaciones basadas en la simulación de luz artificial y natural
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Abstract

This project is aimed at making the most of the experience and knowledge in the field of global illumination acquired in previous projects by the participant research groups. The goal is to design and develop graphics interfaces applied to sustainable lighting design. Our proposal aims at applying the know-how of the research groups to the improvement of lighting design at different levels: from interior lighting design to urban environments. In order to develop usable prototypes it is very important to move away from the simplifications that are usually assumed in global illumination computations. These simplifications usually lead to unacceptable results that cannot be used in real-world applications.

The project deals with the problem of simultaneous and efficient use of artifical and natural light in a way that the tools developed allow for a optimum use of natural light resources, and at the same time, to improve the luminaire design process to optimize its performance. This will bring benefits in energy savings and light pollution reduction.

Another important issue is the use of optical properties captured from real-world materials that are used in the simulations. This is the only way to guarantee the usability of the results. There are two main aspects to consider: the obtention of real-world data from measurements, and the efficient representation of this data.

Finally, due to the high computational cost of most of the techniques proposed, the project also deals with the use of parallel processing and super-computing technologies.
Keywords:

1 Project Goals

The project goals can be summarized as follows:

1. Design and development of software tools for inverse reflector design. The idea is to improve the design process, and the optimization of the lighting efficiency. The benefits should be energy savings and lighting pollution reductions. This goal has three tasks devoted:

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- Task Z-1: Inverse reflector design based on a theoretical inverse reflector calculation using a direct search based technique.
  Schedule: months 1-36
- Task Gi-2.2: the use of near-field light sources [5] is a must if we want reliable results from the lighting simulations. This task aims at simplifying the near-field representation to make them usable into global illumination algorithms.
  Schedule: months 1-24
- Task Gi-1.1: starting from the work developed by [4] the goal is to overcome the simplifications assumed in this work. The goal is to include near-field light sources, complex material representations, and more flexible surface representations.
  Schedule: months 1-36

2. Design and development of software tools for integration if artificial and natural lighting. The goal is to provide tools for sustainable building, with applications ranging from interior design to large area urban design. This goal has three tasks devoted:

   - Task Gr-1.1: use of Monte-Carlo techniques for lighting simulation in arquitectonic environments, and its application to artificial and natural lighting.
     Schedule: months 1-6
   - Task Gr-1.2: lighting component analysis for complex environments: direct solar illumination, artificial lighting, indirect skylight illumination, ... etc.
     Schedule: months 6-24
   - Task Gi-1.2: natural lighting in complex environments. The goal is to produce semi-interactive tools for speeding up the design process in building design.
     Schedule: months 1-36

3. Light transport optimization using high-performance computing (parallel computing, GPUs, GRID technologies, ...). The idea is to optimize the lighting computations previously developed.

   - Task Gr-2.2: Study of time efficiency and implementation of several optimized algorithms for advanced density estimation in photon-mapping related algorithms. This task includes both theoretical complexity analysis and heuristic time cost evaluation. Implementation of different variants and evaluation of benefits.
     Schedule: months 1-18
   - Task Gr-2.4: Design and implementation of parallell algorithms for global illumination Monte-Carlo techniques, using PC clusters and advanced graphics hardware. Evaluation of different options for load balancing and algorithm vectorization in the context of Global illumination algorithms.
     Schedule: months 1-36
   - Task Z-2: Code optimization for Global Illumination algorithms, and parallelization on shared and distributed memory systems.
     Schedule: months 1-36

4. Optimization of complex material models in the context of global illumination methods.

   - Task Gr-2.1: efficient importance sampling of Bidirectional Reflectance Distribution Functions (BRDFs) in order to use arbitrary material representations.
     Schedule: months 1-18

5. Design and development of graphical interfaces to allow users the use of the techniques developed into the project. Assess of usability.

   - Task Gr-3.1: design and implementation of a interface to allow multiple scene formats to be loaded and edited, including optical properties (BRDFs), and multiple types of light sources.
     Schedule: months 6-18
   - Task Gr-3.2: development of software tools to integrate all subsystems for light source design, scene modeling, lighting simulation and lighting assessment.
     Schedule: months 18-36

2 Achievements

The project achievements are herein summarized and classified into the global project goals:

2.1 Inverse Reflector Design

Task Z.1: Inverse reflector design based on a direct search technique

This task is scheduled from month 1 to 36. The goal of this task is to design and implement an algorithm for the inverse reflector design, starting from a direct search technique. Direct searches carry out sequential checks of possible solutions, defining a given strategy to compute the next trial solution. In this way, they try to get a feasible solution in a faster manner. The task accomplish the search, research and implementation of a feasible direct search method, together with a theoretical inverse reflector calculation to provide a test bed for the validation of the algorithm.

- *SubTask Z-1.1: Theoretical inverse reflector calculation*

  In order to validate the direct search method for the inverse reflector design, trial reflectors have to be computed. In this subtask we have focused on obtaining theoretical solutions. We have selected some near-field light sources and scene settings in order to calculate in a theoretical way the shape of the reflector.

  Since the theoretical inverse calculation for a general reflector is complex, we have made some simplifications and assumptions in the settings of the testes. We calculate axially symmetrical reflectors. In this way we deal with a usual shape in industrial reflector design. Working with the profile of a reflector of revolution, together with a near-field light source, we can also spend more efforts in obtaining more accurate solutions. For light sources we use isotropic point light sources, which do not occlude the lighting conditions of the reflector to calculate.

We have used two theoretical methods to inverse calculate the shape of the reflectors, one analytical and other numerical. Analytical solutions are computed by integrating the reflection's law. Numerical solutions are computed comparing the available fluxes, computed from the light source, with the needed fluxes, defined for the near-field light source.

The outcome of this subtask is a theoretical computed test bed which will act as the income of the SubTask Z-1.4, validating the direct search technique selected in SubTask Z-1.2 and implemented in SubTask Z-1.3.

- *SubTask Z-1.2: Search of a numerical method for the inverse reflector design*

  Parallel to the carrying out of the SubTask Z-1.1, SubTask Z-1.2 was performed. The aim of this task is the search of a feasible algorithm to solve the inverse reflector design, which is an optimization problem.

  The selected algorithm was the *Hooke-Jeeves* method, also named *Pattern Search*. The algorithm try to minimize (optimize) an objective function, which computes the error between the desired near-field light source and the computed by the trial solution. We use a mean squares error function since it is a very common function in data comparison.

  The optimization process done by the Hooke-Jeeves method is achieved by the sequential modification of a given initial guess reflector. We use NURBS surfaces to represent the reflectors due to two reasons. First, the use of NURBS are widely extended in the industrial CAD design. Second, the use of a NURBS instead of a triangle mesh to represent a reflector, simplifies the operation of the Hooke-Jeeves algorithm. In this way the algorithm only has to deal with few control points which represent the NURBS, and not with thousand vertices in a triangle mesh.

  In spite of the speedup achieved by using NURBS, we have introduced some simplifications in order to trade-off between accuracy and time of computation. For the moment, the algorithm deals only with axially symmetrical reflectors, defined as a revolution NURBS surface from a given NURBS curve (the revolution profile). In this way, a profile curve of three to ten control points is enough to design a detailed reflector of revolution. Again, isotropic light sources are used to avoid occluding lighting. Finally, the reflector is designed with a perfect specular material.

  In order to compute the near light field we use global illumination techniques, specifically a method named Photon Mapping. This technique is a physically based simulation of the light transport.

- *SubTask Z-1.3: Implementation of the numerical method for the inverse reflector design*

  The outcome of this subtask is the implementation and integration of the selected optimization Hooke-Jeeves method into a rendering library for fast physically based simulation of the global illumination. The design, optimization and parallelization of this rendering system is described in detail in Task Z-2. In this SubTask Z-1.3 we also implement a comprehensive library to manage NURBS surfaces and curves. The programming language selected was C++, giving a cross-platform support for its compilation.

  The implementation of the optimization method is finished, but we are enhancing it by implementing it as a generic solver for optimization problems, decoupling the solver from the kind of optimization problem to solve.

- *SubTask Z-1.4: Validation and parallelization of the numerical method for the inverse reflector design*

  The goal of this subtask is to validate the direct search method, called Hooke-Jeeves, by the comparison of the obtained approximate results with the theoretical calculated results. Therefore, this subtask will have as income the test bed calculated in SubTask Z-1.1. The development of this subtask also includes the parallelization of the Hooke-Jeeves algorithm.

  As initial steps in this subtasks we are on the research of the behavior of the Hooke-Jeeves algorithm. After this early stage a complete validation and the parallelization, both at CPU level (with threads) and at Cluster level (with MPI), will have to be performed.

Task Gi-2.2: use of near-field representations

This task is scheduled from month 1 to 24, and the final goal was to develop a new representation for near-field measurements of light sources. The goals has been fully accomplished and the results are shown here [1]. This report presents a new technique for data compression for near-field measurements. The result is a much more compact representation of the lighting distribution, and allows the light source to be used in different global illumination algorithms.

Task Gi-1.1 : inverse reflector design

This task is scheduled from month 1 to 36. The main goal is to design an implement a prototype for inverse reflector design, overcoming some of the limitations of the state of the art techniques. In a first step, we have evaluated the current solutions in this area. The results have been published here [21].The conclusions presented in this report show that the state of the art solutions to the problem of inverse reflector design are quite simple, and all of them make strong assumptions that simplify the problem in order to make it computationally affordable.

We have been working in a more general approach to the problem in order to make as less simplifications as possible. This work was finished by the end of 2005 and the latest results have been published here [4].

In a joint work with University of Zaragoza, the algorithm presented in [4] has been re-implemented to work in a parallel computer. Inverse design are computationally very expensive and one of the way to improve the speed of the calculations is to modify the algorithm so it can work in super-computers. The results of this work have been published here [13].

However, the algorithm developed in this task is still based on some simplifications that are not suitable for industry-level results. Those simplifications are:

1. Use of far-field light sources. This type of representations do not yield accurate results when the illuminated surfaces are close to the source, and this is happens when dealing with reflectors.

2. Use of low resolution polygonal meshes as reflector representation.

In the last year we have been working on finding out solutions for these limitations. In special, we are considering the use of near-field representation for the bulbs, and the use of NURBS as a surface representation for the reflector. These two issues have come up because our relationship with HELLA [6], a major manufacturer of light and electronics for the automotive industry. After several meetings, the University of Girona has signed a confidentiality agreement with this company to exchange data and knowledge in order to cooperate to develop new solutions for inverse reflector design. We have just received the first data in December 2006 and we have just begun to test it with our new ideas.

In this task we are slightly delayed by two reasons: we have spent too many time on Task Gi-2.2, and our cooperation with HELLA has changed slightly our work plan, but in a good sense. We have now a very precise idea of what is needed in the industry, and how far a big company as HELLA has gone in the area of inverse reflector design. The main conclusions that have to guide our work in the last year are:

- The use of near-field light sources is a must, Otherwise the results cannot be accurate.
- The use of NURBS as a surface representation is almost mandatory since it is the standard in high-end CAD software used by these companies. That means that we cannot longer use our previous approach of vertex optimizing [4].
- The lighting restrictions for automotive optical sets are very specific. We will have to develop new error criteria to meet these specific needs.

2.2 Natural and Artificial Lighting

Task Gi-1.2: natural lighting in complex environments

In this task we have focused our work on providing tools for the improving the lighting design process of architectural environments. In particular, we want to develop new techniques that effectively can be used into building design to optimize the use of natural lighting. The impact of such tools is clear: less energy consumption, less costs, and improved visual comfort.

The first approach was to develop a scan-line based method that projects light from sky patches and produces an hierarchical subdivision of the surfaces that adapts to the illumination changes. The results of the work were published here [22].

However, the surface hierarchy hast to be computed using a software scan-line algorithm that makes the computation too slow (tens of minutes) for an interactive tools. Thus, the next goal is to come up with a new method that do not compute illumination, but visibility. This will allow to use the visibility information with different sky configurations without any recomputation. Moreover, we want to perform this visibility computations in less than a minute, so the geometry of the building can be also changed and at the same time keep the whole process interactive.

2.3 High-Performance Computing

Task Z-2: Code optimization for Global Illumination algorithms, and parallelization on shared and distributed memory systems.

For this task we have started from our existing rendering system ALEPH. Its main features are:

- basic magnitude in ALEPH is spectral radiance, and color is handled with a spectral representation
- can manage scenes defined with parametric surfaces, from triangles to bicubic patches, defined implicitly

- the Radiance Equation is solved using MonteCarlo methods, where sampling is performed with rays
- results are numerical values for spectral radiance or irradiance

From this system we built a new system called SIRIG, where we can introduce all this enhancements. To compare with the old system we choose a standard model from the Stanford Scanning repository and rendered it with the old and the new system.

- *SubTask Z-2.1: Algorithmic and code-level optimization of GI algorithms, focused on MonteCarlo ray tracing and photon mapping*

  Many data structures in ALEPH have been redesigned or reworked in order make them safe for the next steps (optimization, parallelization). Some restrictions have also been imposed to the design, like abandoning parametric surfaces in favor of triangles. This allows to better streamline ray tracing operations and to simplify them.

  Some new data structures have been introduced, like the 'light-cache', to allow new simulation algorithms like photon mapping.

  And other have been added in parallel with existing ones to build algorithms better than those already present in ALEPH, like the kd-tree for spatial indexing, which behaves much better than voxel grids or octrees.

  We performed some tests to see if it would be feasible to use vectorized instructions offered by nowadays processors (SSE,MMX, 3DNow). This preliminary tests showed that this instruction sets were very powerfully but also very limited in their use. They give their full potential only for certain problems and data structures, and were not suitable for our design.

  With this software enhancements we got speedups in the 5x to 12x range.

  Research work using this results has been published in international journals ([7],[8],[9]), international congresses ([12],[14],[15], [16],[17],[18]) or is still in review process ([10],[11]).

- *SubTask Z-2.2: Parallelization on shared memory systems*

  There are two main time-consuming algorithms in the new system: the photon shooting pass and the ray tracing pass. We have parallelized both on shared memory systems, using the available system facilities.

  To test our implementation, we have used both Linux and Windows, basing the implementation on the native multiprocessing facilities (POSIX Threads for Linux and native WinThreads for Windows). The implementation spawns several threads for each parallel task we want to perform, and the work for this task is split in subtasks or jobs, that all the threads can pull from a shared work queue (in a master-slaves design). Some SMP-safe data structures have been implemented for this task, like concurrent queues, locks or monitors (on top of system calls).

  The system has been evaluated on several hardware types, to detect possible bottlenecks like excessive locking. We have tested it on different parallel architectures Intel HyperThreading Pentium4, Intel Core Duo, AMD Turion Dual Core, and AMD Quad Opteron. Efficiency of the parallel version of the software highly depends on the hardware. In our experiments it could go from 60% to 95%.

If we join software optimization and parallel processing, we can get up to a 50x speedup factor on a Quad Opteron box.

Research work using this results has been published in international congresses ([13], [19]) or is still in review process ([20]).

- *SubTask Z-2.3: Parallelization on distributed memory systems*

  The data structures and the load leveling algorithms have been prepared to be used on a distributed system.

  The hardware system has been designed. We choose to use the same systems described in SubTask Z-2.2 to build an initial cluster, that will grow in the near future.

  Some initial tests have been done for the parallelization over a cluster. The system is built for INDAL, SA, It is build of one front-end and six worker nodes, which use Pentium4 processors. The parallelization just spreads the rendering work as individual frames for an animation, no intra-frame parallelism is used. Our main goal is to use intra-frame parallelism to higher frame rates.

2.3.1 Task Gr-2.2. Theoretical and empirical study of the different Density Estimation algorithms,

In this task we focused on advanced density estimation techniques for photon-mapping related algorithms like density estimation on the tangent plane (DETP) [25],[26] or ray-maps [32]. While these algorithms have shown to greatly improve radiance reconstruction from photon histories, they introduce high computation time costs because they require a huge number of ray-disc or ray-ball intersection tests, instead of the simpler point-in-ball query which is needed for basic photon-mapping.

In order to reduce computation time of these algorithms we have designed and implemented two techniques: *Sphere-Cache*, which on a list of spheres which allow fast discarding of potential ray-disc intersection tests, and *Disc Indexing*, a more standard approach which uses octrees to build a spatial index with discs referenced from leaf nodes.

A study of the time complexity of raw DETP, Sphere Cache and Disc Indexing has been made. Integral geometry was used to achieve results which are scene-independent. The formula for the expected computation time of each technique as a function of the complexity of the scene, the illumination and other parameters of the simulation allows us to choose the most efficient technique in each case. Testing the algorithms for different scenes show a good correlation between expected and measured computing times. Results have been presented in WSCG'2006 conference [29], and in the Eurographics Spanish chapter annual conference [28].

This study was later applied in the context of interactive rendering, by using a software system capable of radiosity computation at interactive rates for scenes with moving objects. The characteristics of interactive rendering give us opportunities for more efficient algorithms by reusing information from previous frames [27]. The theoretical study proved useful to pinpoint the most suitable algorithm in this context. Results have been presented in WSCG'2007 conference [30].

2.3.2 Task Gr-2.4 - Usage of advanced hardware and computer networks

Generating photo-realistic images is a compute-intensive task which requires efficient techniques and software/hardware architectures to be accomplished in an affordable manner. In this task we deal with high computation time involved in physically based rendering. We have explored the feasibility of solutions which take advantage of modern high performance hardware and fast computer networks. This are the three hardware environments we have addressed:

- Single instruction multiple data (SIMD) capabilities in standard CPUs (SSE instructions sets)
- Advanced programmable graphics hardware (GPUs) with multiple floating-point units (FPUs)
- High bandwidth local area networks with concurrently processing PCs (PCs clusters)

Regarding GPUs, we have implemented the sphere cache technique for advanced density estimation [25],[26] using modern programmable graphics cards. We also developed reference and highly optimized CPU implementation, which makes use of SSE instructions and coherent memory accesses.

We have analyzed execution times from both implementations. GPU implementation takes advantage of multiple FPUs, however it suffers from (a) relatively slow data transfer rate between RAM and GPU memory and (b) vectorized programming requirements, which makes it hard to adapt algorithms originally designed for sequential CPUs. Design of GPU programs should focus on minimization of data transfers and efficient data layouts in texture memory.

Our GPU implementation run times are comparable to optimized, SSE-based CPU implementation ones for cards manufactured in 2005 (nVidia 7800 series). However, GPUs vendors are nowadays increasing the performance of these class of hardware, for instance by increasing the number of FPUs per card, or by increasing GPUs cache memory size and bandwidth. We have run our GPU implementation on a recent card model (nVidia 8800 series), and for this implementation, we have obtained a 5x speedup factor with respect to the optimized CPU implementation, thanks to improved hardware capabilities. As a result, we conclude that GPU implementation is a valuable tool for producing high time efficient rendering systems, as it is the case for our density estimation algorithm.

Regarding PC clusters, we have developed a rendering system which runs concurrently on multiple PCs running Linux. Processes communicate via MPI library. At each node, the system takes advantage of SSE instructions for efficient ray-triangle intersections. We have a cluster where each node is equipped with a GPU, thus we plan to take advantage of that in order to further reduce running times.

2.4 Complex Materials

2.4.1 Task Gr-2.1: Efficient Importance sampling of BRDFs

This task is related to the problem of BRDF sampling in Monte-Carlo based rendering algorithms (both those based on path tracing from the observer and those based on photon simulation from light sources). These class of algorithms need to use a probability density function (PDF) which correctly matches each surface BRDFs. This means that, in absence of information about irradiance, the PDF function used should be proportional to or almost proportional to the BRDF, in order to avoid high variance or error.

Moreover, a time efficient direction generator algorithm is also required. This algorithm must output sampling directions distributed according to the PDF. There is no single analytic PDF which is well fitted for arbitrary BRDFs (including a wide set of analytically defined BRDFs and tabulated or measured BRDFs).

We have designed and implemented a new sampling method with reduced variance, which is based in a PDF which is constructed for each BRDF in the scene, as other authors have done [33]. In our case, the PDF is stored as a quadtree with more resolution in those areas of the sphere where BRDF exhibits more changes. Direction generation algorithm uses a traversal process over this tree, and this traversal can be efficiently implemented so its time cost is minimized. At leaf nodes, efficient rejection sampling is done (with an *a priori* bounded number of trials because of BRDFs variation is bounded in each leaf node). This ensures that the PDF is exactly proportional to the BRDF and can be sampled fast.

We have implemented this PDF and integrated it in a Monte-Carlo rendering system. We have compared the error (due to variance) produced by our algorithm with that obtained from standard simple analytic PDFs, for scenes with various well known analytic BRDFs. Results from these simulations show that, for any given fixed output error, computing time is equal or even less with these new algorithm than the one obtained with standard PDFs which had been manually fitted to the material BRDFs.

2.5 Graphical User Interfaces

2.5.1 Task Gr-3.1: Interface for editing scene properties

In this task we sought solutions to the needs for software which enables its users to describe the reflective properties of any given 3D scene. While nowadays there are a number of both free and commercial 3D modeling packages (like Blender or 3D Studio Max) available, these packages usually lack the ability to assign advanced material properties which are required as an input for physically based renderers. Each rendering system uses its own format for describing material properties. Thus, we needed a system which enables us to assign BRDFs, textures, etc... to the objects in a scene. Moreover, users should be capable of visually evaluating the impact of different values of BRDFs parameters on the look of final images, thus allowing them to select the values which more fits their needs.

In this line, we have already implemented and tested these software systems:

1. **BRDFs assignment tool**
   We have developed a Java3D multiplatform application which imports 3D scene files (i.e. Autocad .dxf, Kinetix 3D Studio, VRML, Wavefront .obj, etc.) and allows its users to edit the BRDF properties and also to assign different instances of the function to different surfaces in the scene. Output scene file is generated with this tool in a format suited for our renderers, that also includes definitions of extended light sources, with information about their location and characteristics.

2. **BRDFs visualization tool**
   In addition another tool has been implemented to visualize the BRDF applied to a scene in real time using programmable graphics hardware (GPU). Reflectance functions have been implemented as GLSL (OpenGL Shading Language) shaders. The application allows users to interactively modify shader's parameters, while an image is displayed which shows the impact of these changes on the look of the geometry.

3. **BRDFs parameters editing tool**
   A BRDF parameters editor is included in the previously described system (although this editor

can be used as a standalone application). This software allows to interactively define and control the appearance of a material with more than fifteen different reflectance functions. A display of BRDFs shape is available to users, both as a flat 2D plot, or as a full 3D depiction. BRDFs parameters can be interactively modified, with immediate feedback to users, who can evaluate the impact of that change on BRDF shape.

2.6 Other Activities

- **University of Girona**

  There has been a research line that began before the project started, and even it is not strictly related to any task, it has produced very good results, and it has provided knowledge and new ideas for Task 1.1 (inverse reflector design). We have worked in interactive reflection and refractions on curved objects. This work has produced two publications [23, 24].These two publications are a joint work with REVES research group of the INRIA Sophia Antipolis center, in France. This work has allowed us to get a deep understanding of the GPUs architecture and has the method presented can be adapted to provide a very efficient solution for inverse reflector lighting calculations.

- **University of Granada**

  From February to July 2005 Miguel Lastra did a five months research stay at Technical University of Vienna, where he collaborated with members of Computer Graphics and Algorithms Research department leaded by Werner Purgathofer, in the context of research project entitled *treelumination*. Miguel did adapted our previously implemented DETP software to GPU architectures, in close collaboration with Dr. Michael Wimmer and Dr. Stefan Jeshke.

  Starting at December 2006, Rosana Montes has done a three months research stay in the Institute of Software and Multimedia-Technology (Technische Universitat Dresden) in collaboration with Computer Graphics and Visualization chair. Collaboration has been closer to Professor Stefan Gumhold and Sören König, extending their scanner 3d setup for dynamic acquisition and also working in an estimate of the BRDF function of simple objects.

3 Results

3.1 Students

- University of Girona

  There are three Ph.D. students working for the project right now. Pau Estalella got a FI grant from Ministerio de Educación y Ciencia on 2003 and he has been involved in the project since the beginning. He is expecting to defend his thesis on September 2007. Albert Mas got a grant from the University of Girona and he began to work in the project since January 2006, and his work is related to tasks Gi-1.1 and Gi-2.2. He is expected to finish hi thesis on 2008. Carles Bosch has been hired by the project since June 2005 and he is working in task 1.2. He is writing his Ph.D now while working in the project.

- University of Granada

There are currently two Granada University's Ph.D. students involved in the project, both are University staff members, and they are involved in undergraduate teaching at the *Departamento de Lenguajes y Sistemas Informáticos*, in Computer Science related degrees. Rosana Montes is *Profesora Asociada* (although she has been just accredited to become *Profesora Colaboradora*), she is working on BRDF sampling algorithms, which is her Ph.D.'s main subject. She plans to defend her Ph.D. on 2007.Rubén García is currently *Profesor Ayudante*, his research is related to the study of time complexity and efficiency of several algorithms for advanced density estimation for photon-mapping related Global Illumination algorithms. He expects to finish his Ph.D. on 2008.

- University of Zaragoza

  There are two Ph.D. students working for the project right now. Adolfo Muñoz is Profesor Ayudante of 2nd year, and he has been involved in the project since the beginning, and works mainly in the Global Illumination part of the project. He is working on his thesis and expects to finish it by end of 2008. Oscar Ansón is Profesor Ayudante of 2nd year, he has been involved in the project since the beginning, and works mainly in the Inverse Reflector Design part of the project. He is working on his thesis and expects to finish it by end of 2008.

3.2 Technology Transfer

- University of Girona

  The University of Girona has signed two collaboration agreements with three companies.

  Espacio Solar is a SME company that elaborates natural lighting projects and also is a manufacturer of passive lighting devices. At this moment we are developing a tool for interarctive natural lighting design.

  Fundación Ductil Benito is a company that manufactures luminaires for urban lighting. We are collaborating in the field of inverse reflector design.

  HELLA is a world leader in automotive lighting manufacturing and we are collaborating to find new specific solutions for inverse reflector design in teh car industry.

- University of Zaragoza

  The University of Zaragoza mantains a collaboration agreement with the company INDAL Iluminación Técnica, SA (Valladolid). As a result of this collaboration, a small PC cluster has been built for INDAL to test and transfer paralleization algorithms and technology on an industrial lighting system.

3.3 Research Collaboration outside the project

- University of Girona

  We have collaborated with the REVES group of the INRIA Sophia-Antipolis research center in France. Group leader George Drettakis has participated in two of the publications of the project [2, 3].

- University of Granada

  José Miguel Mantas is involved in active collaboration with other research groups in order to explore the benefits of PC clusters and graphics hardware for general purpose computation.

  In close collaboration with members of the research project *Nonlinear diffusion and kinetic equations: asymptotic behaviour and numerical approximation* leaded José Antonio Carrillo (ICREA-UAB) we have developed an strategy to obtain efficient implementations of Implicit -Explicit Runge-Kutta methods (IMEXRK) for PC clusters. Results have been published in the Euro-par conference [31].

  Members of EDANYA (Differential Equations, Numerical Analysis and Applications Research Group - University of Málaga) have developed optimized parallel numerical software based on finite volume techniques to simulate shallow water systems on PC clusters and using SSE instructions sets. We have jointly analyzed ways to implement that software on GPUs and GPUs clusters, which can further reduce computation times.

- University of Zaragoza

  We have established a contact for collaboration with the MOAR (Mother Of All Renderers) Project. This project aims to develop the next–generation rendering system, to supercede other systems like Radiance. Main leadership of the project is carried by Alan Chalmers (currently in Bristol University) and Greg Ward. The group showed a big interest about our system.

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