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Form 101 - Application for a Grant

Send to NSERC with your attachments, if applicable

Reference Number: 125534882

Applicant: Wolfgang Heidrich — **NSERC PIN:** 242351

British Columbia

Program: Discovery Grants - Individual

Application Title: Computational imaging for graphics and vision

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Wolfgang Heidrich

Form 101 - Application for a Grant

Electronic Attachments:

Budget Justification - budget justification (pdf)
Research Support - other support (pdf)
Proposal - proposal (pdf)
References - references (pdf)
Research Contributions 1 - ACM TOG (Siggraph Asia) article on fluid imaging
Research Contributions 2 - Marr Prize Hon. Ment.:ICCV paper on BRDF Measuring
Research Contributions 3 - ACM TOG (Siggraph) article on garment capture
Research Contributions 4 - ACM TOG (Siggraph) article on HDR displays

Wolfgang Heidrich

F100/Personal Data Form

Electronic Attachments:

Contributions - contributions (pdf)

Natural Sciences and Engineering Research Council of Canada | Conseil de recherches en sciences naturelles et en génie du Canada

1507

FORM 101
Application for a Grant
PART I

Institutional Identifier	
System-ID (for NSERC use only)	125534882
Date	2009/10/27

Family name of applicant	Given name	Initial(s) of all given names	Personal identification no. (PIN)
Heidrich	Wolfgang	W.	**Valid** 242351

Institution that will administer the grant	Language of application	Time (in hours per month) to be devoted to the proposed research / activity
British Columbia	[X] English [ ] French	10

Type of grant applied for	For Strategic Projects, indicate the Target Area and the Research Topic; for Strategic Networks and Strategic Workshops indicate the Target Area.
Discovery Grants - Individual	

Title of proposal
Computational imaging for graphics and vision

Provide a maximum of 10 key words that describe this proposal. Use commas to separate them.
imaging, 3D scanning, fluid imaging, computational photography, computational cameras & optics, tomography

Research subject code(s)		Area of application code(s)	
Primary	Secondary	Primary	Secondary
2707	2603	802	801

CERTIFICATION/REQUIREMENTS

If this proposal involves any of the following, check the box(es) and submit the protocol to the university or college's certification committee.

Research involving : Humans [ ] Human pluripotent stem cells [ ] Animals [ ] Biohazards [ ]

Does any phase of the research described in this proposal a) take place outside an office or laboratory, or b) involve an undertaking as described in Part 1 of Appendix B?

[X] NO [ ] If YES to either question a) or b) – Appendices A and B must be completed

TOTAL AMOUNT REQUESTED FROM NSERC

Year 1	Year 2	Year 3	Year 4	Year 5
80,500	80,500	80,500	80,500	80,500

SIGNATURES (Refer to instructions "What do signatures mean?")

It is agreed that the general conditions governing grants as outlined in the NSERC *Program Guide for Professors* apply to any grant made pursuant to this application and are hereby accepted by the applicant and the applicant's employing institution.

Applicant

Head of department

Applicant's department, institution, tel. and fax nos., and e-mail

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Dean of faculty

President of institution (or representative)

The information collected on this form and appendices will be stored in the Personal Information Bank for the appropriate program.
PROTECTED WHEN COMPLETED

Version française disponible

Canada

Personal identification no. (PIN)	Family name of applicant
Valid 242351	Heidrich

SUMMARY OF PROPOSAL FOR PUBLIC RELEASE (Use plain language.)

This plain language summary will be available to the public if your proposal is funded. Although it is not mandatory, you may choose to include your business telephone number and/or your e-mail address to facilitate contact with the public and the media about your research.

Business telephone no. (optional): 1 (604) 822-4326

E-mail address (optional): heidrich@cs.ubc.ca

Realistic computer graphics has become a core technology for many applications that are of importance to both industry and society at large. Some examples include design applications (e.g. interior- and industrial design), medical applications (e.g. surgical training simulators), education (e.g. learning software), heritage projects (virtual museums), as well as entertainment (e.g. special effects for movies, computer games).

Although much progress has been made on realistic computer graphics in the context of entertainment, the methods developed for this purpose emphasize manual interaction and artistic control to fine-tune the resulting images. This is undesirable in most other applications, where the computer generated images need to quantifiably represent existing real-world objects. To tackle this issue, several subproblems need to be addressed. First, physical models of real-world objects have to be acquired through imaging and other measurement techniques. Second, captured real world objects and phenomena need to be analyzed, and computational models need to be extracted for their behavior. Finally, algorithms need to be developed that are capable of using realistic, physically accurate models in rendering processes.

Following these long-term goals, the goals for this application are novel developments in the following areas:
- Automatic methods for measuring and processing objects with complex optical properties, such as translucent or highly specular objects
- Imaging methods for dynamic phenomena such as fluid flow and fire
- Systematic analysis of dynamic phenomena based on measurements, and the development of computational models that can be used in simulations.
- Efficient, high-quality rendering algorithms for the acquired models.

Other Language Version of Summary (optional).

Personal identification no. (PIN)	Family name of applicant
Valid 242351	Heidrich

Before completing this section, **read the instructions** and consult the *Use of Grant Funds* section of the NSERC Program Guide for Professors concerning the eligibility of expenditures for the direct costs of research and the regulations governing the use of grant funds.

TOTAL PROPOSED EXPENDITURES (Include cash expenditures only)

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
1) Salaries and benefits					
a) Students	39,500	39,500	39,500	39,500	39,500
b) Postdoctoral fellows	25,000	25,000	25,000	25,000	25,000
c) Technical/professional assistants	0	0	0	0	0
d)	0	0	0	0	0
2) Equipment or facility					
a) Purchase or rental	5,000	5,000	5,000	5,000	5,000
b) Operation and maintenance costs	0	0	0	0	0
c) User fees	1,500	1,500	1,500	1,500	1,500
3) Materials and supplies	1,500	1,500	1,500	1,500	1,500
4) Travel					
a) Conferences	4,500	4,500	4,500	4,500	4,500
b) Field work	0	0	0	0	0
c) Collaboration/consultation	2,000	2,000	2,000	2,000	2,000
5) Dissemination costs					
a) Publication costs	1,500	1,500	1,500	1,500	1,500
b)	0	0	0	0	0
6) Other (specify)					
a)	0	0	0	0	0
b)	0	0	0	0	0
TOTAL PROPOSED EXPENDITURES	80,500	80,500	80,500	80,500	80,500
Total cash contribution from industry (if applicable)					
Total cash contribution from university (if applicable)					
Total cash contribution from other sources (if applicable)	0	0	0	0	0
TOTAL AMOUNT REQUESTED FROM NSERC (transfer to page 1)	80,500	80,500	80,500	80,500	80,500

Budget Justification

The vast majority of the budget is dedicated to supporting salaries of students and post-doctoral fellows. The major items are:

- **Two Ph.D students ($19,000/year/student + benefits)**: the research projects outlined in this proposal require extensive experimentation with camera systems and other imaging hardware. Two full-time Ph.D students are required to master this research program. Initially, these two students will be Bradley Atcheson (current Ph.D student) and Benjamin Cecchetto (current M.Sc student, expected to transition into the Ph.D program).

- **One half of a post-doctoral salary ($22,000/year + benefits)**: the proposed research program has both significant theoretical and experimental components. For the latter part, a more experienced researcher in addition to the applicant is instrumental. A post-doctoral fellow will bring enough experience to set up and operate sophisticated experimental equipment that is already present in the applicant's lab, and help train students in the use of such experimental setups. A similar position is currently held by Dr. Ivo Ihrke, who is, however, going to accept a faculty position starting with the new year. A half salary for a replacement for Dr. Ihrke is deemed sufficient since most individuals of interest would likely hold or qualify for at least a partial fellowship.

- **Equipment purchases ($5,000/year)** include items such as workstations for the students, but also minor upgrades and replacements of smaller pieces of equipment, such as cameras.

- **User fees ($1,500/year)** fall into two categories. The first category is departmental charges for central services such as file servers and research networks. The second category is usage fees for rapid prototyping equipment or machine shops, both of which are used to build custom mounting hardware for experimental setups.

- **Conference travel ($4,500/year)**: since peer-reviewed conferences are the primary means of disseminating research in computer graphics and machine vision, each student, the post-doctoral fellow, and the applicant each need to attend at least one conference a year.

- **Collaboration costs ($2,000/year)** refer to travel of the applicant or his students to other research groups (for example at the University of Toronto, Stanford University, or the Max-Planck-Institut für Informatik in Germany) for joint research projects, or to the hosting of collaborators at UBC.

- **Publication costs ($1,500/year)** refer to page charges for journal or conference publications, such as ICCV or CVPR. Alternatively, some of the funds from this budget item can also be used towards additional conference travel.

Relationship to Other Research Support

I currently have the following sources of research funding, other than my existing Discovery Grant:

- An industrial research chair from Dolby Canada ($150,000/year). This funding is provided specifically for research in high dynamic range imaging and perception. The Discovery Grant will be used to support students and a post-doctoral fellow working on topics outside this scope, namely in the areas of 3D scanning, visible light tomography, and computational photography. These activities currently make up for about 50% of my research activities.
- A MITACS Seed Project ($60,000/year, shared with two co-PIs) in computational optics. This grant has a minor overlap with parts of the the proposed research, but the grant will end with the financial year in May 2010.
- A part of an NSERC Strategic Grant (about $20,000/year) on HDR imaging. The focus of this grant overlaps with my research chair, but not is unrelated to the research program proposed here.

I have applied for the following funding:

- Research project, GRAND NCE (amount TBD). If the GRAND NCE (for which I am a co-applicant and designated theme leader) turns out to be successful, my individual sub-project will support research in fluid imaging and some aspects of geometry capture. However, this funding will be spread among a large number of researchers. The funding for individual researchers is not by itself expected to be sufficient to allow me to continue supporting all my students in this research area. The combination of the GRAND NCE project with an increased Discovery grant is required to strengthen and expand on my current activities in computational imaging.
- An NSERC RTI ($25,700). This grant will provide some much-needed upgrades to experimental hardware. In particular, it will provide motorized actuators for positioning cameras, light sources, and scan objects relative to each other. This equipment will be of great use to the research program outlined here, but the RTI program does not cover the salary and other non-equipment expenses.

Proposal

This is my third application for an NSERC Discovery Grant since I joined UBC in 2000. Since then, I have co-authored over 50 publications and one book. I have supervised over 40 graduate students, all of whom have immediately found employment in their research ares. Most of these students still live and work in Canada, while a minority has moved on to either academic or industrial careers in the US and Europe. A collaborative research project on a new display technology and associated image processing algorithms was spun off into a startup company, which in turn was acquired by Dolby Labs and transformed into Dolby Canada. Since 2008 I have held an industrial research chair sponsored by Dolby Canada.

Recent Progress

My core research interests lie at the intersection of computer graphics, low level machine vision, and imaging. In particular, I focus on the pipeline from acquisition of accurate object descriptions to optical simulation and final display. My recent research efforts are split roughly equally between two topics: high dynamic range imaging and displays, as well as model capture using cameras and imaging techniques.

High Dynamic Range Imaging and Display.

A major aspect of my research over the past several years has been work on High Dynamic Range (HDR) imaging and display. Dynamic range is also referred to as contrast, i.e. the ratio of the brightest to the darkest representable luminance value. The traditional imaging pipeline (cameras, image processing algorithms, image and video encodings, as well as displays) is limited to a dynamic range of about 500:1, while the human visual system can process a simultaneous scene contrast of 50,000:1 or more, and can adapt to a much larger range, from starlight to direct sunlight (about 14 orders of magnitude). This discrepancy represents one of the most obvious failings of the traditional imaging pipeline if the goal is perceptual realism. HDR imaging attempts to replace the standard imaging pipeline with components that exhibit performance more similar to the human visual system. My own contributions in this area include:

- **HDR Displays.** A center piece of my work on HDR imaging has been the development of new HDR display technology (11) in collaboration with the group of Dr. Whitehead (UBC Physics & Astronomy). The design of the display exploits limitations of the human visual system with respect to glare around local high contrast edges to present an image that is visually indistinguishable from a full HDR scene. Specifically, the HDR display technology can produce contrast ratios of up to 150,000:1 and intensities similar to typical day-time environments. This represents a 300-fold improvement of the contrast ratio (dynamic range) over current technology used in computer displays, television sets, and movie theaters. As a result, this new display technology can represent vivid colors and intensity ranges that rival those of natural environments. Using this technology, we can for the first time give a realistic impression of real-world environments such as night driving scenarios, where headlights of oncoming cars may cause significant enough glare to eliminate visibility of the remaining environment.

- **HDR Image Processing.** The special construction of the HDR display technology does not lend itself to simple pixel-by-pixel image display. Instead, it requires on-the-fly image processing of input HDR images or video streams to filter and analyze different spatial frequency bands. My students and I have identified this problem, and developed the first algorithms for this purpose (13, 11). These methods and variants developed by others (e.g. (9)) are currently being used in commercial implementations of the HDR display technology.

- **Human Perception and HDR.** Since the HDR display technology allows for the first time the reproduction of images with an intensity range encountered in normal day-to-day environments, such displays have been used in a variety of perceptual studies (e.g. (3) and many more). My own work in this area has focused on the question of viewer preferences for brightness and contrast settings and the impact of ambient illumination (4). I have also analyzed color reproduction of HDR imagery, as well as the impact of color on the legibility of visual information in low light environments. The relevant references on my perception work do not fit on the publication page, and can instead be found on the personal data form.

- **Commercialization and Technology Transfer.** The HDR display technology and associated software algorithms have resulted in a number of patents and patent applications, and they were the key technologies behind a UBC spin-off called BrightSide Technologies. In 2007, Dolby Labs acquired BrightSide, and transformed it into Dolby Canada, a research facility with currently about 20 research staff, located in Vancouver. Our HDR display technology and the associated image processing algorithms are now integrated into modern television sets as *local dimming* technology. Local dimming TVs are widely available, and are projected by industry analysts to become the dominant TV technology by 2011. Except for special high-end displays (16), these commercial products do not yet meet the specifications of the BrightSide/Dolby prototype displays, but the performance discrepancy between the BrightSide prototype displays and off-the-shelf TV sets is expected to diminish in coming years.

  Following the acquisition of BrightSide, Dolby established an industrial research chair for me, which continues to support my work in this area. Dr. Seetzen, a former Ph.D student supervised by Dr. Whitehead and myself, and a driving force behind the commercialization efforts, was awarded the top prize of the 2009 NSERC Innovation Challenge Award for his efforts.

My work on HDR technology is well supported by my industrial chair as well as a number of federal research grants a MITACS Seed Project, and, most recently, an NSERC Strategic Grant. The project proposed in the current application is, however, outside the scope of HDR, and thus requires separate funding.

Model Capture

My second focus area over the past several years has been the capture of detailed models to serve as input for computer graphics. This is the area in which I propose to continue research under this Discovery Grant.

- **Appearance and Light Capture.** A key factor in the quality of computer-generated images are detailed descriptions of the optical material properties in a scene. A common model for these optical properties is the so-called Bi-Directional Reflectance Distribution Function (BRDF), and its measurement has been the focus of extensive work in computer graphics and machine vision. I have worked on this problem for a number of years (e.g. (10)), but recently my students and I developed a new optical setup for measuring BRDFs of material samples, and combined it with a novel basis function measurement approach that produces high-quality BRDF models within a minute as opposed to hours (1, 2). This work won a Marr Prize honorable mention at ICCV 2007.

Just as important as reflectance models are good models of the emission characteristics of light sources. In (12), we devised a light-field approach to capturing near field emission characteristics of complex light sources. This work is also the first to combine sound sampling and reconstruction of light fields with radiometric consistency.

- **Geometry Capture.** Scanning of 3D geometry is one of the traditional topics in machine vision. Multi-view stereo refers to a class of solutions in which surface points are triangulated from a collection of (more than two) individual cameras. Our algorithm based on scaled window matching on binocular pairs, combined with sophisticated post-processing of the acquired point cloud (7) outperforms competing methods on standard benchmarks (14) in terms of both precision and speed. The performance of our method makes it suitable for application to video sequences, allowing us to capture garments worn by actors (8, 15). For this application we also used novel geometry processing techniques to replace traditional tracking with a cross-parameterization approach in order to establish temporal correspondences between points in different time steps.
- **Visible Light Tomography.** Traditional computer vision approaches do not work on transparent media such as glass or gas volumes. For such settings, visible light tomography is a viable alternative. I have proposed to use visible light tomography on transparent solids (6), which is made possible by eliminating refraction using an index matching approach. More recently, my students and I have demonstrated a tomographic method to use the ray refraction in a gas plume to directly acquire the gas density on a dense volumetric grid (5), using a so-called *Background-Oriented Schlieren Imaging* system. Our work enables us to measure time-varying, non-stationary flows on a dense volumetric grid, a first not only in computer graphics but also in the field of fluid imaging. Consequently, we have been working to not only present the work at graphics venues, but also present a quantitative analysis in the fluid imaging community.

Other Work

Over the years I have published work on a number of other topics, including GPU-based rendering, stochastic sampling strategies for local and global illumination, viewpoint selection using an entropy measure, sound measurement, and several more.

Objectives

Over the past two decades, the computer graphics community has taken great strides in visually realistic, physics-based simulation of natural phenomena such as smoke, cloth, fluids (gases and liquids), etc. Unfortunately, while physical simulation can help us visualize phenomena we could not reproduce in real life (e.g. large explosions), the realistic simulation of many everyday phenomena is hitting a computational ”brick wall”. The main cause is the complexity, multitude, and interaction of the physical processes involved. Indeed, common events such as the lighting of a match, the burning of a sheet of paper or some other solid fuel, and the flow of water in a shallow, rocky stream are simply too complex to model computationally with today's methods. Similarly, simulations of human facial motions still suffer from unrealistic artifacts and fail to express the range of human emotions in a believable fashion. The key goal of this project is to develop optical and camera setups, imaging techniques, as well as reconstruction algorithms that together establish capture as viable alternative to simulation, much like traditional motion capture is now a widely used alternative to character animation.

The specific targets for this project are:

- New scanning technologies for transparent objects.
- Highly detailed marker-free facial capture based purely on passive illumination.
- New setups and algorithms for practical capture of liquids and gases.
- Systematic analysis of specific fluid phenomena using the developed methods, and derivation of data-driven models and heuristics that can be fed back into computer simulations.

Pertinent Literature

See last page.

Methods and Proposed Approach

The proposed research will build on my earlier work in similar areas, and expand it to allow for the capture of new object types. I will also expand on the analysis of acquired data using the developed imaging methods. In particular, the research will be based on the following four avenues:

- New scanning technologies for transparent objects will be developed. The tomographic reconstruction methods developed in my group for fluid imaging do also apply to transparent solids *if appropriate ray deflection measurements can be obtained.* In case of gas flows, such deflections can be obtained using our Schlieren setup. For solids, however, the deflections are too strong for this approach to work, and a different mechanism is required. We will develop a new deflection measurement approach similar to environment matting, but with guaranteed angular measurement precision and with automatic error detection and correction.
- Detailed marker-free facial capture will be based on the use of a camera array in combination with our multi-view stereo algorithm and cross-parameterization based on optical flow tracking. The detail provided by 16 HD video cameras is sufficient to track surface detail at the level of hair follicles, without having to resort to markers or active lighting. This approach will for the first time allow for detailed facial capture in which the image sequences can also be used as live video in augmented reality-style applications, or as dynamic texture maps for purely virtual facial replacements.
- New setups and algorithms for practical capture of liquids and gases will be developed based on our previous Schlieren setup. The goal is to strip down the hardware requirements to the bare minimum, and to obtain fluid data with as little as one or two cameras.

- Based on both our existing fluid imaging technology and the planned improvements, we will run large-scale experiments in capturing specific flow phenomena, such as fluid-solid interactions, turbulent flows, interactions of compressible and incompressible flows, etc. We will use these measurements to develop data-driven models for the individual phenomena that can be applied in both computer graphics simulations, as well as in computational fluid dynamics.

Anticipated Significance

The capturing technologies technologies and algorithms developed in this project should be widely applicable in the computer graphics industry, and should therefore be of commercial interest to Canada's strong computer games and film industries. In the context of the HDR display, I have already demonstrated the ability to transfer research results from academia to an industrial setting. I believe similar approaches can be successful in the area of 3D capture and imaging. For example, I have established initial contacts to Vancouver startup company 3D3 Solutions, which is focusing on 3D scanning technology and has shown an interest in earlier capture methods developed in my group.

In addition to computer graphics applications, I am also considering applications in other domains. For example, our Schlieren tomography setup provides imaging capabilities that exceed the abilities of state-of-the-art techniques used in the fluid imaging community, which in turn are used to study flows in a range of scientific and engineering disciplines. Another example of possible cross-disciplinary uses of methods developed in my group is the application of our transparent object scanning methods to the problem of examining living organisms. I am in initial contact with UBC biologists who research the biomechanics of jellyfish. We believe our method can provide the first method for *in vitro* volumetric imaging of these animals. In this way, I believe that the research proposed here can not only have a strong economic impact on Canada, but can also help to advance basic scientific research in other disciplines.

Training

Training of highly qualified personnel is an integral part of this proposal. The vast majority of the budget is dedicated towards this goal, either directly (through salaries) or indirectly (through supporting conference attendance for the trainees). As with all my trainees, I will work closely with the two students and one PostDoc requested under this grant.

I take great pride in the accomplishments of my students, as illustrated by a number of awards, including Dr. Ghosh's Alain Fournier Thesis Award (best Canadian dissertation in graphics), Dr. Seetzen's NSERC Innovation Challenge Award, as well as a number of conference best paper awards, CRA undergraduate awards, and a multitude of university and government fellowships. More importantly, my students continue to do well after leaving UBC, both in industry and in academia. For example, former trainees of mine hold or have accepted positions such as Director of the HDR program at Dolby Labs (Dr. Seetzen), permanent research positions at INRIA Bordeaux (Dr. Granier) and the USC Institute for Creative Technologies (Dr. Ghosh), as well as faculty positions at Max-Planck-Institute for Computer Science (Dr. Ihrke), Bangor University (Dr. Mantiuk), and UBC (Dr. Tam).

Literature

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14 mview. http://vision.middlebury.edu/mview/.

15 T. Popa, Q. Zhou, **D. Bradley**, V. Kraevoy, H. Fu, A. Sheffer, and W. Heidrich. Wrinkling captured garments using space-time data-driven deformation. In *Computer Graphics Forum (Proc. Eurographics)*, pages 427–435, 2009.

16 http://www.sim2usa.com/home/us/node/564.