Application

2015-03-31

2015-05462 **Ynnerman, Anders** **NT-14**

Information about applicant

Name: Anders Ynnerman

Doctorial degree: 1992-06-05

Birthdate: 19630326

Academic title: Professor

Gender: Male

Employer: Linköpings universitet

Administrating organisation: Linköpings universitet

Project site: Institutionen för teknik och naturvetenskap (ITN)

Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): Illumination of spatio-temporal volumetric data in interactive visualization

Project start: 2016-01-01

Project end: 2019-12-31

Review panel applied for: NT-14, NT-2

Classification code: 10299. Annan data- och informationsvetenskap, 21102. Mediateknik, 10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)

Keywords: Volume Visualization, Illumination, Time-varying data, Interactive Visualization

Funds applied for

Year:	2016	2017	2018	2019
Amount:	1,669,869	1,708,741	1,748,584	1,789,424

Participants

Name: Patric Ljung
Doctorial degree: 2006-10-06
Birthdate: 19680328
Academic title: Doktor
Gender: Male
Employer: Linköpings universitet

Name: Charles Hansen
Doctorial degree: 1987-06-01
Birthdate: 19541011
Academic title: Professor
Gender: Male
Employer: University of Utah

Name: Timo Ropinski
Doctorial degree: 2015-11-29
Birthdate: 19760603
Academic title: Professor
Gender: Male
Employer: Ulm University

Descriptive data

Project info

Project title (Swedish)*

Belysningsmodeller för tidsvarierande volymetriska data i interaktiv visualisering

Project title (English)*

Illumination of spatio-temporal volumetric data in interactive visualization

Abstract (English)*

Light interactions captured within an image are crucial for spatial comprehension including the perception of structures as well as depth relations. Advanced and global illumination models for participating media are computationally very demanding and have in the past primarily been used when static data is considered. To an increasing degree data that needs to be visualized is large-scale and time-varying. This poses serious challenges in terms of available bandwidth for data transport, storage capacity, and rendering performance. Despite this need for analyses of time-varying data rather little research has been dedicated towards the integration of advanced volumetric illumination models in time-varying volume visualization.

Within this project we plan to develop methods for advanced illumination models in time-varying volume visualization. We will take a starting point in the human perception of change over time of illumination and data and use these insight to develop efficient methods that reduce both computational and data transfer requirements. Our goal is to enable use of physically based light transport in participating media based on photon propagation. In the project we will also investigate the novel use of sparse representations of light information based on compressed sensing. We will also develop tailored data structures that allow for multi-resolution access of spatio-temporal data sets.

The data used in the project will come from a range of existing collaborations and give us access to large scale simulations of turbulence in air flow, petascale molecular dynamics simulations and data captured in state-of-the-art time resolved X-ray computed tomography.

Popular scientific description (Swedish)*

Ljus är den fundamentala förmedlaren av visuell information. Ljus transporter inte bara information om innehållet i pixlarna på en bildskärm till näthinnan i det mänskliga ögat, det spelar också en fundamental roll i hur bilder skapas och ljussättningen gör det lättare att visualisera och förstå mycket stora och komplexa datamängder. Det är ett väl etablerat faktum att ljussättningen i en bild spelar en avgörande roll när en människa analyserar dess innehåll. Med hjälp av noga specificerat och designat ljus, kan det mänskliga ögat lättare uppfatta viktiga strukturer i data, t.ex. globala viktiga strukturer som kastar skuggor, lokala detaljer som framhävs i ljuset, samt krökning av objekt och ytor. Användning av belysning för dessa perceptuella ändamål har sedan länge varit känt bland konstnärer. Bland de första som gjorde detta i större omfattning och med systematik var de Venetianska 1400-tals konstnärerna Giorgione (1478 - 1510) and Titian (1485 - 1576).

Det väldokumenterade behovet av att använda ljus i visualisering har föranlett betydande forskningsinsatser och utveckling av ett stort antal metoder för att hantera ljus i visualisering och konstellationen av forskare som deltar i denna ansökan ligger i täten av forskarvärlden inom detta område. Det är idag möjligt att göra interaktiv belysning av komplexa och stora data. Data som hanteras är emellertid statisk, dvs. ändrar sig inte över tiden, vilket leder till att en rad förenklingar kan användas i beräkningen av ljuset.

Även om fenomen som representerar statiska data är mycket viktiga att analysera, t.ex. data från datortomografer och magnetkameror på sjukhusen, är inom många områden de intressanta fenomenen upplösta i tiden, dvs. data ändrar sig med tiden, och när man visualiserar data är det en ström av data som man vill interaktivt visualisera och varje tidssteg är en hel datavolym i rumsdimensionen. Volymsvisualisering görs idag nästan uteslutande på grafikprocessorer (GPU). Utmaningen när tidsvarierande volymer visualiseras är att en ny datavolym måste hanteras minst 20 ggr per sekund. Då varje tidssteg kan bestå av många Gb, och i vissa tillämpningar Tb, ställer detta oerhört stora krav på att snabbt förflytta data till GPU och att snabbt skapa den bildström som användaren ska interagera med.

I detta projekt fokuserar vi på att utveckla metoder som gör det möjligt att globalt belysa data i den interaktiva ström av bilder som beskrivs ovan. Global belysning innebär att skuggor kastas mellan strukturer och att ljuset studsar och sprids inuti volymen. Det är mycket krävande beräkningar som behöver genomföras för att på ett fysikaliskt korrekt vis beräkna ljusets transport och att göra detta på en strömmande tidsserie av stora och komplexa data är en mycket stor utmaning. För att möta denna utmaning kommer vi att ta fram metoder som förlitar sig på att datatransport och beräkningar kan reduceras genom att förändringar i tiden av både data och ljusinformation kan approximeras och kondenseras utan att vi människor uppfattar att all information inte uppdateras med samma upplösning i tid och rum. En viktig del av projektet är därför att förstå vilka typer av approximationer som kan göras inom ramen för acceptabla visuella fel och utveckla algoritmer baserade på dessa insikter. Vi kommer också att utveckla nya strukturer för effektiv hantering av data i den strömmande interaktiva visualiseringspipelinen.

Exempel finns ofta inom områden där man simulerar fysikaliska fenomen som utvecklar sig över tiden eller inom områden där sensorer med tidsupplösning används. Dessa kan komma från t.ex. senaste typen av datortomografer (röntgen) som nu kan köras med tidsupplösning. Viktiga tidsvarierande volymsdata finns inom många andra områden som t.ex. simuleringar av luft- och vattenflöden, rök och eld mm. Ett mycket intressant område är studier av data från molekyldynamiksimulering som genererar mycket stora tidsupplösta data över stort antal molekyler och över längre tidsperioder.

En av styrkorna bakom projektet är den uppställning forskare som kommer att delta. Vi har världsledande experter som täcker in grundläggande ljusforskning inom datorgrafik, effektiva algoritmer för volymsvisualisering, samt bild- och signal analys. Vi har dessutom kopplat till projektgruppen ett flertal ledande forskare inom valda tillämpningar. Detta är en ovanligt förekommande typ av gruppering som gör det möjligt att attackera dessa utmanande forskningsfrågor.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*

1. Naturvetenskap > 102. Data- och informationsvetenskap (Datateknik) > 10299. Annan data- och informationsvetenskap

2. Teknik > 211. Annan teknik > 21102. Mediateknik

1. Naturvetenskap > 102. Data- och informationsvetenskap (Datateknik) > 10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)

Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

Volume Visualization

Keyword 2*

Illumination

Keyword 3*

Time-varying data

Keyword 4

Interactive Visualization

Keyword 5

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

This project focuses on method developments in visualization research. Ethical considerations primarily concern data that will be used as for testing and showcasing of results. Most of this data will be from computer simulations of phenomena that are not subject to ethical consideration. Data from medical scanning will also be used and for this data we will rely on the policy and regulations at the Center for Medical Image Science and Visualization.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

PURPOSE AND AIMS

To an increasing degree, data of high interest describes dynamic phenomena spanning orders of magnitude in both space and time. The underlying mission of the proposed project is to develop methods that effectively visualize this kind of time-varying data through interactive animation sequences. The impact of the results will be found in a wide range of data intensive applications in the academic as well as the commercial sectors.

The illumination used in the rendering of an image and sequences of images has an enormous impact on how the information is interpreted by a human observer. By careful design of the lighting setup, the illumination can reveal strong visual cues [1], such as overall impression of global structures, local details, curvature of surfaces and volumetric structures that would otherwise be hidden to the observer. Global illumination approaches provide superior clarity to the data sets being visualized. In general high quality and interactive lighting in visualization is a great challenge due the computational complexity of calculating light transport at speeds enabling interactive visualization. When visualizing time-varying data in animated sequences the problem becomes even more challenging as, in a naive approach, the illumination of the data needs to be recalculated for each frame of data. This means that illumination models for time-varying data have to a large extent been limited to local lighting effects and non-physically based computations, and have thus put constraints on the number, position and generality of the light sources and indeed the sizes of the individual frames of data. In this project we target the research challenges involved in taking illumination of time-varying data to the next level of sophistication by enabling interactive global illumination. The overall goal of the proposal is to:

> *Enable interactive use of global and physically-based illumination in visualization of large-scale time-varying volumetric data by exploiting spatial and temporal coherence of data and light from a human perception point of view*

As shown by our track record we have played a leading role in the development of illumination of static volumes of scalar data. This, together with our novel work on knowledge-based data reduction of data in the spatial domain puts us in a position to develop new and efficient methods for global illumination of dynamic data at interactive frame rates. One of the key components of the research agenda is the understanding of the unique aspects of illumination of time-varying data and from a human perception point of view gaining the understanding of which approximations, without causing serious visual artifacts, that can be made in the calculation of illumination of time-varying data.

The project has been designed to address some of the most pertinent challenges in reaching this goal. Thus we address several of the stages of the visualization pipeline of time-varying data where we have identified research topics with potentially high impact on the overall performance and quality. The topics are:

- Analysis of the perceptual relevance, with respect to illumination, view, features and data structures, that will feed back into the visualization pipeline to guide and optimize rendering, illumination and out-of-core data streaming.
- Exploiting the spatio-temporal coherence in object-space for global light propagation and photon mapping using illumination warping of temporal photon beams and Sequential Monte-Carlo sampling.

Figure 1: Example of benefits when applying global illumination to a fine-detailed volume visualization of micro CT scan of the insides of a fly head. Left: traditional diffuse illumination. Right: illumination through global illumination where fine structures appear much more clearly.

- Investigate and develop compressed sensing strategies and algorithms for 3D and 4D illumination and light propagation that exploits the spatio-temporal coherence.
- Supporting data structures tailored towards the specific needs of progressive and dynamic illumination computation which leverages state-of-the-art GPUs and solid state disks I/O.

In the project plan we describe a progressive research agenda based on four sub-projects that will enable us to reach the ambitious overall goal stated above. It should be noted that the project will create, and capitalize on, synergies with other related projects within the unique constellation of researchers.

Survey of the Field

The visualization and rendering of volumetric data has attracted much attention over the last two decades, yet it remains challenging due to the sheer size, especially for time-varying data.

In 1999, Shen et al. [2] introduced the Time-Space Partitioning (TSP) tree. It is designed to capture and exploit temporal and spatial coherence by constructing an octree representation of the spatial domain and store a binary search tree covering the time domain in each node. By separating the time domain from the spatial domain, this scheme can efficiently handle data sets with a large discrepancy between the resolutions in those domains. During the tree traversal, nodes are selected satisfying temporal and spatial errors based on user-specified thresholds. In recent years, this work has been extended by more elaborate methods to determine the error in the temporal and spatial domains, in particular the transfer function has been utilized to varying degrees [3].

Ljung et al. [4] demonstrated an optimized brute-force approach supporting arbitrary playback rate of temporal data, both volumetric and particle data. The system, however, supported only a static spatial resolution while the temporal aspect provided full flexibility as data was streamed in real-time. For static data, octrees and blocking techniques have been deployed to enable graceful degradation and level-of-detail rendering. Members of the group have extensively studied adaptive data management and rendering techniques [5, 6, 7]. It was shown that significant data reduction can be achieved when the visualization parameters were taken into account, specifically using the transfer function in conjunction with simplified local data distribution representations.

In recent years, volumetric illumination models have gained increasing attention. While Max laid the theoretical foundation in his seminal paper on optical models for volume rendering [8], it took seven years until the first interactive volume rendering technique based on phase functions was proposed [9]. It accounts only for light scattered around the dominant direction of incident light, but neglects scattering of outgoing light on its way towards the eye. This type of scattering has been incorporated by Ropinski et al. [TR11, TR36][1]. They propose an approach based on the volume itself, which is therefore applicable to any volume rendering technique.

To incorporate visibility effects, ambient occlusion techniques have successfully been applied to enhance the perception of spatial relationships for isosurface rendering [10]. More recently techniques have been proposed to calculate ambient occlusion for direct volume rendering. Hernell et al. [AY23, AY53, AY56] exploit acceleration data structures, which allow to simulate soft shadow effects using ambient occlusion. While these techniques rely on the optimized data structures to allow fast visibility recalculation upon transfer function changes, Ropinski et al. [TR16] support dynamic updates by utilizing local histograms. More recently, Kronander et al. [AY15] have taking this trend one step further and used spherical harmonic lighting in order to perform efficient visibility calculation and storage.

Jönsson et al. [AY14] have realized interactive volumetric illumination within the area of photon mapping. While their approach enables multiple light sources, the interactivity is lost when significant and large changes occur in the data, or the transfer function drastically changed, as a high quantity of the photons has to be re-traced and updated to generate high-quality images without visual artifacts, and therefore the method is not adapted to time-varying data.

Project Description

The challenges outlined in the introduction, and to reach the overall goal of this project, we divide the project into four closely related sub-projects (SPs): real-time perceptual relevance analysis, efficient interactive global illumination of time-varying data, efficient sparse representations of global illumination, and efficient data structures for time-varying data and meta-data encoding. Below we will describe the involved sub-projects and their share on the overall goal in more detail.

SP 1: Perceptual Relevance for Global Illumination and Data Streaming

A key aspect of an efficient visualization pipeline, especially considering highly demanding illumination computations, is to focus the efforts where they are delivering most value, or alternatively, avoid work where it is less relevant and would not contribute significantly. The goal with analyzing the perceptual relevance in the generated images is to depict what parts of the images are more relevant based on our knowledge and understanding of the human vision system. The result is a perceptual relevance map that will allow the visualization pipeline to prioritize and balance the workload between rendering tasks, global illumination calculations and data streaming, given limited computational resources, memory and data data transfer bandwidth. In each aspect of the rendering, illumination, and data streaming there are quality choices to be made. These choices of quality span both image-space and object-space as well as across the temporal domain.

We have in our prior work identified significant opportunities to reduce the workload by taking some perceptual relevance aspects into account primarily for rendering and illumination aspects in object-space for static, non-varying, volumes [5]. In this proposal we seek to develop further additional metrics of perceptual relevance and include advanced illumination aspects and time-varying

[1] Citations with AY or TR refers to publications in Anders Ynnerman's or Timo Ropinski's publication lists.

volumetric data. Some of the challenges we face are:

- ▶ detecting regions in object-space where global illumination can be ignored or coarsely sampled, both spatially and temporally.
- ▶ detecting regions in object-space where lower spatial and temporal resolution can be selected for the data.
- ▶ predict and identify regions in image-space where sampling can be reduced, again both in the temporal domain and spatially.

The metrics generated for the perceptual relevance maps must be able to guide a quality selection stage to prioritize the more important areas in image-space as well as transferring this relevance metric into object-space. In addition, necessary meta-data about the data will be instrumental to classify the nature of changes in the data and also identify the visibility. We plan to precompute some meta-data to aid in this process, such as local data distribution of small neighborhoods and compactly represent these, to provide means to efficiently estimate each local neighborhood's visual appearance and how it will evolve over time in the data.

Conversely, we suggest an approach to tile up the display region to attribute each tile with local perceptual relevance metrics. The CIE*Luv perceptually-adjusted color space is a suitable candidate for its simplicity. More advanced perceptual spaces will be considered at later stages. This allows us to defined metrics at different scales, spanning fine-detail and medium to low frequency properties of the image perceptual appearance. Specifically of interest is how the medium to low illumination distribution can be quantified to aid in the quality selection for the global illumination estimation across image and object space.

The Perceptual Relevance Map is seen as consisting of a set of metrics and measures from scene analysis, deriving perceptual information from the camera image-space, the data object-space in the form of tiles of local neighborhoods and multi-resolution aggregates, and the illumination through the photon distribution. Some of the metrics and measures that are intended as a baseline for the perceptual relevance map are as follows:

- ▶ Scene luminance dynamics at different frequency ranges. Both global and local variations are of relevance and can be derived from the intensity, L, in the CIE*Luv color space. This analysis is inherently well-suited for highly data-parallel processing systems such as GPUs.
- ▶ The range of the visible depth is an important measure to determine how far into the data the illumination needs to be considered. In addition, it can be used to define the extent of transmittance for photon beams. The visible depth also provides information on the quality of the data that is required in object-space.
- ▶ Current global illumination, or photon density accumulation, in particular for 4D Photon Maps as outlined in SP2 and SP3, will provide useful information when correlated with other metrics to further aid in data and illumination quality aspects. This relates both along the camera view path as well as the path from a location in object space to photon emitters.

The outcome of this sub-project will be application-specific, spatio-temporal relevance maps providing the basis for the work described in the following sub-projects.

SP 2: INTERACTIVE GLOBAL ILLUMINATION STRATEGIES FOR TIME-VARYING DATA

Photon mapping [11, 12, 13] is an effective method for global illumination computations that is often used in high quality offline rendering applications. This versatile Monte Carlo algorithm enables efficient rendering by separating the light transport computation into two steps. First photons are emitted from light sources into the scene, performing a random walk while interacting with the media. The result is a photon map, which describes the illumination in the media through a spatial (3D) density distribution. In a second *gathering* step, the incident radiance is computed along viewing rays cast from the camera by performing a kernel density estimation of the precomputed photon map distribution. A key benefit of photon mapping is that it allows the expensive global illumination computation is decoupled from the view computations. In other words, changing camera position does not require the light transport to be recomputed. This property makes photon mapping a widely used method for simulating high quality global illumination in off-line rendering software [14]. However, the photon mapping technique has not been extensively used for interactive volume rendering due to the amount of computation needed to recompute the photon map when rendering parameters change, essential to visualization applications. In preliminary work [AY14], we have developed the first technique for interactive volumetric photon mapping of static data. This is achieved by encoding a compressed history which describes the rendering parameters affecting the photon. Photons that are affected by a parameter change can then be found efficiently at run time using an efficient search algorithms and recomputed. The unaffected photons can be kept, resulting in large performance savings. While this technique enables interactive rendering of static data, it is still an open problem how to perform interactive photon mapping for time-varying volume data. The major challenge is that both the photon map and the gathering process need to be reevaluated for each volume time step.

In this sub project we plan to extend the traditional concept of a static spatial 3D photon map to a spatio-temporal 4D photon map encoding the photon distrubution over space and time. This concept will allow us to exploit both the spatial and the time-varying correlations in the photon distribution but requires *two key challenges* to be solved. First, computing and representing the 4D photon map. Second, kernel density estimation in 4D, required in the gathering process. Both these steps are computationally expensive, which prohibits a straight forward approach using traditional methods.

The first challenge we will address by adapting the data structures and efficient history search algorithms developed in the preliminary work [AY14]. This will enable us to compute a 4D photon map sequentially by incrementally updating photons given a 3D photon map at the first time step. Since the data is assumed to correlate both spatially and in time, meaning that if a photon requires recomputation, it is likely that it will end up in roughly the same place as before. It is also likely that photons originating from the same place will change in the same way. By computing the location of a sub set of the photons and then applying a warping of the photons emitted from the same location we can get a good estimate of the new photon distribution. The new photon distribution only needs to be corrected, which is a much less expensive operation than recomputing the whole path. For this purpose, we will also investigate sequential Monte Carlo methods [15].

The second challenge involves performing $N \times D$ kernel density estimations from the 4D photon map, N being the number of rays cast from the camera and D the number of samples along each ray. As an example, N is about two million for a screen with high definition resolution (1920×1080) and D is in the thousands for a 512^3 voxel data set with two samples per voxel. A typical dataset will therefore require in the order of 10^9 kernel density estimates for the gathering process. We plan to build a view-dependent 3D density estimate on a regular grid, spatially co-located with the volume, from the 4D photon distribution. This will enable us the reduce the number of expensive kernel density estimates to the resolution of the 3D grid and at the same time utilize cheap hardware accelerated interpolation for the $N \times D$ density estimates.

SP 3: 4D COMPRESSED SENSING APPROACHES FOR PHOTON MAPPING

Ray-casting and photon mapping for volume rendering are challenging sampling problems. During rendering, the goal is to numerically integrate the light emanating from the light sources as it scatters through the volume. This is, as described in SP2, carried out by tracing photons though the volume to create a photon-map, which is sampled to estimate the radiance scattered along the viewing rays. The high spatial and temporal resolution in the volumetric data produced by current and future modalities turns this into a computational problem of high complexity. It is therefore highly important to develop new theory and algorithms for efficient sampling and signal reconstruction for the ray integration and photon density estimation.

In this subproject, we will approach this pertinent problem using compressed sensing (CS). CS states that if a signal can be represented in basis in which it is sparse[2], it can be accurately reconstructed at sampling rates well below the Nyquist frequency [16]. To enable the use of CS and its solid mathematical foundation for visualization of large-scale time-resolved volumetric data, we will develop basis functions which admits sparse representations of volumetric (3D) and temporally resolved volumetric (4D) data.

These basis functions, for 3D and 4D volumetric signals, will be based on the learning-based approached developed in our recent work in compressive image reconstruction [17]. In [17], we developed a CS method for image reconstruction, where a dictionary of basis functions (admitting sparse signal representation of visual data) is trained on image (2D), video (3D), and light field (4D) data. In this project, we will extend and adapt these basis functions to high resolution temporally resolved volumetric data. We will investigate the use of these basis functions both for the original volume and the photon map described in SP2. It should be noted that the original data set and the photon map are both stored in a regular 3D grid at each time step, but that the photons are stored at random positions as opposed to every voxel. To solve this, we will develop a new training algorithm designed for 3D and 4D volumetric data, and the error measures required in the optimization of the basis functions. A part of this challenge is also to assemble a number of representative volumtetric data sets to serve as training sets for the original volume and the photon map. Another interesting research problem is to derive theoretical bounds for the relation between photon density and accuracy in the reconstruction. This is highly important in order to enable high quality lighting computations in the rendering. To enable real-time visualization and interactive parameter adjustments of e.g. transfer functions, we will develop algorithms and data structures suitable for parallel computations and GPU implementations. Similarly to e.g. [17], we will map the nD volumetric signals to equivalent 1D forms in order to enable the use of efficient solvers in the CS computations.

A important side-benefit of these basis functions is that they do not only enable the use of CS methods, they can also be used to efficiently compress 3D and 4D data with near optimal signal reconstruction. We believe that the development of adaptive learning-based basis functions and CS algorithms described here will introduce a step change in how we process, interact with and visualize large-scale volumetric data in the time domain.

[2] A signal is called sparse in a basis if most of its coefficients are zero in that basis.

SP 4: DATA STRUCTURES FOR ILLUMINATION AND TIME-VARYING VOLUMETRIC DATA

This sub-project is targeting work on efficient data structures for visualization and illumination of time-varying volumetric data sets. There are several aspects that need to be considered. Efficient encoding and compression of the time-varying data itself is essential to support continuous streaming of data from secondary storage such as high-speed solid state disks. The storage structure and organization also need to support retrieval at multiple resolution levels, both spatial and temporal. In contrast to encoding and compression of image and video data, where the final color values are known at the time of encoding, for scientific data, and also medical data, the final appearance are not known and may be dynamically changed during the visualization session.

In our prior work we have shown that a multi-resolution blocking solution is highly efficient and allows compact representations of both data [7] and illumination encoding [AY15, AY23, AY53]. The representation, and its encoded meta-data, however, did not consider a temporal domain and the possibility of temporal level-of-detail. Extending this approach is not straight forward and the best suitable approach depends on the actual use case, whether there is a preference to scale arbitrarily in both space and time or is there a preference to linking temporal and spatial scales. As part of this sub-project we will implement a selected set of approaches and explore how well suited they are for typical use cases. Recent work also shows novel methods to incorporate efficient compression of data for visualization purposes that allows application dependent choices of rate, precision, or accuracy priority, Lindström [18]. These choices can be adaptively chosen down to block-level and we see a huge potential benefits of these recent advances to be incorporated in our block-based strategy when extending it into the temporal domain. Throughout the course of the project we will establish criteria for optimal structure and compression of time-resolved volumetric data using recent novel compression techniques, especially for floating point data.

The photon beams can essentially be stored as connected particles and one of the challenges are to be able to efficiently query them based on spatial, and temporal location, in order to perform the kernel density estimation that will form the view dependent 3D illumination volume. An extremely efficient representation for these spatial queries on massively parallel hardware are hash tables, which we have used in previous work and plan to extend to the time domain. A second challenge is to deal with the number of kernel density estimates necessary to create the 3D illumination volume and its storage requirement. This needs to be fast since it well be performed each time the camera changes. As multi-resolution data representations and the use of varying resolution, level-of-detail, throughout the object-space are highly efficient for the data domain they are also highly efficient for the storage of illumination information. As shown in Hernell et al. [AY53], utilizing the multi-resolution volume representation provides significant speed-up in global light propagation. Our strategy in this proposal is to extend the scope of knowledge for level-of-detail selection to also include the temporal aspect. By encoding the local frequency distribution of data values, not only in a block-based spatial domain, but also over time intervals we can allow efficient strategies to prioritize and budget for necessary storage and updates of the illumination volume.

STAFFING AND TIME PLAN

To reach the ambitious goal of the project, it will be staffed with senior researchers, the co-applicants, as well as a new Ph.D student. The Ph.D student will first work on SP1 to implement initial perceptual relevance metrics and analysis methods, which will provide necessary feedback to drive the global illumination algorithms and to provide the data management subsystem with priorities for data streaming. The main work will afterwards be conducted with a focus on sub-projects SP2. To address the novel ideas of using compressed sensing in SP3 we will have a close collaboration with Dr. Jonas Unger and his team of researchers on light field methods. Erik Sundén, who is the research engineer, will focus on the supporting software and data structures described in SP4. As a part of the collaboration with Prof. Charles Hansen, co-applicant, Ph.D students at the SCI institute at the University of Utah will collaborate with us on SP1 and SP2.

SIGNIFICANCE

The primary significance of the proposed project is found in the establishment of an understanding of the importance of illumination in time-varying volume data visualization and also a fundamental understanding of the possible approximations of the illumination calculations in the time domain of participating volumetric media. Based on these insights the project will lead to implementation of novel data handling and processing in visualization of large-scale and complex time-varying data in many application domains. The impact on these domains can be very large and we have therefore teamed up with a set of strategic partners that will provide data and participate in the evaluation of developed methods.

Through our collaboration with Prof. Dan Henningson at the Linné Center FLOW at the Royal Institute of Technology in Stockholm we will have access to state-of-the-art data from computational fluid dynamics simulations. A typical simulation makes use of 10 billion grid points and in total consumes approximately 10 million core hours. To interactively visualize the time evolution of this kind of data with global illumination enhancing details in the data is the core mission of the project. Another source of similar data is through our collaboration the team headed by Prof. Masha Kuznetsova at NASA, Goddard Space Flight Center. We will have access to multi-model data from space weather simulations, which are used in routine forecasting of the conditions in the magnetosphere which influence satellite communication and electrical power transmission on the earth. The large number of models used and the varying resolution and time stepping in the simulations will pose interesting challenges to the project.

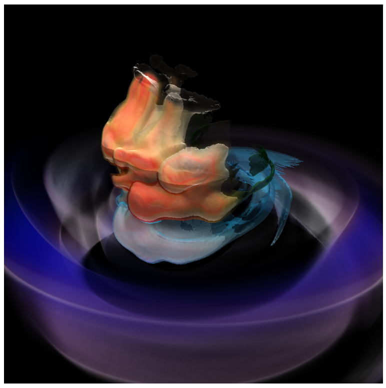

Figure 2: Visualizing a time-varying MHD simulation with volume rendering used for predicting space weather.

In state-of-the-art Molecular Dynamics (MD) simulations a very large number of particles are simulated over long time scales. Through a collaboration with Prof. Erik Lindahl at the SciLife Lab in Stockholm we will have access to MD simulations of up to 100 000 atoms over millions of time steps. Important vibratory movements of atoms are occurring at very short time-scales and over short distances whereas the global evolution of the simulation is very slow. It has previously been shown that illumination of static molecular data is one of the key components in producing effective visualization of complex structures. To extend this to the time domain is a very exciting opportunity.

Another kind of data that showcases the significance of the project is the new data coming from 4D CT scanning. Through our partnership with the Center for Medical Image science and Visualization (CMIV) at Linköping University, headed by Prof. Anders Persson, we will have unique access to 4D CT scanning data which will serve as examples sensor based data that need interactive setting of parameters such as transfer functions and for each time step requires rapid volume rendering and illumination. Global illumination can here be the key to provide context over time as the resolution in the dime domain can in these data sets be limited.

PRELIMINARY RESULTS

In collaboration with NASA's Goddard Space Flight Center, we investigated and confirmed the feasibility of utilizing Time Space Partitioning (TSP) trees[2] on modern graphics architectures for visualization of time-varying volume data. In this collaboration, we received the results of time-varying MHD simulations used to predict coronal mass ejections, solar flares, or single proton events. The TSP architecture was implemented allowing us to visualize a dataset, consisting of 1000 time steps with 500 MiB each, at interactive frame rates. In Figure 2, several attributes of one time step of an MHD simulation are visualized with volume rendering. This preliminary work needs, however, further studies to reach full operational quality. We already gathered the expertise to implement the efficient reuse of temporally coherent data as described by Crassin et al. [19].

Furthermore, the proposing group of researchers has over the past decade(s) built up a strong research record in fields including scientific and medical visualization, computer graphics, HDR imaging and evaluation. Research results that are of particular interest to this project are the investigations of multi-resolution data structures, light propagation and ambient occlusion [AY53, AY53, TR16, AY23, AY14], HDR light field capture, analysis and rendering [20], as well as our initial work on using spherical harmonics representations for illumination [AY15, AY48] and representation of materials [TR11]. Figure 3 shows light propagation with photons applied to a volume data set [21]. The goal for the proposed project is to obtain the visual quality shown in this rendering of a static data set for time-varying interactive visualization.

Figure 3: Volume rendering with global illumination using photon mapping.

To enable research in the addressed areas, it is essential to have powerful software tools. One of the co-applicants is a project manager of an open source visualization platform named Inviwo (Interactive Visualization Workshop), www.inviwo.org, which consists of modern architecture and a flexible pipeline that enables complex volume visualizations by combining several functional building blocks, each performing a specific task, while allowing a high degree of flexibility and extendability as well as interactive frame-rates through OpenGL/OpenCL functionality. Within this platform we have implemented a prototype GPU-based beam ray casting approach for volume illumination and the first results are encouraging. Inviwo will serve as the software foundation for the work described in this proposal yielding rapid development and testing cycles.

INTERNATIONAL AND NATIONAL COLLABORATION

We have extensive networks in the visualization community and contacts with experts in the application domains. On the core visualization side of the project we will collaborate with several world-leading visualization experts including Prof. Han-Wei Shen from Ohio State University, USA, Prof. Hamish Carr from University of Leeds, UK, Prof. Ivan Viola from Vienna University of Technology, Austria, Prof. Renato Pajarola from the University of Zürich, Dr. Julius Parulek from University of Bergen, and Dr. Peter Lindström at Lawrence Livermore National Labs, California, USA, who also will collaborate on compression of scientific data. These experts have participated in the discussions behind this project and will be partners on described sub-projects. On the application side we have collaborations with domain experts, as described in the Significance section above. These collaborations will ensure access to data and user participation and feedback throughout the project.

REFERENCES

[1] M.S. Langer and H.H. Bülthoff. Depth discrimination from shading under diffuse lighting. *Perception*, 29:649–660, 2000.

[2] Han-Wei Shen, Ling-Jen Chiang, and Kwan-Liu Ma. A fast volume rendering algorithm for time-varying fields using a time-space partitioning (TSP) tree. *IEEE Conference on Visualization*, pages 371–377, 1999.

[3] Steven Martin and Han-Wei Shen. Interactive transfer function design on large multiresolution volumes. In *IEEE Symposium on Large Data Analysis and Visualization (LDAV)*, pages 19–22, 2012.

[4] Patric Ljung, Mark E. Dieckmann, Niclas Andersson, and Anders Ynnerman. Interactive Visualization of Particle-In-Cell Simulations. In *IEEE Visualization 2000, Proceedings*, pages 469–472,592. IEEE, 2000.

[5] P. Ljung, C. Lundstrom, A. Ynnerman, and K. Museth. Transfer function based adaptive decompression for volume rendering of large medical data sets. *Proceedings of the IEEE*, 10:04, 2004.

[6] P. Ljung, C. Lundstrom, and A. Ynnerman. Multiresolution interblock interpolation in direct volume rendering. In *Proceedings Eurographics/IEEE Symposium on Visualization*, pages 259–266. Citeseer, 2006.

[7] P. Ljung. Adaptive sampling in single pass, GPU-based raycasting of multiresolution volumes. In *Eurographics/IEEE VGTC Workshop on Volume Graphics*, pages 39–46, 2006.

[8] Nelson Max. Optical models for direct volume rendering. *IEEE Transactions on Visualization and Computer Graphics*, 1(2):99–108, 1995.

[9] Joe Kniss, Simon Premoze, Charles Hansen, and David Ebert. Interactive translucent volume rendering and procedural modeling. In *IEEE Visualization*, pages 109–116, 2002.

[10] James Stewart. Vicinity shading for enhanced perception of volumetric data. In *IEEE Visualization*, page 47, 2003.

[11] Henrik Wann Jensen. Global illumination using photon maps. In *Rendering Techniques*, pages 21–30. Springer-Verlag, 1996.

[12] Henrik Wann Jensen and Per H. Christensen. Efficient simulation of light transport in scences with participating media using photon maps. In *Proceedings of SIGGRAPH 1998*, SIGGRAPH '98, pages 311–320. ACM, 1998.

[13] Toshiya Hachisuka, Shinji Ogaki, and Henrik Wann Jensen. Progressive photon mapping. *ACM Transactions on Graphics (Proceedings of ACM SIGGRAPH Asia 2008)*, pages 130:1–130:8, 2008.

[14] Pixar. Pixar's renderman products, 2015. [Online; accessed 30-March-2015].

[15] Arnaud Doucet and Adam M Johansen. A tutorial on particle filtering and smoothing: Fifteen years later. *Handbook of Nonlinear Filtering*, 12:656–704, 2009.

[16] D.L. Donoho. Compressed sensing. *IEEE Transactions on Information Theory*, 52(4):1289–1306, April 2006.

[17] Ehsan Miandji, Joel Kronander, and Jonas Unger. Compressive image reconstruction in reduced union of subspaces. In *Eurographics 2015*, May 2015.

[18] Peter Lindstrom. Fixed-rate compressed floating-point arrays. *IEEE Transactions on Visualization and Computer Graphics*, page 1, 2014.

[19] Cyril Crassin, Fabrice Neyret, Sylvain Lefebvre, and Elmar Eisemann. Gigavoxels: Ray-guided streaming for efficient and detailed voxel rendering. In *Symposium on Interactive 3D Graphics and Games (I3D)*, pages 15–22, 2009.

[20] Jonas Unger. *Incident Light Fields*. PhD thesis, The Department of Science and Technology, Linköping University, The Institute of Technology, January 2009. Linköping Studies in Science and Technology, Dissertations, No. 1233.

[21] Daniel Jönsson, Joel Kronander, Timo Ropinski, and Anders Ynnerman. Historygrams: Enabling Interactive Global Illumination in Direct Volume Rendering using Photon Mapping. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2364–2371, 2012.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

BACKGROUND

The work on high-quality illumination in interactive volume visualization accounted for in this report stems from the grant, *VR grant: 2011-420-89001-27*. The continued support from the Swedish Science Council has been of crucial importance for the build up of the Scientific Visualization group at Linköping University over the past decade. The illumination related research has been one of the cornerstones in this effort. The impact of this grant can not be underestimated in the way that it has contributed to us being able to place Sweden on the international visualization research arena.

RELATION TO APPLICATION

The work accounted for in this report is related to proposed project as it provides the foundation for the continued research on applications of global illumination to time-varying volumetric data. The proposed project is in practice a direct continuation of previous grant, although there is technically a one year gap, and much of our prior results will be extended for interactive illumination of time-varying data, where novel challenges lie ahead.

SCIENTIFIC RESULTS

A compilation of the main results of the project so far is provided in the survey journal article about interactive volumetric illumination techniques [1], which features several techniques stemming from this grant. The focus of this project has been on enabling general, flexible, high quality, accurate and interactive use of advanced illumination in volume graphics. This has been done through several contributions and we here give a few highlights.

In the work by Kronander et al. [2], we exploit the knowledge encoded in the transfer function to reduce the data together with basis functions that encode the visibility. A multi-resolution data structure is used to enable compact storage in the spatial domain, while spherical harmonics is used to encode the visibility of the angular domain. Previous methods often constrain the number of light sources that can be used but this method enables the use of multiple dynamic light sources without extensive recomputation.

Image Plane Sweep Volume Illumination [3] allows advanced illumination effects to be integrated into a GPU-based volume ray-caster by exploiting the plane sweep paradigm. By using sweeping, it becomes possible to reduce the illumination computation complexity and achieve interactive frame rates, while supporting scattering as well as shadowing. Since all illumination computations are performed directly within a single rendering pass it does not require any preprocessing and has a very low memory overhead.

The most recently presented technique [4], named Historygrams, enables advanced material properties and light setups through the use of the physically based photon mapping technique. Traditionally, photon mapping has been very expensive to compute and only used in offline computations. This work enables interactive editing of transfer functions by only recomputing the parts of the light transport solution that actually changes.

SCIENTIFIC PRODUCTION

Below we give a list of publications that have been generated in the project. There are more publications that are related to this work and which have benefited from the results presented in the publications.

1. Daniel Jönsson, Erik Sundén, Anders Ynnerman, and Timo Ropinski. A Survey of Volumetric Illumination Techniques for Interactive Volume Rendering. *Computer Graphics Forum*, 33(1):27–51, 2014.
2. Joel Kronander, Daniel Jönsson, Joakim Löw, Patric Ljung, Anders Ynnerman, and Jonas Unger. Efficient Visibility Encoding for Dynamic Illumination in Direct Volume Rendering. *IEEE Transactions on Visualization*

Visibility Encoding for Dynamic Illumination in Direct Volume Rendering. *IEEE Transactions on Visualization and Computer Graphics*, 18(3):447–462, 2012.

3. Erik Sundén, Anders Ynnerman, and Timo Ropinski. Image Plane Sweep Volume Illumination. *IEEE Transactions on Visualization and Computer Graphics*, 17(12):2125–2134, 2011.
4. Daniel Jönsson, Joel Kronander, Timo Ropinski, and Anders Ynnerman. Historygrams: Enabling Interactive Global Illumination in Direct Volume Rendering using Photon Mapping. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2364–2371, 2012.
5. Jonas Unger, Joel Kronander, Per Larsson, Stefan Gustavson, and Anders Ynnerman. Image based lighting using HDR-video. In *Eurographics 24th Symposium on Rendering 2014*: Posters, 2014.
6. Jonas Unger, Joel Kronander, Per Larsson, Stefan Gustavson, Joakim Löw, and Anders Ynnerman. Spatially varying image based lighting using HDR-video. *Computers & Graphics*, 37(7):923–934, 2013.
7. Stefan Lindholm, Daniel Jönsson, Hans Knutsson, and Anders Ynnerman. Towards data centric sampling for volume rendering. *SIGRAD 2013*, page 55, 2013.
8. Tiago Etiene, Daniel Jönsson, Timo Ropinski, Carlos Scheidegger, João Comba, L. Gustavo Nonato, Robert M. Kirby, Anders Ynnerman, and Cláudio T. Silvia. Verifying Volume Rendering Using Discretization Error Analysis. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 20(1):140–154, 2014.
9. Joakim Löw, Joel Kronander, Anders Ynnerman, and Jonas Unger. Abc-brdf models for accurate and efficient rendering of glossy surfaces. In *Eurographics 24th Symposium on Rendering*: Posters, 2013.
10. Daniel Jönsson, Erik Sundén, Anders Ynnerman, and Timo Ropinski. Interactive Volume Rendering with Volumetric Illumination. In *Eurographics STAR program*, 2012.
11. Daniel Jönsson, Per Ganestam, Anders Ynnerman, Michael Doggett, and Timo Ropinski. Explicit Cache Management for Volume Ray-Casting on Parallel Architectures. In *EG Symposium on Parallel Graphics and Visualization (EGPGV),* pages 31–40. Eurographics, 2012.
12. Joakim Löw, Joel Kronander, Anders Ynnerman, and Jonas Unger. BRDF models for accurate and efficient rendering of glossy surfaces. *ACM Transactions on Graphics (TOG)*, 31(1):9:1–9:14, January 2012.
13. Claes Lundström, Thomas Rydell, Camilla Forsell, Anders Persson, and Anders Ynnerman. Multi-touch table system for medical visualization: Application to orthopedic surgery planning. *IEEE TVCG(Vis Proceedings)*, 17(12):1775–1784, 2011.

Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Anders Ynnerman	20
2	Participating researcher	Timo Ropinski	20
3	Participating researcher	Patric Ljung	30
4	Participating researcher	Charles Hansen	5
5	Other personnel without doctoral degree	Erik Sundén	50
6	PhD Student	Ny Doktorand	100

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Anders Ynnerman	10	188,183	192,887	197,709	202,652	781,431
2	Participating researcher	Timo Ropinski	10	125,025	128,151	131,355	134,639	519,170
3	Participating researcher	Patric Ljung	10	94,644	97,010	99,435	101,921	393,010
4	Other personnel without doctoral degree	Erik Sundén	30	180,633	185,149	189,778	194,522	750,082
5	Other personnel without doctoral degree	PhD	100	497,156	509,585	522,324	535,382	2,064,447
	Total			1,085,641	1,112,782	1,140,601	1,169,116	4,508,140

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Universitetslokaler	108,800	111,520	114,308	117,166	451,794
	Total	108,800	111,520	114,308	117,166	451,794

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Resor	Projektresor	50,000	50,000	50,000	50,000	200,000
2	IT abonnemang	Univ It -kostnader	26,720	27,388	28,073	28,775	110,956
	Total		76,720	77,388	78,073	78,775	310,956

Depreciation costs

	Depreciation cost	Description	2016	2017	2018	2019	Total
1	Computers	Computers with high-end GPUs	30,000	30,000	30,000	30,000	120,000
2	Storage	Data Server	20,000	20,000	20,000	20,000	80,000
	Total		50,000	50,000	50,000	50,000	200,000

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	1,085,641	1,112,782	1,140,601	1,169,116	4,508,140		4,508,140
Running costs	76,720	77,388	78,073	78,775	310,956		310,956
Depreciation costs	50,000	50,000	50,000	50,000	200,000		200,000
Premises	108,800	111,520	114,308	117,166	451,794		451,794
Subtotal	1,321,161	1,351,690	1,382,982	1,415,057	5,470,890	0	5,470,890
Indirect costs	348,708	357,051	365,602	374,367	1,445,728		1,445,728
Total project cost	1,669,869	1,708,741	1,748,584	1,789,424	6,916,618	0	6,916,618

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Prof. Anders Ynnerman, is the PI of the project. He is the head of the division for Media- and Information Technology at Linköping University and director of the Norrköping Visualization Center. He will contribute to the project with his experience of volume rendering, computational methods and medical applications. He will also be the overall project co-ordinator as as well as participate in the SPs. Ynnerman will dedicate 20% of his time to the project. Funding for this effort will partly come from Ynnerman's faculty funding. He was is appointed "contract professor" at LiU, which guarantees him financial support for research efforts.

Prof. Timo Ropinski, is an internationally leading expert in the field of illumination in volume rendering and has published several high impact papers in the area. He has also given tutorials on advanced illumination at the most prestigious graphics and visualization conferences. Ropinski will dedicate 10% of his research time to the project.

Dr. Patric Ljung, obtained his Ph.D in 2006 under the supervision of the PI. His thesis focused on methods for efficient DVR. Ljung was employed at Siemens Corporate Research in Princeton, NJ, between 2007 and 2013 as Research Scientist and Project Manager. He is currently a senior lecturer at Linköping University since late 2013.
In this project he will work on perceptual relevance metrics and data structures and GPU performance issues.
His participation at 10% would be funded by the proposed project.

Prof. Charlse Hansen, is a world leading authority on scientific visualization. Hansen has extenisve experience of large scale simulations and the visual analysis of simulation data. He will participate in the project as a part of a long term collaboration between the SCI institute and the Norrköping Visualization center. His will participate in this project at 5% of his time and his efforts will be funded by resources from the SCI institute.

Erik Sundén, is a reserach engineer in the division and an expert on volumetric illumination. He is one of the key programmers behind the Open Source software inWivo, which will form the software base for the proposed project. He will dedicate 50% of his time to the project in synergy with the work he is conducting with funding from the Swedish eScience Reserach Center (SeRC)

New Ph.D student, will be recruited at the beginning of 2016 pending the outcome of the present proposal.
The Ph.D student will form the core of the "Time-varying Volume Volume Graphics" subgroup within research division.

Equipment
The project will be conducted at the Norrköping Visualization Center and its research unit, C-research. This means that all the equipment at the center will be available for use in the project. The equipment ranges from a large scale dome theater, seating 100 people, semi immersive collaborative environments for groups of people, and individual visualization units with multimodal interaction devices. The primary equipment for the proposed projects is, however, GPU units of the latest kind and the equipment budget specifies the procurement of new GPUs throughout the project period. We are also requesting funding for a small scale data server to host the increasingly large time-resolved data sets that we will work on in this project. For large scale simulation and data storage and acces we will rely on the national infrastructure for computing (SNIC). For medical applications the project is also connected to the Center for Medical Image Science and Visualization (CMIV) and access to the latest imaging modalities will provide challenging volumetric data sets.

Travel
We expect to publish the results at the leading international conferences in the field such as IEEE Visualization, EuroGraphics, EuroVis and Volume Graphics. We will thus need reasonable travel budget to be able to attend these conferences.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

	Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019	Total
1	SFO	Lund universitet	ELLiiT, 10% Ropinski	2009-00970	171,504	175,792	180,186	184,691	712,17
2	SFO	KTH	SeRC, 20% Sundén		174,491	178,853	183,324	187,908	724,57
3	KAW	Anders Ynnerman	Projektbidrag, 20% Ljung		507,217	519,897	532,895	546,217	2,106,22
4	LiU	Anders Ynnerman	Fakultetsmedel, 10% Ynnerman		253,608	259,949	266,477	273,109	1,053,14
5	SCI instiute	Charles Hansen	Fakultetsmedel, 5% Hansen		126,804	129,974	133,224	136,554	526,55
	Total				1,233,624	1,264,465	1,296,106	1,328,479	5,122,67

CV and publications

CV

ACADEMIC DEGREES

B.Sc.	Physics Department, University of Lund, Lund, Sweden and
Dec. 1986	University of Sussex, Brighton, England. First Class Honors
Fil.Lic.	Physics Department, University of Göteborg, Göteborg, Sweden
Jan. 1991	Title: Coupled-Cluster Calculations of Matrix Elements and Ionization Energies, Advisor: Ann-Marie Pendrill
Ph.D.	Physics Department, University of Göteborg, Göteborg, Sweden
June 1992	Title: Atomic Coupled-Cluster Calculations, Advisors: Ann-Marie Pendrill & Ingvar Lindgren

PROFESSIONAL EXPERIENCE

1999-present	**Professor** Department of Science and Technology, LiU, Research time: 50%
2010-present	**Director** Norrköping Visualization Center - C
2007-present	**Head of Division** Media- and Information Technology (MIT), Department of Science and Technology, LiU
1999-2009	**Director** Norrköping Visualization and Interaction Studio (NVIS), Department of Science and Technology, LiU
2002-2006	**Director** Swedish National Infrastructure for Computing (SNIC)
2002-2003	**Deputy Head of Department**, Department of Science and Technology, LiU
1998-2002	**Director** Swedish National Supercomputer Centre (NSC), LiU
1998-1999	**Lecturer** Department of Physics and Measurements, LiU
1997-1998	**Guest Researcher** Physics Department, University of Warwick, Coventry, England
1995-1997	**Research Officer** Swedish Council for High Performance Computing and Swedish Council for Engineering Sciences, Stockholm, Sweden
1993-1995	**Research Associate** Computer Science, Vanderbilt University, Nashville, USA
1992-1993	**Postdoc** Clarendon Laboratory, University of Oxford, Oxford, England

SUPERVISION

Graduate students: Name, (year of dissertation) – Björn Olsson (2004, Lic), Patric Ljung (2006), Anders Henrysson (2007), Karljohan Lundin (2007), Claes Lundström, (2007), Jimmy Johansson (2008), Jonas Unger (2009), Stephen Petersson (2010), Petter Bivall Persson (2010), Katerina Vrotsou (2010), Frida Hernell (2011), Magnus Axholt (2011), Umut Kocak (2012), Nguyen Tan Khoa (2014), Stefan Lindholm (2014), Daniel Jönsson (2015). Joel Kronander (2015), Gabriel Eilertsen (2016), Ehsan Miandji (2017), Ali Samini (2018), Saghi Hajisharif (2018).
Postdocs: Name, (Period) – Katerina Vrotsou (2011-2012), Daniel Forsberg (2012-2014), Jonas Lantz (2012-2014), Martin Falk (2013-2015), Peter Steneteg (2012–2015).

CURRENT RESEARCH INTEREST

Large-scale data sets in visualization and computer graphics, direct volume rendering including data reduction and volumetric lighting techniques, immersive visualization techniques, image based lighting techniques using light fields and volume haptics for exploration of scientific data, visual learning and communication. He is author of more than 150 papers on computational science and visualization research. His current h-index is 26.

Key Entrepreneurial & Leadership Achievements

1995-1996	Administrating the build-up of the Swedish HPC Infrastructure.
1998–2002	Directing NSC and Expanding and improving computing services to the academic community as well as to Saab and SMHI.
2001	Founder of the Center for Medical Image Science and Visualization (CMIV).
2002–2006	Initiator and first director of the Swedish National Infrastructure for Computing (SNIC).
2004	Founder of Sciss AB based on research and development in astrovisualization.
2007–2014	Heading the build-up and operations of the Visualization Center - C in Norrköping. (The center has approximately 150 FTEs employed within the consortium, including 75 FTEs at the MIT division.)
2009–	Coordinating the LiU participation in the Swedish eScience Research Center.

Awards, Honors & Acknowledgements

2012	Given then S:t Olof Gold Medal by Norrköping Municipality
2012	Appointed Fellow of the Eurographics Association
2011	Awarded the Royal Engineering Science Academy Gold Medal
2010	Winner of the Swedish Knowledge Award (Kunskapspriset)
2009	Winner of the Athena Award for best medical clinical research in Sweden
2007	Winner of the Golden Mouse Award for Swedish IT-person of the year
2007	Winner of Akzo Nobel Science Award
2007	Affiliated Professor with the Royal Institute of Technology
2006	Elected member of the Royal Engineering Science Academy

Selected Current Commissions of Trust

2012 –	Chair of NTA digital project hosted by KVA and IVA
2013 –	Chair of the Swedish Research Council Investigation on eInfrastructures
2013 –	Board member of the Foundation for Strategic Research
2002 –	Chairman of the Scientific Council at CMIV
2010 –	Vice chairman of the Swedish eScience Research Center (SeRC)
2010 –	Board member of Norrköping Visualization AB
2014 –	Chairman of the Östergötlands Sjukhusclowner association

Selected Recent Academic Community Participation

- Associate Editor of IEEE Transactions on Visualization and Computer Graphics
- Associate Editor of Computers and Graphics
- Chair of the Eurographics Association and Member of the Executive Committee
- Papers Chair of IEEE Scientific Visualization 2013 and 2014
- General Chair and Papers Chair of VCBM 2012, Chair of EuroGraphics 2010, Chair of Volume Graphics 2008, General Chair and Papers Chair of EuroVis 2007, Co-chair of VCBM (2012)
- Program Committee Member of: EuroGraphics (2009), IEEE Vis (2008, 2009, 2010), EuroVis (2007,2008, 2009, 2010, 2013, 2014), PacificVis (2008, 2009, 2010), SCCG (2009), BioVis (2012)

1. Higher Education Qualifications

12/2002	**Diplom** (Computer Science with minor in Biology), University of Münster (Germany), Title: Development of an Object-Oriented Interface for the Radiance Lighting Framework (Grade: very good).
04/2001	**Staatsexamen** teaching certificate graduation (Computer Science and Biology, SekI/SekII), University of Münster (Germany) (Grade: very good).

2. Doctoral Degree

11/2004	**Ph.D.** in Computer Science, University of Münster (Germany), Title: 3D Magic Lenses and Virtual Reflections: Real-Time Approaches for Improving Interactive Visualization, Supervisor: Klaus Hinrichs (Grade: *magna cum laude*).

3. Postdoctoral Positions

2004–2011	**Project Leader** in the Collaborative Research Center SFB 656 (Project Z1), University of Münster (Germany). Interactive 3D-Visualization of Multiparametric Cardiovascular Imaging Data.

4. Docent Qualification

12/2009	**Habilitation** (*venia legendi*) in Computer Science, University of Münster (Germany), Title: Supporting Spatial Awareness and Multimodality in Interactive Volume Visualization.

5. Present Position

since 11/2014	**Professor** for Visual Computing, Ulm University (Germany).

6. Previous Positions and Periods of Appointment

2011–2014	**Professor** for Interactive Visualization, Linköping University (Sweden).
2004–2011	**Senior Research Fellow** Department of Computer Science, University of Münster (Germany).
2008–2011	**Associated Researcher** European Institute of Molecular Imaging, Münster (Germany).
2009–2012	**External Lecturer** Wilhelm Büchner Hochschule, Darmstadt (Germany).
2001–2004	**Research and Teaching Assistant** University of Münster (Germany).

7. Supervision

2011–2014	Khoa Tan Nguyen (Main Supervisor, Thesis Defense: March 07, 2014).
2008–2011	Jörg-Stefan Praßni (Secondary Supervisor, Thesis Defense: 2012).
2006–2010	Jörg Mensmann (Secondary Supervisor, Thesis Defense: 2010).
2005–2009	Jennis Meyer-Spradow (Secondary Supervisor, Thesis Defense: 2009).

Awards, Honors & Acknowledgments

2013	Second Best Paper, Spring Conference on Computer Graphics 2013.
2011	Honorable Mention, Eurographics Price for Visual Computing in Medicine 2011.
2010	Winning Entry, IEEE Visualization Contest 2010.

2009	Honorable Mention for Best Paper, EGUK Theory and Practice of Computer Graphics 2009.
2008	Best Paper Award, Virtual Reality International Conference 2008.
2008	Honorable Mention for Best Poster, IEEE Virtual Reality Conference 2008.

Selected Commissions of Trust

since 04/2013	Chairman of the national Swedish Eurographics Chapter (SIGRAD).
since 05/2013	Area leader within the national Swedish Excellence Center for Information and Communication Technology (ELLIIT).
since 01/2012	Community Coordinator within the national Swedish e-Science Research Center (SeRC).
since 04/2010	Board member of the chapter Visual Computing in Biology and Medicine of the German Computer Society.
2013–2014	Member of the Scientific Council of the Center for Medical Image Science and Visualization (CMIV), Linköping University Hospital.
since 2008	Jury Member MedVis Award (Karl-Heinz-Höhne Award).

International Conference Keynotes

2014	Keynote at the Spanish Computer Graphics Conference 2014 (CEIG2014).
2012	Keynote at the Australasian Computer Science Week 2012 (ACSW2012).
2011	Keynote at Image and Vision Computing NZ 2011 (IVCNZ2011).

Selected External Grants as PI

2012–2014	Swedish Research Council (VR) (2,4 MSEK).
2010–2011	German Research Foundation (DFG), SFB 656-PM9 (28.000 €).
2009–2011	German Research Foundation (DFG), SFB 656-Z1 (494.800 €).
2005–2009	German Research Foundation (DFG), SFB 656-Z1 (268.100 €).
2005–2009	European Institute of Molecular Imaging (EIMI) (36.000 €).
2007–2009	Olympus Soft Imaging Solutions GmbH (27.000 €).
2010–2011	Federal Ministry of Education and Research (BMBF) (13.000 €).

Selected Recent Academic Community Participation

- **Co-Chair** EG Visual Computing in Biology and Medicine (2012, 2014).
- **Co-Chair** SIGRAD Conference on Visual Computing (2013).
- **Associated Guest Editor** Computer Graphics Forum 2013 (for invited Articles from EG Visual Computing in Biology and Medicine 2012).
- **Chair** German Computer Society Workshop Visual Computing in Medicine 2010.
- **International Program Committee Memberships** IEEE Scientific Visualization (2013–2014), IEEE Symposium on Biological Data Visualization (2012–2014), EG Price for Visual Computing in Medicine (2013), IEEE Pacific Visualization (2012–2014), EG/VGTC Conference on Visualization (2009–2011,2014), EG Workshop on Visual Computing for Biology and Medicine (2008, 2010), Eurographics Conference (2013–2014), Computer Graphics International (2013-2014), IEEE Pacific Visualization Notes (2014), Image and Vision Computing NZ (2011–2013), Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (2013–2014), SIGRAD Conference on Interactive Visual Analytics (2012, 2014), Spring Conference on Computer Graphics (2009–2014), GI Workshop Computer-Assisted Neurosurgery (2012).

Curriculum Vitae Patric Ljung

1. Higher education qualification: Master of Science in Information Technology, 2000. Linköping University, Sweden.

2. Degree of doctor: PhD in Scientific Visualization, 2006. Dissertation title ”Efficient Methods for Direct Volume Rendering of Large Data Sets“, supervisor Professor Anders Ynnerman. Department for Science and Technology, Linköping University, Sweden.

3. Postdoctoral positions: Not applicable.

4. Qualification required for appointment as a docent: Not applicable.

5. Specialist certification or relevant: Not applicable.

6. Present position: Senior Lecturer at Linköping University since Oct. 2013.

7. Previous positions:

- 2007–2013 Research Scientist/Project Manager, Siemens Corporation, Corporate Technology, Princeton NJ, USA
- 2001–2006 Lecturer, Lab Manager, Teaching, Linköping University
- 1989–1995 System Developer, Technical Software Development, Bull AB

8. Supervision: Managed 12 Software Engineers and 15 Interns during 2007-2013.

9. Deductible time. No time with relation to “young researcher” condition is deductible. Other breaks in research activities include 6 years at Siemens Corporation, Princeton NJ, USA.

10. Other information of interest as follows:

Research interest

The primary research focus is to develop visualization methods that enable large scale visualisation, interactive rendering technologies, immersive environments, software architectures for visualization.

Commissions of trust

2010 Co-chair for IEEE/Eurographics Symposium on Volume Graphics

2008, 2009 IPC member, IEEE Scientific Visualization conference

2010 IPC member, Visual Computing in Biology and Medicine (Eurographics Workshop)

2010 Member of Review Board for the National Library of Medicine (NIH/NLM), Bethesda MD, USA

Selected invited talks

2008-2012 “Rapid Application Development using the eXtensible Imaging Platform”, RSNA2008, RSNA2009, RSNA2010, RSNA2011, RSNA2012, Chicago IL, USA.

2008-2010 “Rapid Application Development using the eXtensible Imaging Platform”, SIIM2008 Seattle WA, SIIM2009 Charlotte NC, SIIM2010 Minneapolis MN.

2006 “Efficient Methods for Direct Volume Rendering of Large Data Sets”, University of Stuttgart, Germany

2006 “Efficient Methods for Direct Volume Rendering of Large Data Sets”, University of Tübingen, Germany

Industrial and academic profile

Patric Ljung currently holds a position at Linköping University, since October 2013, as Senior Lecturer in Immersive Visualization at the Department for Science and Technology. His research interest is large scale visualisation technologies, both in display formats as

Biographical Sketch: Charles Hansen
Scientific Computing and Imaging Institute
School of Computing
University of Utah

A. Education:

Memphis State University	B.S.	1981
University of Utah	Ph.D.	1987
INRIA, France	Postdoc	1987-1988

B. Research and Professional Experience:
Professor, School of Computing, University of Utah, 2005-present.
Associate Director, SCI Institute, University of Utah, 2005-present.
Visiting Professor, University Joseph Fourier, Grenoble, 2011-2012.
Visiting Scientist, ARTIS Group, INRIA Rhone-Alps, 2004-2005.
Associate Professor, School of Computing, University of Utah, 1998-2005.
Research Associate Professor, Department of Computer Science, University of Utah, 1997-1998.
Visualization Lead, Advanced Computing Laboratory, LANL, 1989-1997.
Postdoctoral Research Scientist, INRIA, 1987-1988.

C. Synergistic Activities:
- IEEE Large Data Visualization, Conference Co-Chair: 2014
- IEEE Visualization, Papers Co-Chair: 2007, 2008
- Eurographics Short Papers Co-Chair: 2006
- IEEE Transaction on Visualization and Computer Graphics, Ed. Board 2003-2006, 2012-present
- IEEE Transaction on Visualization and Computer Graphics, Assoc Editor-in-Chief 2003-2007
- IEEE/Eurographics Eurovis Program Committee: 2006, 2007, 2008
- Eurographics Workshop on Parallel Graphics and Visualization Program Committee: 2006, 2007, 2008
- **IEEE Visualization Best Paper award**: 1998, 2001, 2002
- **IEEE Technical Achievement Award** "For Seminal Work on Tools for Understanding Large-Scale Scientific Data Sets", October 2005
- **IEEE Pacific Vis Best Paper award**: 2010

D. Students:
Carson Brownlee (PhD 2013) Mathias Schott (PhD 2011), Siddarth Shankar (MS 2009), Jianrong Shu (MS 2009), Joshua Strattom (MS 2008) Guo-Shi Li (PhD 2008), Aaron Knoll (PhD 2008), Joe Kniss (PhD 2006), Milan Ikits (PhD 2006), Chris Wyman (Ph.D. 2004), Shaun Ramsey (Ph.D. 2004), Paul Hinker (PhD 1993), Greg Roth (MS 2007,) James Bigler (MS 2004), John McCorquodale (MS 2003), Charles Schmidt (May 2003), Eric Luke (MS 2002), Joe Kniss (MS 2002), Ashutosh Mehndiratta (MS 2002), Phil Sutton (MS 2000), Tushar Udeshi (MS 1999), Mark Schmelzenbach (ME 1999), Michelle Miller (ME 1998), Pat McCormick (MS 1996),

Collaborators:
Sean Ahern-ORNL, Jim Ahrens-LANL, Wes Bethel-LBNL, Georges-Pierre Bonneau-INRIA, Kadi Bouatouch-INRIA, Hank Childs – Uoregon, David Ebert-Purdue University, Thomas Ertl-University of Stuttgart, Christoph Garth-University of Kaiserslautern, Michael Gleicher-UWisc, Ganesh Gopalakrishnan-UCSD, Markus Hadwiger-KAUST, Hans Hagen-University of Kaiserslautern, Bernd Hamann-UC Davis, Thiago Ize – University of Utah, Chris Johnson-University of Utah, Kennth Joy-UC Davis, Aaron Knoll–TACC UTexas, Daniel Laney-LLNL,

Pat McCorrmick-LANL, Al McPherson-LANL, Michael Papka–ANL, Steve Parker-NVIDIA, Valerio Pascucci-Univerity of Utah, David Pugmire-ORNL, Claudio Silva-NYU-Poly, , Xavier Tricoche-Purdue University, Ingo Wald–INTEL, Daniel Weiskopf-University of Stuttgart, Eugene Zhang-Oregon State University well as content, i.e. large scale data. He is managing a group of 8 with a mix of lecturers, post-docs, PhD students and engineers.

At Siemens Corporate Research he has been involved in several Product and R&D projects, published about 10 peer-reviewed papers, several invention disclosures and patent applications. He has had the role as Technical Lead for smaller R&D projects and contributed to grant proposals with several grants/projects financed. In addition he has supervised international interns and visiting PhD students. He has furthermore presented one of Siemens' visualization and imaging software tools at RSNA and SIIM during several years and also participated with leading researchers in tutorials and classes at SIGGRAPH, SIGGRAPH|Asia, IEEE Visualization and Eurographics. In 2010 he co-chaired Eurographics/ IEEE Volume Graphics symposium and he has also served on the board of reviewers for NIH, NLM as well as made numerous reviews for IEEE TVCG, Eurographics journals, and many conference submissions.
A long-term duty has been managing and working with a team on real-time Ultrasound Imaging and Visualization for Siemens Ultrasound, under regulated software development processes and quality management systems for medical imaging products, and since 2010 introducing agile development processes (scrum). As part of this project he worked with several teams in USA, Europe and India. He also made several clinical site visits to better learn and understand end- user requirements and environments. In his role as Project Manager he worked with smaller teams, 4-10 people, and had direct contact with customers. These projects require to follow regulated software development processes and quality management systems, according to FDA and European regulations.

During his PhD studies he held lectureship position and he was a part of the faculty and a newly created research group lead by Professor Anders Ynnerman. The topic of his dissertation is Efficient Methods for Direct Volume Rendering of Large Data Sets and applied to medical imaging. The thesis include 9 publications out of over 20 peer-reviewed international publications produced during his time at Linköping University, contributing to establishing this new and growing research group as an internationally recognized top research group.
In addition to PhD studies he contributed to the teaching of classes and labs in Scientific Visualization and Virtual Reality. Some students claimed positions at Digital Domain, DreamWorks Studios, Sony Pictures Imageworks, to name some examples. He also acted as Technical Manager of the 3D Visualization and Interaction Studio known as NVIS during its build-up. NVIS almost daily held public and private presentations and was the predecessor to the Visualization Center C.

At Bull AB Patric Ljung developed software applications and software infrastructure for industrial technical solutions, telecommunications, and software tools with an emphasis on soft real-time systems, performance optimization, high-throughput data processing, network communication and high-level application protocols.
Other topics: Embedded systems, network device drivers, Compilers/Linkers, I/O & communication management/optimization, Web servers, CGI scrips, PLC interfaces, serial communications and protocols. Class library design and implementations for Event and Message based applications.
Platforms: Unix/AIX/D-nix, Microsoft Windows, MS-DOS, Mac OS, proprietary embedded OSs.

Publication list

Anders Ynnerman has published more than 150 papers. The five publications most important to this project are marked with a superscript star (*). Citation information has been collected from google scholar as of March 2015.

5 Most Cited Publications in Visualization

[1] Claes Lundström, Patric Ljung, and Anders Ynnerman. Uncertainty visualization in medical volume rendering using probabilistic animation. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1648–1655, November–December 2007. Number of citations: 79.

[2] Claes Lundström, Patric Ljung, and Anders Ynnerman. Local histograms for design of transfer functions in direct volume rendering. *IEEE Transactions on Visualization and Computer Graphics*, 12(6):1570–1579, November–December 2006. Number of citations: 80.

[3] P. Ljung, C. Winskog, A. Persson, C. Lundström, and A. Ynnerman. Full body virtual autopsies using a state-of-the-art volume rendering pipeline. *IEEE Transactions on Visualization and Computer Graphics*, 12(5):869–876, September–October 2006. Number of citations: 64.

[4] P. Ljung, C. Lundström, A. Ynnerman, and K. Museth. Transfer Function Based Adaptive Decompression for Volume Rendering of Large Medical Data Sets. In *IEEE Volume Visualization and Graphics Symposium 2004*, pages 25–32, October 2004. Number of citations: 57.

[5] K. Lundin, A. Ynnerman, and B. Gudmundsson. Proxy-based haptic feedback from volumetric density data. In *In Proceedings of Eurohaptics 2002*, pages 104–109, University of Edindburgh, United Kingdom, 2002. Number of citations: 70.

Refereed Journal Publications 2007–2014

[6] Stefan Lindholm, Daniel Jönsson, Charles Hansen, and Anders Ynnerman. Boundary aware reconstruction of scalar fields. *IEEE Transactions on Visualization and Computer Graphics*, 20(12):2447–2455, 2014. Number of Citations: 0.

[7] Julius Parulek, Daniel Jönsson, Timo Ropinski, Stefan Bruckner, Anders Ynnerman, and Ivan Viola. Continuous levels-of-detail and visual abstraction for seamless molecular visualization. *Computer graphics forum (Print)*, 33(6):276–287, 2014. Number of Citations: 0.

[8] Stefan Lindholm, Martin Falk, Erik Sundén, Alexander Bock, Anders Ynnerman, and Timo Ropinski. Hybrid data visualization based on depth complexity histogram analysis. *Computer graphics forum (Print)*, 2014. Number of Citations: 1.

[9] Joel Kronander, Stefan Gustavson, Gerhard Bonnet, Anders Ynnerman, and Jonas Unger. A unified framework for multi-sensor HDR video reconstruction. *Signal Processing : Image Communications*, 29(2):203–215, 2014. Number of Citations: 4.

[10] Tiago Etiene, Daniel Jönsson, Timo Ropinski, Carlos Scheidegger, Joao L. D. Comba, Luis Gustavo Nonato, Robert M. Kirby, Anders Ynnerman, and Claudio T. Silva. Verifying volume rendering using discretization error analysis. *IEEE Transactions on Visualization and Computer Graphics*, 20(1):140–154, 2014. Number of Citations: 5.

[11] Jonas Unger, Joel Kronander, Per Larsson, Stefan Gustavson, Joakim Löw, and Anders Ynnerman. Spatially varying image based lighting using HDR-video. *Computers & Graphics*, 2013. Number of Citations: 5.

[12] Katerina Vrotsou, Anders Ynnerman, and Matthew Cooper. Are we what we do? exploring group behaviour through user-defined event-sequence similarity. *Information Visualization*, 2013. Number of Citations: 1.

[13] Claes Lundström, Anders Persson, Steffen Ross, Patric Ljung, Stefan Lindholm, Frida Gyllensvärd, and Anders Ynnerman. State-of-the-art of visualization in post-mortem imaging. *Apmis*, 120(4):316–326, 2012. Number of Citations: 10.

[14] *, Daniel Jönsson, Joel Kronander, Timo Ropinski, and Anders Ynnerman. Historygrams : Enabling interactive global illumination in direct volume rendering using photon mapping. *IEEE Transactions on Visualization and Computer Graphics*, 18(12):2364–2371, 2012. Number of Citations: 8.

[15] *, Joel Kronander, Daniel Jönsson, Joakim Löw, Patric Ljung, Anders Ynnerman, and Jonas Unger. Efficient visibility encoding for dynamic illumination in direct volume rendering. *IEEE Transactions on Visualization and Computer Graphics*, 18(3):447–462, 2012. Number of Citations: 26.

[16] Joakim Löw, Joel Kronander, Anders Ynnerman, and Jonas Unger. BRDF models for accurate and efficient rendering of glossy surfaces. *ACM Transactions on Graphics*, 31(1), 2012. Number of Citations: 19.

[17] Mark Eric Dieckmann, Gianluca Sarri, Gareth Murphy, Antoine Bret, Lorenzo Romagnani, Ioannis Kourakis, Marco Borghesi, Anders Ynnerman, and Luke Drury. PIC simulation of a thermal anisotropy-driven weibel instability in a circular rarefaction wave. *New Journal of Physics*, 14(023007), 2012. Number of Citations: 2.

[18] Claes Lundström, Thomas Rydell, Camilla Forsell, Anders Persson, and Anders Ynnerman. Multi-touch table system for medical visualization: Application to orthopedic surgery planning. *IEEE Transactions on Visualization and Computer Graphics*, 17(12):1775–1784, 2011. Number of Citations: 19.

[19] Gianluca Sarri, Gareth Charles Murphy, Mark Eric Dieckmann, Antoine Bret, Kevin Quinn, Ioannis Kourakis, Marco Borghesi, Luke Drury, and Anders Ynnerman. Two-dimensional particle-in-cell simulation of the expansion of a plasma into a rarefied medium. *New Journal of Physics*, 13(7):073023–1–073023–23, 2011. Number of Citations: 11.

[20] Erik Sundén, Anders Ynnerman, and Timo Ropinski. Image plane sweep volume illumination. *IEEE Transactions on Visualization and Computer Graphics*, 17(12):2125–2134, 2011. Number of Citations: 10.

[21] Stefan Lindholm, Patric Ljung, Claes Lundström, Anders Persson, and Anders Ynnerman. Spatial conditioning of transfer functions using local material distributions. *IEEE Transactions on Visualization and Computer Graphics*, 2010. Number of Citations: 11.

[22] Joel Kronander, Jonas Unger, Torsten Moeller, and Anders Ynnerman. Estimation and modeling of actual numerical errors in volume rendering. *Computer Graphics Forum*, 29(3):893–902, 2010. Number of Citations: 6.

[23] *, Frida Hernell, Patric Ljung, and Anders Ynnerman. Local ambient occlusion in direct volume rendering. *IEEE Transactions on visualization and computer graphics*, 16(4):548–559, 2010. Number of Citations: 25.

[24] Stefan Lindholm, Patric Ljung, Markus Hadwiger, and Anders Ynnerman. Fused Multi-Volume DVR using Binary Space Partitioning. In Hans-Christian Hege, Ingrid Hotz, and Tamara Munzner, editors, *EuroVis09: Eurographics/ IEEE Symposium on Visualization*, pages 847–854, Berlin, Germany, 2009. Eurographics Association. Number of citations: 13.

[25] J. Unger, S. Gustavson, P. Larsson, and A. Ynnerman. Free form incident light fields. *Computer Graphics Forum*, 27(4), 2008. Number of citations: 16.

[26] K. Lundin, M. Cooper, and A. Ynnerman. Haptic rendering of dynamic volumetric data. *IEEE Transactions on Visualization and Computer Graphics*, 14(2):263–276, March–April 2008. Number of citations: 18.

[27] Claes Lundström, Patric Ljung, and Anders Ynnerman. Uncertainty visualization in medical volume rendering using probabilistic animation. *IEEE Transactions on Visualization and Computer Graphics*, 13(6):1648–1655, November–December 2007. Number of citations: 79.

[28] P. Ljung, C. Winskog, A. Persson, C. Lundström, and A. Ynnerman. Forensic virtual autopsies by direct volume rendering. *IEEE Signal Processing Magazine*, 24(6):112–116, November 2007. Number of citations: 3.

[29] K. Lundin, M. Cooper, A. Persson, D. Evestedt, and A. Ynnerman. Enabling design and interactive selection of haptic modes. *Virtual Reality Journal*, 2007. Number of citations: 26.

[30] J. Unger, S. Gustavson, and A. Ynnerman. Spatially varying image based lighting by light probe sequences. *The Visual Computer*, 23(7):453–465, 2007. Number of citations: 8.

REFEREED CONFERENCE PUBLICATIONS 2007–2014

[31] Stefan Lindholm, Daniel Forsberg, Anders Ynnerman, Hans Knutsson, Mats Andersson, and Claes Lundström. Towards clinical deployment of automated anatomical regions-of-interest. In *Eurographics Workshop on Visual Computing for Biology and Medicine :*, Eurographics Workshop on Visual Computing for Biology and Medicine, pages 137–143, 2014. Number of citations: 0.

[32] Khoa Tan Nguyen, Håkan Gauffin, Anders Ynnerman, and Timo Ropinski. Quantitative analysis of knee movement patterns through comparative visualization. In *ISVC 2013: 9th International Symposium on Visual Computing, July 29-31, Rethymnon, Crete, Greece*, 2014. Number of citations: 0.

[33] Khoa Tan Nguyen, Anders Ynnerman, and Timo Ropinski. Analyzing and reducing dti tracking uncertainty by combining deterministic and stochastic approaches. In *Advances in Visual Computing*, pages 266–279. Springer Berlin Heidelberg, 2013. Number of citations: 2.

[34] Joel Kronander, Stefan Gustavson, Gerhard Bonnet, Anders Ynnerman, and Jonas Unger. A unified framework for multi-sensor HDR video reconstruction. *Signal Processing: Image Communication*, 2013. Number of citations: 4.

[35] Stefan Lindholm, Daniel Jönsson, Hans Knutsson, and Anders Ynnerman. Towards data centric sampling for volume rendering. In *SIGRAD 2013 :*, 2013. Number of citations: 0.

[36] Khoa Nguyen, Alexander Bock, Anders Ynnerman, and Timo Ropinski. Deriving and visualizing uncertainty in kinetic pet modeling. In *Deriving and Visualizing Uncertainty in Kinetic PET Modeling: EG Visual Computing for Biology and Medicine*, 2012. Number of citations: 2.

[37] Claes Lundström, Anders Persson, Steffen Ross, Patric Ljung, Stefan Lindholm, Frida Gyllensvärd, and Anders Ynnerman. State-of-the-art of visualization in post-mortem imaging. *Acta Pathologica, Microbiologica et Immunologica Scandinavica (APMIS)*, 120(4):316–326, 2012. Number of citations: 10.

[38] Daniel Jönsson, Per Ganestam, Michael Doggett, Anders Ynnerman, and Timo Ropinski. Explicit cache management for volume ray-casting on parallel architectures. In *Eurographics Symposium on Parallel Graphics and Visualization (2012)*, Eurographics Symposium on Parallel Graphics and Visualization, pages 31–40, 2012. Number of citations: 1.

[39] Magnus Axholt, Martin A. Skoglund, Stephen D. O'Connell, Matthew D. Cooper, Stephen R. Ellis, and Anders Ynnerman. Accuracy of eyepoint estimation in optical see-through head-mounted displays using the single point active alignment method. In *IEEE Virtual Reality Conference 2012*, 2011. Number of citations: 1.

[40] Magnus Axholt, Martin Skoglund, Stephen O'Connell, Matthew Cooper, Stephen Ellis, and Anders Ynnerman. Parameter estimation variance of the single point active alignment method in optical see-through head mounted display calibration. In *Proceedings of the IEEE Virtual Reality Conference*, IEEE Virtual Reality Conference, pages 27–24. IEEE, 2011. Number of citations: 12.

[41] T. K. Nguyen, A. Eklund, H. Ohlsson, F. Hernell, P. Ljung, C. Forsell, M. Andersson, H. Knutsson, and A. Ynnerman. Concurrent volume visualization of real-time fMRI. In *IEEE/EG International Symposium on Volume Graphics*, pages 53–60, May 2010. Number of citations: 10.

[42] Magnus Axholt, Martin Skoglund, Stephen Peterson, Matthew Cooper, Thomas Schön, Fredrik Gustafsson, Anders Ynnerman, and Stephen Ellis. Optical see-through head mounted display: Direct linear transformation calibration robustness in the presence of user alignment noise. In *Proceedings of the Human Factors and Ergonomics Society 54rd Annual Meeting 2010*. Human Factors and Ergonomics Society, 2010. Number of citations: 6.

[43] M. Felsberg, F. Larsson, H. Wang, A. Ynnerman, and T. Schön. Torchlight navigation. In *International Conference on Pattern Recognition*, 2010. Number of citations: 3.

[44] Michael Felsberg, Fredrik Larsson, Wang Han, Anders Ynnerman, and Thomas Schön. Torch guided navigation. In *Proceedings of SSBA symposium 2010*, pages 8–9, 2010. Number of citations: 1.

[45] Staffan Klashed, Per Hemingsson, Carter Emmart, Matthew Cooper, and Anders Ynnerman. Uniview - Visualizing the Universe. In *Eurographics 2010 - Areas Papers*, EG 2010 - Short papers, Norrköping, Sweden, 2010. Eurographics Association. Number of citations: -.

[46] A. Eklund, M. Andersson, H. Ohlsson, A. Ynnerman, and H. Knutsson. A brain computer interface for communication using real-time fMRI. In *International Conference on Pattern Recognition*, 2010.

[47] A. Eklund, H. Ohlsson, M. Andersson, J. Rydell, A. Ynnerman, and H. Knutsson. Using real-time fMRI to control a dynamical system by brain activity classification. In *Proceedings of International Conference on Medical Image Computing and Computer-Assisted Intervention (MICCAI'09)*, London, UK, September 2009. Springer. Number of citations: 4.

[48] Joakim Löw, Anders Ynnerman, P. Larsson, and J. Unger. HDRlight probe sequence resampling for realtime incident light field rendering. In *Proceedings of the Spring Conference on Computer Graphics*, pages 23–25, April 2009. Number of citations: 4.

[49] Karljohan Lundin Palmerius, Matthew Cooper, and Anders Ynnerman. Flow field visualization using vector field perpendicular surfaces. In *Proceedings of the Spring Conference on Computer Graphics*, pages 35–42, April 2009. Number of citations: 11.

[50] Lena Tibell, Matthew Cooper, Anders Ynnerman, Gunnar Höst, and Petter B Persson. Improved feature detection over large force ranges using history dependent transfer functions. In *Third Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, WorldHaptics 2009*, volume 3, pages 476–481, Salt Lake City, Utah, USA, 2009. IEEE, USA. Number of citations: 2.

[51] A. Eklund, H. Ohlsson, M. Andersson, J. Rydell, A. Ynnerman, and H. Knutsson. Using real-time fMRI to control a dynamical system. In *Proceedings of the ISMRM Annual Meeting (ISMRM'09)*, Honolulu, Hawaii, April 2009. Number of citations: 4.

[52] H. Ohlsson, J. Rydell, A. Brun, A. Ynnerman J. Roll M. Andersson, and H. Knutsson. Enabling bio-feedback using real-time fMRI. In *Proceedings of IEEE Conference on Decision and Control*, 2008. Number of citations: 6.

[53] F. Hernell, P. Ljung, and A. Ynnerman. Interactive global light propagation in direct volume rendering using local piecewise integration. In *Proceedings of Volume Graphics*, 2008. Number of citations: 14.

[54] K. Vrotsou, A. Ynnerman, and M. Cooper. Seeing beyond statistics: Visual exploration of productivity on a construction site. In *Proceedings of International Conference Visualisation in Built and Rural Environments*, 2008. Number of citations: 4.

[55] M. Jern, J. Rogstadius, J. Åström, and A. Ynnerman. Visual analytics presentation tools applied in html documents. In *Proceedings of Information Visuualization 08*, 2008. Number of citations: 12.

[56] *, Frida Hernell, Patric Ljung, and Anders Ynnerman. Efficient ambient and emissive tissue illumination using local occlusion in multiresolution volume rendering. In *Proceedings of International Symposium on Volume Graphics*, 2007. Number of citations: 28.

[57] F. Hernell, A. Ynnerman, and Ö. Smedby. A blending technique for enhanced depth perception in medical x-ray vision applications. In *Proceedings of Medicine Meets Virtual Reality, 2007*, pages 1–8, 2007. Number of citations: -.

[58] Petter B Persson, Matthew Cooper, Lena Tibell, Shaaron Ainsworth, Anders Ynnerman, and Bengt-Harald Jonsson. Designing and evaluating a haptic system for biomolecular education. In *Proceedings of IEEE Virtual Reality Conference, 2007*, pages 171–178, Charlotte, North Carolina, USA, 2007. IEEE Computer Society Press, Piscataway, NJ, USA. Number of citations: 2.

RESEARCH REVIEW ARTICLES 2007–2014

[59] *, Daniel Jönsson, Erik Sundén, Anders Ynnerman, and Timo Ropinski. A survey of volumetric illumination techniques for interactive volume rendering. *Computer graphics forum (Print)*, 33(1):27–51, 2014. Number of Citations: 3.

[60] Daniel Jönsson, Erik Sundén, Anders Ynnerman, and Timo Ropinski. State of the art report on interactive volume rendering with volumetric illumination. In *Eurographics 2012 - State of the Art Reports*, Eurographics 2012 - State of the Art Reports, pages 53–74, 2012. Number of citations: 10.

PATENTS

[61] Patric Ljung and Anders Ynnerman. Computer processing of multi-dimensional data, May 10 2011. US Patent 7,940,270.

[62] Claes Lundström, Anders Ynnerman, and Patric Ljung. Method for reducing the amount of data to be processed in a visualization pipeline, May 3 2011. US Patent 7,936,930.

[63] P. Ljung, A. Ynnerman, C. Lundström, S. Bergström, and A. Ernvik. Image data set compression based on viewing parameters for storing medical image data from multidimensional data sets, related systems, methods and computer products. 11613447 (US application no), 2006.

[64] P. Ljung, A. Ynnerman, C. Lundström, S. Bergström, and A. Ernvik. Systems for visualizing images using explicit quality prioritization of a feature(s) in multidimensional data sets, related methods and computer products. 11614387 (US application no.), 2007.

REPORTS

[65] Anders Ynnerman, editor. *Swedish science cases for e-infrastructure*. Swedish Research Council, 2014. ISBN: 978-91-7307-240-3.

[66] Anders Ynnerman. The swedish HPC landscape 2006–2009. Technical report, Swedish National Infrastrucure for Computing, 2006.

[67] Anders Ynnerman, editor. *SNIC Progres Report 2003–2005*. Swedish Research Council, 2006.

THESIS WORK

[68] A. Ynnerman. Coupled-Cluster calculations of matrix elements and ionization energies. Master's thesis, University of Gothenburg, 1991.

[69] A. Ynnerman. *Atomic Coupled-Cluster Calculations*. PhD thesis, University of Gothenburg, 1992.

PUBLIC ENGAGEMENT IN SCIENCE RECENT HIGHLIGHTS

2010 –	Regular Kosmos 3D presentations in the Norrköping Dome - An interactive visualization of the universe
2007 –	Regular talks on medical visuallization in locations world-wide.
2010	TED talk on Medical Visualization (400 000 views)
2014	Invited talk at the British Museum on visualization of mummies.
2015	Keynote on visualisation at SAP innovation forum 2015

Selected publications since 2007 and 5 most cited.
Citation data obtained from Google Scholar.

1. Peer-Reviewed Original Articles

[1] Julius Parulek, Daniel Jönsson, Timo Ropinski, Stefan Bruckner, Anders Ynnerman, and Ivan Viola. Continuous Levels-of-Detail and Visual Abstraction for Seamless Molecular Visualization. *Computer Graphics Forum*, 2014. (conditionally accepted).

[2] Tiago Etiene, Daniel Jönsson, Timo Ropinski, Carlos Scheidegger, João Comba, L. Gustavo Nonato, Robert M. Kirby, Anders Ynnerman, and Cláudio T. Silvia. Verifying Volume Rendering Using Discretization Error Analysis. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 20(1):140–154, 2014. Number of Citations: 2.

[3] *Daniel Jönsson, Erik Sundén, Anders Ynnerman, and Timo Ropinski. A Survey of Volumetric Illumination Techniques for Interactive Volume Rendering. *Computer Graphics Forum*, 2013. (accepted for publication), Number of Citations: 1.

[4] Alexander Bock, Erik Sundén, Bingchen Liu, Burkhard Wuensche, and Timo Ropinski. Coherency-Based Curve Compression for High-Order Finite Element Model Visualization. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 18(12):2315–2324, 2012. (acceptance rate: 27.2%, impact factor: 2.215), Number of Citations: 3.

[5] *Daniel Jönsson, Joel Kronander, Timo Ropinski, and Anders Ynnerman. Historygrams: Enabling Interactive Global Illumination in Direct Volume Rendering using Photon Mapping. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 18(12):2364–2371, 2012. (acceptance rate: 27.2%, impact factor: 2.215), Number of Citations: 4.

[6] Timo Ropinski, Stefan Diepenbrock, Stefan Bruckner, Klaus Hinrichs, and Eduard Gröller. Unified Boundary-Aware Texturing for Interactive Volume Rendering. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 18(11):1942–1955, 2012. (impact factor: 2.215).

[7] *Erik Sundén, Anders Ynnerman, and Timo Ropinski. Image Plane Sweep Volume Illumination. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 17(12):2125–2134, 2011. (acceptance rate: 25.3%, impact factor: 2.215), Number of Citations: 9.

[8] Stefan Diepenbrock, Jörg-Stefan Praßni, Florian Lindemann, Hans-Werner Bothe, and Timo Ropinski. 2010 IEEE Visualization Contest Winner: Interactive Planning for Brain Tumor Resections. *IEEE Computer Graphics and Applications*, 31(5):6–13, 2011. (invited article, impact factor: 1.411), Number of Citations: 2.

[9] Timo Ropinski, Steffen Oeltze, and Bernhard Preim. Survey of Glyph-based Visualization Techniques for Spatial Multivariate Medical Data. *Computers & Graphics*, 35(2):392–401, 2011. (impact factor: 1.0), Number of Citations: 18.

[10] *Florian Lindemann and Timo Ropinski. About the Influence of Illumination Models on Image Comprehension in Direct Volume Rendering. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 17(12):1922–1931, 2011. (acceptance rate: 25.3%, impact factor: 2.215), Number of Citations: 20.

[11] Timo Ropinski, Christian Döring, and Christof Rezk-Salama. Advanced Volume Illumination with Unconstrained Light Source Positioning. *IEEE Computer Graphics and Applications*, 30(6):29–41, 2010. (invited article, impact factor: 1.724), Number of Citations: 6.

[12] Jörg-Stefan Praßni, Timo Ropinski, and Klaus Hinrichs. Uncertainty-Aware Guided Volume Segmentation. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 16(6):1358–1365, 2010. (acceptance rate: 26.5%, impact factor: 1.922), Number of Citations: 27.

[13] Timo Ropinski, Sven Hermann, Rainer Reich, Michael Schäfers, and Klaus Hinrichs. Multimodal Vessel Visualization of Mouse Aorta PET/CT Scans. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 15(6):1515–1522, 2009. (acceptance rate: 26.7%, impact factor: 2.35), Number of Citations: 20.

[14] Jennis Meyer-Spradow, Timo Ropinski, Jörg Mensmann, and Klaus Hinrichs. Voreen: A Rapid Prototyping Environment for Raycasting-Based Volume Visualizations. *IEEE Computer Graphics and Applications*, 29(6):6–13, 2009. (impact factor: 1.759), Number of Citations: 54.

[15] Jennis Meyer-Spradow, Lars Stegger, Christian Döring, Timo Ropinski, and Klaus Hinrichs. Glyph Based SPECT Visualization for the Diagnosis of Coronary Artery Disease. *IEEE Transactions on Visualization and Computer Graphics (TVCG)*, 14(6):1499–1506, 2008. (acceptance rate: 25.5%, impact factor: 2.445), Number of Citations: 12.

[16] Timo Ropinski, Jennis Meyer-Spradow, Stefan Diepenbrock, Jörg Mensmann, and Klaus Hinrichs. Interactive Volume Rendering with Dynamic Ambient Occlusion and Color Bleeding. *Computer Graphics Forum*, 27(2):567–576, 2008. (acceptance rate: 19.3%, impact factor: 1.86), Number of Citations: 47.

[17] Jörg Mensmann, Timo Ropinski, and Klaus Hinrichs. Interactive Cutting Operations for Generating Anatomical Illustrations from Volumetric Data Sets. *Journal of the WSCG – 16th International Conference in Central Europe on Computer Graphics, Visualization and Computer Vision*, 16:89–96, 2008. (acceptance rate: 12.6%), Number of Citations: 4.

2. Peer-reviewed Conference Contributions (Selection)

[18] Khoa Tan Nguyen, Anders Ynnerman, and Timo Ropinski. Quantitative Analysis of Knee Movement Patterns through Comparative Visualization. In *Visualization in Medicine and Life Sciences*, 2014. (conditionally accepted).

[19] Khoa Tan Nguyen and Timo Ropinski. Large-Scale Multiple Sequence Alignment Visualization through Gradient Vector Flow Analysis. In *IEEE Symposium on Biological Data Visualization*, pages 9–16, 2013.

[20] Khoa Tan Nguyen, Anders Ynnerman, and Timo Ropinski. Analyzing and Reducing DTI Tracking Uncertainty by Combining Deterministic and Stochastic Approaches. In *International Symposium on Visual Computing*, pages 131–139, 2013.

[21] Julius Parulek, Timo Ropinski, and Ivan Viola. Seamless Visual Abstraction of Molecular Surfaces. In *Spring Conference on Computer Graphics*, pages 120–127, 2013.

[22] Khoa Tan Nguyen and Timo Ropinski. Feature Tracking in Time-Varying Volumetric Data through Scale Invariant Feature Transform. In *SIGRAD*, 2013.

[23] Neda Rostamzadeh, Daniel Jönsson, and Timo Ropinski. Comparison of Volumetric Illumination Methods by Considering the Underlying Optical Models. In *SIGRAD*, 2013.

[24] *Alexander Bock, Norbert Lang, Gianpaolo Evangelista, Ralph Lehrke, and Timo Ropinski. Guiding Deep Brain Stimulation Interventions by Fusing Multimodal Uncertainty Regions. In *IEEE Pacific Visualization*, pages 97–104, 2013. (acceptance rate: 28.8%).

[25] Bingchen Liu, Alexander Bock, Timo Ropinski, Martyn Nash, Poul Nielsen, and Burkhard Wuensche. GPU-Accelerated Direct Volume Rendering of Finite Element Data Sets. In *Image and Vision Computing NZ*, pages 109–114, 2012. (acceptance rate: 18.8%), Number of Citations: 1.

[26] Stefan Diepenbrock and Timo Ropinski. From Imprecise User Input to Precise Vessel Segmentations. In *EG Visual Computing for Biology and Medicine*, pages 65–72, 2012. Number of Citations: 2.

[27] Khoa Tan Nguyen, Alexander Bock, Anders Ynnerman, and Timo Ropinski. Deriving and Visualizing Uncertainty in Kinetic PET Modeling. In *EG Visual Computing for Biology and Medicine*, pages 107–114, 2012.

[28] Daniel Jönsson, Per Ganestam, Anders Ynnerman, Michael Doggett, and Timo Ropinski. Explicit Cache Management for Volume Ray-Casting on Parallel Architectures. In *EG Symposium on Parallel Graphics and Visualization (EGPGV)*, pages 31–40, 2012. Number of Citations: 1.

[29] Daniel Jönsson, Erik Sundén, Anders Ynnerman, and Timo Ropinski. Interactive Volume Rendering with Volumetric Illumination. In *Eurographics STAR program*, 2012. Number of Citations: 7.

[30] Stefan Diepenbrock, Timo Ropinski, and Klaus Hinrichs. Context-Aware Volume Navigation. In *IEEE Pacific Visualization Symposium (PacificVis 2011)*, pages 11–18, 2011. Number of Citations: 5.

[31] Jörg Mensmann, Timo Ropinski, and Klaus Hinrichs. Slab-Based Raycasting: Exploiting GPU Computing for Volume Visualization. In *Springer Communications in Computer and Information Science (CCIS)*, volume 229, pages 246–259. Springer, 2011. Number of Citations: 1.

[32] Florian Lindemann and Timo Ropinski. Advanced Light Material Interaction for Direct Volume Rendering. In *IEEE/EG International Symposium on Volume Graphics*, pages 101–108, 2010. Number of Citations: 10.

[33] Christian Meß and Timo Ropinski. Efficient Acquisition and Clustering of Local Histograms for Representing Voxel Neighborhoods. In *IEEE/EG International Symposium on Volume Graphics*, pages 117–124, 2010. Number of Citations: 6.

[34] Jörg Mensmann, Timo Ropinski, and Klaus Hinrichs. A GPU-Supported Lossless Compression Scheme for Rendering Time-Varying Volume Data. In *IEEE/EG International Symposium on Volume Graphics*, pages 109–116, 2010. Number of Citations: 12.

[35] Jörg Mensmann, Timo Ropinski, and Klaus Hinrichs. An Advanced Volume Raycasting Technique using GPU Stream Processing. In *Proceedings of the 5th International Conference on Computer Graphics Theory and Applications (GRAPP10)*, pages 190–198, 2010. Number of Citations: 16.

[36] Timo Ropinski, Christian Döring, and Christof Rezk-Salama. Interactive Volumetric Lighting Simulating Scattering and Shadowing. In *IEEE Pacific Visualization (PacificVis 2010)*, pages 14–22, 2010. (acceptance rate: 32.0%), Number of Citations: 26.

[37] Jörg-Stefan Praßni, Timo Ropinski, Jörg Mensmann, and Klaus Hinrichs. Shape-based Transfer Functions for Volume Visualization. In *IEEE Pacific Visualization (PacificVis 2010)*, pages 55–63, 2010. (acceptance rate: 32.0%), Number of Citations: 26.

[38] Jörg-Stefan Praßni, Timo Ropinski, and Klaus Hinrichs. Efficient Boundary Detection and Transfer Function Generation in Direct Volume Rendering. In *Proceedings of Vision, Modeling, and Visualization (VMV09)*, pages 285–294, 2009. Number of Citations: 9.

[39] Timo Ropinski, Ivan Viola, Martin Biermann, Helwig Hauser, and Klaus Hinrichs. Multimodal Visualization with Interactive Closeups. In *EGUK Theory and Practice of Computer Graphics (TPCG09)*, pages 17–24, 2009. (Honorable Mention for Best Paper), Number of Citations: 7.

[40] Timo Ropinski, Jörg-Stefan Praßni, Frank Steinicke, and Klaus Hinrichs. Stroke-Based Transfer Function Design. In *IEEE/EG International Symposium on Volume and Point-Based Graphics*, pages 41–48, 2008. Number of Citations: 30.

[41] Jörg Mensmann, Timo Ropinski, and Klaus Hinrichs. Accelerating Volume Raycasting using Occlusion Frustums. In *IEEE/EG International Symposium on Volume and Point-Based Graphics*, pages 147–154, 2008. Number of Citations: 8.

[42] Frank Steinicke, Gerd Bruder, Timo Ropinski, and Klaus Hinrichs. Moving Towards Generally Applicable Redirected Walking. In *Proceedings of the 10th Virtual Reality International Conference (VRIC08)*, pages 15–24, 2008. (Best Paper Award), Number of Citations: 23.

[43] Timo Ropinski and Bernhard Preim. Taxonomy and Usage Guidelines for Glyph-based Medical Visualization. In *Proceedings of the 19th Conference on Simulation and Visualization (SIMVIS08)*, pages 121–138, 2008. Number of Citations: 25.

[44] Timo Ropinski, Jens Kasten, and Klaus Hinrichs. Efficient Shadows for GPU-based Volume Raycasting. In *Proceedings of the 16th International Conference in Central Europe on Computer Graphics, Visualization (WSCG08)*, pages 17–24, 2008. (acceptance rate: 29.6%), Number of Citations: 22.

[45] Frank Steinicke, Timo Ropinski, Gerd Bruder, and Klaus Hinrichs. Interscopic User Interface Concepts for Fish Tank Virtual Reality Systems. In *Proceedings of the IEEE Virtual Reality Conference (VR07)*, pages 27–34, 2007. (acceptance rate: 20.0%), Number of Citations: 25.

[46] Timo Ropinski, Jennis Meyer-Spradow, Michael Specht, Klaus Hinrichs, and Bernhard Preim. Surface Glyphs for Visualizing Multimodal Volume Data. In *Proceedings of Vision, Modeling, and Visualization (VMV07)*, pages 3–12, 2007. Number of Citations: 17.

[47] Timo Ropinski, Jörg-Stefan Praßni, Jan Roters, and Klaus Hinrichs. Internal Labels as Shape Cues for Medical Illustration. In *Proceedings of Vision, Modeling, and Visualization (VMV07)*, pages 203–212, 2007. Number of Citations: 17.

[48] Frank Steinicke, Gerd Bruder, Klaus Hinrichs, and Timo Ropinski. Simultane 2D/3D User Interface Konzepte für Autostereoskopische Desktop-VR Systeme. In *4. Workshop AR/VR*, pages 125–132. GI-Fachgruppe VR/AR, 2007. Number of Citations: 2.

[49] Frank Steinicke, Timo Ropinski, Gerd Bruder, and Klaus Hinrichs. Towards Applicable 3D User Interfaces for Everyday Working Environments. In *International Conference on Human-Computer Interaction (INTERACT07)*, pages 546–559. Springer LNCS 4662, 2007. (acceptance rate: 33.0%), Number of Citations: 2.

[50] Frank Steinicke, Timo Ropinski, Gerd Bruder, and Klaus Hinrichs. 3D Modeling and Design Supported via Interscopic Interaction Strategies. In *Proceedings of the HCI International (HCI07)*, pages 1160–1169, 2007. Number of Citations: 1.

3. Review Articles

[51] Timo Ropinski, Steffen Oeltze, and Bernhard Preim. Survey of Glyph-based Visualization Techniques for Spatial Multivariate Medical Data. *Computers & Graphics*, 35(2):392–401, 2011. (impact factor: 1.0), Number of Citations: 18.

[52] Frank Steinicke, Gerd Bruder, Klaus Hinrichs, Timo Ropinski, and Marco Lopes. 3D User Interfaces for Collaborative Work. In Ioannis Pavlidis, editor, *Human Computer Interaction*, pages 279–294. InTech, 2008.

[53] Timo Ropinski, Jennis Meyer-Spradow, Frank Steinicke, and Klaus Hinrichs. Supporting Spatial Cognition in Vascular Visualization. In Feng Dong, George Ghinea, and Sherry Y. Chen, editors, *User Centered Design for Medical Visualization*, pages 114–135. Idea Group, 2008.

[54] Jennis Meyer-Spradow, Timo Ropinski, and Klaus Hinrichs. Supporting Depth and Motion Perception in Medical Volume Data. In Lars Linsen, Hans Hagen, and Bernd Hamann, editors, *Visualization in Medicine and Life Sciences (Mathematics+Visualization)*, pages 121–133. Springer, 2007.

4. Books and Book Chapters

[55] Timo Ropinski and Jonas Unger, editors. *Proceedings of the SIGRAD Conference on Visual Computing*. SIGRAD, 2013.

[56] Timo Ropinski. Advanced Direct Volume Visualization in Medical Applications. In Bernhard Preim and Charl Botha, editors, *Visualization in Medicine: Theory, Algorithms, and Applications*. Morgan Kaufmann, 2nd edition, 2013. to appear.

[57] Timo Ropinski, Anders Ynnerman, Charl Botha, and Jos Roerdink, editors. *Proceedings of Eurographics Visual Computing for Biology and Medicine*. Eurographics Association, 2012.

[58] Frank Steinicke, Gerd Bruder, Klaus Hinrichs, Timo Ropinski, and Marco Lopes. 3D User Interfaces for Collaborative Work. In Ioannis Pavlidis, editor, *Human Computer Interaction*, pages 279–294. InTech, 2008.

[59] Timo Ropinski, Jennis Meyer-Spradow, Frank Steinicke, and Klaus Hinrichs. Supporting Spatial Cognition in Vascular Visualization. In Feng Dong, George Ghinea, and Sherry Y. Chen, editors, *User Centered Design for Medical Visualization*, pages 114–135. Idea Group, 2008.

[60] Jennis Meyer-Spradow, Timo Ropinski, and Klaus Hinrichs. Supporting Depth and Motion Perception in Medical Volume Data. In Lars Linsen, Hans Hagen, and Bernd Hamann, editors, *Visualization in Medicine and Life Sciences (Mathematics+Visualization)*, pages 121–133. Springer, 2007.

4. PATENTS

[61] Timo Ropinski, Frank Steinicke, and Klaus Hinrichs. Method and Arrangement for Monoscopically Representing at least one Area of an Image on an Autostereoscopic Display Apparatus and Information Reproduction Unit Having such an Arrangement, 2006. (International Patent Application No. PCT/DE2006/001994, 14.11.2006).

5. OPEN ACCESS COMPUTER PROGRAMS

[62] Timo Ropinski et al. Inviwo - Interactive Visualization Workshop. (http://www.inviwo.org, since 2012). A visual computing research platform, which supports the rapid development of data processing and visualization algorithms.

[63] Timo Ropinski et al. Voreen - Volume Rendering Engine. (http://www.voreen.org, since 2004). An open source visualization framework written in C++ which supports GPU-based ray-casting, and is used within research projects at different institutions around the world.

[64] Timo Ropinski et al. tgt - Tiny Graphics Toolbox. (http://viscg.uni-muenster.de/73-Tiny-Graphics-Toolbox.html, since 2005). A modular computer graphics library based on OpenGL, which provides a large collection of 3D rendering components. It has been developed to support teaching in computer graphics and visualization.

6. POPULAR SCIENCE ARTICLES/PRESENTATIONS

[65] Timo Ropinski. Exploiting Visual Pattern Recognition in Biological Visualization. SciLife Lab, Karolinska Institute, 2014.

[66] Timo Ropinski. Visual Computing Techniques for Spatial Data. Swedish e-Science Education (SeSE), University of Uppsala, 2013.

[67] Timo Ropinski. Incorporating Uncertainty in the Visual Analysis Process. Nordic Symposium on Digital Pathology, 2013.

[68] Timo Ropinski. Certainly Uncertain - Medical Data from Multiple Sources. Visualization in Medicine and Life Sciences, 2013.

[69] Timo Ropinski. State of the Art in Biomedical Visualization. Center for Biomedical Engineering, University of Bern, 2013.

[70] Timo Ropinski. Visual Analysis of Large Data Sets. National Supercomputing Center Sweden, 2013.

[71] Timo Ropinski. Visual Computing as Interplay between Human and Computer. Karolinska Hospital, 2013.

[72] Timo Ropinski. Recent Advances in Volume Visualization. University of Würzburg, 2012.

[73] Timo Ropinski. Visual Data Analysis and Problem Solving as an Interplay Between Man and Machine. FindOut Technologies AB, 2012.

[74] Timo Ropinski. Supporting Image Analysis through Visualization. SciLife Lab Uppsala, 2012.

[75] Timo Ropinski. Visualization in Data Intensive Domains. The Swedish e-Science Workshop, 2012.

[76] Timo Ropinski. Interactive Visual Problem Solving. Siemens Corporate Research (SCR) Princeton, 2011.

[77] Timo Ropinski. Bringing the Human in the Loop with Visualization. Halmstad University, 2011.

[78] Timo Ropinski. Problem Solving Through Visual Computing. KTH Royal Institute of Technology, 2011.

[79] Stefan Diepenbrock, Jörg-Stefan Praßni, Florian Lindemann, Hans-Werner Bothe, and Timo Ropinski. 2010 IEEE Visualization Contest Winner: Interactive Planning for Brain Tumor Resections. *IEEE Computer Graphics and Applications*, 31(5):6–13, 2011. (invited article, impact factor: 1.411), Number of Citations: 2.

[80] Timo Ropinski. Basic Visualization of Multimodal Medical Data. Molecular Imaging Summer School, Rügen, 2011.

[81] Stefan Diepenbrock, Jörg-Stefan Praßni, Florian Lindemann, Hans-Werner Bothe, and Timo Ropinski. Interactive visualization techniques for neurosurgery planning. In *Short and Areas Papers and Medical Prize Awards*, 2011. article, accepted, honorable mention for Eurographics Medical Price.

[82] Berk Geveci (Organizer), Utkarsh Ayachit, Jeffrey Baumes, Michael Bostock, Vadim Ogievetsky, Brian Wylie, Timothy M. Shead, Emanuele Santos, Timo Ropinski, and Jörg-Stefan Praßni. DIY Vis Applications. In *IEEE Visualization Tutorials Program*, 2010.

[83] Stefan Diepenbrock, Jörg-Stefan Praßni, Florian Lindemann, Hans-Werner Bothe, and Timo Ropinski. Pre-Operative Planning of Brain Tumor Resections. IEEE Visualization Contest 2010, 2010. article, winning entry.

[84] Christof Rezk-Salama (Organizer), Markus Hadwiger, Timo Ropinski, and Patric Ljung. Advanced Illumination Techniques for GPU Volume Raycasting. In *ACM SIGGRAPH Courses Program*, 2009. Number of Citations: 62.

[85] Markus Hadwiger, Patric Ljung, Christof Rezk-Salama, and Timo Ropinski (Organizer). Advanced Illumination Techniques for GPU-Based Volume Ray-Casting. In *EG Eurographics Tutorials Program*, 2009. Number of Citations: 3.

[86] Christof Rezk-Salama (Organizer), Markus Hadwiger, Timo Ropinski, and Patric Ljung. Advanced Illumination Techniques for GPU-Based Volume Ray-Casting. In *ACM SIGGRAPH Asia Courses Program*, 2008. Number of Citations: 3.

[87] Timo Ropinski (Organizer), Christof Rezk-Salama, Markus Hadwiger, and Patric Ljung. GPU-Based Volume Ray-Casting with Advanced Illumination. In *IEEE Visualization Tutorials Program*, 2008. Number of Citations: 4.

Research publications Patric Ljung, 2006-2014

Database used for citations: Google Scholar
Dr. Ljung has in total 50 publications, including 7 granted patents.
Dr. Ljung has been working in the industry 2007-2013 at Siemens Corporation.

1. Five most cited publications

Revealing structure within clustered parallel coordinates displays
J Johansson, P Ljung, M Jern, M Cooper
Information Visualization 2005, IEEE Symposium on, 2005, 125-132
Number of citations: 130

Local histograms for design of transfer functions in direct volume rendering
C Lundstrom, P Ljung, A Ynnerman
Visualization and Computer Graphics, IEEE Transactions on 12 (6), 2006, 1570-1579
Number of citations: 80

Uncertainty visualization in medical volume rendering using probabilistic animation
C Lundstrom, P Ljung, A Persson, A Ynnerman
Visualization and Computer Graphics, IEEE Transactions on 13 (6), 2007, 1648-1655
Number of Citations: 79

Full body virtual autopsies using a state-of-the-art volume rendering pipeline
P Ljung, C Winskog, A Persson, C Lundstrom, A Ynnerman
Visualization and Computer Graphics, IEEE Transactions on 12 (5), 2006, 869-876
Number of citations: 64

Transfer function based adaptive decompression for volume rendering of large medical data sets
P Ljung, C Lundstrom, A Ynnerman, K Museth
Volume Visualization and Graphics, 2004 IEEE Symposium on, 2004, 25-32
Number of citations: 57

2. Peer-reviewed original articles

***Efficient visibility encoding for dynamic illumination in direct volume rendering**
J Kronander, D Jonsson, J Low, P Ljung, A Ynnerman, J Unger
Visualization and Computer Graphics, IEEE Transactions on 18 (3), 447-462, 2012
Number of citations: 26

***Local ambient occlusion in direct volume rendering**
F Hernell, P Ljung, A Ynnerman
Visualization and Computer Graphics, IEEE Transactions on 16 (4), 548-559, 2010
Number of citations: 25

Spatial Conditioning of Transfer Functions using Local Material Distributions
Stefan Lindholm, Patric Ljung, Claes Lundström, Anders Persson and Anders Ynnerman.

IEEE Transactions on Visualization and Computer Graphics (Proceedings Visualization 2010), Vol. 16, No. 6, Nov.-Dec. 2010, Salt Lake City, USA.
Number of citations: 11

Advancing the State of the Art for Virtual Autopsies - Initial Forensic Workflow Study
Isabella Scandurra, Camilla Forsell, Anders Ynnerman, Patric Ljung, Claes Lundström and Anders Persson.
Studies on health technology and informatics, Vol. 160, 2010.
Number of citations: 1

Fused Multi−Volume DVR using Binary Space Partitioning
S Lindholm, P Ljung, M Hadwiger, A Ynnerman
Computer Graphics Forum 28 (3), 847-854, 2009
Number of citations: 13

Scene graph-based construction of CUDA kernel pipelines for XIP
V Gidén, T Moeller, P Ljung, G Paladini
MICCAI 2008 Workshop on High-Performance Computing
Number of citations: 4

Uncertainty Visualization in Medical Volume Rendering Using Probabilistic Animation
Claes Lundström, Patric Ljung, Anders Persson and Anders Ynnerman.
IEEE Transactions on Visualization and Computer Graphics (Proceedings Visualization 2007), Vol. 13, No. 6, Nov.-Dec. 2007, Sacramento, USA. (Best Paper nominee, as one of five papers out of 216 submitted.)
Number of citations: 79

3. Peer-reviewed conference contributions

Evaluation of effects of JPEG2000 compression on a computer-aided detection system for prostate cancer on digitized histopathology
Scott Doyle, James Monaco, Anant Madabhushi, Stefan Lindholm, Patric Ljung, Lance Ladic, John Tomaszewski, Michael Feldman.
Biomedical Imaging: From Nano to Macro, 2010 IEEE International Symposium on
Number of citations: 4

Real-time surface analysis and tagged material cleansing for virtual colonoscopy
C Russ, C Kubisch, F Qiu, W Hong, P Ljung
Proceedings of the 8th IEEE/EG international conference on Volume Graphics 2010
Number of citations: 1

Concurrent volume visualization of real-time fMRI
Tan Khoa Nguyen, Anders Eklund, Henrik Ohlsson, Frida Hernell, Patric Ljung, Camilla Forsell, Mats Andersson, Hans Knutsson, Anders Ynnerman
Proceedings of the 8th IEEE/EG international conference on Volume Graphics, 2010
Number of citations: 10

Nature of streamlines for Berry−type wave functions in open 3D cavities
KF Berggren, P Ljung
MATHEMATICAL MODELING OF WAVE PHENOMENA: 3rd Conference on Mathematical Modeling of Wave Phenomena, 20th Nordic Conference on Radio Science and Communications, 2009.
Number of citations: 4

***Interactive global light propagation in direct volume rendering using local piecewise integration**
Frida Hernell, Patric Ljung, Anders Ynnerman
Proceedings of the Fifth Eurographics/IEEE VGTC conference on Point-Based Graphics and Volume Rendering, 2008
Number of citations: 14

***Efficient ambient and emissive tissue illumination using local occlusion in multiresolution volume rendering**
Frida Hernell, Patric Ljung, Anders Ynnerman
Proceedings of the Sixth Eurographics/IEEE VGTC conference on Volume Rendering, 2007
Number of citations: 28

Depth Cues and Density in Temporal Parallel Coordinates.
J Johansson, P Ljung, MD Cooper
Proceedings Eurographpics/IEEE-VGTC Symposium on Visualization, 35-42, 2007
Number of citations: 21

4. Review papers

State-of-the-art of visualization in post-mortem imaging
Claes Lundström, Anders Persson, Steffen Ross, Patric Ljung, Stefan Lindholm, Frida Gyllensvärd, Anders Ynnerman
Acta Pathologica, Microbiologica et Immunologica Scandinavica, Volume 120, pages 316–326, 2012
Number of citations: 10

***Forensic Virtual Autopsies by Direct Volume Rendering**
Patric Ljung, Calle Winskog, Anders Persson, Claes Lundström, and Anders Ynnerman.
IEEE Signal Processing Magazine, Vol. 24, No. 6, Nov. 2007. (Invited paper)
Number of citations: 3

5. Books and book chapters

No recent

6. Patents

US Patent 7,830,381: **Systems for visualizing images using explicit quality prioritization of a feature (s) in multidimensional image data sets, related methods and computer products.**
P Ljung, C Lundström, A Ynnerman. 2010. Number of citations: 20

US Patent 7,936,930: **Method for reducing the amount of data to be processed in a visualization pipeline.** P Ljung, C Lundström, A Ynnerman. 2011. Number of citations: 1

US Patent 8,295,620: **Image data set compression based on viewing parameters for storing medical image data from multidimensional data sets, related systems, methods and computer products.** A Ernvik, S Bergström, C Lundström, P Ljung, A Ynnerman. 2012. Number of citations: 2

US Patent 7,940,270: **Computer processing of multi-dimensional data.** P Ljung, A Ynnerman. 2011. Number of citations: 1

US Patent 8,494,250: **Animation for conveying spatial relationships in three-dimensional medical imaging.** BA Mcdermott, MM Smith-Casem, P Ljung, S Wiesner. 2013. Number of citations: 0

US Patent 8,425,422: **Adaptive volume rendering for ultrasound color flow diagnostic imaging.** S Srinivasan, P Ljung, BA McDermott, MM Smith-Casem. 2013. Number of citations: 1

US Patent 8,922,554**: Three-Dimensional Reconstruction for Irregular Ultrasound Sampling Grids.** M Smith-Casem, P Ljung, G Stordeur, JH Mo, B McDermott. 2011. Number of citations: 1

7. Self-developed open access computer software

None.

8. Popular science articles/presentations

None.

9. Other publications

Advanced illumination techniques for GPU volume raycasting
M Hadwiger, P Ljung, CR Salama, T Ropinski
ACM SIGGRAPH ASIA 2008 courses, 1
Number of citations: 76

GPU-based volume ray-casting with advanced illumination
M Hadwiger, P Ljung, CR Salama, T Ropinski
Eurographics 2009-Tutorials, 39-211
Number of citations: 4

Charlse Hansen has published more than 400 papers. The five publications most important to this project are marked with a superscript star (*). Citation information has been collected from google scholar as of March 2015.

5 Most Cited Publications

[1] Joe Kniss, Gordon Kindlmann, and Charles Hansen. Multidimensional transfer functions for interactive volume rendering. *Visualization and Computer Graphics, IEEE Transactions on*, 8(3):270–285, 2002. Number of citations: 536.

[2] *, Steven Parker, Michael Parker, Yarden Livnat, Peter-Pike Sloan, Charles Hansen, and Peter Shirley. Interactive ray tracing for volume visualization. In *ACM SIGGRAPH 2005 Courses*, page 15. ACM, 2005. Number of citations: 480.

[3] Joe Kniss, Gordon Kindlmann, and Charles Hansen. Interactive volume rendering using multi-dimensional transfer functions and direct manipulation widgets. In *Proceedings of the conference on Visualization'01*, pages 255–262. IEEE Computer Society, 2001. Number of citations: 445.

[4] Charles D Hansen and Chris R Johnson. *The visualization handbook*. Academic Press, 2005. Number of citations: 372.

[5] Kwan-Liu Ma, James S Painter, Charles D Hansen, and Michael F Krogh. Parallel volume rendering using binary-swap compositing. *Computer Graphics and Applications, IEEE*, 14(4):59–68, 1994. Number of Citations: 333.

Refereed Journal Publications 2007–2014

[6] Aaron M Knoll, Ingo Wald, and Charles D Hansen. Coherent multiresolution isosurface ray tracing. *The Visual Computer*, 25(3):209–225, 2009. Number of Citations: 42.

[7] Aaron Knoll, Younis Hijazi, Andrew Kensler, Mathias Schott, Charles Hansen, and Hans Hagen. Fast ray tracing of arbitrary implicit surfaces with interval and affine arithmetic. *Computer Graphics Forum*, 28(1):26–40, 2009. Number of Citations: 35.

[8] *, Mathias Schott, Vincent Pegoraro, Charles Hansen, Kévin Boulanger, and Kadi Bouatouch. A directional occlusion shading model for interactive direct volume rendering. *Computer Graphics Forum*, 28(3):855–862, 2009. Number of Citations: 44.

[9] Aaron Knoll, Younis Hijazi, Rolf Westerteiger, Mathias Schott, Charles Hansen, and Hans Hagen. Volume ray casting with peak finding and differential sampling. *Visualization and Computer Graphics, IEEE Transactions on*, 15(6):1571–1578, 2009. Number of Citations: 35.

[10] Michael Gleicher, Danielle Albers, Rick Walker, Ilir Jusufi, Charles D Hansen, and Jonathan C Roberts. Visual comparison for information visualization. *Information Visualization*, 10(4):289–309, 2011. Number of Citations: 70.

[11] Yong Wan, Hideo Otsuna, Chi-Bin Chien, and Charles Hansen. An interactive visualization tool for multi-channel confocal microscopy data in neurobiology research. *Visualization and Computer Graphics, IEEE Transactions on*, 15(6):1489–1496, 2009. Number of Citations: 38.

[12] G-S Li, Xavier Tricoche, Daniel Weiskopf, and Charles Hansen. Flow charts: Visualization of vector fields on arbitrary surfaces. *Visualization and Computer Graphics, IEEE Transactions on*, 14(5):1067–1080, 2008. Number of Citations: 18.

[13] Guo-Shi Li, Xavier Tricoche, and Charles Hansen. Physically-based dye advection for flow visualization. *Computer Graphics Forum*, 27(3):727–734, 2008. Number of Citations: 13.

[14] Ingo Wald, Heiko Friedrich, Aaron Knoll, and Charles D Hansen. Interactive isosurface ray tracing of time-varying tetrahedral volumes. *Visualization and Computer Graphics, IEEE Transactions on*, 13(6):1727–1734, 2007. Number of Citations: 16.

[15] Thiago Ize and Charles Hansen. Rtsah traversal order for occlusion rays. *Computer Graphics Forum*, 30(2):297–305, 2011. Number of Citations: 13.

[16] Mathias Schott, AV Pascal Grosset, Tobias Martin, Vincent Pegoraro, Sean T Smith, and Charles D Hansen. Depth of field effects for interactive direct volume rendering. *Computer Graphics Forum*, 30(3):941–950, 2011. Number of Citations: 6.

[17] David Chisnall, Min Chen, and Charles Hansen. Ray-driven dynamic working set rendering. *The Visual Computer*, 23(3):167–179, 2007. Number of Citations: 3.

[18] Thiago Ize, Carson Brownlee, and Charles D Hansen. Real-time ray tracer for visualizing massive models on a cluster. In *EGPGV*, pages 61–69, 2011. Number of Citations: 10.

[19] Attila Gyulassy, Natallia Kotava, Mark Kim, Charles D Hansen, Hans Hagen, and Valerio Pascucci. Direct feature visualization using morse-smale complexes. *Visualization and Computer Graphics, IEEE Transactions on*, 18(9):1549–1562, 2012. Number of Citations: 6.

[20] Carson Brownlee, Vincent Pegoraro, Siddharth Shankar, Patrick S McCormick, and Charles D Hansen. Physically-based interactive flow visualization based on schlieren and interferometry experimental techniques. *Visualization and Computer Graphics, IEEE Transactions on*, 17(11):1574–1586, 2011. Number of Citations: 4.

[21] Liang Zhou, Mathias Schott, and Charles Hansen. Transfer function combinations. *Computers & Graphics*, 36(6):596–606, 2012. Number of Citations: 1.

[22] Yong Wan, A Kelsey Lewis, Mary Colasanto, Mark van Langeveld, Gabrielle Kardon, and Charles Hansen. A practical workflow for making anatomical atlases for biological research. *Computer Graphics and Applications, IEEE*, 32(5):70–80, 2012. Number of Citations: -.

[23] Tobias Martin, Guoning Chen, Suraj Musuvathy, Elaine Cohen, and Charles Hansen. Generalized swept mid-structure for polygonal models. *Computer Graphics Forum*, 31(2pt4):805–814, 2012. Number of Citations: 11.

[24] Jonathan Brouillat, Christian Bouville, Brad Loos, Charles Hansen, and Kadi Bouatouch. A bayesian monte carlo approach to global illumination. *Computer Graphics Forum*, 28(8):2315–2329, 2009. Number of Citations: 6.

[25] *, Mathias Schott, Tobias Martin, AV Pascal Grosset, Sean T Smith, and Charles D Hansen. Ambient occlusion effects for combined volumes and tubular geometry. *Visualization and Computer Graphics, IEEE Transactions on*, 19(6):913–926, 2013. Number of Citations: 1.

[26] Tony McLoughlin, Mark W Jones, Robert S Laramee, Rami Malki, Ian Masters, and Charles D Hansen. Similarity measures for enhancing interactive streamline seeding. *Visualization and Computer Graphics, IEEE Transactions on*, 19(8):1342–1353, 2013. Number of Citations: 18.

[27] Yong Wan, Hideo Otsuna, and Charles Hansen. Synthetic brainbows. *Computer Graphics Forum*, 32(3pt4):471–480, 2013. Number of Citations: 1.

[28] L Zhou and C Hansen. Guideme: Slice-guided semiautomatic multivariate exploration of volumes. *Computer Graphics Forum*, 33(3):151–160, 2014. Number of Citations: 1.

[29] Stefan Lindholm, Daniel Jonsson, Charles Hansen, and Anders Ynnerman. Boundary aware reconstruction of scalar fields. *Visualization and Computer Graphics, IEEE Transactions on*, 2014. Number of Citations: -.

REFEREED CONFERENCE PUBLICATIONS 2007–2014

[30] Aaron Knoll, Younis Hijazi, Charles Hansen, Ingo Wald, and Hans Hagen. Interactive ray tracing of arbitrary implicits with simd interval arithmetic. In *Interactive Ray Tracing, 2007. RT'07. IEEE Symposium on*, pages 11–18. IEEE, 2007. Number of Citations: 46.

[31] E Wes Bethel, Chris Johnson, Ken Joy, Sean Ahern, Valerio Pascucci, Hank Childs, Jonathan Cohen, Mark Duchaineau, Bernd Hamann, Charles Hansen, et al. Scidac visualization and analytics center for enabling technology. *Journal of Physics: Conference Series*, 78(1):012032, 2007. Number of Citations: 3.

[32] E Wes Bethel, Chris Johnson, Sean Ahern, John Bell, Peer-Timo Bremer, Hank Childs, Estelle Cormier-Michel, Marc Day, Eduard Deines, Tom Fogal, et al. Occam's razor and petascale visual data analysis. *Journal of Physics: Conference Series*, 180(1):012084, 2009. Number of Citations: 3.

[33] Aaron Knoll, Sebastian Thelen, Ingo Wald, Charles D Hansen, Hans Hagen, and Michael E Papka. Full-resolution interactive cpu volume rendering with coherent bvh traversal. In *Pacific Visualization Symposium (PacificVis), 2011 IEEE*, pages 3–10. IEEE, 2011. Number of Citations: 8.

[34] Carson Brownlee, Vincent Pegoraro, Singer Shankar, P McCormick, and C Hansen. Physically-based interactive schlieren flow visualization. In *Pacific Visualization Symposium (PacificVis), 2010 IEEE*, pages 145–152. IEEE, 2010. Number of Citations: 2.

[35] Min Chen, Hans Hagen, Charles D Hansen, Arie E Kaufman, Min Chen, Hans Hagen, Charles D Hansen, and Arie Kaufman. Scientific visualization (dagstuhl seminar 11231). *Dagstuhl Reports*, 1(6):1–23, 2011. Number of Citations: 1.

[36] *, Mathias Schott, Tobias Martin, AV Pascal Grosset, Carson Brownlee, Thomas Hollt, Benjamin P Brown, Sean T Smith, and Charles D Hansen. Combined surface and volumetric

occlusion shading. In *Pacific Visualization Symposium (PacificVis), 2012 IEEE*, pages 169–176. IEEE, 2012. Number of Citations: 4.

[37] Yong Wan, Hideo Otsuna, Chi-Bin Chien, and Charles Hansen. Fluorender: an application of 2d image space methods for 3d and 4d confocal microscopy data visualization in neurobiology research. In *Pacific Visualization Symposium (PacificVis), 2012 IEEE*, pages 201–208. IEEE, 2012. Number of Citations: 10.

[38] Markus Üffinger, Filip Sadlo, Mike Kirby, Charles Hansen, and Thomas Ertl. Ftle computation beyond first-order approximation. In *Eurographics (Short Papers)*, pages 61–64, 2012. Number of Citations: 5.

[39] Natallia Kotava, Aaron Knoll, Mathias Schott, Christoph Garth, Xavier Tricoche, Christoph Kessler, Elaine Cohen, Charles D Hansen, Michael E Papka, and Hans Hagen. Volume rendering with multidimensional peak finding. In *Pacific Visualization Symposium (PacificVis), 2012 IEEE*, pages 161–168. IEEE, 2012. Number of Citations: -.

[40] Mark Kim, Guoning Chen, and Charles Hansen. Dynamic particle system for mesh extraction on the gpu. In *Proceedings of the 5th Annual Workshop on General Purpose Processing with Graphics Processing Units*, pages 38–46. ACM, 2012. Number of Citations: 3.

[41] Grzegorz Karol Karch, Filip Sadlo, Daniel Weiskopf, Charles D Hansen, Guo-Shi Li, and Thomas Ertl. Dye-based flow visualization. *Computing in Science and Engineering*, 14(6):80–86, 2012. Number of Citations: 2.

[42] Yong Wan, Hideo Otsuna, Chi-Bin Chien, and Charles Hansen. Interactive extraction of neural structures with user-guided morphological diffusion. In *Biological Data Visualization (BioVis), 2012 IEEE Symposium on*, pages 1–8. IEEE, 2012. Number of Citations: 4.

[43] Carson Brownlee, Thomas Fogal, and Charles D Hansen. Gluray: Enhanced ray tracing in existing scientific visualization applications using opengl interception. 2012. Number of Citations: 5.

[44] Charles D Hansen. Gpuflic: interactive and accurate dense visualization of unsteady flows. *Eurographics/IEEE-VGTC Symposium on Visualization*, pages 29–34, 2011. Number of Citations: -.

[45] *, Carson Brownlee, Thiago Ize, and Charles D Hansen. Image-parallel ray tracing using opengl interception. In *Proceedings of the 13th Eurographics Symposium on Parallel Graphics and Visualization*, pages 65–72. Eurographics Association, 2013. Number of Citations: 4.

[46] Thomas Höllt, Guoning Chen, Charles D Hansen, and Markus Hadwiger. *Extraction and visual analysis of seismic horizon ensembles*. Eurographics, 2013. Number of Citations: 2.

[47] T Hollt, Ahmed Magdy, Guoning Chen, Ganesh Gopalakrishnan, Ibrahim Hoteit, Charles D Hansen, and Markus Hadwiger. Visual analysis of uncertainties in ocean forecasts for planning and operation of off-shore structures. In *Visualization Symposium (PacificVis), 2013 IEEE Pacific*, pages 185–192. IEEE, 2013. Number of Citations: 4.

[48] Liang Zhou and Charles Hansen. Transfer function design based on user selected samples for intuitive multivariate volume exploration. In *Visualization Symposium (PacificVis), 2013 IEEE Pacific*, pages 73–80. IEEE, 2013. Number of Citations: 6.

[49] AV Pascal Grosset, Mathias Schott, G-P Bonneau, and Charles D Hansen. Evaluation of depth of field for depth perception in DVR. In *Visualization Symposium (PacificVis), 2013 IEEE Pacific*, pages 81–88. IEEE, 2013. Number of Citations: 3.

[50] Mark Kim and Charles Hansen. Gpu surface extraction using the closest point embedding. In *IS&T/SPIE Electronic Imaging*, pages 93970B–93970B. International Society for Optics and Photonics, 2015. Number of Citations: -.

RESEARCH REVIEW ARTICLED AND BOOK CHAPTERS 2007–2014

[51] Christoph Garth, Guo-Shi Li, Xavier Tricoche, Charles D Hansen, and Hans Hagen. Visualization of coherent structures in transient 2d flows. In *Topology-Based Methods in Visualization II*, pages 1–13. Springer Berlin Heidelberg, 2009. Number of Citations: 56.

[52] E Wes Bethel, Hank Childs, and Charles Hansen. *High Performance Visualization: Enabling Extreme-Scale Scientific Insight*. CRC Press, 2012. Number of Citations: 22.

[53] Younis Hijazi, Aaron Knoll, Mathias Schott, Andrew E Kensler, Charles D Hansen, and Hans Hagen. Csg operations of arbitrary primitives with interval arithmetic and real-time ray casting. In *Scientific Visualization: Advanced Concepts*, pages 78–89, 2010. Number of Citations: 2.

[54] Charles D Hansen, Min Chen, Christopher R Johnson, Arie E Kaufman, and Hans Hagen. *Scientific Visualization: Uncertainty, Multifield, Biomedical, and Scalable Visualization*. Springer, 2014. Number of Citations: -.

PATENTS

[55] Hideo Otsuna, Yong Wan, Charles D Hansen, and Chi-Bin Chien. Interactive extraction of neural structures with user-guided morphological diffusion, October 11 2013. US Patent App. 14/051,947.

CV

Name: Anders Ynnerman	**Doctorial degree:** 1992-06-05
Birthdate: 19630326	**Academic title:** Professor
Gender: Male	**Employer:** Linköpings universitet

Research education

Dissertation title (swe)

Dissertation title (en)

Atomic Coupled-Cluster Calculations

Organisation	Unit	Supervisor
Göteborgs universitet, Sweden Sweden - Higher education Institutes	Fysik, inst för	Ann-Marie Pendrill

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
10302. Atom- och molekylfysik och optik	91-7032-717-3	1992-06-05

CV

Name: Patric Ljung	**Doctorial degree:** 2006-10-06
Birthdate: 19680328	**Academic title:** Doktor
Gender: Male	**Employer:** Linköpings universitet

Research education

Dissertation title (swe)

Dissertation title (en)

Efficient Methods for Direct Volume Rendering of Large Data Sets

Organisation	Unit	Supervisor
Linköpings universitet, Sweden Sweden - Higher education Institutes	Institutionen för teknik och naturvetenskap (ITN)	Anders Ynnerman

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)	91-85523-05-4	2006-10-06

CV

Name: Charles Hansen	**Doctorial degree:** 1987-06-01
Birthdate: 19541011	**Academic title:** Professor
Gender: Male	**Employer:** University of Utah

Research education

Dissertation title (swe)		
Dissertation title (en)		
CAGD Based Computer Vision		
Organisation	**Unit**	**Supervisor**
University of Utah, USA Not Sweden - Higher Education institutes	Computer Science	Tom Henderson
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
10207. Datorseende och robotik (autonoma system)		1987-06-01

CV

Name: Timo Ropinski	**Doctorial degree:** 2015-11-29
Birthdate: 19760603	**Academic title:** Professor
Gender: Male	**Employer:** Ulm University

Research education

Dissertation title (swe)		
Dissertation title (en)		
3D Magic Lenses and Virtual Reflections: Real-Time Approaches for Improving Interactive Visualization		
Organisation	**Unit**	**Supervisor**
University of Muenster, Germany Not Sweden - Higher Education institutes		
Subject doctors degree	**ISSN/ISBN-number**	**Date doctoral exam**
10202. Systemvetenskap, informationssystem och informatik (samhällsvetenskaplig inriktning under 50804)		2015-11-29

Publications

Name: Anders Ynnerman	**Doctorial degree:** 1992-06-05
Birthdate: 19630326	**Academic title:** Professor
Gender: Male	**Employer:** Linköpings universitet

Ynnerman, Anders has not added any publications to the application.

Publications

Name: Patric Ljung	**Doctorial degree:** 2006-10-06
Birthdate: 19680328	**Academic title:** Doktor
Gender: Male	**Employer:** Linköpings universitet

Ljung, Patric has not added any publications to the application.

Publications

Name: Charles Hansen	**Doctorial degree:** 1987-06-01
Birthdate: 19541011	**Academic title:** Professor
Gender: Male	**Employer:** University of Utah

Hansen, Charles has not added any publications to the application.

Publications

Name: Timo Ropinski	**Doctorial degree:** 2015-11-29
Birthdate: 19760603	**Academic title:** Professor
Gender: Male	**Employer:** Ulm University

Ropinski, Timo has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.