Report from Dagstuhl Seminar 19262

Astrographics: Interactive Data-Driven Journeys through Space

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Abstract

This report documents the program and outcomes of the Dagstuhl Seminar 19262 "Astrographics: Interactive Data-Driven Journeys through Space". The seminar consisted of introductory talks, which are presented first in this documents, followed by discussions in break-out groups whose results were reported back to all participants after each break-out session.

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1 Executive Summary

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For the majority of human existence, the visual language has been successfully used to communicate complex ideas that span across borders of knowledge, experience, age, gender, culture, and time. These aspects also make it an effective form of expressing workflows in scientific data analysis as well as the communication of scientific discoveries to broad audiences. The Dagstuhl Seminar 19262 brought together researchers from computer science, content producers, learning and communication experts, and domain experts from astronomy and astrophysics to define the emerging field of interactive visualization of space exploration and astronomy, referred to as Astrographics. This seminar played an important role in the ongoing process of removing the clear division between using visualization to enable scientific discoveries by subject-matter experts (exploratory visualization) and using visual representations to explain and communicate the results of such exploratory science to a greater, general audience (explanatory visualization). Designing the available visualization tools to serve both roles at the same time increases the overlap between these two aspects of visualization and allows scientists to better explain their findings and, at the same time, enables the general public to use similar tools for their own, guided, discovery and actively participate in the scientific process. The field of astronomy and astrophysics has been at the forefront of this process since the beginning as it is a primary example of a domain in which exploratory and explanatory visualizations have served important but distinct roles. For this reason, astrographics was chosen as the domain in which to explore the challenges and opportunities that arise when combining exploratory and explanatory techniques. The bulk of work in this seminar occurred in focussed break-out sessions that reported their findings back to the group and opened up the topics for joint discussions. Topics of these break-out sessions included discussions on better integration of software tools, improvements of analysis tools, preparing astrographics software packages to improve the quality of public presentations, the ability of sharing presentations both in spatially distant locations as well as saving them for later playback. Finally, there was a working group to work on a decadal white paper for astronomy [1].

References

1 Jacqueline K. Faherty, Mark SubbaRao, Ryan Wyatt, Anders Ynnerman, Neil deGrasse Tyson, Aaron Geller, Maria Weber, Philip Rosenfield, Wolfgang Steffen, Gabriel Stoeckle, Daniel Weiskopf, Marcus Magnor, Peter K. G. Williams, Brian Abbott, Lucia Marchetti, Thomas Jarrrett, Jonathan Fay, Joshua Peek, Or Graur, Patrick Durrell, Derek Homeier, Heather Preston, Thomas Müller, Johanna M Vos, David Brown, Paige Giorla Godfrey, Emily Rice, Daniella Bardalez Gagliuffi, Alexander Bock. IDEAS: Immersive Dome Experiences for Accelerating Science. arXiv preprint arXiv:1907.05383, 2019

2 Table of Contents

Break-out Groups

3 Overview of Talks

3.1 Developing Tools for Increased Access to Astrophysics in OpenSpace

Brian Abbott (AMNH – New York, US)

I attended the AstroGraphics meeting in order to discuss the various ways in which we can advance OpenSpace for all types of users. Developing and disseminating astrophysics data within OpenSpace is the overarching goal, for researchers and the public alike, and I wish to discuss the methods to achieve these goals. The result of these advancements will open up access to scientists, who will explore their data in new, insightful ways, and to the public, who will be inspired by their immersion in the universe and enhance their interest in STEM fields.

Presentation Tools

Methods of creating so called Show Kits that include information for training purposes as well as for use in production and storytelling is a large part of opening access to power users. Kits that include flightpaths, documentation, annotationed flights embedded within interactive timelines and overlaid in a video version of the content, and an audio component will serve to provide tools for production and live programming, but will also be critical for training presenters.

Showlettes

Show Kits can be composed of individual showlettes, which are bite-sized stories that contain a beginning, middle, and end, but are confined to one action of concept. For example, exploring the Apollo 11 landing site may be one showlette. Or, the radio sphere with the exoplanets may be one showlette. These showlettes could be combined to form longer shows that take on a broader narrative. Showlettes could be tied together by their beginning and end points, or perhaps these points are adjustable. Some OpenSpace development would be required to make this possible.

Authoring Tools

Authoring Tools are an immediate need for OpenSpace in order to increase access for power users and data holders. The goal is to transform OpenSpace from "under-the-hood," script-based access to more of a "plug-and-play" model, where the user does not need to know or interact with the underlying scripting language. A data questionnaire could be developed to accommodate the import process and generate the underlying scripts on the fly. Tools such as these will cater to all levels of groups who wish to go beyond the distributed offerings of OpenSpace and build their own datasets, and will lower the bar for researchers and power users to use openSpace to interact with their own data and develop stories around those data.

Domecasting Network

In order to build a more cohesive community, we want to develop a streaming network so that users are aware of streaming and domecasting events and can plan for them. Building a domecasting network will allow high-end scientific data to reach audiences all over the world. And, such a network will foster more communication between users and enhance the resources available for everyone.

3.2 Astrographics: Introduction of NAOJ and OAO / IAU

Hidehiko Agata (NAOJ – Tokyo, JP)

Introduction of 4D2U project: Our universe encompasses all of space and time. The most immense cosmic structures – galaxies gathered into clusters and superclusters – dominate the universe everywhere we look. Astronomers constantly work to understand these structures bit by bit. The Four- Dimensional Digital Universe (4D2U) project is an outgrowth of their search for cosmic understanding. The project's goal is to visualize astronomical data in a way that helps watchers feel as if they are witnessing the unfolding of our universe. "Four dimensions" refer to the three dimensions of space and the one dimension of time embedded in their data. "Digital" refers to computer graphics visualizations of digital data. The resulting acronym is "4D2U", and it is also astronomy's way of saying "4D to you". The 4D2U is a long-term project by the National Astronomical Observatory of Japan (NAOJ). We plan to continue improvements in our visualization data library and further development of new visualization platforms, including domed and portable theaters. We hope you'll have the opportunity to experience 4D2U. The project hosts public showings every two months at the NAOJ headquarters in Mitaka, Japan.
https://4d2u.nao.ac.jp/english/index.html
https://4d2u.nao.ac.jp/html/program/mitaka/index_E.html

Introduction of OAO/IAU: The IAU Office for Astronomy Outreach (OAO) is IAU's hub for coordinating its public outreach activities around the world. The OAO coordinates and and supports worldwide efforts to enhance public knowledge, appreciation and education of astronomy and related sciences. The OAO promotes public awareness of the IAU activities and coordinate and manage the IAU international outreach campaigns. The OAO maintain and coordinate the IAU network of National Outreach Coordinators (NOC), who will be responsible for the implementation of the proposed IAU outreach initiatives at national level and for maintaining the relationship with the national communities of amateur astronomers. The OAO act as the central information hub for disseminating IAU related public outreach activities around the world, as a facilitator for best practices, providing guidance and delivering regular information about ongoing activities in astronomy communication.
https://www.iau.org/public/
https://www.iau-100.org/

3.3 Introductory Presentation – Linköping University

Emil Axelsson (Linköping University, SE)

I am a Research Engineer at Linköping University and one of the software developers of the OpenSpace software. Me and my colleagues have long had the vision of building a tool that can be equally helpful for public science communication as it is for scientific visualization and visual data analysis. While some of these visions have been turned into reality over the years, the aspect of using our virtual reality representation of the universe as a science tool have been one of the more fuzzy ones. After this Dagstuhl seminar, I no longer feel that this goal is fuzzy: Instead, it is clear that there are several of us who share this vision, and that our ideas are coming together into a new way of using astronomy tools and visualization software together to analyze data and communicate science.

When I arrived to this Dagstuhl seminar, I was excited about the opportunity to discuss connecting OpenSpace to analysis tools used by astronomers. It was amazing to meet the brains behind prominent astronomy software packages, such as Glue, Astropy, and Aladin. I was thrilled by how we shared this common vision and were able to sit together for a few hours and create a first proof of concept of how we link our tools together. I'm very excited to continue working together with the people I've met here, to create new ways to visualize astronomy data for science and communication!

3.4 Bringing together professional astronomy and EPO visualization software tools

Thomas Boch (Université de Strasbourg – Strasbourg, FR)

I am a research engineer at CDS (Centre de Donnés astronomiques de Strasbourg) since 2002. My activities for 17 years have involved the development of software tools and systems to enable efficient access to the reference data we host at CDS, through Virtual Observatory . In the last decade and with the advent of large astronomical surveys like Gaia or Pan-STARRS, the Big Data has become another dimension to take into account. We have developed a multi-resolution approach to this challenge, supported by the HiPS (Hierarchical Progressive Surveys) format, which has gained traction as more than 600 astronomical surveys (mostly images) are available as HiPS collections (as of June 2019).

While developing the Aladin applications, I was also attracted by the nice aesthetics presented by the planetarium softwares. This seminar has been a great opportunity for me to learn about up to date tools and techniques used for education and public outreach in domes and planetariums. I have been particularly impressed and inspired by the potential of OpenUniverse, especially for the exploration of planetary surfaces.

During the break-out sessions, I created a prototype connecting Aladin Lite to OpenSpace, as a proof of concept. This has showed some interesting potential and interest. More generally, collaboration between the professional astronomy visualisation and the EPO/planetarium communities is of mutual benefit and I feel very grateful for having the opportunity to participate in this seminar and make useful connections with people I hope to work with in the future.

3.5 OpenSpace – Visualizing the universe

Alexander Bock (Linköping University, SE & University of Utah, US)

I presented an overview of the OpenSpace platform that aims to provide an astrovisualization toolkit to visualize the entire universe. These visualizations cover a large range of datasets as well as scales, ranging from millimeter sized rocks on Mars all the way out to the edge of the observable universe. The software is catered to serve three distinct target audiences: The public can be reached both through the use of presentations as well as self-directed discovery in exhibition spaces. A second target audience is visualization researchers that can use a common software framework to conduct novel research. A third target audience are domain scientists that can use the same software to conduct their own research as is used for public presentations, for example planetarium domes. I presented a selection of previous works that have already been published or shown to the public. Many of the presented examples were the result of Master thesis works, of which I exemplified three in the initial presentation. These examples covered the flyby of the New Horizons spacecraft at Pluto in 2015, volumetric rendering of Coronal Mass Ejections from the Sun, all the way to representations of the traffic on the NASA Deep Space Network. Concluding the talk, I showed institutions that already make use of OpenSpace in public programming and provide food for through on how we can continue the development of astrographics tools to increase their reach, particularly in the case of interaction techniques.

3.6 David Brown

Dave Brown (Microsoft Research – Redmond, US)

My research interests focus around data visualization in plan and mixed reality, using devices large and small, and with an emphasis on storytelling. I have also long had an interest in astrographics, having met Curtis Wong through a project I was working on to visualize the solar system and its surroundings on table-top form factor devices. I subsequently worked for Curtis at Microsoft Research, and got to know other members of the team behind WorldWideTelecsope, and key visionaries in this area such as Alyssa Goodman. This Dagstuhl was a perfect intersection between my current research in data-driven storytelling and desire to do more with astronomical data. It gave me both an opportunity to share some of my work with the other participants, and for me to learn from experts in the astrographics and full-dome experiences domain. After so many interesting discussions and much brainstorming with the other attendees, I am convinced that full-dome data-exploration and storytelling is an un-tapped opportunity for any data-driven research and communication, and that it overlaps with my current research in exploring how collaboration and mixed reality can benefit data visualization. This Dagstuhl was therefore an unprecedented opportunity for me to forge new networks with people with similar interests but who worked in fields that I would not otherwise have had the opportunity to meet. I am looking forward to future work with these new-found colleagues.

3.7 Exploring the Galaxy Using Virtual Reality

Melvyn Davies (Lund Observatory, SE)

I am a dynamic theoretical astrophysicist who studies the evolution of exotic objects (planetary systems, black holes and explosive events) in crowded places. How does one explore the rich diversity of stellar systems? This is an enormous visualisation challenge. In particular in Lund we are exploring how one can use Virtual Reality to explore rich stellar data sets. Using Unity we are learning how to interact with point cloud data: the positions and velocities of an ensemble of stars where each point also possess other attributes such as stellar age and chemical abundance. Our goal is to employ this technology for scientific discovery with observational data from the ESA Gaia astrometric mission together with outputs of computer simulations of galaxy formation. During the seminar, we discussed a broad range of important issues concerning the use of Virtual Reality and Augmented Reality. The diversity of the knowledge present was enormously helpful in understanding the future prospects and a way forward.

3.8 Planetariums as a Research Tool

Carter Emmart (AMNH – New York, US)

For twenty years I have been with the American Museum of Natural History (AMNH) helping to craft public demonstration of our state of knowledge about the universe using data visualization. The planetarium as a hemispherical projected image of the night sky with its attendant motions, movements of celestial objects, simulated views from different latitudes and times across the precession cycle has from the start been accurate science visualization, portrayed two dimensionally. Research trends in immersive data visualization explored in the last two decades of the twentieth century became possible to display in planetarium domes at the turn of the Millennium when AMNH renovated the Hayden Planetarium, recasting its presentations from the tradition of Sky Shows toward new programming termed Space Shows using data visualization to portray the universe accurately in three dimensions. In both cases of the traditional 2D and modern 3D display capabilities of the planetarium, the primary purpose has been to service public understanding through informal education. Planetariums have been on the receiving end of science as an effective demonstration tool. While modern capability of 3D interactive display affords data exploration, aspirations of using planetariums as scientific tools of discovery have to date remained a noble vision. The June, 2019 Dagstuhl Astrographics seminar afforded a very unique, narrow time window for a potent mix of talent across the field that forged an exploration of data flow using open tools (OpenSpace, Glue, CDS Aladin) bridging scientific investigation directly into planetarium display with its capacity for audiences numbering in the hundreds. I raised a question at the conclusion of Astrographics if what we were seeing was useful to the scientists represented in the meeting, and their resounding response was yes is was. Going forward, this new beginning will develop this trend further which holds great potential for the field of data visualization supporting scientific investigation in planetariums worldwide.

3.9 Introductory Presentation – American Museum of Natural History

Jackie Faherty (AMNH – New York, US)

I am a senior scientist and senior education manager jointly in the departments of Astrophysics and Education at the American Museum of Natural History. Scientifically I am interested in exploring questions of the tail end of the star formation process. I am specifically focused on studying the fundamental properties of low mass stars, brown dwarfs, and exoplanets. My research is greatly influenced by big data surveys such as ESA's Gaia observatory. In addition I have found that large astronomical data sets are best investigated scientifically using visualization tools as an aid. This has brought me to the Astrographics workshop as I am in constant search of software packages that will help with interpreting scientific content. As I work in the planetarium world, I am exposed constantly to visualization tools for the purpose of education – reaching the general public. I see an important collision in today's technologically advanced world between the scientific agenda of researchers in the era of big data and the sophisticated tools being used today to educate and inspire the general public.

3.10 CosmoScout VR: Interactivity and Immersion for Space Data Exploration and Mission Planning

Andreas Gerndt (DLR – Braunschweig, DE)

Although the German Aerospace Center (DLR) is not directly addressing astrophysics, many institutes of DLR are on earth system modeling, planetary research, atmospheric research, space mission planning, space operation, on-orbit-servicing, space situational awareness, air-borne observation, and sensor-data related applications. The observation and simulation data can become extremely large. Additionally, heterogeneous data exploitation requires software solutions which are distributed, scalable, and reliable. On the Dagstuhl seminar, I could give in insight into DLR's manifold space activities and the interactive data exploitation software we have been developing. Already 10 years ago, the DLR Institute of Simulation and Software Technology realized the need to process the huge High-Resolution Stereo Camera (HRSC) dataset on a global scale on a sphere in virtual environments. HRSC is a DLR camera sensor on the Mars Express orbiter capturing stripes of the surface of Mars with extraordinarily precise specification of slopes. An accurate data exploration requires a distortion free mapping also on the poles and appropriate tools for measuring, annotation, and navigation. To close gaps between stripes, arbitrary sensor datasets can be merged on the fly to one data product. Virtual reality devices have been integrated to sense the height-field for accurate measurements and to deform the terrain interactively for reconstructing 3D fault displacements. Autonomous crater detection based moon lander required simulators with physical-based Moon rendering. And for Earth observation data, the interactive terrain renderer has been extended with approaches for atmospheric volumetric and time-depended data visualization. Climate research datasets exceeds Peta-bytes of data, so that the framework has been extended to remote high-performance post-processing on supercomputers. And finally, space mission planning demanded the visualization of the whole solar system with accurate time-dependent trajectory specifications based on SPICE kernels. High-resolution star maps allow space system simulators which rely on star trackers. On-orbit servicing simulation of spacecraft requires photo-realistic rendering of the scenario in space. All these features are now available in the open-source software framework CosmoScout VR. It works as a stand-alone application. With its plug-in concept, it additionally enables the extension of arbitrary functionalities. But as it comes as a set of libraries, tailored applications for specific purpose can be implemented as well. With the basic VR software layer, it always scales from single laptop application to CAVE-like immersive multi-projection systems. And finally, it is platform independent and supports Windows and Linux operating systems. Thus, CosmoScout VR is available for all who are interested in a holistic solution to explore the solar system in 3D and time. Its approaches can clearly contribute to the astrophysics community. It was great to meet all the people at Dagstuhl to discuss their requirements in visualizing astrophysical data and to figure out opportunities of interactive exploration.

3.11 Astrographics, Exploranation, and Dagstuhl

Alyssa A. Goodman (Harvard-Smithsonian Center for Astrophysics, US)

For the first many years of my professional career, I was lonely living at the intersection of astrophysics and data visualization. Even when I attended my first "astro-visualization" meeting back at KICP in Chicago in 2005, I felt like an outsider, as I was not part of the planetarium community where most research scientists (like me) felt "visualization" and "visual communication" belonged. At that Chicago meeting, I presented my group's first attempts to use Medical Imaging software on Astronomy data, under the "Astronomical Medicine" project at Harvard's Initiative in Innovative Computing. At the same meeting, Curtis Wong presented his ideas about how to create what ultimately became WorldWide Telescope (WWT, worldwidetelescope.org) , which I was later honored to help Curtis and Jonathan Fay create.

By now, over a decade past the release of WWT, my collaborators and I have created the open-source glue visualization environment (glueviz.org), which lets users "glue" together data sets, visualizations, and software tools, including WWT. Interest in, and usage of, glue from all quarters of astronomy and the broader scientific world is on the rise, which thrills me. My colleagues in Astronomy have, over just the past five years or so, rapidly come to hunger for visualization tools and innovations, thanks to the advent of ever-larger and more complex data sets, as well as more sophisticated statistical approaches, all of which essentially require visualization to understand.

Here at Dagstuhl, I witnessed a transformation. Before the meeting, WWT was the only full-featured "sky browser" available in glue via its plug-in architecture. But now, after just 2 days of discussion and hacking, the research and planetarium communities in astronomy have come together to link up their "exploratory" and "explanatory" tools into amazing "exploranation" mash-ups that will transform how the public experiences real data, and how and where researchers view their data. For example, as a result of our extensive discussions and real-time hacking/collaboration, Aladin (a European program widely used in Astronomy research), as well as glue, can now both communicate with OpenSpace (an immersive 3D data-driven visualization environment used in the planetarium community). My astronomy colleagues and I have already–just in the last day of the Dagstuhl meeting–begun to use these newly-linked tools to explore and discover new, 4D-spacetime, relationships between stars and gas in the Milky Way.

Back-and-forth travel from "exploration" to "explanation" in visualization holds tremendous promise for both professionals and the wider public's understanding of science, and this first Astrographics Dagstuhl Seminar will stand out in the future as key to enabling this two-way travel!

3.12 Plenary Astrographics Presentation

Charles D. Hansen (University of Utah – Salt Lake City, US)

I am a faculty member of the Scientific Computing and Imaging Institute at the University of Utah. One of the primary application foci of the SCI Institute has continued to be biomedicine; however, SCI Institute researchers also address challenging computational problems in a variety of application domains, including materials, manufacturing, defense, and energy. SCI Institute research interests generally fall into the areas of scientific visualization, scientific computing and numerics, image processing and analysis, and scientific software environments. SCI Institute researchers also apply many of the above computational techniques within their own particular scientific and engineering subspecialties, such as fluid dynamics, biomechanics, electrophysiology, bioelectric fields, parallel computing, inverse problems, and neuroimaging. A particular hallmark of SCI Institute research is the development of innovative and robust software packages, including the SCIRun scientific problem-solving environment, Seg3D, ImageVis3D, VisTrails, ViSUS, Cleaver, and map3d. All these packages are broadly available to the scientific community under open-source licensing and are supported by web pages, documentation, and user groups.

My research area is in scientific visualization. Volume visualization has been one of the areas where I have made contributions. Bring better illumination models to bring out more structure in 3D data, providing multi-dimensional transfer functions to better examine data and methods for large-scale rendering and analysis. I have incorporated research results into large-scale software projects. One such project is FluoRender. FluoRender is an interactive rendering tool for confocal microscopy data visualization. It combines the rendering of multi-channel volume data and polygon mesh data, where the properties of each dataset can be adjusted independently and quickly. The tool is designed especially for neurobiologists, allowing them to better visualize confocal data from fluorescently-stained brains, but it is also useful for other biological samples.

In Astrographics, I have made contributions from methods to visualize galaxy formation in collaboration with Elena D'Onghia (UWisc/Harvard) to methods for visualization of magnetic pole reversal with Ben Brown (UWisc). For the future of Astrographics, the combination of techniques, methods, and tools to aid in the exploration and explanation of scientific data is important. I participate in the OpenSpace project which brings NASA mission, astronomy data, and astrophysics data to the public through planetarium presentations.

3.13 Tom Kwasnitschka

Tom Kwasnitschka (GEOMAR Helmholtz Centre for Ocean Research Kiel, DE)

As a marine geologist, my research focuses on the exploration of oceanic volcanism down to extreme depths of several kilometres. Since most of such research is carried out using remotely operated diving robots, we heavily rely on remote sensing, manipulation and powerful visualization tools to build situational awareness of abyssal environments.

My work aims to reflect the entire value-added chain of the scientific process. Formulating research questions based in physical volcanology, I entertain projects for the design and construction of deep ocean cameras and optical sensing equipment such as LED lighting. My processing method of choice is photogrammetry because the high-resolution, color re-creation of underwater outcrops caters to the first-person based interpretation schemes of classic field geology. In order to do so, the photogrammetric models need to be adequately viewed and manipulated in spatially immersive environments, which my group designs, builds and operates. We focus on domes, drawing from the developments in the planetarium field throughout the last 15 years, as domes have a number of advantages when it comes to mult-viewer situations.

With a background in the planetarium business, my ties to astrovisualization are explained. I believe that even localized visualizations should be nested in the global perspective of a virtual globe, and that such a virtual globe is naturally part of a system that also simulates the proximal and distal cosmic phenomena. Therefore, I try to lobby for a broadening of scope and capabilities of astrovisualization software packages such as the ones used for domes and planetariums, especially towards the accomodation of earth science based data sets. This must also come with a refinement of tools to allow manipulation and agile interaction with the data behind a simulation, since exploratory visualization should always offer a quantitative, added value to the scientific process. Thus, and lastly, it is important to install measures to quantify the (hopefully positive) impact of visualization efforts to sustain and broaden its acceptance.

3.14 OpenSpace Amplification for VR and Other Disciplines

David H. Laidlaw (Brown University – Providence, US)

My research interests are in supporting scientific research with visualization and computation. I study efficacy of visualization methods and devices, with a recent focus on virtual reality displays. In this meeting I would like to explore how to make astrographics tools like OpenSpace work on more visualization devices. I am also interested in how ocean and bay science on earth might be supported by astrographics tools and how new data types (eg, lidar and ocean/bay sampling) might be incorporated.

3.15 Marcus Magnor

Marcus A. Magnor (TU Braunschweig, DE)

Humans have been fascinated by astrophysical phenomena since prehistoric times. But while the measurement and image acquisition devices have evolved enormously by now, many restrictions still apply when trying to estimate the three-dimensional structure of extraterrestrial objects. The most notable limitation is our confined vantage point, disallowing us to observe distant objects from different points of view. In an interdisciplinary German-Mexican research project with Wolfgang Steffen, partially funded by German DFG and Mexican CONACyT, we evaluated different approaches for the reconstruction of plausible three-dimensional models of planetary nebulae. The team was comprised of astrophysicists working on planetary nebula morphology and computer scientists working in the field of constrained reconstruction and physically correct rendering of astrophysical objects.

3.16 Thomas Müller

Thomas Müller (Haus der Astronomie – Heidelberg, DE)

The main task of the Haus der Astronomie is public outreach for the Max Planck Institute for Astronomy and public outreach of astronomy in general. We offer regular series of lectures, guided tours, workshops, teacher training and a lot more. My research interests cover relativistic visualization and any other kind of visualization in astronomy and astrophysics. My daily work is to help MPIA scientists in any questions of visualization, develop standalone exploratory and explanatory visualization applications for scientists, public outreach, and our in-house planetarium.

3.17 Josh Peek

Joshua Eli Goldston Peek (Space Telescope Science Inst. – Baltimore, US)

As an data-oriented astronomer working on diffuse structures in the universe, my world is ruled by a number of principles. Firstly, collaboration. Since the data I use is not dominated by a single data collection mode, but rather comes from radio, optical, simulation, space, ground, IFU, spectral, etc sources, I often work closely with experts to achieve data synergy. Each data set has its own quirks limits and biases. Secondly, dimensionality. As derived from the first, each data set provides incredibly high dimensional data, and combined the dimensionality is incredible. Lastly, the visual. The structures we explore are not always entirely encapsulated by points, but rather are extended and cannot be simply shown in scatter plots.

All of these things drive me toward astrographic analyses; using advanced visualization tools to explore complex overlapping data sets and exploring them with colleagues.

3.18 Lucian Pleasea

Lucian Plesea (ESRI – Redlands, US)

I have a long history of working with remote sensing imagery and data, initially for NASA and later for Esri, with the main goal of making such data available to the public at large. Visualization such data properly is very important, the volume and scale of the available datasets only make this visualization more challenging. It is only natural that planetariums are some of the best venues for astro-graphics, and I have been collaborating with NASA and AMNH to achieve a seamless and rapid infusion of planetary imagery data into planetarium visualization. The OpenSpace software is a remarkable advance in the astro-graphics field, the features and capabilities already exceed many commercial alternatives. Since it is open source and has relatively modest minimum hardware requirements, it is widely available to anyone interested. This positive impression of OpenSpace was widely shared by the workshop participants. Since I am also a member of the OpenSpace project advisory board, it was great to see how well received the OpenSpace development effort is. The workshop at Dagstuhl represented a great opportunity for me to meet with specialists working directly in the astro-graphics field, and to better understand the current state of the art, with its challenges and limitations. As a result of the workshop, I have a list of new action items I set for myself, and new motivation to continue to be an active contributor to astro-graphics.

3.19 Sebastian Ratzenböck

Sebastian Ratzenböck (Universität Wien, AT)

I am a PhD student at the data science platform at the University of Vienna focussing on extracting physical knowledge from the Gaia data set by employing machine learning methods. In a quest to better understand the structure formation of the milky way I am currently tailoring clustering algorithms to more robustly extract open clusters. For me data visualisation and data analysis, such as the clustering process, share a common basis as both tools are trying to make sense of the great unknown hidden in the data which essentially consists of numbers stored somewhere on hard drives. This notion of discovery and making sense of the data is now becoming more and more relevant as the astronomy community is facing massive amounts of data from survey like Gaia or Pan-STARRS1. Moreover, especially in astronomy where the search for structure involves the position space the focus on visualisation is a crucial part of the analysis and eventually telling the story behind the findings.

This seminar has been a first chance for me to get immersed into the joint field of astronomy and visualization and to meet the people on the forefront of that community. People here have in just two days managed to join softwares which further progresses and facilitates the ability to do exploratory data analysis. Furthermore, we discussed the fundamental structure of the data analysis pipeline from data discovery, data accessibility, transparent analysis especially regarding VIS tools and eventually novel analysis techniques such as Machine Learning in the context of Astrographics.

3.20 Thomas Robitaille

Thomas P. Robitaille (Aperio Software – Leeds, GB)

I am a scientific software developer working on a variety of open source projects related to visualization and astrographics. One of my key interests is making it possible for researchers to have access to tools for interactive data analysis, and in particular using different tools together seamlessly. At this workshop, I learned about a variety of advanced visualization tools being developed, and decided to work on developing a proof-of-concept of how to use the OpenSpace application with the glue data visualization software. This will allow researchers to carry out advanced data analysis, linking datasets together, and exploring interesting subsets of data while also being able to visualize these data and subsets in realistic rendering of the universe.

3.21 Introductory Presentations

Filip Sadlo (Universität Heidelberg, DE)

My research interests in astrophysical visualization range from the early Universe to planet formation. I would like to employ topological techniques to analyze the structure of the early Universe and planet formation, with a particular focus on its multi-scale nature. Besides the growing range of scales, I see challenges for future astrophysical visualization research in merging and completing heterogeneous data and a tighter coupling of the visualization concepts to the governing physical laws.

3.22 Wolfgang Steffen

Wolfgang Steffen (Universidad Nacional Autonoma de Mexico – México, MX)

Volume rendering of astronomical nebulae in interactive dome software is still underdeveloped with all the rest. We have built software (Shape) that allows to generate volumetric 3-D models, but integrated them into presentation software has been a problem in various ways: rendering quality, size limits and opacity rendering whenever there are non-volumetric objects present, too. Solutions to these problems and finding data format standards would be extremely helpful once hardware will become common place that is able to support high resolution volumetric models.

3.23 Introductory Presentation – Planetarium of the Natural History Museum Vienna

Gabriel Stöckle (Naturhistorisches Museum Wien, AT)

I am responsible for the digital planetarium in the Natural History Museum Vienna. The museum is one of the largest and most important natural history museums in the world with a unique collection. The planetariums purpose is to be an addition to the museum and to visualize and explain nature. We are not really doing scientific visualization yet but work rather as a planetarium with live presentations and fulldome cinema. Now with modern visualization techniques, I think a planetarium can become a tool to visualize scientific data interactively. We have Open Space installed and running (with support from the Gene Payne from the Scientific Computing and Imaging Institute in Utah) and hope to implement modern visualisation technologies in the dome.

My personal background is that I was working for the Astronomisches Rechen-Institut in Heidelberg, Germany promoting Virtual Observatory Tools and Grid Computing before I became responsible for the planetarium. Now with Open Space I found an open source software to visualize astronomical data on the dome, tested and installed it our dome and therefore was invited to come to Dagstuhl. My hope was to improve it into an tool to present interactively data on the dome.

Here in Dagstuhl, I met amazing people and we made great advances in visualizing astronomical data with the help of the developers of glue (Thomas Robitaille) and aladin (Thomas Boch). They were able to connect the Open Space Software with glue. They were able to select subsamples of data interactively and visualize these subsamples interactively in open space, which means also on the dome. I hope that this interactive data selection and presentation technique can also become a tool for researchers in the dome.

Next to this I could learn a lot about presentation techniques listening to the presentation of Carter Emmart from the American Natural History Museum in New York. I learned a lot and will use his presentation of the moon and mars as an inspiration for our own liveshows.

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3.24 Data to Dome

Mark Subbarao (Adler Planetarium – Chicago, US)

I am interested in exploring the potential of digital planetariums and research grade visualization facilities. The term Data to Dome refers to a strategy to simplify and streamline the process of going from scientific discovery to planetarium visualization and presentation. This strategy included the development of new data and interoperability standards and well as the professional development of planetarium staff. We also hope to realize the power of the modern planetarium as a research grade visualization facility by introducing the capabilities in the software to go beyond presentation and enable interrogation of the data. With these new capabilities we have large collaborative data exploration and discovery facilities that have already been built and paid for in almost every major city of the world.

3.25 Interactive planetarium visualization

Edwin A. Valentijn (University of Groningen, NL)

We had extensive exchanges with the planetariums which are involved in interactive visualization and who are keen on bringing in new content on a very regular basis – also in relation to the Data-to-Dome initiative. Further progress of Data-to-Dome heavily depends on the involvement of the planetarium display system providers, Focus was a.o. on bringing current research into planetariums and to lower the threshold for researchers to present their work in a planetarium environment. A splinter session was organized with so called power users, Adler-Chicago, Morrison-San Francisco, Hayden – New York, Heidelberg, Norrköping, and DOTliveplanetarium–Groningen discussing common interests. In this context, the OpenSpace project was perceived as an important and promising way forward and new collaborations have been initiated. Real time streaming of 360 degree live content towards the planetariums was also discussed, but there was not a strong interest. Dotliveplanetarium is building a platform for this. In short, the workshop helped very much to settle new international relations and collaborations and helped to identify common interests. Some follow-up work visits have been planned.

In the seminar highlights we note: "We initiated to set up new collaborative IPS working groups for trans-national collaborations and exchange of data and content" Edwin Valentijn, Mark SubbaRao "We perceived a new and enthusiastic community dedicated to enhance planetarium visualisation for modern research, knowledge dissemination and outreach."

3.26 Visualization, Relativity, and Astrographics

Daniel Weiskopf (Universität Stuttgart, DE)

My background is in visualization in general and covers a wide range of topics in scientific visualization, information visualization, and visual analytics. In particular, I am interested in the application of visualization related to astronomy and astrophysics. One example is visualization for special relativity [1, 4] and general relativity [5]. These kinds of visualization can be used for public outreach by incorporating concepts of explanatory and illustrative visualization, for example, for museum exhibitions [2]. Also, immersive virtual environments played a big role for such applications early on, as demonstrated for a virtual "flight simulator" for special relativity [3]. Another example of previous work in astrographics includes the reconstruction and rendering of nebulae, relying on efficient rendering methods and reconstruction schemes [6].

For future research, I am interested in further integrating astrographics and advanced visualization: How can astrographics benefit from recent developments in visualization research? And how will the special requirements of astrographics influence visualization? In particular, I see the need for further research on combining explanation and exploration in visualization, which directly links to questions related to methods for data-oriented storytelling. What are design principles and data-transformation methods that support storytelling? What are the differences between storytelling in astrographics and other application domains?

I also see a productive link between astrographics and other areas of visualization in the form of immersion: The recent trend toward immersive analytics brings 3D representations and immersion into the focus of visualization research [7]. How do these new approaches relate to already established ways of presenting visualizations in immersive planetarium environments? How can immersive analytics be used in astrographics?

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3.27 Astrographics in Context

Ryan Wyatt (California Academy of Sciences – San Francisco, US)

All visualizations require interpretation, and my interest as an astronomer turned educator center on leveraging visualizations for outreach to broad audiences. I am fundamentally a user of astrographics software, not a developer, so I want to consider how software can best enable educators to share visually compelling and scientifically accurate visualizations—and how these tools can support astronomical discovery.

I have several core interests in astrographics. First, the community must recognize the need to develop and refine presentation tools in astrographics software: particularly allowing for smooth transitions in scale (the ability to "fly" through data is key to providing continuity and context) and adjustability in terms of visual representations (essential for fine-tuning representations that will be accessible and comprehensible to a wide range of consumers). Second, our software needs to provide interpretive layers—both for educators and for our audiences—along the lines of the metadata enabled by the Astronomy Visualization Metadata (AVM) standard. Third, we need to make experiences interactive for our audiences, and although my primary interest is in mediated or guided experiences, it is also worth considering a broader definition that emphasizes agency on the part of novice users, although there are many attendant challenges—especially in terms of the scaffolding required for audiences to make sense of visualizations. Lastly, I am interested in ensuring that the wide range of tools (especially covering both research and education) remain extensible, compatible, and interoperable.

Dagstuhl Seminar 19262, "Astrographics: Interactive Data-Driven Journeys through Space," gave several of us the opportunity to consider how tools developed for educational use—specifically in planetarium domes—could support research. The resulting white paper, IDEAS: Immersive Dome Experiences for Accelerating Science, was submitted to the Astro2020 Decadal Survey on Astronomy and Astrophysics. As noted in the paper's abstract, "Planetariums can and should be used for the advancement of scientific research. [...] We propose a transformative model whereby scientists become the audience and explorers in planetariums, utilizing software for their own investigative purposes."

3.28 Exploranation – A New Science Communication Paradigm

Anders Ynnerman (Linköping University, SE)

The rapid development of computer hardware for visualization, together with new and improved methods and software, enables interactive exploration of complex and large-scale data on commodity graphics processing units (GPUs). Scientific data is also to an increasing degree published as "Open Data". These three trends together make it possible to let visitors to public venues, such as science centers and museums, themselves become explorers of scientific data using the same tools, methods, data and even hardware that researchers are using in scientific exploration. This change of use of visualization in public spaces from the traditional explanatory visualization to an exploratory approach has been referred to as "Exploranation", a euphemism encapsulating the confluence of explanation and exploration.

Exploranation, however, is in need of further research as challenges appear when interactive visualization is used in science communication. For installations enabling free exploration intuitive and robust interaction are key features. It is also important to address issues arising in non-linear storytelling. If there are specific learning goals expressed, non-invasive guidance has to be used to ensure that goals are reached and this without disturbing the notion of free exploration.

In the case of live facilitated presentations using interactive data exploration many of these challenges also appear. In addition, the role and importance of the facilitator needs to be further researched in the context of performativity and the expression and transfer of tacit knowledge. An important aspect of live presentations is also the navigation and piloting. To enable a facilitator/presenter to both navigate and present, high level tools combining story telling with navigation and data processing need to be developed.

4 Break-out Groups

4.1 Domecasting + Authoring Tools

Alexander Bock (Linköping University, SE & University of Utah, US), Brian Abbott (AMNH – New York, US), Charles D. Hansen (University of Utah – Salt Lake City, US), and Wolfgang Steffen (Universidad Nacional Autonoma de Mexico – México, MX)

This breakout session focussed around the use of astrovisualization tools in the context of domecasting, and how to create authoring tools such that novice users are able to quickly generate new content that can be shared with a wide audience. Domecasting in this context refers to the ability to connect multiple instances of a software together and replicate the input from one master computer to connected clients. This technique can, for example be used to share a live presentation given by a subject-matter expert in a specific location and share both audio and visual results with multiple other locations that are located in other places around the globe. This method relies on the ability for each client installation to run the visualization tool locally such that images can be generated which are optimal for the geometry of the facility. This is necessary as the connected geometries might vary greatly, from flat screens, to virtual reality headsets, and planetariums, making a custom solution for each installation an essential requirement. While discussing the technical details of the currently implemented solution of open-source software in this area, it was determined that each vendor/provider uses a closed system that are currently unable to interoperate. This lead to the discussion to create a common format that can be used to allow domecasting between different astrovisualization software vendors and provide a common interface that new software can integrate. While this method does not ensure that all vendors will provide the same functionality, it is the first step in ensuring that these features can be implemented in the future. A substantial part of this discussion was also devoted to the concept of recording and authoring flight paths, i.e. the path of the virtual camera in both space and time through the visualization. Representations of these flight paths might be standardized to the extent that they can be shared between different vendors. Furthermore, participants voiced their wish for improving the current state of these flight paths to make it possible to add additional information to these flight paths that is shown to a potential presented in a public environment, informing them about potential topics that might be discussed while automatically following a set camera movements. This thread of sparked a lengthy discussion on a concept called "Showkits" which were physical materials and props prepared by the American Museum of Natural History many years ago that could be sent to school teachers and other museums to support their efforts while giving a live presentation. Annotated flight paths that also include additional media would be moving this concept to the modern age and would make it possible to disseminate the didactics on how to give live presentations to a larger audience, and would also provide the ability to create a central location to share these showkits to train new pilots or have people self-train based on these materials. The end result of this part of the discussion was defining terminology for future work surrounding this concept. A modern "Showkit" is a directed graph of "showlets" which can be navigated by the user at their own pace. A "showlet" is a collection of assets including media resources, such as audio transcripts of a subject-matter expert, videos to be included in the presentation, and presenter notes for the pilot of the presentation. The connection between different "showlets" would occur through the use of either pre-recorded or dynamically generated flight paths. A similarly lively discussion occurred around the topic of authoring tools that would provide a larger amount of people with the possibility to create new content that can be shared with a large number of planetariums. First and foremost on the agenda was the topic of interoperability between different vendors. A perfect content authoring tool would export the resulting content in a format that can be easily converted between different vendors such that content only needs to be generated once and can be reused by any vendor. A long in-depth discussion followed on the merits of providing different complexities of authoring tools, one for the casual user that does not provide as many detailed options, all the way to the expert user who can include specialized code for rendering new datasets, which can then be shared with other users. Returning the discussion to the showlets, it was determined that it would be most beneficial to have different tools to be able to create individual assets, then combining different assets into showlets using a separate application and then finally integrating different showlets into entire shows or showkits using yet another application. Using this three-stage process it would be possible to specialize each tool for its intended purpose and optimize it for its niche.

4.2 Quo vadis Astrovisualization software?

Alexander Bock (Linköping University, SE & University of Utah, US), Tom Kwasnitschka (GEOMAR Helmholtz Centre for Ocean Research Kiel, DE), David H. Laidlaw (Brown University – Providence, US), and Thomas Müller (Haus der Astronomie – Heidelberg, DE)

This break-out session investigated where different publicly available astrovisualization software should go and focus their efforts on to be effective tools at communicating astronomy and astrophysics research. These discussions were not each explored in detail, but it was rather designed as a more general brainstorming sessions. The first large component of desired features included support for GIS (Geographic information system) algorithms that would make it possible for users to import their own specialized data. One aspect of this is having the ability for scientists to add custom data loaders for their own specialized formats to shorten the path between exporting data from specialized analysis tools into the visualization frameworks. These also include supporting new rendering primitives, such as raster images, polygons, and geolocators, but also reducing the friction to import other external data sources, such as georeferenced images in common data formats, such as GeoTIFF. Desired operations for these GIS datasets are mostly related to measuring; being able to measure height information, the value of individual pixels, and other tools to verify the visualization. A concrete example for these tools are the ocean/bay science, where information for most of the Earth's ocean surface is available and has not yet been utilized for visualization purposes or public outreach. Another wish for astrovisualization tools is the increased support for more virtual reality devices. These include virtual reality headsets, both commercially available headsets as well as research devices, but also CAVE environments.

Both directions require further research before they can be used in regular programming for a wider audience as, for example, guided navigation techniques have to be further developed first. Another type of large data that is currently not handled broadly is point cloud data, particularly data acquired from LiDAR sensors. Participants were particularly focussed on the ocean surface scanning that has occurred over the past years, which resulted in a large amount of available point cloud data that is currently underutilized due to the lack of visualization techniques. Issues that were raised are the handling of memory requirements as these datasets usually tend to be very large, and special care needs to be taken when simplifying them. One suggestion simplification technique that was discussed in detail were methods of transforming the LiDAR point clouds into polygonal representations that could be displayed and stored much more efficiently and would not lose much information in the process. Lastly, the participants discussed potentially adding complex rendering techniques to these softwares, such as wormhole or blackhole renderings that would operate in real-time. These techniques would make it possible to illustrate the effects of gravity for high-school level students that already have some familiarity with the matter, but lack intuitive representations except for high-budget hollywood movies. Providing these students with the ability to change gravitational parameters and allowing them to dynamically inspect the results could potentially have large benefits in conveying these complex topics.

4.3 Towards Augmented Reality Astronomy Research in the mid 2020s

Melvyn Davies (Lund Observatory, SE), Dave Brown (Microsoft Research – Redmond, US), Alyssa A. Goodman (Harvard-Smithsonian Center for Astrophysics, US), and Joshua Eli Goldston Peek (Space Telescope Science Inst. – Baltimore, US)

Much of astronomy research requires collaborative, high-dimensional data exploration. It is collaborative because astronomers measure the same objects and structures with many different methods, and no one person can be an expert in all technical domains. It is high-dimensional because each of these methods can add many new dimensions to each object. Software like glue can allow a single user to explore these data, but when we are talking about large complex data sets in multiple dimensions, the immediacy and structure of true 3D representations in real space dramatically increases the depth of understanding of relative scale and structure.

Virtual reality offers a new window into this world, with much advanced tools developed by VR experts and powered by the gaming industry. But VR structurally limits collaboration – communication between astronomers happens via facial interaction and body posture, which is why most remote group meetings happen via video chat, rather than simply audio call.

Our group investigated the idea of how augmented reality and mixed reality might open up a space for collaborations of research astronomers to explore data together. We used a mixed-reality headset (a version 1 HoloLens) to drive home the point that data exploration is much richer in 3D.

VR experts explained the various pros and cons of VR headsets and tooling; how progress has been made in making the tools better for data exploration. The concept of the ease of access curve, with viz-cave most difficult to access, shading to VR and MR devices, all the way to AR-enabled phones, which most participants already had, was discussed. We focused on practical matters – what it would look like for research astronomers to mix in AR and MR tooling into their daily workflow.

The concept of merging glue, HoloLens, and ARKit2/Tango (phone) AR technologies was discussed. It was agreed that such an arrangement made some sense as a toolchain for casual visual exploration and was not out of reach – glue can stage the data and cast it to the internet, a single MR user could see a 3D data structure and provide 3D brushing capabilities, and anyone with a phone could participate in viewing the 3D space.

4.4 Decadal White Paper: Immersive Dome Experiences for Accelerating Science

Jackie Faherty (AMNH – New York, US), Brian Abbott (AMNH – New York, US), Alexander Bock (Linköping University, SE & University of Utah, US), Dave Brown (Microsoft Research – Redmond, US), David H. Laidlaw (Brown University – Providence, US), Marcus A. Magnor (TU Braunschweig, DE), Thomas Müller (Haus der Astronomie – Heidelberg, DE), Joshua Eli Goldston Peek (Space Telescope Science Inst. – Baltimore, US), Wolfgang Steffen (Universidad Nacional Autonoma de Mexico – México, MX), Gabriel Stöckle (Naturhistorisches Museum Wien, AT), Mark Subbarao (Adler Planetarium – -Chicago, US), Daniel Weiskopf (Universität Stuttgart, DE), Ryan Wyatt (California Academy of Sciences – San Francisco, US), and Anders Ynnerman (Linköping University, SE)

Astrophysics lies at the crossroads of big datasets (such as the Large Synoptic Survey Telescope and Gaia), open source software to visualize and interpret high dimensional datasets (such as Glue, WorldWide Telescope, and OpenSpace), and uniquely skilled software engineers who bridge data science and research fields. At the same time, more than 4,000 planetariums across the globe immerse millions of visitors in scientific data. We have identified the potential for critical synergy across data, software, hardware, locations, and content that—if prioritized over the next decade—will drive discovery in astronomical research. Planetariums can and should be used for the advancement of scientific research. Current facilities such as the Hayden Planetarium in New York City, Adler Planetarium in Chicago, Morrison Planetarium in San Francisco, the Iziko Planetarium & Digital Dome Research Consortium in Cape Town, and Visualization Center C in Norrköping are already developing software which ingests catalogs of astronomical and multi-disciplinary data critical for exploration research primarily for the purpose of creating scientific storylines for the general public. We propose a transformative model whereby scientists become the audience and explorers in planetariums, utilizing software for their own investigative purposes. In this manner, research benefits from the authentic and unique experience of data immersion contained in an environment bathed in context and equipped for collaboration. Consequently, in this white paper we argue that over the next decade the research astronomy community should partner with planetariums to create visualization-based research opportunities for the field. Realizing this vision will require new investments in software and human capital.

4.5 Presentation & Authoring

Jackie Faherty (AMNH – New York, US), Brian Abbott (AMNH – New York, US), Hidehiko Agata (NAOJ – Tokyo, JP), Alexander Bock (Linköping University, SE & University of Utah, US), Dave Brown (Microsoft Research – Redmond, US), Charles D. Hansen (University of Utah – Salt Lake City, US), Tom Kwasnitschka (GEOMAR Helmholtz Centre for Ocean Research Kiel, DE), Wolfgang Steffen (Universidad Nacional Autonoma de Mexico – México, MX), Gabriel Stöckle (Naturhistorisches Museum Wien, AT), Mark Subbarao (Adler Planetarium – Chicago, US), Ryan Wyatt (California Academy of Sciences – San Francisco, US), and Anders Ynnerman (Linköping University, SE)

Astrographics come to life when coupled with story—either in a live presentation or a pre-recorded narrative. Presentation and authoring are thus core functions of astrographics tools, and we address priorities and goals for improving these functions.

As one participant noted, "personal presentation is the most powerful means of communication," and live presentation forms the core of the astrographics experience in planetariums and other venues. The community should support presenters in becoming the best they can be, and both training and tool development were identified as key in advancing the field.

There is also the desire to capture the essential qualities of a live presentation—for sharing with other presenters and venues, for domecasting from one theater to another, or for authoring a playback version of the content

4.6 Software Integration

Alyssa A. Goodman (Harvard-Smithsonian Center for Astrophysics, US), Emil Axelsson (Linköping University, SE), Thomas Boch (Université de Strasbourg – Strasbourg, FR), Carter Emmart (AMNH – New York, US), Andreas Gerndt (DLR – Braunschweig, DE), David H. Laidlaw (Brown University – Providence, US), Thomas Müller (Haus der Astronomie – Heidelberg, DE), Thomas P. Robitaille (Aperio Software – Leeds, GB), and Edwin A. Valentijn (University of Groningen, NL)

It can be argued that before this seminar that the planetarium was not a scientific tool. Merging the tools and methods of science into the immersive dome display environment of the planetarium has been envisioned but the results of this gathering have enabled the fledgling steps toward this goal. With capacities upward to several hundred in one place, and ability to network such facilities together worldwide the planetarium community has always held the potential for wide scale group immersion. From this point forward, scientists with tools familiar to them can now use the global planetarium network for focused interaction with their data to concentrate and multiple mental solutions on vital scientific line of inquiry. While tested in academia and industry it can be argued that the results of this seminar have enabled a vital linkage for large scale data immersion like never before, which in essence is a paradigm shift.

4.7 How do we, planetaria, get better together and share / stream content?

Edwin A. Valentijn (University of Groningen, NL), Carter Emmart (AMNH – New York, US), Jackie Faherty (AMNH – New York, US), Mark Subbarao (Adler Planetarium – Chicago, US), and Ryan Wyatt (California Academy of Sciences – San Francisco, US)

We had an intense brainstorming session in which we have assessed many current aspects of collaborations in between planetaria and with vendors. We summarize the recommendations phrased at this brainstorm on various topics.

- Streaming in real time full dome live content from an event to dome(s): There is not not so much interest in the general community, but DOTliveplanetarium will pursue this and report on its merits to the other participants.
- Streaming in real time live full dome content between different planetariums (domecasting): This is an interesting mode of operation and allows sharing content. OpenSpace can/should be the preferred platform for this, facilitating both sending and receiving streams. We suggest a community effort to help OpenSpace to achieve this goal.

4.8 Support for Analysis Tools

Anders Ynnerman (Linköping University, SE)

This breakout session focussed on aspects of data analysis. The broad-ranging discussion can be grouped into three topics: flow from data discovery to data analysis; making the visualization traceable; and novel analysis techniques with a particular focus on Artificial Intelligence/Machine Learning.

A challenge in data discovery is simply to be aware of a certain data set. We discussed how one might help people find data sets. We also noted how as a starting astronomer, it's hard to combine things. Data integration is elusive as compared to working within a single data set. Data sources and links embedded in images have a lot to do with lineage and traceability, and the smooth transition from discovery to analysis. Visual flow is needed for really low friction interactions (find the data quickly) – tools of visualization can be used for data discovery before exploration. Broad explorations needed for hypothesis generation. In our view, we haven't yet applied the methods of visualization to questions of data discovery

How does one best capture a visualization session? Being able to reproduce the dialogue of such a session has benefits in many domains: it can help in teaching and training users and the promotion of best practice. Done well, it can aid in scientific discovery. We discussed a number of issues and technical details related to traceability. It is not obvious how best to capture the visualization. For example in going from the initial data to the final visualization, one may take a relatively circuitous path with a number of blind alleys. Does one remove some of these? All of these? Mistakes can provide valuable lessons. They may lead to discoveries of ways forward by other subsequent users. One should therefore compress with caution. We have code for tracking code (version control). Do we have visualization for tracking visualization? We noted in the discussion that viztrails goes somewhat in this direction.

Very much connected with the above discussion are the prospects to use AI/ML to aid users. This support can take many formats. For example, recommender systems can help users to find data sets (the unknown unknowns) – those who looked at X, also looked at Y…We noted how this could be applied to both data sets and research papers. In a broad sense, we identified three types of AI augmentation: one could help speed the visualization process along by doing the same functions as a user but just more quickly; one could also provide faster fitting; and perhaps most significantly one could provide deeper insight. In this third type of support, we envisage the AI system to help show the way, ie help turn a novice user into a more-experienced user. We did however note some possible pitfalls. The AI could for example make erroneous inferences about the users intentions: for example recommending colour maps to demarcate certain parts of the data whereas in reality the user is interested in other parts: emphasising the peaks when the user wishes to find the troughs.

4.9 Virtual Presenters

Anders Ynnerman (Linköping University, SE) and Carter Emmart (AMNH – New York, US)

An exciting new development in computer graphics and data analysis is the embodiment of the visualization/narration system itself as an avatar, or cognitive companion. For some tasks, such as training, natural interaction, and presentation of aggregated information, the avatar could be manifested as a photo-real digital human. For other tasks, the cognitive companion can be represented as visualizations of multi-source aggregated data. One of the most natural human-friendly approaches to interfacing to the system is for the user to simply be able to ask informed questions about the application domain, and to expect contextualized, insightful answers. For instance, whether the modality used in the interface is an avatar or visualization of complex data, one still wants to ask questions to the avatar, or about the visualization, as if one is having a dialogue with a literate, expert, in short a cognitive assistant.

As an example of possibilities for new levels of interaction with human representations are rapidly opening up through recent advances in visual representation of human avatars imaging using light field displays supporting virtual human style interaction. A light field display is a system which offers viewing of stereoscopic 3D-images from arbitrary positions without 3D-glasses. Compared to traditional 2D displays which shows a 2D image these, new displays show 4D light fields, which for each pixel encodes the angular intensity variations making it a see-through window into the virtual 3D-world. Light field viewing experiences will fundamentally change our notion of a display, how we use it and how we develop content for it.

An exciting possibility is thus the development of a Q&A systems tailored for visual science communication. IBM introduced Watson (www.ibm.com), a technology platform based on natural language processing and machine learning intended to analyze large amounts of unstructured data, and to query the results to provide deep insight about a particular application domain. The combination of natural interaction with human representations using technologies such as light field displays, where avatar representations act as conveyors of information and ultimately, with such a Q&A systems could lead to a virtual guide that would further increase the possibilities to provide engaging and explainable visualization for general audiences.

Hand-held navigation interface for controlling dome software via a smartphone or similar pressure-sensitive touchscreen device would be useful. In the planetarium setting, a presenter typically discusses with the audience while the pilot must remain at a desktop computer station to drive and navigate the presentation's software. For even simple programs to be engaging, a production necessitates two performers: the pilot and a presenter, who can remain visible and accessible to the audience. Similar to a drone controller, a handheld device to control the camera path would eliminate the pilot. Having virtual joystick controls for the left/right thumbs allows arbitrary (within the constraints of dome comfort) camera motions for flying through a scene. Additionally, one could use the accelerometers of a device such as an iPhone to control the camera path freeing the presenter to focus on the dome and move through a scene.

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