Scientific and Information Visualization - Possibilities and Challenges

Thomas Odaker, Dieter Kranzlmüller
with support from Jutta Dreer

Visualization
What is Visualization?

What is visualization?

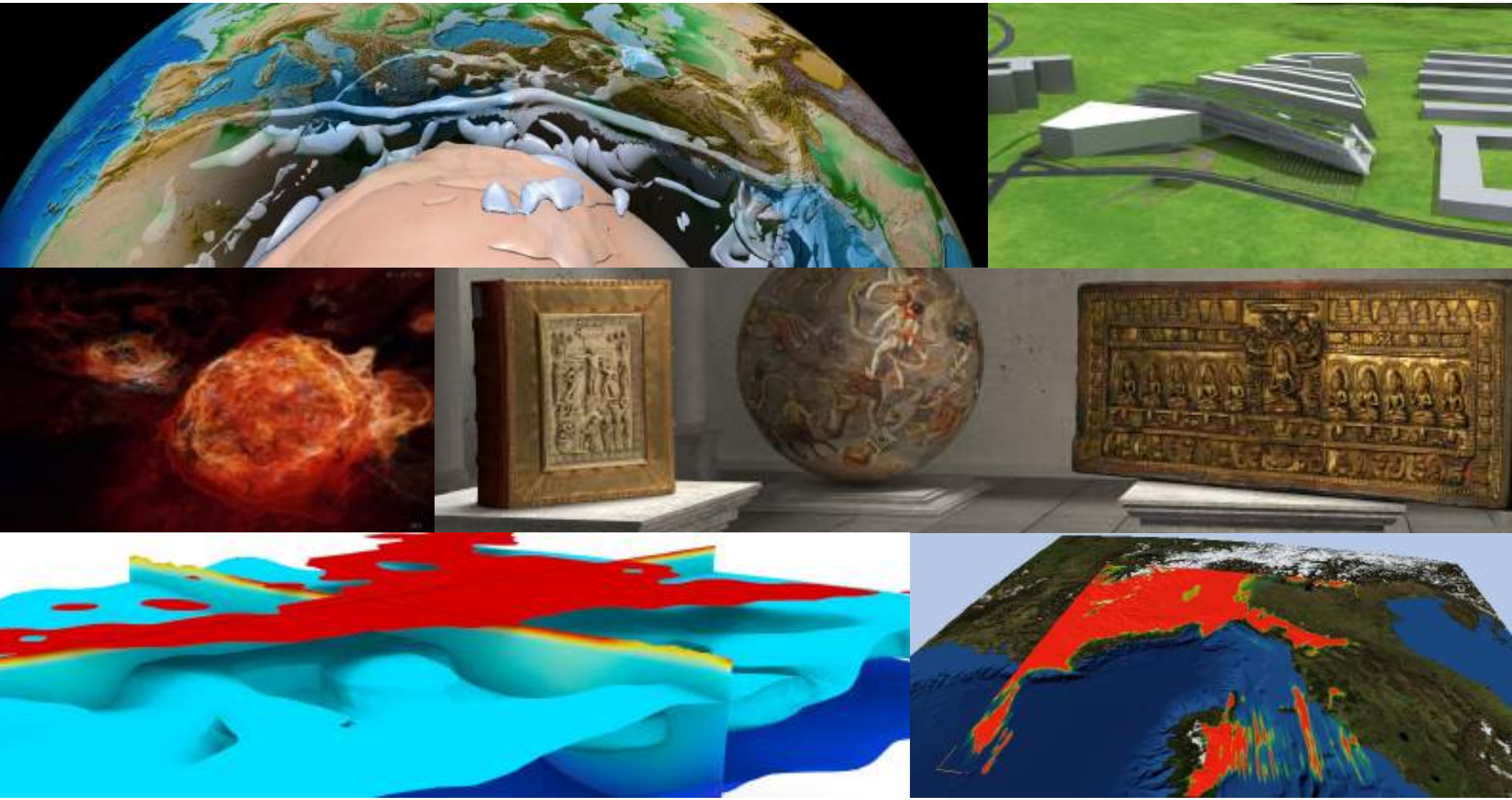
- The creation of a visual representation of complex datasets
- Aims to make the data easily understandable

Usually, visualization relies on the methods of computer graphics to generate the imagery

Nowadays, visualization is used in almost every field of research:

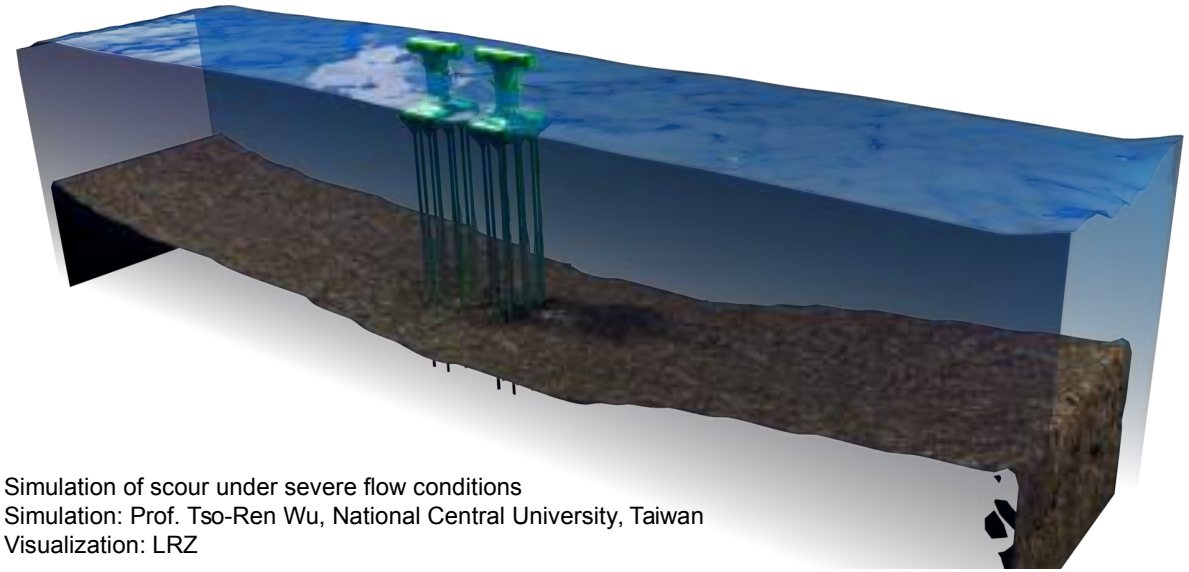
architecture, archaeology, geophysics, material sciences, history of art, medicine, meteorology, glaciology, bioinformatics, zoology, physics, logistics, chemistry, …

Visualization



Visualization
Why do we need Visualization?

"*A picture is worth a thousand words*"



Simulation of scour under severe flow conditions
Simulation: Prof. Tso-Ren Wu, National Central University, Taiwan
Visualization: LRZ

- Scientific data can be incredibly complex (sometimes even terabytes of data)
- Understanding the data is crucial for gaining knowledge
- Retrieving information from datasets can be very difficult
- Visualization can help us to understand the data and the information it contains

Visualization
Interactive Visualization

Ideally, visualization is interactive

- User can interact with the visualization
- Many input devices available
  (mouse, keyboard, controller, wand, …)
- Interactivity can greatly improve visualization
  - Simple movement, looking at the visualization from “the right angle”
  - Selection of data
  - Manipulation of data
- Interactivity poses new challenges
  - High framerates required
  - Processing of user inputs

Visualization

Visualization can be separated into *scientific visualization* and *information visualization:*

Scientific visualization:

- Display of complex datasets
- Natural representations of data
- Helps to understand the data

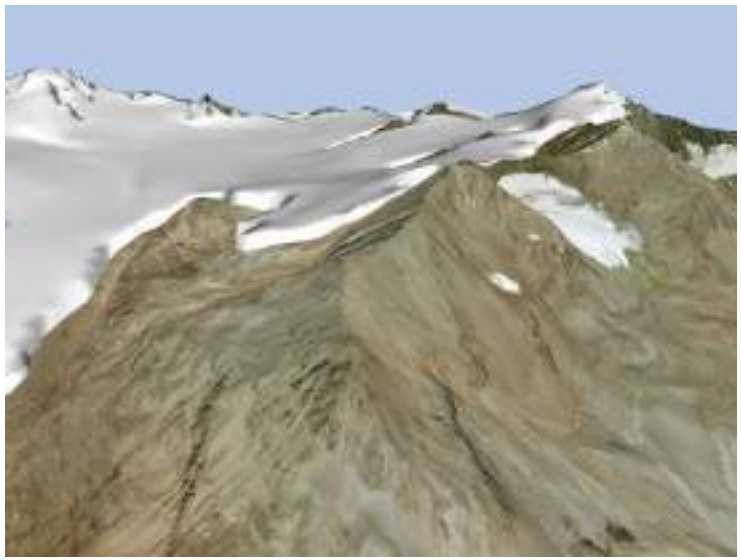
Information visualization:

- Enhanced display of contained information
- Create visualizations of data to illustrate certain information
- Helps to understand information extracted from the data

Scientific Visualization

Scientific visualization relies on the methods of computer graphics

- Creates natural representations of data
- Allows scientists to understand their data
- Aims to visualize the data itself rather than extracted information



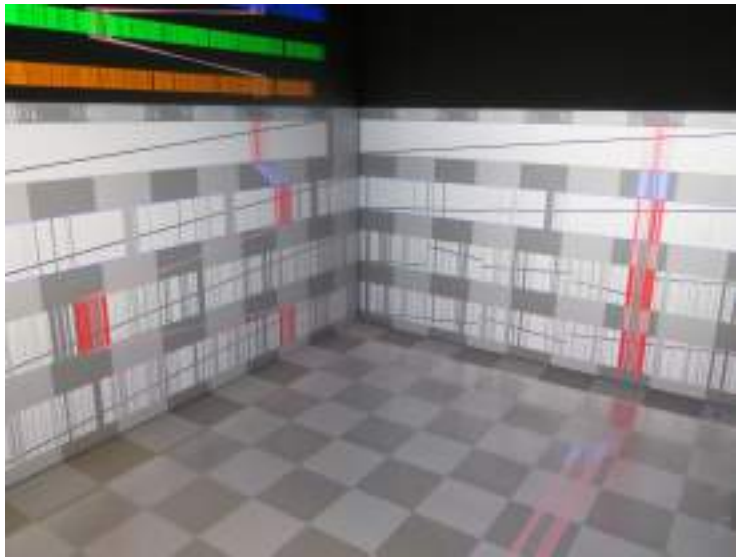
Historical glacial advance
Dr. Ludwig Braun, Dr. Markus Weber, Bavarian Academy of Science and Humanities
Jutta Dreer, LRZ
Anton Koslow, Ludwig-Maximilians-Universität

Scientific and information visualization are not strictly separated

Information Visualization

Information visualization usually deals with abstract data

- Data is extracted from a dataset
- A visual representation is chosen (designed so humans can recognize patterns, relationships, context, …)
- Often abstract representations to visualize certain aspects of the dataset
- Usually deals with very large amounts of data



Comparing genomes in virtual reality
Mr.SymBioMath project (funded by the EU)
Dr. Balázs Tukora, Dr. Christoph Anthes, Paul Heinzlreiter, LRZ

Visualization
Tools

For many scenarios, certain visualization techniques are commonly used (e.g. volume rendering for medical imaging)

Software tools aim to make visualization easier and more accessible

Many tools are available for visualization

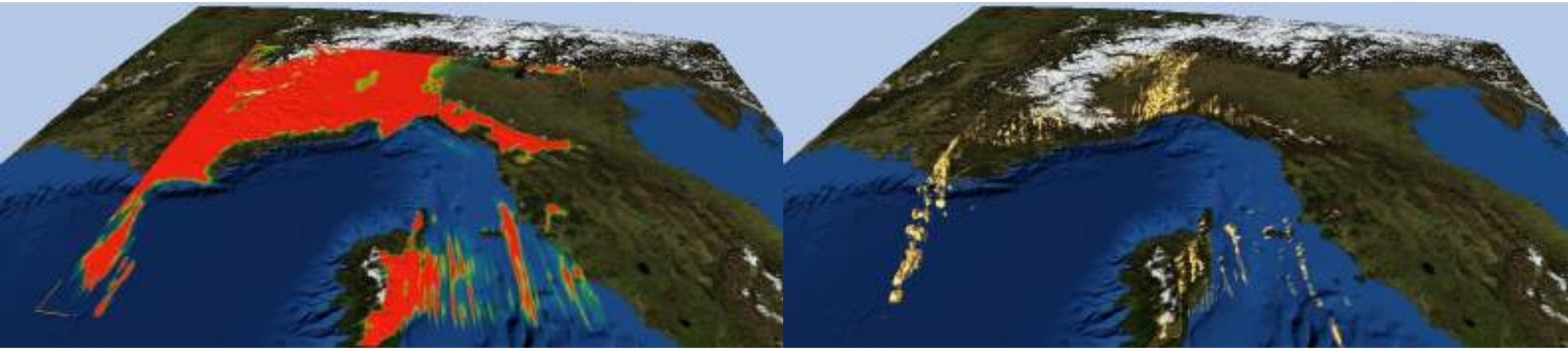
- Amira
- Covise
- Paraview
- …

Software for Visualization:
Amira

Amira is a 3D visualization and analysis software for scientific data:

- 3D modular software development environment for visualization applications
- Emphasis on life science and material science data, but also used as a general purpose tool
- Support for stereoscopic rendering
- Support for multi-display environments
- Commercial product

Software for Visualization:
Amira – Project Showcase: DRIHM



Analysis of intense rain in Liguria
Dr. Antonio Parodi, DRIHM project leader, CIMA research foundation
Visualization: Jutta Dreer, LRZ

DRIHM – Distributed Research Infrastructure for Hydro-Meteorology

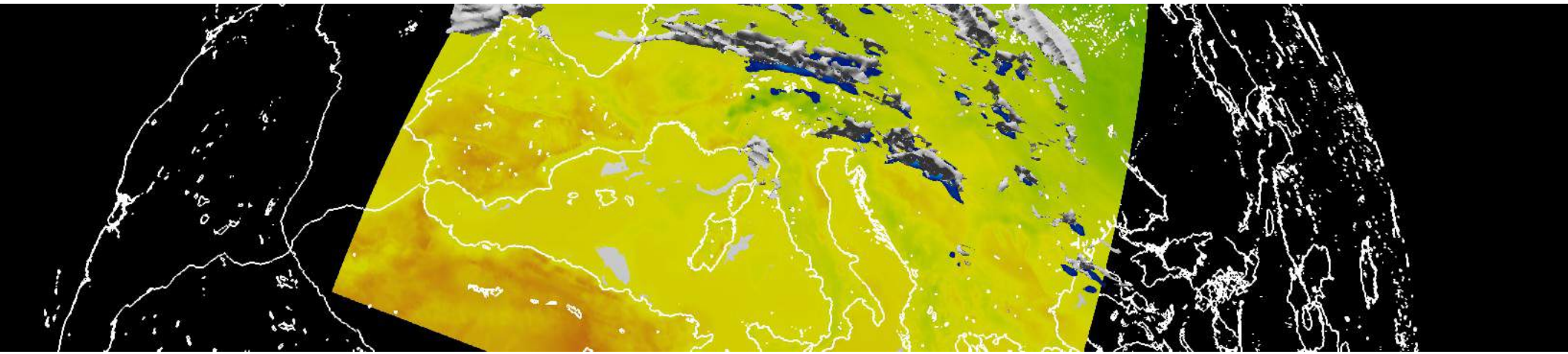
- Climate research project funded by the EU
- Developing and providing tools to predict the effects of meteorological events on the environment
- Examination of weather events (e.g. flash flood in Genoa 2011)
- Visualization crucial to evaluate model and simulation data

Software for Visualization:
Covise

COllaborative VIsualization and Simulation Environment:

- Developed by HLRS (University of Stuttgart)
- Extendable, modular software environment
- Emphasis on engineering sciences, but also for other visualization use cases
- Collaborative visualization and data analysis
- Support for stereoscopic rendering and multi-display environments
- Open Source since 2015

Software for Visualization:
Covise – Project Showcase: ClimEx



Prof. Ralf Ludwig, Ludwig-Maximilians Universität
Visualization: Jutta Dreer, LRZ

ClimEx project

- Assessment of the effects of climate change on hydrological extreme events such as flooding and droughts
- Relies on data from Bavaria and Québec
- Coupling HPC models for climate and hydrology, workflow and data management

Software for Visualization:
Paraview

Open-source data analysis and visualization application

- Application for interactive, scientific visualization
- Integrated level of detail system to maintain interactive framerates
- Used in many scientific communities (not restricted to certain domains)
- Developed to support very large datasets (using distributed memory computing resources)
- Designed to scale well (even runs on supercomputers and clusters)

Software for Visualization:
Limitations

Sometimes, standard software tools cannot fulfil the requirements for the visualization:

- Custom input data
- Custom file formats
- Extremely large datasets
- Pre-processing of datasets
- Highly optimized processing of huge datasets required
- Custom visualization requirements by scientists
- …

For such cases, custom visualizations usually provide the best results

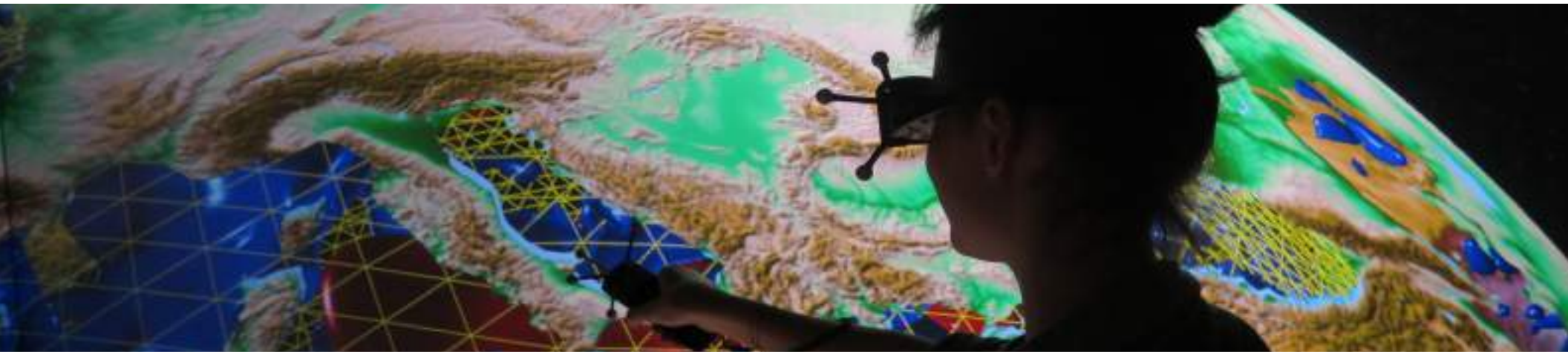
Custom Visualizations
Project Showcase: Geophysics

Prof. Dr. Hans-Peter Bunge, Dr. Bernhard S.A. Schuberth, Ludwig-Maximilians-Universität
Visualization: Markus Wiedemann, Michael Käsdorf, LRZ

Geophysicists developed a simulation of the convection currents in earth's mantle

- Period of 200 millionen years, 2 millionen year time steps
- About 607 GB of raw data in 2015
- About 13 000 GB of raw data in 2017, not including data for continental drift
- No software tool could fulfil the requirements for the visualization

Custom Visualizations
Project Showcase: Geophysics

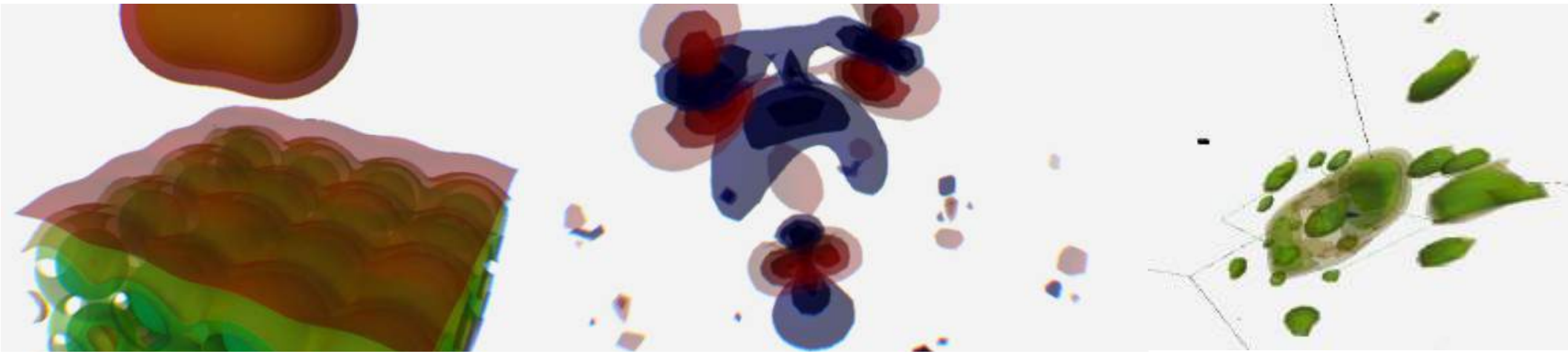


Prof. Dr. Hans-Peter Bunge, Dr. Bernhard S.A. Schuberth, Ludwig-Maximilians-Universität
Visualization: Markus Wiedemann, Michael Käsdorf, LRZ

Visualization developed by the LRZ

- Developed in virtual reality to provide an intuitive and easy to understand representation of the model
- Visualization revealed previously unnoticed inaccuracies and artefacts in the simulation data
- Simulation has been improved based on feedback derived from the visualization

Custom Visualizations
Project Showcase: Material Sciences

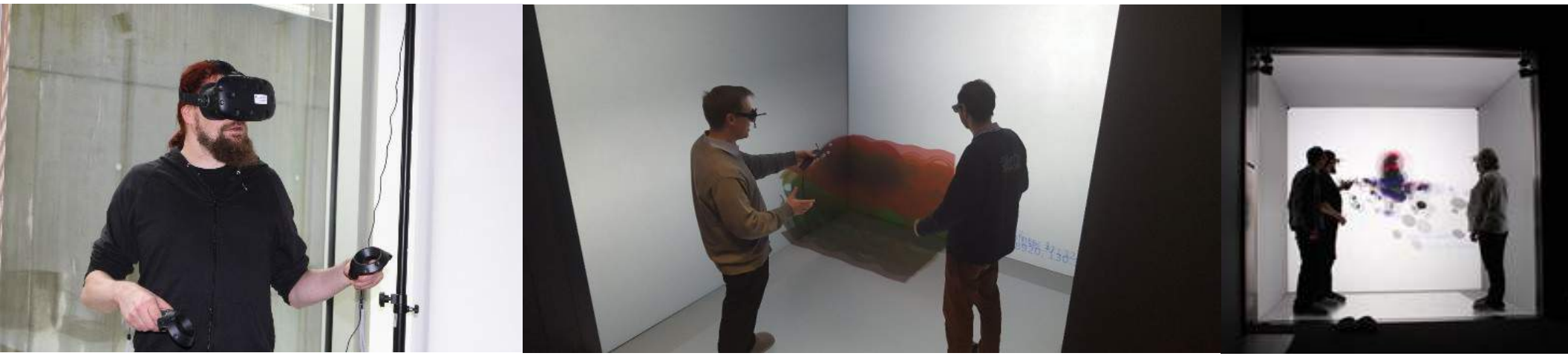


Dr. Rubén Jesús García-Hernández , LRZ

NOMAD – NOvel MAterials Discovery

- Project funded by the EU
- Project is dedicated to Big data in material sciences
- NOMAD creates, collects, stores and cleanses data
- Data is produced by chemical simulations
- Goal is to not only provide the data itself, but also the tools to understand and properly use it

Custom Visualizations
Project Showcase: Material Sciences



Dr. Rubén Jesús García-Hernández , LRZ

Visualization is an important part of NOMAD

- Visualizations are used to enable understanding of the large volume of data
- Virtual reality is used to “bring the user to the nanoscale“
- Support for a wide variety of devices (from Google Cardboard to multi-display environments)
- Provides a way to understand the data for everyone

Challenges of Visualization

Visualization is a challenging topic:

- Identifying the “best” way to visualize a dataset
- Pre-processing data
- Tailoring a visualization to existing constraints (available hardware, devices, …)
- Interactivity
- …

Challenges of Visualization
The Human Factor

Often researchers producing the data are not experts in computer graphics/visualization (and vice versa)

- Mutual lack of knowledge
- Communication can be very difficult (requires good knowledge of the other party's topic)
- Person doing the visualization needs to identify what the relevant part of a dataset is
- Researcher should be aware of the limitations of computer graphics and hardware
- Finding a common ground can be a long and difficult process
- Lack of communication/common ground can greatly increase the difficulty and lower the quality of the visualization

Challenges of Visualization
Data Pre-processing

Visualization and data pre-processing are often tightly linked together

- Data needs to be extracted from the dataset (especially true for information visualization)
- Large datasets may need to be reduced in size
- Storing data in an efficient layout for later processing
- Processing existing datasets into new types of data (e.g. creating meshes from simulations)
- Gathering statistics from datasets

Challenges of Visualization
Hardware Limitations

Visualization is often restricted by the available hardware (especially true for real-time, interactive visualizations)

- Simulations may take days, weeks or months to compute
- Waiting days for a single image is not fun (and usually not useful)
- Real-time visualizations compute a new image every few milliseconds
- Graphics hardware is limited (memory constraints, …)
- Tailoring visualizations to the limitations of output devices (computer monitor, head-mounted displays, stereoscopic displays, …)

Challenges of Visualization
Interactivity

Reacting to user input adds an additional layer of complexity

- User input is unpredictable
- Update of the visualization based on user input should be immediate (avoid waiting times)
- Requires high framerates
- Changes in perspective (controlling the camera) is relatively easy
- Data selection and modification by the user can be very challenging

Conclusion

- Visualization of data is useful, sometimes even crucial to understanding it
- Visualization can reveal (unexpected) phenomena, patterns, … that are very hard to notice in the data
- Commonly available tools can make life a lot easier for scientists

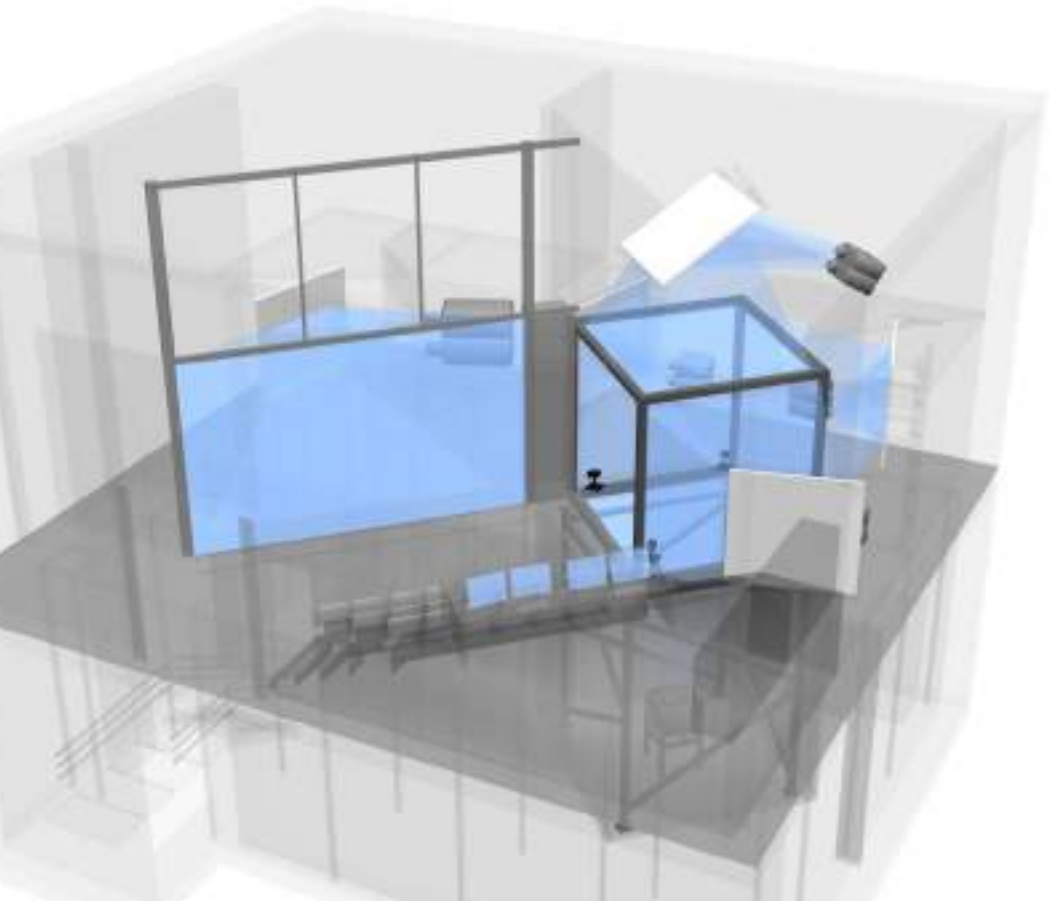
- Visualization is not easy … good visualization is often very hard
- Software tools cannot fulfil all requirements
- Developing a good visualization can be just as labour intensive as producing the data

V2C
Visualization at the LRZ

Centre for Virtual Reality and Visualisation (V2C)

- Building finished in 2011
- Interior design and media installation setup in january 2012
- Opening celebration on 25.10.2012

Installations at the V2C



Powerwall

- 4k display
- passive stereo
- tracking system

5-sided projection installation

- 10 projectors
- active stereo
- tracking system

Compute infrastructure for the visualization of large datasets

- Shared memory machine for the Powerwall
- 12 compute nodes for the 5-sided projection installation

Mission of the V2C

Service provider

- Providing visualization infrastructure
- Preparation of datasets
- Providing standard software solutions for visualization
- Development of custom visualizations and software

Research

- Advancing research in the areas of visualization and VR
- Supervision of students' theses
- Research cooperations