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Aims and Scope
The periodical *Dagstuhl Reports* documents the program and the results of Dagstuhl Seminars and Dagstuhl Perspectives Workshops.
In principal, for each Dagstuhl Seminar or Dagstuhl Perspectives Workshop a report is published that contains the following:
- an executive summary of the seminar program and the fundamental results,
- an overview of the talks given during the seminar (summarized as talk abstracts), and
- summaries from working groups (if applicable).

This basic framework can be extended by suitable contributions that are related to the program of the seminar, e. g. summaries from panel discussions or open problem sessions.

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Report from Dagstuhl Seminar 19151

Visual Computing in Materials Sciences

Edited by

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Abstract

Visual computing has become highly attractive for boosting research endeavors in the materials science domain [1]. Using visual computing, a multitude of different phenomena may now be studied, at various scales, dimensions, or using different modalities. This was simply impossible before. Visual computing techniques generate novel insights to understand, discover, design, and use complex material systems of interest. Its huge potential for retrieving and visualizing (new) information on materials, their characteristics and interrelations as well as on simulating the material's behavior in its target application environment is of core relevance to material scientists. This Dagstuhl seminar on Visual Computing in Materials Sciences thus focuses on the intersection of both domains to guide research endeavors in this field. It targets to provide answers regarding the following four challenges, which are of imminent need:

- **The Integrated Visual Analysis Challenge** identifies standard visualization tools as insufficient for exploring materials science data in detail. What is required are integrated visual analysis tools, which are tailored to a specific application area and guide users in their investigations. Using linked views and other interaction concepts, these tools are required to combine all data domains using meaningful and easy to understand visualization techniques. Especially for the analysis of spatial and temporal data in dynamic processes (e.g., materials tested under load or in different environmental conditions) or multimodal, multiscale data, these tools and techniques are highly anticipated. Only integrated analysis concepts allow to make the most out of all the data available.
- **The Quantitative Data Visualization Challenge** centers around the design and implementation of tailored visual analysis systems for extracting and analyzing derived data (e.g., computed from extracted features over spatial, temporal or even higher dimensional domains). Therefore, feature extraction and quantification techniques, segmentation techniques, or clustering techniques, are required as prerequisites for the targeted visual analysis. As the quantification may easily end up in 25 or more properties to be computed per feature, clustering techniques allow to distinguish features of interest into feature classes. These feature classes may then be statistically evaluated to visualize the properties of the individual features as well as the properties of the different classes. Information visualization techniques will be of special interest for solving this challenge.
- **The Visual Debugger Challenge** is an idea which uses visual analysis to remove errors in the parametrization of a simulation or a data acquisition process. Similarly, to a debugger in computer programming, identifying errors in the code and providing hints to improve, a visual debugger in the domain of visual computing for materials science should show the following characteristics: It should indicate errors and identify wrongly used algorithms in the data analysis. Such a tool should also identify incorrect parameters, which either show no or very limited benefit or even provide erroneous results. Furthermore, it should give directions on how to improve a targeted analysis and suggest suitable algorithms or pipelines for specific tasks.

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- **The Interactive Steering Challenge** uses visual analysis tools to control a running simulation or an ongoing data acquisition process. Respective tools monitor costly processes and give directions to improve results regarding the respective targets. For example, in the material analysis domain, this could be a system which provides settings for improved data acquisition based on the current image quality achieved: If the image quality does no more fulfill the target requirements, the system influences all degrees of freedom in the data acquisition to enhance image quality. The same holds for the materials simulation domain. Visual analysis can help to steer target material properties in a specific application environment by predicting tendencies of costly simulation runs, e.g., using cheaper surrogate models.

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1 Executive Summary

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In this Dagstuhl workshop, we brought together computer and computational scientists interested in building tools for use in visual computing with material scientists with expressed interest in using such tools. As would be anticipated when one brings together two distinct fields, the initial challenge we encountered was that of language. Although both groups came together having experiences with visual computing tools – some as developers and some as users – although they often used the same terms, they semantically meant different things. We found that the Dagstuhl philosophy of "immersion" was most helpful to this issue as having several days together helped break down these barriers. Over the course of the week, we interspersed talks by computational scientists and material scientists. The talks by computational scientists often presented their current understanding of what kinds of tools are needed, demonstrations of current tools they have developed in collaboration with domain-specific experts, and success stories of applications they have currently impacted. The talks by the material scientists often presented a description of the tools they currently use, the positive points and deficiencies of current tools, the types of features that they would like to see in future tools, and examples of current challenge problems and how they might be impacted by the next generation of tools.

Fundamental Results:

1. The systems that are desired by many material scientists will be used both for exploration and for interactive steering. When used for exploration, material scientists want tools that not only present the data with its corresponding reliability (uncertainty) bounds, but which also give predictive capabilities such as where next to sample.
2. There is a general acknowledgement that both automation and interactivity are needed. Automation of tasks and procedures through AI and Machine Learning can be used to help deal with the volumes of data being produced – helping scientists sift through the field of possibilities to isolate those places for which they should expend human effort. At the same time, there are many current practices that continue to require "the human in the loop" to make decisions. In such cases, tools are needed that have smart defaults but yet allow the user to explore, navigate and possibly refine data.
3. Although many current tools used for material science applications leverage previous visualization and interaction technologies, there is still much to be done. Many material science applications require specialization of currently existing algorithms and techniques, especially in cases of real-time systems. Furthermore, many techniques originally designed for batch or manual processing need to be re-engineered to allow for the interactive procedures required by current and future material science application scientists.
4. With regards to visualization scientists, there is a need for both data and tasks. Many researchers requested data on which they can try their methods. In addition to the data itself, descriptors of the data are necessary so that it can be interpreted properly. Once read into their system, the visualization scientists then requested a collection of tasks (driven by the material science domain experts) which would help drive their tool development and evaluation.

Final Comments

Due to the ever-increasing interest in this topic, we foresee that future review articles and/or special issues of journals driven by multilateral research cooperations between seminars' participants will be an outcome of this workshop. To ensure and stimulate further cooperation in this field, a list of specific follow up activities has been elaborated and discussed with the participants. All in all, a fruitful discussion was stimulated across the two domains throughout the complete week of this Dagstuhl workshop which will become more obvious in joint research efforts of all kinds.

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Working groups

Panel discussions

3 Overview of Talks

3.1 Intuition-based Visual Analysis of Microstructures

Amal Aboulhassan (Material Solved – Alexandria, EG)

In our ongoing research, we propose a new direction of analyzing microstructures based on an intuitive visual analysis paradigm. We enable the researchers to predict the structure-function relationships even if modelling techniques or experimental data are limited due to various reasons (multi-scale and multiphysics phenomena occurring during the process, or limited access to the measurements). Our paradigm aims to include the human intuition into the analysis process naturally. It is achieved through an instantaneous update of the properties due to the edits in the microstructure. For example, the user immersed in the microstructure finds a small potential defect or bottleneck, removes it manually and gets an instant update on the properties. To enable such instant feedback the online analysis of the existing information is needed. In an ideal case scenario, the optimal update is also suggested. To handle the latter situation the inverse problem needs to be solved. Both these scenarios rely on two critical elements: (i) enabling the user to alter parts of the data and (ii) quantifying how these edits influence the overall performance. Editing the microstructures on the fly and link it with the properties is a challenging problem since this type of data is complex and big in many cases. Visual analysis and exploration is one strong potential solution in this case. Finally, once the ideal update to the structure is identified, the question remains – how to modify the manufacturing process to realize this editing? – which is an open problem in materials science.

3.2 Inline inspection and dynamic angle acquisition

Jan De Beenhouwer (Universiteit Antwerpen – Wilrijk, BE)

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In conventional X-ray-CT inspection of objects generated from a computer-aided design (CAD) model, a 3D CT reconstruction of the object is compared with the reference CAD model. This is a cost inefficient and tedious procedure, unsuitable for inline inspection. Alternatively, X-ray radiography based inspection is fast but fails to provide full 3D inspection. Here, we propose an inspection scheme based on a limited set of radiographs, which are dynamically selected during the scanning procedure. An efficient framework is described to determine the optimal view angle acquisition from a given CAD model and to automatically estimate the object pose in 3D with a fast, iterative algorithm that dynamically steers the acquisition geometry to acquire the set of chosen projections.

3.3 Tomography and the challenges in visualization

Gursoy Doga (Argonne National Laboratory – Lemont, US)

X-ray tomography is a nondestructive imaging technique that provides the internal structure of samples and its implementations at synchrotrons is heavily used by materials scientists. However, as the applications are pushed further into the nanoscale, the radiation dose limited conditions become more apparent, leading to challenges in achieving high resolution reconstructions. In this talk I will introduce a set of new computational imaging techniques that can yield superior reconstructions for high-speed or photon-limited imaging conditions when implemented as an integral part of the imaging setup. This approach requires re-design of both hardware and software components of a tomography system such that the overall performance is optimized rather than optimizing individual components. I will highlight some of the main challenges in visualization and other parts of this system compared to conventional systems.

3.4 Droplets, Bubbles and other Material Structures

Thomas Ertl (Universität Stuttgart, DE)

Visualization research at the University of Stuttgart contributes to material science in several large interdisciplinary projects primarily in the context of simulation-based research. The SFB 716 focused on particle simulation for which we developed MegaMol, a visualization framework providing advanced interactive visualization techniques for large particle datasets. The presented examples cover space-time clustering of atoms in laser ablation, extracting stacking faults, debugging clustering criteria in nucleation simulations, or discovering flexo-electricity effects in cracking metal oxides. The SFB/TRR 75 deals with droplet behavior under extreme conditions. By direct multi-phase flow simulation, breakup and coalescence of droplets are studied which pose many visualization challenges like coupling the spatial representation with space-time diagrams showing the topological evolution or tracking droplet dynamics over time. In the new SFB 1313 on interfaces in porous media we study the relation of CO2 bubbles and its porous surrounding geometry in saturated sandstone. The distribution of these bubbles does influence seismic properties of the material which will influence measuring leakage in CO2 sequestration. We present an analysis pipeline which groups extracted bubbles and surrounding structures according to their similarity and clusters them, allowing visual comparison after registration. By investigating bubble size and shape distribution, effects on phase velocity dispersion could be demonstrated.

3.5 The visualization challenge of tensor-valued strain data from loading experiments to predict mechanical failure

Christian Gollwitzer (BAM – Berlin, DE)

Concrete bars were subjected to mechanical load in different configurations (uniaxial pressure, double punch test and reinforcement bar pullout) until the samples were broken. During the loading, the samples were observed using X-ray computed tomography. Digital Volume Correlation (DVC) was then used to measure the deformation field in the sample between the unloaded state and the individual load steps. It would be valuable to predict the failure of the sample from the small deformations inside the sample. Classic failure criteria for concrete (Drucker-Prager, von Mises) were tested to evaluate the correlation between the location of the final cracks and the locations indicated by the failure criteria. Due to the derivative of the measured deformation fields for the failure criteria, the data is very noisy which makes the predicted locations of failure hard to see. On the other hand, displaying the projection of the deformation field across the crack direction indicates, that the information of the crack location is contained in the data. The challenge was formulated to derive a good visualization indicating only the failure location without computing noise-prone numerical derivatives.

3.6 Reformation and Sparse Interaction in Visualization

Eduard Gröller (TU Wien, AT)

Data visualization provides computer-supported interaction with visual representations of (abstract) data to amplify cognition. The increasing complexity of data requires interaction support and simplification of visual representations, also in light of investigating ensembles of data. Motivated by historical examples, typical case scenarios from various domains are discussed. These include: curved planar reformations, myocardium unfolding to bull's-eye plots, knowledge-based navigation, molecular dynamics exploration, defects analysis in industrial XCT data, and comparisons of large sets of volumetric data.

3.7 MESHFREE: CFD-simulation with interactive/computational steering

Hans Hagen (TU Kaiserslautern, DE)

MESHFREE is an innovative, gridfree simulation tool in fluid and continuum mechanics, developed by Fraunhofer ITWM. The numerical modelling is based on a cloud of points carrying all relevant physical information. Due to the meshfree character, it almost naturally mimics applications with free surfaces, moving geometries, and fluid structure interaction

(FSI). The gridfree setting of the method allows local/global refinement of the pointcloud (adaption of numerical resolution) as well as immediate response of the simulation towards changes in the geometry (adaption to form changes). Both types of adaptions may be subject to interactive steering, to be performed while the simulation is running. On-the-fly adaption of parameters of a running simulation is highly efficient, saving a lot of computation time as well as man-power in optimizing simulation results, especially in industrial design cycles. Only gridfree simulation methods provide the full potential to interactive steering. Based on a body inside of a flow, we will show how to: (1) interactively adapt the (local) refinement of the numerical pointcloud in order to gain a requested quality of the computed result (let us say the resistance force), and (2) interactively perform a simple shape optimization of the body towards some optimization constraint (let us say the minimization of resistance force).

3.8 Tomviz: An open source integrated tool for analysis, visualization, and debugging

Marcus Hanwell (Kitware – Clifton Park, US)

The Tomviz project has been funded by the US Department of Energy SBIR program, and offers a permissively licensed open source tool for tomography. It uses JSON to describe its pipeline, including all processing steps, and visualization parameters. This is coupled with a Python-centric data processing pipeline, and wrapped C++ taking advantage of parallelism and GPUs for visualization. Recently "live updates" were added to aid in the development of and debugging of reconstruction parameters in challenging atomic/high resolution scanning transmission electron microscopy tomography. The live updates of the pipeline as data is acquired on a microscope will also be described as it pertains to aiding in data acquisition. More generally at Kitware we develop a number of open source libraries, and open source tools for scientific data including VTK, ParaView, ITK, CMake, and others. There is a new project with a national lab to extend Tomviz to help their beamline tomography users, and a new project with another national lab to process 4D STEM data using HPC resources for very high data rate acquisitions. A recent Phase I SBIR seeks to develop a general framework for high data rate 4D STEM microscopy, offering a Python/C++ library for processing, web-based data management platform, and web application visualizing/previewing data. At the core the development of open source platforms as collaborative research and development platforms offers viable business models that can help drive open, reproducible science workflows forward.

3.9 Visually assisted reconstruction of geometric objects in microscopic data

Hans-Christian Hege (Konrad-Zuse-Zentrum – Berlin, DE)

The reconstruction of geometric objects from voxel data is a very common task in many fields, including almost all natural, materials, engineering, environmental and life sciences, as well as other fields such as archaeology. Research in image and geometry processing over the past decades has provided solutions for image denoising, image registration, image segmentation, surface and volume mesh creation that enable us nowadays to build up a generic geometry reconstruction pipeline in which at each stage a particular algorithm can be plugged in, selected from a small set of field-proven algorithms. This results in a fully automated reconstruction. The only phase for which considerable progress is still required is image segmentation. Here we should continue to strive for a smaller set of general applicable approaches that meet the needs of a wide range of applications with rather different needs (in terms of image properties, prior knowledge and segmentation objectives). Machine learning methods are particularly promising here.

Focusing on the situation, where the generic reconstruction pipeline needs to be extended or modified by some complex operation, the following strategy has proven to be successful: First, try to bridge the difficult/complex parts of the geometry reconstruction pipeline with manual, interactive, visually supported operations. Second, apply the resulting pipeline to real-world data sets, thereby creating (hopefully) ground truth results and getting more insight into the problem while solving it manually. Finally, utilize the gained insight and the established ground truth results to algorithmize the remaining manual portion. Do this gradually, until (ideally) no manual interaction is left. This approach has proven to be successful in many applications where a pure computer-vision approach, trying to solve the entire problem algorithmically from the beginning, would have failed. The strategy is illustrated on the example of two problems: (a) the reconstruction and quantification of dislocation substructures from stereo-TEM and (b) the reconstruction and unrolling of ancient papyri from μCT.

3.10 Imaging and Tracking Dynamic Phenomena in Materials Research

Wolfgang Heidrich (KAUST – Thuwal, SA)

Many applications in Material Science require imaging of time-varying data as well as an analysis of the motion fields between different configurations. In this talk I will focus on joint 4D (space+time) geometry and motion analysis using new tomographic reconstruction methods. These methods are applicable in any scenario where either a) a time-varying phenomenon is investigated with tomographic methods (X-ray, EM etc), and the time scale of the motion is comparable the frame rate of projections in the imaging system, or b) whenever the sample undergoes uncontrolled deformation during the scanning process (e.g. drift, heat expansion, or sample degradation). I will illustrate the methods using examples from composite material analysis and material porosity analysis among others. I will also highlight the relationship of these methods to recent fluid imaging methods.

3.11 Quantitative X-ray computed tomography for materials sciences

Johann Kastner (FH Oberösterreich – Wels, AT)

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X-ray computed tomography (XCT) currently transforms from a qualitative diagnostic tool to a quantitative characterization method. Quantitative XCT is the combination of XCT with quantitative 3D image analysis. Only through preprocessing and data enhancement, segmentation, feature extraction and quantification, rendering of the results, in-depth insights into XCT data a sample may be facilitated. In the beginning of industrial XCT, XCT images were generated mainly for visual inspection. The most important application of quantitative XCT is metrology Additionally, quantitative XCT is increasingly used for extracting a large variety of characteristics of materials and samples:

- Characterization of pores metallic and polymeric foams
- Porosity evaluation of metals and polymers
- Determination of fiber orientation, diameter and length of fiber-reinforced polymers as well as their distributions
- Fiber bundle extraction and characterization of technical textiles
- Quantitative data concerning the 3D structure of inhomogeneous metals or other materials (e.g., interconnectivity, sphericity, etc.)
- 3D characterization of isolated discontinuities such as cracks, voids, inclusions, delamination, etc.
- Phase identification and characterization
- Physical and mechanical properties (physical density, crack growth, wear) and, to a certain extent, chemical composition (alloy and phase identification, impurities)

3.12 Uncertainty Quantification and Its Role in Materials By Design

Robert Michael Kirby (University of Utah – Salt Lake City, US)

When computational methods or predictive simulations are used to model complex phenomena such as the response of physical systems to a range of conditions or configurations, researchers, analysts and decision-makers are not only interested in understanding the data but are also interested in understanding the uncertainty present in the data as well. Quantification, communication and interpretation of uncertainty are necessary for the understand and control of the impact of variability; these three – quantification, communication and interpretation of uncertainty – help add both understanding and robustness to the design process. In this talk, we present an overview of the multiscale modeling and uncertainty quantification efforts accomplished as part of the Center for Multiscale Modeling of Electronic Materials (MSME), a collaborative partnership between academia and the Army Research Laboratory. In particular, we will focus on our successes in cross-cutting areas – bringing uncertainty quantification techniques originally developed within a particular discipline to a broader class of materials by design problems. We will also attempt to address the question of "why now?" – what current factors and trends explain the recent rise in uncertainty quantification efforts, and what we can learn from these trends.

3.13 Advanced impact damage characterisation of composite laminates by X-ray Computed Tomography

Fabien Leonard (BAM – Berlin, DE)

One of the great strengths of X-ray computed tomography over conventional inspection methods (ultrasound, thermography, radiography) is that it can image damage in 3D. However for curved or deformed composite panels, it can be difficult to automatically ascribe the damage to specific plies or inter-ply interfaces. An X-ray computed tomography (CT) data processing methodology is developed to extract the through-thickness distribution of damage in curved or deformed composite panels. The method is applied to [(0°/90°)2]s carbon fibre reinforced polymer (CFRP) panels subjected low velocity impact damage (5 J up to 20 J) providing 3D ply-by-ply damage visualisation and analysis. Our distance transform approach allows slices to be taken that approximately follow the composite curvature allowing the impact damage to be separated, visualised and quantified in 3D on a ply-by-ply basis. In this way the interply delaminations have been mapped, showing characteristic peanut shaped delaminations with the major axis oriented with the fibres in the ply below the interface. This registry to the profile of the panel constitutes a significant improvement in our ability to characterise impact damage in composite laminates and extract relevant measurements from X-ray CT datasets.

3.14 Through the micro-CT and what we found there? Quantifying images of fibrous materials

Stepan V. Lomov (KU Leuven, BE)

Description of a textile composite microstructure involved, identification of individual yarns/fibrous plies in the textile reinforcement. definition of local parameters of fibrous geometry: local fibre directions, local fibre volume fraction and description of the amount and (especially in the case the textile is a reinforcement of an impregnated composite) morphology of voids. The advanced method for acquiring such a description is micro-computed (micro-CT) tomography, which is a powerful tool for imaging of the internal structure of materials. The result of a micro-CT imaging is a 3D array of values ("grey scale"), which characterise the X-ray attenuation in the corresponding locations in the material. The challenge of the textile materials characterisation using micro-CT images is quantification of the image, identifying the parameters of the microstructure by analysis of the grey scale array. Such a quantification can be partially done by image thresholding and binarisation, which is the most common way of the 3D image processing. However, direction-related features are not easily determined using the binarisation. The paper describes methods and the software (VoxTex), which analyse the grey scale array to produce the description of the textile microstructure as an array of volume elements (voxels), each of element carrying information of the fibre directions and fibre volume fraction in it. Apart from that, the void contents and the voids morphology in textile composites are characterised. The methods are based on a two-parameters analysis of the image: local grey scale value and anisotropy, defined via the structure tensor of the grey scale field [1]. The paper presents validation of the VoxTex quantification of fibre directions and voidage measured with independent methods and overviews application of the methods to different problems related to details of the fibrous microstructure of textiles.

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3.15 Experiences with synchrotron users working in material science and some of their challenges in the domain of 'The integrated Visual Analysis'

Lucia Mancini (Elettra – Sincrotrone Trieste S.C.p.A. – Trieste, IT)

Imaging techniques based on the use of hard X-rays play an important role in several research fields and industrial applications. Many topics in medicine, biology, material science, geosciences and cultural heritage studies can be afforded thanks to the high potential and large applicability of hard X-ray imaging techniques. In the last twenty years a great effort has been devoted to the development of X-ray computed microtomography (micro-CT) techniques, both employing microfocus and synchrotron radiation sources. Nowadays, these techniques allows to produce 3D or 4D (dynamic) micro-CT images of the internal structure of objects at the micron- and submicron- scale. Investigations performed directly in the 3D domain overcome the limitations of stereological methods usually applied to microscopy-based analyses and a non-destructive method is more suitable for further complementary analyses and for precious or unique samples (fossils and archeological finds, in-vivo imaging, etc ...). In the field of materials science, an intriguing challenge is to extract directly from 3D and 4D images some parameters allowing to characterize structural, chemical and physical properties of the studied materials. However, accurate image processing, analysis and visualization methods for an effective assessment of these parameters are still an open issue especially in the case of time-resolved and multi-scale and multi-modal CT experiments. In this talk, thanks to the experience gained working in collaboration with several users of the SYRMEP beamline of the Elettra synchrotron facility or working as user in different laboratories and synchrotron facilities, several scientific applications of advanced hard X-ray imaging techniques will be presented trying to critically expose the progress, limitations and open problems in the different fields.

3.16 Why do we need visual and automatised data reduction schemes in X-ray experiments?

Rajmund Mokso (Lund University, SE)

Tomographic measurements at synchrotron and laboratory X-ray sources are today fast and come with a large data sizes. Visualisation is important at various stages of these studies and we may distinguish between three types of visualisation tools as a function of time counted from the start of an X-ray imaging experiment. First we aim to follow the acquisition process itself but visualising the streams of data. At this stage we would need to employ robust and simple visualisation tools which will enable quick decision making during the acquisition. The second stage is just after the data is acquired. The tomographic reconstruction is fast and in the majority of cases we rely on visualising a gray scale image of one slice as quality control. Here we would welcome the visualisation of the features of interest in 3D instead of the gray scale slice. In the third stage for the final quantification of the volumes, the challenge is in decomposing the found quantities (e.g. particle shapes, orientations or curvatures) into as simply as possible arrays to characterise the material in 3D and often in a time resolved manner. Owners of imaging data are most often not experts in image analysis or visualisation, accordingly the tools must be well documented and as simple to work with as possible. The actual computing time and performance in terms of speed is only important for the first group of these tools used during the acquisition. The remaining two groups must focus on user friendly operation and the capability to deal with volumes of at least 2k x 2k x 2k pixels.

3.17 The DQS Advisor: A Visual Interface to Recognize Tradeoffs in Dose, Quality, and Reconstruction Speed and ColorMapND: A Data-Driven Tool for Mapping Multivariate Data to Color

Klaus Mueller (Stony Brook University, US)

The DQS Advisor: Achieving high-quality CT reconstructions from the limited projection data collected at reduced x-ray radiation is challenging, and iterative algorithms have been shown to perform much better than conventional analytical schemes in these cases. A problem with iterative methods in general is that they require users to set many parameters, and if set incorrectly high reconstruction time and/or low image quality are likely consequences. Since the interactions among parameters can be complex and thus effective settings can be difficult to identify for a given scanning scenario, these choices are often left to a highly-experienced human expert. The DQS Advisor is a computer-based assistant that allows users to balance the three most important CT metrics – dose (D), quality (Q), and reconstruction speed (S) – by ways of an intuitive visual interface. Using a known gold-standard, the system uses an evolutionary optimization algorithm to generate and learn the most effective parameter settings for a comprehensive set of DQS configurations. A visual interface then presents the numerical outcome of this optimization, while a matrix display allows users to compare the corresponding images. The interface allows users to intuitively trade-off GPU-enabled reconstruction speed with quality and dose, while the system picks the associated parameter settings automatically. Once this knowledge has been generated, it can be used to correctly set the parameters for any new CT scan taken at similar scenarios.

ColorMapND: In volume visualization transfer functions are widely used for mapping voxel properties to color and opacity. Typically, volume density data are scalars which require simple 1D transfer functions to achieve this mapping. If the volume densities are vectors of three channels, one can straightforwardly map each channel to RGB which requires a trivial extension of the 1D transfer function editor. We devise a new method that applies to volume data with more than three channels. These types of data often arise in scientific scanning applications, where the data are separated into spectral bands. Our method expands on prior work in which a multivariate information display was fused with a perceptual color map in order to visualize multi-band 2D images. In this current work we extend this joint interface to blended volume rendering. We design a set of functionalities and lenses that allow users to interactively control the mapping of the multivariate volume data to color and opacities. The latter enables users to isolate or emphasize volumetric structures with desired multivariate properties that can be identified in the joint interface. We also show that our method enables more insightful displays even for RGB data. We demonstrate our method with three datasets obtained from spectral electron microscopy and high energy X-ray.

3.18 Topology-driven approaches for analysis and visualization of material structures

Vijay Natarajan (Indian Institute of Science – Bangalore, IN)

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Data resulting from high fidelity computational simulations and high resolution imaging devices is becoming increasingly complex in terms of the number of features. Topological structures such as the contour tree, mapper, Reeb graph, and Morse-Smale complex provide abstract representations of features in the data that are succinct and amenable to visual analysis. Topological Data Analysis (TDA) refers to the study of such abstract representations for data analysis. These structures support feature detection, extraction, comparison, and tracking and hence enable methods for effective visualization and exploration of feature-rich data sets. In this talk, I will first give an introduction to TDA with a focus on scientific data. Next, I will introduce the problem of symmetry and similarity detection in scientific data and describe its role in the design of feature-directed visualization methods. I will present algorithms to detect symmetry and discuss applications to visualization, interactive exploration, and visual analysis of time-varying and multivariate data.

3.19 Next Generation NDT – An Enabling Technology for the Industry of the Future

Ahmad Osman (HTW – Saarbrücken, DE)

Joint work of Ahmad Osman, Bernd Valeske

The digital transformation has high influence on our society and a clear impact on almost every industrial segment. This essentially includes the technologies and tools for the factory of the future, medical and health care systems as well as materials development and processing. In order to continue serving as an enabling technology in industrial sectors (automotive, railway, infrastructure etc.), Nondestructive Testing (NDT) has to raise to a next level, the so called NDT 4.0 or Next Generation NDT. In modern NDT, sensors are considered not only as data providers but data processing is expected to be sensor integrated and to guide the data acquisition strategy. Modern sensor systems will be capable of transferring the big data into smart data with information that helps monitoring and optimizing production processes and products throughout their complete life cycles. Such cognitive systems will be able to autonomously specify the optimal settings for data acquisition: how, where and which data are required to assess a scene. NDT sensor systems with embedded intelligence, i.e. AI-algorithms for real time data processing and evaluation, will be part of IoT. These smart devices produce data and decisions which are saved into a digital product memory that describes the history and changes in the product properties. This upcoming evolution of sensor systems requires a radical transformation on several levels such as the qualification courses of NDT personnel, on human-machine interaction modes etc. The sensor systems should be able to guide the human in his inspection task, thereby reducing the complexity of his work, accelerating the evaluation through on-site visualization and feedback to the operator. In this work, we present features and algorithms for smart NDT inspection system which can be used for ultrasound probes, eddy current probes or micro-magnetic sensor systems. For the ultrasound probes, the sensor position is tracked using commercial webcams. The operator is not expected to follow specific trajectories in scanning the surface of a structure. The camera system tracks the probe position and acquired A-scans per position are simultaneously transferred to parallel processes. The quality of these raw signals is autonomously verified according to several criteria. Feedback is given to the operator in case where settings deviations occur or unsatisfactory data are generated. The operator can then repeat the scan to cover the indicated area. Qualified A-scans are then reconstructed into a three dimensional volume. The volumetric data are visualized in real time via various ways of augmented reality, for example on AR-lenses. The data reconstruction is done in 3D using online capable method, referred to as progressive Synthetic Aperture Focusing Technique (SAFT). The presented system is an enabler for a more flexible, faster and unconventional qualification of personnel. It eases the task of appropriate data interpretation and guarantees optimized scanning settings, repeatable and reliable quality control results for onsite inspection tasks. The system can be easily integrated into digital surrounding for data communication. As the system can be used to cover large surfaces, aspects related to big data handling, data reduction, sparse data representation, inline data processing and visualization are challenges that are currently being addressed in ongoing research and development activities at Fraunhofer Institute for Nondestructive Testing.

3.20 Quantitative analysis of CT data using Machine Learning

Sidnei Paciorník (BAM – Berlin, DE)

Joint work of Sidnei Paciorník, Renata Lorenzoni, Sergei Evsevleev, Giovanni Bruno

One of the most difficult steps in image analysis for Materials Science is segmentation. Traditionally, objects would be discriminated by their intensity, contour or texture. However, there are many situations in which none of these approaches work and, importantly, it is difficult to extrapolate from one problem to another. Moreover, there is no analytical or general way to decide the best segmentation method. It is always a trial and error situation. Deep Learning (DL) Convolutional Neural Networks (CNN) bring a new perspective to this problem. Using as input data the individual pixel/voxel intensities, the CNN automatically extracts discriminating features and can converge to a set of classes/objects given a reasonable training set. The training, which also serves as ground truth, is typically defined as regions of each object/class manually outlined by the user. This is the most work intensive step. However, once the network produces a reliable segmentation, in principle it can be directly applied to similar images with no further effort. This approach was used to segment two challenging sample types: a 3-phase Strain Hardening Composite Cement (SHCC) imaged by lab-scale microCT and a 5-phase Metal Matrix Composite (MMC) imaged by synchrotron microCT. In both cases morphological features included elongated fibers and more equiaxial objects. Initial results using the same network architecture – the so-called U-Net [1, 2] were very promising. Fibers and other phases were automatically segmented with good agreement with the ground truth. Different training strategies involving data augmentation were tested. Transfer learning between different samples was also successful by adding a small amount of training data to a previously trained network. These initial results raise several questions about the best strategy for using DL CNN's in image segmentation. Is there an ideal CNN architecture? How large must the training set be? Which parameters should be included in the data augmentation procedure? How should we proceed from 2D to 3D training set creation? What is required in terms of network architecture and GPU capabilities to obtain true 3D segmentation?

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3.21 Application of Machine Learning tools for quantitative 3D-4D materials science

Guillermo Requena (DLR – Köln, DE) and Federico Sket (IMDEA Materiales – Madrid, ES)

Neural networks (NN) have become a state of the art tools for the analysis of imaging data and the prediction of process behaviour in several fields such as medicine, earth observation and climate research. In the present contribution we explore the use of machine learning tools based on neural networks to solve current 3D and 4D material issues that can hardly be approached using classical methods. Two examples are given: (1) Segmentation of 3D imaging data using convolutional neural networks: the separation of microstructural constituents in multiphase materials can be a tedious task that requires several hundreds of hours of human work to obtain trustable 3D or 4D data for subsequent analysis. We implemented a U-net-based CNN architecture that is able to achieve at least 94% accuracy in the segmentation of absorption plus phase contrast tomography images in Al-Si alloys. Open challenges to further advance in the segmentation of 3D-4D data were also presented. (2) Understanding and prediction of mechanical properties of materials: as an example of the use of NN for the prediction of material behaviour, a framework combining design of experiment (DoE), computational micromechanical modelling, and Neural network is presented. An analytical surrogate model including some material properties was obtained and the possibility to extend it by incorporating more material properties and other simulated failure modes across relevant length scales discussed. Finally, two examples on which NN could assess the production process of materials were presented, one for in-situ curing of composite materials and other for selective laser melting manufacturing. In combination with in-line sensoring of the production process the challenge of collect data from the process as it occurs, training a machine learning algorithm to analyse them, and predict or decide in-line improvements and/or corrections was presented.

3.22 Multivariate Data Analysis using Fiber Surfaces for Material Science

Gerik Scheuermann (Universität Leipzig, DE)

Application like structural mechanics of composite materials or geomechanics of nuclear waste deposits require the analysis of multiple scalar fields at the same time. An example is provided by all invariants of tensors. A more complicated example are variables from different models in coupled simulations where structural mechanics, hydrology, and thermodynamics are simulated at the same time, all creating multiple variables to study. In this talk, I present three case studies in material science where we used tailored visualization techniques like effective combination of tensor fields to show potential failure, fiber surfaces of the stress tensor invariant space, and exploration of three scalar attributes at the same time. The studied materials are short glass fiber reinforced polymers, a hybrid metal-carbon fiber reinforced polymer component, and a combination of different rock layers in geomechanics.

3.23 Image modelling and computational materials science

Katja Schladitz (Fraunhofer ITWM – Kaiserslautern, DE)

Material versatility is ever-increasing, accompanied by need for more complex and precise structures and properties. The rise in complexity requires continued development of scalable and dedicated analysis tools, which again enable further optimization and research. Fraunhofer

ITWM and TU Kaiserslautern (departments of Computer Science and Mathematics), having decades of joint experience, form a group of leading experts in complex analysis tool development. We are working to bring new algorithms and methods for visualization, inspection, modelling and simulation of material structures and properties to the market. In order to precisely model the structural properties, material representations must first be deduced from measurements, e.g. image data of various dimensions and types/modalities. Deduction of complex materials micro-structures such as fiber reinforced composites, as well as complex surfaces calls for custom developed algorithms, which further need to be verified and validated. Validation requires the ground truth representation, which is unfortunately often unavailable due to the fact that there is no other measurement method or the phenomenon to be captured is extremely rare. Only way out, when the ground truth is unavailable, is modelling of the surface, material or structure and simulation of the imaging method. Moreover, stochastic geometry models for complex materials micro-structures are the key ingredient for so-called virtual materials design. Not only the right trade-off between the truth and physical or geometric model has to be found, models have to be visually convincing too. Atop of the correctness of the model, results of geometric analysis (curvatures, orientations) and of simulations (stress, strain, temperature...) must be visualized in a way which allows intuitive analysis and evaluation. This task is challenging, considering that we are dealing with local results on complex micro-structure as well as the embedded micro-structural information in a multi-scale simulation. However, we have developed many significant contributions to modelling, simulation and visualization and are continuously working on new ones, thanks to wide variety of collaborations with mechanical, process and civil engineers.

3.24 Visual Comparison of Ensemble Datasets

Johanna Schmidt (AIT – Austrian Institute of Technology – Wien, AT)

Comparative visualization refers to the process of using visualization techniques to understand how different datasets are similar or different, and to be able to interactively explore these differences. Comparison is getting an increasingly important task in data analysis, as it can be very cumbersome in case many data items, or complex data items have to be compared. Visualization systems successively have to move from representing one phenomenon to allowing users to analyze several datasets at once. Large data collections that contain a lot of individual, but related, datasets with slightly different characteristics can also be called ensembles. In the course of this talk a technique for the comparative visualization of 2D image datasets and for the comparison of 3D shapes are introduced. Both techniques focus on the scalable analysis to support ensemble analysis. When comparing 2D images, we propose to not only outline the differences in the data, but also to use clustering and interactive widgets to further understand the structure of the differences – how many images are affected by the difference, and how to they look like. For analyzing 3D shapes we went one step further, since here we are not only able to study individual differences, but it is also possible to understand relations between differences, e.g., if differences are always caused by the same ensemble item. We achieve this by aligning regions of interest on a reference shape as axes in a parallel coordinate plot, and then draw polylines for all ensemble items according to its error rate in the specific regions. This way the error rate of ensemble items over several regions of interests can be studied. In the course of material sciences, comparative visualization can be targeted towards the comparison of different segmentation results, either in 2D images or as 3D shapes. According to the challenge "The Visual Debugger", comparative visualization can support users to understand and analyze differences in the data being introduced when running certain feature extraction mechanisms (e.g., segmentation) with different parameters. Comparative visualization can also be seen as an extension for parameter space analysis.

3.25 Features of tensor fields (latent model) extracted from Kalman filter tracking data

Jeff Simmons (AFRL – Wright Patterson, US)

Traditional homogenization approaches produce mesoscale representations by developing a Representative Volume Element (RVE) whose properties are, with acceptable scatter, independent of position in the material. This is accomplished by biasing the analysis with an Independent and Identically Distributed (iid) assumption on the microstructural elements. That is, in order to reduce the variance to the point that the volume element is representative, it is necessary to invoke an iid assumption, which is inconsistent with the existence of an anomalous condition. Such occurrences are simply treated as outliers and "averaged away" in the process. We propose an alternative approach of applying a model-based bias, specifically, that the fibers behave as streamers in a laminar flowing fluid. With this model, the fiber orientation becomes the basis for the mesoscale representation. By analogy with fluid dynamics and the tracking discipline, we refer to this orientation as the 'velocity.' Following successful approaches in fluid dynamics analysis, we can extract a 'velocity gradient' from the data. The velocity may be extended to be a continuum field by the hypotheses that (1) the velocity field is smooth and (2) that it matches the computed velocity values at the fiber detection points. With these assumptions, the velocity field may be expanded into a Taylor's series about a detection point and the velocity gradient appears naturally as the second order coefficient. This is evaluated from a set of detection points in the neighborhood of the target point by the pseudoinverse of the matrix of distances of the neighboring detection points on the computed changes in velocity from the target point and the neighboring points. Local homogeneous strains produced in the neighborhood of fibers, as the reference frame is translated down the fiber axes, can then be computed from the symmetric part of the velocity gradient. The rotation produced by this motion, the chirality, may be computed from the anti-symmetric component. Non-uniformities can then be computed by performing an anomaly test on the fiber velocities by classifying velocities having a likelihood below a threshold as being anomalous. A consistency check, in which the anomalous classification persists through multiple successive layers is used to differentiate a true anomaly from one resulting from detection noise. It is suggested that this approach may be used to coarse grain many other microstructures by s suitable choice of biasing model. Additional image processing steps needed to extract the fiber detection positions are also described.

3.26 Machine Learning for Material Sciences: Computer Vision at Scientific Facilities

Daniela Ushizima (Lawrence Berkeley National Laboratory, US)

URL http://bit.ly/idealdatascience

Advances in imaging for the design and investigation of materials have been remarkable: the growth of X-ray brilliance and extremely quick snapshots have enabled the description of dynamic systems at the atomic scale; micro CT has focussed on capturing shape and structural properties of new compounds to measure the function and resilience of new materials. Our recent efforts in machine learning applied to image representation and structural fingerprints have streamlined sample sorting and ranking including the identification of special material configurations from million size datasets.

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3.27 Visual Debugging in Particle-Based Simulation

Daniel Weiskopf (Universität Stuttgart, DE)

Visualization can play an important role for debugging because it allows us to potentially identify problems in a dataset that might be connected to issues earlier in the data production pipeline. Here, I focus on particle-based simulation as the source of data, leading to multivariate data sets in which particles are associated with multiple attributes (such as pressure, forces, etc.). The specific use case is smoothed particle hydrodynamics (SPH). I report on our experiences with a visualization system that combines spatial representations of the particles with non-spatial views such as scatterplots and parallel coordinates plots that show multivariate attributes. With such a system, we were able to identify problems with a software implementation, but we were also able to identify the impact of different models and parameters on the simulation results. Finally, I discuss the role of debugging in the larger setting of visual data analysis as well as challenges specific to visual debugging in materials sciences.

3.28 Visualization of Quantitative Data Derived from Volumetric Imaging

Thomas Wischgoll (Wright State University – Dayton, US)

This presentation discusses techniques and issues with obtaining quantitative data from imaging technology at high levels of accuracy. Current techniques are capable of deriving quantitative data from volumetric images at sub-voxel levels. However, there are limitations stemming from the fact that there are issues with different artifacts, such as noise, partial volume effects, etc., that lead to uncertainties inherently encoded within the data. Awareness of that fact can help improve the segmentation of the data and as a result the quantitative information extracted. The quantitative data can then be used for additional modelling and further analysis.

4 Working groups

4.1 Working Group Discussion Summary: Ensembles, uncertainty and parameter space analysis, multi objective / multi parameter optimization

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

The following topics were discussed:

- UQ: not much data available, many phantoms but no specific phantom available, uncertainty on grey values not available by CT device manufacturers or detector manufacturers. Uncertainty information is mainly available on derived data (e.g. metrology); aleatoric part of uncertainty can be estimated by repeated measurements, but epistemic error remains unknown ==> Finding: info on uncertainty missing.
- Parameter space analysis: Used in a very focused way for optimizing specific algorithms or specific parts of a quantification pipeline for a new experiment. Parameter space analysis should also be important for materials design. Question: is Parameter space analysis here the correct term or does materials science rather need an analysis of the solution space? Question: What is the solution space ==> highly dependent on the application
- Where can Vis actually help? ==> only where the human is in the loop Data processing for Materials Science ==> characterization of materials Comparative Visualization is a big issue for setting up experiments and analyses
- Can Vis help for DoE (Design of Experiments)? For example more coarse simulation methods (e.g., using surrogate models) can help to reduce the need for extensive and complex simulations but still find the sweet spot. Question: Can automatic DoE algorithms be combined with human (not yet formalized or quantified) knowledge?

- Come up with a pipeline – what is the current pipeline? Measurements ==> raw data ==> scripts/tools to get the info they are after.
- Questions:
  - Can we add to/streamline that workflow?
  - In need of more expertise.
  - What tools are available?
  - What are the bottlenecks?
- Uncertainties:
  - What sources of uncertainty are there?
  - Are we even the right group to address this?
  - Doesn't seem to be much data, so vis is hard
- Parameter Space:
  - All are so different: reconstruction, each material is different, really tricky
  - Try to optimize typically mechanical properties of the final result
  - How can we support this? Can visualization actually support this or are there better mathematical tools?
  - Visualization is out of the game whenever the human is out of the game.
  - But if things are really high-dimensional you will not be doing things completely automatically.
  - Can we help with the design of experiments?
  - Maybe help with questions like how to get the voids smaller or other structural questions.
  - Human is looking for correlations with the hope of finding relations
  - But again – how could we support that?
  - Is visualization used in the design of experiments? Selectively. Some people in materials find it unscientific. More like data science than materials science. But this is going to go railway
  - Cheap preview. Simple simulation to narrow down possibilities. In-silico modeling to reduce cost
  - In an engineering application using simulation/visualization – find places where bad effects occur and what the conditions will be to produce those results.
  - In a science application – situational awareness.
  - Can we look to how wet-labs use simulation?
  - Seems to be some reluctance to use vis.

4.2 Working Group Discussion Summary: Image Processing

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

The group was lead by a presenter, Wolfgang Heidrich, who summarized topics related to volume correlation, denoising and segmentation. The state of the art for these three areas are summarized as follows:

1. Volume correlation: Local DVC (neighbourhood based), and optical flow in computer vision can be better than local DVC.
2. Denoising: 99% time materials scientists use Median and Gaussian, and Sparsity-based (like TV denoising) from the data processing specialist or non-local means give better results, but are rarely applied in practice
3. Segmentation: Deep learning produces very good results, and transfer learning is frequently used to a pretrained network and update the training.

The needs and barriers in these three areas can be summarized as follows:

1. Volume Correlation
   a. Need: Fibre breaking in a synchrotron CT measurement: loading along the feature direction is difficult to see.
   b. Need: Evaluation of DVC algorithms in realistic conditions.
   c. Barrier: Window problem of optical flow.
   d. Barrier: Missing texture. Introduction of artificial tracer particles is not always easy.
2. Denoising
   a. Need: Faster acquisition gives noisy data.
   b. Need: Killing artifacts and detect hidden features. Get simple examples where denoising helps to find features.
   c. Need: Concrete solution: e.g. publish the algorithm at TomoBank.
   d. Need: Web page / Resource / network with implementations of different algorithms – like TomoBank.
   e. Barrier: Implementations not readily available NLM is available, but other denoising are not.
   f. Barrier: Distinguishing features from noise is hard, real features might be deleted.
3. Segmentation
   a. Need: Multilevel heterogeneity. Fibre material, organised in bundles of fibres. The individual fibres are to small to be detected or segmented.
   b. Need: Superresolution can be used to improve the segmentation..
   c. Need: Theoretical analysis could be useful, but is not available.
   d. Need: Segmentation thresholds have a strong influence on the results. E.g. porosity values are dependent on segmentation thresholds.
   e. Need: Segmentation can be implemented by discrete optimization.
   f. Need: Segmentation of medical data?
   g. Barrier: Superresolution: available processing power.

To summarize, the main barriers expressed during this session were related to accessibility for the material science community and related to real data for verification for those people doing optimization.

4.3 Working Group Discussion Summary: Machine Learning

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

Tools:

Tools need to be made available with machine learning/deep learning to material scientists. Trying to understand results and limitations.
- Which network architectures are more successful for certain problems?
- Which knobs need to be adapted?

Discussion Topics:

We discussed a lot on ground truth and measures of quality and generalizability of network architectures and parameters. The group reflected on the following issues:
- Connectivity of microstructural constituents is important in many cases. How to train and test with respect to connectivity?
- Convolutional CNNs may not work if applied to graph structures?
- Can other information be used in addition to voxel intensities? Surface normals, curvature and depth for example -> use it as input to deep learning. What is the consequence for the required training set?

Segmentation as one of the most urgent issues.

Tomographic data:

Typically reconstructed as isotropic data whereas microscopy data can be strongly anisotropic, thus looking in a traversal direction is considerably different from any orthogonal direction. Contrast is often different on different devices; histogram matching as a possible solution or re-training with one slice from the new dataset to adjust weights. Noise reduction and image fusion are other issues for deep learning.

Training data:

Transfer learning for similar data. Training data with damages and artifacts, e.g. beam hardening and streaking.

TomoBank:

Database with annotated training data and challenges, e.g. streak metal artifacts. Role of data augmentation: U-Net people use distortion and noise. What are the right data augmentation techniques for tomography. Examples where data augmentation was negative in certain cases in terms of accuracy where mentioned. Networks should be uploaded? How? What format? Exchange/share networks with data. Archival of networks/data. Perhaps only little re-training is required.

SciVis Contest:

Create a visualization contest. Which data/problem is most urgent? What are metrics for the quality of the result? For image analysis: It would be Dice-coefficient, Hausdorff distance? But for a visualization contest. Structural similarity as a quality criterion. Sensitivity/specificity. Insights/hypothesis/influence on problem solving related to material science visualization.

2D vs 3D:

Training of the network in 2D vs. 3D. 3D as interpolated from 2D slices.

4.4 Working Group Discussion Summary: Materials Science Applications for Visualization Beyond Existing Tools (requirements for vis tools from materials sciences perspective)

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), and Rüdiger Westermann (TU München, DE)

For these breakout groups, we split the group randomly into two subsets containing both material scientists and visualization scientists. Both groups were posed the same question.

Materials Science Applications for Visualization Beyond Existing Tools (requirements for vis tools from materials sciences perspective) Working Group Discussion: Group A:

Our lead-off question to this group was as follows: Material scientists: Tell us the science problems you want to solve. Visualization scientists: Where can Vis help solve those particular problems?

The challenges we decided on could all fit within a topic of "Steering Acquisition," but each could be useful as a separate goal. These are:
1. Real time dynamic sensing for data acquisition,
2. Accelerated understanding of the materials state for decision making,
3. Identification of interesting events and accelerated discovery of materials property,
4. Real time design of experiments that is robust to changes in strategies during data collection.

To accomplish this, it is envisioned that we design a challenge to the community that will establish a benchmark problem that can be reused for additional efforts.

Accelerate Discovery and Determination of Material Properties
- How to improve visibility of your structure without losing the context.
- Tracking dynamic phenomena.
- Design of experiments. Why is it not used more regularly? Maybe use visualization to aid the design of experiments.

Detect, track and predict behavior from anomalies
- Identify things that are similar and/or symmetries.

Steering Acquisition
- Dynamic Control
- Early detection of characteristics to steer/optimize further data acquisition.
- Maximize information obtained while reducing the acquisition of "useless" data.
- Tracking dynamic phenomena.
- Combine exploratory approaches with optimization of data acquisition.
- Take advantage of visualization to accelerate useful data acquisition.
- Find a common set of samples/phantoms to work on.

Dynamic Sensing Simulation
- The relevance of simulation to help in optimizing acquisition.

Data fusion
- Visualization as a tool to facilitate and optimize fusion

Materials Science Applications for Visualization Beyond Existing Tools (requirements for vis tools from materials sciences perspective) Working Group Discussion: Group B:

Our lead-off question to this group was as follows: Material scientists: Tell us the science problems you want to solve. Visualization scientists: Where can Vis help solve those particular problems?

Problems and Tasks identified by the Material Scientists

- Overview:
  Get a concise and quick overview of the data right after recording it, show interesting points immediately (holes, pores, cracks), find slices that are of interest. Find interesting points in a volume Find slices with something different than the canonical slices ("first 10")
- In-situ experiments:
  The in-situ experiments require to adapt several forces to the material (temperature, pressure) and record the results. The application of these forces causes the microstructures in the material to change. Experiments can be very different, taking a long time with only a view changes, or events that happen very suddenly (e.g., brittle material under load, cracks happen soon, in contrast to laser powder melting, stabilize melting). For these experiments, at the long run, an automatic decision system should be available to automatically adjust the experiment parameters. In the meantime, visualization can help to visualize the intermediate steps, for an interactive steering of the process. Visualization can help here in the following ways:
  - Timely feedback during the experiment. Possibility of on-line data reduction and preliminary segmentation during the experiment, to better use beamtime. Especially badly needed for fast experiments. Offline-evaluation of data often leads to the problem, that the data cannot be used in the end (extract characterization quickly from the measurement data to get an overview. Very big volumes, many parameters, need to understand that)
  - Parameter visualization to understand the causality between material and experiment parameters (e.g., how does an experiment parameter affect the physical material properties). For example, there can be more roughness in the prepared material, how does this impact the final part
  - Vector field visualization to understand forces

  - Pore tracking over several timesteps (pore segmentation works fine, but the tracking over several timesteps is still a problem – maybe also integrate physical properties of the pore?)
  - Comparative visualization to understand where and when events occurred in the data
  - Change detection to see which parts of the data that has been recorded during the experiment can be thrown away
  - Prediction to better steer the acquisition times of the machines, trigger when something important is going to happen (more a computational effort, not a visualization topic)
- Visualization or large 3D data structures:
  Apart from large volume data, other large 3D structures like skeletons have to be studied. This is currently a problem due to occlusions in 3D. Other options like projections into 2D space would be of help here, where patterns can be analyzed more easily in 2D.
- Visualization or large 3D data structures:
  Apart from large volume data, other large 3D structures like skeletons have to be studied. This is currently a problem due to occlusions in 3D. Other options like projections into 2D space would be of help here, where patterns can be analyzed more easily in 2D.
- Visualization of clustering parameters:
  When clustering pores with multiple criteria, it is often hard to understand the relation between these pores. Visualizations towards the representation of cluster parameters (e.g., in a graph, similar to MegaMol that Tom Ertl showed in his talk) could help the domain experts to better understand the clusterings.
- Segmentation Crowd Challenge:
  Getting better, faster and more accurate segmentation algorithms is still an open issue. A common crowd challenge on segmentation, including machine learning, would be of interest – how could gamification be included?
- Suggestion from the VIS community: Tensor field data
  Tensor field data is used, data sets are available. New CT techniques like SAXS-CT and Nested tensor tomography allow to record more data (e.g., spectrums) for all data points. However, there not so many applications for these types of CTs yet, mainly because it takes a lot of time to acquire a sample.
- Suggestion from the VIS community: Measurement uncertainty
  Currently material scientists trust their measurements (e.g., for segmentation), so there is no need for the visualization of measurement uncertainty

4.5 Working Group Discussion Summary: Multilateral Cooperation

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

The discussion group on multilateral cooperation was finished with a list of concrete action items to be pursued after this Dagstuhl workshop:

1. **Benchmarking datasets**
   As a free initiative datasets will be provided in order to facilitate a benchmark across participating groups. The benchmark will contain, datasets, currently applied protocols,

data analysis pipeline as well as parametrization. The goal is to have a documentation of a complete workflow in order to either come up with improved results, to compare with existing results, as well as to improve specific steps in a workflow. Benchmarking and testcases may contain permeability analysis, porosity, fiber breakage, generalization of internal structure (connectivity, topology) as well as other aspects. In this context als a SciVis Contest may be targeted.

2. **Plenary talk at Materials conferences**
   Plenary Talks on Visual Computing in Materials Sciences are planned at Composite Conferences. Conferences of interest will be the European conference on composite materials or the TexComp.
3. **Special issue in journal**
   As a direct outcomes of this workshop two special issues in the domain of Visual Computing in Materials Science are planned. More specifically, "Computer Graphics & Applications", as well as "Materials" will be targeted.
4. **Viewpoints article**
   Visualization Viewpoints article offer detailed technical opinions on trends in visualization?
5. **Dagstuhl seminar report**
   Another direct output of the workshop is a cumulative report of all talks and discussion groups which is found in this report.
6. **Tutorials**
   A tutorial in Visual Computing in Materials Sciences will be targeted in an upcoming conference. As primary venues conferences on Materials will be targeted. Euromat will be the primary candidate for this purpose.
7. **Further workshops**
   An joint workshop is planned in Lund at MaxIV for 2019. In addition the submission of proposal regarding a Dagstuhl workshop, an Erice Workshop or a Banff workshop on this or a related topic will be discussed by the end of 2019.

Additional Materials Provided As Part Of Breakout Sessions:
Here is the link to the SciVis contest which was mentioned in the discussions: http://sciviscontest.ieeevis.org/. Some of the data sets are still available.

The new DFG-funded Collaborative Research Center 1313 at the University of Stuttgart on "Interface-Driven Multi-Field Processes in Porous Media – Flow, Transport and Deformation" https://www.sfb1313.uni-stuttgart.de/index.html will have a dedicated project for providing benchmarks for porous media simulation. https://www.sfb1313.uni-stuttgart.de/research-areas/project-area-d/research-project-d3/. A first version can be found here: https://arxiv.org/abs/1809.06926

4.6 Working Group Discussion Summary: Shared Data Set and Benchmark Problems

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

TomoBank:

All datasets will be available at the following link: https://tomobank.readthedocs.io/en/latest/source/dagstuhl.html The following datasets were added by various members of the workshop as part of a dataset and benchmark problem working group:

- **Dataset 1:** Description: Multiphase engineering alloys: Al-Si alloys, Ti alloys. The data covers 3D networks in the same sample before and after heat treatment [1]. When comparing small regions of the networks [1] before heat treatment and after heat treatment, disconnections have occured in these specific reions.
  Questions: What has changed after the heat treatment? Connectivity? Morphology? How can we visualize the changes in 3D for the whole network? Can we identify/quantify this regions and, more importantly, visualize them clearly in large structures Tasks:
  1. Segmentation of raw data: TBD
  2. Topological descriptors of segmented data
  3. 3D visualization of geometrical features

  Download Link: will be uploaded to tomobank, data also available through direct Contact: Guillermo Requena (guillermo.requena@dlr.de);
- **Dataset 2:** Description: Water migration in one-sided heated concrete. A paper is available here: https://link.springer.com/article/10.1007/s10921-018-0552-7 Concrete bars were heated in one end, which causes the water inside the concrete to evaporate, condense deeper in the concrete in pores and lead to a water wave. This can lead to explosive spallation of the concrete and causes problems (tunnel fire accidents). The data set consists of several consecutive rounds of cone-beam CT while the concrete is heated.
  Tasks:
  - Better reconstruction (SpaceTimeTomography?) that takes into account the sample expansions during the experiment
  - Determination of the water content (by subtracting expansion corrected volume data)
  - 3D / 4D visualisation of the migration of the water. In the paper, there is no “convincing” visualization of the water migration and condensation.

  Download Link: The paper is not open access, but a preprint can be made available upon request.
  Contact: Bartosz Powierza (Bartosz.Powierza@bam.de);

References

1 K Bugelnig, F Sket, H Germann, T Steffens, R Koos, F Wilde, E Boller, G Requena, Influence of 3D connectivity of rigid phases on damage evolution during tensile deformation of an AlSi12Cu4Ni2 piston alloy, Materials Science and Engineering: A 709, 193-202

4.7 Working Group Discussion Summary: Suggestions for further discussions

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

- **Datasets & Tasks**
  From the visualization side, it would be great to get access to datasets and specific tasks. There was the suggestion to upload data to the Tomobank and also attach specific tasks to it, so that visualization people could work on them.
- **SciVis Challenge**
  Starting a SciVis challenge on the topic would also include more visualization people, and hopefully result in many suggestions how to visualize the data (and also many citations, since this data is publicly available and people will use it as a benchmark).
- **Review Paper**
  The material scientists are lacking a better overview on the available software tools and how they could use them. There was the suggestion to write a review paper, with materials scientists as co-authors, published in the material science community, where important tasks are outlined, with suggestions which visualization techniques and software tools to use.
- **Software tools**
  As mentioned above, an overview of available techniques and software tools would be of great help for the material scientists.
- **Pipeline**
  A possible pipeline could be Experiment -> data Processing -> Visualization. Therefore, data processing is the missing link here in this group (machine learning would be a way to avoid image processing).

4.8 Working Group Discussion Summary: Time-Varying Data

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

The group was formed by two materials scientists and two computer vision people. During the session, the problems in materials science where the evolution can provide much more information were highlighted. Then, selected experiments were shown where the use of 3D + time experiments provide a lot of information that needs extraction and evaluation.

The discussion was oriented to a couple of examples where visual computing could help:

1. Tracking features in consecutive volumes during time: Here, it was mentioned that there are a couple of tracking algorithms that could be used for particle tracking but there is no reliable open source tool for that purpose. Even commercial tools are not so efficient

in that sense. Even more, the possibility to track particles with the ability to filter some of characteristics while tracking was proposed.
2. Link the 2D to the 3D space: With the intention to avoid recording and storing not useful data, it is important to be able to, either detect some changes in the acquisition in 2D or with analysis in in-line reconstruction in 3D. A visual analysis of some parameters should be able to trigger the data collection systems when some important change is detected. This is especially important for fast occurring processes where the data acquisition is a constrain because of memory, storage, or other limitations.

4.9 Working Group Discussion Summary: Tools

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), and Rüdiger Westermann (TU München, DE)

- **Tomviz**
  Further information: The Tomviz project is a cross platform, open source application for the processing, visualization, and analysis of 3D tomographic data. It is developed in C++, using Qt, building on VTK, ParaView, ITK, Python, SciPy and NumPy. The complete pipeline of data processing steps from alignment and reconstruction to visualization and analysis of 3D data can be presented, saved, and restored. A suite of Python tools for 3D analysis is packaged to accommodate custom algorithms. The initial focus was on high resolution scanning transmission electron microscopy, but that has been broadened to include improved support for other types of tomographic data. Tomviz can load custom Python scripts in the user's home directory to add new extensions to its menus for processing. Tomviz is tested and packaged on Windows, macOS, and Linux with full source code available on GitHub.
  Link: https://tomviz.org/
  Licencing: 3-clause BSD
  Contact person: Marcus D. Hanwell (marcus.hanwell@kitware.com)
  Datasets: A sample tilt series and reconstruction are included with the package, also links to a Nature Data paper with CC-BY licensed data sets hosted on Figshare.
- **open_iA**
  Further information: open_iA is an open source tool for the visual analysis and processing of volumetric datasets, with a focus on industrial CT datasets. As graphical user interface the cross-platform framework Qt is used, which facilitates an easy to use and attractive interface. In-house visualisation and image processing algorithms are supported by algorithms of the ITK and VTK toolkit, which make open_iA a powerful tool for both 3D visualisation and CT data analysis. open_iA is capable of loading various volume dataset formats as well as different surface model formats. It provides slice by slice navigation in its 2D views, common 3D navigation with arbitrary cutting planes in the 3D view, together with custom views for individual visualization. open_iA is easily extensible and serves as central development platform of the research group computed tomography @ University of Applied Sciences Upper Austria, Wels Campus and therefore integrates all algorithms and methods developed within the group.

Link: https://github.com/3dct/open_iA Licencing: GPLv3
Contact person: Christoph Heinzl (c.heinzl@fh-wels.at)
Datasets: Sample datasets are provided with the respective tools

- **aRTist**
  Further information: Simulation tool for X-ray radiography and CT. A few CT examples are shown on the gallery page: http://artist.bam.de/en/gallery/index.htm
  Link: http://aRtist.bam.de
  Link: https://github.com/ElettraSciComp/Pore3Dcencing
  Licencing: commercial, evaluation licenses available, within projects licenses are usually granted for free for project partners
  Contact person: Carsten Bellon (Carsten.Bellon@bam.de)
- **Super-resolution CT reconstruction**
  Further Information: tomographic reconstruction tool for datasets with very thin features (fibers or sheets). This is research code with datasets, as well as the scientific publications.
  Project page: https://vccimaging.org/Publications/Zang2018SuperResolutionCT/
  Code:https://drive.google.com/open?id=1Ws454D65kopVprnuVP_OMajbtRN0Um24
  License: Creative Commons, attribution noncommercial
  Contact: Wolfgang Heidrich (Wolfgang.Heidrich@kaust.edu.sa)
- **Space-Time Tomography**
  Further Information: tomographic reconstruction of 4D time varying data. Research code + datasets + scientific publication.
  Project page: https://vccimaging.org/Publications/Zang2018Space-timfore/
  Code: https://github.com/gmzang/SpaceTimeTomography
  License: Creative Commons, attribution noncommercial
  Data: https://repository.kaust.edu.sa/handle/10754/627676
  Contact: Wolfgang Heidrich (Wolfgang.Heidrich@kaust.edu.sa)
- **Pore3D**
  Further Information: Pore3D is a software toolbox for processing and analysis of three-dimensional images. The core of Pore3D consists in a set of state-of-the-art functions and procedures for performing filtering, segmentation, skeletonization of 3D data and extraction of quantitative parameters. A full control of algorithms parameters and intermediate results is possible at each step of the analysis.. Easy integration with other sw tools is possible (fro GUI, 3D visualization, . . .). Although three-dimensional data can be produced by several techniques (for instance: magnetic resonance, X-ray scattering or confocal microscopy), the library was developed and optimized for Computed Tomography data. Pore3D features are available through the high-level scripting environment IDL and it has been tested with IDL 64-bit from versions 6.4 to 8.5.
  The original project page can be found at: http://www.elettra.eu/pore3d/ but now the sw is available on Github.
  Main bibliographic reference at: https://www.sciencedirect.com/science/article/pii/S0168900210002615 Code: https://github.com/ElettraSciComp/Pore3D License: The project is licensed under the GPL-v3 license
  Contact: Lucia Mancini (lucia.mancini@elettra.eu); (pore3d@elettra.eu)
- **SYRMEP Tomo Project (STP)**
  Further Information: SYRMEP Tomo Project (STP) has been developed for the users of the SYRMEP beamline of the Elettra synchrotron facility (http://www.elettra.eu) to perform the digital image processing required by parallel beam absorption and propagation-based phase contrast CT experiments. This sw is routinely used at by all SYRMEPl users

during CT experiments but the underlying idea is also to let users perform post-beamtime optimization, fine tuning and/or additional tests with common hardware at their home institution. The software has been also developed for teaching and educational purposes. SYRMEP Tomo Project is available only for Windows 64-bit machines.
Main bibliographic references are: http://dx.doi.org/10.3233/FI-2015-1273 and http://dx.doi.org/10.1186/s40679-016-0036-8.
Code: https://github.com/ElettraSciComp/STP-Gui
License: The project is licensed under the GPL-v3 license.
Data: Many datasets from the SYRMEP beamline are available on TomoBank at the link https://tomobank.readthedocs.io/en/latest/

- **PITRE and H-PITRE**
  Further Information: PITRE (Phase-sensitive x-ray Image processing and Tomography REconstruction) is a software developed by INFN Trieste n order to facilitate and standardize the simulation and elaboration of X-ray phase contrast images. The acronym PITRE in Italian is pronounced /'pi.tre/; the pronunciation is the same of "P3", which is then chosen as a logo for the PITRE program. A batch processing manager for PITRE, called PITRE_BM, can execute a series of tasks ("jobs"), which is created via PITRE, without manual intervention.
  H-PITRE (High-performance software for Phase-sensitive x-ray Image processing and Tomography REconstruction) is a fast tomography reconstruction program which uses the parallel computing abilities of NVIDIA GPU (Graphics Processing Unit).
  Code: https://sites.google.com/site/rongchangchen/
  License:
  Data:
- **TTK, Topology ToolKit**
  Further Information: Open-source library and software collection for topological data analysis integrated with visual exploration tools. It is built as a general purpose library, not specific to material science. Easy-to-use plugins for the visualization front end ParaView. All data format and interaction support is available thanks to ParaView. Written in C++ but has bindings (VTK/C++, Python) and command line support.
  Link: https://topology-tool-kit.github.io
  Licensing: BSD
  Mailing List: (ttk-users@googlegroups.com)
- **ASTRA Toolbox**
  Further information: The ASTRA Toolbox is a MATLAB and Python toolbox of high-performance GPU primitives for 2D and 3D tomography. We support 2D parallel and fan beam geometries, and 3D parallel and cone beam. All of them have highly flexible source/detector positioning. A large number of 2D and 3D algorithms are available, including FBP, SIRT, SART, CGLS. The basic forward and backward projection operations are GPU-accelerated, and directly callable from MATLAB and Python to enbale building new algorithms. The source code of the ASTRA Toolbox is available on GitHub.
  Link: www.astra-toolbox.com
  License: GPLv3
  Contact person: Jan de Beenhouwer (jan.debeenhouwer@uantwerpen.be)
- **MegaMol**
  Further Information: Megamol is a visualization framework for large particle data. It originated from research in the DFG Collaborative Research Center 716 and provides

advanced visualization techniques for point-based data like molecular dynamics, SPH, laser point clouds etc.
Link: https://megamol.org/ https://www.sfb716.uni-stuttgart.de/index.en.html
Contact person: Guido Reina (guido.reina@visus.uni-stuttgart.de)

- **Gephi**
  Further information: Open-source tool for the visualization of large graphs and networks.
  Link: https://gephi.org/
  Licencing: Open-source
- **Orange**
  Further information (Daniel Weiskopf): "Data Mining Fruitful and Fun: Open source machine learning and data visualization for novice and expert. Interactive data analysis workflows with a large toolbox." (quote from their web page). A general framework for useful, e.g., for multidimensional data. Comes with interactive visualization As discussed in the breakout group 2 on Thu, multidimensional data analysis could play a role in some applications
  Link: https://orange.biolab.si/
  License: GNU General Public License as published by the Free Software Foundation; either version 3.0 of the License, or (at your option) any later version.

5 Panel discussions

5.1 Overview Talk and Discussion Summary: Application of Machine Learning tools for quantitative 3D-4D materials science!

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

The discussion circled on topics regarding the applicability of the tools and methods which were presented by the speakers. Special interest was seen in the different ML techniques as well as how and where to use them.

5.2 Overview Talk and Discussion Summary: Machine Learning for Material Sciences: Computer Vision at Scientific Facilities

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

In the discussion, the different ML techniques were addressed, which the speaker is using for segmentation and classification of their dataset. The core tool was pyCBIR, a python tool for content-based image retrieval (CBIR) capable of searching for relevant items in large databases given unseen samples. Furthermore, techniques and neural networks architectures such as those found in LeNet, AlexNets and U-Net were discussed as well as their applicability for different scenarios. Finally Xi-Cam was briefly introduced by the speaker, a versatile interface for visualization and data analysis providing workflow for local and remote computing, data management, and seamless integration of plugins.

5.3 Overview Talk and Discussion Summary: Real-time data analysis and experimental steering: Do we need it? Are we ready for it?

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

The author summarized three challenge areas: 1) capturing ultra-fast and ultra-slow processes; 2) detecting spatially rare events in large volumes at meso/nano scale resolutions; and 3) enabling multi-dimensional enquiry to explore spaces of higher dimension and size. The hope is that real-time data collection and steering can bring the following benefits: 1) collect only relevant data; 2) instrument error correction; 3) optimize temporal and spatial resolution; 4) zoom-in at different length scales; and 5) minimize radiation damage to specimens. It is clear that the user (scientist) is needed in the loop, but the role of the user is changing. Previous generations did lots of hand-tuning of parameters, whereas the current generation relies on smart defaults. Moving forward, tools are needed to both help allow exploration of the data (parameters, solution space, etc.) and to allow specialized enquiry.

5.4 Overview Talk and Discussion Summary: Through the micro-CT and what we found there? Quantifying images of fibrous materials

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

This talk presented recent advances in the imaging of fiber composite materials. The goal of the work was to determine the internal structure of the fibrous material through images. This was done by inferring a structure tensor from the image data, from which a classification and an orientation of the material can be deduced. Studies were done to understand the impact of image quality on the structural tensor that is inferred. Based upon the structural tensor that is inferred, one desires a quantification of the fibrous structures and a seamless transfer of data to mechanical modeling software, allowing the calculation of various quantities. Questions were related to the similarities between this work and what is done in the medical imaging world, what modeling assumptions were used (such as assuming symmetry of the structural tensor), and concerning the use of higher-order tensors for input into damage models (and how that damage information is used). The speaker proposed a benchmark exercise that could be used by the imaging / visualization community to test their algorithms / tools.

5.5 Panel Discussion Summary: The Integrated Visual Analysis Challenge 1

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

In the integrated visual analysis challenge we touched on the core intersection between visualization and materials science. From the talks and upcoming panel discussions it became clear that in the daily work of materials scientists, image processing and feature detection techniques are of very high importance. The discussion focussed on concrete hints to advanced techniques in either field, which can help materials scientists to more accurately and efficiently analyse their datasets. In particular, techniques that can employ temporal coherence in the reconstruction step turned out to be of interest. Due to the complexity of the structures in high-resolution measured data, visual data analysis is considered an important ingredient. To the visualization community it became clear how huge and well-resolved scanned materials can be, and that real-time capabilities often play a central role in large-scale research facilities.

5.6 Panel Discussion Summary: The Integrated Visual Analysis Challenge 2

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

This session was a continuation of the visual analysis challenge. As mentioned earlier, we touched on the core intersection between visualization and materials science. From the talks and upcoming panel discussions it became clear that in the daily work of materials scientists, image processing and feature detection techniques are of very high importance. The discussion focussed on concrete hints to advanced techniques in either field, which can help materials scientists to more accurately and efficiently analyse their datasets. In particular, techniques that can employ temporal coherence in the reconstruction step turned out to be of interest. Due to the complexity of the structures in high-resolution measured data, visual data analysis is considered an important ingredient. To the visualization community it became clear how huge and well-resolved scanned materials can be, and that real-time capabilities often play a central role in large-scale research facilities.

5.7 Panel Discussion Summary: The Interactive Steering Challenge

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

This session focussed on the presentation of various computational steering techniques and tools designed for material and engineering design. In all cases, researchers were able to leverage some existing technologies. However, it was clear that considerable effort still needed to be expended to adapt current analysis and visualization tools to the needs of the domain scientists. For instance, acceleration of techniques to enable real-time analysis, visualization and refinement were needed, as well as new APIs to enable efficient data transfer, etc. Questions about the balance between quantitative and qualitative visual comparisons were proposed, as well as how important is it that tools represent solutions which are feasible to manufacture or produce. It is clear that there are many things still needed to bridge current tool technologies and the needs of material science domain experts.

5.8 Panel Discussion Summary: The Quantitative Data Visualization Challenge 1

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

This session focussed on various visualization algorithms, their application to materials science problems, and the lessons learned. Topics such as the current role of interactivity in procedures that in the future will be automated, uncertainty quantification and its visualization, and the use of novel visualization techniques to displaying both similarities and differences as seen in various material science applications. The questions related to understanding the role of automatic learning (deep neural nets) and interpretability, how material scientists use robustness information, and a greater understanding of how symmetries can be exploited when employing segmentation algorithms.

5.9 Panel Discussion Summary: The Quantitative Data Visualization Challenge 2

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

This session focussed on various topics related to the quantitative use of analysis and visualization in material science. The first two talks focussed on recent efforts on materials containing fibers; how to interpret, model, visualize and reason about fiber orientations and defects were discussed. We then transitioned to talks about the use of machine learning and image processing / computer vision when doing quantitative analysis of material science data. A consistent issue that was brought up was the need for benchmark problems (i.e. ground truth) and for training data.

5.10 Panel Discussion Summary: The Visual Debugger Challenge

Christoph Heinzl (FH Oberösterreich – Wels, AT), Robert Michael Kirby (University of Utah – Salt Lake City, US), Stepan V. Lomov (KU Leuven, BE), Guillermo Requena (DLR – Köln, DE), Rüdiger Westermann (TU München, DE)

This session focussed on the use of visual computing as a "debugging" tool within the materials science pipeline. The discussion was mainly about the use of visualization for parameter-space navigation and ensemble visualization. It turned out that in many applications in materials science there is a need for exploring the similarities and dissimilarities between multiple data sets, e.g. from measurements with different doses or reconstruction algorithms. Also the possibility to directly visualize datasets from different measurements or simulation technologies was requested. The discussion was also about which kind of interactivity is required in materials science. It seemed that interactive visual exploration of 3D data sets is desired, yet the community has some experience in this field. Concrete use cases where the different kinds of interaction can be demonstrated are highly appreciated.

6 Acknowledgements

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Report from Dagstuhl Seminar 19152

Emerging Hardware Techniques and EDA Methodologies for Neuromorphic Computing

Edited by

Krishnendu Chakrabarty[1], Tsung-Yi Ho[2], Hai Li[3], and Ulf Schlichtmann[4]

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 19152 "Emerging Hardware Techniques and EDA Methodologies for Neuromorphic Computing," which was held during April 7–10, 2019 in Schloss Dagstuhl – Leibniz Center for Informatics. Though interdisciplinary considerations of issues from computer science in the domain of machine learning and large scale computing have already successfully been covered in a series of Dagstuhl seminars, this was the first time that *Neuromorphic Computing* was brought out as the focus.

During the seminar, many of the participants presented their current research on the traditional and emerging hardware techniques, design methodologies, electronic design automation techniques, and application of neuromorphic computing, including ongoing work and open problems. This report documents the abstracts or extended abstracts of the talks presented during the seminar, as well as summaries of the discussion sessions.

Seminar April 7–10, 2019 – http://www.dagstuhl.de/19152
2012 ACM Subject Classification Computer systems organization → Neural networks, Hardware → Biology-related information processing, Hardware → Hardware-software codesign
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1 Executive Summary

Hai Li (Duke University – Durham, US)

The explosion of *big data* applications imposes severe challenges of data processing speed and scalability on traditional computer systems. However, the performance of von Neumann architecture is greatly hindered by the increasing performance gap between CPU and memory, motivating active research on new or alternative computing architectures. Neuromorphic computing systems, that refer to the computing architecture inspired by the working mechanism of human brains, have gained considerable attention. The human neocortex system naturally possesses a massively parallel architecture with closely coupled memory and computing as well as unique analog domain operations. By imitating this structure, neuromorphic computing systems are anticipated to be superior to conventional computer systems across various application areas. In the past few years, extensive research studies have been performed on developing large-scale neuromorphic systems. Examples include IBM's TrueNorth chip, the SpiNNaker machine of the EU Human Brain Project, the BrainScaleS neuromorphic system developed at the University of Heidelberg, Intel's Loihi etc. These attempts still fall short of our expectation on energy-efficient neuromorphic computing systems with online, real-time learning and inference capability. The bottlenecks of computation requirements, memory latency, and communication overhead continue to be showstoppers. Moreover, there is a lack of support in design automation of neuromorphic systems, including functionality verification, robustness evaluation and chip testing and debugging. Hardware innovation and electronic design automation (EDA) tools are required to enable energy-efficient and reliable hardware implementation for machine intelligence on cloud servers for extremely high performance as well as edge devices with severe power and area constraints.

The goal of the seminar was to bring together experts from different areas in order to present and to develop new ideas and concepts for emerging hardware techniques and EDA methodologies for neuromorphic computing. Topics that were discussed included:

- Neuroscience basics
- Physical fundamentals
- New devices and device modeling
- Circuit design and logic synthesis
- Architectural innovations
- Neurosynaptic processor and system integration
- Design automation techniques
- Simulation and emulation of neuromorphic systems
- Reliability and robustness
- Efficiency and scalability
- Hardware/software co-design
- Applications

The seminar facilitated greater interdisciplinary interactions between physicists, chip designers, architects, system engineers, and computer scientists. High-quality presentations and lively discussions were ensured by inviting carefully selected experts who participated in the seminar. All of them have established stellar reputations in the respective domains. As a result, we developed a better understanding of the respective areas, generated impetus for new research directions, and ideas for areas that will heavily influence research in the domain of neuromorphic design over the next years.

At the end of the seminar, we identified the following four areas as being among the most important topics for future research: *computing-in-memory*, *brain-inspired design and architecture*, *new technologies and devices*, and *reliability and robustness.* These research topics are certainly not restricted to and cannot be solved within one single domain. It is therefore imperative to foster interactions and collaborations across different areas.

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3 Overview of Talks

3.1 Challenges in Circuit Designs for Computing-in-Memory and Nonvolatile Logics for Edge Computing

Meng-Fan Chang (National Tsing Hua University – Hsinchu, TW)

Joint work of Meng-Fan Chang, CX Xue

Memory has proven to be a major bottleneck in the development of energy-efficient chips for artificial intelligence (AI). Recent memory devices not only serve as memory macros, but also enable the development of computing-in-memory (CIM) for IoT and AI chips. In this talk, we will review recent trend of Intelligent IoT and AI (AIoT) chips. Then, we will examine some of the challenges, circuits-devices-interaction, and recent progress involved in the further development of SRAM, emerging memory (STT-MRAM, ReRAM and PCM), nvLogics and CIMs for AIoT chips.

3.2 System-Level Design Methodology for Compute-in-Memory DNN Architecture

Chia-Lin Yang (National Taiwan University – Taipei, TW)

Joint work of Chia-Lin Yang, Hsiang-Yun Cheng, Tzu-Shien Yang, Meng-Yao Lin
Main reference Meng-Yao Lin, Hsiang-Yun Cheng, Wei-Ting Lin, Tzu-Hsien Yang, I-Ching Tseng, Chia-Lin Yang, Han-Wen Hu, Hung-Sheng Chang, Hsiang-Pang Li, Meng-Fan Chang: "DL-RSIM: a simulation framework to enable reliable ReRAM-based accelerators for deep learning", in Proc. of the International Conference on Computer-Aided Design, ICCAD 2018, San Diego, CA, USA, November 05-08, 2018, p. 31, ACM, 2018.
URL http://dx.doi.org/10.1145/3240765.3240800

Compute-in-memory (CIM) provides a promising solution to improve the energy efficiency of neuromorphic computing systems. Memristor-based crossbar architecture has gained a lot of attention recently. A few studies have shown the successful tape out of CIM ReRAM macros. However, how to integrate these macros together to handle large-scale DNN models still remains a challenge in terms of reliability and performance. In this talk, I will cover two main issues of the system-level design for Compute-in-Memory DNN architecture. First, I will introduce a simulation framework, DL-RSIM. DL-RSIM simulates the error rates of every sum-of-products computation in the memristor-based accelerator and injects the errors in the targeted TensorFlow-based neural network model. A rich set of reliability impact factors are explored by DL-RSIM, and it can be incorporated with any deep learning neural network implemented by TensorFlow. This tool enables design space exploration considering inference accuracy, performance and power tradeoffs. Second, I will present a new methodology for exploiting sparsity on a crossbar architecture. Existing sparsity solutions assume an over-idealized ReRAM crossbar architecture assuming an entire 128x128 or 256x256 crossbar array could be activated in a single cycle. However, due to power constraints and reliability issues, vector-matrix multiplication needs to be operated in a smaller granularity, called operation unit (OU), in practice. This finer granularity of computation presents a new opportunity for exploiting sparsity.

3.3 Neuromorphic computing architectures for IoT applications

Federico Corradi (Stichting IMEC Nederland – Eindhoven, NL)

Joint work of Federico Corradi, Giacomo Indiveri, Francky Catthoor
Main reference Corradi F. et al., "ECG-based Heartbeat Classification in Neuromorphic Hardware", IEEE International Joint Conference on Neural Networks (IJCNN), 2019.

Neuromorphic computing is a promising approach for developing new generations of smarter and adaptive computing technologies that can drastically change the way in which we think of computers, and in which we interact with artificial systems. In this approach, brain-inspired models of neural computations, based on massively parallel networks of low-power silicon neurons and synapses are implemented in electronic microchips [1]. These novel devices represent the third generation of neural networks which not only allows us to investigate at the theoretical level the possibilities of using time as a resource for computation and communication but can also shed light in the way in which our own brain works. This talk will describes recent efforts in building microchips and architectures of spiking neurons that can go beyond standard von Neumann machines [3]. In particular, I will showcase an ultra-low power architecture that target always-on wearable monitoring and other internet of things applications [2, 4].

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3.4 Logic Synthesis for Hybrid CMOS-ReRAM Sequential Circuits

Rolf Drechsler (Universität Bremen, DE)

Joint work of Saman Froehlich, Saeideh Shirinzadeh, Rolf Drechsler
Main reference Saman Froehlich, Saeideh Shirinzadeh, Rolf Drechsler: "Logic Synthesis for Hybrid CMOS-ReRAM Sequential Circuits," IEEE Computer Society Annual Symposium on VLSI Miami, Florida, U.S.A., July 15-17, 2019.

Resistive Random Access Memory (ReRAM) is an emerging nonvolatile technology with high scalability and zero standby power which allows to perform logic primitives. ReRAM crossbar arrays combined with a CMOS substrate provide a wide range of benefits in logic synthesis. However, the application of ReRAM to sequential circuits has not been studied. We present a general synthesis approach for hybrid CMOS-ReRAM sequential architectures, which aims to minimize the CMOS overhead.We apply this general approach to different design methodologies, such as BDD-based design and AIGs. In the experiments we show that ReRAM allows for a significant reduction in CMOS size.

3.5 Cognitive Computing-in-Memory: Circuit to Algorithm

Deliang Fan (University of Central Florida – Orlando, US)

Main reference Shaahin Angizi, Jiao Sun, Wei Zhang, Deliang Fan: "GraphS: A Graph Processing Accelerator Leveraging SOT-MRAM", in Proc. of the Design, Automation & Test in Europe Conference & Exhibition, DATE 2019, Florence, Italy, March 25-29, 2019, pp. 378–383, IEEE, 2019.
URL https://doi.org/10.23919/DATE.2019.8715270

In-memory computing architecture is becoming a promising solution to reduce massive power hungry data traffic between computing and memory units, leading to significant improvement of entire system performance and energy efficiency. Meanwhile, emerging post-CMOS non-volatile memory, like Magnetic Random Access Memory (MRAM) or Resistive RAM (ReRAM), has been explored as next-generation memory technology that could be used not only as high performance memory with non-volatility, zero leakage power in un-accessed bit-cell, high integration density, but also as an efficient neuromorphic computing-in-memory platform. In this talk, Dr. Deliang Fan, from University of Central Florida, Orlando, FL, presents his recent synergistic research in cognitive computing-in-memory, including two main topics: 1) deep neural network (DNN) acceleration-in-memory system with both in-memory-logic design and hardware driven neural network optimization algorithm; 2) end-to-end ReRAM crossbar based neuromorphic computing EDA tool powered by a robust neural network mapping framework that adapts to existing non-ideal effects of crossbar structure.

For the first DNN computing-in-memory topic, it involves both the NVM based in-memory logic design and hardware aware DNN weight ternarization algorithm. First, in order to efficiently implement fast, reconfigurable in-memory logic without energy consuming intermediate data write back, two different logic-sense amplifier designs are presented. They could implement reconfigurable complete Boolean logic and full adder in only one cycle by simultaneously sensing two or three resistive memory cells in the same bit-line. Then a fully parallel multi-bit adder is presented. The related works are published in ASPDAC 2019[1], DATE 2019[2] and DAC 2019[3]. To further make the DNN algorithm intrinsically match with the developed in-memory logic platform, a DNN weight ternarization algorithm is introduced to fully ternarize all weight parameters into two states (i.e. +1, 0, -1), which brings three main benefits: 1) model size is compressed by 16X; 2) multiplication and accumulation based convolution operations are converted into adder only computation due to fully ternary weights. Different ternarization algorithms are published in WACV 2019[4] and CVPR 2019[5], both showing less than 2% top-1 accuracy drop when fully ternarizing DNN including the first layer and last layer.

For the second ReRAM crossbar based neuromorphic computing topic, a comprehensive framework called PytorX is introduced. It performs end-to-end (i.e. algorithm to device) training, mapping and evaluation for crossbar-based deep neural network accelerator, considering various non-ideal effects (e.g. Stuck-At-Fault (SAF), IR-drop, thermal noise, shot noise and random telegraph noise) of ReRAM crossbar when employing it as a dot-product engine. In particular, to overcome IR drop effects, a Noise Injection Adaption (NIA) methodology is introduced by incorporating statistics of current shift caused by IR drop in each crossbar as stochastic noise to DNN training algorithm, which could efficiently regularize DNN model to make it intrinsically adaptive to non-ideal ReRAM crossbar. It is a one-time training method without need of retraining for every specific crossbar. The related paper is published in DAC 2019[6] and PytroX code will be released in Github.

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5 Zhezhi He and Deliang Fan. *Simultaneously Optimizing Weight and Quantizer of Ternary Neural Network using Truncated Gaussian Approximation*. Conference on Computer Vision and Pattern Recognition (CVPR), June 16-20, 2019, Long Beach, CA, USA

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3.6 Scaling-up analog neural networks – practical design considerations

Alex Pappachen James (Nazarbayev University – Astana, KZ)

Main reference Olga Krestinskaya, Aidana Irmanova, Alex Pappachen James: "Memristive Non-Idealities: Is there any Practical Implications for Designing Neural Network Chips?", in Proc. of the IEEE International Symposium on Circuits and Systems, ISCAS 2019, Sapporo, Japan, May 26-29, 2019, pp. 1–5, IEEE, 2019.

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The implementation of analog neural networks in a memristive crossbar faces several challenges. The impact of non-idealistic behavior of devices and network components poses challenges to designing specifications for neural networks. The performance and reliability analysis of memristive neural networks involve a careful look into the device to device variability, signal integrity issues, signal noise issues, thermal issues, packaging issues, device aging, line resistors, device faults, and process variation. The scaling of analog neural networks are limited by such non-idealities [2], and to counter this the performance analysis needs to be mapped and benchmarked with the degradations from non-idealities. The analog networks are ideally suitable for near-sensor edge AI computing[3], where the signal degradation from the source is limited, and where the information processing can be done in a near-continuous mode of operation.

The memristor crossbar as a dot product engine for analog neural networks can be used for achiving low power and low area density for different types of networks such as hierarchical temporal memories, convolutional neural networks and binary neural networks [1]. In analog neural network implementations, the mapping of weights to specific resistance levels in memristor is challenging over a period of time due to physical stress on the devices over continuous read-write cycles. Even if it is programmed to a specific level, we notice that the number of levels within a memristor is an important factor in determining the robustness of the analog neural network towards performance indicators such as recognition accuracy in a classification task [2]. It is important to also take into account the variability of conductance states between the devices within a crossbar along with non-idealities of interfacing circuits in the system level performance evalution and design of analog neural networks to ensure reliability of a given system application.

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3.7 Resource-aware machine learning and data mining

Jian-Jia Chen (TU Dortmund, DE)

Joint work of Sebastian Buschjäger, Kuan-Hsun Chen, Jian-Jia Chen, Katharina Morik
Main reference Sebastian Buschjäger, Kuan-Hsun Chen, Jian-Jia Chen, Katharina Morik: "Realization of Random Forest for Real-Time Evaluation through Tree Framing", in Proc. of the IEEE International Conference on Data Mining, ICDM 2018, Singapore, November 17-20, 2018, pp. 19–28, IEEE Computer Society, 2018.
URL http://dx.doi.org/10.1109/ICDM.2018.00017

The performance of machine learning and data mining algorithms are constrained by the underlying computing platforms. On one hand, the platform defines how fast a machine learning algorithm can be executed; on the other hand, the machine learning algorithm should be adaptive to be efficiently executed on different platforms. In this talk, I will summarize my perspectives of such resource-aware machine learning and data mining algorithms. Specifically, I will address by using simple decision trees or random forests, that are widely used in many applications. We show that effective configurations of cache layout can improve the performance of decision trees significantly. We also show that tuning hyper-parameters in machine learning algorithms can be constrained by the resources and demonstrate how to use model-based optimization (MBO) to handle such configurations in a resource-efficient manner.

3.8 Turing, or Non-Turing? That is the question

Johannes Schemmel (Universität Heidelberg, DE)

Neuromorphic computing, as a realization of Non-Turing, in-memory, event-based computing, will allow us to overcome the power wall our CPU-centric CMOS technology is facing. But that does not mean that the era of Turing-based computing will come to an end soon, or that Turing-based computing does not have its place in the neuromorphic world.

Our work in the area of neuromorphic computing is based on the premise that the biological brain is the ultimate cognitive system, especially considering its low power consumption of approximately 20 Watts. Each of the billions of neurons constituting the brain receives signals from thousands of others. Thereby forming a dense network of interconnects. This exchange of information happens at special sites of transmission, the synapses. The receiving neuron integrates its synaptic inputs continuously over space and time, thereby computing without a central clock or any global addressing schemes. Temporal and spatial correlations determine the dynamics of the system, and the synapse becomes the central point of learning. Any correlation depends on the interconnection schemes between the neurons, which is determined by the growth and development of the synaptic connectome.

Any theories we derive from experimental observations of this cellular interplay can be formulated in the language of mathematics. This leads to incredible complex systems of billions of coupled differential equations. Numerical simulations provide most of the insight we can get from these descriptions of biology. Numerical simulations including the temporal evolution of the synaptic connectome are currently only feasible for small networks. The power-wall our current CMOS technology is facing gives us not much hope for the future, as long as we rely on contemporary computing architectures.

Dedicated accelerators are one possible solution. They can improve the power-efficiency of these kind of simulations by several orders of magnitude. One special kind of accelerator are the physical model systems we presented in this talk: they solve the differential equations by emulating their dynamics in analog CMOS circuits instead of numerical calculations.

The state of the system is represented by physical quantities like voltage, current and charges instead of binary numbers. This approach was first published by Carver Mead in the 1980ies. The implementation we present is different from this initial work by biasing the transistors near or even within strong inversion instead of deep sub-threshold, utilizing transistors closer to their minimum size. This allows a higher component density and, due to the strongly reduced mismatch, a better calibratability and repeatability of the neuron and synapse parameters.

The natural time constants at these higher bias points lead to time constants several orders of magnitude shorter than in biology. This effectively accelerates the emulation of the underlying model, therefore the term "accelerated analog neuromorphic hardware" for our kind of neuromorphic systems.

The BrainScaleS-1 (BSS-1) system uses these principles to create highly connected systems from multiple microchips, each implementing 512 neurons and 114k synapses. The BSS-1 system is usually trained by hardware-in-the-loop methods, using an external compute cluster to calculate the synaptic connectome.

The analog emulation of a neural network, running at 10000 times the speed of its biological example within a BSS-1 system formed by more than 400 interconnected chips, realizes one of the very few implementations of true non-Turing computing worldwide. Alternatively, this program-free mode of computation is sometimes called non-Von-Neumann computing. Looking more closely, Turing-based computation is still utilized for a multiple of purposes in the BSS-1 system: training, system initialization, hardware calibration, runtime control and the handling of all input and output data is performed by a complex, multi-tiered software stack.

To create a self-sufficient, scalable neuromorphic system that has a minimized communication demand with any external hardware, all of this functions have to move inside of the system, similar to the self-sufficiency we observe in biology. In other words and to stay withing the analogy: we have to move everything besides the simple synapse and neuron models into our microchips. Functions performed by the Astrocytes, the cell-nuclei, the intercellular, dendritic and axonal transport systems as well as the peripheral nerves connecting the brain with its body.

This will not be achievable by analog, dedicated hardware in the foreseeable future. Mostly, because we do not know enough details of these processes yet. Our hardware systems need a lot of flexibility regarding the implementation of theses features. With the second generation BrainScaleS architecture, BrainScaleS-2, we devised a solution to this issues, originally called "hybrid plasticity". The key aspect of which is the demotion of the analog neuromorphic part from the center of the system to the role of a co-processor.

The BSS-2 architecture is based on a high-bandwidth link between an SIMD microprocessor and an accelerated analog neuromorphic core, where the CPU takes over every role not covered by the neuromorphic core.

This Turing-non-Turing hybrid allows the realization of on-chip learning, calibration, initialization and environmental simulation. The accelerated analog core emulates the network in continuous time and performs all performance and energy intensive operations, like measuring spatial and temporal correlations or solving the differential equations that govern the membrane voltages. The network will always perform without any intervention from the CPU. But it will be a static system, where no parameters change anymore. The dynamic adjustment of all parameters, from synaptic weights, network topology to neuron parameters, is controlled by the CPU, allowing the full flexibility of software-defined algorithms for the implementation of learning algorithms. Since the CPU does not need to look at every individual spike, the learning speed is also accelerated, usually by the same factor as the network time constants. Therefore, learning processes need only seconds instead of tens of minutes.

This talk explains the Heidelberg BrainScaleS-2 accelerated analog neuromorphic architecture and demonstrates how it balances Turing and Non-Turing computing to combine power efficiency with the necessary flexibility and programmability.

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3.9 Reliability / Robustness of Neuromorphic Computing Architectures – Has the time come yet?

Bing Li (TU München, DE) and Ulf Schlichtmann (TU München, DE)

Joint work of Shuhang Zhang, Grace Li Zhang, Bing Li, Hai (Helen) Li, Ulf Schlichtmann
Main reference Shuhang Zhang, Grace Li Zhang, Bing Li, Hai Helen Li, Ulf Schlichtmann: "Aging-aware Lifetime Enhancement for Memristor-based Neuromorphic Computing", in Proc. of the Design, Automation & Test in Europe Conference & Exhibition, DATE 2019, Florence, Italy, March 25-29, 2019, pp. 1751–1756, IEEE, 2019.
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Neuromorphic Computing is a rapidly emerging, very promising area of computing. Understandably, research focuses on determining the most efficient architectures, circuit design concepts etc. But as we have learned from traditional CMOS technology, reliability and robustness are very important areas of concern [2, 3, 4, 5]. For instance, memristors can only be programmed reliably for a given number of times. Afterwards, the working ranges of the memristors deviate from the fresh state. As a result, the weights of the corresponding neural networks cannot be implemented correctly and the classification accuracy drops significantly. To counter this effect, software training and hardware mapping can be combined to extend the lifetime of memristor crossbars up to 11 times, while the accuracy of classification is maintained [1].

Broadly speaking, neuromorphic computing schemes with CMOS-based devices and emerging technologies all face reliability and robustness challenges, specially when the feature size of the manufacturing technology is reduced further to achieve a higher integration density. In "classical", von-Neumann-based computing, analysis and optimization of reliability and robustness has already become as important as considering area, performance and power. How about neuromorphic computing? Since AI based on neuromorphic computing is often intended to be used significantly in safey-critical applications such as autonomous driving, has now already the moment come to pose the question – has the time come already now to worry about reliability and robustness of neuromorphic computing?

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3.10 Memory Device Modeling for the Simulation of Neuromorphic Systems

Darsen Lu (National Cheng Kung University – Tainan, TW)

With the recent advancement in the internet and mobility, which generated massive amounts of data, deep learning has become a powerful tool in creating domain-specific intelligence, and has found application in many areas. Hardware acceleration of deep learning becomes essential given the large computational power requirement, especially during training. Analog neuromorphic computation may be the ultimate (best) hardware for deep learning given its significantly lower power compared to the digital counterpart.

Analog neuromorphic computation often uses non-volatile memory devices as basic element (synapse). We have developed, in collaboration with our colleagues at NCKU, compact models for ferroelectric memory, resistive memory, phase change memory, and flash and have used them towards neuromorphic circuit applications.

To translate compact-model-based device characteristics to estimated system-level performance such as recognition rate, power consumption, and circuit speed, a simulation platform is required. We have developed simNemo, a platform which predicts deep learning performance for given memory device characteristics, circuit architecture, and neural network model. So far we have focused on modeling resistive RAM devices in MLP neural networks, and have using the MNIST database for benchmark.

Through the process of building and using simNemo, we have learned the challenges of analog neuromorphic computing and its EDA methodologies. First, even though device-to-device variation can be compensated by weight adjustment during traning to some extent, there is a limit. If the variation is too large, it can limit the synaptic degree of freedom such as allowing only positive or negative weight. Second, cycle-to-cycle variation, which in many cases is the fundamental property of a memory device, cannot be compensated by training. However, it can be mitigated by special programming technique. Take the memristor/RRAM for example, we may program the device with large current so that it achieves a very low resistivity, and the impact of cycle-to-cycle variation due to a single trapping or de-trapping event becomes minimal. Third, linearity and symmetry are very important properties for memory devices used for neuromorphic applications. Symmetry is more important, as non-symmetric positive versus negative weight updates may even cause training algorithm to fail by introducing bias towards a certain direction, so that the algorithm never converges to the optimal point. On the other hand, closed-loop programming is one way to overcome this issue. Forth, endurance is a challenge for online training since the memory device needs to be updated many times. The use or larger batch size helps. Fifth, analog-to-digital conversion always introduce quantization error. One solution is digital-assisted training of analog neuromorphic systems by storing weight update residues in a digital form during training. Finally, analog summing of current poses the dynamic range challenge as each wire has certain noise floor. This can be solved by the integrate-and-fire circuitry at the output to effectively increase the dynamic range of current sum.

3.11 Processing Data Where It Makes Sense in Modern Computing Systems: Enabling In-Memory Computation

Onur Mutlu (ETH Zürich, CH)

Main reference Onur Mutlu, Saugata Ghose, Juan Gómez-Luna, Rachata Ausavarungnirun: "Processing Data Where It Makes Sense: Enabling In-Memory Computation", CoRR, Vol. abs/1903.03988, 2019.
URL https://arxiv.org/abs/1903.03988

Today's systems are overwhelmingly designed to move data to computation. This design choice goes directly against at least three key trends in systems that cause performance, scalability and energy bottlenecks: 1) data access from memory is already a key bottleneck as applications become more data-intensive and memory bandwidth and energy do not scale well, 2) energy consumption is a key constraint in especially mobile and server systems, 3) data movement is very expensive in terms of bandwidth, energy and latency, much more so than computation. These trends are especially severely-felt in the data-intensive server and energy-constrained mobile systems of today.

At the same time, conventional memory technology is facing many scaling challenges in terms of reliability, energy, and performance. As a result, memory system architects are open to organizing memory in different ways and making it more intelligent, at the expense of slightly higher cost. The emergence of 3D-stacked memory plus logic, the adoption of error correcting codes inside the latest DRAM chips, and intelligent memory controllers to solve the RowHammer problem are an evidence of this trend.

In this talk, I will discuss some recent research that aims to practically enable computation close to data. After motivating trends in applications as well as technology, we will discuss at least two promising directions: 1) performing massively-parallel bulk operations in memory by exploiting the analog operational properties of DRAM, with low-cost changes, 2) exploiting the logic layer in 3D-stacked memory technology in various ways to accelerate important data-intensive applications. In both approaches, we will discuss relevant cross-layer research, design, and adoption challenges in devices, architecture, systems, applications, and programming models. Our focus will be the development of in-memory processing designs that can be adopted in real computing platforms and real data-intensive applications, spanning machine learning, graph processing, data analytics, and genome analysis, at low cost. If time permits, we will also discuss and describe simulation and evaluation infrastructures that can enable exciting and forward-looking research in future memory systems, including Ramulator and SoftMC.

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3.12 Low Power Embedded Machine Intelligence on a Neurosynaptic Processor

Qinru Qiu (Syracuse University, US)

Spiking neural networks are rapidly gaining popularity for their brain-inspired architecture and operation. It has the potential to achieve low cost, high noise resilience, and high energy efficiency due to the distributed nature of neural computation and the use of low energy spikes for information exchange. This talk introduces our work on applying the neurosynaptic processor, such as IBM TrueNorth, to implement different neural networks. How distributed learning can potentially be achieved in a stochastic spiking neural network will also be discussed. It is the first work to implement not only feedforward networks, but also recurrent networks on the spiking based neurosynaptic processor. It has the potential to enable energy efficient implementation of a wider range of applications and very low cost, in hardware learning.

3.13 Hardware and Software for Spike-based Memristive Neuromorphic Computing Systems

Garrett S. Rose (University of Tennessee, US)

Main reference James S. Plank, Catherine D. Schuman, Grant Bruer, Mark E. Dean, and Garrett S. Rose, "The TENNLab Exploratory Neuromorphic Computing Framework," IEEE Letters of the Computer Society, vol. 1, pp. 17–20, July-Dec. 2018.
URL https://doi.ieeecomputersociety.org/10.1109/LOCS.2018.2885976

Given the slow down in Moore's Law scaling and limits in classic von Neumann computer architectures, spike-based neuromorphic computing has gained increasing interest for a range of potential applications. Here we consider spiky neuromorphic systems where neurons are implemented using analog/mixed-signal CMOS and synapses are built from memristors (or "memory resistors"). The specific neuromorphic framework presented also allows for recurrent pathways in the networks constructed, a feature that is particularly useful for stateful neuromorphic processing. One such spiky recurrent neuromorphic system is mrDANNA (Memristive Dynamic Adaptive Neural Network Array), a hybrid CMOS/memristor implementation from the University of Tennessee. A full mrDANNA system offers the potential to construct small neural network applications operating on a fraction of the power consumed by analogous deep learning systems.

3.14 DNN on FPGA and RRAM

Yu Wang (Tsinghua University – Beijing, CN)

URL https://nicsefc.ee.tsinghua.edu.cn/projects/neural-network-accelerator/

Artificial neural networks, which dominate artificial intelligence applications such as object recognition and speech recognition, are in evolution. To apply neural networks to wider applications, customized hardware are necessary since CPU and GPU are not efficient enough. FPGA can be an ideal platform for neural network acceleration (inference part) since it is programmable and can achieve much higher energy efficiency compared with general-purpose processors. However, the long development period and insufficient performance of traditional FPGA acceleration prevent it from wide utilization.

We propose a complete design flow to achieve both fast deployment and high energy efficiency for accelerating neural networks on FPGA [FPGA 16/17]. Deep compression and data quantization are employed to exploit the redundancy in algorithm and reduce both computational and memory complexity. Two architecture designs for CNN and DNN/RNN are proposed together with compilation environment. Evaluated on Xilinx Zynq 7000 and Kintex Ultrascale series FPGA with real-world neural networks, up to 15 times higher energy efficiency can be achieved compared with mobile GPU and desktop GPU.

We talk about why we start Deephi (DL is a uniform respresentation of $y = f(x)$). We also show the collective figure about all the current inference accelerator, and point out the 1-10TOPS/W limitation by the current technology. Meanwhile it is worth to think about where the computing is happening: cloud + edge + end devices, and the application domains defines the AI chips.

Another important perspective is the software toolchain/compiler is very important AI chips. We talk about the recent compiler design for CPU/GPU/FPGA, and try to think about the right tool for neurotrophic computing. We will discuss the possibilities and trends of adopting emerging NVM technology for efficient learning systems to further improve the energy efficiency. We would like to call for some kind of collaborative effort on the open software design for Neuromorphic computing or the computing in memory research.

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Report from Dagstuhl Seminar 19171

Ethics and Trust: Principles, Verification and Validation

Edited by

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Abstract

This report documents the programme of, and outcomes from, the Dagstuhl Seminar 19171 on *"Ethics and Trust: Principles, Verification and Validation"*. We consider the issues of ethics and trust as crucial to the future acceptance and use of autonomous systems. The development of new classes of autonomous systems, such as medical robots, "driver-less" cars, and assistive care robots has opened up questions on how we can integrate truly autonomous systems into our society. Once a system is truly autonomous, i.e. learning from interactions, moving and manipulating the world we are living in, and making decisions by itself, we must be certain that it will act in a safe and ethical way, i.e. that it will be able to distinguish 'right' from 'wrong' and make the decisions we would expect of it. In order for society to accept these new machines, we must also trust them, i.e. we must believe that they are reliable and that they are trying to assist us, especially when engaged in close human-robot interaction. The seminar focused on questions of how does trust with autonomous machines evolve, how to build a 'practical' *ethical* and *trustworthy* system, and what are the societal implications. Key issues included: Change of trust and trust repair, AI systems as decision makers, complex system of norms and algorithmic bias, and potential discrepancies between expectations and capabilities of autonomous machines. This workshop was a follow-up to the 2016 Dagstuhl Seminar 16222 on *Engineering Moral Agents: From Human Morality to Artificial Morality.* When organizing this workshop we aimed to bring together communities of researchers from moral philosophy and from artificial intelligence and extend it with researchers from (social) robotics and human-robot interaction research.

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2012 ACM Subject Classification Computer systems organization → Robotic autonomy, Hardware → Functional verification, Human-centered computing → HCI theory, concepts and models
Keywords and phrases Verification, Artificial Morality, Social Robotics, Machine Ethics, Autonomous Systems, Explain-able AI, Safety, Trust, Mathematical Philosophy, Robot Ethics, Human-Robot Interaction
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1 Executive Summary

Astrid Weiss (TU Wien, AT)
Michael Fisher (University of Liverpool, GB)
Christian List (London School of Economics, GB)
Marija Slavkovik (University of Bergen, NO)

Academics, engineers, and the public at large, are all wary of *autonomous systems*, particularly robots, drones, "driver-less" cars, etc. Robots will share our physical space, and so how will this change us? With the predictions of roboticists in hand, we can paint portraits of how these technical advances will lead to new experiences and how these experiences may change the ways we function in society. Two key issues are dominant once robot technologies have advanced further and yielded new ways in which we and robots share the world: (1) will robots behave *ethically*, i.e. as we would want them to, and (2) can we *trust* them to act to our benefit. It is more these barriers concerning ethics and trust than any engineering issues that are holding back the widespread development and use of autonomous systems. One of the hardest challenges in robotics is to reliably determine desirable and undesirable behaviours for robots. We are currently undergoing another technology-led transformation in our society driven by the outsourcing of decisions to intelligent, and increasingly autonomous, systems. These systems may be software or embodied units that share our environment. The decisions they make have a direct impact on our lives. With this power to make decisions comes the responsibility for the impact of these decisions – legal, ethical and personal. But how can we ensure that these artificial decision-makers can be *trusted* to make safe and *ethical* decisions, especially as the responsibility placed on them increases?

The related previous Dagstuhl Seminar 16222 on *Engineering Moral agents: From human morality to artificial morality* in 2016, highlighted further important areas to be explored, specifically:

- the extension of 'ethics' to also address issues of 'trust';
- the practical problems of implementing ethical and trustworthy autonomous machines;
- the new verification and validation techniques that will be required to assess these dimensions.

Thus, we thought that the area would benefit from a follow-up seminar which broadens up the scope to Human-Robot Interaction (HRI) and (social) robotics research.

We conducted a four-day seminar (1 day shorter than usual due to Easter) with 35 participants with diverse academic backgrounds including AI, philosophy, social epistemology, Human-Robot Interaction, (social) robotics, logic, linguistics, political science, and computer science. The first day of the seminar was dedicated to seven invited 20-minute talks which served as tutorials. Given the highly interdisciplinary nature of the seminar, the participants from one discipline needed to be quickly brought up to speed with the state of the art in the discipline not their own. Moreover, the goal of these tutorials was to help develop a common language among researchers in the seminar. After these tutorials we gave all participants the chance to introduce their seminar-related research in 5-minute contributed talks. These talks served as a concise way to present oneself and introduce topics for discussion.

Based on these inputs four topics were derived and further explored in working groups through the rest of the seminar: (1) Change of trust, including challenges and methods to foster and repair trust; (2) Towards artificial moral agency; (3) How do we build practical systems involving ethics and trust? (2 sub-groups) (4) The broader context of trust in HRI:

Discrepancy between expectations and capabilities of autonomous machines. This report summarizes some of the highlights of those discussions and includes abstracts of the tutorials and some of the contributed talks. Ethical and trustworthy autonomous systems are a topic that will continue to be important in the coming years. We consider it essential to continue these cross-disciplinary efforts, above all as the seminar revealed that the "interactional perspective" of the "human-in-the-loop" is so far underrepresented in the discussions and that also broadening the scope to STS (Science and Technology Studies) and sociology of technology scholars would be relevant.

2 Table of Contents

3 Overview of Tutorials

3.1 Tutorial: Robot Ethics – Towards Trustworthy AI agents

Raja Chatila (Sorbonne University – Paris, FR)

Joint work of Contributions of authors of Ethically Aligned Design (IEEE) and members of the EU High-Level Expert Group on AI.
URL https://ethicsinaction.ieee.org,
https://ec.europa.eu/digital-single-market/en/high-level-expert-group-artificial-intelligence

A computational intelligent system, a robot, is a set of algorithms designed by humans, using data (big/small/sensed) to solve [more or less] complex problems in [more or less] complex situations. The system might include the capability of improving its performance based on data classification (e.g., deep learning) or on evaluating previous decisions (e.g., reinforcement learning).

Such systems could be regarded as “autonomous” in a given domain and for given tasks as long as they are capable of accomplishing their tasks despite environment changes within this domain (this is close to the notion of robustness). Autonomy is related to the complexity of the domain and of the task.

Computerized technical systems, especially those used in critical applications, must be trustworthy to reliably deliver the expected correct service. The academic and industrial communities developing software-based systems have produced several techniques to achieve their dependability or resilience. Software validation and verification techniques, such as error detection and recovery mechanisms, model checking, detection of incorrect or incomplete system knowledge, and resilience to unexpected changes due to environment or system dynamics, have been developed and used.

However, as decisions usually devoted to humans are being more and more delegated to machines, sometimes running computational algorithms based on learning techniques using data, operating in complex and evolving environments, new issues have to be considered.

First, can such systems make ethical decisions? The answer is negative. Ethical discernement is not a mere computational process. Second, should the AI “black-box” justify moving away from procedures that guarantee a trusted operation of the system? This is both an ethical and a technical question to the designers. Key features such as transparency, explainability and accountability become of prime importance. What technical and non-technical new measures should be taken then in the design process and in the governance of these systems?

A summary of the IEEE global Initiative on Ethics of Autonomous and Intelligent Systems, as well as the Ethics Guidelines for Trustworthy AI of the European High-Level Expert Group on AI shed light on these issues.

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3.2 Tutorial: Formalizing Ethical Choice

Franz Dietrich (Paris School of Economics & CNRS, FR)

Our reason-based formalism for rational choice (which Christian List and I are developing) can be used to represent moral theories. Almost any plausible moral theory can indeed be represented in terms of two parameters: (i) a specification of which properties of the objects of moral choice matter in any given context, and (ii) a specification of how these properties matter. This yields a very general taxonomy of moral theories, in which we can formally distinguish between consequentialist and non-consequentialist theories, between universalist and relativist theories, between agent-neutral and agent-relative theories, between monistic and pluralistic theories, between atomistic and holistic theories, and between theories with and without a teleological structure. (based on joint work with Christian List)

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3.3 Tutorial: Social Robots – To Be Trusted?

Marc Hanheide (University of Lincoln, GB)

This talk aims to provide a (quite shallow) overview into the domain of social robots. It collates a number of (sometimes controversial) definitions and their criticism, as well as offering links to challenges and open debates grounded in practical experience. I consider that (i) robots are not treated as "social equals", (ii) social robots are often about social evocation (or deception?) and that (iii) "sociabilty" can serve as a means to build "better robots".

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3.4 Tutorial: Trust in Human-Robot Interaction

James E. Young (University of Manitoba – Winnipeg, CA)

The field of Human-Robot Interaction proposes that, in many ways, people treat and respond to robots as life-like things. Drawing from this, social robotics is the broad study of how robots themselves can be seen as social actors, which leads to the investigation of robots using human-like social interaction techniques to work with people. Following, if we consider robots as social actors, then issues of trust arise. The human-robot interaction community has broadly explored trust and related concepts. This includes human trust in robot informers (e.g., kiosks), including for vulnerable populations such as children. As part of this, the community has mapped out robot and interaction design strategies for managing trust (e.g., increasing or decreasing) in a range of situations, leading to work in persuasion, and even obedience to robots. With all of this in perspective, I raise the question of whether we, as a society, should accept the idea that machines without emotional or moral regulating systems, with perfect memories and algorithmic accuracy, can use human language to impact people.

3.5 Tutorial: Trust in Robots is Multi-Dimensional Too

Bertram F. Malle (Brown University – Providence, US)

Different definitions, theories, and measurements of trust are distributed over multiple literatures, and it is unclear how they can all be integrated. I suggest that there is not one correct definition of trust but people have a multidimensional conception of trust. On the one hand, they can experience capacity trust, which breaks into perceptions of the agent in question as capable to a certain degree and as reliable to a certain degree; on the other hand, they can experience moral trust, which breaks into perceptions of the agent as sincere to a certain degree and as ethical to a certain degree. I offer empirical evidence for these conceptual distinctions in people's lay understanding of trust and introduce a new measurement instrument for assessing these multiple dimensions. Finally, I draw implications for the role of trust in human-robot interaction, including how one would conduct verification tests for moral trust and how one could better assess calibrated trust within a multidimensional framework.

3.6 Tutorial: Two Kinds of Trust in Robots

Andreas Matthias (Lingnan University – Hong Kong, HK)

URL https://andreasmatthias.com/dagstuhl2019/

We can distinguish two different kinds of trust: trust in a process and trust in value alignment. Only process-trust can be achieved through certification of robots. Values-trust requires an individual, personal alignment of values between the user and the robot that is the basis for the robot to treat the user as a Kantian "end". Is it doubtful whether values-trust can be achieved within the framework of existing economical structures in the technology sector.

3.7 Tutorial: Machine Ethics – Philosophical Approaches

Thomas Michael Powers (University of Delaware – Newark, US)

After reviewing some formalizable ethical theories, I argue for a particular minimal conception of machine ethics as a starting point—a "coded ethics". Coded ethics begins with conventional, accepted moral rules that apply to specific contexts, and implements them in engineered systems in response to a growth in morally-relevant capabilities of the system. The central feature of a coded ethics is the implementation of ethical rules when any new capability of the system threatens moral values (privacy, safety, etc.). There is no artificial consciousness or intentionality required for coded ethics; the machine follows accepted normative reasoning–it makes moral decisions–that protect or promote the interests of humans and other moral patients. A coded ethics might implement any number of basic deontological prescriptions and proscriptions, depending on the given context: rules against privacy violations, non-combatant harm, and non-compensated costs, etc. The proposed coded ethics is an elaboration of Adaptive Incremental Machine Ethics found in Powers (2011), Incremental Machine Ethics, IEEE Robotics and Automation 18:1.

4 Overview of Contributed Talks

4.1 How Is This Fair? Formalising Contextual Adherence to Moral Values

Andrea Aler Tubella (University of Umeå, SE)

Joint work of Andrea Aler Tubella, Virginia Dignum, Andreas Theodorou, Frank Dignum

In this short presentation, I introduce ongoing research on the formalisation of contextual adherence to moral values. If AI is to be deployed safely, then people need to understand how the system is interpreting and whether it is adhering to the relevant moral values. Even though transparency is often seen as the requirement in this case, realistically it might not always be possible or desirable, whereas the need to ensure that the system operates within set moral bounds remains. We present an approach to evaluate the moral bounds of an AI system based on the monitoring of its inputs and outputs. We place a ‘Glass Box’ around the system by mapping moral values into contextual verifiable norms that constrain inputs and outputs, in such a way that if these remain within the box we can guarantee that the system adheres to the value(s) in a specific context.

4.2 Being Responsible for Someone Else’s Actions

Jan M. Broersen (Utrecht University, NL)

Human agents are responsible for their own actions. And in so far AIs are mere tools, humans are also responsible for the actions of the AIs they employ. However, in a future where AIs are ubiquitous, things will not be so clean cut. First of all there is the possibility that AIs will become so advanced that some would want to attribute agency to them of the kind that comes with the responsibility that humans have. Second, there is the way in which actions of AIs express the agency of many different humans involved in the deployment or design of an AI. One central theme that pervades these issues is how one agent can be responsible for another agent’s actions (the second agent maybe being an AI or a cooperating human). The formal logic study of the transitivity of the responsibility relation has not been taken up yet in any serious way.

4.3 Four Papers in the Philosophy of Technology

Einar Duenger Bøhn (University of Agder, NO)

I work on four papers. One where I defend what I call informationalism, which is the view that reality is most fundamentally pure information. Second, a paper called AlphaMoral, where I develop the idea that artificial morality can be developed through board games. Third, a paper called The Moral Turing test, where I defend the moral Turing test as a good test for artificial morality. Fourth, popular pieces where I argue that smartphones should have an age limit.

4.4 What Can We Prove About Ethical Reasoning Systems?

Louise A. Dennis (University of Liverpool, GB)

Joint work of Louise A. Dennis, Michael Fisher, Alan Winfield, Martin Mose Bentzen, Felix Lindner, Paul Bremner, Matt Webster, Marija Slavkovik

I discussed work on the verification of ethical reasoning systems, specifically the properties that could be verified. I characterised these systems as one where some explicit encoding of ethics was given to a decision system. These systems were then verified using model-checking. I tentatively categorised the properties into those that verified the implementation of the decision process (properties of the form "the most ethical choice is always made according to the ethical theory used to make the decision"); "sanity checking" properties of the encoding of the ethics (for instance that a house is always evacuated in the case of a fire); and checking of specific scenarios which might also allow inclusion of probabilistic evaluation of outcomes.

4.5 Verification for Robotics and Autonmous Systems

Clare Dixon (University of Liverpool, GB)

Main reference Matt Webster, David Western, Dejanira Araiza-Illan, Clare Dixon, Kerstin Eder, Michael Fisher, Anthony G. Pipe: "An Assurance-based Approach to Verification and Validation of Human-Robot Teams", CoRR, Vol. abs/1608.07403, 2016.
URL http://arxiv.org/abs/1608.07403

In this introductory talk I explained my background and interests related to the workshop themes. In particular I discussed the EPSRC funded project Trustworthy Robot Assistants a joint project between the Universities of Liverpool, Hertfordshire and Bristol Robotics Lab. We considered two use cases, a domestic robot assistant and collaborative manufacture and three verification and validation (V&V) methods. The V&V methods were formal verification, simulation based testing and real robot experiments. We believe that using these methods to inform and update the inputs to the other methods leads to improved V&V for systems. More details can be found at www.robosafe.org.

I also mentioned interests relating to formal verification for swarm robotics and the development of calculi and provers for temporal and agent logics and their application to problems. Publications can be found at http://cgi.csc.liv.ac.uk/∼clare/.

4.6 Learning Rules for Ethical Machines

Abeer Dyoub (University of L'Aquila, IT)

Codes of ethics are abstract rules. These rules are often quite difficult to apply. Abstract principles such as these contain open textured terms that cover a wide range of specific situations. These codes are subject to interpretations and might have different meanings in different contexts. There is an implementation problem from the computational point of view with most of these codes, they lack clear procedures for implementation. In this work we present a new approach based on Answer Set Programming and Inductive logic Programming for monitoring the employees behavior w.r.t. ethical violations of their company's codes of ethics.

4.7 Perspicuous Computing

Holger Hermanns (Universität des Saarlandes, DE)

Joint work of Christel Baier, Raimund Dachselt, Vera Demberg, Bernd Finkbeiner, Holger Hermanns, Jörg Hoffmann, Markus Krötzsch, Rupak Majumdar
URL https://www.perspicuous-computing.science/

From autonomous vehicles to smart homes and cities – increasingly computer programs participate in actions and decisions that affect humans. However, our understanding of how these applications interact and what are the causes of a specific automated decision cascade is lagging far behind. It is nowadays virtually impossible to provide scientifically well-founded answers to questions about the exact reasons that lead to a particular decision, let alone about accountability in case of the malfunctioning of, say, an exhaust aftertreatment system in a modern car. The root of the problem is that contemporary systems do not have any built-in concepts to explicate their behaviour. They calculate and propagate outcomes of computations, but are not designed to provide explanations. They are not perspicuous.

This talk highlights the need for establishing a science of perspicuous computing as the key to enable comprehension in a cyber-physical world. And it surveys focused activities that are currently being ramped up as part of the DFG-funded Transregional Collaborative Research Centre 248 – CPEC.

4.8 Crowd-Sourcing Tests – Can This Increase Public Trust?

Kerstin Eder (University of Bristol, GB)

Joint work of Kerstin Eder, Dejanira Araiza-Illan, Tony Pipe
Main reference Matt Webster, David Western, Dejanira Araiza-Illan, Clare Dixon, Kerstin Eder, Michael Fisher, Anthony G. Pipe: "An Assurance-based Approach to Verification and Validation of Human-Robot Teams", CoRR, Vol. abs/1608.07403, 2016.
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URL https://doi.org/10.1145/3022099.3022101

While *trust* is subjective – it can be gained and lost, re-gained and lost again over time – the *trustworthiness* of a system should be demonstrable. Because no single technique is adequate to cover a whole system in practice [1], at the Trustworthy Systems Laboratory in Bristol (http://www.bristol.ac.uk/tsl) we are working on a variety of complementing techniques to enable system designers and robotics engineers to gain confidence in the correctness of the robotic and autonomous systems they develop. These techniques include, but are not limited to:

- design techniques – systems that are simple by design are also understandable;
- analysis techniques that enable transparency – systems that provide an insight into how they make decisions, why they act in a certain way or how they use resources become understandable;
- verification and validation techniques – rigorous proof complemented by simulation-based testing and real-world testing can provide convincing evidence of a system's trustworthiness.

Systems that use Artificial Intelligence (AI) are a particular challenge when it comes to demonstrating their trustworthiness. Nevertheless, to make robots and autonomous systems truly useful, they have to be both powerful and smart. To achieve the latter, AI techniques, Machine Learning in particular, are what we rely on, with research actively exploring the use of these techniques in safety-critical applications such as autonomous driving.

An important research question we are exploring in this context is how we can exploit the power of AI in verification [2]. In addition, we are currently developing a game-based application that aims to crowd-source test cases for autonomous driving. This opens up interesting opportunities for research and also offers a platform for public engagement where players can gain confidence in the behaviour of autonomous vehicles in a simulated environment.

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4.9 Transparency: For Interaction or for Societal Discourse?

Kerstin Fischer (University of Southern Denmark – Sonderborg, DK)

URL https://portal.findresearcher.sdu.dk/en/publications/when-transparent-does-not-mean-explainable

In this talk, I discuss some problems with transparency about robot capabilities: First, signaling what a robot can and cannot do is far from trivial due to the way social signals work. Second, in order to achieve social interaction with robots, i.e. in order to share social spaces with robots, robots need to use (and understand) social signals – which are often shortcuts to rich meanings and invite inferences to many further capabilities. If robots don't use these signals, they will be very tiresome to use; if they use them, they contribute to the illusion of life-like beings with more capabilities than they actually have, which is desired in the case of social robots, but which may hinder societal discourse about robots in society.

4.10 Hybrid Ethical Reasoning in HERA

Felix Lindner (Universität Freiburg, DE)

Joint work of Martin Mose Bentzen, Robert Mattmueller, Bernhard Nebel
Main reference Felix Lindner, Martin Mose Bentzen, Bernhard Nebel: "The HERA approach to morally competent robots", in Proc. of the 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2017, Vancouver, BC, Canada, September 24-28, 2017, pp. 6991–6997, IEEE, 2017.
URL https://doi.org/10.1109/IROS.2017.8206625

Hybrid Ethical Reasoning Agents (HERA) are capable of computing permissibility judgments under various ethical principles. The talk briefly gives an introduction to the technical aspects of HERA, presents a generalization to the case of judging action sequences rather than individual actions, and shows how explanations of permissibility judgments can be computed. Finally, Immanuel is presented–a robot that implements HERA and which can have moral discussions with humans.

4.11 Enabling People Who Design Machines That Influence People

AJung Moon (Open Roboethics Institute – Vancouver, CA)

From recommender systems to interactive robots, many autonomous intelligent systems we design and deploy today hold the promise to address some of the world's toughest problems. They have also been the source of social, ethical, and legal issues on a global scale. Open Roboethics Institute conducted a series of studies that demonstrate multiple approaches to incorporating human values into machines that influence people's decisions and behaviours. This includes the discovery of what factors affect our design decisions that have moral implications, and analysis of organizational values to create value-alignment in the design and operational decisions pertaining to the autonomous intelligent machines.

4.12 Robot Wrongs and Robot Rights: What Can Economic Theory Tell Us?

Marcus Pivato (University of Cergy-Pontoise, FR)

There are three kinds of morally relevant interactions with artificial intelligences ("robot"):
(1) Robots can act on humans
(2) Robots can interact with other robots
(3) Humans can act on robots

Class (1) raises the question: How to design robots that behave ethically? This leads to the question: what is ethical? Social choice theory and social welfare theory provide a mathematical framework for specifying and analysing consequentialist ethical theories.

Class (2) suggests treating robot-robot interactions using game theory. Indeed, game theory might be more suitable for robots than for humans, because robots can be programmed to be perfectly "rational" (in the economic sense of the word) and commit to strategies which lead to socially efficient equilibria.

Class (3) raises the question: Can a robot be a moral patient? On the plausible premise that moral patiency depends on "consciousness" or "sentience", this raises the question: Could a robot ever be conscious or sentient? If we someday design robots that are conscious or sentient, then we will need to develop a theory of "sentient agent well-being" which applies to both humans and robots.

4.13 Ethics and Trust in Sociotechnical Systems

Munindar P. Singh (North Carolina State University – Raleigh, US)

I make the case for a sociotechnical systems perspective on ethics and trust. Specifically, I advocate moving away from the current emphasis on individual decision making about ethical dilemmas to how we might design (micro)societies in which humans and agents coexist. Concerns of justice and norms are essential in developing computational formalizations of sociotechnical systems, both to evaluate such systems as designers and for agents to function in them as members.

4.14 What Does It Mean to Trust a Robot?

Kai Spiekermann (London School of Economics, GB)

We experience all kinds of different "trust talk":
- "I trust my car to get us to Trier."
- "I trust the IT guy to set up my network credentials correctly."
- "I trust my neighbour to water the plants while I'm away."
- "I trust my friends [to do what friends do]."

Some trust talk is about reliability (car, IT guy). In the reliability sense, we trust because we think the system is well built, the person well trained, incentivized, etc. But in the deeper sense we trust because we expect the trusted agent to be committed. The difference can be seen when considering adequate responses to failure: If we have reliability-trust and experience failure, we tend to feel disappointed. By contrast, if we have commitment-trust and experience failure, we tend to feel betrayed. We can draw a further distinction by looking at how precise and explicit the expected actions are codified. On the face of it, in the context of moral machines the idea of reliability trust for highly specified behaviour is most immediately applicable, but the most challenging issues arise in relation to commitment trust and in relation to expected actions that are not precisely codified.

4.15 From Values to Support

Myrthe Tielman (TU Delft, NL)

I am interested in personal assistive technology, systems which support us in daily life activities. In order to enable such systems to understand our motivations better, we propose to use value-based reasoning. Through linking values to actions we gain insight into what to support people with. Ideally, we will also be able to use values to reason about support itself, as well as being able to use them when explaining the systems behavior back to the user.

4.16 Machine Ethics: Test, Proof or Trust?

Suzanne Tolmeijer (Universität Zürich, CH)

In this talk, I introduced work in progress on a survey paper for the field of machine ethics. A classification framework is introduced with three dimensions: purely ethical, purely technical, and the overlapping implementation category. Some interesting findings are presented, including that half of the selected papers do not present a proper evaluation for their ethical machine.

4.17 Designing Normative Theories of Ethical Reasoning: Formal Framework, Methodology, and Tool Support

Leon van der Torre (University of Luxembourg, LU)

Joint work of Christoph Benzmüller, Xavier Parent, Leendert W. N. van der Torre
Main reference Christoph Benzmüller, Xavier Parent, Leendert W. N. van der Torre: "Designing Normative Theories of Ethical Reasoning: Formal Framework, Methodology, and Tool Support", CoRR, Vol. abs/1903.10187, 2019.
URL http://arxiv.org/abs/1903.10187

The area of formal ethics is experiencing a shift from a unique or standard approach to normative reasoning, as exemplified by so-called standard deontic logic, to a variety of application-specific theories. However, the adequate handling of normative concepts such as obligation, permission, prohibition, and moral commitment is challenging, as illustrated by the notorious paradoxes of deontic logic. In this article we introduce an approach to design and evaluate theories of normative reasoning. In particular, we present a formal framework based on higher-order logic, a design methodology, and we discuss tool support. Moreover, we illustrate the approach using an example of an implementation, we demonstrate different ways of using it, and we discuss how the design of normative theories is now made accessible to non-specialist users and developers.

5 Working groups

5.1 Change of Trust – Challenges and Methods to Foster and Repair Trust

Myrthe Tielman (TU Delft, NL), Clare Dixon (University of Liverpool, GB), Marc Hanheide (University of Lincoln, GB), Felix Lindner (Universität Freiburg, DE), Suzanne Tolmeijer (Universität Zürich, CH), Astrid Weiss (TU Wien, AT)

The major discussion topic of this group was: *Change of trust – Challenges and methods to foster and repair trust.* In the first breakout session four main topics of interest for further discussion were identified: (1) identification of failure and generation of explanation for failures; (2) likability vs. trustworthiness; (3) empowerment and putting users in control; and (4) trustworthiness of humans (from a robot perspective).

(1) Regarding failures and explanations, it was discussed that firstly different types of failures need to be distinguished: (1) misunderstood/unexpected behaviour (unexpected communicational effect) and (2) actual system failures (crashes) or wrongly taken actions (e.g. the robot being stuck). In both cases, it was agreed that *explanations* for the end user are key to restore trust. Subsequently, the generation of explanations was discussed. Methods, such as plan-based explanations related to previous decisions were suggested, but questions came up about the correct level of detail of abstractions and human-comprehensible explanations. It was agreed that explanations to end users however do not necessarily need to be in natural language, but can use cues such as closed eyes, blinking lights, nodding head etc. Overall, the aim of explanations should be to increase transparency and understandability in order to repair trust in a failure situation. Other relevant aspects with respect to failures and explanations that were discussed were that repetition should be avoided and reduced. In long runs, robots must not do the same mistakes again. It rather must form a model of the individual user's beliefs (beliefs of beliefs). In general individualisation was also considered key for maintaining trust in HRI. However, one of the big challenges is to understand/recognize when and where users' expectations are violated. The idea came up if a classification of failures and their risk impact for trust (potentially even with a mitigation) could be developed. This idea was later followed up in the subsequent breakout sessions and a preliminary *Failure Taxonomy* was developed. It is planned to elaborate this further as a publication for the 2020 HRI conference.

(2) With respect to likability vs. trustworthiness, the discussion revealed that so far most of the HRI research focuses on the fact that transparency-through-explanation increases the trustworthiness of the system, but through that not necessarily the system's likability [3]. In other words, the relation between transparency through explainability, trustworthiness, and likability are not necessarily positively correlated. Here a potential for significant future research was identified.

(3) As a third topic it was discussed how putting users in control can be achieved through explanations and mitigation strategies in failure situations [2]. Our working hypothesis was that trust can be improved if users are involved in fixing the failure, e.g. pushing the robot out of a problem zone or putting it back into a charging station. However, related research already showed that there are potential cultural differences; e.g. that Japanese think that only experts should fix a robot, but not layman [1]. Similarly, the aspect was discussed if little failures might deliberately foster engagement and subsequently trust (research has already shown that the imperfect robot is more likable [5]).

(4) Finally, the issue of how far humans are trustworthy in Human-Robot Interaction was discussed. Aspects such as hostility (e.g. factory workers who fear replacement) and curiosity (e.g. kids in a museum "playing" with the robot). But how to make humans more compliant in the interaction? We discussed options such as justification for their actions, call/involvement of an authority and mimicking emotions. When presenting these thoughts in the plenary an interesting discussion on *"joint-human-robot-failure-recovery-and-trust-repair"* evolved which also identified novel research directions.

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5.2 Towards Artificial Moral Agency

Kai Spiekermann (London School of Economics, GB), Jan M. Broersen (Utrecht University, NL), Einar Duenger Bøhn (University of Agder, NO), Kerstin I. Eder (University of Bristol, GB), Christian List (London School of Economics, GB), Andreas Matthias (Lingnan University – Hong Kong, HK), Marcus Pivato (University of Cergy-Pontoise, FR), Thomas Michael Powers (University of Delaware – Newark, US), Teresa Scantamburlo (University of Venice, IT), Marija Slavkovik (University of Bergen, NO), and Leon van der Torre (University of Luxembourg, LU)

Starting questions: Can AI systems be genuine moral decision makers?
Observation: Some seminar participants think the answer is clearly 'yes', some think the answer is clearly 'no'. Where does this disagreement come from?

A minimal condition of agency (not necessarily moral). A basic (necessary but not sufficient) prerequisite for agency is that we can coherently take an intentional stance towards the system. For example, if a dog is after the sausage in my pocket, we observe a behaviour (following me, trying to get close to my pocket, responding to changes of sausage position, perhaps signalling to me that it wants the sausage) that is best explained by assuming that the dog has intentions, specifically the intention to get hold of and eat the sausage. By contrast, an intentional stance is not plausible towards a raindrop falling to earth (intentions are not necessary for a plausible explanation of the raindrop behaviour). Similarly, chairs and tomatoes do not warrant taking an intentional stance.

A taxonomy of agents (thin vs. thick)

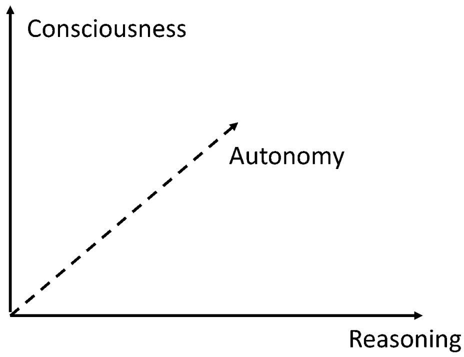

Figure 1 A taxonomy of (not yet necessarily moral) agents: from thin to thick on three dimensions.

Here are some examples of agents that can be classified according to this scheme:

Agent	Reasoning Capacity	Autonomy	Consciousness
Humans	High	High	High
Chimps	Low	High	High
Self-driving car	Intermediate?	Quite high	None
Thermostat	None/Low	None/Low	None

The Moral Turing Test. The basic idea of the standard Turing test is to check whether an observer can distinguish between a black-boxed human and a black-boxed artificial agent (specifically, a Turing machine), purely on the basis of symbolic input and output. The standard Turing test is usually construed as a diagnostic test for human-like intelligence. It is not normally construed as a test for moral behaviour. The idea behind the moral Turing test is to amend the standard Turing test so as to turn it into a diagnostic test for moral capacities. The moral Turing test exists in different versions: (1) Restrict conversation to moral issues and (2) VR setup.

The moral Turing Test tests for observable moral speech or action behaviour. One concern that was raised was that the test, if taken as a test for moral competence, might also invite abuse, e.g. by setting (morally indefensible) standards for human moral agents.

The Traditional and the Moral Chinese Room Argument. We set out the standard argument as presented by Searle, and possible charitable interpretations of it. In its basic setting, there is a human operator in a room who receives written messages in Chinese. The operator does not understand Chinese but has an operating manual that instructs her to respond to those messages in appropriate ways. Technically, we can think of the operator as executing a suitably programmed Turing machine or algorithm that symbolically converts Chinese inputs into adequate Chinese responses, but does so in an entirely syntactic manner. John Searle's claim is that there is no understanding of Chinese going on anywhere here, and therefore that syntactic processing alone is insufficient to generate semantic understanding.

One influential response is to concede that the operator does not understand Chinese, but to argue that the system as a whole does, where this is defined as the composite, consisting of the operator, the manual, and any storage shelves serving as memory in the room. This response is called the "systems response".

The group discussed the systems response in detail and critically investigated its plausibility. After discussing the standard Chinese room argument the group turned to the moral version of the argument. This is basically like the standard argument, except that the communication is restricted to or focused on morally relevant content. The question is whether this argument might in any way establish that purely syntactic machines are not capable of genuine moral understanding and moral agency. Many members of the group expressed the view that the moral Chinese room argument is less compelling than the standard one. One question to be asked is whether semantic understanding or full-blown intentionality in the sense discussed by Searle is necessary for moral agency. Those in the group who do not adhere to a very thick understanding of moral agency tend to think that the answer to this question is negative. (Note that this might not carry over to views about moral patiency.) While the group did not discuss moral patiency in great detail, several members of the group agreed that phenomenal consciousness is a necessary condition for moral patiency, but not for moral agency.

Conceptions of Autonomy. The group noted that there is not one single canonical definition of autonomy, even in debates about agency, but that there are a variety of surprisingly different definitions. These include, among others, definitions of autonomy as:

- unpredictability (though might this render a random walker autonomous?);
- choosing their own preference (might this lead to an infinite regress?);
- self-legislating (though what does this mean precisely?);
- having free choices (though there are many different notions of freedom out there);
- not being (too) influenced by the environment.

We focused, in particular, on the following three different notions of autonomous systems:

- As goal/preference revising / self-legislating systems;
- As systems that pursue set goals without direct intervention (IEEE);
- As systems that can only/best be predicted by running the system.

It was noted that verification (i.e. the process used to gain confidence in the correctness of a system with respect to its specification) requires the specification of the behaviour to be verified, and that this was problematic / challenging for some of these notions of autonomy.

5.3 How Do We Build Practical Systems Involving Ethics and Trust?

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There is clearly no one unique way to approach the construction of artificial systems that are both ethical and trustworthy. Our working group considered both the variety of ideas, methods and techniques that might contribute to the construction of such systems and, via the consideration of two case studies, attempted to identify the gaps in our understanding which needed to be filled before such systems were possible.

Pathways. We identified a number of ideas that were necessary for the construction of such systems and categorised these into stages in a pathway that leads from the abstract to the concrete. Although we used the term pathway we did not, by this, intend that an ethical and trustworthy system should be constructed first by selecting a philosophical standpoint and then moving towards the ever more concrete, just that an ethical and trustworthy system must involve concepts from all stages in a pathway but may have been designed and constructed in an iterative process where choices at all stages interacted with each other. The stages in the pathway we identified and some of the possible choices within that stage are set out below:

- philosophy: ethics, law, sociology, psychology, politics
- ontology: stakeholder, autonomy, norms, reasons, intentions, plans, values
- theories: deontic logic, rights & duties, norms & obligations, agent theory
- design techniques: model architecture, data selection
- implementation techniques: programming languages, NN structure, machine learning, synthesis
- analysis techniques: data analysis, theorem proving, testing, simulation, (code) review

One possible such path to ethical and trustworthy artificial systems goes from Philosophy and Law through Reasons/Intentions/Plans/Values to Deontic Logic and Agent Theory terminating in declarative or normative programming frameworks of various flavours (see [2]) to which a variety of analysis techniques can be applied in order to demonstrate the trustworthiness of the final implementation.

Desiderata for Analysis of "AI" Systems which help build justifiable trust. A number of missing tools and techniques were identified for the later stages in the pathways, those at the more concrete and computational end. In particular we identified the need for novel or better techniques and tools to support the development of sub-symbolic systems (typified by deep neural networks) which do not manipulate explicit human-understandable representations in order to make decisions. However, related to this we argue that for a system to genuinely embody ethics it will be necessary to have architectures which combine symbolic and sub-symbolic reasoning and tools for developing, verifying and validating such systems. We will want symbolic representations because ethical reasoning is generally about how users believe something should behave which may be easy to state symbolically but difficult to express sub-symbolically. We may nevertheless want sub-symbolic reasoning to handle other aspects of control and decision making including the implementation of the situational awareness that will trigger ethical reasoning. While not exactly a combination of symbolic and sub-symbolic reasoning, the GenEth system [1] is an example of a system that uses machine learning to construct and explicit representation of ethical rules. A variety of techniques will be required in order to justify confidence in a system's trustworthiness. These include, but are not limited to,

- explanation mechanisms for symbolic and sub-symbolic reasoning – systems that allow us an insight into how they make decisions, explain why they act in a certain way or how they use resources become understandable and thus trustworthy; and
- verification and validation techniques – rigorous proof complemented by simulation and end-user testing can provide convincing evidence of a system's trustworthiness.

In order to explore these ideas in greater depth, the group focused on two case studies.

Case Study: Complex System of Norms. We consider a system in which a hierarchy of explicit norms are used to control ethical reasoning and identified a number of issues relating to the construction of such a system. A key issue in such a system will be handling conflicts between norms. These may involve problems that are traditionally considered ethical dilemmas (such as trolley problems) but may also involve other kinds of conflicts.

A simple example of a dilemma-style conflict is when some action is both obligated and prohibited by the norms. There are techniques that can be used to detect potential conflicts at design (e.g. using techniques like those in [4]) time but these inevitably involve some way of capturing the contexts the system may find itself in and so it may also be necessary to use runtime techniques to detect when a conflict has arisen.

A complex hierarchy of norms is likely to arise because norms are being sourced from a variety of places. For instance, some norms may be legal, some may be related to professional practice (e.g., in healthcare situations) and some may be social. Tracking the sources of norms may be a key to discovering inconsistencies and preventing conflicts.

It may be, however, that conflicts arise not because of explicit dilemmas but because of conflicts between norms and lower level processes. For instance, many robotic systems are engineered with low-level obstacle avoidance processes that take precedence over explicit reasoning. Such behaviour might cause a norm to be violated. In a complex system, norms are also likely to be context sensitive, determining whether a norm applies will depend upon the system's situational awareness which is likely to depend upon sub-symbolic processes for, for instance, image classification. The way probabilistic and possibly faulty assessments of situations interact with normative reasoning was both theoretically and practically unclear.

When a conflict arises it is then necessary to decide what to do. During system design, there is time for design processes to determine this, but at runtime this may not be possible. In some systems it may be possible to implement an "ethical fail safe", but where such an option does not exist, other methods might be needed such as selecting one of the possible actions at random, or having some kind of sub-symbolic "shadow" (possibly in a similar way to [6]) of the explicit norms which is used to make decisions when the explicit system is unable to. Explicit reasoning about potential sanctions for norm violation might also assist in the resolution of conflicts [7]. Ideally, once conflicts are resolved, norms are updated to reflect the resolution.

Algorithmic Bias. We observed that discussion of algorithmic bias, its definition, causes and mitigation was currently a topic of much active research which the working group unfortunately had little expertise in (Some preliminare references are [3, 5]). We also noted that the term "bias" was overloaded in the communities involved. For the purposes of the discussion we agreed to consider bias to be when information related to, for instance, a protected characteristic such as gender, race, religion or sexual orientation, was used as part of a decision-making process when the information was in reality irrelevant to the outcome - for instance taking gender into account when predicting success at an office job. We noted that discussion of algorithmic bias tended to focus on sub-symbolic systems but that bias is possible even with explicitly engineered norms:

- Biases in context detection and classification where a sub-symbolic system attributed characteristics to people based on stereotypes could lead to an explicitly normative system making biased decisions based upon that classification.
- Prioritisation between norms (or possibly other interactions) can create bias, for instance norms around parenting tend to affect women more than men and so the priority given to such norms might disadvantage one of these groups – this may depend upon the deployment context.
- Norms themselves can be biased (for instance the norm that women and children should be evacuated first in an emergency).

Techniques for defining and detecting bias therefore have potential application to both symbolic and sub-symbolic systems if appropriately constructed.

Case Study: Sub-symbolic Algorithmic Bias. We considered the possibility of sub-symbolic algorithmic bias in the construction of ethical and trustworthy systems. Assuming we have an adequate definition of bias, the two key problems become how to detect if a system is biased and how to fix a biased system.

(1) How to detect if a system is biased? At design time the provenance of the data can be analysed in order to assess the likelihood of bias being present in the data. Where particular groups who may be biased against can be identified, it is possible to perform statistical analyses of the performance of the system in order to identify potential bias and to have experts inspect the system's output on specific examples in order to determine if it is making appropriate decisions. A particular research challenge in this context is the definition and validation of fairness metrics that can be used to identify bias automatically.

(2) How can biased training data and biased systems be fixed? Once bias is detected, then the reasons for the bias need to be analysed. In general, this requires explanation techniques for analysing decision making in sub-symbolic systems. If non-biased data (or a non-biased subset of data) or missing data can be identified, then the system can be retrained and then re-evaluated for bias. However, techniques may be required to fix biased data or to explicitly screen decisions for bias, where no unbiased data is available. This may itself involve the use of sub-symbolic techniques. The group was aware that there was active research in these areas but was not familiar with the literature.

Conclusion. We considered a number of issues relating to the construction of ethical and trustworthy systems both at the symbolic and sub-symbolic level. We identified a lack of theories, techniques and tools at the more concrete end of the pathways to constructing such systems, in particular the need to combine symbolic and sub-symbolic reasoning to allow ethics/norms to be analyzed and manipulated at both levels. We considered two particular examples of systems that presented challenges to ethics and trustworthiness: systems that use complex sets of explicit norms and the problem of algorithmic bias. The problem of conflicts and dilemmas was of major concern for systems of explicit norms but we also concluded that algorithmic bias could arise not only from biased data, but also from explicit norms and the interaction of explicit norms with biased systems. As a result we identified the following important research questions:

- How can we combine symbolic and sub-symbolic reasoning to enable both flexible reasoning and explicit representations?
- What techniques can we develop to enable us to better analyse and modify the behaviour of sub-symbolic systems (e.g., debuggers, profilers).
- What techniques can we develop to verify and validate the behaviour of sub-symbolic systems (including formal methods and simulation/test-based approaches).
- How can we monitor sub-symbolic systems to detect and contain undesirable behaviour?
- How can/should autonomous systems explain their behaviour?
- How should an autonomous system resolve an ethical/normative conflict in situations where no "ethical fail safe" exists?
- How can we detect "algorithmic bias" in both symbolic and sub-symbolic systems, related to this how do we adequately define algorithmic bias?
- If no unbiased training data exists, how do we correct for bias in sub-symbolic systems?

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5.4 The Broader Context of Trust in HRI: Discrepancy between Expectations and Capabilities of Autonomous Machines

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One of the first steps to discussing ethical and trustworthy robots is to take stock of the complex human responses that autonomous machines trigger. Certain robot features may cause human trust, but they may be superficial triggers of trusting feelings or properties that actually justify such trust. However, the challenge is even broader. We need to build a systematic understanding of how design choices affect a complex variety of human responses—including not only trust but other cognitive, emotional, and relational ones. Importantly, these responses often do not reflect the real capabilities of the designed robot, causing discrepancies between what humans perceive the robot to be and what it actually is. We summarize here some of these discrepancies and ways to mitigate them.

The Multidimensionality of Human Reactions. Human responses to robots comprise a wider range of dimensions and are caused by a wide array of factors. Humanoid robots can elicit in-group bias [3], cheater detection [9], spontaneous visual perspective taking [15], and gaze following in infants [10]. Such responses are influenced by the robot's social role [7], people's expectations about robots e.g. [11], their expertise e.g. [4], and even psychosocial predispositions such as loneliness [8]. Humanlike appearance is a particularly powerful cause, leading people to see robots as more intelligent, more autonomous, and as having more mind ([1]; [2]; [14]). But people treat even disembodied technologies similar to human beings [12] and respond to them with behavior that is conventionally appropriate [5]; [16].

If trust is only one response within a manifold of interrelated responses, it becomes unclear which properties of a machine superficially trigger trust and which ones justify trust. Moreover, recent studies indicate that the concept of trust itself is multidimensional. That is, one could trust another human (or perhaps robot) owing to different kinds of evidence—their reliability, competence, sincerity, or ethical integrity ([13]; see http://bit.ly/MDMT_Scale).

Discrepancies Between Human Perceptions and Actual Robot Capacities. Current robot design tends to integrate a large number of social cues into robots' behavior and appearance. However, when interacting with humans, social cues are symptoms of true underlying processes, but robots that show these same cues usually do not have these underlying processes. For example, robots using gaze cues are seen as indicating joint attention and an understanding of a speaker's instructions [6], but robots can produce these behaviors without actually understanding the speaker's communication at all. Equipping a robot with such cues is therefore confusing, if not deceptive, because it creates the impression that the robot has capabilities it does not actually have. Mismatches between expected and real capabilities pose manifest risks. Users may entrust the robot with tasks that the robot is not equipped to do and will be disappointed, frustrated, or distressed when they discover the robot's limited capabilities. In turn, such users will no longer use the product, write scathing public reviews, or even sue the manufacturer.

Discrepancies between perceived and actual capacities of robots have multiple sources. Public media and its frequent exaggerations of technical realities is one source. Deceptive advertisement of robotic products, especially those for social robots intended for consumers, is another. Researchers using Wizard-of-Oz methods can also contribute to spreading false beliefs, because they create an illusion of capacities of the robotic platform, and thorough debriefing after such experiments is often lacking. Finally, since humans acquire capabilities in a particular order such that more basic capabilities provide the basis for more complex ones, they find it hard to imagine that a robot can have a sophisticated ability without having acquired all the more basic capabilities [4].

How to Combat the Discrepancies. How can people recover from mismatches between perception and reality? Currently we do not know. It would take a serious research agenda to understand the conditions of recovery and correction, and it would take multiple approaches. First, because we as yet have no systematic mapping between the specific robot features that elicit specific affective and cognitive responses in humans, we need carefully controlled experiments to establish these causal relations. Second, to better separate deeply ingrained and unchangeable responses from culturally learned and correctable ones, we need to compare response patterns of young children and adults, as well as of people from different cultures. Third, to truly understand how human responses to robots can change we need longitudinal studies that consider the full array of multi-dimensional responses and measure how they change as a result of interacting with robots over time.

High-quality longitudinal research faces numerous obstacles: from cost, time, and required management efforts to participant attrition and ethical concerns of their privacy, from the familiar high rate of mechanical robot failures to their unforeseen effects on daily living. Smaller initial steps are possible, however, to study temporal dynamics that will advance knowledge but also provide a launching pad for genuine longitudinal research. For example, experiments can compare people's responses to a robot with or without information about its true capacities and assess whether people are able to adjust their perceptions. Other experiments can present a robot twice and track people's changing representations from the first to the second encounter, perhaps unfolding differently depending on the specific response dimension. Short-term longitudinal studies could also bring participants back to the laboratory more than once and distinguish people's adjustments to the specific robot (if they encounter it again) from adjustments of general beliefs about robots (if they encounter a different robot).

Another path to handling mismatches between perceived and real robot capabilities is to prevent such discrepancies in the first place. One strategy is incremental robot design—the commitment to advance robot capacities in small steps, each of which is well grounded in user studies and eases people into a changing reality of capacities. Another is to build users' understanding of the robot's behavior by revealing its actual causes and also explicate the robot's limitations. Designers and manufacturers may be reluctant or unable to offer effective explanations of the machine's real capacities (e.g., because of communicative distance between manufacturer and user or because of user suspicion), so the machine might be in the best position to explain its own behavior and limitations. People's perceptions may be stubborn, but explanations that arise in the immediate context of human-robot interaction and in repeated communications might break through people's expectations and inferences and, over time, alleviate discrepancies between perceived and actual robot capacities.

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Report from Dagstuhl Seminar 19172

Computational Creativity Meets Digital Literary Studies

Edited by

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Abstract

This report documents the outcomes of Dagstuhl Seminar 19172 "Computational Creativity Meets Digital Literary Studies", held from April 22 to April 25, 2019. Computational Creativity and Digital Humanities are emerging, interdisciplinary fields still experiencing significant growth and development in terms of community, research questions, methods, and approaches. Computational Storytelling as a prominent subfield within Computational Creativity that has mostly focused on planning stories – thus simulating a logically coherent plot – could fruitfully extend its horizon to narrative concepts like narrative style, chronology of narratives, focalization and perspective. These narratological concepts have been investigated by literary scholars for a long time. Yet, operationalization of these concepts is required when used as the basis for computational modelling. This in turn sharpens the definitions of theoretical considerations and can feed back into theoretical discussions in the literary studies. Moreover, there are obvious connection points between Computational Creativity and Natural Language Processing on the one hand, and between Natural Language Processing and Digital Literary Studies on the other hand. However, these connections currently are not transitive. The goal of the seminar was to establish international links between all three disciplines and among involved researchers through presentations by participants and extensive group-work sessions.

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1 Executive Summary

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Literary studies (LS) is a subfield of the humanities that provides a diversity of possible views on its objects of investigation. The universal approach to literary texts does not exist, instead there are many, sometimes incompatible theories that can be applied for the interpretation of literary texts. Additionally, with the emerging of the Digital Humanities (DH) the deployment of computational methods has been introduced into LS, leading to a further expansion of the range of theories and methodologies of text analysis and interpretation. Against that backdrop in the last decade much effort has especially been put into developing approaches that cover rather complex concepts for text analysis, including, among other, network theory (e.g., [7]) and approaches from distributional semantics for topic modelling and word vector estimation (e.g., [8]). This considerably changed the prerequisites of DH research in the field of LS. In many cases it is no longer possible to simply apply a predefined tool or algorithm, requiring traditionally trained LS scholars to move away from their disciplinary paradigm of individual research and towards adapting collaborative modes that can provide both LS and computational expertise. Researchers in Natural language processing (NLP) have shown considerable interest in text-based DH research. This interest is not only motivated by the diversity and complexity of the research questions, which offers an ideal testbed for the development of new methods and combined workflows, but also by the nature of texts found in the context of these research questions which are often diverse with respect to their lexical and syntactic range – meeting the need for this type of data in work aiming for more flexible NLP approaches. Computational Creativity (CC) is a multidisciplinary endeavour, modelling, simulating or replicating aspects of creativity using a computer, in order to achieve one of several ends: Either to construct a program or computer capable of human-level creativity, or to better understand human creativity and to formulate an algorithmic perspective on creative behaviour in humans, or to design programs that can enhance human creativity without necessarily being creative themselves (a concise overview of the main aspects of the field has, for instance, been laid out by [1]). One of CC's most popular subfields is Computational Storytelling (CS), where researchers hitherto have mainly thought about the structure and logical implications of building blocks of stories, leaving most other dimensions of narrative construction out of consideration.

Taking stock of this overall state of affairs and the specific situation in the respective fields, the seminar was constructed around several main challenges:

- One of the major challenges in DLS is the approximation of concepts with computational approaches to, i.e. their operationalization, that not only requires a translation of the concepts, but also a deep understanding of the deployed computational approaches used. This gap can be tackled best by providing expertise from the fields concerned. Whereas NLP is already accepted as such a field (but still needed), CS has not been taken much into consideration yet. A second type of collaboration that still needs to be intensified is the one that connects the interpretative, manual annotations from DLS (e.g., [4]) with computational approaches to text analysis and generation.
- NLP has focused on a limited variety of texts in its beginnings and suffers from a bias towards newspaper texts. Even though there are efforts towards more diverse and flexible text processing, the constant lack of data is a problem. DH and CC offer a variety of texts to improve this situation – but are hitherto underused in that capacity.
- CC, CS focuses almost exclusively on plot and logical structure of storytelling. However, a narrative is a complex web of different factors that are well-investigated in classical disciplines. While much work is based on formalist theories about narrative (especially [9]), other approaches from narrative theory still need to be explored better. For example, CS could benefit from the well-established fields of semiotics (e.g., [5]) and structuralism (e.g., [3]) as well as from more recent, reader-oriented developments in cognitive and empirical narratology (e.g. [6]; [2]).

In order to make researchers from the participating communities a) aware of the challenges and the corresponding opportunities an interdisciplinary meeting like the seminar offered, and b) make them take advantage of these opportunities still on-site, the seminar was split between presentations from researchers describing their recent work and questions they wanted to highlight for the audience, and "hackathon" phases in which decidedly interdisciplinary teams of participants worked on concrete projects.

The following pages summarize the content of these presentations and the outcomes of the group projects.

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2 Table of Contents

3 Overview of Talks

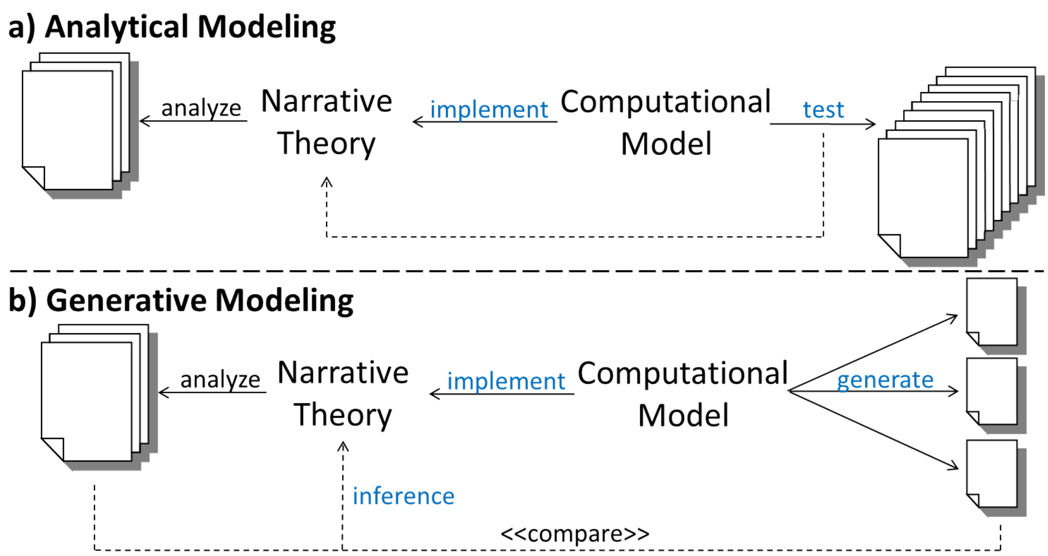
3.1 Generative Modeling: A Unifying Approach to Digital Literary Studies and Computational Storytelling

Leonid Berov (Universität Osnabrück, DE)

Main reference Leonid Berov: "Steering Plot Through Personality and Affect: An Extended BDI Model of Fictional Characters", in Proc. of the KI 2017: Advances in Artificial Intelligence – 40th Annual German Conference on AI, Dortmund, Germany, September 25-29, 2017, Proceedings, Lecture Notes in Computer Science, Vol. 10505, pp. 293–299, Springer, 2017.
URL http://dx.doi.org/10.1007/978-3-319-67190-1_23

In my contribution I introduce Generative Modeling (GM) as a new method of digital literary studies (DLS) and demonstrate how it allows to incorporate work from computational storytelling (CS) into DLS.

I contrast GM with the prevalent approach to DLS, which I describe as Analytical Modeling (AM). In AM, the goal is to operationalize a narrative theory or concept in a computational model (usually through natural language processing and machine learning approaches), which can then be used to automatically analyze a large corpus of narratives. This allows to automatically test hypotheses, e.g. about the prevalence of certain narratological features during a literary period, and from that draw inferences on narrative theory. In GM, the computational operationalization is one that is using the underlying theory as a source of first principles which are used to *(re-)generate* existing stories (using e.g. multi-agent simulation or planning approaches). By comparing the so generated stories generated with their naturally occurring counterparts, inferences can be drawn on the employed narrative theory.



To exemplify this approach, I present results from generative modeling based on Ryan's (1991) possible-worlds theory of plot. The modeling was performed by implementing Ryan's narrative semantics using a Belief-Desire-Intention based multi agent simulation system. Plot, which in Ryan's theory is a temporally ordered set of actions, happenings and mental events, emerges in this system from the interaction of individual agents and the story world, and can be captured using a graph representation. This approach uncovered that the employed narrative theory is underspecified with regards to affectivity as well as interindividual differences in fictional characters, which could be solved by incorporating Alan Palmer's (2004) insights on fictional minds into the character architecture. With this extension in place the resulting generative model was successful in re-creating the plot of the folk tale "The Little Red Hen". Using the results of this model I demonstrate the three potential contributions GM can make to narrative theory: (1) Raise issues unforeseen at higher level of abstraction, (2) uncover dynamic properties of analytical theories by varying parameters and (3) empirically test predictions.

I then argue that the autonomous generation of stories can be seen as a process that "exhibits behaviors that unbiased observers would deem to be creative" (Colton 2012) if–instead of manually recreating existing stories–new stories are being generated. This demonstrates that GM can be also seen as contributing to research in the field of CS, and is a viable route for exploring how insights from DLS and CS can be mutually benefiting: The role of DLS for CS is to provide computational models of stories, which a creative process can operates on in search of good stories. The role of CS for DLS is to provide means for the exploration of dynamic properties of the constraint space set up by individual narrative theories, by automatically generating stories rooted in these constraints.

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3.2 From Conceptual Blending to Visual Blending And Back

João Miguel Cunha (University of Coimbra, PT) and Amilcar Cardoso (University of Coimbra, PT)

Conceptual Blending [1] is defined as a mental operation that leads to new meaning by conceptual compression. A blend is a concept that borrows structure from other concepts but has its own emergent structure. This talk presents the basics of how the operation has been computationally implemented by our group, briefly describing Divago [2] and DivagoFlow [3], two incarnations of the same computational approach. Current challenges involve dealing with big knowledge bases that enlarge the possibilities of creating interesting blends [4], but at the same time impose higher performance requirements [5].

On the other hand, Visual Blending concerns the production of visual artefacts by merging existing ones. The combination of Conceptual Blending and Visual Blending, which we refer to as Visual Conceptual Blending [6], attributes a conceptually-grounded nature to the visual blends and has the potential to increase guidance in their production.

We describe the development of a system for the visual representation of concepts through visual blending of emoji – Emojinating [7, 8]. We then focus on how the interaction between the fields of Computational Creativity and Natural Language Processing, addressing how it may lead to further improvement of the system and possible applications.

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3.3 Multilingual Ontologies for the Representation and Instantiation of Annotation Schemes for Folk Tales

Thierry Declerck (DFKI – Saarbrücken, DE)

Main reference Thierry Declerck, Lisa Schäfer: "Porting past Classification Schemes for Narratives to a Linked Data Framework", in Proc. of the 2nd International Conference on Digital Access to Textual Cultural Heritage, DATeCH 2017, Göttingen, Germany, June 1-2, 2017, pp. 123–127, ACM, 2017.
URL https://doi.org/10.1145/3078081.3078105

In this contribution we summarize past and current work, which started with the development of an annotation scheme for fairy tales, and which was extended to the generation of a large ontology that integrates elements of classical indexation and classification schemes in the broader field of folk tale studies. The resulting structured data set also allows the embedding of fairy tale texts in automated processing scenarios. A development of our work in this area led for example to the automatic recognition of characters in fairy tales, their role in dialogues and their emotions, which serves as the basis for a TextToSpeech scenario that "reads out" fairy tale texts. This result is based on a cooperation with students of Computational Linguistics at the University of Saarland, which took place in in the form of Bachelor or Master theses, or also in the form of software projects.

It started with Antonia Scheidel's master thesis on the annotation of fairy tales with Proppian functions. Antonia Scheidel developed a new annotation scheme, according to which fairy tales can be queried for text properties, temporal structures, characters, dialogues, and Propp's functions (see http://www.coli.uni-saarland.de/~ascheidel/APftML.xsd for the annotation schema, and http://www.coli.uni-saarland.de/~ascheidel/APftML.xml for an annotated tale). An annotation scheme is important in so far as automated systems have a goal in which they can map their results. If fairy tales are also annotated manually with the annotation scheme, the results of the automatic processing can be compared with the human annotations.

Building on this, Nikolina Koleva has worked in her Bachelor thesis on an automated system to process fairy tale text (she has worked with 2 examples; "The Magic Swan Geese", an English version of a Russian fairy tale, and "Väterchen Frost", a German version of a Russian fairy tale). She implemented a program that analyses the text according to linguistic criteria, with the aim of identifying the characters in it and storing them in a database. This database is of the "ontology" type: logical operations can be performed in it. The background is a formal description of what can occur in the fairy tales, including an ontology of family relationships. Thus the system can recognize that in the text "the daughter" is the same person as the "sister", if the context suggests this. Recognized characters in the fairy tale are thus assigned to more general categories and can be semantically annotated.

A group of students worked on extensions of the above mentioned works within the scope of a software project. They have extended the annotation scheme with more detailed dialogue descriptions and with the coding of emotions. The ontology has also been extended to include a description of dialogues (questions, answers, monologues, etc.), including the encodings of the participants and the dialogue changes. Also 6 basic emotions (fear, sadness, joy, etc.) are coded in the ontology. A main extension of the past work is that synthetic voices also play a role. Once a character has been recognized, for example the Princess in the fairy tale "The Frog King", additional characteristics are coded (e.g. age, etc.). A previously defined synthetic voice is automatically added to the character. The folk tale can be analysed by the ontology-driven system, which is activating the voices of the different characters (and of the narrator) so that the story can be "told" to the user (see https://bit.ly/1BDmCZ9 for a link to a resulting audio file).

The next step was realised in the context of two software projects, and consisted in porting two "classical" indexing and classification schemes for folk tales into an ontology. The schemes are the "Thompson-Motif-Index of Folk-Literature" (TMI) and the Aarne-Thompson-Uther classication of tale types (ATU). This work resulted in the creation of a large ontology (containing more than 60000 classes) that is integrating motif elements elements and broader folk tale types. The TMI ontology is available at: http://www.dfki.de/lt/onto/narratives/TMI/.

Finally, the Proppian functions and characters were added to the ontology, with some examples of annotations of folk tale texts included. In this case we added to all the classes of the specific Proppian elements labels in various languages, implementing thus a multilingual ontology that could be used as a knowledge base for multilingual text analysis. The resulting ontology is available at: https://www.dfki.de/lt/onto/narratives/Propp/.

3.4 NLP for Narrative Understanding

Mark Finlayson (Florida International University – Miami, US)

Joint work of Mark Finlayson, Joshua D. Eisenberg, Labiba Jahan, Mustafa Ocal

One of the long-held goals of natural language processing (NLP) is understanding the meaning of narratives. Despite this, there remain many NLP tasks specific or highly useful to narrative that receive very little attention in the NLP community. My laboratory, the Cognac Lab (Cognition, Narrative, & Culture) focuses on solving numerous narrative-specific NLP tasks as steps toward the long-term goals of deeper understanding of culture, cognition, and their relationship. I describe many of these tasks in this talk, and give details of our approaches to and results on four:

1. story detection
2. animacy detection
3. timeline extraction
4. learning Proppian functions

I conclude by noting that computational approaches to narrative have overwhelmingly taken a formalist–and, more broadly, structuralist–point of view, and wonder whether NLP might be profitably applied to other, post-structuralist, modes of literary criticism.

3.5 Open challenges in computational storytelling

Pablo Gervás (Complutense University of Madrid, ES)

Stories are very present in people's life, and usually in forms much more complex than those contemplated by computational storytelling, which usually focus either on generating new stories from scratch or dynamically adapting an interactive plot to allow for users choices while still leading to endings conceived by an author. People tell stories to get a point or a message across, and decisions on story content and story structure are highly constrained by the point or message in question. The comparison between these two separate views of storytelling indicates a gap that computational storytelling should aim to cover in the near future. Important pending challenges include addressing the layered, structural and multifunctional complexity of discouse (at least to the level described by Genette's work on narrative discourse) and the reflective cyclic nature of the process of writing, revising and validating a draft intended for a particular purpose. Our work for the past twenty years combines the tasks of building satisfactory plots and of composing a narrative discourse. It covers some of Genette's basic features (focalization, time of narration, order or speed) but more work is needed.

3.6 Does Intentionality Matters When Engaging With Computational Storytelling?

Christian Guckelsberger (Queen Mary University of London, GB)

Joint work of Christian Guckelsberger, Christoph Salge, Simon Colton
Main reference Christian Guckelsberger, Christoph Salge, Simon Colton: "Addressing the "Why?" in Computational Creativity: A Non-Anthropocentric, Minimal Model of Intentional Creative Agency", in Proc. of the Eighth International Conference on Computational Creativity, Atlanta, Georgia, USA, June 19-23, 2017., pp. 128–135, Association for Computational Creativity (ACC), 2017.
URL http://computationalcreativity.net/iccc2017/ICCC_17_accepted_submissions/ICCC-17_paper_37.pdf

The work of Literary Studies and Natural Language Processing (NLP) has traditionally been based on human-authored literary artefacts. But can we still apply the same methods when working with artefacts generated by Computational Storytelling systems? How robust e.g. is the interpretative framework of Literary Studies with respect to machine-authored artefacts? To provide a solid foundation for the successful collaborations of these three disciplines, this talk focusses on a potential source of disagreement: the importance of intentionality. The dominant position in Literary Criticism is post-structuralist, according to which an author's intentions should not play a role in the interpretation of their work. We contrast this view with the crucial role of intentionality in Computational Storytelling. More specifically, we identify intentionality at the very basis of artefact creation. Furthermore, we show that intentionality is key to investigate central questions of autonomy and creativity in Computational Storytelling systems, with practical implications for the attribution of authorship and copyright. We use our findings to motivate open questions on the importance of intentionality across all disciplines.

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3.7 Computational Creativity Meets Digital Literary Studies – Thoughts and Experiences in Digital Literary Studies by a Computational Linguist

Jonas Kuhn (Universität Stuttgart, DE)

Main reference Jonas Kuhn: "Computational Text Analysis within the Humanities: How to Combine Working Practices from the Contributing Fields?" In Language Resources and Evaluation. To appear.

The contribution starts out from the relation between inputs (text or spoken utterances) and outputs (some representation of meaning) underlying standard characterizations of the process of analysis or "interpretation" in Linguistics and Computational Linguistics/Natural Language Processing (NLP) – applied to ordinary communicative exchanges. Given a particular utterance context, competent speakers are generally able to select among a (potentially large) set of candidate representations. The process of language generation/production can be conceptualized as the reverse relation – and again, listeners are able to make a contextually appropriate selection. Empirical data supporting the construction and/or evaluation of models for the processes can be obtained by corpus annotation – when an effective intersubjective operationalization of the underlying conceptual representation is in place. When the context is clear, multiple annotators should generally converge on the same selection among available candidates. It is common to make a distinction among various levels of representation (morphology, syntax, sentence and discourse semantics), even though there are cross-level interactions. Annotated corpora with input/output pairs along these lines have been crucial for a fruitful exchange between Linguistic and NLP work.

In Literary Studies, the texts under consideration do not serve an ordinary communicative exchange. A literary scholar's goal is rather to uncover the significance/meaning/interpretation of a text at a secondary symbolic level – explicitly or implicitly following some framework/theory of literary interpretation. Literary texts are typically assumed to give rise to multiple interpretations (depending on framework, e.g., a psychoanalytical vs. Marxist vs. feminist interpretation framework), which are equally valid. Hence it is not a possibility to copy the forced-choice corpus annotation methodology from linguistic/NLP work. Digital Literary Studies commonly restricts the target of analysis processes to descriptive (narratological) categories that pertain to a relatively "superficial" level of referential text meaning. The contribution laid out how effective target categories can be identified across specific projects, supporting workflows for model building that benefit both Humanities scholars applying the models within a hermeneutic research process and computationalist researchers optimizing the computational models based on suitably representative data (this approach is explored in the Center for Reflected Text Analysis, CRETA, in Stuttgart; compare for example Kuhn, to appear). Intersubjective agreement is hard to achieve at the secondary level of literary interpretation, so most work in Digital/Computational Literary Studies refrains from crossing the level of descriptive text analysis (even though literary theorists emphasize that frameworks of interpretation constrain what is an appropriate interpretation, striving for a systematic account of how to proceed in interpretation).

In its last part, the contribution observes that the reversal of the process of analysis/interpretation – which is essentially being modeled in AI research on Computational Creativity – is not commonly pursued in Digital Literary Studies. However, formalized models that characterize the set of alternative realizations of some underlying (analytical/interpretive) concept could contribute a handle for controlling the space of possible text interpretation: although intersubjective agreement at "deeper", interpretive levels cannot be expected, the realization sets for a concept under consideration in the course of theory building/refinement take the shape of alternative text variantsfor a passage in the original primary text. As such, they can be compared (by set intersection etc.) across frameworks and thus avoid at least certain problems of incommensurability. In addtion, comparing text variants is a tangible mode for exploring theories – possibly opening up ways for reader experiments/annotation efforts with limited training.

Incorporating a bidirectional view on text analysis/production may thus open up highly fruitful avenues in Computational Literary Studies.

3.8 The LdoD Archive as a creative textual environment and a model of literary performativity

Manuel Portela (Universidade de Coimbra, PT)

As both conceptual and technical artifact, the LdoD Archive: Collaborative Digital Archive of the Book of Disquiet contains an innovative model not only for the acts of reading, editing and writing, but also for the reimagination of the book as a network of reconfigurable and dynamic texts and structures [1]. Recreating the textual and fictional universe of Fernando Pessoa's Book of Disquiet according to ludic principles of textual manipulation, the LdoD Archive fosters new reading, editing, and writing practices. Its programmed features can be used in multiple activities, including leisure reading, study, analysis, advanced research, and creative writing. Through the integration of computational tools in a simulation space, it brings together textual production, textual reception and textual analysis in its experimentation with the procedurality of the digital medium. This experimentation is based on a complex ecology of programs, tools and algorithms whose end result can be described as an evolutionary textual environment.

The LdoD Archive has been designed to be a human-assisted reading, editing and writing computational system. The range of collaborative interactions extend from the fully human to the fully automated with various levels of intermediation in between.[1] Interactors experience their actions not only as a series of textual possibilities that emerge from a range of predefined values and parameters, but also as an open exploration of literary performativity itself [2]. According to its simulation rationale, each output is the result of an individual action in which the algorithmic production of the system is modified by intentions and procedures of the interactor. Outputs (whether taking the form of reading trails, edited sequences, classification taxonomies, macro visualizations or new texts) are not entirely determined by the system's internal logic since they will capture the human processing of its programmed processing.

If we think of it in ethical terms, we could say that the LdoD Archive is not a system for automating literary production, reception and analysis. In this respect, it sets itself apart from dominant engineering approaches to computational creativity in artificial intelligence and from dominant digital humanities approaches to textual processing. Rather, its ecology of machine-assisted human action and human-assisted machine action turns algorithmic processes into literary procedures for opening up textual spaces to critical and creative explorations. The result is an evolutionary textual environment fed by the unpredictability and creativity of human interactors in a live, time-distributed and collaborative social process. Its purpose is to instantiate the conditions that allow the reiteration of the relation between potentiality and actuality for each individual role- playing action. Given that this complex computational environment originated in an attempt to model the processuality of bringing a book into existence (in this particular case the Book of Disquiet by Fernando Pessoa), we can say that the bibliographical imagination itself is reconfigured as a physical force in the dynamics that produces the literary as material poetics and social semiotic practice.

[1] Examples related to each of the literary acts that we have modelled in the LdoD Archive: reading can be performed according to the sequence of particular expert editions of the Book of Disquiet, but also according to sequences that are recommended by the system based on various criteria or based on various types of visualization of textual relations; editing can be based on manually arranging texts according to individually established criteria, but also assisted or fully automated by algorithmic processes; writing also ranges from human authored variations derived from Pessoa's texts to fully automated recreations using electronic literature tools (which explore permutation and multimedia integration, for instance).

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3.9 Experiences with MEXICA and the social sciences

Rafael Pérez y Pérez (Universidad Autonoma Metropolitana – Cuajimalpa, MX)

Joint work of Vicente Castellanos, Inés Cornejo
Main reference Rafael Pérez y Pérez: "MEXICA: 20 years – 20 stories [20 años – 20 historias]". Denver, CO: Counterpath Press, 2017.
URL http://counterpathpress.org/mexica-20-years-20-stories-rafael-perez-y-perez
Main reference Rafael Pérez y Pérez: "A computer-based model for collaborative narrative generation", Cognitive Systems Research, Vol. 36-37, pp. 30–48, 2015.
URL http://dx.doi.org/10.1016/j.cogsys.2015.06.002

This talk is divided in four sections:

1. MEXICA and emotional relations as a way to understand the world
2. Representation in MEXICA of emotional relations
3. The Maya's project
4. Conclusions

One of MEXICA's main claims is that emotional relations and conflicts between characters are essential for:

- Making sense of the world
- Remembering previous experiences
- Picturing future possible scenarios

Based on such emotional relations, I claim that the MEXICA model can be used to represent and generate narratives about different cultures. To test our claim, we, an interdisciplinary group, are starting a project whose goal is to study the narratives of Mayas that left their towns to immigrate to the USA, worked there and then returned back to Yucatán. We will use such narratives to feed MEXICA and study the new narratives it produces. We believe that this type of interdisciplinary projects will produce novel and interesting knowledge for both, social sciences and computational creativity.

3.10 Adaptation of the Shared Task Format for the Digital Humanities

Nils Reiter (Universität Stuttgart, DE) and Evelyn Gius (TU Darmstadt, DE)

Joint work of Evelyn Gius, Nils Reiter, Marcus Willand

Our presentation was about the organization of the first Shared Task (ST) to annotate literary phenomena and introducing the approach to the digital humanities as a fruitful format. Generally speaking, teams participating in a shared task propose a solution for the problem determined by the organizers, who evaluate the solutions on a shared (but secret) data set, such that the results are comparable. This makes shared tasks competitive. Particularly in natural language processing (NLP), these research constellations are widespread and a major incentive for progress on important topics such as syntactic parsing. For the first shared task in the digital humanities we have decided on a two-phased approach. The first shared task – "SANTA": Systematic Analysis of Narrative Texts through Annotation – is dedicated to the creation of annotation guidelines for the phenomenon of narrative levels. The guidelines submitted form the basis for the task of the second shared task: the automated identification of narrative levels based on data annotated according to the guidelines (to be advertised in 2020). By focusing on guideline creation first, we want to make sure that automatic discovery systems employ concepts that are actually relevant (also) for literary studies. In order to facilitate this, we have adapted the work distribution and developed an evaluation procedure covering three dimensions – conceptual coverage, applicability and usefulness. We expect such modified STs to help in addressing many other problems in the humanities, which makes them relevant to the digital humanities by nature. They are particularly appropriate where computational procedures are applied to concepts in the humanities in order to operationalize the latter in an intersubjective negotiation process.

3.11 Computational Literary Studies

Nils Reiter (Universität Stuttgart, DE), Evelyn Gius (TU Darmstadt, DE), and Jonas Kuhn (Universität Stuttgart, DE)

Joint work of Fotis Jannidis, Evelyn Gius, Jonas Kuhn, Nils Reiter, Christof Schöch, Simone Winko

The talk gives an overview both of the German Research Foundation (DFG) funding instrument of priority programmes as well as a description of the goals, methods and current status of the priority programme *computational literary studies* (CLS). Priority programmes are a funding line for emerging research areas. If a priority programme is funded, a fixed amount of funds is set aside for projects in this area. Individual projects still undergo the regular reviewing process.

The aim of CLS is to systematically enhance our understanding of how formal models can be used in literary studies. The following research aspects are central for the priority programme:

- Identification of methods in computer science and computational linguistics with relevance for the analysis of literary texts,
- Application of existing algorithms to new data sets to generate new knowledge about cultural phenomena, changes and structures,

- Research on existing algorithms to extend them, to find ways to adapt parameters and to improve the understanding of their interaction with literary texts,
- Formal modelling of concepts relevant to literary studies, whereby the depth of formal modelling of literary phenomena is scalable,
- Integration of results of quantitative-empirical research into the qualitative-hermeneutic research process and the formation of theory and concepts.

A central and important property of the priority programme CLS is the interaction and collaboration between funded projects. To foster this, and to also ensure sustainable data management and long term availability, projects will be clustered both according to research objects and methods and regularly meet. Central coordinating positions are also planned.

The priority programme CLS was established in 2018. Individual projects are currently under review.

3.12 Storytelling with Alexa and Nao

Philipp Wicke (University College Dublin, IE) and Tony Veale (University College Dublin, IE)

Storytelling is a process that reveals how language, interaction and communication between humans can work. We tell stories to inform and to explain, to entertain and transport to other worlds. We use stories to create order in the world and the mass of data it presents us with. While modern technologies provide us with endless opportunities, the need for old- fashioned storytelling becomes ever more pressing. Our project explores a marriage of modern AI techniques and creative performance to use software to generate stories and embodied machines (anthropomorphic robots) to enact them.

The field of computational storytelling is one in many in the relatively new domain of computational creativity. Nonetheless, its serious attempts are as early as 1977, when the TALE-SPIN system was able to generate diverse stories from character profiles or a given morale [1]. Since then, the field has spawned a variety of different story generation systems [2], [3], [4]. Our project considers the pairing of two CC systems in the same thematic area, a speech-based story-teller (with Alexa) and an embodied story-teller (using a NAO robot). Working together, these two compensate for each other's weaknesses while creating something of comedic value that neither has on its own. Both systems perform a double act that is built on a blackboard architecture, allowing them to act on information invisible to the audience. An example performance can be found at https://bit.ly/2SNeeHQ.

Future work will investigate the different modalities of the interaction and their contributions to the performance.

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4 Working groups

4.1 Working Group Reports

Evelyn Gius (TU Darmstadt, DE), Leonid Berov (Universität Osnabrück, DE), Mark Finlayson (Florida International University – Miami, US), and Philipp Wicke (University College Dublin, IE)

Joint work of the entire seminar

The seminar participants split up into working groups for two sessions, one Wednesday in the late morning and one Wednesday afternoon. The group constitution was chosen by the organizers such that participants with diverse backgrounds were represented in all groups. This concept meant to emphasize common difficulties in interdisciplinary work, motivating the participants to develop communication strategies and a feeling for potential issues in interdisciplinary projects in their group phase. Additionally, these different backgrounds should contribute to develop ideas for projects, proposals or road maps for joint ventures of these fields.

4.2 Interprethon

Members: Thierry Declerck, Christopher Hench, Enric Plaza, Sarah Schulz, Philipp Wicke

Summary: This working group first discussed the general definition of well-known open problems such as evaluation in automatic computational creativity but also the focus on interpretation and different literary theories or also a potential lack thereof in literary studies. These discussions led to an idea for a "Call for participation" for an event which could fertilize these two discussed areas which have thus far only been discussed inside of the respective fields by bringing together scholars from both fields. "Interprethon" should aim at bringing together scholars from the Computational Creativity and the Literary Studies communities to offer a platform for cross-fertilization on practical issues as well as discussion and evaluation of literary artifacts created by diverse AI systems. Through a feedback loop between literary scholars and computer scientists discussing and understanding various aspects of the creative process and its outcome, we would expect to learn how to not only improve literary artifact generation systems, but develop a new framework for the analysis of such artifacts – a new type of literary artifact demands updating our traditional methods of literary analysis. An additional result of the event would be the beginnings of informative evaluation techniques of literary artifact generation systems related to audience, values, . . . , etc.. Participants could demonstrate their own use cases and receive feedback from experts with the opportunity to accommodate this feedback to improve the systems utility and value for the literary community. Literary scholars in turn may strengthen and push methods and theories to new limits on novel artifacts becoming increasingly present in our society.

4.3 A mid-term research agenda for a holistic approach to digital literary studies

Members: Amílcar Cardoso, Jonas Kuhn, Leonid Berov, Manuel Portela, Sina Zarrieß

Summary: This working group initiated their discussion by establishing a common terminology in digital literary studies, operating by comparison to the digital study of language. The established common ground for the ensuing discussion was that all fields involved interact with the 'literary artefact'. Literary scholars depart from a text and come up with new conceptualizations, while computational storytelling algorithms depart from conceptualizations and generate stories. Based on this analysis, the group identified similarities and differences in these two approaches regarding the underlying conceptions, input, output and intermediary tasks. Using this outline the existing potential for collaboration between the fields by combining parts of these processes were discussed. This raised interesting challenges that result from the different traditions of the participating fields, and impede any straight forward exchange of already existing algorithms or data. These challenges need to be addressed first, before any integrative software systems can be developed to implement such combined approaches on a meaningful scale. The results of this work group can be seen as the foundation for a white paper that structures and outlines a mid-term research agenda for a holistic approach to digital literary studies that incorporates methodologies from computational creativity, respectively a theory-grounded approach to computational storytelling that incorporates conceptions from literary theory.

4.4 What is a Good Narrative?

Members: Evelyn Gius, Kai-Uwe Kuühnberger, Oliver Kutz, Carlos Leon, Rafael Pérez y Pérez

Summary: Our working group started its discussion by exploring commonalities in the fields of story generation, language processing and (digital) literary studies. Fur this purpose, we tried to look at three aspects: methods, topics/problems, and data. Even though talks from all fields concerned had been given in the seminar, it was not a straightforward task to identify aspects the different fields share when dealing with narratives. Especially the connection between generation and analysis of narratives seemed both the most helpful and the most difficult point to get at. The discussion then developed further towards the question of quality assurance in the work with narratives. There, evaluation was considered a core issue by all participants. Even though it concerns clearly different aspects (e.g., evaluating the quality of a generated story vs. evaluating the quality of the analysis of a narrative), evaluation was considered a critical issue in all fields because there seems to be a lack of well-established methods for evaluation so far. Here again, an interdisciplinary collaboration seems to be promising. We think of interdisciplinarity as the generation of new knowledge that could only emerge as a result of the (methodological, epistemological, practical...) interplay between two or more disciplines. After having discussed the challenges of interdisciplinary work and possible ways of fostering it, we decided to design a workshop that would explore this further. The workshop is envisaged as an event during the "Summer of Knowledge" hosted by the Research Centre for Knowledge and Data of the Free University

of Bozen-Bolzano in September 2020 in Bolzano, Italy [2]. Since the call is still in work in progress, we only provide the description of the central ideas here. The call will be published on the Summer of Knowledge website in summer 2019.

The core question of the workshop will be: "What is a Good Narrative?" The workshop is planned with participants coming from different research areas, in particular digital literary studies, narratology, computational literary creativity, computational modeling of narrative cognitive modeling. The participants will share a common interest in narratology, computational approaches, plot generation, analysis of narrative, and cognition. Here are some exemplary questions that tackle the quality of narratives from the perspective of generation and/or analysis:

- How can we identify good narratives?
- What makes stories similar
- How to identify (sub-)stories?
- Which methods can be used to model narratives?
- What is it that makes a narrative creative?
- What is the relation between generation and evaluation in a narrative production process?
- How can narratives be interpreted?
- What are narratives made of?

The workshop aims at bridging the gap between different approaches towards modeling narratives in different fields. Therefore, we would like to especially encourage submissions combining generative and analytical approaches. The modeling of narratives can, among others, include computational approaches, narratological approaches, hermeneutic approaches, visual narratives, cognitive approaches like conceptual blending, analogy making, metaphor, image schemas, and the like. We are looking for submissions as results of collaborations between two or more of the following fields: cognition, narratology, computer science, ontology, computational creativity, literary studies. Papers can range from theoretical contributions to mixed method approaches and computational modelling. And finally, we are thinking about having a rather unusual, but in our view very important restriction: Since papers should integrate insights from at least two fields, we are planning to accept only papers with authors from at least two fields and to request a section in each paper that elaborates on the establishment of the interdisciplinary collaboration.

4.5 A Roadmap for Driving Progress

Members: Mark Finlayson, Marina Grishakova, Hannu Toivonen, Tony Veale, João Miguel Cunha, Tarek R. Besold

Summary: Working group 5 formulated a medium-term plan for driving progress at the intersection of computation and narratology and literary studies. The plan was motivated by a 50-year vision–a "mission" in the terminology of Horizon Europe–which we nominally designated "Universal Understanding": namely, the idea that discussion of narrative and literature forms an interdisciplinary space of discussion for large, inclusive topics (such as love, war, friendship, justice, etc.) that allows societies to move toward mutual understanding by disparate groups.

[2] https://summerofknowledge.inf.unibz.it/

This ultimate goal was deemed especially relevant today given the clear breakdowns in inter- and intra-societal understanding in first world countries (e.g., the rise of extremism and populism, growing inequality in wealth and political power). The group proposed two medium-term milestones along the path to the 50-year goal: a 5-year goal of explainable AI via narrative (XAI-N), and a 10-year goal of explainable "anything" via narrative (XAny-N). These two medium-term goals were conceived of as follows. Both of these medium-term goals were seen as tasks that would address two field-specific problems, namely that (1) computationalists and humanists still have great difficulty communicating with each other; (2) computationalists suffer from shallow use of narrative and literary theory; and (3) humanists are still resistant to scientific and computational approaches. XAI-N was conceived as the use of narrative to explain complicated AI systems (such as deep neural nets) through appeal to narrative and literary techniques (aligned with article 13 of the GDPR which calls for "meaningful insight" into automatic decisions). XAny-N was conceived as the analogous extension of this technique to any complex system (e.g., a historical situation or political structure). XAny-N was also conceived to be paired with the development of a "narratology of computation", in which the techniques of narratology would be applied to computational processes and artifacts. One concrete outcome the group envisioned as coming from these medium-term goals was a revolutionary change in the character of both computational and humanist approaches to narrative and literature and the development of narrative meta-hermeneutics based on the use of narratives (grounded in shared intentional (dialogic) systems) as cognitive and exploratory tools and on the integration of computation in narrative practices and theorizing an innovative convergence of narrative tools and information technologies. On the way to XAI-N, the first medium-term goal, the group proposed several concrete steps. (1) Soliciting position papers from interested parties in the next year; (2) Holding of a "bidirectional" master class on computational and narratological techniques in the summer of 2020; (3) Organization of code camps and exploratory development in the year following the master class; (4) Writing of proposals aimed at XAI-N against the anticipated 2021 DFG Priority Programmes call (in Germany) on Computational Literary Science, and possibly H2020 or equivalent targets; and (6) Assembly, in parallel with steps 1-5, of an edited volume of foundational works in narrative aimed at computationalists.

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Report from Dagstuhl Seminar 19181

Computational Geometry

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 19181 "Computational Geometry". The seminar was held from April 28 to May 3, 2019 and 40 participants from various countries attended it. New advances and directions in computational geometry were presented and discussed. The report collects the abstracts of talks and open problems presented in the seminar.

Seminar April 28–May 3, 2019 – http://www.dagstuhl.de/19181
2012 ACM Subject Classification Mathematics of computing → Discrete mathematics, Theory of computation → Design and analysis of algorithms, Theory of computation → Data structures design and analysis, Computing methodologies → Shape modeling
Keywords and phrases Computational geometry, polynomial partition, geometric data structures, approximation
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1 Executive Summary

Siu-Wing Cheng
Anne Driemel
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Computational Geometry

Computational geometry is concerned with the design, analysis, and implementation of algorithms for geometric and topological problems, which arise naturally in a wide range of areas, including computer graphics, CAD, robotics, computer vision, image processing, spatial databases, GIS, molecular biology, sensor networks, machine learning, data mining, scientific computing, theoretical computer science, and pure mathematics. Computational geometry is a vibrant and mature field of research, with several dedicated international conferences and journals and strong intellectual connections with other computing and mathematics disciplines.

Seminar Topics

The emphasis of this seminar was on presenting recent developments in computational geometry, as well as identifying new challenges, opportunities, and connections to other fields of computing. In addition to the usual broad coverage of new results in the field, the seminar included broad survey talks on algebraic methods in computational geometry as well as geometric data structures. The former focus area has seen exciting recent progress and the latter is a fundamental topic at the heart of computational geometry. There are numerous opportunities for further cross-disciplinary impact.

Algebraic Methods in Computational Geometry

The polynomial method of Guth and Katz of 2010 has had a fundamental impact on discrete geometry and other areas, which was already envisioned by the talk of Jiří Matoušek at the Annual European Workshop on Computational Geometry in 2011, four years before he passed away. Indeed, the polynomial method has attracted the attention of many researchers, including famous ones like Janos Pach, Micha Sharir, and Terence Tao. Applications have been found not only in making progress on long-standing combinatorial geometry problems, but also in the design and analysis of efficient algorithms for fundamental geometric problems such as range searching, approximate nearest search, diameter, etc. The polynomial method is very powerful and it offers a new research direction in which many interesting new results can potentially be discovered.

Geometric Data Structures

Many beautiful results in geometric data structures have been established in the early days of the field. Despite of this, some long-standing problems remain unresolved and some of the recent progress is in fact made using the polynomial method mentioned previously. Independently, there have been some recent advances in our understanding of lower bounds and the usage of more sophisticated combinatorial constructions and techniques such as shallow cuttings, optimal partition trees, discrete Voronoi diagrams, etc. There are also new applications that require the modeling of uncertain data and hence call for a study of the performance of geometric data structures under a stochastic setting.

2 Table of Contents

Open problems

3 Overview of Talks

3.1 A Review of (some) Data Structure Lower Bound Techniques

Peyman Afshani (Aarhus University, DK)

In this talk, we will have a broad look at the landscape of data structure lower bounds. We will begin by introducing some fundamental lower bound models and then move on to demonstrate the key techniques that enable us prove non-trivial results in each model. These include the pointer machine model, the cell-probe model, the I/O-model, and the semi-group (or group) model. We will also very briefly touch the conditional lower bounds.

3.2 Hard problems in knot theory

Arnaud de Mesmay (University of Grenoble, FR)

Joint work of Arnaud de Mesmay, Yo'av Rieck, Eric Sedgwick, Martin Tancer
Main reference Arnaud de Mesmay, Yo'av Rieck, Eric Sedgwick, Martin Tancer: "The Unbearable Hardness of Unknotting", in Proc. of the 35th International Symposium on Computational Geometry, SoCG 2019, June 18-21, 2019, Portland, Oregon, USA., LIPIcs, Vol. 129, pp. 49:1–49:19, Schloss Dagstuhl – Leibniz-Zentrum fuer Informatik, 2019.
URL http://dx.doi.org/10.4230/LIPIcs.SoCG.2019.49

Quite a few problems in knot theory are extremely hard to solve algorithmically (like testing whether two knots are equivalent), and some of them are not even known to be decidable (like computing the unknotting number of a knot). However, very few hardness results are known. We show how a rather simple construction with Borromean rings can be leveraged to establish a handful of NP-hardness proofs for seemingly unrelated problems. Our main result shows that deciding if a diagram of the unknot can be untangled using at most k Reidemeister moves (where k is part of the input) is NP-hard. We also prove that several natural questions regarding links in the 3-sphere are NP-hard, including detecting whether a link contains a trivial sublink with n components, computing the unlinking number of a link, and computing a variety of link invariants related to four-dimensional topology (such as the 4-ball Euler characteristic, theslicing number, and the 4-dimensional clasp number).

3.3 Plantinga-Vegter algorithm takes average polynomial time

Alperen Ergür (TU Berlin, DE)

Joint work of Felipe Cucker, Alperen A. Ergür, Josué Tonelli-Cueto
Main reference Felipe Cucker, Alperen A. Ergür, Josué Tonelli-Cueto: "Plantinga-Vegter algorithm takes average polynomial time", CoRR, Vol. abs/1901.09234, 2019.
URL https://arxiv.org/abs/1901.09234

We provide smoothed analysis of an adaptive subdivision algorithm due to Plantinga and Vegter. The only available complexity analysis of this algorithm was due to Burr, Gao, Tsigaridas which provided worst case bounds that are exponential in the degree of the input equation. More in the line the practical success of PV algorithm, we provide polynomial bounds in terms of the degree.

3.4 General Polynomial Partitionings and their Applications in Computational Geometry

Esther Ezra (Georgia Tech – Atlanta, US & Bar-Ilan Univ. Ramat Gan, IL)

Joint work of Pankaj Agarwal, Boris Aronov, Esther Ezra, Joshua Zahl
Main reference Pankaj Agarwal, Boris Aronov, Esther Ezra, Joshua Zahl: "An Efficient Algorithm for Generalized Polynomial Partitioning and Its Applications", CoRR, Vol. abs/1812.10269, 2018.
URL https://arxiv.org/abs/1812.10269

Since the celebrated work of Guth in Katz on the Erdos distinct distances problem, polynomial partitioning became a central tool in solving incidence problems, as well as other main problems in discrete geometry. In spite of this progress, the application of polynomial partitioning in solving computational problems received considerably less attention.

Polynomial partitioning for a set of geometric objects forms a space decomposition, such that any component in this decomposition is intersected by a small fraction of the input objects. In this talk, I will survey the polynomial partitioning technique by first presenting the setting of points in d-space, addressed by Guth and Katz, and then discussing polynomial partitioning for general semi-algebraic sets, studied by Guth. I will then describe the algorithmic issues concerning the construction of such polynomials. Whereas there are efficient algorithms to construct polynomial partitionings of the first kind, it is currently unknown how to effectively construct general polynomial partitionings. I will present an efficient algorithm that constructs a general polynomial partitioning for semi-algebraic sets in d-space, which, as a main tool, exploits the concept of "quantifier elimination" combined with "epsilon-approximations". The running time of this algorithm is only linear in the number of input objects. As a preliminary result, I will present an algorithm that constructs a space decomposition for a collection of algebraic curves in 3-space, with complexity bounds similar to those of Guth. These results have several algorithmic implications, including a nearly-optimal algorithm to eliminate depth cycles among disjoint triangles in 3-space, an efficient range-search mechanism in the fast-query/large-storage regime, and an efficient point-location machinery that outperforms traditional point-location machineries exploiting vertical decompositions.

3.5 Approximating the Geometric Edit Distance

Kyle Jordan Fox (University of Texas – Dallas, US)

Joint work of Kyle Jordan Fox, Xinyi Li

We describe the first sublinear approximate strictly subquadratic time algorithms for computing the geometric edit distance of two point sequences in constant dimensional Euclidean space. First, we present a randomized $O(n \log^2 n)$ time $O(\sqrt(n))$-approximation algorithm. Then, we generalize our result to give a randomized alpha-approximation algorithm for any alpha in $[1, \sqrt(n)]$, running in time $\tilde{O}(n^2/\alpha^2)$. Both algorithms are Monte Carlo and return approximately optimal solutions with high probability.

3.6 Geometry and Generation of a New Graph Planarity Game

Wouter Meulemans (TU Eindhoven, NL)

Joint work of Rutger Kraaijer, Marc van Kreveld, Wouter Meulemans, André van Renssen
Main reference Rutger Kraaijer, Marc van Kreveld, Wouter Meulemans, André van Renssen: "Geometry and Generation of a New Graph Planarity Game", in Proc. of the 2018 IEEE Conference on Computational Intelligence and Games, CIG 2018, Maastricht, The Netherlands, August 14-17, 2018, pp. 1–8, IEEE, 2018.
URL https://doi.org/10.1109/CIG.2018.8490404

We introduce a new abstract graph game, Swap Planarity, where the goal is to reach a state without edge intersections and a move consists of swapping the locations of two vertices connected by an edge. We analyze this puzzle game using concepts from graph theory and graph drawing, computational geometry, and complexity. Furthermore, we specify what good levels look like and we show how they can be generated. We also report on experiments that show how well the generation works.

3.7 Multipoint evaluation for the visualization of high degree algebraic surfaces

Guillaume Moroz (INRIA Nancy – Grand Est, FR)

Joint work of Guillaume Moroz, Marc Pouget

The surface solution of a polynomial equation $f(x, y, z) = 0$ can be visualized using for example the marching cube algorithm. This requires to evaluate f on a grid of points in R^3. In this talk, we will review the existing methods to compute the evaluation of a polynomial on multiple points and we will show how some of these methods can be adapted to visualize efficiently algebraic curves and surfaces of degree ranging from 10 to 400.

3.8 Innovations in Convex Approximation and Applications

David M. Mount (University of Maryland – College Park, US)

Joint work of Ahmed Abdelkader, Sunil Arya, Guilherme da Fonseca, David M. Mount

Recently, new approaches to convex approximation have produced major improvements to approximation algorithms for a number of geometric optimization and retrieval problems. These include computing the diameter and width of a point set, kernels for directional width, bichromatic closest pairs, Euclidean minimum spanning trees, and nearest neighbor searching under various distance functions including the Mahalanobis distance and Bregman divergence. In this talk, I will describe these techniques, including Macbeath regions, Delone sets in the Hilbert metric, and convexification, and I will explain how these techniques can be applied to obtain these improvements.

3.9 Geodesic Voronoi Diagrams in Simple Polygons

Eunjin Oh (MPI für Informatik – Saarbrücken, DE)

Main reference Eunjin Oh: "Optimal Algorithm for Geodesic Nearest-point Voronoi Diagrams in Simple Polygons", in Proc. of the Thirtieth Annual ACM-SIAM Symposium on Discrete Algorithms, SODA 2019, San Diego, California, USA, January 6-9, 2019, pp. 391–409, SIAM, 2019.
URL https://doi.org/10.1137/1.9781611975482.25

In the presence of polygonal obstacles, the distance of two points is measured by the length of a shortest path between the two points avoiding obstacles. In this talk, I introduce several recent results on problems defined in polygonal domains including an $O(n + m \log m)$-time algorithm for computing the geodesic Voronoi diagram of m points in a simple n-gon.

3.10 Intersection patterns of sets in the plane

Zuzana Patáková (IST Austria & Charles University Praha)

Joint work of Gil Kalai, Zuzana Patáková

Helly theorem states that to decide whether a finite family of convex sets in $\mathbb{R}^d$ has a point in common, it is enough to test only intersections of d+1 sets. As such, it has applications not only within combinatorial geometry, but also in optimization and property testing.

We discuss related concepts as Helly-type theorems and fractional Helly-type theorems. Apart from that, we focus on the following question: What conditions we need to put on a family of n sets in the plane where no k+1 sets intersect, in order to conclude that the number of intersecting k-tuples is at most cn^{k-1} for some constant c?

We provide a sufficient topological condition which includes much more families than convex sets, for which the answer was known.

3.11 Metric Violation Distance

Benjamin Raichel (University of Texas – Dallas, US)

Joint work of Chenglin Fan, Anna Gilbert, Benjamin Raichel, Rishi Sonthalia, Gregory Van Buskirk
Main reference Chenglin Fan, Benjamin Raichel, Gregory Van Buskirk: "Metric Violation Distance: Hardness and Approximation", in Proc. of the Twenty-Ninth Annual ACM-SIAM Symposium on Discrete Algorithms, SODA 2018, New Orleans, LA, USA, January 7-10, 2018, pp. 196–209, SIAM, 2018.
URL https://doi.org/10.1137/1.9781611975031.14

We introduce and study the metric violation distance problem: given a set of pairwise distances, represented as graph, modify the minimum number of distances such that the resulting set forms a metric. Three variants are considered, based on whether distances are allowed to only decrease, only increase, or the general case which allows both decreases and increases.

We show that while the decrease only variant is polynomial time solvable, the increase only and general variants are Multicut hard. By proving interesting necessary and sufficient conditions on the optimal solution, we provide approximation algorithms approaching our hardness bounds.

3.12 Hitting Convex Sets with Points

Natan Rubin (Ben Gurion University – Beer Sheva, IL)

Main reference Natan Rubin: "An Improved Bound for Weak Epsilon-Nets in the Plane", in Proc. of the 59th IEEE Annual Symposium on Foundations of Computer Science, FOCS 2018, Paris, France, October 7-9, 2018, pp. 224–235, IEEE Computer Society, 2018.
URL https://doi.org/10.1109/FOCS.2018.00030

We show that for any finite set P of points in the plane and $\epsilon > 0$ there exist roughly $\epsilon^{-3/2}$ points that pierce every convex set K with that encompasses at least an ϵ-fraction of P. This is the first improvement of the bound of $O(\epsilon^{-2})$ that was obtained in 1992 by Alon, Bárány, Füredi and Kleitman for general point sets in the plane.

3.13 Hamiltonicity for convex shape Delaunay and Gabriel graphs

Maria Saumell (The Czech Academy of Sciences – Prague, CZ & Czech Technical University – Prague, CZ)

Joint work of Maria Saumell, Prosenjit Bose, Pilar Cano, Rodrigo I. Silveira
Main reference Prosenjit Bose, Pilar Cano, Maria Saumell, Rodrigo I. Silveira: "Hamiltonicity for Convex Shape Delaunay and Gabriel Graphs", in Proc. of the Algorithms and Data Structures – 16th International Symposium, WADS 2019, Edmonton, AB, Canada, August 5-7, 2019, Proceedings, Lecture Notes in Computer Science, Vol. 11646, pp. 196–210, Springer, 2019.
URL https://doi.org/10.1007/978-3-030-24766-9_15

We study Hamiltonicity for some of the most general variants of Delaunay and Gabriel graphs. Instead of defining these proximity graphs using circles, we use an arbitrary convex shape $\mathcal{C}$. Let S be a point set in the plane. The k-order Delaunay graph of S, denoted k-$DG_{\mathcal{C}}(S)$, has vertex set S and edge pq provided that there exists some homothet of $\mathcal{C}$ with p and q on its boundary and containing at most k points of S different from p and q. The k-order Gabriel graph k-$GG_{\mathcal{C}}(S)$ is defined analogously, except for the fact that the homothets considered are restricted to be smallest homothets of $\mathcal{C}$ with p and q on its boundary.

We provide upper bounds on the minimum value of k for which k-$GG_{\mathcal{C}}(S)$ and k-$DG_{\mathcal{C}}(S)$ are Hamiltonian. In particular, we give upper bounds of 24 for every $\mathcal{C}$ and 15 for every point-symmetric $\mathcal{C}$. We also improve the bound for even-sided regular polygons. These constitute the first general results on Hamiltonicity for convex shape Delaunay and Gabriel graphs.

3.14 The maximum level vertex in an arrangement of lines

Micha Sharir (Tel Aviv University, IL)

Joint work of Dan Halperin, Sariel Har-Peled, Eunjin Oh, Kurt Mehlhorn

The level of a point p in an arrangement of a set L of n lines is the number of lines that lie strictly below p. The problem is to find a vertex of maximum level. It was posed as Exercise 8.13 in the "Dutch" textbook, but it hides much more than meets the eye when L is not in general position. We present structural properties of maximum-level vertices (in degenerate arrangements) and develop algorithms that find such a vertex in near-linear time.

3.15 The Blessing of dimensionality: when higher dimensions help

Hans Raj Tiwary (Charles University – Prague, CZ)

Problems in CG often suffer from a curse of dimensionality in that typical dependence of algorithms is exponential in the dimension. In Linear Programming however one can often drastically reduce the size of an LP by introducing extra variables. In geometric terms, many interesting polytopes have exponentially many vertices and facets but are projections of polytopes that can have polynomially many facets. I will present a communication game to obtain such size reductions and illustrate it with a (non-geometric) example: Spanning trees.

3.16 Competitive Searching for a Line on a Line Arrangement

Marc van Kreveld (Utrecht University, NL)

Joint work of Quirijn Bouts, Thom Castermans, Arthur van Goethem, Marc van Kreveld, Wouter Meulemans
Main reference Quirijn Bouts, Thom Castermans, Arthur van Goethem, Marc van Kreveld, Wouter Meulemans: "Competitive Searching for a Line on a Line Arrangement", in Proc. of the 29th International Symposium on Algorithms and Computation, ISAAC 2018, December 16-19, 2018, Jiaoxi, Yilan, Taiwan, LIPIcs, Vol. 123, pp. 49:1–49:12, Schloss Dagstuhl – Leibniz-Zentrum fuer Informatik, 2018.
URL http://dx.doi.org/10.4230/LIPIcs.ISAAC.2018.49

We discuss the problem of searching for an unknown line on a known or unknown line arrangement by a searcher S, and show that a search strategy exists that finds the line competitively, that is, with detour factor at most a constant when compared to the situation where S has all knowledge. In the case where S knows all lines but not which one is sought, the strategy is 79-competitive. We also show that it may be necessary to travel on Omega(n) lines to realize a constant competitive ratio. In the case where initially, S does not know any line, but learns about the ones it encounters during the search, we give a 414.2-competitive search strategy.

3.17 Stability analysis of shape descriptors

Kevin Verbeek (TU Eindhoven, NL)

Joint work of Wouter Meulemans, Kevin Verbeek, Jules Wulms
Main reference Wouter Meulemans, Kevin Verbeek, Jules Wulms: "Stability analysis of kinetic orientation-based shape descriptors", CoRR, Vol. abs/1903.11445, 2019.
URL https://arxiv.org/abs/1903.11445

Motivated by the analysis and visualization of moving points, we study orientation-based shape descriptors on a set of continuously moving points, specifically the minimum oriented bounding box. The optimal orientation of this box may be very unstable as the points are moving, which is undesirable in many practical scenarios. If we bound the speed with which the orientation of the box may change, this may increase the area. In this talk we study the trade-off between stability and quality of oriented bounding boxes.

We first show that there is no stateless algorithm, an algorithm that keeps no state over time, that both approximates the minimum area of the oriented bounding box and achieves continuous motion. On the other hand, if we can use the previous state of the shape descriptor to compute the new state, then we can define "chasing" algorithms that attempt to follow the optimal orientation with bounded speed. Under mild conditions, we show that chasing algorithms with sufficient bounded speed approximate the minimum area at all times.

3.18 A Motion Planning Algorithm for the Invalid Initial State Disassembly Problem

Nicola Wolpert (University of Applied Sciences – Stuttgart, DE)

Joint work of Daniel Schneider, Elmar Schömer, Nicola Wolpert
Main reference Daniel Schneider, Elmar Schömer, Nicola Wolpert: "A motion planning algorithm for the invalid initial state disassembly problem", in Proc. of the 20th International Conference on Methods and Models in Automation and Robotics, MMAR 2015, Międzyzdroje, Poland, August 24-27, 2015, pp. 35–40, IEEE, 2015.
URL https://doi.org/10.1109/MMAR.2015.7283702

Sampling-based motion planners are able to plan disassembly paths at high performance. They are limited by the fact that the input triangle sets of the static and dynamic object need to be free of collision in the initial and all following states. In real world applications, like the disassembly planning in car industry, this often does not hold true. Beside data inaccuracy, this is mainly caused by the modeling of flexible parts as rigid bodies, especially fixture elements like clips. They cause the invalid initial state disassembly problem. In the literature there exists no algorithm that is able to calculate a reasonable disassembly path for an invalid initial state. Our novel algorithm overcomes this limitation by computing information about the flexible parts of the dynamic object and incorporating this information into the disassembly planning.

4 Open problems

4.1 Problem 1

Jeff Erickson (University of Illinois – Urbana-Champaign, US)

Given a directed graph G embedded on a surface S of genus 2 with some marked edges, compute whether there exists a closed walk in G with more marked edges than unmarked edges that is contractible on S. What is the running time for solving this problem? Is this problem even decidable?

A bit of context to the problem:

This is the simplest open special case of finding negative-weight contractible walks in weighted directed graphs. Even the more general problem can be solved in polynomial time for directed graphs on the torus (via homology and linear programming) or directed graphs on surfaces with boundary (via CFG-shortest-paths algorithms). More generally, negative-weight walks with trivial (integer) homology on *any* surface can be found in polynomial time.

An affirmative answer to the following question would yield an algorithm for this problem: Is there a function $f(n)$, such that for any n-vertex directed graph with some edges marked, the shortest majority-marked contractible walk has at most $f(n)$ edges? In particular, a polynomial bound on $f(n)$ would imply a polynomial-time algorithm.

There is no such upper bound for negative contractible walks in real-weighted graphs. Even in graphs with constant complexity on the torus, the shortest negative contractible walk can be arbitrarily long. Any hardness (or undecidability) results for real-weighted graphs and/or higher-genus surfaces would also be interesting.

4.2 Problem 2

Peyman Afshani (Aarhus University, DK)

Consider the following two problems.

1. This is a weighted version of the level set problem. Consider a set P consisting of n points in the plane. We say a subset $S \subset P$ is *separable* if S can be separated from $P \setminus S$ using a line. Consider a function $f : P \to \mathbb{R}^+$. Given a value $w \in \mathbb{R}$, a separable subset $S \subseteq P$ is a w-set if $f(S) \leq w$ and for all separable sets S' such that $S \subsetneq S'$ we have $f(S') > w$. Find a non-trivial upper/lower bound on the maximum number of w-sets for given w. In particular, can we have $\Omega(n^2)$ w-sets for some w? Can we prove an upper bound of $O(n^{3/2})$ for any w?
2. Given a set of n points in the plane with real-valued weight, compute a centerpoint of P, preferably in $O(n \log n)$ time.

4.3 Problem 3

Guillaume Moroz (INRIA Nancy – Grand Est, FR)

Given pairwise distinct areas of all four sides A_1, A_2, A_3, A_4, the volume V, and the radius of the enclosing ball R, how many tetrahedra with this property exist up to isometry?

Conjecture: There exist at most 6 for any combination of those properties.

4.4 Problem 4

Stefan Langerman (UL – Brussels, BE)

Given a set of points P and their Delaunay triangulation, find a vertex separator of size $n^\alpha, \alpha < 1$ in $o(n \log n)$ time for this graph. Similarly, in three dimensions, find a separator with those properties of the graph of the convex hull.

4.5 Problem 5

Antoine Vigneron (Ulsan National Institute of Science and Technology, KR)

Given a partition of the plane, directional cones for each component of the partition, and two points s and t. We want to compute whether there exists a trajectory from s to t which respects the directional constraints. For single component directional cones there is a $O(n \log n)$ algorithm known. For multiple components it is NP-hard. What about symmetric cones with two components? *Clarification*: If the directional cones have multiple connected components, then we are not allowed to use directions from different components during the same visit of the area.

4.6 Problem 6

Hans Raj Tiwary (Charles University – Prague, CZ)

Do there exist polytopes P_1, P_2, Q such that
1. $P_1 \times P_2$ is a projection of Q, and
2. $xc(Q) \leq xc(P_1) + xc(P_2) - -1$,

where $xc(P)$ of a polytope P denotes the minimum number of facets of any polytope that projects to P. It is known that if either P_1 or P_2 is a pyramid, then this does not exist.

4.7 Problem 7

Birgit Vogtenhuber (TU Graz, AT)

Given a straight-line drawing of a complete graph K_n and a value $k \in \mathbb{N}$, does there exist a 2-coloring of edges such that there are less than k monochromatic crossings? Does this problem have a polynomial time algorithm?

4.8 Problem 8

Hsien-Chih Chang (Duke University – Durham, US)

Given two strings A and B ($n := |A|, m := |B|$), does there exist a data structure with
- $O((nm)^{1-\epsilon})$ preprocessing time (for some $\epsilon > 0$)
- $\tilde{O}(m^{1-\delta})$ query time for some $\delta > 0$ checking whether $LCS(A[i \dots j], B) = LCS(A[i \dots j+1], B)$

This problem is interesting for any values of m. Especially, data structure for $m = n^c$ for some $c > 0$ would be sufficient. Note that computing $LCS(A[i \dots j], B)$ is equivalent to computing the shortest path distance from node i at the top row to node j at the bottom row in the dynamic-programming graph, which is planar.

4.9 Problem 9

Hans Raj Tiwary (Charles University – Prague, CZ)

Given 0/1 polytopes P_1, P_2, Q (i.e., polytopes where all vertices are in $\{0,1\}^d$) defined by inequalities, we want to know whether $P_1 + P_2 = Q$, where the addition is the Minkowski sum. For general polytopes this problem is known to be (co)NP-complete.

4.10 Problem 10

Suresh Venkatasubramanian (University of Utah – Salt Lake City, US)

Consider the n-dimensional hypercube, and given n curves $\alpha_i : [0,1] \to [0,1]^n$ with
- $\alpha_i(0) = (0, \dots, 0, 1, 0, \dots, 0)$, where the ith position is 1
- $\alpha_i(1) = (1, \dots, 1)$
- $\forall i, j \; \forall t \leq t', d(\alpha_i(t), \alpha_j(t)) \geq d(\alpha_i(t'), \alpha_j(t'))$

where d is the euclidean distance.

Question: What tools are applicable to this setting?

4.11 Problem 11

Maarten Löffler (Utrecht University, NL)

Let T be a tree with $n = k^2$ vertices. A perfect plane grid drawing of a tree is a bijection from the tree nodes to the nodes of a regular $k \times k$ grid such that

1. the edges are preserved and embedded by straight lines, and
2. there are no crossing edges, and
3. no edge is going through a node.

Question 1: What is the runtime of deciding whether this is possible for a tree. (NP-hard? polynomial?)

Let d be the maximal degree of a node in T.

Question 2: What is a function of the maximal degree $d(n)$ such that a perfect plane grid drawing is always possible?

Question 3: Even for $d = 3$, is such an embedding always possible?

4.12 Problem 12

Kyle Jordan Fox (University of Texas – Dallas, US)

Given the complete graph K_n with each edge colored either red or blue, and each edge has a non-negative edge weight. Find the minimum weight perfect matching with an odd number of red edges.

Known: There exists a randomized pseudo-polynomial algorithm.
Question: What is the complexity of this problem?
Applications: Max cut on surface graphs, matroid girth.

4.13 Problem 13

Siu-Wing Cheng (HKUST – Kowloon, HK)

This open problem is about self-improving sorting. Given numbers $x_1, \ldots, x_n$ drawn independently from distributions $D_1, \ldots, D_n$, i.e. $x_i \sim D_i$ for all i. We first allow for an arbitrarily long learning phase which has $O(n^{1+\epsilon})$ space. Then there is the limiting phase in which we want to sort new instances in $O(\frac{1}{\epsilon}(n + H))$ expected time with high probability, where H is the sum of the entropies of the D_i. There was a result at ISAAC'18 about this problem. Can more general input model be allowed?

4.14 Problem 14

Maria Saumell (The Czech Academy of Sciences – Prague, CZ & Czech Technical University – Prague, CZ)

Shamos [1] conjectured that the Delaunay triangulation always contains a Hamiltonian cycle. Dillencourt [2] disproved this conjecture, but he also showed that Delaunay triangulations are *almost* Hamiltonian [3], in the sense that they are 1-tough.[1]

[1] A graph is *1-tough* if removing k vertices from it results in $\leq k$ connected components.

Given a planar point set S and two points $p, q \in S$, the k-Delaunay graph (k-DG) with vertex set S has an edge pq provided that there exists a disk with p and q on the boundary containing at most k points of S different from p and q. The following question arises: What is the minimum value of k such that the k-Delaunay graph of any point set S is Hamiltonian? Chang et al. [4] showed that 19-DG is Hamiltonian, and Abellanas et al. [5] lowered this bound to 15-DG. Currently, the lowest known bound is by Kaiser et al. [6] who showed that 10-DG is Hamiltonian. Despite this, it is conjectured that 1-DG is Hamiltonian [5]. Is this conjecture true?

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Report from Dagstuhl Seminar 19182

Multi-Document Information Consolidation

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 19182 "Multi-Document Information Consolidation". At this 5-day Dagstuhl seminar, an interdisciplinary collection of leading researchers discussed and develop research ideas to address multi-documents in machine learning and NLP systems. In particular, the seminar addressed four major topics: 1) how to represent information in multi-document repositories; 2) how to support inference over multi-document repositories; 3) how to summarize and visualize multi-document repositories for decision support; and 4) how to do information validation on multi-document repositories. General talks as well as topic-specific talks were given to stimulate the discussion between the participants, which lead to various new research ideas.

Seminar April 28–May 3, 2019 – http://www.dagstuhl.de/19182
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1 Executive Summary

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Today's natural language processing (NLP) systems mainly work on individual text pieces like individual sentences, paragraphs, or documents. For example, most question answering systems require that the answer to a user's questions is provided in a single document, ideally in a single sentence. If the information is scattered across documents, most systems will fail. The capability of current systems to link information across multiple documents is often limited.

This is in strong contrast to how humans answer difficult questions or make complex decisions. We usually read multiple documents on a topic and then infer the answer to the question or we make a decision based on the evidence we found. In most cases, we consolidate the information across multiple sources. Further, considering only one document can create a biased or incomplete view on a topic. Many aspects in our life are open for multiple interpretations and each author must limit which and how to present information in a document. By reading multiple documents, we are able to identify overlaps, differences, and opposing views between authors. Considering and merging these possible opposing views can be a crucial step in everydays decision making. For example, when booking a hotel, one might read multiple user reviews and create an internal understanding of positive and negative aspects of the hotel.

At this 5-day Dagstuhl Seminar, an interdisciplinary collection of leading researchers discussed and develop research ideas that will lead to advanced multi-document information consolidation systems and enable modern NLP systems to profit from a multi-document perspective.

The seminar was centered around four major themes: 1) how to represent information in multi-document repositories; 2) how to support inference over multi-document repositories; 3) how to summarize and visualize multi-document repositories for decision support; and 4) how to do information validation on multi-document repositories. Questions of semantics, pragmatics (author perspectives, argumentation), representation, and reasoning (including spatio-temporal reasoning and entailment) arose across these themes.

Information Representations and Inference are the theoretical foundation that allows systems to extract information from multiple documents and to infer new knowledge. The challenge is to find a representation that can broadly be used. Multiple documents are likely to bring up multiple perspectives and identifying the relations between them is at the heart of multi-document inference.

A connection to real applications, used in actual user scenarios, is critical for the advancement of the multi-document information consolidation field. Multi-document systems are especially useful in situations where users must make complex decisions. In such situations, users often search for sources that provide information or arguments for or against certain decisions. Hence, one working group focused on Multi-Document Systems in User Decision Scenarios. In order to provide value to users, the systems must return true statements (accurate syntheses) given all the available context. Otherwise, the user lose their trust in the system. However, the internet is full of statements that are intentionally or unintentionally misleading. So how do we identify these misleading statements and avoid that those are presented to a user without the necessary context? This research question was addressed by a working group focusing on Information Validation for Multi-Document Scenarios.

Seminar participants, including established experts and promising young researchers from academia and industry, had the opportunity to present research ideas, to outline their vision regarding the future of multi-document information consolidation technologies, and to collaborate in discussion groups led by the seminar organizers.

Each seminar participant joined two themes with regular cross-theme meetings. As the topics are quite novel in the research community, no established terminology and task definition exists. Hence, participants discussed how these tasks can be defined such that these can be scientifically studied. For example, what does it mean to validate a claim? The participants discussed issues with existing approaches and proposed new research topics, that could be the content of a Ph.D. thesis.

The last day of the seminar was used to summarize results and to create collaborations for future research projects. In total, 12 joint research ideas were proposed. For most of the ideas, this is a new collaboration.

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3 Invited Talks

3.1 Question-drive Information Consolidation

Jonathan Berant (Tel Aviv University, IL)

Humans often have complex information needs when performing activities such as learning about a new topic, performing research, or planning a future activity. Such scenarios invariably lead to questions that require deep understanding of questions and consolidation of information across multiple information sources. In this talk, I will present two lines of work focusing on the problem of answering complex questions, which require on-the-fly information consolidation. In the first thread, complex questions are handled by decomposing them into simpler questions and consolidating the information through symbolic operations. I will briefly describe past and ongoing work on building both models and datasets for question decomposition and question understanding. In the second thread, I will describe ongoing work on differentiable graphs, where information is represented with a graph structure, and information consolidation is performed with an end-to-end differentiable model over this graph. I will also discuss use cases in which these two opposing approaches are suitable.

3.2 Claim Validation by Humans and Machines: Where We Are and the Road Ahead

Iryna Gurevych (TU Darmstadt, DE)

Claim validation is a highly demanding expert task which prevents the proliferation of misinformation. In the recent years, we have seen a rapidly increasing interest in this problem domain. This interest is due to both the task significance and the impressive advances in AI-/NLP-based approaches. The talk will present novel datasets and problem definitions and experimental results related to automated claim validation. Information consolidation is an important, but yet untapped research direction for claim validation. Systems presenting just raw lists of evidences are insufficient to support humans in the challenging tasks of validating claim. We will conclude by outlining some open challenges for future research.

3.3 Consolidating Social, Behavioral and Textual Information

Dan Goldwasser (Purdue University – West Lafayette, US)

In this talk I will describe ongoing work, aiming to consolidate textual information, consisting of many interconnected documents, as well as social and behavioral information, capturing how these documents are shared and the reactions their contents receive. Formulating a broad definition of information consolidation which takes into account both aspects, would allow us to answer questions about the social and behavioral context in which documents appear (i.e., "how to combine documents by the same author, to capture their perspective on a topic"), as well as exploit this structure to derive a supervision signal for identifying patterns in textual information (i.e., "how to exploit social information to identify that documents contain inconsistent information"). I will discuss our current efforts focusing on political discourse analysis on social media, online debate networks and partisan news analysis.

3.4 Multi-Document Summarization: from state-of-the-art to open research questions

Giuseppe Carenini (University of British Columbia – Vancouver, CA)

In essence, a multi-document summarizer is a system that takes as input a set of documents and generates a summary as output. Given this high-level view, we can start envisioning a design space for multi document summarization (MDS) by identifying key properties of the possible inputs, of the possible outputs and of the summarization process itself. In this talk, I will characterize such a design space, so that both the state of the art and open research questions in MDS can be better framed, discussed and understood.

3.5 Knowledge Base Population

Heng Ji (Rensselaer Polytechnic Institute – Troy, US)

Traditional Information Extraction techniques pull information from individual documents in isolation. However, in many real applications such as disaster management, intelligence analysis and scientific discovery, users might need to gather information that's scattered among multiple documents from a variety of sources. Complicating matters, these facts might be redundant, complementary, incorrect, or ambiguously worded; the extracted information might also need to augment an existing Knowledge Base (KB), which requires the ability to link events, entities, and associated relations to KB. This problem is called Knowledge Base Population (KBP). In this talk, I will introduce the state-of-the-art techniques for two core tasks in KBP: entity discovery and linking and slot filling, and discuss the remaining challenges and potential solutions. Then I will present several new research directions, including (1) moving from entity-centric KBP to event-centric KBP which requires event actuality extraction and truth finding across documents; (2) extend KBP to a multi-media multi-lingual paradigm; (3) background knowledge acquisition to enhance the quality of KBP capabilities.

4 Working Group – Information Representation

Many text-driven applications need to consider information that is consolidated across multiple texts. Such applications may benefit from an intermediate representation that effectively and informatively consolidates such cross-text information, making it more easily and uniformly accessible for downstream applications. The Information Representation workgroup discussed various aspects of developing such useful representation frameworks. The discussion covered challenges related to logical constructions, semantic phenomena and learning approaches, as well as potential tasks and datasets that could drive future research in this relatively unexplored space.

Throughout the sessions, four participants presented a short pitch related to multi-text information consolidation. Dipanjan Das explored "requirements" of a distributed representation for a human-computer conversation scenario. Keeping track of the multiple previous speech acts, together with their joint meaning, seem to be key aspects for delivering useful answers for user's open-domain questions. Sebastian Arnold suggested a vector space approach for representing local "hotspots" of selected aspects (e.g. topics or named entities) coherently over long documents, building on existing sentence embeddings and aligning them with the context of the document using distant supervision. Ivan Titov presented a recently proposed method for learning interpretable classification models, and speculated how it may be integrated with graph convolutional neural networks (GCNs), which are effective for integrating information across documents while relying on structured representations (e.g., coreference chains). Finally, Omri Abend specified challenges and insights raised in cross-language information consolidation. Since both the cross-language and the cross-document settings deal with linguistic realization diversity, i.e. different ways to express the same content, both confront similar phenomena, e.g. lexical differences, grammatical differences, different social connotations and different narrative styles.

Several important features for an explicit symbolic representation of multi-text information were brought up in discussions. Predicate-argument relationships were proposed consensually as a backbone of such semantic representations. Nevertheless, other layers of representation were deemed crucial. Cross- and intra- document Coreference for entities and events is a key component for identifying overlapping and complementary information. Temporal links between mentioned events, or a tidy timeline alignment of which, along with a set of discourse relations as causality and conditionality, are also essential for capturing the information conveyed by a set of texts. Aside from explicit denotation of specific semantic aspects, a notable core principle of information representation for multi-text consolidation was considered to be decomposability, that is, the breakdown of sentences into smaller meaning units, allowing for fine-grained cross-document alignment of "minimal" information units.

A major topic of discussion regarded the fundamental dichotomy of distributed (continuous) vs. explicit (symbolic) meaning representations. While contemporary contextualized vector-space representations have demonstrated great utility for many natural language understanding tasks, the multiple-text setting might benefit from the advantages of explicit representations. Specifically, the group enumerated several phenomena for which explicit representations would be desirable. These include logical aspects, such as quantification of entities and set membership (do "several blue and green pillows" correspond to "a dozen of colorful pillows"); capturing implicit entailed relations and arguments ("ex-wife" entailing a "divorce" event or status); and explicitly maintaining inference relations, such as entailment, equivalence or contradiction.

4.1 Talk – Representations for Open-Domain Conversation

Dipanjan Das (Google – New York, US)

We speculate about a scenario where a human is interacting with a system that can return answers to questions in a conversational scenario. In this talk, we explore "requirements" of a distributed representation that could serve as a "memory" for enabling this system.

4.2 Talk – Challenges in Cross-linguistic Information Consolidation

Omri Abend (The Hebrew University of Jerusalem, IL)

The talk discussed challenges that come up in cross-linguistic information consolidation. Many translation divergences (different ways of expressing similar content in different languages) also show up when consolidating information within a single language, underscoring the importance of this perspective. Examples discussed include lexical differences, grammatical differences, different social connotations and different narrative styles.

4.3 Talk – Distributed Representation of Local Information in Long Documents

Sebastian Arnold (Beuth Hochschule für Technik Berlin , DE)

This pitch talk introduces our vision of a neural document representation for multi-document passage retrieval. The challenge is to represent local "hotspots" of selected aspects (e.g. topics or named entities) coherently over long documents. Our current work on SECTOR utilizes existing sentence embeddings and aligns them with the context of a document using distant supervision. This allows us to retain the vector space of the embedding and retrieve coherent passages across multiple documents.

4.4 Talk – Towards Interpretability in Multi-Document Question Answering

Ivan Titov (University of Edinburgh, GB)

Graph convolutional neural networks (GCNs) are effective tools for integrating information across documents while relying on structured representations (e.g., coreference chains). Unfortunately, predictions of GCNs are hard to interpret and validate. In contrast, for classification problems, we have recently proposed a method for effectively learning interpretable / sparse models. I speculate how merging the two ideas can lead to interpretable and also effective models for multi-document QA.

5 Working Group – Inference

The goal of this working group was to discuss problems, formulations, and possible approaches, that pertain to inference with respect to natural language text and, in particular, inference that arises in the context of dealing with multiple documents or multiple information sources. The presentations and discussions allowed us to develop better understanding of the keys issues involved in inference with multiple texts, develop important working examples, learn about existing research efforts, and identify research directions. In particular, we discussed and presented some of the existing datasets that could help drive future research in these directions.

5.1 Talk – Multi-passage Summarization for Query-specific Article Summarization

Laura Dietz (University of New Hampshire – Durham, US)

The TREC Complex Answer Retrieval track (TREC CAR) is a shared task about responding to web search requests with machine-constructed comprehensive articles. Such articles can be in the style of a Wikipedia page, how-stuff-works article, or grade-school textbook chapter. The purpose of this article is to inform the user about different important facets of the query. So far, our work is focused on the IR-side: (1) retrieving paragraph-length passages on the topic, (2) identifying which concepts/entities are central to the topic, and (3) arranging paragraphs into an outline.

I would like to use the opportunity of this Dagstuhl seminar focus on the multi-paragraph summarization aspects of this work — I am hoping to solicit some help/ideas/advice from the community. In return I can provide lots and lots of train/test data and intermediate results from the IR stage. While the shared task at TREC is focused on IR (ranking and selection of paragraphs), a holistic solution needs to also address challenges in multi-document summarization.

The pitch talk mostly focuses on the problem – not a solution. We have some initial data to demonstrate the difficulty of the problem. For example, ROUGE/ROUGE-SU is not a useful metric here; the word overlap of similar content is negligible; at the same time multiple subtopics are present, but difficult to extract and identify.

5.2 Talk – Inference in the age of DL?

Yoav Goldberg (Bar-Ilan University – Ramat Gan, IL)

I focus on the machine-learning sense of 'Inference', in which we are looking to solve an argmax problem over a large and somewhat structured space. This has been a major research area in structured prediction. Is this still needed in the deep learning era? I will take the provocative view that this is not needed, and that good enough networks model the inference as part of their learning process. The talk hopes to initiate discussion on this issue.

5.3 Talk – Top-down and bottom-up success in computational semantics

Alexander Koller (Universität des Saarlandes, DE)

A quick history lesson

- Back in the old days, when we did "computational semantics", inference meant "logical inference". The idea was to map sentences to formulas of predicate logic or some such (what is today called "semantic parsing") and then run a sound and complete theorem prover to perform the inference.
- Around 2000 there was much talk in the computational semantics community about shared tasks. The idea was repeatedly rejected because people didn't think about end-to-end tasks, but about mapping from language to specific semantic representations, and couldn't agree on a type of representation.
- Then Ido came along with "textual entailment", which was a shared task that computational semanticists should have been able to handle. But it turned out that the coverage issues were so severe that the old-school systems were useless, and these methods fell out of fashion very quickly.

Top-down vs bottom-up success

- The common view that old-school computational semantics (OSCS) has failed is an example of top-down thinking about scientific success. OSCS set its aims very high: to be able to understand all language that a human does; let's say, to answer all questions about a text that a human could. This goal is not achieved until it is achieved fully. Thus OSCS is "failed" because it did not achieve the end goal fully.
- The common view that we have recently made tremendous progress in NLU, including with respect to semantics, using neural methods is an example of bottom-up thinking of scientific success. There is a constant stream of new tasks and datasets on which neural methods have improved the state of the art; each of these counts as a success; the question of whether this gets us closer to any end goal is not a major issue.
- Good science needs both perspectives. Without the bottom-up perspective, progress is hard to make and quantify; without the top-down perspective, progress may climb the wrong hill. We need to stay humble and occasionally recalibrate by thinking about the end goal. Don't be too proud of this technological terror you've constructed.

- We need to define and work on tasks that strike a good balance between ambitious and doable, and maybe take more risks regarding the community's ability to solve the task within a year.

  Datasets vs tasks
- There is a disturbing trend in recent NLP to define a specific dataset for a task, then train and evaluate models on this dataset, and call it a success if the model performs well on it. This makes a lot of sense, but only if the dataset reflects all the important aspects of the task. Often, though, the dataset is either very restricted (BaBI, Squad), or the distribution of the language in the dataset is disconnected from that in real text. We should be aware of this, make sure not to overinterpret results on such data, and work towards datasets that reflect the underlying task more and more accurately.
- Meaning has a lot of facets. Not all of these will be relevant for each task. Thus, it is really important to think about what task we're looking at before we decide which facets of meaning our formal representation needs to capture.

5.4 Talk – Abstractive Multi-Document Summarization: Opportunities and Challenges

Fei Liu (University of Central Florida – Orlando, US)

Joint work of Fei Liu, Kristjan Arumae, Logan Lebanoff, Kaiqiang Song, Kexin Liao, Sangwoo Cho

Humans can consolidate textual information from multiple sources and organize the content into a coherent summary. Can machines be taught to do the same? The most important obstacles facing multi-document summarization include excessive redundancy in source content, less understood sentence fusion, and the looming shortage of training data. In this talk I present our recent work tackling these issues through decoupling of content selection and surface realization.

We introduce a novel framework guiding extractive summarization (content selection) using question-answering rewards. We argue that quality extractive summaries should contain informative content so that they can be used as document surrogates to answer important questions, thereby satisfying users' information needs. The question-answer pairs can be conveniently developed from human abstracts. The system learns to promote summaries that are informative, fluent, and perform competitively on question-answering.

We further present an initial investigation into an adaptation method enabling an encoder-decoder model trained on single-document summarization data to work with multiple-document input. Parallel data for multi-document summarization are scarce and costly to obtain, therefore a low-cost adaptation method is highly desirable. Experimental results show that our system compares favorably to state-of-the-art extractive and abstractive methods judged by automatic metrics and human assessors.

Finally, we utilize structure-infused copy mechanisms to encourage salient source words and relations to be preserved in the summary, thereby preventing a summary from dramatically changing the meaning of the original text. I conclude the talk with a discussion of the challenges and opportunities associated with abstractive multi-document summarization.

5.5 Talk – Towards Brainstorming with Spoken Dialog Systems

Kentaro Torisawa (NICT – Kyoto, JP)

In this pitch talk, I'll talk about our spoken dialog system WEKDA, which can chat with users using a wide range of knowledge extracted from 4-billion Japanese Web pages. The knowledge extraction is done by our Web-based open-domain QA system WISDOM X, which provides answers to given questions using the 4-billion Web pages and has been publicly available since 2015 (https://wisdom-nict.jp/). WEKDA automatically generates questions for WISDOM X even from non-question inputs and composes responses to users based on WISDOM X's answers. The final goal of the WEKDA project is to enable it to conduct brainstorming with users through spoken dialogs, using knowledge extracted from a large collection of documents and hypotheses generated from the knowledge. As a future research plan, I'll discuss the possibility of using the auto-generated causal hypotheses in the brainstorming dialogs and list several technical problems.

6 Working Group – Information Validation

Multi-document systems often require the compression of information, as we often have millions of documents with different perspectives for a certain topic. However, how can we ensure that the condensed representation is actually true?

We face the challenge that a sheer amount of documents on every topic is available, and some documents will contain information that is intentionally or unintentionally misleading or plain wrong. Assessing the validity of information is a crucial step in multi-document information consolidation systems. Incorporating misleading or wrong information into a representation can have a snowball effect and many false statements could be inferred from this information. Finally, presenting clearly wrong statements to users can destroy the trust of the user into the system.

The working group started with identifying issues in information validation:

- Sources provide conflicting information, potentially with serious consequences
- Wrong facts are not limited to the political domain, but are also present in the medical domain Source may have agendas and motivations, leading to a biased or wrong presentation of information
- It is extremely difficult to differentiate between wrong information and legitimate opposing perspectives on a topic.

The discussion in the working group were accompanied by selected invited talks throughout the 5 days. Iryna Gurevych started with a talk on *Claim Validation by Humans and Machines: Where We Are and the Road Ahead*, which presented recent work on new datasets and problem definitions for claim validation and argument retrieval. Dan Roth presented the *Perspective Dataset*, which contains 1000 claims with different (potentially opposing) perspectives on these claims. Andreas Vlachos presented the *FEVER Shared Task*, with 185k claims verified on Wikipedia. Coreference resolution is a crucial step for find opposing views on a claim across source, hence Nafise Moosavi gave a talk about *More Applicable Coreference Resolvers* and their shortcomings in community question answering scenarios. The final talk was by Ayal Klein on *Minimal Statements in NL-based Semantic Representation*. Statements are often embedded in long, complex sentence. Mapping those across documents can significantly be simplified, if they are mapped to minimal statements, containing one atomic information.

The working group spent time on defining and discussing future research directions and projects. Hereby, the group identified the following research questions as especially important to advance the field of claim validation:

- Realistic public dataset needed – For example, using BoolQ questions and rephrasing them to claims and using Wikipedia as a source of evidence
- Claim validation in the medical domain – A dataset could be constructed based on PubMed and provide scientific evidence for health-related claims
- Claim classification (e.g., factual, subjective, unverifiable, multi-perspective) – similar to question type classification, could help finding better strategies for claim validation
- Claim decomposition – How can a claim be decomposed into smaller units, which are easier to check?
- Controversial claims – How to design systems that find and presents opposing (but legitimate) views on a given, controversial topic?
- Interpretable results – How should a system reason about the own decision, which statements are credible and which are not?
- Removing (partial) redundancy in paraphrased evidences: this is a fundamental problem since the user wants to have a compact overview of all evidence.
- Evidence sufficiency: when is the set of evidence sufficient to resolve the claim? How to account for the sources' trustworthiness and speaker attribution?

6.1 Talk – Minimal Statements in NL-based Semantic Representation

Ayal Klein (Bar-Ilan University – Ramat Gan, IL)

For identifying the overlap of multi-document information, e.g. in the context of evidence aggregation, we should account for any information conveyed by a sentence. Such minimal information units can be captured by meaning representations that account for the semantic relations between sentence's concepts in neo-Davidsonian style graphs, e.g. AMR, SDP, etc. These formalisms are hard to apply for new domains, as they require supervised models and expert annotations. In this talk, I presented our ongoing effort of constructing a crowdsourcable semantic representation, extending the QA-SRL paradigm in which valuable semantic analysis of the sentence can be retrieved from laymen through simple tasks.

6.2 Talk – More Applicable Coreference Resolvers

Nafise Sadat Moosavi (TU Darmstadt, DE)

Coreference resolution has been recognized as an essential step for various tasks like question answering, summarization and fact checking. In order to benefit from coreference resolution in downstream tasks, we need to (1) discriminate coreference relations which would have more impact on target tasks, and (2) develop more generalizable systems since we do not have coreference annotations for downstream datasets. In this presentation, I briefly present our work in these two directions.

6.3 Talk – Perspective Dataset

Dan Roth (University of Pennsylvania – Philadelphia, US)

We construct PERSPECTRUM, a dataset of claims, perspectives and evidence, making use of online debate websites to create the initial data collection, and augmenting it using search engines in order to expand and diversify our dataset. We use crowdsourcing to filter out noise and ensure high-quality data. Our dataset contains 1k claims, accompanied by pools of 10k and 8k perspective sentences and evidence paragraphs, respectively. We provide a thorough analysis of the dataset to highlight key underlying language understanding challenges, and show that human baselines across multiple subtasks far outperform machine baselines built upon state-of-the-art NLP techniques.

6.4 Talk – FEVER Shared Task

Andreas Vlachos (University of Cambridge, GB)

Fact checking is the task of verifying a claim against sources such as knowledge bases and text collections. While this task has been of great importance for journalism, it has recently become of interest to the general public as it is one of the weapons against misinformation. In this talk, I will first discuss the task and what should be the expectations from automated methods for it. Following this, I will present our approach for fact checking simple numerical statements which we were able to learn without explicitly labelled data. Then I will describe how we automated part of the manual process of the debunking website emergent.info, which later evolved into the Fake News Challenge with 50 participants. Finally, I will present the Fact Extraction and Verification shared task, which took place in 2018 and our upcoming plans for the second edition.

7 Working Group – User Decision Support Systems

Decision makers frequently need to synthesize information across many documents for decision support. In NLP, these syntheses are typically static text summaries, however, there is increasing interest in interactive multimedia "summaries", such as timelines, graphs, or spatial visualizations, or extended information exploration dialogs. This group will focus on a taxonomy of, and best practices for, interactive decision support systems over multi-document repositories.

7.1 Talk – MultiConVis: A Visual Text Analytics System for Exploring a Collection of Online Conversations

Giuseppe Carenini (University of British Columbia – Vancouver, CA)

In this talk, I present MultiConVis, a visual text analytics system designed to support the exploration of a collection of online conversations. The system tightly integrates NLP techniques for topic modeling and sentiment analysis with information visualizations, by considering the unique characteristics of online conversations. The resulting interface supports the user exploration, starting from a possibly large set of conversations, then narrowing down to the subset of conversations, and eventually drilling-down to the set of comments of one conversation. Our evaluations through case studies with domain experts and a formal user study with regular blog readers illustrate the potential benefits of our approach, when compared to a traditional blog reading interface.

7.2 Talk – Real-time Twitter Analysis for Disaster Management

Kentaro Torisawa (NICT – Kyoto, JP)

We give demos of two large-scale NLP systems, DISAANA and D-SUMM, which were developed to help disaster victims and rescue workers in the aftermath of large-scale disasters. Immediately after disasters, much useful information is transmitted into cyberspace, especially for such social media as Twitter. Nevertheless, because most people are overwhelmed by the huge amount of information, they are unable to make proper decisions and much confusion ensued. DISAANA provides a list of answers to questions such as "What is in short supply in City X?" and displays locations related to each answer on a map (e.g., locations where food is in short supply) in real time using Twitter as an information source. D-SUMM summarizes the disaster reports from a specified area in a compact format and enables rescue workers to quickly grasp the whole situations from a macro perspective. We also show how the systems are used in actual disaster situations by Japanese local governments and how we are going to extend the whole framework by introducing so-called "chatbots" on chat apps.

8 Open problems

The group brainstormed about open research challenges in the four respective working areas.

8.1 Multi-Document Representations

- Research challenge: create challenge data sets and probe symbolic and distributed representations for handling of phenomena including: quantification/set membership; implicit relations/arguments; factuality; uncertainty; attribution
- Research challenge: from reports of sports games/controversies from different perspectives, or scientific findings reported in the media, or chains of reporting on an ongoing event – create a consolidated objective report

- Research challenge: representations that incorporate or produce discrete representations
- Research challenge: modeling coreference as part of "self-supervised" learning of representations
- Research challenge: (use wikipedia hyperlinks to) build a dataset that has pairs of paragraphs and a "hypothesis" that can be inferred from the consolidated paragraphs but not from the individual ones

8.2 Multi-Document Inference

- Research challenge: construct a multi-faceted summary to convey the information from the document repository to readers
- Research challenge: construct a summary to achieve complete understanding of a topic or event described in a document repository
- Research challenge: construct an update/timeline summary
- Research challenge: construct a deep abstract of source content without hallucination (where "deep" means neural?)
- S Combine symbolic and continuous semantics: because they are complementary How to combine? (1) use symbolic to represent input structure and continuous to represent nodes; (2) use symbolic to form loss functions; (3) use symbolic structure to enforce constraints over continuous; (4) convert continuous to symbolic to show a user / edit / perform symbolic inference later; (5) combine graph embeddings with text embeddings; (6) reason with symbolic, compute with continuous

8.3 Multi-Document Information Validation

- Research challenge: given a corpus, derive the probability for a claim to be true and present evidence/perspectives which rationalize the probability
- Research challenge: create realistic public dataset for fact checking
- Research challenge: claim validation in the medical domain
- Research challenge: claim validation annotation – existing data sets are either synthetic or have inconsistent annotations. How can we collect and annotate good data for this task?

8.4 Multi-Document User Decision Support Systems

- Research challenge: categorizing user intents, goals, and tasks
- Research challenge: Implementation issues
  - Selecting and consolidating the content (including communicating what the system is not showing/telling and supporting serendipity)
  - Learning from users (machine in the loop, including user intent refinement)
  - Explainability and sourcing
  - Supporting interaction from high level overview of repository to individual documents
- Research challenge: Evaluation
  - The NLP community should be open to a variety of evaluation methods for interactive tasks (automatic over corpus is not always feasible or best)
  - Some components may be susceptible to automatic evaluation

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