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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 16231

Immersive Analytics

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 16231 "Immersive Analytics". Close to 40 researchers and practitioners participated in this seminar to discuss and define the field of Immersive Analytics, to create a community around it, and to identify its research challenges. As the participants had a diverse background in a variety of disciplines, including Human-Computer-Interaction, Augmented and Virtual Reality, Information Visualization, and Visual Analytics, the seminar featured a couple of survey talks on the first days, followed by plenary and working group discussions that were meant to shape the field of Immersive Analytics. As an outcome, a book publication is planned with book chapters provided by the participants.

Seminar June 5–10, 2016 – http://www.dagstuhl.de/16231

1998 ACM Subject Classification H.1 Models and Principles, H.1.2 [User/Machine Systems] Human Factors, Human Information Processing, H.3 Information Storage and Retrieval, H.3.4 [Systems and Software] Performance Evaluation (Efficiency and Effectiveness), H.5 Information Interfaces and Presentation, H.5.0 General, J. Computer Applications, J.0 General

Keywords and phrases Visual Analytics, Immersion, Human-Computer Interaction, Augmented Reality, Virtual Reality

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1 Executive Summary

Tim Dwyer
Nathalie Henry Riche
Karsten Klein
Wolfgang Stuerzlinger
Bruce Thomas

Immersive Analytics is an emerging new field that studies technologies facilitating a deep cognitive, perceptual and/or emotional involvement of humans when understanding and reasoning with data.

Immersive technologies are commonly defined as technologies aiming at blurring the line between physical and virtual worlds, by employing multimodal input and multi-sensory output to create a state of immersion, i.e. a deep mental involvement of a person into an activity and/or an intense concentration or complete absorption into the activity that one does.

The term Immersive Analytics was coined a few years ago, but there is no precise definition of the concept so far, and the corresponding research is scattered across several fields and communities. Hence our goal for this seminar was to discuss and define the field of Immersive Analytics, and to create a community around it. In addition, we planned to develop an outline for a book on the topic.

During the working group and discussion sessions, the participants investigated the potential and the challenges of immersive analytics for research and commercial applications, as well as a variety of aspects like multi-sensory data representation, immersive human-centered data analysis, interaction for immersive analysis, immersion for data-driven narratives, and the use of immersive analytics concepts in application areas like the life sciences and air traffic control.

During the first plenary sessions, major topics for discussion were defined and clustered into working groups, and the participants then joined the proposed working groups based on common interest. Later, the participants could switch between the groups. Each of the working groups was meant to outline a chapter of the book publication. For some of the topics, discussions continued in the evening hours, which were also used to experience new technologies like the Microsoft HoloLens.

2 Table of Contents

3 Overview of Talks

The seminar featured two types of talks – invited talks of half an hour that provided a general overview and an introduction into a field for participants from other fields, and lightning talks of five minutes each for short presentations of current work or open perspectives.

Invited Talks

There were four invited talks meant to introduce the state of the art in broad topics related to Immersive Analytics.

3.1 Augmented Reality

Dieter Schmalstieg (TU Graz, AT)

Augmented Reality is an emerging new medium, with the potential of becoming very important for mobile computer use. However, creating Augmented Reality applications that go beyond proof of concept is very challenging, as it requires the successful combination of many non-trivial elements: The technology must be real-time, human-in-the-loop, accurate and precise, context-aware, and work outdoors, operated by potentially naive users. The talk will draw examples from 20 years of experience in Augmented Reality research to highlight trends and directions for future real-world systems.

3.2 The Role of Space in Immersive Analytics

Chris North (Virginia Polytechnic Institute – Blacksburg, US)

In this talk, we examine the importance of space, large spaces in particular, in immersive analytics. Big display spaces play four fundamental roles in immersive analytics of big data: (1) Space for big visualization enables multi-scale insight and efficient physical navigation with natural visual aggregation in the presence of big data. (2) Space for big interaction enables users to interact at multiple levels of scale, with multiple data objects, through multiple devices. (3) Space for big cognition enables users to efficiently externalize their cognitive and analytical processes. (4) Space for big algorithms enables users and machine learning algorithms to collaborate through a spatial common ground. Continuing research into these four roles of space will enable researchers to push forward in the immersive analytics agenda.

3.3 Data Physicalization

Yvonne Jansen (University of Copenhagen, DK)

Data physicalizations are data-driven physical artifacts which may involve the use of computers, either to fabricate them or to actuate them. As physical artifacts they allow people to immerse themselves in data representations without the need to leave the physical reality. In this talk, I illustrate different use cases for data physicalizations in data communication, art, and research, and I give an overview of recent empirical work investigating how people engage with data in physical form.

3.4 Virtual Reality Overview: Virtual Reality, Augmented Reality, Physical-Virtual Reality

Gregory F. Welch (University of Central Florida – Orlando, US)

This talk presents a high-level overview of Virtual Reality, including the related areas of Augmented Reality and Physical-Virtual Reality. The talk includes some historical perspectives on the technologies and example use cases, and examples of modern systems for visual simulation, locomotion, and interaction. Visual simulation examples include head-worn displays, fixed displays, and full-surround visualization systems.

4 Lightning Talks

The following lightning talks were presented during the seminar, in the order given:

- *Todd Margolis* – Immersive Analytics for Business Intelligence
- *Steffen Oeltze-Jafra* – Potential Application of Immersive Analytics: Multidisciplinary Clinical Decision Making in Tumor Boards
- *Jon McCormack* – Immersive Technologies for Education, Research and Data Analytics at Monash SensiLab
- *Christophe Hurter* – Augmented Tower of Air Traffic Controllers
- *Raimund Dachselt* – Spatially-aware Magic Lenses and Body-centered Data Interaction
- *Barrett Ens* – Spatial Analytic Interfaces
- *Kim Marriott* – Data Visualisation without Vision: Accessible Graphics
- *Benjamin Bach* – Interactive Exploration of Space-time Cubes (work in progress)
- *Frank van Ham* – Technology means versus user goals
- *Dieter Schmalstieg* – Collaborative Seamless Display
- *Carla Freitas* – Research on Interaction Techniques, Information Visualization and Virtual Reality at UFRGS
- *Mark Hancock* – Game and Interaction Science: Using Principles from Games to Design Novel Interfaces that Compel and Motivate
- *Jonathan Roberts* – Multi-sensory visualization including haptification (moving visualization beyond WIMP)

- *Maxime Cordeil* – Collaborative visualisation + tangible interactions in Virtual Reality
- *Chris North* – Be the Data: Embodiment for Analytics Education
- *Bruce Thomas* – Situated Analytics
- *Pourang Irani* – Ubiquitous Analytics

5 Working groups

5.1 Immersive Analytics: What, Why, When, How, ...

Pourang P. Irani, Frank van Ham, Nathalie Henry, Roland Fernandez, Aaron Quigley, Karsten Klein, Falk Schreiber, Hans-Christian Hege, and Tobias Isenberg

This grouped discussed the definition and scope of Immersive Analytics. The primary question considered is: "What is Immersive Analytics?", but for that matter "what is immersion?" and for that matter "what is analytics?". We consider the different types of immersion possible, not just immersive VR/AR but also narrative immersion and so on. We consider several different visions for people immersed in their data analysis tasks: today, five years from now, 20 years from now, 50 years from now and 500 years from now. We consider a number of different scenarios for immersive analytics and how we can advance the state of the art.

5.2 Interaction for Immersive Analytics

Raimund Dachselt, Steven Drucker, Tim Dwyer, Carsten Goerg, Todd Margolis, Chris North, Uwe Woessner, and Wolfgang Stuerzlinger

We discuss the central role of interaction in immersive analytics. Particularly, we focus on the fundamental interaction and analysis tasks that enable effective visual analytics. We revisit task taxonomies from previous work in visual analytics. We then consider input modalities and techniques in natural user interfaces and immersive environments. On the basis of this analysis we identify appropriate mappings from interaction techniques to tasks. We divide these mappings into three categories: (1) direct adaptation of existing immersive interaction techniques to basic visual analytics operations; (2) identification of missing mappings; (3) the potential for new immersive environments to enable new modalities. Finally, this leads to a discussion of the opportunities, limitations and resulting research challenges.

5.3 Immersive Human-Centered Computational Analytics

Wolfgang Stuerzlinger, Tim Dwyer, Raimund Dachselt, Steven Drucker, Carsten Goerg, Todd Margolis, Chris North, and Uwe Woessner

In this chapter we seek to elevate the role of the human in human-machine cooperative analysis through a careful consideration of immersive design principles. We consider both strategic immersion through more accessible systems as well as enhanced understanding and control through fluid immersive interfaces. We extend the classic sense-making loop from visual analytics to incorporate multiple views, scenarios, people, and computational agents. We consider both sides of the machine / human collaboration: allowing the human to more fluidly control the machine process; and also allowing the human to understand the results, derive insights and continue the analytic cycle. We also consider system and algorithmic implications to enable real-time control and feedback in immersive human-centered computational analytics.

5.4 Design Considerations for Immersive Data-Driven Narratives

Maxime Cordeil, Mark Hancock, Petra Isenberg, Bongshin Lee, Todd Margolis, Steffen Oeltze-Jafra, Huamin Qu, and Chris Weaver

We discuss design considerations for experiencing immersion when interacting with data-driven narratives. By immersion we refer to moments during a data analysis where participants feel a deep cognitive, perceptual and/or emotional involvement with data. Immersion in related media such as books, films and music has been studied extensively in social sciences and psychology. Our design considerations for immersive data-driven narratives build on these studies. We elaborate on the potential of immersive data-driven narratives by analyzing multiple case studies according to our considerations.

5.5 Situated Analytics

Pierre Dragicevic, Barrett Ens, Niklas Elmqvist, Pourang Irani, Yvonne Jansen, Dieter Schmalstieg, Aurelien Tabard, Bruce H. Thomas, and Gregory F. Welch

People are increasingly becoming interested in understanding data associated with objects, locations, or persons in their everyday life. For example, imagine hunting for a house by walking through the neighborhood in which you want to live and basing your choice on social media posts in the area, census data, and traffic data over time, or imagine collaboratively reorganizing a factory floor for different machines and stations with a team of different experts by optimizing space, safety, and economical constraints based on past manufacturing data, power and ventilation requirements, worker preferences, past accidents, and legal concerns. For the first time both the technology – such as sensors, wearable displays, natural user interfaces, and augmented reality devices – as well as the data sources – such as dynamically updating social media, ubiquitous sensor information, and large-scale movement data – exist to make this vision a reality. In this chapter, we introduce the concept of situated analytics as the use of data representations organized in relation to relevant objects, places, and persons for the purpose of understanding, sensemaking, and decision-making. After defining this new concept, we characterize its components in greater detail, including the users, tasks, data, representations, interactions, and analytical processes involved in situated analytics. We then examine case studies of projects and products that exemplify situated analytics in action. Based on these case studies, we derive a set of design guidelines for building situated analytics applications, and finally outline a research agenda of challenges and research questions to explore in the future.

5.6 Multisensorial Representation and Interaction with Data

Jon McCormack, Benjamin Bach, Christophe Hurter, Kim Marriott, Takayuki Itoh, Carla das Sossas Freitas, and Jonathan Roberts

This chapter explores opportunities and challenges for developers and users to utilize and represent data through many sensory channels for the purpose of understanding and interacting with data. While visual cues are traditionally used for visual analytics, immersive multimodal analytics offers many opportunities. Users are able to view the data in new ways, variables from complex datasets can be represented through different senses, presentations are more accessible and can be personalized to specific user needs, interactions can involve many senses to provide natural and transparent methods, all these techniques enable users to obtain a better understanding of the underlying information. While the emphasis of this chapter is towards non-visual immersive analytics, we do discuss how visual presentations are integrated with different modalities, and the opportunities of mixing several sensory signals, especially including the visual domain.

5.7 Challenges in Evaluating Immersive Analytics

Petra Isenberg, Mark Hancock, Bongshin Lee, Roland Fernandez, Carla Freitas, and Tobias Isenberg

We consider questions surrounding how we can advance the science of Immersive Analytics through rigorous hypothesis testing and the challenges for doing so. For example: *Immersion as a phenomenon we can assess through measurement? Use a grounded theory approach to understanding it? If we want to measure immersion – what are the metrics?*

In the end it was decided that this should not be a separate chapter but that the ideas and considerations should be rolled-in to other chapters throughout the book.

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Report from Dagstuhl Seminar 16232

Fair Division

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 16232 "Fair Division". The seminar was composed of technical sessions with regular talks, and discussion sessions distributed over the full week.

Seminar June 5–10, 2016 – http://www.dagstuhl.de/16232
1998 ACM Subject Classification I.2.11 Distributed Artificial Intelligence
Keywords and phrases cake cutting, computational social choice, envy-freeness, fair division
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Edited in cooperation with Nhan-Tam Nguyen

1 Executive Summary

Yonatan Aumann
Steven J. Brams
Jérôme Lang
Ariel D. Procaccia

Fair division has been an active field of research in economics and mathematics for decades. More recently, the topic has attracted the attention of computer scientists, due to its algorithmic nature and its real-world applications. There had been a first Dagstuhl Seminar on fair division, in 2007, and none since. The aim of the 2016 Dagstuhl seminar on fair division was to bring together top researchers in the field, from among the multiple disparate disciplines where it is studied, both within computer science and from economics and mathematics, to share knowledge and advance the state of the art.

The seminar covered fair division of both divisible and indivisible goods, with a good mix between economics and computer science (with a significant number of talks being about economics *and* computer science). Topics included algorithms, lower bounds, approximations, strategic behavior, tradeoffs between fairness and efficiency, partial divisions, alternative definitions of fairness, and practical applications of fair division. The ratio between the number of participants with a main background in computer science and in economics was about 3–1, with a couple of participants with another main background (mathematics or political science). This ratio is similar to the corresponding ratios for Dagstuhl seminars on computational social choice (2007, 2010, 2012, 2015).

The seminar started by a short presentation of the participants (3 minutes per attendee). The rest of the seminar was composed of technical sessions with regular talks, and discussion sessions distributed over the full week (Tuesday morning, Tuesday afternoon, Wednesday morning, Friday morning). One of these discussion sessions was specifically about *Fair division in the real world*, two were about open problems, and one was about high-level thoughts about the topic and its future. Moreover, there was a significant amount of time left for participants to interact in small groups.

2 Table of Contents

3 Overview of Talks

3.1 A discrete and bounded envy-free cake cutting protocol for any number of agents

Haris Aziz (Data61 / NICTA – Sydney, AU) and Simon William Mackenzie (UNSW – Sydney, AU)

Main reference H. Aziz, S. Mackenzie, "A Discrete and Bounded Envy-Free Cake Cutting Protocol for Any Number of Agents", arXiv:1604.03655v10 [cs.DS], 2016.
URL http://arxiv.org/abs/1604.03655v10

We consider the well-studied cake cutting problem in which the goal is to find an envy-free allocation based on queries from n agents. The problem has received attention in computer science, mathematics, and economics. It has been a major open problem whether there exists a bounded and discrete envy-free protocol. We resolve the problem by proposing a discrete and bounded envy-free protocol for any number of agents. The maximum number of queries required by the protocol is a power tower of n of order six. We additionally show that even if we do not run our protocol to completion, it can find in at most n^{n+1} queries a partial allocation of the cake that achieves proportionality (each agent gets $\frac{1}{n}$ of the value of the whole cake) and envy-freeness. Finally we show that an envy-free partial allocation can be computed in n^{n+1} queries such that each agent gets a connected piece that gives the agent $\frac{1}{3n}$ of the value of the whole cake.

3.2 Complexity of Manipulating Sequential Allocation

Haris Aziz (Data61 / NICTA – Sydney, AU), Sylvain Bouveret (LIG – Grenoble, FR & Université Grenoble-Alpes, FR), Jérôme Lang (University Paris-Dauphine, FR), and Simon William Mackenzie (UNSW – Sydney, AU)

Joint work of Haris Aziz, Sylvain Bouveret, Jérôme Lang, Simon William Mackenzie
Main reference H. Aziz, S. Bouveret, J. Lang, S. Mackenzie, "Complexity of Manipulating Sequential Allocation," arXiv:1602.06940v1 [cs.GT], 2016.
URL http://arxiv.org/abs/1602.06940v1

Sequential allocation is a simple allocation mechanism in which agents are given pre-specified turns and each agents gets the most preferred item that is still available. It has long been known that sequential allocation is not strategyproof. This raises the question about the complexity of computing a preference report that yields more additive utility than the truthful preference. We show that is NP-complete. In doing so, we show that a previously presented polynomial-time algorithm for the problem is not correct. We complement the NP-completeness result by two algorithmic results. We first present a polynomial-time algorithm for optimal manioulation when the manipulator has Boolean utilities. We then consider stronger notions of manipulation whereby the untruthful outcome yields more utility than the truthful outcome for all utilities consistent with the ordinal preferences. For this notion of manipulation, we show that there exists a polynomial-time algorithm for computing a manipulation.

3.3 Nash Social Welfare Approximation for Strategic Agents

Simina Brânzei (The Hebrew University of Jerusalem, IL), Vasilis Gkatzelis (Stanford University, US), and Ruta Mehta

Main reference S. Brânzei, V. Gkatzelis, R. Mehta, "Nash Social Welfare Approximation for Strategic Agents," arXiv:1607.01569v1 [cs.GT], 2016.
URL http://arxiv.org/abs/1607.01569v1

The fair division of resources among strategic agents is an important age-old problem that has led to a rich body of literature. At the center of this literature lies the question of whether there exist mechanisms that can implement fair outcomes, despite the agents' strategic behavior. A fundamental objective function used for measuring fair outcomes is the *Nash social welfare* (NSW), mathematically defined as the geometric mean of the agents' values in a given allocation. This objective function is maximized by widely known solution concepts such as Nash bargaining and the competitive equilibrium with equal incomes.

In this work we focus on the question of (approximately) implementing this objective. The starting point of our analysis is the Fisher market, a fundamental model of an economy, whose benchmark is precisely the (weighted) Nash social welfare. We study two extreme classes of valuations functions, namely perfect substitutes and perfect complements, and find that for perfect substitutes, the Fisher market mechanism has a constant price of anarchy (PoA): at most 2 and at least $e^{\frac{1}{e}}$ (≈ 1.44). However, for perfect complements, the Fisher market mechanism has an arbitrarily bad performance, its bound degrading linearly with the number of players.

Strikingly, the Trading Post mechanism – an indirect market mechanism also known as the Shapley-Shubik game – has significantly better performance than the Fisher market on its own benchmark. Not only does Trading Post attain a bound of 2 for perfect substitutes, but it also implements almost perfectly the NSW objective for perfect complements, where it achieves a price of anarchy of $(1 + \epsilon)$ for every $\epsilon > 0$. Moreover, we show that all the equilibria of the Trading Post mechanism are pure (so these bounds extend beyond the pure PoA), and satisfy an important notion of individual fairness known as proportionality.

3.4 Equitable cake cutting

Katarina Cechlarova (Pavol Jozef Safarik University – Kosice, SK)

Joint work of Katarina Cechlarova, J. Dobos, E. Pillarova

The cake is represented by real interval [0,1] and each of n playes has her valuation of the cake in the form of a nonatomic probability measure. We look for equitable divisions, i.e. such that the values received by players by their own measures are equal, and everybody gets one contiguous piece. We show that such divisions always exist but they cannot be computed by a finite algorithm. Therefore we propose a simple algorithm to find approximately equitable divisions.

3.5 The Power of Swap Deals in Distributed Resource Allocation

Yann Chevaleyre (University of Paris North, FR)

Joint work of Y. Chevaleyre, A. Damamme, A. Beynier, N. Maudet

In the simple resource allocation setting consisting in assigning exactly one resource per agent, the top trading cycle procedure stands out as being the undisputed method of choice. It remains however a centralized procedure which may not well suited in the context of multiagent systems, where distributed coordination may be problematic. In this paper, we investigate the power of dynamics based on rational bilateral deals (swaps) in such settings. While they may induce a high efficiency loss, we provide several new elements that temper this fact: (i) we identify a natural domain where convergence to a Pareto-optimal allocation can be guaranteed, (ii) we show that the worst-case loss of welfare is as good as it can be under the assumption of individual rationality, (iii) we provide a number of experimental results, showing that such dynamics often provide good outcomes, especially in light of their simplicity, and (iv) we prove the NP-hardness of deciding whether an allocation maximizing utilitarian or egalitarian welfare is reachable.

3.6 Dividing homogeneous divisible goods among three players

Marco Dall'Aglio (LUISS Guido Carli – Rome, IT)

Joint work of Marco Dall'Aglio, Camilla Di Luca, Lucia Milone
Main reference M. Dall'Aglio, C. Di Luca, L. Milone, "Characterizing and Finding the Pareto Optimal Equitable Allocation of Homogeneous Divisible Goods Among Three Players," arXiv:1606.01028v1 [math.OC], 2016.
URL http://arxiv.org/abs/1606.01028v1

We consider the division of a finite number of homogeneous divisible items among three players. Under the assumption that each player assigns a positive value to every item, we characterize the optimal allocations and we develop two exact algorithms for its search. Both the characterization and the algorithm are based on the tight relationship two geometric objects of fair division: the Individual Pieces Set (IPS) and the Radon-Nykodim Set (RNS).

3.7 Price of Pareto Optimality in Hedonic Games

Edith Elkind (University of Oxford, GB)

Joint work of Edith Elkind, Angelo Fanelli, Michele Flammini

Price of Anarchy measures the welfare loss caused by selfish behavior: it is defined as the ratio of the social welfare in a socially optimal outcome and in a worst Nash equilibrium. A similar measure can be derived for other classes of stable outcomes. In this paper, we argue that Pareto optimality can be seen as a notion of stability, and introduce the concept of Price of Pareto Optimality: this is an analogue of the Price of Anarchy, where the maximum is computed over the class of Pareto optimal outcomes, i.e., outcomes that do not permit a deviation by the grand coalition that makes all players weakly better off and some players strictly better off. As a case study, we focus on hedonic games, and provide lower and upper bounds of the Price of Pareto Optimality in three classes of hedonic games: additively separable hedonic games, fractional hedonic games, and modified fractional hedonic games; for fractional hedonic games on trees our bounds are tight.

3.8 Approximating the Nash Social Welfare

Vasilis Gkatzelis (Stanford University, US), Simina Brânzei, Richard Cole, Gagan Goel, and Ruta Mehta

We study the problem of allocating a collection of items among a set of agents with the goal of maximizing the geometric mean of their utilities, i.e., the Nash social welfare. We consider both the computational tractability of this problem as well as the issues that arise when the participaring agents behave strategically, aiming to maximize their own utility.

When the items are divisible, the problem of maximizing the Nash social welfare is known to be computationally tractable, so we focus on the strategic interactions among the agents that arise when their preferences are private. We first analyze the efficiency of simple mechanisms in terms of their price of anarchy using the Nash social welfare measure. That is, we study the ratio of the optimal Nash social welfare for a given instance and the Nash social welfare at the worst Nash equilibrium, and we prove upper and lower bounds for this ratio [3]. Furthermore, we design novel mechanisms that achieve strategy-proofness by keeping some of the items unallocated. We show that these mechanisms combine strategy-proofness with a good approximation of the optimal Nash social welfare [2].

When the items are indivisible, the problem of maximizing the Nash social welfare becomes APX-hard, even when the valuations of the agents are additive. Our main result is the first efficient constant-factor approximation algorithm for this objective. We first observe that the integrality gap of the natural fractional relaxation is exponential, so we propose a different fractional allocation which implies a tighter upper bound and, after appropriate rounding, yields a good integral allocation [1].

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3 Simina Brânzei and Vasilis Gkatzelis and Ruta Mehta, Nash Social Welfare Approximation for Strategic Agents. arxiv (http://arxiv.org/abs/1607.01569) 2016

3.9 Matroids and Allocation of Indivisible Goods

Laurent Gourves (University Paris-Dauphine, FR)

Joint work of Laurent Gourves, Carlos A. Martinhon, Jerome Monnot, Lydia Tlilane

We propose an extension of the allocation of indivisible goods to matroids in the sense that the agents get elements that form a base of a matroid. We present some exchange properties that can be used for a matroid extension to MMS and the Cut and Choose protocol, together with an expansion of a matroid that helps to maximize the utilitarian social welfare, with upper bounds on the number of elements that each agent receives.

3.10 The redesign of the Israeli medical internship lottery

Avinatan Hassidim (Bar-Ilan University – Ramat Gan, IL)

Joint work of Arnon Afek, Noga Alon, Slava Bronfmann, Avinatan Hassidim, Assaf Romm

Acquiring an Israeli m.d. requires performing an internship in one of the hospitals in Israel. In the past, interns were assigned using a variant of Random Serial Dictatorship. We redesigned the market to use a proprietary algorithm achievement a benefit in satisfaction.

3.11 Procedural Justice in Simple Bargaining Games

Dorothea Herreiner (Loyola Marymount University, US)

Giving an affected person some control in a decision-making process generally increases the satisfaction with the outcome because participation contributes to procedural justice. Empowering a receiver in a simple bargaining game by providing the option to reject a proposal (ultimatum game) instead of imposing a proposal (dictator game) leads to more equitable outcomes as Shor (2007) shows. Whether empowerment itself matters, i.e. the fact that the receiver can influence outcomes, or the implicit recognition by the proposer that the receiver is disadvantaged, i.e. the intention behind the empowerment, remains an open questions addressed in this experimental study. Several variants of Shor's empowerment game (choice between ultimatum and dictator game) are considered where the choice to empower the receiver is made by the proposer, randomly, or a third party. Significant differences emerge between proposals depending on the empowerment of the receiver and in the frequency with which the receiver is empowered; the intentionality behind the empowerment decisions, however, does not seem to make a significant difference.

3.12 Inheritance Game

Mehmet Ismail (Maastricht University, NL)

A couple delegates a person, D, to divide a cake (their inheritance) of unit length among their children, players A and B. Players are in separate rooms and each have half of the cake on the table in front of them. Each chooses (e.g., by cutting) a piece from the cake, $[0, 1/2]$. The rules are as follows:

1. If some of the players disagree with the rules, nobody will receive anything. The choice 0 expresses disagreement.
2. Otherwise, players receive their own piece. And, if there is some piece left from either player, D will pay each an extra 1 unit of money (as he'd like to taste the cake and convince them to agree with this rule).

The unique Nash equilibrium is $(0, 0)$, which resembles a Bertrand duopoly outcome since 0 is weakly dominated by any strategy. Unlike in the duopoly game, however, all strategies but $1/2$ are dominated. Thus, the only undominated strategy profile is $(1/2, 1/2)$, which is also the unique maximin equilibrium [1]. Each has a profitable deviation from this profile, but the deviator would receive a smaller piece than the non-deviator, which gives incentives to free ride on the deviators: a social dilemma situation.

References

1 Mehmet Ismail. *Maximin Equilibrium: A Minimal Extension of Maximin Strategies*. 2014.

3.13 Making the Rules of Sports Fairer

Mehmet Ismail (Maastricht University, NL) and Steven J. Brams

Main reference S. J. Brams , M. S. Ismail , "Making the Rules of Sports Fairer," SSRN, 2016.
URL http://dx.doi.org/10.2139/ssrn.2737672

In the beginning of my presentation, I ran a mini tournament on Catch-Up [1], which is a two-person game in which players alternate removing numbers from an initial set $\{1, 2, \ldots, n\}$. Players begin with scores of 0, and the acting player removes numbers (which are added to his score), one by one, until his score *equals* or *exceeds* the opponent's score. If the scores are tied, the game is drawn; otherwise, the player with the higher score wins.

I then presented "Making the Rules of Sports Fairer," which is a joint work with Steven J. Brams. In this paper, we argue that the rules of many sports are not fair – they do not ensure that equally skilled competitors have the same probability of winning. As an example, the penalty shootout in soccer, wherein a coin toss determines which team kicks first on all five penalty kicks, gives a substantial advantage to the first-kicking team, both in theory and practice. We show that a so-called Catch-Up Rule for determining the order of kicking would not only make the shootout fairer but also is essentially strategy proof. By contrast, the so-called Standard Rule now used for the tiebreaker in tennis is fair. We briefly consider several other sports, all of which involve scoring a sufficient number of points to win, and show how they could benefit from certain rule changes, which would be straightforward to implement.

References

1 Aaron Isaksen, Mehmet Ismail, Steven J. Brams, Andy Nealen. *Catch-Up: A Game in Which the Lead Alternates. Game & Puzzle Design* 1, no. 2:38–49. 2015.

3.14 Open Problems: Rules That Make Service Sports More Competitive

Mehmet Ismail (Maastricht University, NL), Steven J. Brams, D. Marc Kilgour, and Walter Stromquist (Swarthmore College, US)

The Standard Rule – presently used in badminton, racquetball, squash, and volleyball – says that the player who *won* the last point serves for the next point, whereas the so-called Catch-Up Rule says that the player who *lost* the last point serves for the next.

The open problem was that the probability of the first-serving player winning is the same under both Standard Rule and Catch-Up Rule, which was solved by Walter Stromquist, one of the participants at Dagstuhl Seminar.

3.15 Direct algorithms for balanced two-person fair division of indivisible items: A computational study

Marc Kilgour (Wilfrid Laurier University, CA) and Rudolf Vetschera

Direct algorithms for the balanced fair division of indivisible items between two persons are assessed computationally. Several algorithms are applied to all possible fair-division problems with 4, 6, 8, and 10 items to determine how well the algorithms do at achieving various fairness properties such as envy-freeness, Pareto-optimality, and maximinality.

3.16 Maximin Envy-Free Division of Indivisible Items

Christian Klamler (Universität Graz, AT), Steven J. Brams, and Marc Kilgour (Wilfrid Laurier University, CA)

Assume that two players have strict rankings over an even number of indivisible items. We propose two algorithms to find balanced allocations of these items that are maximin – maximize the minimum rank of the items that the players receive – and are envy-free and Pareto-optimal if such allocations exist. To determine whether an envy-free allocation exists, we introduce a simple condition on preference profiles; in fact, our condition guarantees the existence of a maximin, envy-free, and Pareto-optimal allocation. Although not strategy-proof, our algorithms would be difficult to manipulate unless a player has complete information about its opponent's ranking. We assess the applicability of the algorithms to real-world problems, such as allocating marital property in a divorce or assigning people to committees or projects.

3.17 What is the highest guaranteed maximin approximation?

David Kurokawa (Carnegie Mellon University – Pittsburgh, US)

Joint work of David Kurokawa, Ariel D. Procaccia, Junxing Wang

The maximin share guarantee is one of the few well-established notions of fairness in the setting of fairly dividing indivisible goods. Although believed to always exist, [Procaccia and Wang, Fair Enough: Guaranteeing Approximate Maximin Shares, EC 2014] showed that in very intricately constructed examples, the property is not guaranteeable – but were only able to demonstrate the absence in examples with high approximations to the maximin share guarantee. In the same work, they showed that a 2/3 approximation does always exist. This leads to a natural question of what is the highest guaranteed maximin approximation? We explore previous techniques of approximation and examine where they break down to improve the bound and also touch upon finding examples with worse guarantees.

3.18 Fair Division under Additive Utilities: good and bad news

Hervé J. Moulin (University of Glasgow, GB)

Joint work of Anna Bogomolnaia, Herve Moulin

Modern economic analysis mostly dismisses additive utilities that ignore complementarities between commodities. But recent work on the practical implementation of fair division rules in user-friendly websites (Spliddit, Adjusted Winner) gives a central role to this simple preference domain for compelling practical reasons, and brings back into sharp focus the 1959 results of Eisenberg and Gale on linear economies. Think of distributing the family heirlooms between siblings, splitting the assets of a divorcing couple, or allocating job shifts between substitutable workers: most people cannot form sophisticated preferences described by general utility functions, just like participants in a combinatorial auction do not form a complete ranking of all subsets of objects. Thus individual preferences are elicited by a simple bidding system: you distribute 100 points over the different goods, and these weights define your additive utility. The proof of the pudding is in the eating: thousands of visitors use these sites every month, fully aware that their bid is interpreted as their additive utility. Fairness as equal opportunities is achieved by the familiar Competitive Equilibrium with Equal Incomes. When dividing goods this rule is normatively compelling. Because it also maximizes the Nash product of utilities, it is unique utility-wise, continuous in the utility matrix, and easy to compute. It also guarantees that more manna to divide is never bad news for any participant (Resource Monotonicity), that by raising my bid on a certain good I cannot end up with a smaller share of that good (Responsive Shares), and that the size of my bids for the goods I do not eat is irrelevant (Independence of Lost Bids). The latter property is characteristic. When dividing bads, the Competitive Equilibria with Equal Incomes captures all the critical points of the Nash product of utilities, and is still characterized by Invariance of Lost Bids. It can be severely multi-valued: up to $2^{\min\{n,p\}} - 1$ distinct utility profiles with n agents and p goods. Moreover any single-valued efficient division rule attempting to implement equal opportunities faces two severe impossibility results: no such rule can be resource monotonic and guarantee the fair share; no such rule can be Envy-Free and continuous in the utility parameters. The fair division of bads is not a piece of cake.

3.19 Strategy-Proofness of Scoring Allocation Correspondences for Indivisible Goods

Nhan-Tam Nguyen (Heinrich-Heine-Universität Düsseldorf, DE)

Joint work of Nhan-Tam Nguyen, Dorothea Baumeister, Joerg Rothe
Main reference N. Nguyen, D. Baumeister, J. Rothe, "Strategy-Proofness of Scoring Allocation Correspondences for Indivisible Goods", in Proc. of the 24th Int'l Joint Conf. on Artificial Intelligence (IJCAI'15), pp. 1127–1133, AAAI Press, 2015.
URL http://ijcai.org/Abstract/15/163

We study resource allocation in a model due to Brams and King [1] and further developed by Baumeister et al. [2]. Resource allocation deals with the distribution of resources to agents. We assume resources to be indivisible, nonshareable, and of single-unit type. Agents have ordinal preferences over single resources. Using scoring vectors, every ordinal preference induces a utility function. These utility functions are used in conjunction with utilitarian social welfare to assess the quality of allocations of resources to agents. Then allocation correspondences determine the optimal allocations that maximize utilitarian social welfare.

Since agents may have an incentive to misreport their true preferences, the question of strategy-proofness is important to resource allocation. We assume that a manipulator has responsive preferences over the power set of the resources. We use extension principles (from social choice theory, such as the Kelly and the Gardenfors extension) for preferences to study manipulation of allocation correspondences. We characterize strategy-proofness of the utilitarian allocation correspondence: It is Gardenfors/Kelly-strategy-proof if and only if the number of different values in the scoring vector is at most two or the number of occurrences of the greatest value in the scoring vector is larger than half the number of goods.

References

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2. Baumeister D, Bouveret S, Lang J, Nguyen N, Nguyen T, Rothe J (2014) Scoring rules for the allocation of indivisible goods. In: Proceedings of the 21st European Conference on Artificial Intelligence, IOS Press, pp. 75–80

3.20 The Single-Peaked Domain Revisited: A Simple Global Characterization

Clemens Puppe (KIT – Karlsruher Institut für Technologie, DE)

Main reference C. Puppe, "The Single-Peaked Domain Revisited: A Simple Global Characterization," Manuscript, March 2016.
URL http://micro.econ.kit.edu/downloads/Charact-SP.pdf

It is proved that, among all restricted preference domains that guarantee consistency (i.e. transitivity) of pairwise majority voting, the single-peaked domain is the only minimally rich and connected domain that contains two completely reversed strict preference orders. It is argued that this result explains the predominant role of single-peakedness as a domain restriction in models of political economy and elsewhere. The main result has a number of corollaries, among them a dual characterization of the single- dipped domain; it also implies that a single-crossing ('order-restricted´) domain can be minimally rich only if it is a subdomain of a single-peaked domain. The conclusions are robust as the results apply both to domains of strict and of weak preference orders, respectively.

3.21 Preferences over Allocation Mechanisms and Recursive Utility

Uzi Segal (Boston College, US) and David Dillenberger

We deal with a simple problem: There are n units of two types that need to be allocated among n people, one per person. Preferences are stochastic. Each person prefers good 1 with probability q and good 2 with probability $1 - q$. These probabilities are independent across individuals. We analyze several allocation mechanisms with different levels of knowledge and show that:

1. Mechanisms may be identical from an ex-post point of view, but not ex-ante, as individuals are not indifferent between them.
2. Preferences over some well known mechanisms are linked to different forms of rejection and acceptance of ambiguity.
3. Both the well known top-cycle and serial-dictatorship mechanisms are inefficient.

3.22 Fair Division of Land

Erel Segal-Halevi (Bar-Ilan University – Ramat Gan, IL)

Joint work of Yonatan Aumann, Avinatan Hassidim, Shmuel Nitzan, Erel Segal-Halevi, Balazs Sziklai
URL http://erelsgl.github.io/topics/en/fairness/

The talk is a short summary of my Ph.D. research (2013–2016). The goal of this research is to apply cake-cutting algorithms for dividing land. I present several issues that have to be addressed.

1. Geometry: When dividing land, in contrast to cake, the two-dimensional geometric shape of the pieces is important.
2. Redivision: Dividing land, in contrast to cake, is an on-going process. Land often has to be re-divided. The re-division process should be fair both for the old and for the new agents.
3. Group ownership: The ownership of land, in contrast to cake, is often shared among several individuals, such as family members. Each of these members may have different preferences.
4. Land-value data: For land, in contrast to cake, there exist detailed value maps, which can be used to test the performance of cake-cutting algorithms.

3.23 Fairness and False-Name-Proofness in Randomized Allocation of a Divisible Good

Taiki Todo (Kyushu University – Fukuoka, JP), Yuko Sakurai, and Makoto Yokoo

Cake cutting has been recognized as a fundamental model for allocating a divisible good in a fair manner, and several envy-free cake cutting algorithms have been proposed. Recent works reconsidered cake cutting from the perspective of mechanism design and developed strategy-proof cake cutting mechanisms; no agent has any incentive to cheat them by misrepresenting her utility function. In this talk I consider a different type of manipulations; each agent might create fake identities to cheat the mechanism. Such manipulations have been called Sybils or false-name manipulations, and designing robust mechanisms against them, i.e., false-name-proof, is a challenging problem. I first present an impossibility result, which states that no false-name-proof mechanism simultaneously satisfies envy-freeness and Pareto efficiency. I then present a new mechanism that is optimal in terms of worst-case loss among those that satisfy false-name-proofness, strong envy-freeness, and a weaker efficiency property. To improve the efficiency, I also provide another mechanism that satisfies a weaker notion of false-name-proofness, as well as strong envy-freeness and Pareto efficiency. Furthermore, I give a short discussion on the effect of introducing agents' costs for managing fake accounts.

3.24 Deceased Organ Matching in Australia and New Zealand.

Toby Walsh (UNSW – Sydney, AU)

I discuss how we might match deceased organs to patients more effectively. One of the primary goals is to match the quality of the deceased organ and the patient due to the increasing age of donated kidneys. I formulate this as an online problem, discuss axiomatic properties and propose some novel mechanisms.

Participants

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Grenoble-Alpes, FR
- Simina Brânzei
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Report from Dagstuhl Seminar 16241

Graph Polynomials: Towards a Comparative Theory

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 16241 "Graph Polynomials: Towards a Comparative Theory".

The area of graph polynomials has become in recent years incredibly active, with new applications and new graph polynomials being discovered each year. However, the resulting plethora of techniques and results now urgently requires synthesis. Beyond catalogues and classifications we need a comparative theory. The intent of this 5-day Seminar was to further a general theory of graph polynomials.

Seminar June 12–17, 2016 – http://www.dagstuhl.de/16241

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1 Executive Summary

Jo Ellis-Monaghan
Andrew Goodall
Johann A. Makowsky
Iain Moffatt

The intent of this 5-day Seminar was to develop a general theory of graph polynomials. Graph polynomials have played a key role in combinatorics and its applications, having effected breakthroughs in conceptual understanding and brought together different strands of scientific thought. The characteristic and matching polynomials advanced graph-theoretical techniques in chemistry; the Tutte polynomial married combinatorics and statistical physics, and helped resolve long-standing problems in knot theory. The area of graph polynomials is incredibly active, with new applications and new graph polynomials being discovered each year. However, the resulting plethora of techniques and results now urgently requires synthesis. Beyond catalogues and classifications we need a comparative theory.

There is a long history in this area of results in one field leading to breakthroughs in another when techniques are transferred, and this Seminar leveraged that paradigm. More critically, experts in the field have recently begun noticing strong resonances in both results

Figure 1 *Above left*: J. Ellis-Monaghan, I. Moffatt, J. A. Makowsky. *Above middle*: A. Goodall, I. Moffatt. *Above right*: E. Gioan, B. Courcelle, B. Bollobás, J. Oxley, L. Kauffman, S. Backman. *Below left*: A. De Mier, N. Jonoska, L. McMahon. *Below middle*: J. Nešetřil, , K. Morgan, A. Goodall, I. Moffatt. *Below right*: The audience at large. Pictures courtesy J. A. Makowsky.

and proof techniques among the various polynomials. The species and genera of graph polynomials are diverse, but there are strong interconnections: the Seminar initiated work on creating a general theory that will bring them together under one family. The process of developing such a theory of graph polynomials should expose deeper connections, giving great impetus to both theory and applications. This has immense and exciting potential for all those fields of science where combinatorial information needs to be extracted and interpreted.

The Seminar provided conditions ripe for cross-fertilization of ideas among researchers in graph theory and topological graph theory, in logic and finite model theory, and in current biocomputing and statistical mechanics applications. During the Seminar the participants were offered a conspectus of the broad area of graph polynomials. The view was confirmed that a synthetic approach is needed in order to see the wood for the trees. The discussions and collaborations initiated at the workshop promise well for the development of a unified theory of graph polynomials. This Seminar represented a convincing beginning, and, hopefully, similar meetings in future will further the envisaged project.

In the light of our stated goals, the Seminar provided ample time for discussion groups and tutorials. The participants (44) of the Seminar included some of the leading experts in combinatorics, knot theory, matroid theory and graph polynomials from Europe, the Americas, Asia and Australia. The composition of participants was both age and gender balanced with a quarter of the participants being women. The younger researchers (more than a quarter of the participants) profited from intense contacts and discussions with their more experienced colleagues. An inspiring problem session brought about particular directions for further research.

2 Table of Contents

Open problems

3 Overview of Talks

3.1 Fourientations and the Tutte Polynomial

Spencer Backman (Universität Bonn, DE)

A fourientation of a graph G is a choice for each edge of the graph whether to orient that edge in either direction, leave it unoriented, or biorient it. I will describe a 12 variable expansion of the Tutte polynomial in terms of fourientation activities due to myself, Sam Hopkins, and Lorenzo Traldi, which specializes to known subgraph and orientation expansions. Time permitting, I will explain applications of this expression to the theory of zonotopes, hyperplane arrangements, chip-firing, and the reliability polynomial.

3.2 Which Graph Polynomials Have the Difficult Point Property?

Markus Bläser (Universität des Saarlandes, DE)

A class of graph polynomial has the difficult point property if for all graph polynomials G from this class, the following holds: If G is #P-hard to evaluate at one single point, then it is #P-hard to evaluate at (Zariski) almost all points. We present some rather general classes with the difficult point property and review some techniques how to prove that a class has the difficult point property.

3.3 Bill Tutte and His Polynomial

Béla Bollobás (University of Cambridge, GB & University of Memphis, US)

The influence of W.T. Tutte on our lives and on modern mathematics is hard to overestimate. In my brief talk I shall say a few words about Tutte's work during WWII, and his contribution to mathematics, with emphasis on his polynomial. In addition, I shall point out some of the many important extensions of this polynomial.

3.4 Introduction to Multimatroids and Their Polynomials

Robert Brijder (Hasselt University – Diepenbeek, BE)

Multimatroids have been introduced by Bouchet in a series of papers in the 1990s. Multimatroids generalize delta-matroids (which includes all matroids) and isotropic systems, and various interesting properties of these latter combinatorial structures carry over naturally to multimatroids. Unfortunately, the promising multimatroid theory has only scarcely been picked up by the community.

We give an introduction to multimatroids and give a general (multivariate) multimatroid polynomial that generalizes various well-known polynomials, such as the interlace polynomial, the Penrose polynomial, and the Tutte polynomial on the diagonal. We also show that various evaluations and recursive relations carry over to this general domain.

The multimatroid polynomial also generalizes the Martin polynomial of 4-regular graphs. We finally focus on the open problem of formulating a multimatroid version of the Martin polynomial of Eulerian graphs in general.

3.5 Tutorial: Aspects of the Characteristic Polynomial

Ada Sze Sze Chan (York University – Toronto, CA), Krystal Guo (University of Waterloo, CA), and Gordon Royle (The University of Western Australia – Crawley, AU)

In this session, we will discuss a number of our favourite techniques, results and open problems related to the characteristic polynomial.

Topics will include

(a) elementary spectral results relating the spectrum to graph properties (not covered in Monday's talk) and interlacing
(b) highly structured graphs such as strongly regular and distance regular graphs
(c) relationships between the characteristic polynomial and the walk-generating function of a graph

and others as determined by the intersection of the presenters' expertise and audience wishes.

3.6 An Introduction to the Theory of Matroids

Carolyn Chun (Brunel University London, GB) and James Oxley (Louisiana State University – Baton Rouge, US)

Matroids were introduced by Hassler Whitney in 1935 to provide a common framework for viewing dependence in linear algebra and graph theory. They arise naturally in optimisation as structures for which a greedy strategy always produces an optimal set. This talk will introduce matroids. It will discuss some well-known examples of these structures and some of their basic operations, and will conclude by addressing questions relating to matroids that are raised by the audience. No prior knowledge of matroid theory will be assumed.

3.7 Computations of Monadic Second-Order Definable Polynomials by Fly-Automata

Bruno Courcelle (University of Bordeaux, FR)

Most graph polynomials can be defined by monadic second-order (MSO) formulas. This is the case of the Tutte polynomial and the interlace polynomial. We take "defined" in a wide sense. In particular, if an integer value $f(G)$ attached to a graph is defined as the number of assignments (X, Y, Z) that satisfy an MSO formula phi(X,Y,Z) in graph G, it is "MSO-defined".

The MSO model-checking problem is FPT for tree-width, and even for clique-width in some cases, and so is the computation of $f(G)$ as above. Proofs can be given by constructions of finite automata that process algebraic terms describing the input graphs. However, these automata are inevitably huge and cannot be implemented by means of transitions tables. Fly-automata do not use such tables : their states are described (by finite words, according to some syntax) and their transitions are defined by "small" efficient programs. They overcome in many cases the "huge size problem". They can compute values, not only check membership. They can compute MSO definable graph polynomials.

The talk will show how these automata can be constructed from MSO formulas and report computer experiments.

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3 B. Courcelle, I. Durand: Computations by fly-automata beyond monadic second-order logic. Theor. Comput. Sci. 619: 32–67 (2016)

3.8 Transition Polynomials: Definitions, Properties, and Interrelations

Jo Ellis-Monaghan (Saint Michael's College – Colchester, US)

As deletion-contraction reductions are to edges, so are transition systems to vertices. The Tutte polynomial is the universal object for deletion-contraction invariants, while the generalised transition polynomial is universal for the wide variety of polynomials that are defined via recursions that involve transition systems at a vertex. This tutorial will give an overview of the defining properties and supporting algebraic structures for transition polynomials. We will review several examples such as the Martin polynomial, Kauffman bracket, Penrose polynomial, and topological transition polynomial, showing them to be specialisations of a universal generalised transition polynomial. We will conclude with connections among transition polynomials, deletion/contraction invariants, and even the interlace polynomial. We wish we knew how the Characteristic polynomial fit in among these interrelations.

3.9 Graph Polynomials: Some Questions on the Edge

Graham Farr (Monash University – Clayton, AU)

Any general theory of graph polynomials will include some functions on graphs and leave others out. We consider some questions about graph polynomials that may lie somewhere near the "edge" of what can be covered by a general theory.

3.10 Polynomials from Grassmannians

Alex Fink (Queen Mary University of London, GB)

Algebraic varieties provide a fertile source of "polynomial" invariants of matroids (and thus graphs), for instance by constructing their cohomology ring, or cohomology class in a larger object. We sketch a substantial part of a construction yielding the Tutte polynomial, while pointing out a few of the myriad variations on the approach.

3.11 Tutorial: Matroid Polytopes, Valuations, and Their Appearance in Algebraic Geometry

Alex Fink (Queen Mary University of London, GB)

Among the numberless axiom systems for matroids is one that presents them as certain 0-1 polytopes. I introduce these polytopes and their anatomy: several more familiar axiom systems are manifest in the polyhedral data. They make some generalisations of matroids natural, e.g. to polymatroids or delta-matroids. They also make it natural to consider a particular linear relation, "valuativity", which is quite obscured from more familiar points of view, but holds of the Tutte polynomial and at least a couple other polynomials from the literature. The universal invariant for valuativity is an understood object, and valuativity is also the property of these polytopes useful in my and Speyer's algebro-geometric construction of Tutte. As time permits I'll explain at least one of that construction and a more elementary one due to myself and Amanda Cameron based on lattice point enumeration.

3.12 On Six Tutte Polynomial Expressions for a Graph on a Linearly Ordered Set of Edges

Emeric Gioan (University of Montpellier & CNRS, FR)

I will present six interrelated general expressions for the Tutte polynomial of a graph, that are available as soon as the set of edges is linearly ordered, and that witness combinatorial properties of such a graph: the classical enumeration of spanning tree activities; its refinement into a four variable expression in terms of subset activities (that corresponds to the classical partition of the set of edge subsets into boolean intervals); the enumeration of orientation-activities for directed graphs; its refinement into a four variable expression in terms of subset orientation-activities (that corresponds to the partition of the set of orientations into active partition reversal classes); the convolution formula for the Tutte polynomial (that does not need the graph to be ordered); and an expression of the Tutte polynomial using only beta invariants of minors (that refines the above expressions). I will mention that these expressions are all interrelated by the underlying canonical active bijection between spanning trees and orientations, subject of a long-term joint work with Michel Las Vergnas.

3.13 Polynomial Graph and Matroid Invariants From Graph Homomorphisms

Andrew Goodall (Charles University – Prague, CZ)

The number of homomorphisms from a graph F to the complete graph K_n is the evaluation of the chromatic polynomial of F at n. Suitably scaled, this is the Tutte polynomial evaluation $T(F; 1-n, 0)$ and an invariant of the cycle matroid of F. Dual to colourings are flows. Tutte constructed his dichromate as a bivariate generalization of the chromatic polynomial and flow polynomial. The Tutte polynomial extends from graphs to matroids more generally.

Motivated by these observations I shall talk about the following questions, answering them in part and highlighting what remains open:

1. Which other graph polynomials arise from counting homomorphisms to the nth term of a sequence of graphs, like the chromatic polynomal from the sequence (K_n)?
2. Which of these yield a cycle matroid invariant? And which of these can be extended to a larger class of matroids closed under duality?

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2 A.J. Goodall, G. Regts and L. Vena Cros, Matroid invariants and counting graph homomorphisms. Linear Algebra Appl. 494 (2016), 263 –273. Preprint: arXiv:1512.01507 [math.CO]

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3.14 Non-Matroid Generalizations of the Tutte Polynomial

Gary P. Gordon (Lafayette College – Easton, US) and Liz McMahon (Lafayette College – Easton, US)

It is possible to imitate the corank-nullity definition of the Tutte polynomial to get a meaningful invariant for combinatorial structures that are not matroids. We explore these, concentrating on trees, rooted trees, and finite subsets of Euclidean space.

3.15 Algorithms for Computing the Tutte Polynomial

Thore Husfeldt (IT University of Copenhagen, DK)

I gave a brief survey of algorithms for computing the Tutte polynomial. The presentation was from the algorithmic perspective, so I focused the attention on computational complexity issues such as worst-case computation times. I sketched the constructions underlying total enumeration, deletion-contraction, and inclusion-exclusion algorithms and gave a brief analysis of their use for computational investigations. A brief connection was made to the current trend in computational complexity that attempts to establish a more fine-grained view of the hardness of NP-hard problems.

3.16 Graph Polynomials from DNA Rearrangements

Natasa Jonoska (University of South Florida – Tampa, US)

Joint work of Masahico Saito, Natasa Jonoska

Nucleotide rearrangements can be modelled by 4-regular rigid vertex graphs, called assembly graphs. They are closely related to double occurrence words, chord diagrams, and circle graphs. Edges of these graphs represent double-stranded DNA molecules, while vertices correspond to DNA recombination sites. Polynomial invariants related to the recombination processes of these assembly graphs are also invariants for circle graphs and chord diagrams. In addition we propose other variations of these invariants. These polynomial invariants are related to the possible products of the rearrangements modelled by the assembly graphs.

3.17 Introduction to Combinatorial Knot Polynomials

Louis H. Kauffman (University of Illinois – Chicago, US)

This talk is self-contained and will begin with an introduction to the bracket polynomial state sum model for the Jones polynomial. We will discuss how this combinatorial knot polynomial is related to the Tutte and to the dichromatic polynomial, the Temperley-Lieb algebra and the Potts model in statistical mechanics. We will discuss how the bracket state sum can be used to prove a number of results in knot theory such as the non-triviality of reduced alternating and adequate knots and links, and the existence of examples of non-trivial links with trivial Jones polynomial. We will then show how the bracket polynomial can be constructed as a state summation using solutions to the Yang-Baxter equation. This provides an entry into the general subject of quantum link invariants, knot polynomials constructed via solutions to the Yang-Baxter equation and via Hopf algebras.We will give a very quick introduction to Khovanov homology, based on the bracket polynomial. The talk will mention an important ancestor of these models – the Penrose state summation for counting colourings of planar graphs, and the speaker's solution to the problem of extending the Penrose structure to non-planar graphs. This will be sufficient material for a first talk. This will be a blackboard talk. It is intended as an introduction to these topics and to open problems related to them. Time permitting, we will discuss skein theory and the other skein polynomials and state sums related to them.

3.18 Tutorial: Khovanov Homology, Dichromatic Polynomial and the Potts Model

Louis H. Kauffman (University of Illinois – Chicago, US)

Khovavnov homology is a way of extracting topological information from the states of the bracket polynomial for a given knot or link via a chain complex associated with these states. If one regards the bracket polynomial as a relative of the Potts model (aka dichromatic polynomial with a physical parameter) (they live in the same parameter space of a generalized bracket that corresponds to a signed Tutte polynomial for the associated Tait graph for the link), then the loops in the states are boundaries of regions of constant spin in the Potts model. This suggests that geometric transitions between states obtained by site re-smoothing should be related to properties of the Potts partition function and that the Khovanov homology should have information relevant to the Potts models. This tutorial explores these questions. We show a direct correspondence with a quantum model and and indirect correspondence with the a Potts model at certain imaginary temperatures. The question is: How can we do better in understanding both the Potts model and the physical nature of Khovanov homology and its relationship with combinatorics.

3.19 Counting Walks and the Resulting Polynomial

Marsha Kleinbauer (TU Kaiserslautern, DE)

Counting the closed walks of length k in a graph G with n vertices is equivalent to finding the sum:

$$w_k \sum_{i=1}^{n} \lambda_i^k$$

where $\lambda_1, \lambda_2, \cdots, \lambda_n$ are the eigenvalues of G. It follows that $w_0 = n$, $w_1 = 0$, w_2 is two times the number of edges in G, and w_3 is six times the number of triangles in G. Extensions of these equations are presented. We present a method that uses generating functions to count certain types of closed walks in a graph.

3.20 4-Dimensional Discrete Ihara-Selberg Function and Binary Linear Codes

Martin Loebl (Charles University – Prague, CZ)

I will show how to write weight enumerator of a binary linear code as 4-dimension discrete Ihara-Selberg function.

3.21 Dichotomy Theorems for Generalized Chromatic Polynomials

Johann A. Makowsky (Technion – Haifa, IL)

Evaluation of the chromatic polynomial is easy on finitely many points, and #**P** hard everywhere else. We call this the difficult point property **DPP**. Let F be a graph property and k be a positive integer. A function $f : V(G) \to [k]$ is an F-coloring if for every $i \in [k]$ the set $f^{-1}(i)$ induces a graph in F. The author and Boris Zilber have shown in 2006 that counting F-colorings with k colors is a polynomial $P_F(G;k)$ in k. We show infinitely many examples of properties F, where **DPP** holds for $P_F(G;k)$, and formulate several conjectures, including also multivariate graph polynomials.

References

1 J. A. Makowsky and T. Kotek and E. V. Ravve, A Computational Framework for the Study of Partition Functions and Graph Polynomials, *Proceedings of the 12th Asian Logic Conference '11*, World Scientific (2013), pages 210–230.

3.22 Some Pictures

Johann A. Makowsky (Technion – Haifa, IL)

The pictures in the report abstract were made by J. A. Makowsky

3.23 Where Do Topological Tutte Polynomials Come From?

Iain Moffatt (Royal Holloway University of London, GB)

I'll give a brief introduction, focussing on how they arise, to the three versions of the Tutte polynomial for graphs in surfaces due to M. Las Vergnas (1978), B. Bollobás and O. Riordan (2001), and V. Krushkal (2012). In particular, I will show how each of these polynomials arises naturally and canonically from attempts to extend the recursive deletion-contraction definition of the Tutte polynomial to graphs in surfaces.

3.24 New Types of Chromatic Factorization

Kerri Morgan (Monash University – Clayton, AU)

The chromatic polynomial $P(G;\lambda)$ gives the number of ways a graph G can be coloured in at most λ colours. A graph G has a *chromatic factorisation* with *chromatic factors*, H_1 and H_2, if $P(G;\lambda) = P(H_1;\lambda) \times P(H_2;\lambda)/P(K_r;\lambda)$ where the chromatic factors have chromatic number at least r and K_r is the complete graph of order r. A graph is said to be *clique-separable* if it contains a clique whose removal disconnects that graph. It is well-known that any clique-separable graph has a chromatic factorisation. Morgan and Farr (2009) found graphs that are not clique-separable, nor *chromatically equivalent* to any clique-separable graphs, but factorised in the same way as clique-separable graphs. In all of these cases, the graphs have a factorisation that "behaves" like the factorisation of a clique-separable graph.

In this talk, we present new results on cases where the chromatic polynomial "factorises" but does not "behave" like the factorisation of clique-separable graphs. We give an infinite family of graphs that that have a chromatic factorisation that is "similar" to a clique-separable graph but one of the chromatic factors does **not** have chromatic number at least r. We also give examples of graphs that have chromatic polynomials $P(G;\lambda) = P(H_1;\lambda) \times P(H_2;\lambda)/P(D;\lambda)$ where D is **not** a complete graph.

3.25 Delta-Matroids

Steven Noble (Brunel University London, GB)

We describe Δ-matroids and their fundamental operations: minors, partial duality and loop complementation. We illustrate these concepts on ribbon graphs and binary Δ-matroids.

In particular for vf-safe Δ-matroids, we explain the 3 minor operations, twisted duality and their implications for Δ-matroid polynomials.

Finally we briefly mention a few new results such as chain and splitter theorems for 2 connected, even or vf-safe Δ-matroids, the 2-sum operation, characterising vf-safe Δ-matroids and counting labelled Δ-matroids.

3.26 Methods in the Study of Real Chromatic Roots

Thomas Perrett (Technical University of Denmark – Lyngby, DK)

Joint work of Carsten Thomassen, Thomas Perrett]

The chromatic polynomial is perhaps the best studied univariate graph polynomial, but many intriguing open problems remain unsolved. In particular the roots of the chromatic polynomial have attracted much attention, and the focus of many results in this subfield is to answer questions of the following type: For a class of graphs $\mathcal{G}$ and a set $D \subseteq \mathbb{C}$, let $R_D(\mathcal{G})$ denote the set of chromatic roots in D of graphs in $\mathcal{G}$. Can we characterise $\overline{R_D(\mathcal{G})}$? Such results are often attractive and surprising. Consider, for example, those of Sokal, Jackson, and Thomassen, which state that, if $\mathcal{G}$ denotes the family of all graphs, then $\overline{R_{\mathbb{C}}(\mathcal{G})} = \mathbb{C}$ and $\overline{R_{\mathbb{R}}(\mathcal{G})} = [32/27, \infty)$. On the other hand, $\overline{R_{\mathbb{R}}(\mathcal{P})}$ is still unknown if $\mathcal{P}$ denotes the planar graphs.

In this talk we promote a construction of Thomassen which, given a graph with certain properties, constructs a sequence of graphs with chromatic roots approaching a given real number. We show that this method is particularly easy to use if one is interested in minor-closed classes of graphs. Indeed, as an example, we show that $\overline{R_{\mathbb{R}}(\mathcal{P})}$ contains the interval $(3, 4)$, except for a tiny interval around $\tau + 2$, where $\tau \approx 1.618$ is the golden ratio. This constitutes a partial converse to a famous theorem of Tutte. Finally, we also discuss the limits of the construction and open problems for which it seems that a new technique is required.

3.27 Algebraic vs Graph Theoretic Properties of Graph Polynomials

Elena V. Ravve (ORT Braude College – Karmiel, IL)

Joint work of Johann A. Makowsky, Elena V. Ravve

Two graph polynomials are d.p.-equivalent (distinctive power equivalent) if they distinguish the same graphs. Graph theoretic properties are properties which are invariant under d.p.-equivalence. Algebraic properties are properties of the particular presentation of the graph polynomial and are not invariant under d.p.-equivalence. We exemplify this notion on the example of the location of the roots of a graph polynomial. Other properties are the unimodality of the coefficients, orthogonality of the polynomials for specific sequences of graphs, etc.

3.28 Deterministic Approximation Algorithms for the Tutte Polynomial, the Independence Polynomial and Partition Functions

Guus Regts (University of Amsterdam, NL)

Joint work of Alexander Barvinok, Viresh Patel, Guus Regts

In this talk I will discuss a general method that yields deterministic polynomial time approximation algorithms for evaluations of the Tutte and independence polynomial on bounded degree graphs as well as for partition functions of vertex- and edge-coloring models on bounded degree graphs. Ingredients of the method include: zero-free regions on bounded degree graphs, low order Taylor approximations of the logarithm of a polynomial and computations of coefficients of graph polynomials.

3.29 The Characteristic Polynomial of a Graph

Gordon Royle (The University of Western Australia – Crawley, AU)

The characteristic polynomial of a graph G is the characteristic polynomial of its adjacency matrix. While there are many different graph polynomials (chromatic, Tutte, matching etc), the characteristic polynomial is perhaps the most heavily studied of all, primaril y because the roots of the characteristic polynomial (i.e. the eigenvalues of its adjacency matrix) carry so much information about s tructure of the graph and its subgraphs. Indeed, a large proportion of the entire field of algebraic graph theory can be viewed as exp loring exactly which properties of graphs are, or are not, reflected in its spectrum.

In this talk, I will outline some of the main properties of the characteristic polynomial of a graph, but also introduce some of the i nteresting open questions that remain. As an example, it is not currently known whether or not almost all graphs are determined up to isomorphism by their characteristic polynomials.

3.30 Introduction to the Bipartition Polynomial and Its Relatives

Peter Tittmann (Hochschule Mittweida, DE)

Let $G = (V, E)$ be a finite simple undirected graph. The *open neighborhood* $N_G(v)$ of a vertex $v \in V$ is the set of all vertices that are adjacent to v in G. The *closed neighborhood* of v is $N_G(v) \cup \{v\}$. Analogously, we define

$$N_G(W) = \bigcup_{v \in W} N_G(v) \setminus W$$

and $N_G[W] = N_G(W) \cup W$ for any vertex subset $W \subseteq V$. For a given vertex subset $W \subseteq V$, let ∂W be the set of all edges of G with exactly one of their end vertices in W, i.e.

$$\partial W = \{\{u, v\} \in E \mid u \in W, v \in V \setminus W\}.$$

The *bipartition polynomial* of G, introduced in [2], is

$$B(G; x, y, z) = \sum_{W \subseteq V} x^{|W|} \sum_{F \subseteq \partial W} y^{|N_{(V,F)}(W)|} z^{|F|}.$$

We give different representations of this polynomial and show its relations to other graph polynomials, including the domination, Ising, cut, independence, Eulerian subgraph, and matching polynomial.

We will discuss the role of linear orderings of the edge set, a modified version of external activity and provide some open problems.

References

1 Markus Dod et al., Bipartition Polynomials, the Ising Model, and Domination in Graphs. Discussiones Mathematicae Graph Theory 35 (2015)2, pp. 335–353.

3.31 Recurrence Relations for Independence Polynomials in Hypergraphs

Martin Trinks (Nankai University – Tianjin, CN)

The independence polynomial of a hypergraph is the generating function for its independent (vertex) sets with respect to their cardinality. This talk aims to discuss several recurrence relations for the independence polynomial using some vertex and edge operations. Further, an extension of the well-known recurrence relation for simple graphs to hypergraphs is proven and other novel recurrence relations are given.

4 Open problems

4.1 The Open Problem Session

Andrew Goodall (Charles University – Prague, CZ) and Iain Moffatt (Royal Holloway University of London, GB)

Problems from the problem session of *Graph polynomials: towards a comparative theory*, Dagstuhl, Monday 13 June to Friday 17 June, 2016. Also from talks given by speakers during the week and submitted by other workshop participants.

4.2 Number of acyclic orientations and its relation to the size of the automorphism group

Spencer Backman (Universität Bonn, DE(

The following is conjectured:

Let G be a vertex-transitive simple graph. Then the number of acyclic orientations of G is at least equal to the size of the automorphism group of G, i.e.,

$$T(G;2,0) \geq |\mathrm{Aut}(G)|.$$

Furthermore, equality holds if and only if $G \cong K_n$.

4.3 Smallest ideal of graph mapping polynomial

Joanna Ellis-Monaghan (Saint Michael's College – Colchester, US)

Given a polynomial P mapping graphs to a commutative ring with unity R, what is the smallest ideal I of R such that graphs $\to R \to R/I$ is tractable to compute?

4.4 4-Colourability of matroid dual graphs (Hassler Whitney, 1993)

Graham Farr (Monash University– Clayton, AU)

A problem of Hassler Whitney from 1932.

Let G be a graph such that there exists a graph H with the property that $T(G^*;x,y) = T(H;x,y)$, where G^* is the matroid dual of G (a cographic matroid).

Are such graphs G 4-colourable?

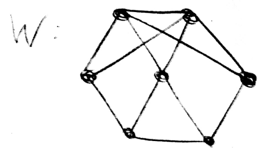
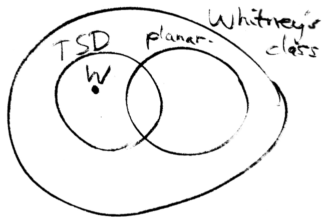


Figure 2 Whitney's example of a graph having a Tutte dual.



1. If G is planar then G^* is also a planar graph and we may take $H = G^*$.
2. A graph G is *Tutte self-dual* (TSD) if $T(G^*; x, y) = T(G; x, y)$, in which case we may take $H = G$.

4.5 Construction of a nice $\widehat{Q}(\Delta)$

Alex Fink (Queen Mary University of London, GB)

Let G be a connected bipartite graph and $V_{\mathrm{e}} \amalg V_{\mathrm{v}}$ its vertex set. A *hypertree* for G is the degree sequence in $Z^{|V_{\mathrm{e}}|}$ of some spanning tree of G (these form a *hypergraphic polymatroid*). Define the bivariate polynomial $Q(G; t, u)$ so that, when t and u are naturals,

$$
\begin{aligned}
Q(G; t, u) = \#\{p \in Z^{|V_{\mathrm{e}}|} : {} & p = a + b + c, \\
& a \text{ is a hypertree of } G, \\
& b_i \in Z_{\le 0},\ \sum_i b_i = -t, \\
& c_i \in Z_{\ge 0},\ \sum_i c_i = u\}.
\end{aligned}
$$

Ehrhart theory guarantees the existence of this polynomial. When all vertices in V_{e} are bipartite, then G is the barycentric subdivision of a graph H; in this case, hypertrees for G are in bijection with spanning trees for H, and $Q(G; t, u)$ contains the same information as $T(H; x, y)$. To wit, with Amanda Cameron we've shown that

$$
\sum_{t,u \ge 0} Q(G; t, u)\alpha^t \beta^u = \frac{T\left(H; \frac{1-\alpha\beta}{1-\beta}, \frac{1-\alpha\beta}{1-\alpha}\right)}{(1-\alpha)^{|V(H)-1|}(1-\beta)^{|E(H)-V(H)+1|}(1-\alpha\beta)}.
$$

Now let Δ be a three-coloured triangulation of the sphere. Then there are six ways to delete one colour class from Δ, leaving a bipartite graph G, and label the other two colour classes V_e and V_v. If V_e is colour i, V_v is colour j, and the deleted colour is k, let $Q_{ijk}(\Delta; t, u) = Q(G; t, u)$. These are interrelated. Firstly,

$$Q_{ijk}(\Delta; t, u) = Q_{ikj}(\Delta; u, t).$$

In the case where all vertices of colour i have degree 4, this is plane graph duality (in general, it's a polymatroid duality). Secondly, Kálmán and Postnikov have shown that

$$Q_{ijk}(\Delta; t, 0) = Q_{jik}(\Delta; t, 0).$$

This is all compatible with the existence of a trivariate polynomial $\widehat{Q}(\Delta; x_i, x_j, x_k)$ such that

$$\widehat{Q}(\Delta; 0, x_j, x_k) = Q_{ijk}(\Delta; x_k, x_j)$$

and such that permuting the colour classes of Δ permutes the variables of $\widehat{Q}(\Delta)$ in the corresponding way.
Problem: Construct a nice such $\widehat{Q}(\Delta)$.

4.6 $\mathrm{hom}(G, \mathrm{Cayley}(A_k, B_k))$

Andrew Goodall (Charles University – Prague, CZ)

Let A_k be an additive Abelian group and $B_k = -B_k \subseteq A_k$ an inverse-closed subset for each $k \in \mathbb{N}$. The graph $\mathrm{Cayley}(A_k, B_k)$ has vertices A_k and edges joining u and v precisely when $u - v \in B_k$.

- When $A_k = \mathbb{Z}_k$ and $B_k = \mathbb{Z}_k \setminus \{0\}$, $\mathrm{Cayley}(A_k, B_k) = K_k$ and $\mathrm{hom}(G, K_k) = P(G; k)$ is the chromatic polynomial of G evaluated at k.
- When $A_k = \mathbb{Z}_{sk}$ and $B_k = \{kr, kr+1, \ldots, k(s-r)\}$ then $\mathrm{hom}(G, \mathrm{Cayley}(A_k, B_k))$ is [1] a polynomial in k. (The minimum ratio s/r such that there exists a homomorphism from G to $\mathrm{Cayley}(\mathbb{Z}_s, \{r, r+1, \ldots, s-r\}$ is the *circular chromatic number* of G.)
- De la Harpe and Jaeger (1995) showed that when $A_k = \mathbb{Z}_k$ and $B_k = B/k\mathbb{Z}$ for some fixed $B = -B \subseteq \mathbb{Z}$ then $\mathrm{hom}(\mathbb{Z}_k, B_k)$ settles eventually to a fixed polynomial in k if and only if B is finite or cofinite. For example $\mathrm{hom}(G, C_k)$ $(B = \{-1, +1\})$ is a fixed polynomial in k only for $k > g(G)$.

Question: When is $\mathrm{hom}(G, \mathrm{Cayley}(A_k, B_k))$ a polynomial in $|A_k|$ and $|B_k|$? (The polynomial here depends on G, but must not depend on k.)

A motivation for this problem is that for each such graph polynomial counting B_k-tensions in A_k (equivalently, vertex A_k-colourings such that adjacent colours differ by an element in B_k) there is a dual graph polynomial counting B_k-flows, which together may be unified in a bivariate polynomial akin to the Tutte polynomial. Interest may then lie in what other combinatorial information is encapsulated in this bivariate polynomial. Also, is there a reduction formula analogous to the deletion-contraction recurrence for the chromatic polynomial?

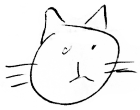
References

1 A. J. Goodall, J. Nešetřil and P. Ossona de Mendez, Strongly polynomial sequences as interpretations of trivial structures, J. Appl. Logic, to appear. Preprint: arXiv:1405.2449 [math.CO]

4.7 Tutte polynomials for matroids and their relationship to other graph polynomials

Joseph Kung (University of North Texas – Denton, US)

By an (n, r)-matroid we mean a rank r matroid with groundset of size n. The Tutte polynomial of an (n, r)-matroid has degree r as a polynomial in x and degree $n - r$ as a polynomial in y. The Tutte polynomials of such matroids span a subspace if $\mathbb{C}[x, y]$ and an upper bound for



$\dim\langle\, T(M; x, y) : M \text{ an } (n, r)\text{-matroid}\,\rangle$

is $(r + 1)(n - r + 1)$.

The dimension is in fact equal to $r(n - r) + 1$.

Problem: Answer the same question for other graph polynomials.

The dimension of the subspace spanned by the graph polynomial for graphs of given order and size serves as a measure of information contained in a graph polynomial: how useful is this way of measuring the combinatorial information contained in a given polynomial graph invariant?

4.8 The Frustration Conjecture

Martin Loebl (Charles University – Prague, CZ)

The Frustration Conjecture. Let $G = (V, E)$ be a graph, $w : E \to \{0, 1, -1\}$, and let there be given g disjoint pairs of edges $p_1, \ldots, p_g$. A perfect matching $M \subseteq E$ is a *parity matching* if $|M \cap p_i|$ is even for all i.

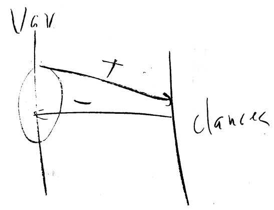
Is it true that there is no algorithm for finding a maximum weight maximum parity matching that has complexity better than 2^g?

Reference: M. Loebl, Parity matching, preprint, 2016. Available at: http://kam.mff.cuni.cz/~loebl/clanky/parityMatching0416.pdf

4.9 A polynomial related to the SAT-problem

Johann A. Makowsky (Technion – Haifa, IL)

Let C be a set of clauses and (V, C, R) a directed graph in which arcs (R) join variables (V) to clauses (C) with direction according to whether the variable is negated or not in the clause. (See figure, right.)



For $A \subseteq V$, define $\mathrm{SAT}(A) = \{c \in C : A \text{ satisfies } c\}$ and the SAT-polynomial in indeterminate X by

$$\sum_{A \subseteq V} \prod_{c \in \mathrm{SAT}(A)} X = \sum_{A \subseteq V} X^{|\mathrm{SAT}(A)|}.$$

Question: Is this polynomial useful to study the satisfiability problem SAT?

4.10 Independence polynomial of G (Alan Sokal, 2001)

Guus Regts (University of Amsterdam, NL)

A problem of Alan Sokal from 2001. Let $\Delta \in \mathbb{N}$ and let $Z_G(\lambda)$ denote the independence polynomial of G.

For $\epsilon > 0$ is there $\delta > 0$ such that the following holds? For each graph G of maximum degree at most Δ it holds that $Z_G(\lambda) \neq 0$ for λ satisfying

$$\mathrm{Im}(\lambda) < \delta,$$
$$0 \leq \mathrm{Re}(\lambda) \leq (1-\epsilon)\frac{(\Delta-1)^{\Delta-1}}{(\Delta-2)^{\Delta}}.$$

Note. It is known that $Z_G(\lambda) \neq 0$ if $|\lambda| \leq \frac{(\Delta-1)^{\Delta-1}}{\Delta^{\Delta}}$.

4.11 Tutte polynomials of medial graphs

William Whistler (Durham University, GB)

Are the Tutte polynomials of the medial graphs of different plane embeddings of a given planar graph identical?

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Report from Dagstuhl Seminar 16251

Information-centric Networking and Security

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Abstract

In recent years, Information-centric Networking (ICN) has received much attention from both academic and industry participants. ICN offers a data-centric means of inter-networking that is radically different from today's host-based IP networks. Security and privacy issues in ICN have become increasingly important as ICN technology gradually matures and nears real-world deployment. As is well known, in today's Internet, security and privacy features were originally not present and had to be incrementally and individually retrofitted (with varying success) over the last 35 years. In contrast, since ICN-based architectures (e.g., NDN, CCNx, etc.) are still evolving, it is both timely and important to explore ICN security and privacy issues as well as devise and assess possible mitigation techniques.

This report documents the program and outcomes of the Dagstuhl Seminar 16251 "Information-centric Networking and Security." The goal was to bring together researchers to discuss and address security and privacy issues particular to ICN-based architectures. Attendees represented diverse areas of expertise, including: networking, security, privacy, software engineering, and formal methods. Through presentations and focused working groups, attendees identified and discussed issues relevant to security and privacy, and charted paths for their mitigation.

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1 Executive Summary

Christopher A. Wood
Gene Tsudik

Dagstuhl seminar 16251 "Information-centric Networking and Security" was a short workshop held June 19–21, 2016. The goal was to bring together researchers with different areas of expertise relevant to ICN to discuss security and privacy issues particular to ICN-based architectures. These problems have become increasingly important as ICN technology gradually matures and nears real-world deployment.

Threat models are distinct from IP. Differentiating factors between the two include new application design patterns, trust models and management, as well as a strong emphasis on object-based, instead of channel-based, security. Therefore, it is both timely and important to explore ICN security and privacy issues as well as devise and assess possible mitigation techniques. This was the general purpose of the Dagstuhl seminar. To that end, the attendees focused on the following issues:

- What are the relevant threat models with which ICN must be concerned? How are they different from those in IP-based networks?
- To what extent is trust management a solved problem in ICN? Have we adequately identified the core elements of a trust model, e.g., with NDN trust schemas?
- How practical and realistic is object-based security when framed in the context of accepted privacy measures used in IP-based networks?
- Are there new types of cryptographic schemes or primitives ICN architectures should be using or following that will enable (a) more efficient or secure packet processing or (b) an improved security architecture?

The seminar answered (entirely or partially) some of these questions and fueled discussions for others. To begin, all participants briefly introduced themselves. This was followed by several talks on various topics, ranging from trust management and identity to privacy and anonymity. Subsequently, the attendees split into working groups to focus more intensely on specific topics. Working group topics included routing on encrypted names, ICN and IoT, non-privacy-centric aspects of ICN security, as well as trust and identity in ICN. Once the working group sessions were over, a representative from each presented outcomes to all attendees. (These are documented in the remainder of this report.) The major takeaways from the seminar were as follows.

First, the ICN community still does not have a clear answer for how to handle namespace and identity management. While trust management in ICN can be distributed and function without a global PKI, it seems difficult to break away from this model for namespace management and arbitration. This has strong implications on how names are propagated in the routing fabric. Can any producer application advertise any name, anywhere in the network? If not, how can name prefix advertisements be constrained or limited?

Second, given that ICN focuses on object security, the need for and use of transport protocols that provide forward secrecy should be deferred to higher layers. Attendees found that while most ICN-based architectures do not preclude forward secrecy, it should not be a requirement at the network layer.

Third, there is still deep uncertainty about whether ICN should embrace a content locator and identifier split. Names in architectures such as NDN and CCN serve as both a locator and identifier of data, though there are extensions that permit explicit locators (e.g., through the use of NDN LINK objects). This distinction is necessary under the common understanding that routing should concern itself with topological names. Finding data through non-topological names should not be in the data plane as part of the global routing space. However, if we revert to a distinction between topological locators and identifiers, then features unique to ICN become much more limited. One facet that is certainly unique to ICN is how software is written. Specifically, we have the opportunity to move beyond the mental model of a fixed address space and re-design existing network stacks and APIs.

Fourth, privacy seems difficult to achieve without major architectural changes to ICN-based systems. In particular, since data names reveal a great deal of information to the passive eavesdropper, privacy demands that names and payloads have no correlation. However, achieving this seems infeasible without the presence of an upper-layer service akin to one that would resolve non-topological identifiers to topological names.

Lastly, there are no compelling reasons to apply esoteric (and often untested) cryptographic techniques in ICN, at least at the network layer. Computationally bounded and “boring” cryptographic primitives, such as digital signatures, hash functions, etc., should be the extent of per-packet cryptographic processing done by routers. Anything more would become fodder for Denial-of-Service attacks that could render the entire infrastructure ineffective. However, architecture designs should not restrict themselves to specific algorithms. In other words, there must be flexibility in accommodating multiple (and evolving) cryptographic primitives. This could be useful if, for example, post-quantum digital signature schemes become necessary for the longevity of content authenticators.

We thank Schloss Dagstuhl for providing a stimulating setting for this seminar. Much progress was made over the course of the seminar and since its completion. This is mainly because of the ease of face-to-face collaboration and interaction at Dagstuhl.

2 Table of Contents

3 Overview of Talks

3.1 Threat Models for ICN

Ersin Uzun (Xerox PARC – Palo Alto, US)

IP-based networks helped to create today's world of content but was not designed for it. ICN attempts to move away from: (a) the communication model that is all about hosts and a point-to-point conversation between them, (b) the host-based central abstraction in the network, and (c) security problems of the current IP-based Internet architecture. The ICN emphasis on object security instead channel security is one step towards this transition. To quantify the degree by which security is improved, a thread model is needed. These threat models must be tailored toward the particular design challenge, such as infrastructure protection, user-friendly key distribution and trust management and enforcement, and content protection and access control. We discuss some necessary elements of threat models for these scenarios and suggest a strategy to use them in the ICN security design process.

3.2 Cryptographic Algorithms and Security Protocols for ICN

Christopher A. Wood (University of California – Irvine, US)

We present a survey of old and new cryptographic algorithms and security protocols with relevance to ICN packet processing, routing, and object security. Select topics include integrity and authenticity, privacy, and availability, as these are the main security goals of ICN-based architectures. The objective is to stimulate useful discussions about the characteristics and implementation of security services and properties that future ICN-based architectures might provide.

3.3 Violating Consumer Anonymity: Geo-locating Nodes in Named Data Networking

Mauro Conti (University of Padova, IT)

Talking about ICN privacy, we should not focus only on "what" (i.e., the content of a message) and "who" (i.e., the sender, or the receiver, of a message): we should also be worried about protecting "where", meaning the geographical position (or just the position within a network topology) where the message is originated from, or destined to. In fact (as shown in the ACNS'15 paper by Compagno et al. [1]), ICN caching and interest-collapse mechanisms make ICN itself inherently vulnerable to the possibility for an adversary to locate consumers. Interestingly, an approach similar to the one to violate consumer (location) privacy, might be used also to detect eavesdropper. Discussion questions included:

- Exactly what routing information is made available to routing-aware adversaries, and how useful is it to run attacks?
- By observing past traffic, can one infer where interests will be routed in the network?
- What capabilities does the adversary possess?
- How does this compare to similar attacks in IP?

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3.4 ABE in ICN

Ashish Gehani (SRI – Menlo Park, US)

The ENCODERS information-centric networking system was designed for publish-subscribe applications running over a mobile ad hoc network. It uses multi-authority attribute-based encryption to allow content access to be scoped to selected nodes in the system. Since the system is completely decentralized, peers serve as brokers that match content from publishers with interests expressed by subscribers. In order to perform such a match, an intermediate node must be authorized to see both the relevant content tags and subscriber interests. All of this has been described in a previous publication [1].

The talk described the following unpublished observation. The access control policies applied to the metadata (content tags and subscriber interests) effectively create reachability constraints that are independent from the one defined by the routing protocols. (This is because the access control defines which brokers can match and therefore route traffic.) Consequently, this security-routing interaction must be treated carefully during policy definition. We examined this empirically for a number of routing and access control policies.

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3.5 Project Origin: A peer-to-peer object store for CCN

Marc Mosko (Xerox PARC – Palo Alto, US)

Project Origin is a BitTorrent-like system that uses concepts of nameless objects and custodian routing to achieve a scalable, secure content distribution system. In this talk we present the initial design of Project Origin in the context of CCN.

3.6 In-Network Processing and Related Laws

Tohru Asami (University of Tokyo, JP)

The Internet has a history of adapting the existing law system to new business paradigms. One such paradigm is in-network processing, which, in recent years, has expanded to aid and impact routing, forwarding, packet replication, packet splitting and merging, quality of control, caching, and others. The relationship between these services and existing laws has been a continual tussle. When and how does caching affect copyright laws? When do other services violate the Secrecy of Correspondence (SoC) statute? Moreover, Deep Packet Inspection on SSL/TLS connections, while technically feasible, may violate the SoC statute and various other privacy rules. Thus, there has been a recent push for all-or-nothing secrecy, which unfortunately stifles network business opportunities. In this talk, we advocate for controllable privacy that allows secrecy preferences to be expressed in packet headers. We claim that ICN packet headers should be constructed to allow privacy and secrecy preferences to be expressed by their senders. This is one area where ICN can innovate to allow in-network processing to continue without violating existing laws.

4 Working groups

4.1 Names and Locators

Marc Mosko (Xerox PARC – Palo Alto, US)

This working group discussed locators and fetching data with non-topological names (or even topological names that are cached off-path). Routing should, it seems, only concern itself with topological names or addresses. Finding data (objects) with non-topological names should not be done in the data plane. It should be done via a service.

In CCN, the service could resolve a named root manifest to then resolve locator names by hash. In NDN, it resolves the link routing hints to allow off-path interest forwarding. In TagNet, there is a distinction between Locator names and Descriptor names. Locator names have a strong binding between their name and a point of attachment. Descriptor (hash) names, on the other hand, are free-form and could be present anywhere. One resolves a tag query (of either type) to a topological locator and then does data transfer on that locator.

This lead to a discussion on locator and identifier split. Should CCN embrace this, or continue on with its mixed use of the name? For example, if there is a clear locator field and then a clear identifier tuple (name, [keyed restriction], [hash restriction]), one would get full matching expressivity with the functionality of nameless object locators. A similar approach could be done in NDN, though with a different tuple. There was no consensus on this idea, though it is worth exploring.

There was also some discussion on the benefit of ICN if one still needs to do an external name to address lookup. Why bother if one still needs a DNS-like function? One partial answer is that in the non-global routing space (i.e., data center, maybe IoT, some internal applications), one could inject all names into the internal routing protocol and realize the full benefit of application-specific names. Another argument is that it improves how one writes software to not have to deal with IP addresses and host-based networking. One could also see benefits from a re-designed network stack beyond sockets.

4.2 ICN and IoT

Edith Ngai (Uppsala University, SE)

The Internet of Things (IoT) is connecting billions of smart devices (e.g., sensors) and is growing very fast. We expect more than 1 million networked "things" per square kilometer in 2030. In this group, we tried to explore how much data density we can afford and how we communicate with the "things" (say, directly to the sensors, or indirectly through the cloud or gateways). We discussed the potential of implementing ICN for the IoT. For instance, the ICN routers connecting to sensors can cache sensor data to improve the performance of data dissemination. Users can obtain data directly from the sensors and the ICN routers, without going through the cloud. This raised several security concerns:

- How are sensors securely configured at the time of initialization?
- How can software updates be performed securely?
- How can we handle ICN mobility for IoT? For example, each sensor may have a unique publisher identity. How do mobility and naming affect the scalability of routing?

We also discussed the potentials and concerns of caching data at the sensors. First, sensors are resource limited devices. However, memory resources may increase and the price will go down. Second, it is advantageous to retrieve data directly from the sensors in some use cases (e.g., to control home lighting without going through the cloud). Third, when using cryptography on sensors, the encryption time could be long and cause a delay in data retrieval. Lastly, sensors have to be always on to listen to the interests, which may consume a lot of energy. Scheduling or adaptive duty cycles might be considered to mitigate this.

Based on these observations, our summary and future plan is as follows. First, we plan to come up with sample IoT use cases, which allow us to understand more about the security needs and communication patterns in ICN for IoT. Second, we will aim at answering the following questions: How does IoT benefit from ICN? How does one securely configure and bootstrap sensors? And what is the cost of providing security for IoT data?

4.3 Security, Not Privacy

Craig Partridge (BBN Technologies – Cambridge, US) and Ghassan Karame (NEC Laboratories Europe – Heidelberg, DE)

The "No Privacy" security working group sought to answer the following question: is an ICN security architecture easier to devise if the designs fundamentally make privacy hard to achieve? In particular, the group discussed:

- What ICN entities (content consumers, hosts, routers, content creators) need identities?
- What entities can simply operate with a public and private key pair but no formal name?

- Does splitting routing out as an application help?
- Do interests need to be authenticated at each router?

The group achieved a simple security model. Members of the group hope to write up the result as a short paper.

4.4 Trust and Identity in ICN

Jan Seedorf (NEC Laboratories Europe – Heidelberg, DE & Hochschule für Technik – Stuttgart, DE), Kenneth L. Calvert (University of Kentucky – Lexington, US), and Christopher A. Wood (University of California – Irvine, US)

In an ideal ICN architecture, applications should be able to express their trust preferences or policies and let the "middleware" enforce them. This raises two important questions: (1) what is the minimum set of policies that can be factored out of all trust models, and (2) what is the middleware that does this enforcement? The trust schemas pioneered by the NDN architecture [1] are exemplary of the common rules that can be used to express most trust models. Among other things, they specify what keys are allowed to sign what data. Since both keys and data are named resources in NDN and other ICN architectures, this means that a schema allows for arbitrary hierarchical trust models. It remains to be seen if other non-hierarchical trust models will be applicable to ICN.

To address the second question, we had to agree upon what the network is responsible for enforcing. (This is discussed at length in [2].) First and foremost, network layer "trust enforcement" should not prohibit or prevent other application-layer trust models. This means that the network functionality must be simpler than that which is supported by the middleware. Currently, this is comprised of (at most) digital signature and content object hash verification. Behaviors such as certificate chain resolution or key retrieval should not be part of the core network functionality. This means that in the general "network," routers are only responsible for single signature or hash verification. All other network nodes (e.g., consumers and producers) contain the middleware responsible for handling the remaining trust enforcement steps.

After addressing network trust, we turned to identity and discussed the following major questions:

- How are names registered and managed in ICN?
- How can names possibly be location agnostic (without aids such as the NDN LINK)? Is there always a discovery or locator service?

Namespace ownership is intrinsically tied to identity. Thus, namespace advertisements under different namespaces or in different networks must be authenticated with respect to the claimed owner's identity. In this context, an identity is a public and private key pair. We struggled with issues about namespace scale and the practicality of a global namespace. Questions such as, "how do NATs work in a global namespace?," drove the discussion. No consensus or common understanding about how namespaces and identities should be managed was reached.

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4.5 Routing on Encrypted Names

Christopher A. Wood (University of California – Irvine, US), Edith Ngai (Uppsala University, SE), Jan Seedorf (NEC Laboratories Europe – Heidelberg, DE & Hochschule für Technik – Stuttgart, DE), and Matthias Wählisch (FU Berlin, DE)

This group started with a discussion about routing on encrypted names but ended up being an exploration of name privacy and the necessary conditions for it to be possible in different ICN architectures. In this context, we defined name privacy to be the property where a so-called "network name," i.e., the name encoded in a packet, has no correlation or connection with the corresponding content object. Specifically, name privacy means that a network name reveals nothing about the data inside the content object. Ideally, names should reveal no more than what is currently revealed by an IP address and port. After settling on this definition, we laid out our assumptions to use when discussing name privacy, including:

- There is no name discovery process or search engine.
- Content may be requested by an identifier (ID) such as its cryptographic hash digest. Moreover, revealing the content ID does not compromise privacy.
- Consumers know the public key of the producer with which they want to communicate.
- Network names have an implicit routable prefix and application-specific suffix. By default, consumers do not know the locator and identifier split in a name.
- Requests may specify the ID of (1) a signature verification key or (2) the expected content.

To begin, there are fundamentally two ways to request content: (1) with and (2) without a content ID. In case (1), a request name needs to only contain a routable prefix that will move the request to some cache or producer which can return the corresponding content. These locators can be completely separate from the desired content and, therefore, this approach can satisfy our name privacy goal. However, without implicit knowledge about the locator for some desired content, an upper-layer service is necessary to obtain said information.

In case (2), the application-specific suffix of a name must not reveal anything about the data. To achieve this, it must be encrypted. Name encryption introduces a number of other questions, such as how to obtain the routable prefix, what key to use for encryption, and how to "protect" the result. Assume that the routable prefix is known and that the producer public key is used for name suffix encryption. If the resultant content payload is not encrypted then one may be able to infer the name from its contents. Therefore, the content response itself must also be encrypted. This requires requests to carry a consumer-generated key that is protected in a CCA-secure envelope. Otherwise, eavesdroppers could replay requests with the same encrypted name but their own key to obtain a decrypted response.

In all cases, we concluded that to achieve name privacy then one needs some upper-layer service. Whether its role is to provide the routable prefix for a name, encrypt the response, or to separate a content ID and locator via some other means is an orthogonal discussion. Also, name privacy seems to, in most cases, invalidate the utility of shared caches, which puts it at odds with the primary feature of many ICN-based architectures. Thus, our conjecture is that name privacy is not possible natively in the network.

5 Open problems

5.1 Revisiting "Securing the Data Not The Pipe"

Marc Mosko (Xerox PARC – Palo Alto, US)

We revisit the question of securing the data, not the pipe. This has been the running mantra for security in ICN. Is forward secrecy possible in NDN and CCN group access control by encryption? Is the "take what you want" model of group access control, dependent on long-lived keys, realistic for future networks? Is it desirable? Also, is there any role for perimeter security or is encryption enough? In this talk, we pose these questions and others to the group to stimulate a wider discussion.

5.2 Forward Security in ICN?

Christopher A. Wood (University of California – Irvine, US)

Forward secrecy is the property that exposure of a principal's long-term secret keys does not compromise the secrecy of their previously generated ephemeral (session) keys. This is a useful property to have in the presence of eavesdropping attackers intercepting and logging traffic. It minimizes data and key compromise windows and therefore reduces the overall attack surface. However, it requires protocols and techniques for deriving ephemeral keys and then updating them regularly. The single request-response model of many ICN-based architectures does not lend itself to the establishment of forward secrecy without building a higher-layer protocol, such as CCNxKE [1], or involving more exotic cryptographic schemes. Consequently, the majority of work on ICN object security has ignored this property, which puts ICN at odds with best practice techniques used in IP-based protocols. In this talk, we seek to raise awareness of this issue and seek answers to the following important questions. First, under what conditions does transport security require forward secrecy? Second, can object encryption subsume transport security? And lastly, is forward secrecy in ICN needed?

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5.3 Whither ICN Privacy?

Gene Tsudik (University of California – Irvine, US)

What is the future of privacy for ICN? To what, or whom, is ICN privacy related? Existing architectures leak a significant amount of information by default, including: who requests information, whose information is requested, when content is requested, and other miscellaneous properties, e.g., data contents, name, size, etc. As of yet, we have not adequately addressed these privacy problems.

5.4 User-Generated Content in the FIB

Thomas C. Schmidt (HAW – Hamburg, DE)

ICN names are user-generated content in FIBs. In effect, FIBs serve as a (globally) replicated name set wherein any name owner can write into the set. The complexity of this state is influenced by the fact that prefix owners can always de-aggregate and create arbitrary names, even if prefixes are restrictively assigned. However, this raises questions of resource exhaustion attacks on FIBs and general complexity attacks (e.g., hash collisions). Newer attacks try to leak information from the FIB contents to target the forwarding plane. This talk outlines the severity of these problems in hopes of discussing potential solutions.

5.5 Motivating Transport Privacy for Data Structures

Christian Tschudin (Universität Basel, CH)

Beyond ICN packets, ICN programmers will generate linked data, e.g., FLIC [1]. We should provide techniques, services, and recipes for programmers that make transport privacy a trivial. Before doing so, however, we must first define what is transport privacy in the context of ICN.

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Report from Dagstuhl Perspectives Workshop 16252

Engineering Academic Software

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Perspectives Workshop 16252 "Engineering Academic Software".

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1 Executive Summary

Carole Goble
James Howison
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This Dagstuhl Perspectives Workshop brought together activists, experts and stakeholders on the subject of high quality software produced in an academic context.[1] Our current dependence on software across the sciences is already significant, yet there are still more opportunities to be explored and risks to be overcome. The academic context is unique in terms of its personnel, its goals of exploring the unknown and its demands on quality assurance and reproducibility.

We refer to the IEEE Internet Computing article "Better Software, Better Research" [1] which motivated the topic. In this workshop we took the following perspective of a research team which is in either or both of the following situations:

- consuming or producing software as *an output* of the academic process;
- consuming or producing software as *a component* of the research methods.

[1] We include any software which is part of either research processes and/or output, while excluding more generic administrative software for research and education management.

Society is now in the tricky situation where several deeply established academic fields (*e.g.*, physics, biology, mathematics) are shifting towards dependence on software, programming technology and software engineering methodology which are backed only by young and rapidly evolving fields of research (computer science and software engineering). Full accountability and even validity of software-based research results are now duly being challenged.

With the outputs of this interactive and productive perspectives workshop, we strive to contribute in a positive manner to the above challenges. We formulated taxonomies with definitions to clarify the domain, we co-authored concrete policy and process documents to improve the status and recognition of academic software development and academic software engineers, and finally we formulated a list of 18 concrete declarations of intent ("I will" pledges). This list was presented to the WSSSPE community [2] in September 2016 to acquire feedback and it will be the backbone of the Dagstuhl Manifesto document we are editing. It serves to motivate change by proposing policy changes with concrete actions and instilling positive attitudes towards academic software.

Participants. The participants of the workshop came from three major groups. The first group consists of active and visible members of the *global academic software engineering community*. They represent (formal) institutions such as the Software Sustainability Institute, the Software Carpentry Foundation, and eScience and data science centers from across the globe. The second group contributed researchers in *empirical software engineering*, with a specific eye on studying the principles and practices of academic software engineering. The final group contributed *researchers as an audience*: software engineering researchers with a long experience in engineering software for software itself or software for specific academic research fields.

We found that without exception the participants were strongly motivated and able to actively contribute to the proceedings of the workshop; the mix of people proved to be well-balanced. This balance is an accomplishment, given that invitees from computer science were far more likely to know of Dagstuhl workshops than other groups. To attest to our outcomes we've selectively listed three (paraphrased) verbal statements here:

- "The workshop was a transformational experience for me; I've learned an entire new perspective on my field and I intend to apply the insights in my daily practice."
- "I had an epiphany yesterday after dinner; now I understand how to connect the data science research at my university to the computer science department."
- "Before the workshop I had no idea so many initiatives were already underway in [improving] academic software engineering; this has given my understanding of the challenges a real boost and I know what the some of the next steps to take are."

Schedule. The schedule of the workshop was designed to maximize both interactive discussion and work towards tangible outputs. Key points were: to start the day with inspiring presentations to set the stage, then to have at least 40% of the day time allocated to free discussion time, and to explicitly share successes (output) of each day's breakout groups in a plenary session.

The workshop started on Monday with a quick and tightly timed round of 2 minute personal introductions. Otherwise on Monday, Tuesday and Thursday the program was structured equally: in the morning we would have plenary presentations which included exploratory discussions. These sessions were meant to bring everybody up-to-speed with ongoing and past initiatives. During and after lunch we used a board with sticky notes to define break-out groups. Each break-out group was centred around a specific discussion topic and (usually) a specific idea for an output document was associated with it. After coffee we would go back to the same break-out group to collaboratively record the notes and lessons from each group (stored in a shared online document). Between 17:00 and 18:00 we reconvened and harvested the results of each breakout group with the others. People could and did freely switch between breakout groups but this was not a common thing.

On Wednesday we had an "open-mic" session with 8 presentations of around 10 minutes, sharing experiences and results, before we had a long walk in the surroundings. The organizers also designed an initial skeleton structure and ideas for the manifesto that day.

On Thursday afternoon and Friday morning we all worked together on our Dagstuhl Manifesto by first reworking our notes into the ideas around the manifesto, specifically a list of "I will" pledges with references and motivation. Finally, Friday afternoon a small remaining group re-ordered the group's manifesto notes into a well-structured list of 18 pledges. Two of the organizers remained to continue to edit the current report and the manifesto document.

Output. Output documents of the workshop are organized under the "DagstuhlEAS" organisation on GitHub.[2] This currently features 6 draft documents, including the current report and (a) the manifesto, (b) the Research Software Engineering Handbook, (c) a Literature Survey, (d) a Taxonomy on Software Credit Roles, and (e) a Software Award Proposal. Next to these documents, an R&D project proposal was produced on measuring the impact of academic software.

The remainder of this document summarizes the morning sessions by listing the abstracts of each talk, the afternoon breakouts by describing each topic and its results, and finally the research questions on the topic of engineering academic software we have collected.

References

1. Carole Goble. Better software, better research. *IEEE Internet Computing*, 18(5):4–8, Sep 2014.
2. Alice Allen, Cecilia Aragon, Christophe Becker, Jeffrey C. Carver, Andrei Chis, Benoit Combemale, Mike Croucher, Kevin Crowston, Daniel Garijo, Ashish Gehani, Carole Goble, Robert Haines, Robert Hirschfeld, James Howison, Kathryn Huff, Caroline Jay, Daniel S. Katz, Claude Kirchner, Kateryna Kuksenok, Ralf Lämmel, Oscar Nierstrasz, Matthew Turk, Rob van Nieuwpoort, Matthew Vaughn, and Jurgen Vinju. Lightning talk: "I solemnly pledge" – a manifesto for personal responsibility in the engineering of academic software. In *Proceedings of the Fourth Workshop on Sustainable Software for Science: Practice and Experiences (WSSSPE4)*.

[2] https://github.com/DagstuhlEAS

2 Table of Contents

3 Overview of Talks

These are the talks presented in the morning sessions of the workshop, chronologically ordered.

3.1 Sustainable Software for Science

Daniel S. Katz (University of Illinois at Urbana-Champaign, USA)

Progress in scientific research depends on the quality and accessibility of research software at all levels. It is now critical to address many new challenges related to the development, deployment, maintenance, and sustainability of open-use research software: the software upon which specific research results rely. *Open-use software* means that the software is *widely accessible* (whether open source, shareware, or commercial). *Research software* means that the choice of software is *essential to specific research results*; using different software could produce different results.

In addition, it is essential that scientists, researchers, and students are able to learn and adopt a new set of software-related skills and methodologies. Established researchers are already acquiring some of these skills, and in particular, a specialized class of software developers is emerging in academic environments who are an integral and embedded part of successful research teams. WSSSPE[3] provides a forum for discussion of these challenges, including both positions and experiences, and a forum for the community to assemble and act.

This talk focused on the Third Workshop on Sustainable Software for Science: Practice and Experiences (WSSSPE3) [1]. It summarized the discussions, future steps, organization, and status of a set of self-organized working groups on topics including developing pathways to funding scientific software; constructing useful common metrics for crediting software stakeholders; identifying principles for sustainable software engineering design; reaching out to research software organizations around the world; and building communities for software sustainability. Some of these groups have executed these activities that they scheduled, some have in part, and others have not. A point of discussion was why these groups came to these points, and how the WSSSPE community can encourage groups to act.

References

1 Daniel S. Katz, Sou-Cheng T. Choi, Kyle E. Niemeyer, James Hetherington, Frank Löffler, Dan Gunter, Ray Idaszak, Steven R. Brandt, Mark A. Miller, Sandra Gesing, Nick D. Jones, Nic Weber, Suresh Marru, Gabrielle Allen, Birgit Penzenstadler, Colin C. Venters, Ethan Davis, Lorraine Hwang, Ilian Todorov, Abani Patra, and Miguel de Val-Borro. Report on the third workshop on sustainable software for science: Practice and experiences (WSSSPE3). *Journal of Open Research Software*, 4(1):e37, 2016.

[3] http://wssspe.researchcomputing.org.uk

3.2 Supporting Research Software Engineering

Mike Croucher (University of Sheffield, GB)

"Long Tail Science" – attributed to Jim Downing of the Unilever Centre for Molecular Informatics – refers to the large number of small research units that perform a huge amount of research. Much of this research involves the generation of code by relatively untrained and inexperienced programmers.

In this talk, Croucher described the challenges of working as a Research Software Engineer who supports these programmers using the University of Sheffield as a case study and introduced the efforts to build a community ("a union") of Research Software Engineers in the UK.[4]

3.3 Sustainability Design

Christoph Becker (University of Toronto, CA)

Sustainability – the "capacity to endure" – has emerged as a challenge with transformative impact on many disciplines and professions, including software engineering. It requires simultaneous consideration of at least five dimensions: environmental resources, social and individual well-being, economic prosperity, and long-term technical viability. This requires a cross-disciplinary approach to research and design that moves beyond narrow-minded solutionism. It emphasizes that "wicked problems" cannot easily be reduced to puzzle pieces. Systems thinking is needed as much as computational problem solving to achieve an integrated understanding of socio-technical systems. Shifts like that do not come easily, and for most systems, the hidden sustainability effects of past decisions in systems design are unknown. We can call this a system's "sustainability debt".

In this talk, Becker described how synergies across a range of disciplines united by the need for new design approaches focused on sustainability led to the Karlskrona Manifesto for Sustainability Design.[5] He characterized principles of sustainability design and the key influence of requirements activities on the sustainability debt of a system under design. He presented recent efforts to develop this area of research, including an interview study of software professionals, as a starting point to a discussion of barriers and opportunities for sustainability design research.

[4] http://www.rse.ac.uk/who.html
[5] http://www.sustainabilitydesign.org

3.4 What We Have Learned about Using Software Engineering Practices in Scientific Software

Jeffrey Carver (University of Alabama, USA)

The increase in the importance of Scientific Software motivates the need to identify and understand which software engineering (SE) practices are appropriate. Because of the uniqueness of the scientific software domain, existing SE tools and techniques developed for the business/IT community are often not efficient or effective. Appropriate SE solutions must account for the salient characteristics of the scientific software development environment. To identify these solutions, members of the SE community must interact with members of the scientific software community. In this presentation, Carver discussed the findings from a series of case studies of scientific software projects, an ongoing workshop series, and interactions between his research group and scientific software projects.

3.5 Lessons from the YT project

Matthew Turk (University of Illinois Urbana-Champaign, USA)

In this talk, Turk described the engineering practices, both social and technical, around the YT project.[6] He described the positive aspects and the failure modes, and how the YT team attempted to route around these failure modes.

3.6 Software as Academic Output

Caroline Jay and Robert Haines (The University of Manchester, GB)

Software is now considered to be an output of academic research in its own right: venues such as SoftwareX[7] and the Journal of Open Research Software[8] highlight it as a primary contribution, and the UK Research Council includes a software category in the ResearchFish[9] application used to collect the outcomes of research projects. This phenomenon is still fairly recent, however, and two questions arise when trying to determine the validity of – or, arguably, requirement for – software as a product of the research process: (i) when should it be considered an output, and (ii) what form should that output take?

To determine when software should be considered an output, we must consider its role in the research process. Is it a tool for supporting the work, or does it represent the research

6 http://yt-project.org
7 http://www.journals.elsevier.com/softwarex
8 http://openresearchsoftware.metajnl.com/
9 http://www.researchfish.com

itself? To a computer scientist in the field of workflow management, the software would be considered a direct output, integral to the research. To a biologist, this same software would be considered a tool: useful for analyzing results, but not in itself an output of the research. For a bioinformatician both using and developing the tool, the answer is somewhere in the middle: whilst the core research may be in the life science domain, the modifications made to the tool as a result of this work could also be considered an output, advancing workflow management.

If the software is integral to the research – and therefore a potential output – what form should that output take? The FAIRDOM project[10] supports computational research that is FAIR: Findable, Accessible, Interoperable, Reusable. We suggest a modified version of these principles can be usefully applied to software too: it should be Findable, Accessible, Reusable and Extensible. To be findable, software must be searchable and discoverable by others, preferably via a persistent identifier. Accessible software can be viewed and downloaded by others. Reusable software can be re-run, potentially with other input data. Finally, Extensible software can be modified or extended to deal with new situations; to achieve this, the source code should be available.

The FARE principles are a starting point for defining best practice, or the "gold standard" for academic software outputs. An exemplar of the application of these principles is described in the authors' recent paper, "ABC: Using Object Tracking to Automate Behavioural Coding" [1], published at the 2016 ACM CHI conference. The source code is openly available on GitHub, making it accessible and extensible, and both this and the software environment (in a Docker container), are identified by DOIs, making the software findable and reusable.

Following the FARE principles will help to ensure that software intended to be a primary output of research is fit for purpose. Applying them in any situation where software is developed as part of research – whether it is considered a primary output or not – is also recommended, to help ensure that the resulting research is robust and reproducible.

References

1 Aitor Apaolaza, Robert Haines, Amaia Aizpurua, Andy Brown, Michael Evans, Stephen Jolly, Simon Harper, and Caroline Jay. ABC: Using Object Tracking to Automate Behavioural Coding. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems – CHI EA'16*. Association for Computing Machinery (ACM), 2016.

3.7 Software Heritage

Claude Kirchner (Inria – Le Chesnay, FR)

In this talk Kirchner introduced the *Software Heritage* project leaded by Roberto Di Cosmo,[11] in the week just before its launch. A quote from the web site explains the concept and the goals:

"Software Heritage collects and preserves software in source code form, because

[10] http://fair-dom.org
[11] http://www.softwareheritage.org

software embodies our technical and scientific knowledge and humanity cannot afford the risk of losing it. Software is a precious part of our cultural heritage. We curate and make accessible all the software we collect, because only by sharing it can we guarantee its preservation in the very long term."

3.8 Software Metadata: Describing "Dark Software" in Geosciences

Daniel Garijo (Technical University of Madrid, ES)

In this talk Garijo provided an overview of the current state of the art for software description in Geosciences, along with an approach to facilitate this task in OntoSoft, a distributed semantic registry for scientific software.[12] Three key aspects of OntoSoft are: a software metadata ontology designed for scientists, a distributed approach to software registries that targets communities of interest, and metadata crowdsourcing through access control. Software metadata is organized using the OntoSoft ontology, designed to support scientists to share, document, and reuse software, and organized along six dimensions: identify software, understand and assess software, execute software, get support for the software, do research with the software, and update the software.

3.9 Organising a Research Team around the Research Software around the Research Team in Software Engineering

Jurgen J. Vinju (Centrum Wiskunde & Informatica, NL)

Vinju's talk was about the motivation, experiences and lessons learned around the SWAT research group at CWI and its core product used for research and transfer, the meta-programming language and platform, Rascal,[13] which is hosted from the open-source organisation Use The Source.[14]

3.10 Software Citation – Principles, Discussion, and Metadata

Daniel S. Katz (University of Illinois at Urbana-Champaign, USA)

Katz presented an overview of work done by the Force11 Software Citation Working Group[15] [1]. This work includes rationales for citing software, information on the WSSSPE

[12] http://www.ontosoft.org/portal/
[13] http://www.rascal-mpl.org
[14] http://www.usethesource.io
[15] https://www.force11.org/group/software-citation-working-group

and Force11 groups involved in developing software citation principles, and the process used to develop them. It also includes the six principles themselves:

1. the importance of software,
2. the need to credit and attribute the contributions software makes to research,
3. to be able to uniquely identify the cited software software,
4. that the identifiers and metadata about software should be persistent,
5. that citations should enable access to the software and associated information about the software that informs its use, and
6. that citations should facilitate identification of and access to the specific version of software that was used, such as by version number, revision numbers, or variants such as platforms.

The talk also provided practical information on how to semi-automatically take code on GitHub and publish it on Zenodo, obtaining a DOI that can then be cited.[16] Finally, the talk brought up a number of the ongoing discussions at the WSSSPE and Force11 working groups and their determinations, such as what software to cite, how to uniquely identify software, that peer-review of software is important but not required for citation, and how publishers can help.

References

1 Arfon M. Smith, Daniel S. Katz, Kyle E. Niemeyer, and FORCE11 Software Citation Working Group. Software citation principles. *PeerJ Computer Science*, 2:e86, September 2016.

3.11 Best Practices by Any Other Name

Katie Kuksenok (University of Washington – Seattle, USA)

This talk looked at intersections of the technical, social, and cognitive aspects of software engineering in research, and asked how the available community and skill resources could be leveraged. It brought together various elements raised throughout the workshop so far, including different roles that had been identified, the need for software engineers to learn from scientists just as we hope researchers learn software engineering practices, and overcoming communications barriers.

Kuksenok also provided a link to a short blog post summary with figures.[17]

[16] https://guides.github.com/activities/citable-code/
[17] Shortened URL to article at https://medium.com/hci-design-at-uw: https://goo.gl/Lxqrt5.

3.12 ASCL: Restoring Reproducibility – Making Scientist Software Discoverable

Alice Allen (University of Maryland – College Park, USA)

Allen presented an overview of the Astrophysics Source Code Library (ASCL)[18] and its history. She also discussed a few of the changes to the ASCL infrastructure, lessons learned from looking at what other astro code registries and repositories had done, what ASCL did with those lessons, and some of the impact ASCL has had on the community.

3.13 A Short (and Probably Incomplete) History of Research Software Engineers in the UK

Robert Haines (The University of Manchester, GB)

> "*Before software can be reusable it first has to be usable*" – Ralph Johnson, University of Illinois at Urbana-Champaign.

A growing number of people in academia combine expertise in programming with an intricate understanding of research. Although this combination of skills is extremely valuable, these people lack a formal place in the academic system; they are not academics with a personal research agenda. This means there is no easy way to recognize their contribution, to reward them, or to represent their views.

One of the largest obstacles to overcome in recognizing this group of people is that they are often "hiding" in their institutions under a myriad different job titles and roles: Post-Doc, Research Associate, System Administrator, Computer Officer, and so on. In the instance of Post-Docs and Research Associates it is often the case that these people suddenly find that they have written too much code, and not enough papers, and so they fall foul of the usual metrics used to evaluate them for promotion. Being the person in the lab who "knows about computers" can be detrimental to your career.

These topics came up frequently at the Software Sustainability Institute's Collaborations Workshop in 2012. At this "unconference" style event a number of us repeatedly found ourselves in sessions discussing career paths, credit, recognition, metrics and reward, for those of us working in academia, who weren't academics. Without a name, it is difficult for people to rally around a cause, so we created the term Research Software Engineer (RSE) to describe the intersection of "The Craftsperson and the Scholar".[19] RSEs are facilitative, supportive and collaborative; part of the academic community and its institutional memory, providing continuity and stability for its academic software. We also created the UK Community of Research Software Engineers[20] (UKRSE) as a focal point for our future campaigns and the

[18] http://ascl.net
[19] http://www.software.ac.uk/blog/2012-11-09-craftsperson-and-scholar
[20] http://www.rse.ac.uk/

Institute made the promotion of the RSE job role a cornerstone of their policy, lobbying the UK Government and Research Councils for RSEs to be recognized at a high level.

Since 2012 the RSE job role has gained traction in a number of institutions and has been endorsed by the Engineering and Physical Sciences Research Council in the UK (EPSRC). There are groups employing RSEs in University College London, the University of Manchester, the University of Cambridge, the University of Southampton and the University of Sheffield, with more in the process of being set up all the time. The EPSRC has funded seven RSE Fellowships, who have a remit to develop and support software and users of software, and has also funded a network of RSE leaders[21] to further build the community of RSEs and develop the next round of Fellowships.

This year we held the world's first RSE Conference in Manchester, UK.[22] It was the first conference to focus on the practice of research software engineering and included sessions on the issues that affect people who write and use software in research as well as presented talks and workshops where new tools and techniques were taught. The conference attracted over 200 people from 14 countries, so we look forward to further expanding our community and building links with colleagues all over the world in the near future.

3.14 101companies – Making a Failing Project Succeed

Ralf Lämmel (Universität Koblenz-Landau, DE)

Lämmel presented the 101Companies project: a software *chrestomathy*, from "chresto", meaning "useful" and "mathein", meaning "to learn". 101 is a knowledge resource for technological space travel (between all kinds of technological spaces). It can serve to compare technologies, for programming education, and can serve as a playground for student projects. Lämmel discussed some of the challenges the project is experiencing and some of the ways in which it is succeeding.

3.15 UW eScience Institute Initiatives

Cecilia Aragon (University of Washington – Seattle, USA)

Thanks in part to the recent popularity of the buzzword "big data," it is now generally understood that many important scientific breakthroughs are made by interdisciplinary collaborations of scientists working in geographically distributed locations, producing and analyzing vast and complex data sets. The extraordinary advances in our ability to acquire and generate data in physical, biological, and social sciences are transforming the fundamental nature of science discovery across domains. Much of the research in this area, which has become known as data science or eScience, has focused on automated methods of analyzing

[21] http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/N028902/1
[22] https://www.software.ac.uk/blog/2016-10-04-future-rses-looking-rosy-following-phenomenal-conference

data such as machine learning and new database techniques. Less attention has been directed to the human aspects of data science, including how to build interactive tools that maximize scientific creativity and human insight, and how to train, support, motivate, and retain the individuals with the necessary skills to produce the next generation of scientific discoveries.

In this talk, Aragon discussed the history and ongoing initiatives at the UW eScience Institute, including opportunities to participate in the $37.8M Moore/Sloan Data Science Environment at UW, UCB, and NYU, and speculate upon future directions for data science. In particular, she discussed new initiatives at UW such as the eScience Incubator and the Data Science for Social Good program and focused on results of ethnographic studies of their projects and future work in the Data Science Studies working group. She further argued for the importance of a human-centered approach to data science as necessary for the success of 21st century scientific discovery. She attested that we need to go beyond well-designed user interfaces for data science software tools to consider the entire ecosystem of software development and use: we need to study scientific collaborations interacting with technology as socio-technical systems, where both computer science and social science approaches are interwoven.

3.16 The Netherlands eScience Center

Rob van Nieuwpoort (The Netherlands eScience Center (NLeSC), NL)

The Netherlands eScience Center (NLeSC) is the Dutch national hub for the development and application of domain overarching software and methods for the scientific community. NLeSC develops crucial bridges between increasingly complex modern e-infrastructures and the growing demands and ambitions of scientists from across all disciplines. The application of digitally enhanced scientific practices makes sure that returns can be achieved from scientific investments. In support of this goal NLeSC funds and simultaneously funds and participates in multidisciplinary projects, with academia and industry, with optimized data-handling, efficient computing and big-data analytics at their core.

NLeSC contributes exclusively to multidisciplinary projects with the potential to deliver scientific excellence, in terms of breakthroughs and in the realization of unique eScience methodologies. Many organizational practices, such as our open call strategy and other funding models ensure that new projects fulfill these criteria.

Apart from contributions to scientific publications in high-impact scientific journals and conferences, NLeSC's primary deliverables are eScience instruments (*e.g.*, software tools, workflows). Whilst the instruments may include a domain specific component, primarily these tools overarch multiple domains. The instruments are efficient, calibrated, reliable and accessible, and based on excellent standards of code quality utilizing meta-data standards and software development environments. Successful instruments are made publicly available as part of NLeSC's eScience technology platform (eStep) program.[23] This platform provides easy access to the developed tools and instruments to the broader scientific community and industry alike. NLeSC also shares non-scientific technical results, documentation and best practices in the knowledge base that also is a part of eStep.

[23] See also http://estep.esciencecenter.nl

NLeSC also plays a key role in optimizing and disseminating the best practices in the areas of software sustainability and data-stewardship, including the need to engage with communities of practices, data-publishers and related initiatives.

The rapid growth of data and computing initiatives risks unnecessary fragmentation and duplication. NLeSC works with numerous partner organizations, nationally and internationally, to identify common challenges such as training and career support for eScientists, as well as providing thought leadership on issues such as data-stewardship and software sustainability. NLeSC is a joint initiative of the Dutch national research council (NWO) and the Dutch organization for ICT in education and research (SURF).

3.17 On ImpactStory, Scientific Software Map, and depsy

James Howison (University of Texas – Austin, USA)

There is a need to provide insights into the scientific software ecosystem [1]: the set of projects, their software products, their authors, their dependencies, the papers describing them, and papers that have used the software to undertake science. Such insights are useful for many players in the ecosystem, including end-users, software component producers, and ecosystem stewards (funders and senior scientists). Howison presented two systems that have attempted to gather and display this data: depsy.org[24] and the scientific software network map.

Depsy has gathered data from CRAN and PyPI as a starting point. They gather dependency and authorship information from those repositories. They identify the software in the literature using a fulltext keyword search for the name of the package. They are then able to calculate both direct mentions of each package and indirect mentions, using the PageRank algorithm. Depsy is produced by ImpactStory (Heather Piowawar and Jason Priem) [2].

The second system presented was the Scientific Software Network Map by Bogart, Howison, and Herbsleb.[25] The Map is designed to be populated from different ecosystems' software repositories, current work including data from two locations: R scripts on GitHub, and data from the Texas Advanced Computing Center gathered about jobs submitted to their supercomputing infrastructure. The interface uses D3 for the visualizations, and Pyramid, Mongo and Jinja for the web and database framework. Maps are designed to directly address the needs of scientific software producers and stewards for usage-related information about packages. The tool's features include a usage graph over time, a filterable/sortable list of packages, a "co-usage" graph showing what packages were used together, and a listing of external software (*e.g.*, end-user scripts and packages under development) that depend on each package. The co-usage graph could be used to identify previously unknown clusters of packages and to bring their developers together.

References

1 Chris Bogart, James Howison, and James D. Herbsleb. Mapping the Network of Scientific Software. page (Abstract Submission), Washington, D.C., June 2015.
2 Dalmeet Singh Chawla. The unsung heroes of scientific software. *Nature*, 529(7584):115–116, January 2016.

[24] http://depsy.org
[25] http://scisoft-net-map.isri.cmu.edu:7777

3.18 The OSSMETER platform

Jurgen J. Vinju (CWI – Amsterdam, NL)

Vinju briefly introduced the OSSMETER platform[26] for monitoring and comparing open-source software projects in terms of code, activity, issues and community. This open-source project can be used to monitor and assess projects and may be applicable to the domain of scientific software as well.

4 Breakout sessions

The afternoons of the workshop were dedicated to focused break-out groups. The groups were defined in a plenary discussion using a board with sticky notes. Everybody could propose topics. The topics were grouped on the board by topic similarity. Some groups continued over more than one day in order to arrive at a tangible result. All groups made notes into a single shared document. This same document was the source for the current report as well as the manifesto.

The breakout groups are detailed below in arbitrary order.

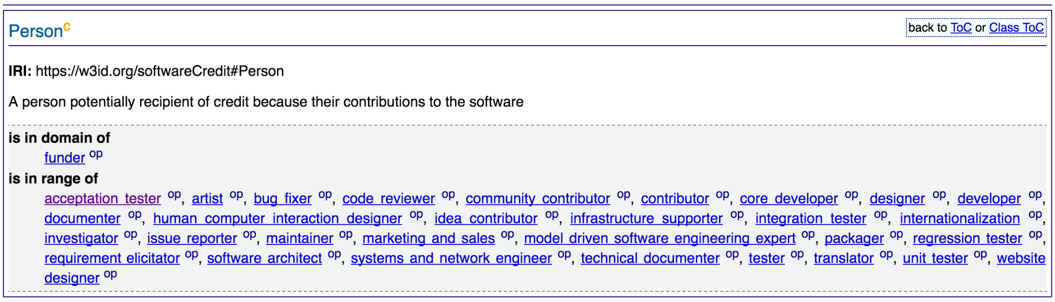
4.1 Research Software Project Typology

Benoit Combemale, Jurgen J. Vinju, Robert Hirschfeld, Ralf Lämmel, Daniel Garijo, Christoph Becker, Caroline Jay, Robert Haines, and Cecilia Aragon

The goal of this group was to characterize academic software projects across different dimensions (*i.e.*, motivation, impact, costs, risks, strengths and weaknesses) so as to analyze their impact in (i) the creation of software outputs, (ii) the acquisition of new funding and (iii) the recognition of adequate author credit. Ideally, this characterization would be structured as an ontology, extending existing software metadata vocabularies,[27] and specializing them for academic software.

The group paid particular attention to the different roles of academic software engineers and researchers in the context of their software projects. This discussion led to the creation of the "Software Credit Role" ontology,[28] which identifies the types of contributions of academic software at any stage of the software development (see Figure 1 for some examples). The ontology will soon extend DOAP[29] and schema.org,[30] and will be mapped to the crosswalk list CodeMeta terms.[31]

[26] http://www.ossmeter.org
[27] For example http://ontosoft.org/ontology/software/
[28] https://w3id.org/softwareCredit
[29] http://usefulinc.com/ns/doap#
[30] http://schema.org/
[31] https://github.com/codemeta/codemeta/blob/master/crosswalk.csv


Person[c] back to ToC or Class ToC

IRI: https://w3id.org/softwareCredit#Person

A person potentially recipient of credit because their contributions to the software

is in domain of

funder [op]

is in range of

acceptation tester [op], artist [op], bug fixer [op], code reviewer [op], community contributor [op], contributor [op], core developer [op], designer [op], developer [op], documenter [op], human computer interaction designer [op], idea contributor [op], infrastructure supporter [op], integration tester [op], internationalization [op], investigator [op], issue reporter [op], maintainer [op], marketing and sales [op], model driven software engineering expert [op], packager [op], regression tester [op], requirement elicitator [op], software architect [op], systems and network engineer [op], technical documenter [op], tester [op], translator [op], unit tester [op], website designer [op]

Figure 1 Excerpt from https://w3id.org/softwareCredit depicting the Person concept with the different roles a person could take upon themselves.

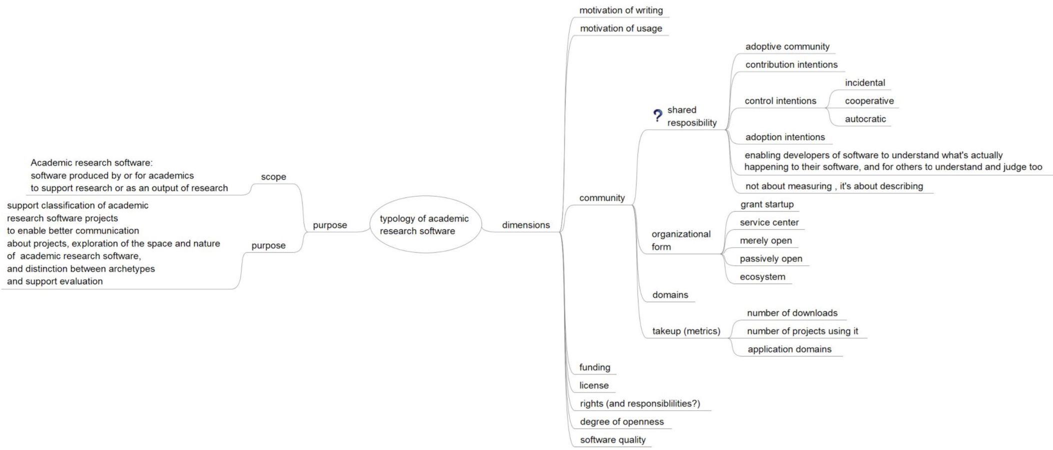


Figure 2 A mindmap of a brainstorm towards an academic software project typology.

The group brainstormed about the project typology in three sessions. The first session led to divisions along the lines of the following concepts: intentions of usage, degree of openness, funding, contributors (single person, group, closed/open community), community (scale, culture, rights, license), maturity (process), accessibility/openness and organizational openness from engineering properties (code quality, test coverage, benchmarking, release management, semantic versioning, etc.).

The second brainstorm refined the outcome of the first one in the mindmap depicted in Figure 2.

The third discussion produced a faceted classification with yet different distinctions mainly focused on purpose, intentions and motivations. This finally resulted in a questionnaire (shaped as an online spreadsheet[32]) which we filled in for a few dozen projects to see if the distinctions would generate a meaningful overview of typical academic software projects.

The group discussions produced enough material to start working on a publication about the topic. We believe that it is important to understand, describe, analyze and improve academic software projects descriptions, as clear classifications of software projects are not currently commonplace.

[32] https://goo.gl/ud5Ik2

4.2 Empirical Study of Software in Conferences

Jeffrey Carver, James Howison, Robert Haines, Caroline Jay, Kevin Crowston, and Oscar Nierstrasz

The goal of this group was to explore the possibility of carrying out an empirical study to better understand *what software is cited in academic conferences in a particular domain*, how such software is cited, and what are common software practices in that domain.

The group mainly focused on identifying (i) potential *research questions* to be addressed, and (ii) *procedural questions* concerning the logistics of carrying out such a study.

Some of the specific research questions considered were:

- Which software ends up being mentioned in papers?
- Who are the developers? (PhD students? Research Software Engineers?)
- What happens to software after the paper is published?
- What software engineering practices are applied? (Version control? Testing?)
- Who pays for software development?
- What problematic issues commonly arise?
- What recommendations would improve the quality of software in the fields?

Procedural questions included:

- How to achieve variance? (Do you code for research questions? Venues? Should a grounded approach be used or should predefined hypotheses be considered?)
- Would machine learning help to classify software in papers?
- How to start? (Which domain to select?)

Katy Huff notes that the Berkeley Institute for Data Science (BIDS, with collaboration from the UW eScience Institute and the NYU center for data science) has collected over 30 case studies from scientists from various domains, synthesized them into lessons learned, and compiled them into a book to be published in 2016 by the University of California Press.[33]

4.3 Examining Sustainability for a Particular Project

Carole Goble, Katie Kuksenok, Christoph Becker, Daniel Garijo, Mike Croucher, and Daniel S. Katz

Sustainability refers to the capacity of a system to endure over time. In the case of software this means that it must continue to be available in the future, on new platforms and meeting new needs.

This breakout group discussed various aspects of sustainability of scientific software: How can we ensure sustainability of scientific software? What does this mean for a particular

[33] https://github.com/BIDS/repro-case-studies

project? Does it make sense to talk about sustainability of software divorced from the sustainability of the team?

To produce sustainable software requires sustaining the project organization – or at least "a" project organization – which produces and maintains the software. With a project we mean an (evolving) team of people and their organization. Sustainability of the software and of an organized group of people who take responsibility for it are clearly entangled, since you can say very little about the technical sustainability of a software system alone without considering the social system. Note that a sustainable team does not imply an immutable team: a sustainable team can grow or shrink, distribute and swap out team members or leadership in the long term.

A key factor related to software sustainability is *technical debt*, *i.e.*, technical shortcuts to achieve a short-term goal that impact long-term quality and maintainability. An example of investment needed to pay off this debt is the effort required to make the code more modular and more amenable to accepting new plug-in components. A challenging scenario would be to conduct an analysis of sustainability debt for specific systems in a short time since there are multiple, interlinked systems, services, communities, and stakeholder groups. A recurring problem is the issue of obtaining funding to maintain scientific software and guarantee its sustainability for the community and the long tail of users. Large projects, funders, publishers, institutions all have an obligation or a role to support (subsidize) the software and the service.

A number of software maturity frameworks were discussed such as the Software Sustainability Maturity Model (SSMM), OSS Watch Openness Rating, NASA Reuse Readiness Rating, CMM, and QSOS. User-producer reciprocity misalignments were discussed leading to an accepted lightning talk at WSSSPE 2016 which credited the seminar (C. Goble (2016), A Simple Profiling Framework for Software User-Producer Reciprocity Review, presented at 4th WSSSPE (Workshop of Sustainability of Science Software Practice and Experience), 2016).

4.4 Making the Impact of Software more Visible

Matthew Vaughn, Katy Huff, Matt Turk, Rob van Nieuwpoort, Alice Allen, Andrei Chiş, Cecilia Aragon, Claude Kirchner, and Daniel S. Katz

A fundamental problem in selected scientific fields, such as physics and astronomy, is that a huge amount of effort is invested in producing scientific software, but only published papers count towards scientists' careers. This leads inevitably to the process, "I write the software and then I write a paper to get credit." We need a cultural change in the scientific community to raise awareness that scientific software itself represents valuable intellectual content and scientific innovation directly and explicitly.

This breakout group discussed the status quo and ways to change it. Journals exist in Computer Science and Bio-Informatics that are home to intellectual contributions of software packages. Several computer science conferences explicitly support "artifact evaluation" where software contributions are scrutinized and appreciated as part of the academic review process. But the appreciation of software as academic output does not seem to be universal across domains.

Appreciation for software seems more natural in Computer Science, which explains recent efforts in this field to making the impact of software visible, yet across the board the field is not particularly ahead in this regard with respect to other fields. An important positive factor is the recent focus in research towards "innovation" and "valorization" which puts tangible and transferable results of Computer Science in the form of working software in the spotlight. Bio-Informatics though, is ahead of the pack, which may be due to its explicit branding as the informatics branch of Biology.

One critical need that was identified is to explicitly include software output into the evaluation processes of both academics and academic institutions. Currently, publishing software may give you a DOI (*e.g.*, via Zenodo[34]) but this neither brings you reputation nor does it contribute to a positive evaluation per se, unless this DOI is indexed as part of your records and citations to it are credited to your metrics. Problems with making software output part of the academic process were discussed. For example, software lasts longer than the citable snapshots we have now, leading to evolving author lists and evolution between software versions, which may in turn lead to software growing far beyond the original scope. Short papers about software are too short to make the academic challenges and contributions observable, while long papers about software hide the software contributions under the traditional paper-style contributions. And finally, reading and appreciating source code is just hard especially if it is not originally written with such an audience in mind.

Several possible solutions were discussed:

- Papers could capture more about the software's intellectual impact; *i.e.*, in a separate section akin to the standard "research method" and "threats to validity" sections.
- Letters of support may be the best way to communicate software impact to tenure committees.[35]
- People could claim their contributions more explicitly: web pages are needed to document software contributions; research software engineers should be motivated to co-author papers; and scientists who develop software must be willing to be proud and certainly unapologetic about their software contributions in front of tenure committees.
- Rubrics and templates for letters of recommendation should be developed to highlight intellectual contributions from code.
- A Research Coordination Network (RCN) workshop[36] should be started to showcase intellectual content for academic software.
- Encourage the formation of a prestigious scientific software award.

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1 Computer Science and Telecommunications Board, Commission on Physical Sciences, Mathematics, and Applications, National Research Council. *Academic Careers for Experimental Computer Scientists and Engineers Committee on Academic Careers for Experimental Computer Scientists.* National Academy Press, 1994.

[34] https://zenodo.org/

[35] This has been the case in Computer Science in the US for about 20 years, due to a National Research Council report [1] that is frequently quoted in such letters.

[36] RCNs are an NSF instrument: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=11691. Presumably similar instruments exist in other countries.

4.5 Reviewing FORCE11 Software Citation Principles

Dan Katz, Robert Haines, James Howison, Katy Huff, Caroline Jay, and Matt Vaughn

This group came together to contribute to the FORCE11 software citation principles. The FORCE11 website[37] says: "Based on a review of existing community practices, the goal of [FORCE11] was to produce a consolidated set of citation principles that may encourage broad adoption of a consistent policy for software citation across disciplines and venues."

The breakout group reviewed the different personas (roles) in relation to the software citation principles to see if their interests were reflected appropriately: reviewer, author of software, designer of citation style, reader of paper, user of software, funding agency, publisher.

This review was passed on to the FORCE11 Software Citation Working Group editors, leading to updates to the citation principles where these were deemed necessary, and the final version was recently published [1], including these updates.

References

1 Arfon M. Smith, Daniel S. Katz, Kyle E. Niemeyer, and FORCE11 Software Citation Working Group. Software citation principles. *PeerJ Computer Science*, 2:e86, September 2016.

4.6 Research Software Engineering Handbook

Jeff Carver, Mike Croucher, Andrei Chiş, Katie Kuksenok, Rob van Nieuwpoort, Kevin Crowston, Robert Haines, and Katy Huff (partial attendance)

This group focused on designing a handbook with practical advice for academic research personnel involved in programming, or management of, a programming project. This audience includes RSEs, PIs, research scientists and graduate students. Though the particular projects and needs vary widely among these people, the breakout group identified a common need for a resource to support the selection and integration of tools and skills from an overwhelmingly wide array of available options. The experiences of Mike Croucher and Rob van Nieuwpoort in supporting scientific groups grounded the discussion, and the concept of the handbook arose from a similar living document developed within van Niewpoort's group.[38]

Many resources exist for learning and improving programming and management skills. Rather than duplicating these existing resources, the handbook will curate and describe them, helping to select and integrate distinct tools and skills through its need-centered organization. The group discussed how to accommodate the wide range of subjects and audiences. The outcome of this discussion was a table of contents with high-level sections articulated around the outstanding need of the reader:

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[37] https://www.force11.org/software-citation-principles
[38] https://nlesc.gitbooks.io/guide/content/

- **Getting started** covers the basics of version control, licenses, citing software, looking for existing solutions, and getting feedback.
- **"I want to code better."** Provides more information on testing, continuous integration, release management, documentation, and other skills that help a programmer to produce higher-quality code.
- **"I want better code."** Focuses on properties of the code produced, not just the approach to production, with the intent of writing more reusable and testable software.
- **"I have a team of developers now. How can I cope with the new challenges ahead?"** Offers additional resources on management and communication processes, formal requirements gathering, and other issues related to moving toward team-based development.
- **"I have my first pull request, and the beginning of a community. What now?"** Returns in more depth to issues of licensing and release management, with added information about community-building and sustainability concerns.

Each section contains 6–10 chapters. In addition to the overall structure, the group discussed an index to tailor recommended chapters to team size (*e.g.*, a graduate student and a PI vs. a 5-person team) and role (*e.g.*, the student who wants to improve vs. the PI who wants to implement better team processes). As an outcome of the breakout sessions, the group refined a detailed table of contents, assigned contributors to each section, and created a GitHub repository to help manage this document.[39]

4.7 Future Research directions

Claude Kirchner, James Williams, Oscar Nierstrasz, Katie Kuksenok, Jurgen J. Vinju, Benoit Combemale, Matt Vaughn, Cecilia Aragon, and Alice Allen

This breakout group discussed a number of possible themes for future research projects or initiatives. Of the topics discussed the following ones were elaborated in enough detail to be included as part of the Dagstuhl Manifesto:

1. *Quantifying the availability of scientific software:* this research would attempt to determine how research software exists, for which domains is it developed, who owns it, who pays for it, who maintains it. The research would also attempt to identify opportunities for reuse, sharing, and collaboration.
2. *Facilitating software discovery within and across disciplines:* the key research question here is to determine, aside from standards, what other approaches can effectively support discoverability of available research software.
3. *Sustainability of software experimentation:* how can we ensure reproducibility of software experiments, not just in the short or medium term, but in the very long term?
4. *Software engineering tools improving productivity by tailoring to intent and skill:* not all research software requires the same development rigor and discipline as commercial software, yet all would benefit from from skills beyond that of "hobbyist" programmers.

[39] https://github.com/DagstuhlEAS/rse-handbook

How can we appropriately select and adapt the level of software engineering discipline appropriate to a given research project?

5. *Re-tooling the bibliographic software toolchain for software citation:* existing bibliographic tools are highly tailored towards academic writing. How do we adapt the metadata and tools to get the right meta-information about software into citations?
6. *Analysis of scientific software ecosystem metadata:* how can we effectively monitor and analyze metadata about research software in the large?

4.8 Design of the Manifesto

Claude Kirchner, Oscar Nierstrasz, James Howison, Katie Kuksenok, and Jurgen J. Vinju

A key goal of this Dagstuhl Perspectives Workshop has been to produce a *Dagstuhl Manifesto*[40] to serve as a roadmap towards future professional software engineering for software-based research instruments and other software produced and used in an academic context.

Throughout the week, each of the breakout groups logged their discussions in a common, shared Google document, and took care to identify specific "pledges" that could serve as input to the manifesto. The goal was to ensure actionable outcomes which called on individuals themselves to act, rather than to ask others to act on their behalf. This intent acknowledges that "we" are the community and that visible action provides "social proof" and motivates others. The pledges were based on a template: (i) the pledge itself, expressed in the form "I will *take some specific actions to support EAS*", (ii) *background* motivating the pledge, (iii) *contradictions or concerns* that could impact the pledge, (iv) specific *actions needed*, and (v) identification of other *players who need to act*.

By the end of the week, some 30-odd candidate pledges had been collected for the manifesto. The manifesto design breakout group then set out to cluster the pledges around common, overarching themes, namely:

(i) Citation & Reviewing;
(ii) Recognition;
(iii) Making intellectual content visible;
(iv) Software Projects; and
(v) Sustainability.

In a subsequent session, the group pared down the list of candidates, eliminating seemingly redundant or confusing pledges, and pledges lacking substantial description, yielding 18 surviving candidates.

Subsequent to the termination of the workshop, a poll was prepared to rank these 18 pledges. The list was subsequently simplified and reduced to 5 key pledges in three categories: (i) Citation, (ii) Careers, and (iii) Development. (The poll has also been run at WSSSPE 2016, though the results have not yet been analyzed.)

At the time of the preparation of this report, a draft manifesto is under preparation as a GitHub project.[41]

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[40] Dagstuhl Perspectives Workshops explore new and emerging topics in Computer Science, and are expected to produce *Dagstuhl Manifestos* that capture trends and developments related to these topics. See: http://www.dagstuhl.de/en/publications/dagstuhl-manifestos/

[41] https://github.com/DagstuhlEAS/draft-manifesto

4.9 Shoot the Dogma and War Stories

Carole Goble (convenor), Kevin Crowston, Jurgen J. Vinju, Alice Allen, Robert Haines, Caroline Jay, Mike Croucher, James Howison, and Katy Huff (partial attendance)

In this relaxed evening session participants let off steam regarding dogmas – a principle or set of principles laid down by an authority as incontrovertibly true – that needed to be challenged, and to relate war stories. Ten dogmas and two war stories were discussed:

1. *Use the best language for the job:* Using whatever language is right for the various components of a system, thinking that component making is "fun" rather than thinking about the total system. The result is build misery and a tower of pain. It is better to have a language that is good enough and fits/the same as the languages you are using than use another language. If the build has taken over the whole development it has become a monster.
2. *Blockchain solves everything:* Security is a life's work and best left to specialists.
3. *C++ is necessary for high performant code:* This is not true and lazy thinking. C is good for parallel computing and the libraries, but keep away from the bells and whistles, and the "++" part of C++.
4. *A code repository gives perfect tracking:* The repository trace is the "farts of dinosaurs" – that is it records what happened long ago and often not the right thing. Histories can be meddled with.
5. *Writing documents using Git is good:* Git is an excellent software writing environment. It is not a document narrative writing environment. Starting up with independent section development has a place, but for one voice narrative it is poor and a sure way to put off collaborators.
6. *Python solves everything:* No-one shot this Dogma. So perhaps it does solve everything.
7. *Docker solves everything:* Docker solves a specific problem, but we should recognise that build systems and dependency management are hard. Silver bullets are just bullets that are useful.
8. *Engineers know best how to estimate effort:* Engineers do not. They have a tendency to be optimistic and want to please, impress, over state their ability, understate complexity and underestimate the available time and the absence of distractions or obstacles. A rule of thumb is to double the unit and raise the unit of estimates (*e.g.*, 1 day = 2 weeks, 1 week = 2 months).
9. *Compute privacy is necessary on shared computing resources:* This is tool privacy, not data privacy. Running tools in secret is unnecessary and, to show their impact, tool usage needs to be tracked.
10. *Agile solves everything:* Agile is a religious fervour that can be considered harmful (thoughtless evangelism is suspicious). Agile is sometimes used as a PRINCE 2.0 backlash. Processes themselves have life and agile can work when thoughtfully used. Studies indicate that using KANBAN (a sub-process of Agile) is better than no set process or a full agile process.

Two war stories were shared:

1. *Frankenstein technology stacks:* A common tale is the legacy technology stack using software often developed by non-software engineers. The result is a "walk of shame" for the software engineers: users are proud and even brag about the software but developers

would rather it was kept quiet. Conclusion: compromise is commonplace but be sure to clarify the impact on the participants.

2. *Wasting participants time:* A tale about starting a citizen science project that gained participants but no resources had been planned when it got going, leading to frustration and wasting the time of the citizens. Conclusion: think through the consequences of success before starting projects that recruit participants.

5 Acknowledgements

We thank all attendees of this Dagstuhl Perspectives Workshop, who have made this into a successful workshop with so many outcomes. In particular, we thank those participants who have provided additional input when preparing and improving this report (in no specific order): Daniel Katz, Daniel Garijo, Alice Allen, Rob van Nieuwpoort, Kateryna Kuksenok, Katy Huff, Caroline Jay, Cecilia Aragon and Robert Haines. Finally, thanks to all the staff at Dagstuhl who have made this possible.

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Report from Dagstuhl Seminar 16261

Integration of Expert Knowledge for Interpretable Models in Biomedical Data Analysis

Edited by

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Abstract

This report documents the talks, discussions and outcome of the Dagstuhl seminar 16261 "Integration of Expert Knowledge for Interpretable Models in Biomedical Data Analysis". The seminar brought together 37 participants from three diverse disciplines, who would normally not have opportunities to meet in such a forum, let alone discuss common interests and plan joint projects.

Seminar June 26 to July 1, 2016 – http://www.dagstuhl.de/16261

1998 ACM Subject Classification J.3 [Life and Medical Sciences] Biology, E.1 Data Structures, F.2 Analysis of Algorithms and Problem Complexity, I.6.4 Model Validation and Analysis, I.6.5 Model Development

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Edited in cooperation with Friedrich Melchert

1 Executive Summary

Gyan Bhanot
Michael Biehl
Thomas Villmann
Dietlind Zühlke

The participants were drawn from three distinct disciplines: Biomedical Research, Machine Learning and Visualizations. On the first day, three overview talks on different aspects of bio-medical research were presented, including an overview of omics and clinical data and databases, a summary of current problems in cancer prognosis and metastasis, and steroid metabolomics and its relevance to disease. On the next two days, there were four overview talks on computer science topics, including machine learning, modeling and visualization. Participants also had the opportunity to give shorter presentations of their current research areas and describe open problems, as well as introduce new and relevant datasets and methods. In total, 16 such short talks were presented, covering various areas of biomedical research and computer science. All talks served as starting points for extensive plenary and individual evening and after dinner discussions about the integration of expert knowledge into data analysis and modeling, specifically targeted to cancer informatics. From these discussions, it was clear that there was an urgent need for interactive collaboration to foster successful analysis and interpretation of biomedical data and the success of such collaboration would hinge on active participation from domain experts from biomedical research, data mining and visualization.

Motivated by this conclusion, we identified a joint project in cancer genomics, which would exploit the expertise represented by the seminar participants. On the fourth day, participants discussed the interactive methodology we will follow in the project. Following this, first results obtained by analysis of cancer data from The Cancer Genome Atlas was presented in a joint talk by representatives from all three disciplines (biology, machine learning, visualization). We will extend this project further in the coming months with active participation from the clinicians and computer scientists. The goal of this effort is not just to solve a relevant and outstanding problem in cancer biology but also to work towards publication of our findings in a high-impact journal authored by all participants. To foster this project, we will establish a Wiki, which will serve as a platform for collaboration and communication.

The participants gave feedback on Friday on the organization and content of the seminar. All participants were appreciative of the open, friendly and constructive atmosphere that made learning and insight possible for experts from very diverse disciplines. Getting to know the basic methods used in each field was seen as the perfect starting point for future collaborations. The idea of a joined wiki page as a collaboration platform as well as the already started joined project were highlighted as especially important. Follow-up-meetings of newly formed interdisciplinary teams were initiated and planned e.g. one in Copenhagen. The participants were very enthusiastic about having a further meeting after about a year to discuss results and new directions resulting from the joint project initiated here. Apart from working on a specific project in cancer biology, the goal of the collaboration is to establish a methodology for interactions, disseminate ideas and protocols among the disciplines and establish a common language to foster understanding.

In summary, biologists, both medical and computational experts in the seminar are enthusiastic about joining forces to solve outstanding problems in understanding biological processes. Many of the machine learning methods presented by participants are ready to be applied in real environments such as in clinical use or in research laboratories, after proper technology transfer. Such technology transfer requires targeted funding and agreed upon protocols to ensure adequate resources and necessary quality control, for subsequent release to the community.

The participants felt that influential members in each community should seek opportunities and avenues to urge the appropriate agencies (NIH, NFS, EU Scientific bodies) to establish a targeted program for technology transfer of computational solutions to challenges in the interpretation of biomedical data. Such a program would solicit competitive funding proposals from groups consisting of both biomedical and computational experts, and require products that are rigorously demonstrated on real problems, as well as satisfy appropriate coding and user interface standards, and where appropriate, satisfy requirements of interfacing or integration with existing established systems currently in use by the community.

In medicine the data is treasure
Whose value's beyond any measure
But it is not surprising
That without analysing
Acquisition is meaningless pleasure

(Michael Biehl and Gyan Bhanot)

2 Table of Contents

3 Overview of Talks

3.1 Mutations and Immune Therapy

Gyan Bhanot (Rutgers University – Piscataway, US)

In this talk, I presented an overview and results from collaborative work I am involved in in an exciting new area of cancer research, which is in the treatment of patients using immune checkpoint blockade therapy. Using data from The Cancer Genome Atlas (TCGA), we find that it is possible to identify a robust mutation burden threshold, which we call the immune Checkpoint Activating Mutation (iCAM) threshold, which can identify subsets of patients likely to respond to immune checkpoint therapy in melanoma, lung, colon, endometrial, stomach, ovarian, cervical, bladder, and breast cancers. Further, We also find that iCAM+ (responsive) patients can be identified with good accuracy using commercially available clinical-grade tumor sequencing assays. Finally, we find that iCAM+ and iCAM- tumors have different underlying mutation patterns, suggesting distinct underlying mechanisms of mutagenesis. The goal of the talk was to explain an exciting new field in cancer biology in simple language to the community of computational experts in the audience so that they could apply some of their expertise to the analysis of diverse and multimodal cancer datasets that are available in the public domain.

3.2 Molecular Landscapes in Renal Cell Carcinoma

Aguirre de Cubas (Vanderbilt University – Nashville, US) and W. Kimryn Rathmell (Vanderbilt University School of Medicine, US)

A common urological malignancy, renal cell carcinoma is a heterogeneous disease, consisting of a number of different cancers, characterized by different histologies, genetic drivers, clinical course, and response to therapy. The majority of RCC's are defined by three major histologic subtypes: 75% are clear cell RCC (CCRCC, KIRC), 15-20% Type 1 or Type 2 papillary RCC (PRCC, KIRP), and 5% chromophobe RCC (ChRCC, KICH). This study evaluated gene expression by RNA-sequencing in 843 TCGA-RCCs (488 KIRC, 274 KIRP, 81 KICH) across histologic subtypes to identify features unique to each subtype and common to multiple subtypes, and included normal kidney tissue samples (n=129). For this, we applied weighted gene coexpression network analysis (WGCNA), a systems biology approach, and identified modules of closely connected co-expressed genes, which may act in a network and may serve as molecular signatures for an underlying phenotype.

WGCNA of mRNA expression data revealed strong immune and vasculature-related gene signatures associated with KIRC, and a significant loss of an ion transport and baso-lateral gene signatures and gain of mitochondrial membrane gene signatures in KIRP and KICH, but not KIRC. All RCCs had upregulation of the ribosomal gene signature compared to normal kidney tissue. These comparisons demonstrate clear genomic differences between the RCC histologic subtypes, as well as common features that unify some or all of the subtypes, which could provide the evidences for novel directions for developing targeted therapeutic interventions that could be effective across subtypes.

3.3 Information richness and data missingness in clinical studies for Heart Failure

Gert-Jan de Vries (Philips Research Lab. – Eindhoven, NL)

Prospective clinical studies typically yield a rich set of patient parameters. This, however, also increases chances of missing some parameters for some patients. Our study into chronic heart failure also shows various patterns of data missingness. Preliminary results from our structured study of the efficacy of various data imputation techniques seem to indicate that there is limited added value of more sophisticated imputation techniques over the relatively simple techniques with respect to the performance of classifiers of 30-day readmission. Other challenges for successful application of such predictive methods in clinical practice include the inherent selection bias that occurs in prospective studies. We showed that this bias has large effect on the generalizability of predictive models and should not be overlooked in model development.

3.4 Feature extraction for x-ray scattering from biomolecules and nanoparticles.

Sebastian Doniach (Stanford University, US)

To obtain information about the structure of biological molecules in terms of atomic positions in the molecule, x-ray crystallography is the principal tool. But what happens if the circumstances are such that a crystal of the molecules of interest is not available? Here, x-ray scattering from a solution of the molecule of interest gives a one-dimensional scattering intensity $I(q)$, as an average scattering over all orientations of the molecule, expressed as a function of the scattering wave vector q defined in terms of the scattering angle, θ.

Features of the molecular structure may be extracted from this function by a variety of methods of which the simplest is the Guinier method which measures the radius of gyration, R_g of the molecule in terms of the Gaussian character of the scattering function at small scattering angles $I(q) \sim \exp(-q^2 R_g^2/3)$. This provides a model-free method for extraction of the feature parameter R_g by fitting the data to the Guinier function at sufficiently small scattering angles. The non-linear nature of this function makes this a "super-resolution" method in which the spatial resolution of the resulting R_g is 2-3 orders of magnitude more accurate than would be given by linear Fourier analysis of the data [1].

In the last few years, the advent of x-ray free electron lasers (xFELs) has now made possible a method to obtain 3-dimensional atomic structures from scattering data of a solution of molecules in the xFEL x-ray beam. In this technique, each flash of the laser beam provides a very high intensity of x-rays in a few 10s of femtoseconds. The scattered x-rays are captured on a 2-dimensional detector as an image which is azimuthally isotropic around the direction of the incoming x-ray beam.

Angular correlators of this image as a function of the azimuthal angle, ϕ, around scattering rings of fixed theta, define a 3-dimensional correlation function $C(q_1, q_2, \psi)$. Here q_1 and

q_2 denote two possible scattering angles, with $\cos(\psi)$ being the angular projection between scattering vectors defined by two points on the scattered image [2].

It may be shown that the average of $C(q_1, q_2, \psi)$ over all orientations of the molecules provides a function from which the atomic structure of the molecules in the solution may in principle be extracted as feature parameters [2]. In practice the experimental determination of the average correlator requires averaging over many thousands of images in order to reduce the background noise due to uncorrelated scattering events [3, 4].

The next step in feature extraction also involves determination of scattering phases as in x-ray crystallography. As is fundamental to image analysis in general, the phase retrieval problem is NP complete and relies on prior knowledge of the chemistry of the molecule, such as is used in molecular replacement, to determine a final structure.

Our group has published a first proof of principle for this method, applied to the example of a disordered suspension of 60 nanometer gold nanoparticles (gold NPs) [3]. A detailed report of xFEL scattering measurements from suspensions of gold NPs has been submitted for publication and is in the refereeing process [4].

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3.5 Feature selection, relevance learning, and causality

Barbara Hammer (Universität Bielefeld, DE)

Machine learning offers valuable methods to infer a regularity from given data, such as a classification prescription for a disease based on characteristic patterns from gene expression levels, SNPs, or any other signal. Formally, given a sufficient amount of training data, classification models can be accompanied by strong guarantees as concerns their validity, such as its performance as evaluated in a cross validation. In practical applications, however, this is often not enough: the models typically act as black boxes and they do not allow an insight into why a classification has been taken. We would like to take a look at a few techniques which enable practitioners to partially open the black box.

Feature selection

Feature selection aims for a selection of features from the given data which are particularly relevant for the given task at hand. Typically, feature relevance is measured by the impact of a feature on the given classifier as concerns its overall classification accuracy, i.e. the features which contribute most to the given classification are selected. There exists a large variety of feature selection techniques together with different software suites [1]. Typically, one distinguishes filter methods (the features are selected by adding relevant ones or deleting irrelevant ones from the full set of features as measured by some general criterion such as e.g. mutual information), wrapper methods (features are added / deleted depending on the performance of a classifier based on the remaining feature set), and embedded methods (feature selection is embedded into the classifier learning e.g. by adding sparsity constraints.)

While feature selection constitutes an ubiquitous technology in classification learning, it faces a few drawbacks: feature selection constitutes a so-called NP-hard problem, i.e. it is not possible to efficiently and reliably select all relevant features from a given data set in case of a large number of features. One particular challenge is faced when features are correlated, and important information is only revealed when a set of features is considered. Further, feature selection typically takes a binary decision, i.e. a feature is selected or discarded, but it is not weighted according to its relevance. Hence ambiguities or different degrees of feature relevance cannot easily be distinguished.

Relevance learning

Relevance learning aims for a solution of these problems by explicitly assigning a real-valued relevance to every feature. This takes into account correlated features and different degrees of feature relevance, since their weighting can be simultaneously and smoothly be adjusted. One particularly elegant way for an efficient relevance learning is offered by its direct embedding into metric based algorithms, such as proposed in [2]. Linear feature weighting essentially corresponds to a change of the data metric, the Euclidean metric is substituted by a general positive semidefinite quadratic form. Hence every metric learning methods can be used for relevance learning, such as successfully demonstrated for so-called generalised matrix learning vector quantisation in challenging biomedical applications [3].

While relevance learning is capable of simultaneously weighting several correlated features, it does not solve the challenges of feature redundancy: for redundant features, practitioners can pick from a set of equal features based on other criteria such as the feature costs. Recently, a very elegant scheme how to judge such settings and how to offer practitioners an interactive tool for an appropriate feature choice has been presented based on a suitable L-1 regularisation [4].

Causality

While relevance learning is capable of efficiently dealing with feature correlations, it restricts the analysis to a mere statistical one: it measures correlation of features rather than causality. While correlated features can be interwoven just based on coincidence, a bias in the measurement, or a hidden cause, causal feature relation characterises the fact that a measurement A causes measurement B, e.g. a genetic marker A can cause a certain disease B. Causality is typically inferred from data gathered in experiments, by manipulating probabilities [5]: A is cause of B if the probability of B is a different one when A is manipulated (but everything else is kept constant) in an experiment. Correlation, on the contrary, only refers to the fact that the probability of B is observed differently, given different instantiations of A, but B itself might be causes by yet another, possibly unobserved C.

Interestingly, under some assumptions, there do exist techniques to infer causality solely based on given measurement data, thus weakening the burden of an additional (possibly impossible or not ethical) experiment [7]. Given two correlated features, it is provably possible to determine the direction of the cause under special conditions such as independence of noise, or nonlinearity of the signals [6, 8, 9, 10]. Given a number of measurements, their overall causality can be determined by an efficient investigation of so-called Markov blankets, such as popular for Bayes network inference [12]. Interestingly, the resulting structure can be beneficial for an increased classification accuracy in biomedical applications, besides their increased interpretability [13]. Still, causal inference constitutes an ongoing research topic with quite a number of challenges ahead, such as cyclic relations [11], and their potential for biomedical applications is not yet fully explored.

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3.6 Statistical inference and dimensionality reduction in evolutionary tree spaces

Hossein Khiabanian (Rutgers Cancer Inst. of New Jersey – New Brunswick, US)

Joint work of Zairis, Khiabanian, Blumberg, Rabadan
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URL http://dx.doi.org/10.1007/978-3-319-09891-3_48
URL http://arxiv.org/abs/1410.0980

Phylogenetic trees are arguably the most common representation of evolutionary processes; they have been frequently used to characterize pathogen spread, the relationship between different species, and the evolution of cancers. Comparison between different trees is a key part of the analysis of evolutionary phenomena, for instance in comparing the evolutionary trajectories of tumors in different patients in relation to their differential response to therapy.

Recently, an elegant approach has been introduced by Billera-Holmes-Vogtmann that allows a systematic comparison of different evolutionary histories using the metric geometry of tree spaces. In this manuscript, we begin by reviewing in detail the relevant mathematical and computational foundations for applying standard techniques from machine learning and statistical inference in these spaces, which we refer to as evolutionary moduli spaces.

The solutions of biological problems often deal with heavily populated phylogenetic trees with many leaves, which are very cumbersome to visualize and analyze in their relevant evolutionary moduli spaces. To address this issue, we introduce *tree dimensionality reduction*, a structured approach to reduce large and complex phylogenetic trees to a distribution of smaller trees. We prove a stability theorem ensuring that small perturbations of the large trees are taken to small perturbations of the resulting distributions.

We then present a series biologically motivated applications to the analysis of genomic data, spanning cancer and infectious disease. The first quantifies how chemotherapy can disrupt the evolution of common leukemias. The second examines a link between geometric information and the histologic grade in relapsed gliomas, where longer relapse branches were specific to high grade glioma. The third concerns genetic stability of xenograft models of cancer, where heterogeneity at the single cell level increased with later mouse passages. The last studies genetic diversity in seasonal influenza A virus. We apply tree dimensionality reduction to project 24 years of longitudinally collected H3N2 hemagglutinin sequences into distributions of smaller trees spanning between three and five seasons. A negative correlation is observed between the influenza vaccine effectiveness during a season and the variance of the distributions produced using preceding seasons' sequence data. We also show how tree distributions relate to antigenic clusters and choice of influenza vaccine. These results provide compelling evidence that our formalism exposes links between genomic data of influenza A and important clinical observables, namely vaccine selection and efficacy.

3.7 Integrative Genomics Analysis Identify Molecular Subtypes of Lung Carinoids

Saurabh V. Laddha (Rutgers Cancer Inst. of New Jersey – New Brunswick, US)

Joint work of Saurabh V. Laddha, Edaise Da Silva, Kenneth Robyzk, Brian R. Untch, Laura H.Tang, Chang S. Chan

Lung carcinoids are a rare and slow growing type of primary lung neoplasms. Recent genomics studies provided more detailed biomarker/molecular subtype classifications of cancers, which bring us to a possibility to accurately classify based on molecular alterations and cell type. Here, we investigated the genomic and molecular alterations to discover subtypes of lung carcinoids (includes 13 atypical and 17 typical samples only) with distinct biological characteristics and identify a set of novel gene signature and biomarkers. We perform targeted sequencing of 354-cancer gene panel (n=29), Transcriptome (n=30) and methylome (n=18) on Lung carcinoids and identified recurrent mutated genes enriched in Histone covalent modifier/Chromatin remodeler, DNA repair and protein kinases pathways. We found 10 samples (30%) with mutations in covalent Histone modifier and SWI complexes with MEN1 and ARID1A being recurrently mutated. Unsupervised clustering and dimensionality reduction were used on expression and methylation level data resulted in 3 robust subtypes from both dataset: Subtype 1(SB1), Subtype 2(SB2) and Subtype 3(SB3). We speculate this subtyping may originate from different cell types and cellular mechanisms. Integrative multilayered data revealed SB2 group samples are enriched for MEN1 gene mutations. Samples in SB1 and SB2 are combination of both typical and atypical carcinoids but interestingly SB3 is enriched for typical carcinoids. Also SB3 is enriched (pval=0.001) for endobronchial lung carcinoids and has better recurrence free survival (Pval=0.003). We found gene and methylation signatures, which alone selectively discriminate subtypes. Immunohistochemistry on selected four key biomarkers stratified subtypes clearly at the protein level (ASCL1 biomarker for SB1, S100 for SB2, ALDH1A1 for SB2 and 3, TTF1 for SB1 and 3) and matches with integrative mutations, gene expression and methylation level classifications for novel Lung carcinoids subtypes.

3.8 Automatic organ delineation of medical images with atlases based on machine learning

John A. Lee (UC Louvain-la-Neuve, BE)

Radiation oncology (RO) treats cancer patient with beams of ionising particles like photons, protons, or even heavier ions. One or several beams are aimed at the tumor (or target volumes), in order to kill cancerous cells. To reach the tumor, these beams typically have to pass through surrounding healthy tissues, including organs at risk, the irradiation of which is the source of secondary effects. Very often, RO is thus compared to a ballistic problem: a tradeoff must be reached between tumor local control and side effects. To this end, medical images are acquired, in order to focus the beams and concentrate the irradiation dose primarily on the target. This evaluation requires to delineate both the target volumes and the organs at risk. While some medical expertise is required for the former ones, delineation of the latter could be automated, at least in theory, in order to spare time during treatment planning. Currently, the main approach of the problem is based on so-called atlases. The atlas consists of one or several template images of some patients, which are delineated beforehand. When the image of a new patient comes in and must be delineated, the atlas is deformed in a non-rigid way to match the new image and the deformed contours are then propagated. This approach is not entirely successful, mainly because it is difficult to model complex deformation between the anatomies of two different patients. Another approach that we have developed consists in training classifiers that learns to label pixels with the correct organ label. Preliminary experiments have been conducted, relying on pre-segmentation of the image into superpixels and computation of features. Then organs are tagged in an iterative/incremental way, one by one. First results show that this method works and can compete with atlases, although it requires more organ labels than these. A new project will start with a single classifier, in the form of a deep convolutional neural network.

3.9 Insight generation from biomedical data with flexible models

Paulo J. Lisboa (John Moores University – Liverpool, GB)

The talk focused on the need to interpret biomedical data models to gain insights and ascertain validity. To this end, specific methodologies were considered. First, flexible models of time-to-event data were shown to model the hazard ratios without recourse to assumptions of proportionality that are typically made in linear models. The resulting survival models give insights into progression of disease over time, with single and competing risks. Second, pn data typical of bioinformatics are susceptible to significant false positive errors and so require the use of specific statistical methodologies for false detection rate control. This is important both for classification and for clustering. Clustering models can also be sensitive to parameter choices, requiring the use of stability measures to ensure that the resulting clusters are robust. These methodologies were outlined and complemented by linear supervised visualization methods which are particularly suitable visualized high-dimensional clusters in low dimensions with little mixing. This was followed by a brief summary of convex non-negative matrix factorization methods to separate linear mixed signals, which was shown to have important medical applications fundamental signal processing method. Finally, the use of information geometry was shown to open-up non-liner classifiers by mapping them onto data structures, which provides a principled approach to patients-like-you representations for access and retrieval of relevant reference cases.

3.10 The stories told by breast cancer whole genome sequencing

John Martens (Erasmus University – Rotterdam, NL)

Joint work of On behalf of the FP7-BASIS consortium
Main reference S. Nik-Zainal, H. Davies, J. Staaf, M. Ramakrishna, D. Glodzik, X. Zou, I. Martincorena, L. B. Alexandrov, S. Martin, D. C. Wedge, P. Van Loo, Y. S. Ju, M. Smid, A. B. Brinkman, S. Morganella, M. R. Aure, O. C. Lingjærde, A. Langerød, M. Ringnér, S.-M. Ahn, S. Boyault, J. E. Brock, A. Broeks, A. Butler, C. Desmedt, L. Dirix, S. Dronov, A. Fatima, J. A. Foekens, M. Gerstung, G. K. J. Hooijer, S. J. Jang, D. R. Jones, H.-Y. Kim, T. A. King, S. Krishnamurthy, H. J. Lee, J.-Y. Lee, Y. Li, S. McLaren, A. Menzies, V. Mustonen, S. O'Meara, I. Pauporté, X. Pivot, C. A. Purdie, K. Raine, K. Ramakrishnan, F. G. Rodríguez-González, G. Romieu, A. M. Sieuwerts, P. T. Simpson, R. Shepherd, L. Stebbings, O. A. Stefansson, J. Teague, S. Tommasi, I. Treilleux, G. G. Van den Eynden, P. Vermeulen, A. Vincent-Salomon, L. Yates, C. Caldas, L. van't Veer, A. Tutt, S. Knappskog, B. K. T. Tan, J. Jonkers, Å. Borg, N. T. Ueno, C. Sotiriou, A. Viari, P. A. Futreal, P. J. Campbell, P. N. Span, S. Van Laere, S. R. Lakhani, J. E. Eyfjord, A. M. Thompson, E. Birney, H. G. Stunnenberg, M. J. van de Vijver, J. W. M. Martens, A.-L. Børresen-Dale, A. L. Richardson, G. Kong, G. Thomas, and M. R. Stratton, "Landscape of somatic mutations in 560 breast cancer whole-genome sequences", in Nature, Vol. 534, pp. 47–54, 2016.
URL http://dx.doi.org/10.1038/nature17676

The analysis of over 1100 breast cancer exome and over 500 whole-genome sequences has advanced our understanding of breast cancer in several ways. First, we now know that at least 93 protein-coding cancer genes carry probable somatically acquired driver mutations. And every breast cancer carries a median of about 3-4 driver gene mutations (range 1-8) in multiple signaling pathways relevant for the genesis and/or progression of breast cancer. Second, twelve different base substitution patterns are observed likely representing 12 different mechanisms responsible for the somatically acquired base substitutions in the breast cancer genome. The most prominent forces include 2 different age-related and 2 different APOBEC-driven mutational substitution patterns. Age-related patterns have been ascribed to unavoidable replication errors occurring in mammary epithelial cells during tissue maintenance; APOBEC-driven patterns are most likely due APOBEC enzymes (APOBEC3B and at least one other family member). The natural role of APOBEC enzymes is to protect tissue against e.g. viral infection mutagenizing the viral genome but for currently unknown reasons these enzymes are erroneously expressed in breast cancer harassing their own genome. Luminal breast cancer overexpressing APOBEC3B, and as a result having a higher mutational load, have an adverse outcome and are less likely to respond to endocrine therapy. Third, and on top of the somatically acquired substitutions, the breast cancer genome is characterized by several different types of rearrangements. Three rearrangement types, characterized by tandem duplications or deletions, appear associated with defective homologous-recombination-based DNA repair: one with deficient BRCA1 function, another with mostly deficient BRCA2 function, and a third of which the genetic cause remains unknown. Finally, intra-tumoral mutational heterogeneity is present in almost every primary breast cancer and usually comprises one dominant tumor clone but next to that several clonally related tumor subclones. Sequencial analysis of samples subsequently revealed that (pre-existent) tumor subclones can be resistant to neo-adjuvant chemotherapy while the dominant clone of the primary tumor is highly responsive. Also, rather than the dominant clone, a hardly detectable subclone can be responsible for the local or distant metastases. The clinical significance of most of these novel observations remains to be understood but we can speculate on it during the discussion.

3.11 Visual Reasoning with High-Dimensional Data

Klaus Mueller (Stony Brook University, US)

The growth of digital data is tremendous. Any aspect of life and matter is being recorded and stored on cheap disks, either in the cloud, in businesses, or in research labs. We can now afford to explore very complex relationships with many variables playing a part. But for this we need powerful tools that allow us to be creative, to sculpt this intricate insight formulated as models from the raw block of data. High-quality visual feedback plays a decisive role here. In this talk I will discuss various platforms we have developed over the years to make the exploration of large multivariate data more intuitive and direct. These platforms were conceived in tight collaborations with domain experts in the fields of climate science, health informatics, and computer systems.

3.12 Integrating and interpreting -omic features to reveal and define the complexity of human cancer

W. Kimryn Rathmell (Vanderbilt University School of Medicine, US)

Using renal cell carcinoma (RCC) as an example, recent high throughput sequencing efforts and analysis of gene expression datasets has revealed high levels of heterogeneity within this class of tumors. It has become clear that the renal cell carcinomas encompass multiple discrete diseases, originating from discrete regions of the kidney nephron, and with unique mutation and genomic attributes. Three recent publications of The Cancer Genome Atlas define the core features of these diseases: clear cell RCC, papillary RCC, and chromophobe RCC. A recent review summarizes these findings. Using expression data, we can subclassify these diseases further, for example the clear cell subtype can be assigned into clear cell A and B (ccA and ccB) subtypes. These subgroupings were developed as a part of an ongoing biology-informatics collaboration, ultimately leading to the development of meaningful subgroups that have important biological attributes. The ccA subgroup applies classical RCC expression features of angiogenesis and beta oxidation metabolism, and is a better prognosis group. The ccB subgroup, by comparison expresses genes associated with invasive growth, such as wnt and TGFbeta signaling. Not surprisingly, this set is independently associated with poor outcome. Many groups have validated these findings in multiple independent datasets, making this one of the only robust expression-based signatures useful in developing the prognosis of cancer. Work with these and other genomic datasets has begun to reveal the full complexity of this cancer, as subsampling has demonstrated that there is heterogeneity of the mutation profile within individual tumors, and has shown us that within one tumor there can co-exist numerous clones that have separate evolutionary phylogeny, and more disturbingly, that metastatic tumors can have even more divergency. Our exploration of the ccA and ccB subgroups shows that of these subsets, one often dominates, but that it is clear both subtypes can co-exist in a single tumor. Functional imaging using glucose uptake positron emission tomography can correlate metabolic signals with the ccB subtype feature set, allowing us to consider imaging-based strategies for knowing the state of disease in the whole individual. More recently, some of the major genetic features that have been linked with RCC include mutations in chromatin modifier genes. These defects play poorly understood roles in promoting tumorigenesis. Our recent work using alignment of shortread sequencing of non-protein bound fractional chromatin shows that major remodeling of the chromatin can occur, and may contribute to the overall evolution of the tumor. In particular, the loss of a single histone methyltransferase leads to the loss of one critical mark of actively transcribed genes, Histone H3 lysine 36 trimethyation. The ultimate impact of this feature disruption, which we have shown promotes tumorigenic phenotypes, on tumor progression molecularly is not certain. In summary, massive sequencing efforts have recently redefined the landscape of renal cell carcinoma, distinguishing between disparate disease types, shedding light on the intratumor heterogeneity and evolutionary strategies at play, and providing us with a new set of features that contribute to the development and progression of this set of cancers.

These findings leave us with an emerging list of questions:

- What additional features are deregulated in response to chromatin remodeling?
- Can modeling help us resolve the connections between histone marks, allowing us to "read" the sentences of the histone code, rather than merely the individual words?
- Recent work with immune checkpoint inhibitor therapy suggests this is effective in a significant proportion of patient. Is there any way to predict this response, or the durability of response?
- Can we use machine learning to understand the evolution of renal tumors?
- Can modeling help us predict the heterogeneity of a tumor, or the pattern of heterogeneity?
- How can we better quantify and use imaging parameters to help guide disease staging, prognosis, or therapeutic decision making?

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3.13 Integrating Expert Knowledge through Interactive Visualization

Timo Ropinski (Universität Ulm, DE)

Analyzing and interpreting imaging data is crucial for many disciplines in science, such as medicine or biology. In the past, two trends could be observed which helped to deal with the challenges involved in the image analysis process. On the one hand, advanced computer vision and image processing algorithms have been applied in order to extract information directly from the data. On the other hand, visualization algorithms have been exploited, which generate expressive representations of the data that allow the user to extract the relevant information by forming a mental model. Both approaches benefit from different capabilities. When applying computer vision based techniques, high throughput computing can be facilitated, while visualizations allow to exploit the robust pattern recognition capabilities of the human observer. While computing is performed with high accuracy and speed, visualization allows to better cope with noise as well as uncertainty and can also facilitate domain knowledge in a more direct way. In my talk I have presented synergies between the two approaches, and delineated compute capabilities and observe capabilities. By taking into account both, a more effective knowledge extraction from imaging data becomes possible. The discussed concepts are demonstrated with several examples from different compute intensive disciplines.

3.14 Learning in the space of models

Peter Tino (University of Birmingham, GB)

I will first introduce the general concept of the emerging field of "learning in the model space". The talk will then focus on time series data. After reviewing some of the existing model based time series kernels, I will introduce a framework for building new kernels based on temporal filters inspired by a class of parametrized state space models known as "reservoir" models. I will briefly outline the key theoretical concepts of their analysis and design. The methodology will be demonstrated in a series of sequence classification tasks and in an incremental fault detection setting. Finally, the framework will be extended to the "parametric case", where curial aspects of the data gene ratio process are known and the observations are sparse and irregularly sampled.

3.15 Visual Exploration and Analysis of Brain Connectivity: Approaches and Challenges

Gunther H. Weber (Lawrence Berkeley National Laboratory, US)

Joint work of Sugeerth Murugesan, Kristofer Bouchard, Jesse A. Brown, Edward Chang, Peter Denes, Max Dougherty, Bernd Hamann, William W. Seeley, Andrew Trujillo, Gunther H. Weber, Associate Member
Main reference S. Murugesan, K. Bouchard, J. A. Brown, B. Hamann, W. W. Seeley, A. Trujillo, G. H. Weber, "Brain Modulyzer: Interactive visual analysis of functional brain connectivity", in IEEE Transactions on Computational Biology and Bioinformatics, 2016, in press.
URL http://dx.doi.org/10.1109/TCBB.2016.2564970

The brain is a highly connected, dynamic system of specialized brain regions interacting in complex ways. Neuroscientists use a variety of technologies to explore connectivity in the human brain, including resting state functional magnetic resonance imaging (fMRI) brain scans and e lectrocorticography (ECoG). In this talk I present a combination of visualization techniques and methods from graph theory and analysis—such as community detection—for analyzing fMRI and ECoG data sets. Providing immediate feedback by displaying analysis results instantaneously while changing parameters gives neuroscientists a powerful means to comprehend complex brain structure more effectively and efficiently and supports forming hypotheses that can then be validated via statistical analysis. Furthermore, I discuss the challenges presented by visualizing clustering results and improved ECoG data acquisition technologies with a large number of recorded channels as well as higher sampling rates.

3.16 Cardiovascularvascular Diseases: From Data Generation to Analysis

Thomas Wischgoll (Wright State University – Dayton, US)

Cardiovascular diseases remain the leading cause of death in Western societies. This presentation will provide insight into the use of expert knowledge and models to derive diagnostic tools that have the potential to aid in the diagnosis of diffuse cardiovascular diseases that tend to be more difficult to detect in CT angiograms. In order to develop these methods more basic research is needed to prove the validity of the approach, including validation of accuracy as well as approach itself. For that, specimens of porcine hearts were prepared and then analyzed followed by a statistical comparison between computed and optical measurements. Similarly, a database of healthy and diseased patient data was used to showcase the effectiveness of the methodology.

3.17 Choice from Noise: Modelling Biology

Röbbe Wünschiers (Hochschule Mittweida, DE)

From a methodological point of view, gene technology is shifting towards engineering. While in the past, the elucidation of gene and gene product function was dominated by trial and error, the new paradigm in genetic engineering (in the framework of synthetic biology) is based on educated predictions. The necessary data come from systems biology and its accompanying methods, as well as from new high throughput methods in nucleic acid sequencing and protein/metabolite detection. These layers of information are used in modelling and simulation. Our research picks up this paradigm in the field of fermentative biogas production and photo-biological hydrogen evolution. During the seminar I tried to draw the attention towards pitfalls in data generation. In heterogeneous biological samples the extraction of biomolecules might be biased due to extraction techniques. This has to be accounted for in downstream data processing and analyses. Furthermore, most investigations limit themselves on transcriptomic data and assume that the abundance of transcripts is proportional to the activity of the encoded proteins, respectively. Post transcriptionally processing and regulations as well as other regulatory processes, e.g. transcript or genome editing, are usually not included. It can be expected that the collaborative interaction of scientists from different fields will help to overcome this shortcomings.

3.18 Integration and relevance analysis of heterogeneous factors for stratification in biology and medicine

Dietlind Zühlke (Seven Principles AG – Köln, DE)

In the talk a research support system is presented, that helps medical researchers to identify diagnostic result patterns that characterise pertinent patient groups for personalized medicine. Example disease is breast cancer. The approach integrates established clinical findings with systems biology analyses. In this respect it is related to personalised medicine as well as translational research. Technically the system is a computer based support environment that links machine learning algorithms for classification with an interface for the medical domain expert. The involvement of the clinician has two reasons. On the one hand the intention is to impart an in-depth understanding of potentially relevant 'omics' findings from systems biology (e.g. genomics, transcriptomics, proteomics, and metabolomics) for actual patients in the context of clinical diagnoses. On the other hand the medical expert is indispensable for the process to rationally constrict the pertinent features towards a manageable selection of diagnostic findings. Without the suitable incorporation of domain expert knowledge machine based selections are often polluted by noise or irrelevant but massive variations. Selecting a subset of features is necessary in order to tackle the problem that for statistical reasons the amount of features has to be in an appropriate relationship to the number of cases that are available in a study (curse of dimensionality). The cooperative selection process is iterative. Interim results of analyses based on automatic temporary feature selections have to be graspable and criticisable by the medical expert. In order to support the understanding of machine learning results a prototype based approach is followed. The case type related documentation is in accordance with the way the human expert is cognitively structuring experienced cases. As the features for patient description are heterogeneous in their type and nature, the machine learning based feature selection has to handle different kinds of pertinent dissimilarities for the features and integrate them into a holistic representation.

4 Working groups

4.1 Wiki "Experts Integrated"

Michael Biehl (University of Groningen, NL) and Friedrich Melchert (Fraunhofer Institut – Magdeburg, DE)

URL https://xprt.webhosting.rug.nl/

The wiki is meant to provide a platform for discussions, exchanging ideas, suggesting concrete problems, initializing collaborations etc. It offers discussion forums, file repositories, event calendar etc.

All participants of the Dagstuhl Seminar have been provisionally registered and should have received a corresponding notification. For completion of the registration process please visit the provided URL and make use of the *"User Wizard"* to set up account and profile.

In case of questions or if the notification was not received please contact Michael Biehl (`m.biehl@rug.nl`) or Friedrich Melchert (`friedrich.melchert@gmail.com`).

4.2 Matlab code available: Learning Vector Quantization, relevance learning and matrix adaptation

Kerstin Bunte (University of Birmingham, GB) and Michael Biehl (University of Groningen, NL)

Learning Vector Quantization [1] (LVQ) constitutes a particularly intuitive approach to prototype-based classification. An important conceptual extension is the use of adaptive distance measures, as for instance in the framework of Generalized Matrix Relevance LVQ (GMLVQ) [2, 3, 4].

An easy-to-use Matlab (TM) code collection for the simplest variants of GMLVQ is provided at http://www.cs.rug.nl/~biehl/gmlvq. The downloadable archive contains code for the basic training process, visualization of learning curves, and validation procedures. A brief documentation and example data sets are also provided.

A more comprehensive collection is available at http://matlabserver.cs.rug.nl/gmlvqweb/web/. It comprises several variants of LVQ and GMLVQ schemes, including supervised dimension reduction and local relevance matrices.

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Report of Dagstuhl Seminar 16262

Automotive User Interfaces in the Age of Automation

Edited by

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Abstract

The next big change in the automotive domain will be the move towards automated and semi-automated driving. We can expect an increasing level of autonomous driving in the coming years, resulting in new opportunities for the car as an infotainment platform when standard driving tasks will be automated. This change also comes with a number of challenges to automotive user interfaces. Core challenges for the assistance system and the user interface will be distributing tasks between the assistance system and the driver, the re-engagement of drivers in semi-automated driving back to the driving task, and collaborative driving in which cars collectively work together (e. g., platoons). Overall, in the coming years we will need to design interfaces and applications that make driving safe while enabling communication, work, and play in human-operated vehicles. This Dagstuhl Seminar brought together researchers from human computer interaction, cognitive psychology, human factors psychology and also from automotive industry and OEMs to discuss the new interface paradigms for (semi-)automated driving.

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1 Executive Summary

Andreas Riener
Susanne Boll
Andrew L. Kun

The next big change in the automotive domain will be the move towards semi-automated and automated driving. The pathway to autonomous driving supported by rapid advance of a wide range of novel vehicle-related technology presents industry, academia, and regulatory agencies with new opportunities and challenges in re-imagining human interactions in the vehicle. While expectations are high towards automated driving the revolution will proceed in incremental steps; with the progress of technology new tasks and driving phases will be supported by automation. All of this will unfold in traffic scenarios in which different levels of automation will coexist for many years in which user interfaces play a key role.

We see three core challenges for automotive user interfaces in the age of automation, which we have addressed during the seminar.

- **Transforming vehicles into places of productivity and play.** People in automated vehicles will be able to turn their attention to non-driving tasks some of the time, or even much of the time. This will allow user interface designers to explore a range of possible interactions, which are might be too distracting in manually driven vehicles. For highly automated vehicles our constraints will have to do less with the driver's attention to the road, and more with the characteristics of the vehicle, such as the area available for interaction, the motion of the vehicle, as well as its computational power and the sensors that are available in the cockpit. User interactions will include other people in the vehicle, but might also include people in other vehicles. Novel user interfaces may turn the car into an infotainment and entertainment platform in which the automation allows for new secondary tasks in the car with driver and passengers that were not possible before.
- **Re-engagement of drivers into the driving task.** As automated driving makes advances, drivers will often be able to disengage from driving, and safely turn their attention to a secondary task. But until our vehicles are fully automated, drivers will eventually have to re-engage in driving. As the non-driving tasks may vary in time but also in the engagement of the user, it will be a challenge to safely and timely return to the primary task. For handling a critical situation the driver must perceive, and act upon, a sequence of information and entities. This can be a complex maneuver in a traffic scenario but also a time critical course of actions in the treatment of an emergency case. Much work needs to be done on user interface design in order to make re-engagement in different kinds of situations and different kinds of complexity safe.
- **Collaboration in mixed traffic scenarios.** Traffic automation will come to the streets peu-a-peu. Thereby and for many years, mixed scenarios in which vehicles with no-, partial-, and full automation will coexist and cooperate in daily traffic. This road sharing involves communicating autonomous operations to the driver of the autonomous car and also a communication strategy to keep non-autonomous vehicles and their drivers in the loop. Road sharing means avoiding collisions, but automated vehicles will also cooperate, for example by traveling in platoons in order to save energy and improve the utilization of the road infrastructure. Research is needed to create user interfaces that allow for safe operation of the vehicle in all of these mixed traffic scenarios.

Along with these topics, we also discussed the role of trust, e. g., how user interfaces will support the communication of trust in typical situations with mixed levels of automation. We further discussed about future technologies in and around the car (e. g., novel sensors, interaction concepts, and feedback systems) and about the recent strategy change of automakers to fund apps and invest a lot in app development to make car dashboards/instrument clusters more sustainable.

This Dagstuhl Seminar brought together researchers from human computer interaction, cognitive psychology, human factors, psychology, and also from automotive industry and OEMs to discuss the new interface paradigms for (semi-)automated driving.

2 Table of Contents

3 Topics Discussed in the Seminar

Based on an in-depth understanding of the many needs of the individual driver(s), individualized design and human factors-centered design is expected to be "the success factor" for automated (maybe even autonomous) driving. Assuming further that stresslessness and wellbeing of the passenger (or, perhaps, the inactive driver in autonomous vehicles) will play a major role in the design of the transportation experience in future cars [1], the exploration of new quality aspects is an important research task to support the broad application of autonomous cars. In addition, autonomous cars may involve entirely new forms of interaction (with drivers, but also with persons in the exterior area) and new in-car services (e.g., sharing of experience changed interaction requirements (negotiation), and car-to-x communication on a broad scale. Driven by the identified research of future automotive user interfaces we will address the following topics in the seminar.

In advance to the seminar we asked the participants some fundamental questions in the area of the seminar, e. g., what they find to be the urgent questions in the coming age of automation, which work inspired them, or what papers they authored in the broader area of automotive UIs in the age of automation.

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3.1 Suggested Readings

Question 1: "What is some publicly available work (e. g., a paper, an app, a prototype, etc.) created by someone else that you find very inspirational in your work related to user interfaces in the age of automation technologies?"

Here is the summary of responses (for sure, some sources were mentioned more than once).

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3.2 Work Authored by Seminar Participants

Question 2: "What is one publicly available work of yours (e. g., a paper, an app, a prototype, etc.) related to the seminar topic that you would like to share with fellow Dagstuhl seminar participants? Please send us a PDF or reference/link."

Summary of responses:

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3.3 Research Questions

Question 3: "What do you consider to be the most interesting research question related to user interfaces for autonomous vehicles? (If you have more than one question, that's great, send them all.)"

The following list of questions (no particular order) was identified by seminar participants before meeting at Dagstuhl and used to structure the seminar and initiate discussions in the field.

- How do we need to design UIs to support adequate situation awareness when driving (highly) automated vehicles?
- How can the automated vehicle act as a cooperative team player and how can this be supported by the UI?
- How can the UI support the development of adequate trust in automated vehicles?
- How can autonomous cars improve life? An increased mobility is expected to be available when autonomous cars are on the road. How can they be part of a better life? How can an autonomous vehicle be integrated harmonically in everyday routine? Once this is explored, designing interventions for the detected scenarios will be more targeted and meaningful. Older drivers who still wish to maintain their driving ability, passengers who are not interested in driving or find it non-ecological or mobility-impaired individuals who will find benefit by the presence of such cars are example personas to design for.
- What are the expected interactions in the car?
- Will the autonomous car be used as a mobile living room? Or maybe as a mobile office?
- How can autonomous cars promote a sustainable society?
- If autonomous transportation becomes a service, as has been suggested, then there is a big change to be expected in mobility. If having one car for many people (even more so an electric car) is more sustainable than having one car per family or per person, why not encourage this? This direction of sustainability in autonomous cars is very promising and little explored, while the persuasive research potential is exciting.
- Can the driver's attention be recaptured by a well-designed DVI after the driver has been doing something other than driving in an SAE Level 3 automated vehicle, and if so how quickly and under what conditions?
- Can driver abuses of SAE Level 2 and 3 automated driving systems (well documented in YouTube videos for available Level 2 systems) be deterred by suitable DVIs, and if so how? What information does the DVI in a highly automated vehicle need to display to the driver and vehicle occupants in order to give them adequate confidence in the competency of the automated driving system?
- How should a highly automated vehicle communicate with vulnerable road users (pedestrians and bicyclists) about its awareness of their presence and its maneuver intentions?
- Under what conditions (if any) should the DVI delay or prevent the driver from stopping or re-taking control of the motion of a vehicle that is being driven by an SAE level 4 or 5 automated driving system?
- These are the three high-level ones I usually set to my students in a lecture I give each year on "HCI in cars" ... For me these are all critical to the success of fully/highly automated vehicles
- How do you design the Human-Machine Interface for automated driving functionality? – including the management of transition periods/warnings, and provision of shared situation awareness for vehicle/driver.
- How do you design the Human-Machine Interface for non-automated driving functionality? – given the freedom for radically different vehicle interiors?
- How do you design the vehicle as a whole as a Human-Machine Interface? For instance, considering how the vehicle communicates its intent to other road users.
- What is the future of Autonomous UI: dull standardized UIs or dynamic, adaptive highly personalized interactions? How can we design a system that allows UIs in Autonomous vehicles to support ALL possible personalized interactions?
- How can we allow for coexistence of automotive UI regulations and personalized information desires when driving is not the primary task?

- What is the right UI approach to move cognitive resources from a non driving to a driving task and what control mechanisms do we need to develop measurements for? Conversational agents are increasingly popular (Siri, Alexa, Cortana, OK Google) are autonomous cars going to produce similar systems like the ones depicted in Science Fiction (KITT, HAL, Jarvis, etc.)?
- What strategies can UI follow to condense and explain effectively highly complex driving scenarios to an unprepared/untrained human driver?
- How removed do users expect to be from the perception-action loop of driving in order for automated driving to be an appealing option?
- How frequently will the user fatigue of (which) non-driving activities and feel compelled to re-evaluate the driving mission (for which aspects)?
- What is an appropriate level of user activity to ensure sufficient user arousal without handicapping vehicle take-over? To what extent can we already measure this from device interactions without the use of physiological measurements?
- Some futurists predict we will not own our car any more in near future. But we can just pick and drive any car in front of our house. If the cars are all equipped in the same way and shared with everyone, and so there is no more "personal" car, how can we "pick" a car and customize it into "my car" when pick? (just put our mobile phone/sim card into the deck?) DeepMind has recently developed a "big red button" to prevent its AI from causing harm. When and how can we stop/turn off AI of the car?
- How can the design of a human machine interface in highly automated driving assist drivers in the transition from driver to passenger role and vice versa?
- How to keep drivers aware of the driving context while they engage themselves in other secondary tasks? What information and presentation forms can increase human's trust in automation?
- How to communicate the intentions of a fully automated vehicle to other non- or semi-automated cars in a mixed traffic situation?
- How can the car become a more central part of people's information lives?
- How can experiences in the vehicle broader our understanding of interaction and emotion?
- How can cars understand and respond to differences in culture and individual preferences in interaction?
- What is expected from interactive cars in long-term relationships with users?
- How do we best approach user testing, in terms of: (a) longitudinal testing (and finding the unexpected use cases), (b) exploring ways of inducing AD experiences by means of non AD-technology?
- How can autonomous cars provide long-term value, i.e. by services, future designs?
- How can we avoid mode confusion and over/under trust, in the process towards fully autonomous cars?
- How do we approach a more holistic communication by the car than predominantly only the visual/audio HMI? I.e. to whom (the "driver" or all passengers?) and by what (how/should we make more use of the vehicle as a whole)?
- According to some statistics in the Western world we'll soon have 50 percent of the drivers licence holders being older than 60–65 yrs: what will be an intuitive automotive user interface/interaction that takes care of legacy habits of a population that learned how to drive when there were NOT Smartphones, Touchscreens, Internet. What are their expectations to feel involved and not disengaged, to develop an appropriate level of trust in the growing automation?

- What are opportunities for keeping the driver in the loop and establish a kind of shared control between user and vehicle?
- How are we going to inform the user about the capabilities of the vehicle (enable the user to build a mental model of the system)? Related questions here are what the users needs are in this respect and how they may change over time as a function of exposure
- Given that autonomous vehicles will capitalize on safety, we may expect that other road users may start to abuse AV technology (in particular, other road users like pedestrians, bicyclists and drivers of non-autonomous vehicles may take advantage of the fact that an autonomous vehicle will have a very defensive driving style). How can we develop the technology such that we find a proper balance between the interests of the users and the interests of other road users?
- How to provide drivers/users (not only in cars) with appropriate levels of transparency and control when interacting with intelligent automated vehicles/systems Ready for a cruise? How to tell an autonomous car where to go
- Is there an uncanny and unsafe valley (of automation) between partial and high automation? Is the region which SAE calls conditionally automated already in the unsafe valley?
- How can we secure the unsafe rims of the valley and build a bridge of safe transitions across the valley?
- What can we do while we drive/are transported with autonomous vehicles?
- How to implement reliable real-time trust calibration in vehicles?
- How could a vehicle provide training to maintain a driver's driving performance?
- How can automated cars provide "driving fun"?
- Driver or Pilot – how to obtain a driving license in the future?
- How do we support drivers to stay in-the-loop and take over in case of emergency?
- How we can get people to feel in an automated vehicle like as sitting in a public transport? Does a antromorphized car concept improve peoples trust in automated vehicles?
- How can evaluation processes of the experience with automated vehicles adapted into the practical work of the industry?
- Identity spoofing – Can driving patterns/profiles (or inspection of driving style) help to uncover faked identities (i.e., normal car pretending to be an emergency vehicle and getting right of way all the time?)
- Overarching question: How do we keep situations of shared or distributed control safe for humans? This has sub-questions such as "How do we keep the human in the loop and aware of their surroundings?" and "What is the fastest and most accurate way to communicate information from the car to the human?".

4 Contributions by Seminar Participants

4.1 Crafting the Foundation of Autonomous Vehicles User Interfaces

Ignacio Alvarez (Intel – Hillsboro, US, ignacio.j.alvarez@intel.com)

The Dagstuhl Seminar on Automotive User Interfaces in the Age of Automation has brought to public discussion the differences and similarities in perspectives, problems, focus and solutions existing in automotive user interface in a multicultural variety of professionals from academia and industry. The introductory talks and discussions made clear that we all share common problems and questions such as trust in autonomous systems, data collection, simulation, creation of scenarios, tools and methods. There are fundamental differences in how we define terms, what methods and tools we apply and how we approach scenario creation and simulation from practices in UI Design / Human Computer Interaction, Psychology, Human Factors and Systems Engineering. However, we proved that exercising focused discussions for agreement and cross-field mapping of definitions and methods we can start to create a framework for common understanding and positioning of our individual research contributions. This has helped us understand our own limitations and the potential or collaborative work. This seminar has created an approach, from a multidisciplinary perspective, to the symbiotic relationship of a highly automated vehicle and human passengers / operators. There are multiple gaps we still need to bridge and evangelize across both industry and academia to design and develop the user interfaces of the next generation of automated vehicles but we have successfully identified common trends in agency and control mechanisms and value propositions. We have also agreed on methods, metrics and systems and the tools that we need to develop to accelerate the adoption of autonomous vehicles.

Main Research Fields: Automotive, HMI, Human-Centered Computing Artificial Intelligence, User Experience.

4.2 Automated Vehicles Should Be Team Players!

Martin Baumann (Universität Ulm, DE, martin.baumann@uni-ulm.de)

My vision of an intelligent automated vehicle is a system that behaves as a team player. This means that the automated vehicle does not substitute the human driver but acts as a supportive agent for the human driver in the driver-vehicle-system. It is transparent, flexible, adaptive, and reliable and possesses a high interactive competence. It takes over control of the driving as much as the driver desires or needs, keeps the driver in the loop if necessary, communicates efficiently, explains in an appropriate way its status, behavior, intentions, and is able to adapt both to the individual driver and the current and upcoming traffic situation. I strongly believe that only with such an automated but interactively competent vehicle it is possible to create a driver-vehicle-system that shows optimal, robust and safe performance by exploiting the strengths and counterbalancing the limitations of each partner in an efficient way.

Main Research Fields: Human Behavior in HMI, Human Factors, Cooperative Driver Assistance and Automation, Cognitive Psychology.

4.3 Attention Shift in Automated Environments

Susanne Boll (Universität Oldenburg, DE, Susanne.Boll@informatik.uni-oldenburg.de)

Even with greatly increased automation in the future, the human will need to be in the loop for monitoring. However, interaction with cyber-physical systems like cars, ships, robots, smart homes, or emergency rooms will change dramatically: (1) humans will interact much less frequently with the larger automated cyber-physical systems than with today's simpler automated systems; (2) human interaction will be needed to a much greater extent for tasks in which the human is superior to the machine and where automation finds its limitations; (3) humans will be free to dedicate more and more of their cognitive resources to other tasks, with their attention shifting only when needed to interact with the automated system.

Future automated cyber-physical systems need to address the challenge of interaction with the human for efficiency and safety under this new paradigm of interaction and shared control. Interfaces currently addressing these requirements for decision making are rather primitive, mostly limited to single, unspecific alerts and auditory cues for gaining and dragging the attention to information and entities. Frequent, often unspecific alerts are leaving the human with the demanding task of identifying and localizing the problem. In the future intelligent attention management will be crucial to successful cooperation between human and machine.

Main Research Fields: Multimodal pervasive interfaces, peripheral and ambient displays for attention shift.

4.4 Research Needs for Designing Vehicle Automation to Be Safer Than Drivers

Linda Ng Boyle (University of Washington – Seattle, US, linda@uw.edu)

Automation is changing the nature of driving. Our vision for the future is often constrained by our knowledge of how things work today given existing infrastructure, policies, and our perceptions of "what is driving". Developing "out of the box" solutions implies that we know how to examine the impact of vehicle automation in the context of the user, vehicle, and environment. There are several key research areas related to the users' ability to adapt appropriately to increasing levels of automation. This includes appropriate trust in the automation, willingness to use, and the operators' ability to be aware of changes in the vehicle state. The changes can include varying levels of automation at the strategic, tactical, and operational level. Drivers' use of automation and their ability to adapt to varying levels of automation is greatly impacted by their experience with the system; which can change negatively, positively, or not at all (Peng and Boyle, 2015). A classification framework for examining human-autonomous interactions is important for future research, one that considers the agents, scenarios, and environments

Main Research Fields: Human Factors in Driving Assessment, Driving Behavior Analysis, Crash and Safety Analysis, Statistical Modeling.

4.5 Driver-Vehicle Communication as the Key for Future Automation

Nora Broy (BMW Group – Garching, DE, Nora.NB.Broy@bmw.de)

Automation plays an increasing role in our everyday life. From switching in telephone networks over automated processes in the industry to the steering and stabilization of ships and aircraft, there are various recent and emerging applications with minimal or reduced human intervention. Also the automotive domain faces a paradigm shift to automated driving which will have a significant impact on our everyday life, our relation to cars, and our mobility behavior. As the automated car offers fantastic possibilities for comfort and safety it also gives the drivers valuable lifetime in order to increase their productivity or to simply find some time to relax while approaching different locations. However, the automation of the driving task will never be perfect, in particular regarding the upcoming decades. Both humans and machines have certain imperfections that make the "driver" vehicle communication as a key for the future of automated cars. I am curious about to see exciting and innovative user interface concepts that contribute to driver vehicle collaboration. In particular, it is necessary that the driver can better understand the complex automation of the vehicle in every situation but also the vehicle has to know its driver and their capabilities. It is up to us HCI and human factors researchers to identify the optimal UI design parameters which ensure an ideal interaction between the automated car and the "driver(s)".

Main Research Fields: Human Factors, Human Machine Interaction.

4.6 Eyes off the Road: How Autonomous Vehicles Will Change In-Car Activities

Duncan Brumby (University College London, GB, d.brumby@ucl.ac.uk)

Just as the arrival of the car more than 100 years ago changed the way that we lived in the past, so the arrival of autonomous vehicles has the potential to profoundly change the way that we live in the future. In the short-term autonomous vehicles hold the potential to alleviate some of the problems currently associated with driving: allowing greater packing of vehicles on highways to ease congestion and freeing the driver from mundane control activities to engage in more rewarding work and leisure activities. In the longer-term there will be further, as yet unimagined, opportunities that will emerge following the mass release of autonomous vehicles on to our roads. The purpose of this Dagstuhl seminar has been to discuss critical issues on the path to an autonomous driving future. For me, the most critical issue is how to manage the handover situation between drivers and automated cars when the driver is immersed in an unrelated activity (i.e., watching a movie, working on a document, having a video chat, etc.). This need was brought into focus today with the tragic news that a person has been killed in a crash while driving with Tesla's "Autopilot" active. The accident occurred when a tractor trailer drove across the highway "against a brightly lit sky". The brakes were neither applied by the Autopilot nor the human driver. How can we design better human-machine interfaces to avoid tragedies occurring again.

Main Research Fields: Multitasking and Interactive Search.

4.7 HMI Design for 2020 and Beyond

Gary Burnett (University of Nottingham, GB, gary.burnett@nottingham.ac.uk)

The research community in Automotive HMI needs to consider how to design interfaces for automated, non-automated driving functionality, as well as the design of the vehicle as a whole HMI for other road users. The HMI, for future vehicles will depend considerable on the level of automation. Whilst there is still a requirement/ desire to manually drive, HMIs will have to be highly adaptive/ adaptable to cope with the move between different ways of the vehicles. Also to deal with the transfer of control issues, an HMI will need to facilitate considerable mutual situation awareness. There is growing desire that a natural language HMI combined with full windscreen Head Up Displays/ ambient displays provide significant potentials for successful outcomes. For fully automated driving, the scope for radically different interiors is much. In this respect, there is a considerable scope for the vehicle to allow more physical movement and use of our bodies, rather than the constrained posture we currently encourage in a car. Many drivers experience considerable problems with their lower back and our sedentary lives lead to rising obesity levels and poor health/ quality of life outcomes. This workshop in Dagstuhl has been extremely rewarding as a mechanism venue for discussing such issues with interesting people in a beautiful location.

Main Research Fields: Human Factors in Transport, Driving Psychology, ADAS, Future of Traffic.

4.8 Driving Headlong into the Uncanny Valley of Automated Driving

Lewis Chuang(MPI für biologische Kybernetik – Tübingen, DE, lewis.chuang@tuebingen.mpg.de)

We expect machines to perform tasks just as we would ourselves, only safer, faster and with less effort. For example, we rightfully assume that shovels move piles of dirt at a faster rate than we could with our bare hands by virtue of their larger "hands". Assuming task competencies by analogies to our own capabilities will not be valid with regards to artificial intelligence, as with self-driving cars. This is because we tend to misunderstand the architecture of our own minds. Artificial intelligence present the semblance of superior human intelligence. Every demonstration of automation in automobiles, from gear transmission to lane change maneuvers to route-planning, further perpetuates the illusion that we are within reach of a cheap equivalent of a human chauffeur. Unfortunately, the algorithms that underlie such technologies are unlike our own minds. Falsely believing that "they" are like "us" could result in subsequent disappointments as we slowly recognize how alien "they" are to "us". As a neuroscientist, I intend to contribute to the field of automated driving by working towards a better understanding of how humans are able to operate automobiles in the first place.

Main Research Fields: Cognition and Control for Man-Machine Systems.

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4.9 H(orse)-Metaphor, Cooperative Automation, Unsafe Valley of Automation and Other Potentially Useful Concepts for Automated Vehicles

Frank Flemisch (Fraunhofer FKIE – Wachtberg, DE, frank.flemisch@fkie.fraunhofer.de)

Almost two decades ago, I threw the spear of intuition into the jungle of automation, and found: a horse. Expedition after expedition, we tamed the horse, developed stirrups and raddle, befriended a whole herd of horses, found mountains of good cooperation, and unsafe valleys of control loss. We documented as thoroughly as possible, but plenty of questions open to explore.

Two decades later at Dagstuhl, with gray hair, I met a colorful tribe of new and old explorer of the jungle. I had five minutes to tell a thousand stories, and failed. My ears, tuned to silent snorts in the distance, were stressed by the noise. How can we ride big waves of innovation and keep our sensitivity? Maybe with good wine and theater play, happy to meet old and new friends.

In our live long exploration of the jungle, in search of a good balance of humans, machines and spaceship Earth, we should beware of the false gods out of the machine, and enjoy our company.

Main Research Fields: Cooperative Automated Driving, Driver Assistance Systems, Human-Machine Interaction.

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4.10 Automated Driving Evolution: from Concrete to Wild Ideas!

Anna-Katharina Frison (TH Ingolstadt, DE, anna-katharina.frison@thi.de)

How is the state of the art of automated vehicle concepts? What are the main topics researchers are interested in? Which methods can be used to generate and evaluate automated driving UI concepts? These were my question I had before coming to Dagstuhl, with a vision of continuous testing application in automated vehicles, which evaluates the passengers experience in a loop and reacts at once by adaptions of the system.

Within the seminar week we collected topics, discussed them and generated and visualized new ideas. All this helped me to answer fragments of my questions.

The state of the art of automated driving seems to be controversially discussed by concrete ideas and concepts which can be already tested with simulators and in the wild, other topics are discussed generally from an overall perspective, e.g. why we are doing "this" (= automated transportation including all levels)? About higher levels of automation, only assumptions can be done, and specific problems concerning methods can only be solved by generative and formative methods. My vision about a continuous evaluation system in an automated vehicle with just-in-time adaptions need a more general contemplation of methods and the special needs of automated vehicles with observing and keeping the evolution of automotive user interfaces in mind.

Main Research Fields: Automated vehicles, Human-Centered Design, User Experience Evaluation Methods.

4.11 Distraction in the (Semi-)Autonomous Car

Christian P. Janssen (Utrecht University, NL, C.P.Janssen@uu.nl)

In a future where vehicles are automated, there might still be situations where the vehicle is (a) not able or (b) not allowed to execute all aspects of a drive. In these instances, the human driver might need to take over or assist the system. To be successful, a driver is required to have some awareness of the situation, and to react in a timely and appropriate fashion to a request by the system. A challenge in this regard is that drivers might (up to that point) not be fully engaged with the driving task in an automated vehicle.

Research has shown that people multitask and (get) interrupt(ed) in many situations (e.g., [1]). This includes distraction in the car (e.g., [2, 3]]). Moreover, initial studies suggest that multitasking and distraction increases with an increase of automation of the car [4]. In the end, with an increase of automation, drivers are less aware of their surroundings and take longer to respond to critical incidents.

This suggests that more research is needed on understanding human attention, multitasking, and distraction in automated vehicles. To be successful, insights are needed on how to measure human behavior, perception, cognition, and actions, as well as on how to predict the impact of human action on traffic system and safety. Such research can then contribute to the prevention of accidents. For example, by helping the user to dedicate sufficient attention to driving or by detecting a lack of attention.

Given the complexity of the problem, a multi-disciplinary perspective is needed (cf. [1]). In this way, careful consideration can be given to systems, humans, design, and safety. The Dagstuhl workshop was fundamental in this regard, as it brought researchers from different disciplines together to identify the key areas that need to be investigated. I look forward to contributing to this exciting area myself. The input that I hope to provide to the community is interdisciplinary as well, including insights from neuroscience (e.g., [5]), applied research on the impact of user interfaces on driving (e.g., [5, 6]), and predictive formal models of cognition (e.g., [7, 8, 9]).

Main Research Fields: Human-Computer Interaction, Cognitive Modeling, Multitasking, Driver Distraction, Human Behavior in Automated Vehicles.

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4.12 Inclusive Design of Automated Vehicles

Myounghoon Jeon (Michigan Technological University, US, mjeon@mtu.edu)

From the traditional Human Factors perspective, a variety of research space on automated vehicles has been identified, including safety, fuel efficiency, trust, complacency, take over, etc. Another critical point is "mobility improvement" for those who used to not drive: e.g., people with disabilities (not able to drive), older adults (gradually losing the ability to drive), and children (not allowed to drive). In a similar way to the first and second waves, these populations have often been excluded in the third wave of "information revolution" (i.e., digital divide). We are interested in "inclusive design" for these people to prevent "automation divide" in the upcoming fourth wave of "AI or Automation" revolution era.

To discuss further, we can think of different scenarios. Even in the "fully automated vehicle" concept, the situation could vary. For example, on the one hand, drivers (or occupants) still "have to" be involved in the loop if the system is not perfect. On the other hand, drivers still "want to" be involved in the loop even though it is not necessary. In either case, an inclusive design approach leads to important research questions.

1) In the "have to" be involved case, are these populations allowed to be in the loop? It is rather a "hard" problem because it would require drivers to be involved in the "maneuvering" level (e.g., blind or older adults for lane keeping when sensors for road markings fail) and/or "control" level (e.g., children or people with mobility disabilities for accelerating/braking when the auto-cruise control fails). 2) In the "want to" be involved case, these people do not need to be engaged in the loop, but they can just ride or transport in a "train-like" concept. Another possibility is that they want to be in the loop, which asks the system to be polite enough to accept the driver's engagement even in the non-necessary case. Then, we need to consider how they could/should/would be involved in the process; whether it is just passive involvement, such as being provided with consistent situation updates or it is more active involvement in which they interact with vehicles by negotiating and making joint decisions. As discussed, this inclusive approach requires more fundamental questions to be answered about the automation concept as well as what type of user interfaces with which modalities we design for them. Moreover, this inclusive design approach is expected to provide a more

comprehensive perspective to prepare futuristic automation services, which will also result in better system design for traditional drivers.

Main Research Fields: Human-Computer Interaction, Affective Computing, Automotive User Interfaces, Driving Psychology, Assistive Technology.

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4.13 Using Design to Understand Interaction with Automation

Wendy Ju (Stanford University, US, wendyju@stanford.edu)

Due to Google [1] and Tesla [2], automated driving has gone from being a fantastical possibility to a practical reality in a short period. The advent of automated driving has important implications for the automotive user interface. To better understand these implications, we might ask: How should the vehicle respond in real-time to changes in the driving environment and the driver's state? How will autonomous vehicles determine and respond to regional and cultural differences in driving style? and How can the car leverage user modeling and adaptation already taking place online and on personal mobile devices?

At Stanford's Center for Design Research, we are performing research on shared control with automation, the driver experience with automated driving, and the opportunities for learning and adaptation in the cars of tomorrow. We are looking to use design research techniques to understand how people will respond both in [3] and out [4] of the car. Methodologically, we employ on-road platforms, in-vehicle experiments, wizard of oz protocols, novel simulator environments and online studies. Moving forward, we seek to define new research areas in autonomous vehicle HMI, to understand methods and measures to be used in autonomous vehicle interaction studies, and to generate cross-cultural and transnational research methods.

Main Research Fields: Human-Robot Interaction, Interfaces for Automated Vehicles, Interactive Device Design, Interaction Design.

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4.14 Transforming Automated Vehicles into Locations for Work and Play

Andrew L. Kun (University of New Hampshire – Durham, US, andrew.kun@unh.edu)

When will cars be truly automated? When will we be able to simply summon a vehicle, and instruct it where to take us, without having to worry about actually driving ourselves? While we do not know the answer to this, it seems fair to say that this day is upon us. Automation is making rapid progress, and there are clear reasons to pursue it aggressively. First, there is safety: an automated vehicle will not fall asleep, it will not be drunk, and it will not be distracted by a text message. Thus, we can reasonably expect that automated vehicles will be safer than human-operated vehicles.

But, there are very good reasons to embrace automation beyond safety. After all, the vehicle can now be transformed into a place where passengers (and we will all become passengers, not drivers), can utilize their time in many different ways. Two of the likely ways are work and play. However, there are many questions regarding the design of the in-vehicle user interfaces for such safe automated vehicles, and a number of these questions were discussed at the Dagstuhl seminar. Relevant questions include, how to design interfaces to promote work and play utilizing the space, computational power, location with respect to other vehicles, as well as without passagers experience motion sickness.

Main Research Fields: UI for Ubiquitous Computing, Cognitive Load in In-Vehicle Settings, Human-Inspired HCI Systems.

4.15 Why Are We Doing This?

Andreas Löcken (Universität Oldenburg, DE, andreas.loecken@uni-oldenburg.de)

I came to Dagstuhl to learn about user interfaces for automated driving. My question was “WHY” or “do we actually need an interface for drivers/controllers/owners, if the car is driving all by itself”. Further, I was interested in which new interfaces we will need. For example: “how can we visualize the car’s mode to other traffic participants and/or the passengers” or “should we communicate the car’s intention, situation awareness, certainty of assessment, etc. in order to increase the driver’s acceptance of, or trust into the automation”. I had very interesting discussions on which information need to be communicated, which driver’s characteristics might be relevant and how to design or test the interaction. I learned much about how researchers with different backgrounds see the problems and where we need to have better terms to be able to discuss more efficiently. I really enjoyed getting to know many smart people and am looking forward to continue the exchange after the seminar. Thank you Andreas, Andrew and Susanne, and also thank you to Dagstuhl!

Main Research Fields: Ambient Automotive Displays.

4.16 To Be Aware or Not to Be Aware, Is That a Question?

Rod McCall (Luxembourg Inst. of Science & Technology, LU, roderick.mccall@list.lu)

Autonomous vehicles open up a whole range of opportunities for the occupants ranging from being able to work or sleeping. However, these new possibilities bring challenges especially as the "driver" may be asked to take back control under certain conditions. We therefore need to map out how vehicles and occupants can create a shared situational awareness, so that both can understand each others abilities, limitations, and current contextual model. Related to this we need to understand the impact of the new possibilities on the construction of situational awareness and which approaches and technologies can be used to overcome the challenges highlighted earlier. There is also a need to discuss and examine the basics of cockpit design.

Main Research Fields: Automated Driving, Augmented Reality, Commuter Behavior, Gamification in Transport.

4.17 A View from the Other Side, Or: the Risk of Driving Blindly on the Road Towards Autonomous Driving

Alexander Mirnig (Universität Salzburg, AT, Alexander.Mirnig@sbg.ac.at)

Coming from an Analytical Philosophy background, I always find it beneficial for all parties involved (and like it personally, I must admit), when things are clearly defined and well-structured. In automated driving research, a good number of concepts, ideas, and even dreams meet, which are not all necessarily compatible with each other. This ranges from automation vs. autonomy (and which of the two we actually want), all the way down to the different levels of automation, where we tend to mix levels, depending on the argument we are trying to make. Want to sell the idea of automated driving to someone? Describe an SAE level 5 scenario with 100% penetration. Want to talk about the current state of usable technology and research? Talk about a fully level 3 scenario. Want to scare someone away from automated driving for years to come? Describe a realistic mixed traffic scenario, with drivers of all skill levels, vehicles of all automation levels, and everything this explosive combination implies. What are our real expectations of automated driving? Is it really "just" about safety and sustainability? What about fun? efficiency? or even vanity? And what about the shift from normal to automated driving? We can't expect to simply flip a switch and skip the mixed traffic phase (which might be considerably longer than we currently anticipate). Many uncertainties and potential hazards in manual traffic are solved via eye contact or estimating the other drivers' behaviors. But if a vehicle has no driver at the wheel or if said driver is reading a book, then how does one execute the normally simple task of establishing eye contact? Similarly, how does one learn and adequately interpret the (standard) behaviors of an automated vehicle? This is only the tip of the proverbial iceberg and it requires a discipline-crossing effort in order o untangle the web of concepts, ideas and expectations surrounding the (sometimes a bit too) intriguing phenomenon of automated driving.

Main Research Fields: Cross-Discipline Knowledge Transfer, Intelligent Handovers in Automated Vehicles, Philosophy of Science for HCI and Definitions.

4.18 New Perspectives on Autonomous Driving

Sebastian Osswald (Audi AG – Ingolstadt, DE, sebastian.osswald@audi.de)

First of all, I really enjoyed getting to know so many new people in the same field of research/interest and meet with colleagues from all over the world I knew before. Dagstuhl provided a great environment for this and the rather remote location is perfect for such a seminar. From an research perspective, it was really great to discuss the up to date topic autonomous driving with so many people from different disciplines. It is very interesting to monitor how oneself is limited sometimes in not being able to change the perspective towards a certain topic. The seminar was further really well structured and the lively group work with so many demonstration videos ended very well. I am looking forward to continue the exchange in the following year and the next seminar.

Main Research Fields: Future User Interfaces and Mobility Concepts, User Behavior, Multimodality in Transport.

4.19 Living Room on the Move? Researching the New Car Space

Ingrid Pettersson (Volvo Cars & Chalmers – Göteborg, SE, ingrid.pettersson@volvocars.com)

As an industrial PhD student from Volvo Cars and Chalmers University of Technology, I research methods for user experience design and evaluation, where autonomous driving provides an interesting study case ([1], [2]). Autonomous vehicles needs to be developed in line with human needs and capabilities, and I find that concepts such as trust [3], emotions and experiences are especially important to explore in relation to the autonomous driving. I believe it is important to explore about how these systems are learned and adopted over time. Thus I am especially interested on how we best approach user testing, from the early explorative studies to longer-term, more directed studies. Furthermore, the introduction of the technology provides a need as well as a possibility to rethink the in-vehicle space and the communication between the car and users.

Main Research Fields: Interaction Design with Focus on Automotive User Experiences.

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4.20 Non-Driving-Related Tasks in Mixed Traffic

Bastian Pfleging (LMU München, DE, bastian.pfleging@ifi.lmu.de)

Automated driving will change how we get from A to B. For the first time the driver will not have to perform the (traditional) driving task during all times of the ride. This will have implications for the automotive user interface due to multiple reasons. On the one hand, the system needs to optimally support hand-over and take-over situation when switching between different levels of automation and shifting responsibility between driver and vehicle. On the other hand, one important aspect are the non-driving-related activities ([1] , e.g., office work, communication, relaxation, media consumption) since drivers want to make use of the time when they do not have to maneuver or monitor the car. Performing such activities poses many questions: Which activities do drivers want to perform while driving automated? Which activities will drivers be able perform during automated driving due to legal, technical or human limitations (e.g., to prevent motion sickness or to ensure safe take-overs)? How can we adapt the cockpit and the user interface to support such activities? Can we design activities in a way that they can be continued seamlessly when switching to lower levels of automation? I expect that the set of supported non-driving-related activities will be a major feature when distinguishing different vehicles and brands. Therefore, it will be important to understand and shape this novel aspect of automotive user interfaces.

Main Research Fields: Multimodal Interaction, Natural User Interfaces, Non-driving-related Activities in Automated Driving.

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4.21 Autonomous Cars: What Will We Do with the Free Time?

Ioannis Politis (University of Cambridge, GB), i.politis@eng.cam.ac.uk

Autonomous cars are a major accomplishment of transportation. In my previous research the main case of focus was the handover of control between the car and the driver. In this situation, the research question was the unexplored topic of how the driver could be effectively informed about the handover (handing control to the car) or takeover (taking control from the car), while their attentiveness maintained. To address this, I envisioned a set of possible situations where a handover would be necessary and designed a set of language-based warnings for these situations. Presenting the cues to distracted drivers in an autonomous car simulator, I found that they were considered appropriate for the situations they addressed, while their urgency was recognized by drivers. In this way novel guidelines on how to provide warnings during an autonomous handover of control were provided ([1, 2]). My interest in autonomous cars also motivated me to be part of a workshop series on user experience of autonomous driving ([3, 4]). A clear outcome of the discussions during these workshops was that autonomous cars will be ubiquitous in the future, introducing the need to design new in-car interactions. The big challenge recognized is how society will use these vehicles, how they will be integrated in everyday life. This motivates exciting research directions; as driver engagement will become sparser, the resources freed will offer a variety of possibilities to utilize time in the car. The parallel blooming of the electric vehicle industry creates even greater implications on sustainability if autonomous cars become mainly electric. There have been views that the autonomous car will no longer belong to one driver. Transportation will rather be provided as a service, changing the traditional model of a personal vehicle. If this will be the case, how will a shared car integrate in the commuting routine and how will society choose to use it? If again not, how will the drivers and their peers use their free time in their personal autonomous car? The consideration when attempting to answer the above will primarily be around societal needs, the driver's mental model and the specifics of the task of operating autonomous vehicles. Interventions exploring this vision can then be created and iterated, in order to provide clear propositions on using autonomous cars for the common good.

Main Research Fields: Multimodal Displays to Alert Drivers, Usability Engineering, Interaction Design.

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4.22 Smart and Adaptive User Interfaces for Automated Vehicles

Benjamin Poppinga (AUDI AG – Ingolstadt, DE, benjamin.poppinga@audi.de)

Partly automated vehicles will become the primary means of transportation in the near future. Without doubt, this will change how we think about our daily commute or any long distance weekend excursions. Our precious time can be used in many alternative ways while we are on the ride, e.g., we can do business, chat with a friend, educate ourselves or even undergo a health checkup. In contrast, there likely will also be situations in which the vehicle will be unable to continue and we as drivers need to take over control quickly to keep the traffic flowing.

This vision illustrates how diverse and dynamic our role in a future vehicle will be. In my opinion, existing interaction concepts and interior designs are mostly unable to allow for this flexibility, because they've been optimized for a single driving task over the past decades. Consequently, a key challenge will be to design future interaction concepts in a way that they primarily support drivers in their main task – whatever this will be – and at the same time allow them to maintain trust, awareness on the traffic situation, and allow for an intuitive handover, if needed. Outside of the vehicle, I see a strong need to investigate the potential interaction concepts and metaphors for mobility services, e.g., the early reservation of a commuter vehicle while maintaining flexible working hours.

Main Research Fields: Location-Based Applications, Smart Interactive Systems, HCI.

4.23 Do We Want to Be Driven by Agents Acting Autonomously and What Are the Grand Challenges on the Way to Fully Automated Road Transport?

Andreas Riener (TH Ingolstadt, DE, andreas.riener@thi.de)

Fully automated vehicles are the future of road transportation and at least with level 5 automation it is expected that they will make our live significantly "better". But do we really want to be driven by agents acting autonomously and what are the grand challenges on the way to fully automated road transport? In this seminar, more than 30 people were meeting for one week to discuss the transition of user interfaces, the incorporation of the user in the driver-vehicle feedback loop, models and methodologies required for testing interaction concepts, transfer of control/de-skilling, etc. Interestingly, quite a significant amount of time was spent on controversial topics such as the loss of "driving fun", ethical issues, economical aspects, or trust and acceptance in future technology. Would you buy or use a vehicle that negotiates with other vehicles around whom to kill when a hazardous traffic accident is unavoidable? Maybe not. But even with one-hundred percent automatism on our future roads, fatal accidents cannot be completely avoided. Can fully automated cars be programmed to act ethically correct? And if not, should the driver be re-engaged (and how?) to make this decision instead of the machine? Will he/she accept? At THI and our newly established research and test center CARISSMA (Center of Automotive Research on

Integrated Safety Systems and Measurement Area), we are contributing to road safety from an integral viewpoint. Of particular interest for my research group are physiologic/ergonomic aspects of traffic, such as cognitive driver modeling, behavioral adaptation, trust/acceptance in technology, ethical constraints, but also the whole range of methodologies used in corporate and scientific research. It was a pleasure for me to co-organize this seminar together with Susanne and Andrew and to hang out with this great people at this great place. I will definitely come back – as organizer or participant. Thanks for your warm hospitality!

Main Research Fields: Cyber-Physical Automotive Systems, Human Factors and Driving Ergonomics, Social-Inspired Mobility Services, (Over)trust, Acceptance, and Ethical Issues in Automated Driving.

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4.24 Who Has the Control? Assisting Hand-Overs in Highly Automated Driving

Shadan Sadeghianborojeni (OFFIS – Oldenburg, DE, shadan.sadeghianborojeni@offis.de)

With the rise of advanced driver assistance systems, automated driving is foreseen to occur in the near future. This, however will not happen over night. According to NHTSA, the next generation of automated vehicles will be "level 3 of automation" which means that the driver has to be ready to take over vehicle control in cases of hazard. This is very different from level 5 automation where automation fully controls the vehicle from a human machine interaction perspective. The transition of control from driver to automation and back can be expensive if the car and human do not have a similar mental model from each others capabilities and responsibilities in different conditions. A smooth transition requires both sides to have an appropriate level of situation awareness about their limitations in different driving situations. Therefore, well designed user interfaces and cues are required to convey this information to both partners. In Dagstuhl seminar 16262 we covered different aspects of control transition which lead to a design approach for supporting handover situations.

Main Research Fields: Human Machine Interaction, Automated Driving, Attention Directing Cues.

4.25 Self-Driving Cars Will Come Faster Than You Think!

Albrecht Schmidt (Universität Stuttgart, DE, albrecht.schmidt@vis.uni-stuttgart.de)

Efficient mobility is essential in a modern society. In many areas of the world (e.g., Beijing, Stuttgart, or the Bay Area) commuting from home and work is becoming more difficult as roads are overcrowded and much time is spent in traffic jams. This hinders productivity and decreases the quality of life for many. Building and improving the road infrastructure is extremely difficult and offers only a long term solution (e.g., creating a new motorway in Germany will take decades). To me, automation in driving is the only viable short-term solution to this problem, as the throughput with automated driving will be much higher than with manual driving. In order to preserve mobility for the masses I expect that automated driving, at least on motorways, will happen much quicker than many people expect. In the automotive industry we are moving towards the most fundamental transformation since its creation over a hundred years ago and we see a clear trend towards automation in research [1]. Even though the way we control cars is rapidly changing, and even though the outcome leads to a new paradigm (self-driving vehicles), I argue that the change is not perceived in this way by the drivers or users. I foresee that drivers experience a gradual and not a radical change. Conceptually, we see a change in control in two dimensions: 1) granularity and 2) immediacy. Traditional car control was on a fine grain timescale, e.g. parking meant to steer and accelerate on a sub-second level. As cars advance parking becomes a higher level decision and the fine grain steering is done automatically. In the future you may get out of the car, and the car parks itself. It can be seen as just another step up in granularity. A car from the 1950 offered very immediate control (e.g. no power steering). As technologies progressed, immediacy was and it will be further reduced. The upcoming transition will nevertheless not be straightforward. There are many technical challenges. I expect that designing the user experience and the interaction requires to address fundamental questions, such as:

- How to deal with different levels of engagement required?
- How to make the users understand what is expected from them at different times while being in the car?
- What activities can be done while being in the car?
- How can we increase the value of the time we spend in transit? Is it entertainment, relaxation, work, communication, or sports?

Overall, I am very optimistic that personal mobility will quickly change to make our life simpler. In the future we may look at phenomena like road accidents and traffic jams and wonder why the transition was not made faster and why we believed for so long that people enjoyed driving.

Main Research Fields: HCI Beyond the Desktop, User Interface Engineering, Driver Assistance Systems.

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4.26 Different Levels of Automation Pose Different Opportunities and Challenges

Steven Shladover (University of California at Berkeley, US, steve@path.berkeley.edu)

The multiple levels of driving automation systems have significantly different driver interface needs and constraints, based on different driver roles and responsibilities. This diversity of levels of automation sometimes makes it challenging to reach common understanding about interactions between the drivers and the automation systems. At the highest levels of automation, the interface mainly needs to provide sufficient information to the vehicle user (who may or may not be a driver) to induce comfort and confidence that the vehicle operations will be safe and dependable. The most challenging issues arise at Level 3, where the driver needs to take the role of "fallback-ready user", who can do whatever he or she wants while the automated driving system (ADS) is driving successfully, but this user also needs to be prepared to intervene very quickly when the ADS encounters a situation that requires driver intervention for safety. This poses such significant challenges with regard to human capabilities to quickly shift attention to a new task and to the design of an effective interface that it raises serious doubts about the viability of Level 3 automation until considerably more research on the control transitions has been accomplished.

Main Research Fields: ITS, Cooperative Transport Systems, Automated Driving, Automation Levels.

4.27 From Horses to Cars and from Cars to Fully Automated – Inclusive – Live-Long Mobility

Christine Sutter (TU Darmstadt, DE, c.sutter@iad.tu-darmstadt.de)

The transition from semi-automated driving to fully automated transportation opens up a vastness of future mobility scenarios and human-machine interactions. Currently, my research interests join the discussion about decisions on function allocations as well as take over procedures for different levels of automation, and centers – from a psychological perspective – specifically around the (limited) capabilities of human information processing and (potential) system failure. Future fully automated transportation will impact traffic safety, hedonic quality of traveling, travel time and lifestyles, and many other aspects in many ways nobody can yet foresee. But anyhow, in future human-technical interactions will still be defined by human capabilities and limitations. And, creatively uniting the best methods, knowledge etc. of different disciplines will still be the most promising way to get people and technical systems adjusted.

Main Research Fields: Ergonomics, Stress and Strain Research, Multimodal Information Processing.

4.28 Why Is My Autonomous Vehicle so Blunt and Why Are Others Treating It so Badly?

Jacques Terken (TU Eindhoven, NL, j.m.b.terken@tue.nl)

Autonomous vehicles are an excellent case for investigating how people deal with novel (and often intelligent) technologies. All kinds of issues come together: acceptance, trust, control, safety, convenience, comfort, to name the most obvious ones. Interesting is that it brings safety-critical automation into the heart of the consumer market. Some of the questions that we have to face are:

- How are we going to help users construct a mental model of what the system can do and cannot do (NOT by a 500 p manual!)?
- Given that autonomous vehicles capitalize on safety, how can we avoid other road users to start abusing the technology ("it's going to stop anyway")?
- How can we build technology that also satisfies the interests of individual people (I want a vehicle that is polite the other road users, except when I'm in a hurry)?

For the interface, I think of the body as an interface; similarly, I see the vehicle itself (both the interior and the exterior) as the interface. Exciting times ahead of us!

Main Research Fields: Automotive Human Factors, Driver Experience.

4.29 Human-Robot Cohabitation in the Age of Autonomous Driving

Mohan Trivedi (University of California, San Diego – La Jolla, US, mtrivedi@eng.ucsd.edu)

Systematic exploration of the role of humans in the age of self-driving and highly automated vehicles is the central focus of our research. With recent advances in embedded sensing, machine perception, learning, and planning, technology takes a step closer towards self-driving automobiles, but many issues are still left unresolved. Toward this end, we highlight research issues as they relate to the understanding of human agents which interact with the automated vehicle. Self-driving and highly automated vehicles are required to navigate smoothly while avoiding obstacles and understanding the high levels of scene semantics. For achieving such goals, further developments in perception (e.g. drivable paths), 3D scene understanding, and policy planning are needed. Designing fully autonomous robotic vehicles that can drive on roads does typically did not require models of drivers and how they interact with vehicles. In contrast, design of intelligent driver assistance systems, especially those for active safety that prevent accidents, requires accurate understanding of human behavior, modeling of human-vehicle interactions, activities inside the cockpit, and prediction of human intent. A human-centered framework for a distributed intelligent system includes the driver, vehicle and environment as three key components. The main idea is to develop an approach to properly design, implement and evaluate methods and computational frameworks for distributed systems where intelligent robots and intelligent humans cohabit, with proper understanding of goals, plans, intentions, risks, and safety parameters. We emphasize the need and the implications of utilizing a holistic approach where driving in a naturalistic context is observed over long periods to learn driving behavior and to predict driver intentions and interactivity patterns. The exciting and expanding research frontiers raise additional questions regarding the ability of techniques to capture context in a holistic manner, handle many atypical scenarios and objects, perform analysis of fine-grained short-term and long-term activity information regarding observed agents, forecast activity events and make decisions while being surrounded by human agents, and interact with humans. Moving towards vehicles with higher autonomy opens new research avenues in dealing with learning, modeling, active control, perception of dynamic events, and novel architectures for distributed cognitive systems. Furthermore, these challenges must be addressed in a safely and within very tight time constraints to avoid collisions or unstable operation.

Main Research Fields: Intelligent Vehicles, Novel Experimental Test Beds, Human-Centered Driver Assistance, Driver Affect.

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4.30 Towards a Seamless Integration of Secondary Tasks

Philipp Wintersberger (TH Ingolstadt, DE), philipp.wintersberger@carissma.eu

From a future highly automated vehicle, I expect it to be a companion rather than a tool. On the one hand, the vehicle should help me to maintain (and of course increase) my driving skills, while on the other it should assist me in side activities. Some of those activities will need more concentration than others, thus knowledge about my schedule, the route, upcoming traffic and potentially hazardous situations might allow a system to help deciding when things are to be done.

For instance, by predicting the chance of an urgent Take-Over, some could derive suggestions on what to do next: The weather is find, streets are clear, sensors work reliable – time to concentrate on important correspondence. String rain, filthy road, high traffic volume – the vehicle presents today's headlines, but expects the driver to be ready for Take-Over. The route is a coastal road with an astonishing view at the sea – now would be the perfect time to do some practice and experience the fun of manual driving (step on the gas – the vehicle will intercept in case of danger). Here at Dagstuhl, reasonable but also provoking ideas can be discussed with colleagues and prominent researchers, and hopefully, some ideas will find their way into upcoming vehicle generations!

Main Research Fields: Human Factors in Automated Driving, Affective Computing, Attentive User Interfaces, Artificial Intelligence.

4.31 Trustworthy Intelligent User Interfaces

Jürgen Ziegler (Universität Duisburg-Essen, DE), juergen.ziegler@uni-due.de

My main motivation for attending this Dagstuhl seminar is to obtain a broader view of the research questions involved in integrating more and more automated functions in cars. The background of my own work in this area is in developing personalized, driver-adaptive navigation systems [1] and user preference models for multimodal transport. I see interesting research questions in providing intelligent user interfaces for future navigation systems which will go beyond directing users to a specific destination but which will also include services like recommending routes and venues that are of interest to the user. Here at Dagstuhl, I particularly liked the open discussion atmosphere and the creative group work. From the discussions I obtained valuable input and ideas concerning topics such as how to increase trust in automated functions. I found it particularly useful to start a discussion on "calibrating trust" for autonomous functions pointing at the fact that we also need to make drivers aware of situations or functions they cannot always trust and which should be monitored. From these discussions, the idea for a late-breaking results paper for this year's AutomotiveUI conference was born which has meanwhile actually been realized.

Main Research Fields: Human-Computer Interaction, Context-Adaptive Systems, Playful Social Interaction, Adaptive Driver Assistance in Vehicles.

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5 Break-Out Groups and Prototyping Sessions

5.1 Understanding the Scopes

To make the process more adaptive to fit the seminar participants' actual research interests, the organizers did not choose to define topics for the break out groups in advance, but to find topics worth being discussed in form of a "brainstorming wall". During the introduction rounds (that were already opened for short discussions with the whole group), most-often mentioned topics were collected on PostIts, organized into associated groups and pinned them on a pin board visible to all participants. In the afternoon, each participant was invited to vote for his favorite topics of interest using self-adhesive colored dots. The result, after re-organization by the workshop organizers on Monday evening, is shown in Figure 1. The identified "blobs" were finally selected as the topics for the break out groups on Tuesday/Thursday and the prototyping session on Wednesday.

Who Are We Designing For?

User interface and vehicle designers as well as user experience practitioners are often challenged with the question for which user group they are designing for – each with different needs, different interests, and very different ways of interacting with technology. In vehicle production, we do not have the luxury of focusing on only one group (at least not so far), i. e., designing vehicles for specific age groups or cultures, that's why interaction designers and engineers must learn to recognize and reconcile the needs of their main user demographics. This problem will remain even with automated driving when using the car as a place for relaxation, entertainment or work.

Defining characteristics, differences, and tensions between individual user groups might help to account for different individuals. An important question in this regard is, whether or not there is a single system suitable for all (or at least most) customers and stakeholders, Is it axiomatic to target user groups differently? A subgroup of the seminar spent an afternoon to discuss this problem and finally came up with a two-dimensional model to

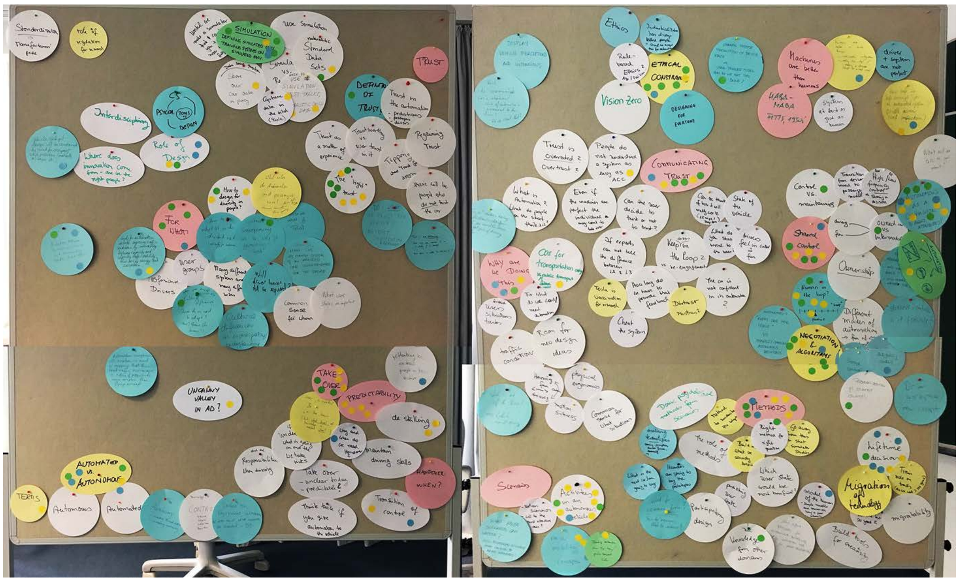

Figure 1 Result of the brainstorming wall after reorganization.
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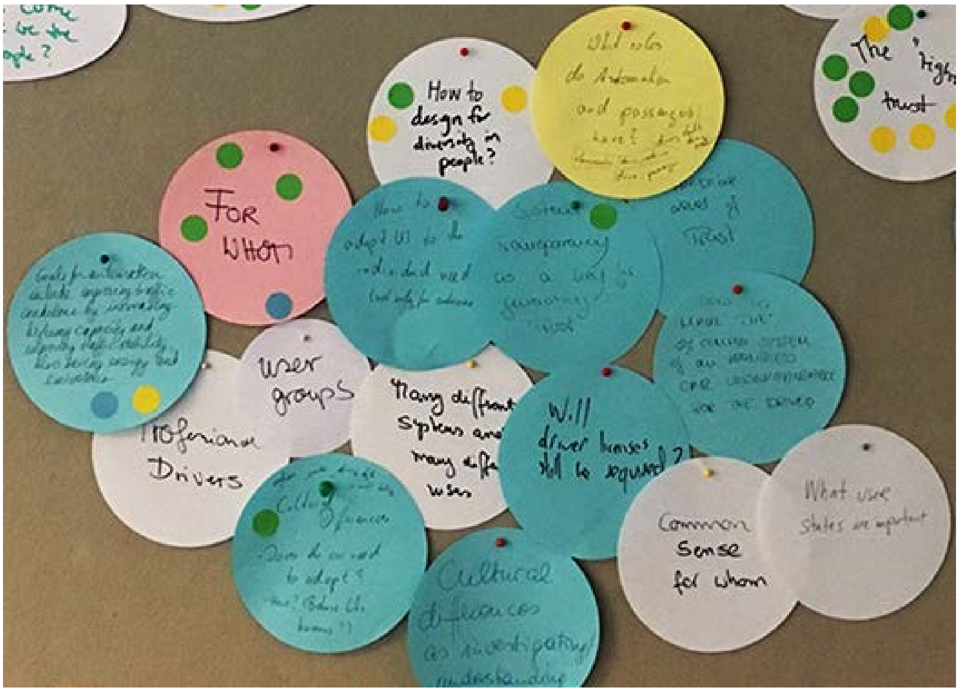

Figure 2 Detail of the brainstorming wall showing main concerns of "Who we are designing for".

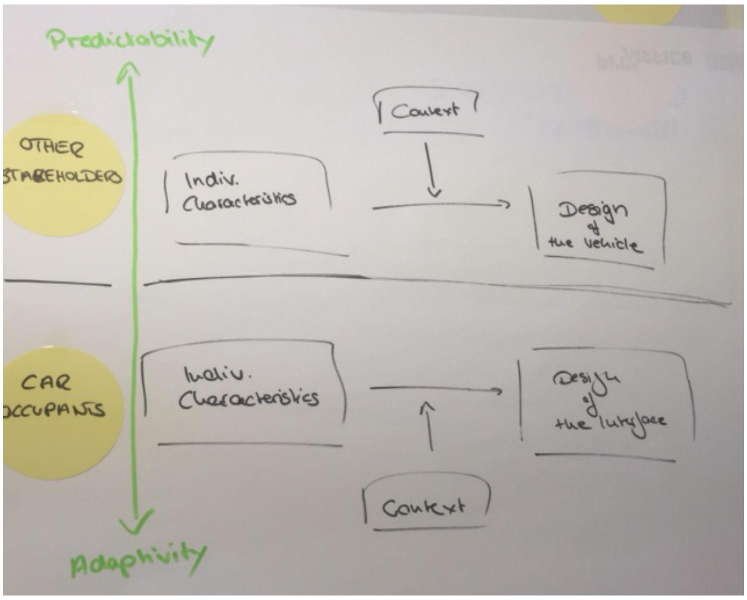

Figure 3 Preliminary model for understanding the role of individual differences in design for automated driving.

differentiate between vehicle occupants (different users) and other stakeholders in the car domain (Figure 3).

Following the discussion, the group defined the following research questions:

- How to call the "driver", e. g., controller, passenger, stakeholder, user, or simply occupant?
- How to adapt the HMI as well as automation behavior to users' characteristics – adaptive (implicit) or adaptable (explicit)?
- Which user characteristics have an impact on the interface design, what is highly important?
- How to model the user?
- What are the (static/dynamic) dimensions to classify them?
- How should HMI look like for drivers, car occupants and other stakeholders?
- Should only a driver or multiple passengers be able to control vehicle functions, and if so, is there a hierarchy?
- Who can control what, how to guarantee access control?
- How to interact with traffic participants outside of the car?
- How to define scenarios, and how link them to user characteristics?

Why Are We Doing This?

Before asking more specific questions about automated driving concepts we need to answer more fundamental questions like: "Why are we doing this?"

As the term "this" is very general and does not divide between different levels of automation it needs to be concertized to get a common understanding about what the breakout group is discussing. Therefore "this" was defined as automated transportation for a wide range of different vehicles (bus, cars, trucks, etc.). This was the basis for a brainstorming to collect possibilities what we can reach with the technology of automated driving (motivations & goals), which we clustered in three different categories: societal (S), personal (P), corporate (C), see Figure 4.

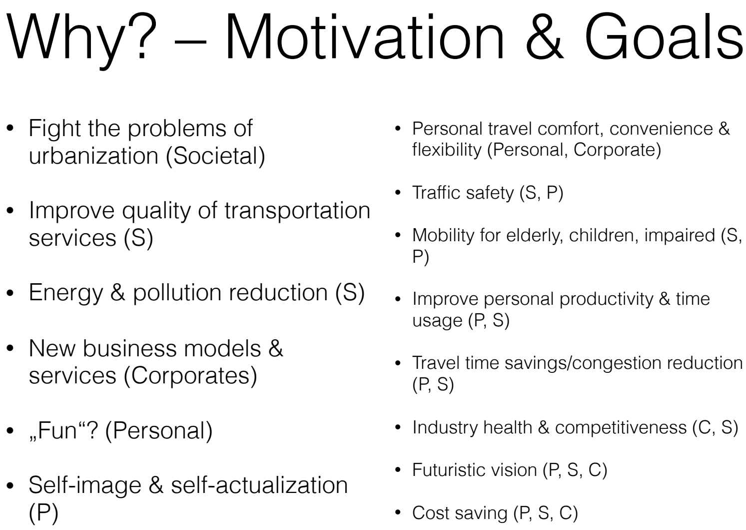

Figure 4 Result of the brainstorming to answer the question: why are we doing "this"?

Discussions showed, that the goals cannot be reached all on the same time. Some of them are now or soon available, instead others are long-term goals.

Research Questions

- How can we support multi-modal transportation?
  - Potential: Time-saving, cost-saving, pollution reduction, environmental protection
  - Approach: Integrated services & consistent view: incl. planning, making reservations, buying
  - Obstacle: companies don't cooperate, no standards
- How can we come up with economically viable business models? Quantifiable benefits & costs?
  - Technological feasibility & timing of availability
  - Safety, security & privacy
- How can we maintain hedonic quality of the driving and the car?
- What will be the purpose of future cars? How can we communicate our plans to the car?

The result of the workshop revealed several hypothesis about the general question "Why": (1) The possibilities of the technology is dependent of the energy resource. (2) Drivers personal experience is essential but dependent from different countries, personal interests, religions, capabilities, etc. (3) Transparency is as well essential for the acceptability of the technology, e.g. privacy and data protection. (4) New aspects like hedonic qualities of the concept of automated driving need to be considered.

Which Activities?

Automated driving, especially levels of high and full automation (according to NHTSA level 3 or higher), will offer a wide range of possibilities. People will be able to use the emerging free time in their vehicles for arbitrary activities, leading to yet unknown vehicle interiors. In a break-out group, we discussed about activities people might desire in future vehicles and their implication on traffic and societies as a whole. Within the discussion, we assumed that all technical constraints as present today will be resolved and only concentrated on what people might want to do, but not how this (technically) be achieved. Also, safety aspects

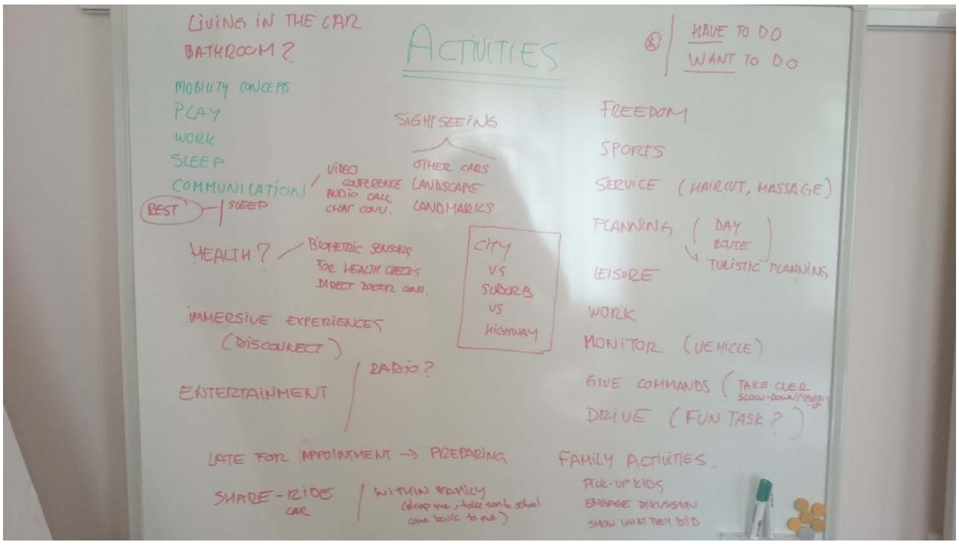

Figure 5 Different core topics emerging from the brainstorming session.

have not been considered as highly important, as latest in the phase of 100% fully connected and automated vehicles, safety measures like seatbelts or adjusted body postures might not play a major role anymore.In a brainstorming session, We collected ideas and identified two groups of activities on a higher level (Figure 5):

- **Productivity:** Including classical workplace-related activities like texting on a computer, communication with others (making the vehicle a meeting room using VR technologies), planning of other tasks, learning and education, or vehicle related activities like monitoring or issuing vehicle commands.
- **Entertainment/Relaxation:** This includes playing games, watching movies, sightseeing when driving through new areas, family- and social related activities but also sleeping and other relaxing activities.

As the discussion proceeded, we realized that most of our thoughts are still constraint by today's vehicle interiors and our narrow perception, but fully automated vehicles would allow much more freedom. We decided for the remaining time to look at a vehicle as an empty shell, leading the discussion into a new direction. We thought about the dimensions of an average minivan and realized that two standardized air plane business class seats would easily fit into it, already allowing to support many of the activities described above. This "empty shell" definition allowed us to think about more severe implications of automated traffic and revealed the great potential of automated traffic. We now briefly report two of the possibilities emerged in our discussions:

- **Vehicles as service facilities:** Imagine you have an important meeting tomorrow morning but really need your hair cut to make a good impression to your partners/customers. The classical way of thinking would suggest your automated vehicle brings you to your hairdresser early in the morning, maybe allowing you to grad some breakfast or read a newspaper while driving. But there is also an alternate future: a hairdresser could make use of a fully automated van (calibrated to generate as low centrifugal force as possible) that's interior serves as his facility. So instead of getting up early to make it to the meeting in time, you could just order a mobile hairdresser that picks you up in the morning to transport you to the place of you meeting while bringing your hair into a presentable shape. This is just one possibility that can be extended – after a hard day of work, another van might bring you home that comes with an integrated sauna and/or massage chair. Doctors, paramedics or arbitrary services could swarm through future cities, allowing people to use the time needed for transportation for something really valuable.

- **Customizable vehicle interiors:** Private fully automated vehicles could be used for many different activities that all might need special devices or vehicle interiors. So instead of designing such a vehicle to become a trade-off that supports all activities badly, some could introduce the concept of third party attachments. The vehicle interior could provide multiple standardized slots for attachments, allowing third parties to design and sell special purpose vehicle interior. People could then build their own vehicles and adjust them to their daily routines and requirements. The same vehicle that contains a mobile office with a desk and a coffee maker could become a mobile sleeping room for a long overnight drive.

Research Questions

- How do we define the space in our vehicle to support the activities we want to do and have to do?
- What does the infrastructure look like to support these activities, and support connectivity to third party manufacturers?
- What would be the business model that car manufacturers need to set up to support such connections?
- What safety/security features are needed to ensure that safety is not hindered by non-driving activities while while the vehicle is safe from external attacks?
- What kind of interface does a vehicle need to provide for a spatial-temporal game-like interface? How can we predict physics to minimize motion sickness, and can the drive be changed to fit the activity?
- Does the vehicle need to recognize what activity you are actually doing?
- What does the vehicle of the future look like?

How to Take Over?

Effective shared control between automated driving systems and human drivers is a topic with many open questions. While current work on so called “Take-Over-Requests” (TORs) often assumes a resumption of full manual vehicle control, different levels of automation (according to SAE) indicate that taking over in future AVs could have different forms at varying extent. We could split the driving tasks into multiple levels to answer the following questions:

- Who has responsibility (Human or ADS)?
- Who has capability (Human or ADS)?
- What is a concrete scenario?

Such a categorization could follow the three classical levels of vehicle control (operational, tactical, strategical), but to fit our requirements we re-define them a little bit and add a fourth level:

- Stabilization (Basic control),
- Guidance – Maneuvers,
- Guidance – Trajectories,
- Strategic – Navigation.

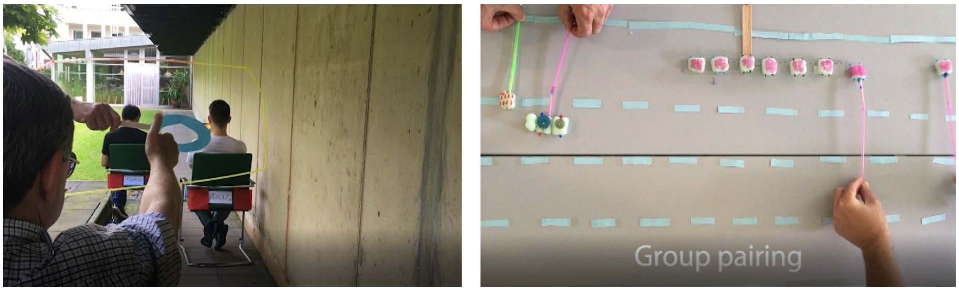

Figure 6 Screen-shots of the prototype video, which show the interaction how to enable the pairing option in a highly automated highway scenario.

A TOR situation in an AV now might contain different subsets of these levels (a driver could be requested for basic vehicle control or navigation only). Differentiating between these levels no allows us to define for each level why a TOR might be issued and how this transfer of control could look like – a TOR emerging at the lowest level (Stabilization) might result from conflicting lane markings, a TOR at the navigation level from missing information due to lost connectivity. At each level, control recovery will require a different reaction time as well as a transfer of a proper mental model to the operator. We now can find strategies to support TORs at the individual levels (a potential framework to achieve this could result from an adaption of the GOMS model). To make further progress in this domain we define the following **research questions**:

- What is the delegation of human-machine responsibilities and capabilities?
- At which level is TOR to occur?
- What is the 'mental model' of the vehicle(-designer) of human capabilities?
- What is the 'mental model' of the human of the vehicle capabilities?
- Are real capabilities in line with expected capabilities?
- How do we define transition (see perspective models)?
- What is an acceptable transition time from automated driving to manual driving?
- How should we allow for a smooth transition, since hands-on/-off is not a good model for human-machine interaction or the assumption of responsibility?
- How do we redefine Situational Awareness (for automated driving)?

5.2 Prototypes

For the prototyping sessions, no topics were given out to the seminar participants. All groups were issued to generate an idea somehow connected with the seminar's overall topic, build up a prototype and make a short video out of it. As material for building the prototype, each group was equipped with arbitrary material, from Lego over toilet paper rolls to straws.

Social Platooning in a Fully Automated Highway Scenario

Social interaction between different drivers is one big opportunity of the technology of automated driving. In a prototyping session we developed a scenario at a fully automated highway where different possibilities are imaginable. Platooning in form of individual pairings of cars to get in contact for example to enable speed dating, but as well group pairings of different vehicles so children in different cars can interact and play together (Figure 6).

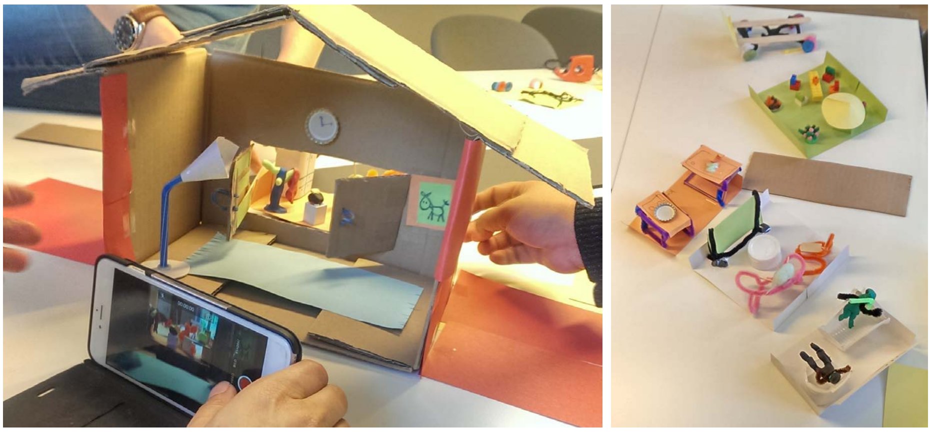

Figure 7 "Dagstuhl Towers" – A room previously mounted on/in a vehicle is now automatically mounted in a free room. The standard apartment with the automated vehicle room attached is seen on the left, various envisioned rooms are shown in the right picture.

Magnetic Moses

As the individual research interests of our group members differed, we decided to look at potential problems of automated traffic from a broad perspective. It quickly became clear, that many advantages associated with automated vehicles strongly depend on their market penetration. In our group we looked at the proposed advantages of reduced congestion and increased traffic flow (maximizing the volume to capacity ratio). Human traffic participants like manually driven vehicles could be a show stopper in this case, as only a few of them could drastically reduce the positive effects of automated driving as a result of their unpredictable behavior. Automated vehicles can drive in platoons with very short headway or dynamically assign vehicle lanes at crossings based on the actual requirements while human traffic participants need clear rules and more space to account for their increased reaction times. The problem to be solved with this prototype was a system trying to integrate human traffic participants (manually driven vehicles or pedestrians) in an intelligent way to account for their weaknesses.

The idea was, that platoons of fully automated vehicles automatically split up to generate buffer zones around human elements. The problem was illustrated at an urban crossing. For instance, a platoon of multiple automated vehicles might open only a little space to allow crossing of another automated vehicle, but a human driver would need a much larger gap or even demands the crossing traffic to stop. Thus an intelligent system will have to know in advance which type of vehicle is approaching as well as details on the actual target to plan for the optimal throughput. As the idea of automatically opening platoons to account for human traffic participants reminded us of the biblical character Moses, we decided to call our system "Magnetic Moses". A prototype of the idea was built in form of a miniature urban crossing and the video was produced using stop-motion technique.

Dagstuhl Towers

This prototype was inspired by automated parking garages and is based around the idea, that entire rooms in future buildings could be automatically mounted on automated vehicles so that users can decide on their own which "context" they want to use for traveling. We created the following scenario and build prototypes to simulate it (Figure 7).

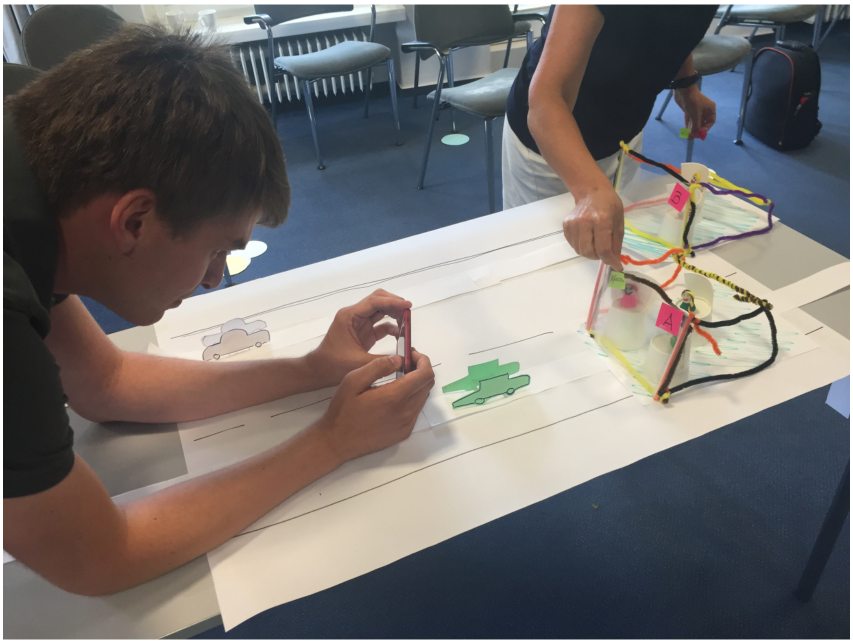

Figure 8 Two vehicles driving on a highway, revealing personal interests and personal details allows a matching algorithm to find similar people "on the road".

»Your mobile office room detaches from the office-building and drives you home, while you continue finishing your work. Your apartment only consists of one room. When needed, you call the mobile kitchen or dining room. If you want to spend some time outside, a mobile balcony can be attached. When you need some more space, the size of your apartment is increased by adding a mobile living room. The bathroom also does not need to be around all day. You just call it when you need to. Similarly, you only call your bedroom, when you are ready to sleep. You could even drive to work in your bedroom, enjoy sleep driving and start to work all refreshed.«

One of the benefits of this idea is the reduced amount of needed living space in dense areas, especially with an increasing population. In addition, having rooms on demand or as a "service" creates new business models. It could be possible to have rooms in different versions ranging from minimalistic to luxurious, depending on resources and needs. It could also enable people to save money by sharing owned rooms. On the other hand, various challenges were identified, for example: (A) How to realize the room attaching system? (B) Can the current infrastructure be changed to make room for automated mobile rooms? (C) Does it really save space in the city, when the unused rooms need to be stored somewhere?

Connecting Car

"Speed Dating" or building social relationships seemed to be a very interesting topic for many seminar participants as second group built such a prototype without knowing from each other. It seems the use case fits well to the automated driving scenario – people can build up social connections like in any other social network, but with the advantage that they can "meet" in reality as they share the same location while still enjoy being a safe space (the own vehicle, Figure 8).

5.3 Methods

Driver-In-The-Loop

One break-out group dealt with the question how to deal with drivers completely "out of the loop", and how to maintain/recover situation awareness for such drivers? A major problem recently emerging is the question, how to deal with drivers that combine multiple level 2 features (according to the SAE levels of automation) and (mis)use as a level 3 automated driving system? Also in this case, initial ideas brought us back to the three levels of vehicle control that could allow to customize an automated vehicle's behavior. Different levels and tasks thus will offer different ways of how to get driver back into the control loop.

Trust in Vehicle Technology

First discussions about the topic revealed a great diversity between participants' understanding of trust and the related concepts, thus it was clear that definitions and potential approaches have to be shaped first. People might trust automation either correspondingly to a systems actual capabilities (appropriate trust) or otherwise will face distrust (systems are not used because of a lack of trust) or overtrust (expectations in a system exceed its actual capabilities.). It quickly became clear, that it cannot be the aim to just increase trust in automated vehicle technology but to find the right balance for each individual. A problem often present in complex automated systems is, that people often do not exactly know about system boundaries. It must be a main target that people actually know in which tasks systems perform good, and in which not. As trust can properly be increased by presenting why-and-how information, a large part of the break out group was to find out which information should be presented to drivers and to what extent. To bring an example, a vehicle emerging a traffic situation with an unpredictable object (like a deer) next to the road section ahead could communicate to the driver that this object has been detected. This could be communicated in different ways, for instance by informing the driver auditory, highlighting the object in a head-up display, by reducing the speed or by a combination of multiple cues. But if the same situation will happen more often, a driver might already trust the system enough that not all of this cues are necessary or become even annoying. Thus optimal trust calibration can only be possible if the amount of feedback steadily varies with respect to the operator.

Taking this into account, we decided to define a framework being capable of representing the whole spectrum of potential driving tasks, that can be split into the three levels operational (low level operations like lateral or longitudinal control), tactical (driving in a platoon of vehicles or overtaking others), and strategical (navigation, etc.) vehicle control (see Figure 9).

The main idea was, that vehicle tasks can be explained to the driver by presenting information concerning each of these levels, and that the amount of information presented might be reduced and shifted from lower levels (for a novice user, the system can explain all details of a maneuver on the operational level) to higher levels (high experienced drivers might be presented only information in the tactical or strategical level as they are well aware of their low-level implications). This idea was then mapped to trust related factors, such as perception, understanding, prediction and adaption. To illustrate the concept, we decided to map all relevant operations of a typical overtaking maneuver into the framework. The idea was further developed after the Dagstuhl Seminar and published in a Work-in-Progress paper to be presented at the AutomotiveUI 2016 conference.

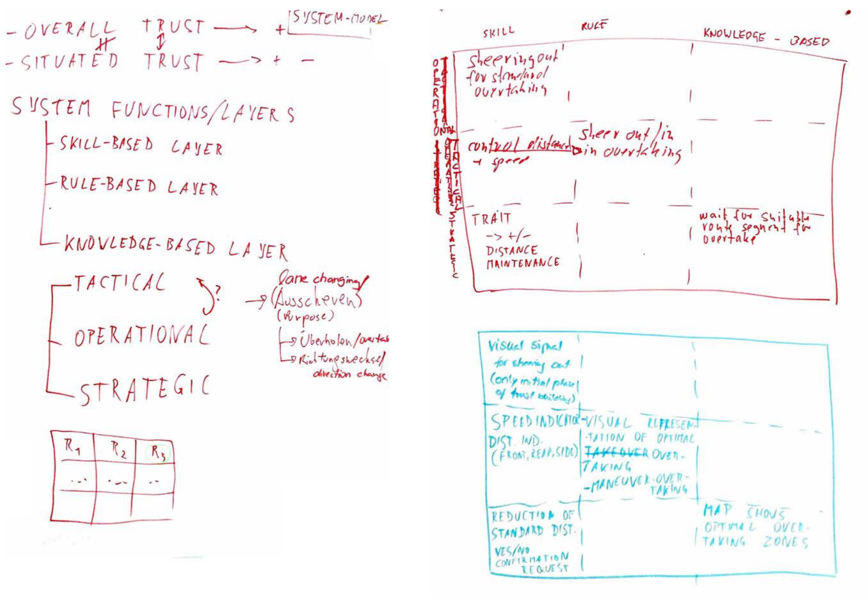

Figure 9 Mapping of vehicle tasks to different levels of vehicle control.

Simulation

A problem in automated driving research is the large variety of different research and data collection methods that make it hard to compare different studies, and challenging to collect similar data in different environments. Before we could start to discuss all the challenges with interdisciplinary participants, we needed to create a common terminology. For example, is a "simulation" referring to a driving simulator study with human participants, or a traffic simulation with simulated agents, or maybe even something different? After many discussions, we came to the conclusion, that we need to consider at least three dimensions when talking about driving research: "How artificial are the agents?", "How real is the environment?" and "How controlled are the scenarios?"

We created a multidimensional space that can be used to classify different user studies. The concept uses the three axes. "Environment" ranges from pure simulation, such as traffic simulations, to real environments, such as a public highway. "Scenarios" ranges from "controlled", like predefined driving tasks in driving simulator, to "natural", like free driving in open world driving simulation. The third axis is "Agents" and ranges from "human user" to "artificial agent". We tested our framework by classifying previous works and experiments as shown in Figure 10. On first sight, the dimension "Agent" seems to be binary. However, the intelligence of artificial agents can vary from very simple to complex or human-like in the context of the experiment. Other dimensions, such as "level of cognitive abstraction", "task complexity", etc. could be defined.

We learned that our framework helps to classify and discuss experiments among people from different disciplines. As a result, the framework can make research contributions more precise while allowing to answer research questions from different perspectives. Further, gaps in existing research can more easily be identified, leading to more synergistically connected research.

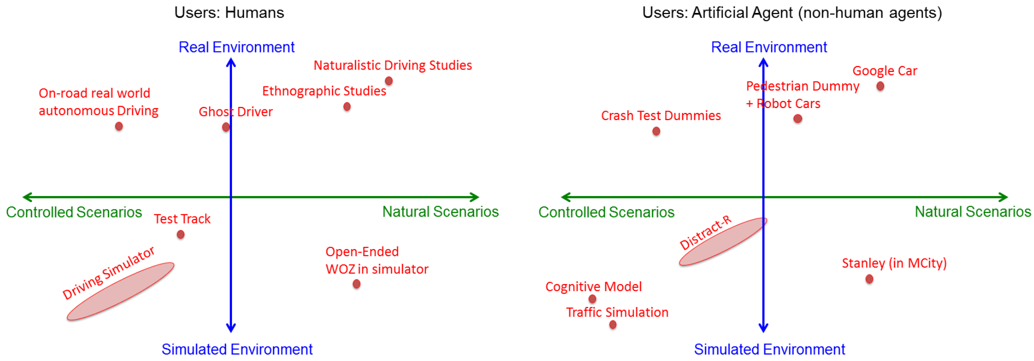

Figure 10 2D-view on the axes of the proposed framework with classified conducted research. Left: scenarios and environment for human agents. Right: scenarios and environment for non-human agents.

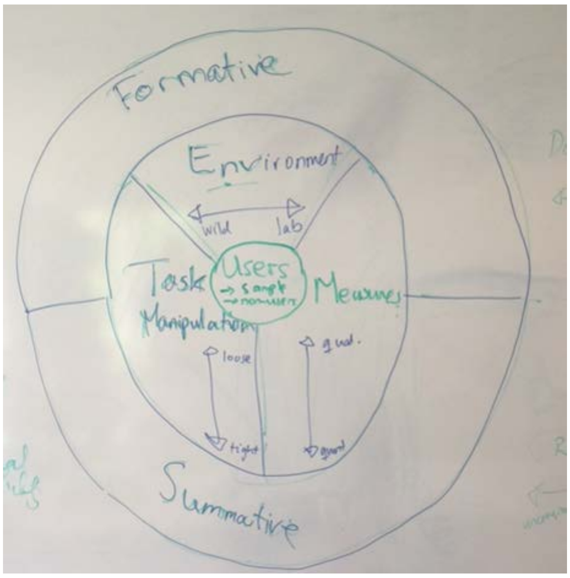

Figure 11 Possibility to categorize methods to find links between certain methods and the context of use of automated driving.

Methods in Automated Driving Research

Discussion about different methods revealed that there exist many methods. But which of them is the most appropriate in a given situation depends of several postulates: what do you mean by using the term "method", furthermore what is the current situation which involves as well as the context of use but moreover the design stage of what you want to explore (Figure 11).

In case of the research of automated driving concepts we need to think about what makes automated driving different but as well interesting to use and to develop certain methods. Therefor we have to categorize them to provide a focus, moreover the context of use for automated driving needs to be defined. The link between methods categories and the context of automated driving will reveal deeper insights into which methods are appropriate and where are still lacks. We therefore ask following research questions.

Research Questions

- What makes the evaluation of an automated driving experience different to any other interface (primary task) test?
  - What constitutes context of use?
  - What "new" methods are required when the traditional primary/secondary task distinctions break down?
- How can we develop new methods for uncovering unconscious/undreamed of requirements in this area?
- How can we combine highly diverse needs (emotional, performance) within methods?

6 Publications Inspired by the Dagstuhl Seminar 16262

The following list summarizes publications (as of November 14, 2016) inspired by the seminar.

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