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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 12101

Computation and Incentives in Social Choice

Edited by

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Abstract

Computational social choice is an active research area that combines tools and techniques of theoretical computer science and AI with those of mathematics, social sciences and economics. The aim of the Dagstuhl Seminar 12101 "Computation and Incentives in Social Choice" was to bring together the experts in these areas in order to discuss recent advances in this field and share open problems. This report collects the material presented during the course of the seminar.

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Edited in cooperation with Gábor Erdélyi

1 Executive Summary

Edith Elkind
Christian Klamler
Jeffrey S. Rosenschein
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The aim of classic social choice theory is to explain how groups of agents can come to a joint decision that reflects the heterogeneous preferences of individual agents. This covers a wide range of scenarios, such as, for example, voting, fair division and ranking. As such, social choice theory enhances our understanding of human societies and can be used as a theoretical foundation for the design of multiagent systems.

In recent years, the study of computational aspects of social choice received a lot of attention from AI and theoretical computer science communities. This interest was motivated by existing and potential applications of social choice ideas in AI settings, which, in turn, highlighted the importance of understanding which of the recommendations of social choice theory are computationally feasible.

The value of algorithmic analysis in the context of social choice stems from the fact that, to be practically applicable, a decision-making rule needs to be efficiently implementable. Indeed, the analysis of computational complexity of well-known voting rules, both in the general case, and in interesting special cases (such as, e.g., single-peaked preferences) is

one of the most actively studied topics in computational social choice, with a number of impressive results obtained so far.

However, computational tractability is not the only criterion for selecting a social choice procedure: an equally desirable feature is *incentive compatibility*, i.e., resilience to dishonest behavior by self-interested participants, who may want to manipulate the outcome of the procedure in their favor. There is an exciting interplay between incentive compatibility and computational tractability: in many settings of interest, computing one's optimal strategy requires solving a hard optimization problem, while acting honestly is computationally easy. Thus, one may view computational complexity as a barrier against strategic behavior, and try to design or identify social choice procedures that make strategizing difficult. This research direction was initiated more than 20 years ago and remains a major research focus of the computational social choice community.

Alternatively, one can deal with manipulative agents in the context of social choice by embracing the strategic behavior rather than trying to prevent it. This can be done either by investigating the outcomes of standard social choice procedures under the assumption that all agents act strategically, or, more ambitiously, by designing social choice procedures that result in desirable outcomes even if agents are not truthful; these two approaches are associated, respectively, with game theory and mechanism design. Both game-theoretic and mechanism design approaches are widely used by the classic social choice community; however, their computational aspects have received relatively little attention so far.

In contrast, algorithmic aspects of strategic behavior in other settings, such as, e.g., matrix games or auctions, have been studied extensively in the last few years. Indeed, computational game theory and algorithmic mechanism design are among the fastest-growing subfields of both AI and theoretical computer science. Thus, in organizing this seminar, we aimed to bring together the researchers in the areas of computational and classic social choice and those in the area of algorithmic game theory. Our goal was to foster a discussion of computational aspects of various forms of strategic behavior in social choice contexts.

Outcomes

The seminar took place on March 4–9, 2012. It was interdisciplinary in nature: among the participants, there were computer scientists, mathematicians, social choice theorists and political scientists. There were 32 regular talks, as well as an after-dinner talk by Virginia Vassilevska-Williams, who spoke about her groundbreaking work on algorithms for matrix multiplication. The seminar talks covered a broad range of topics, such as, e.g., the complexity of dishonest behavior in voting, judgement aggregation, coalitional game theory, and fair division. The program also featured a rump session consisting of short (5–8 minute) talks; these included announcements about events that were likely to be of interest to the seminar participants, short research talks, and presentations of open problems. The participants also used the seminar as an opportunity to continue ongoing research projects or start new ones. We are aware of two research papers that are largely based on discussions that happened during this Dagstuhl seminar; both of them have been recently submitted to the 4th International Workshop on Computational Social Choice. Moreover, several speakers who presented work in progress received useful feedback from other seminar participants, and, as a result, were able to improve or extend their papers significantly. To summarize, the participants of the seminar benefitted from it in a variety of ways: by being exposed to new research results and directions, by getting fresh perspectives on their work, by learning about open problems and initiating new collaborations, and by having an opportunity to work with their co-authors from all over the world on ongoing research projects.

2 Table of Contents

3 Overview of Talks

3.1 Bayesian Vote Manipulation: Optimal Strategies and Impact on Welfare

Craig Boutilier (University of Toronto, CA)

Joint work of Lu, Tyler; Tang, Pingzhong; Procaccia, Ariel; Boutilier, Craig;

Most analyses of manipulation of voting schemes in computational social choice have considered the manipulation problem under two assumptions that greatly diminish their practical import. First, it is usually assumed that the manipulators have full knowledge of the votes of the nonmanipulating agents.

Second, analysis tends to focus on the probability of manipulation rather than its impact on social welfare. We relax both of these assumptions by analyzing optimal Bayesian manipulation strategies when the manipulators have only partial probabilistic information about nonmanipulator votes, and assessing the expected loss in social welfare. We present a general optimization framework for the derivation of optimal manipulation strategies given arbitrary voting rules and distributions over preferences. We theoretically and empirically analyze the optimal manipulability of some popular voting rules using distributions and real data sets that go well beyond the common, but unrealistic, impartial culture assumption. We also shed light, both theoretically and empirically, on the stark difference between the loss in social welfare and the probability of manipulation by showing that even when manipulation is likely, impact to social welfare is slight (and often negligible).

3.2 When Does Approval Voting Make the "Right Choices"?

Steven J. Brams (New York University, US)

Joint work of Brams, Steven J.; Kilgour, D. Marc
Main reference Working paper
URL http://politics.as.nyu.edu/object/stevenbrams

We assume that a voter's approval of a proposal depends on (i) the proposal's probability of being right (or good or just) and (ii) the voter's probability of making a correct judgment about its rightness (or wrongness). The state of a proposal (right or wrong), and the correctness of a voter's judgment about it, are assumed, initially, to be independent. If the average probability that voters are correct in their judgments is greater than $\frac{1}{2}$, then the proposal with the greatest probability of being right will, in expectation, receive the greatest number of approval votes. This result also holds when voters' probabilities of being correct are state dependent but not proposal dependent; when they are functionally related in a certain way; or when voters follow a leader with an above-average probability of correctly judging proposals. Sometimes, however, voters will more frequently select the right proposal by not following a leader and, instead, making their own independent judgments (as assumed by the Condorcet jury theorem). Applications of these results to different kinds of voting situations are discussed.

3.3 On Measuring Nearly Single-Peakedness

Robert Bredereck (TU Berlin, DE)

Many problems in context of voting are NP-hard in general. However, when the elections are single-peaked some voting problems become polynomial-time solvable. Often, real-world elections are not perfectly single-peaked, because some voters behave unexpectedly or few candidates do not fit into the model. In our work in progress, we investigate two distances measuring almost single-peakedness. The first distance is "the number of voters to remove to make the election single-peaked", which is also known as number of mavericks in the literature. The second distance is "the number of candidates to remove to make the election single-peaked". We show NP-hardness for the first distance as well as fixed-parameter algorithms computing both distances. Furthermore, we show that there exist effective data reduction procedures (leading to so-called polynomial-size problem kernels) useful for computing these distances (and the corresponding solution sets).

3.4 Possible and Necessary Winners of Partial Tournaments

Markus Brill (TU München, DE)

Joint work of Aziz, Haris; Brill, Markus; Fischer, Felix; Harrenstein, Paul; Lang, Jérôme; Seedig, Hans Georg
Main reference H. Aziz, M. Brill, F. Fischer, P. Harrenstein, J. Lang, H. G. Seedig, "Possible and necessary winners of partial tournaments," in V. Conitzer and M. Winikoff, (eds.), Proc. of the 11th Int'l Joint Conf. on Autonomous Agents and Multi-Agent Systems (AAMAS). IFAAMAS, 2012.
URL http://dss.in.tum.de/files/brandt-research/partial.pdf

We study the problem of computing possible and necessary winners for partially specified weighted and unweighted tournaments. This problem arises naturally in elections with incompletely specified votes, partially completed sports competitions, and more generally in any scenario where the outcome of some pairwise comparisons is not yet fully known. We specifically consider a number of well-known solution concepts–including the uncovered set, Borda, ranked pairs, and maximin–and show that for most of them possible and necessary winners can be identified in polynomial time. These positive algorithmic results stand in sharp contrast to earlier results concerning possible and necessary winners given partially specified preference profiles.

3.5 An incentive-compatible 2-agent kidney exchange mechanism

Ioannis Caragiannis (University of Patras, GR)

Joint work of Caragiannis, Ioannis; Filos-Ratsikas, Aris; Procaccia, Ariel D.
Main reference I. Caragiannis, A. Filos-Ratsikas, A. D. Procaccia, "An improved 2-agent kidney exchange mechanism," in Proc. of the 5th Int'l Workshop on Internet and Network Economics (WINE'11), LNCS 7090, Springer, pp. 37–48, 2011.
URL http://dx.doi.org/10.1007/978-3-642-25510-6_4

We consider a mechanism design version of matching computation in graphs that models the game played by hospitals participating in pairwise kidney exchange programs. We present a new randomized matching mechanism for two agents which is truthful in expectation and has an approximation ratio of 3/2 to the maximum cardinality matching. This is an improvement over a recent upper bound of 2 [Ashlagi et al., EC 2010] and, furthermore, our mechanism beats for the first time the lower bound on the approximation ratio of deterministic truthful mechanisms. We complement our positive result with new lower bounds. Among other statements, we show that the weaker incentive compatibility property of truthfulness in expectation in our mechanism is necessary; universally truthful mechanisms that have an inclusion-maximality property have an approximation ratio of at least 2.

3.6 Parameterized Complexity Aspects of Optimal Lobbying

Jiehua Chen (TU Berlin, DE)

Joint work of Bredereck, Robert; Chen, Jiehua; Hartung, Sepp; Kratsch, Stefan; Niedermeier, Rolf; Suchý, Ondřej

In a multi-issue election, each voter may "approve" or "disapprove" each individual issue. In the context of attacks on multi-issue elections, Optimal Lobbying asks whether a lobbyist can lobby a given number of voters such that for each issue, there is a majority of voters who vote in favor of the lobbyist.

Here, lobbying a voter means changing this voter's vote completely into the lobbyist's reference. In general, Optimal Lobbying is computational intractable (NP-complete). However, is this problem always hard for realistic scenarios? To address this, Christian et al. [Review of Economic Design 2007] studied the parameterized complexity of Optimal Lobbying and showed that this problem is W[2]-complete in the parameter "number of voters to lobby". In this talk, we look into several additional parameters which describe the structure of the input or the distance to the lobbyist's goal. We gain both tractability and intractability results. We also present an efficient greedy algorithm which solves our problem optimally if the number of issues is at most four.

3.7 Evaluating Resistance to False-Name Manipulations in Elections

Vincent Conitzer (Duke University, US)

Joint work of Waggoner, Bo; Xia, Lirong; Conitzer, Vincent
Main reference B. Waggoner, L. Xia, V. Conitzer, "Evaluating Resistance to False-Name Manipulations in Elections," in AAAI'12, *to appear*.

In many mechanisms (especially online mechanisms), a strategic agent can influence the outcome by creating multiple false identities. We consider voting settings where the mechanism designer cannot completely prevent false-name manipulation, but may use false-name-limiting methods such as CAPTCHAs to influence the amount and characteristics of such manipulation. Such a designer would prefer, first, a high probability of obtaining the "correct" outcome, and second, a statistical method for evaluating the correctness of the outcome. In this paper, we focus on settings with two alternatives. We model voters as independently drawing a number of identities from a distribution that may be influenced by the choice of the false-name-limiting method. We give a criterion for the evaluation and comparison of these distributions. Then, given the results of an election in which false-name manipulation may have occurred, we propose and justify a statistical test for evaluating the outcome.

3.8 Popular Spanning Trees

Andreas Darmann (Universität Graz, AT)

The considered problem combines Combinatorial Optimization with Social Choice Theory. In classic Combinatorial Optimization, costs are assigned to the edges of an undirected graph and one is interested in finding a spanning tree of minimum total cost. In our approach, instead of associating costs with the edges of the undirected graph, it is assumed that individuals have preferences over the single edges. A spanning tree is proposed by an external source (e.g., a central authority), and the goal is to decide on the fairness (or quality) of the proposed solution. Given the individual preferences over the edges, we evaluate quality by means of a Condorcet criterion. In particular, we perform comparisons between spanning trees that are based on scoring functions used in classic voting rules such as approval voting and Borda voting. The focus of our work is laid on the computational complexity involved in deciding on the quality of a spanning tree with respect to the different voting rules adapted.

With our results, the sharp separation line between polynomially solvable and computationally intractable instances is drawn.

3.9 A metatheorem for impossibility results in judgement aggregation

Daniel Eckert (Universität Graz, AT)

Joint work of Eckert, Daniel; Herzberg, Frederik

The close relation between the two major impossibility results in social choice theory, Arrow's "general possibility theorem" and the Gibbard- Satterthwaite theorem, has been explored in several metatheorems. In a model theoretic framework, an analogous metatheorem for impossibility results in the recent literature on judgment aggregation is provided.

3.10 On the geometry of voting rules with respect to the swap distance

Edith Elkind (Nanyang TU Singapore, SG)

Joint work of Obraztsova, Svetlana; Elkind, Edith; Faliszewski, Piotr; Slinko, Arkadii

Axioms that govern our choice of voting rules are usually defined by imposing constraints on the rule's behavior under various transformations of the preference profile. In this paper we adopt a different approach, and view a voting rule as a (multi-)coloring of the election graph—the graph whose vertices are elections over a given set of candidates, and two vertices are adjacent if they can be obtained from each other by swapping adjacent candidates in one of the votes. Given this perspective, a voting rule F is characterized by the shapes of its "monochromatic components", i.e., the sets of elections that have the same winner under F. In particular, it would be natural to expect each monochromatic component to be convex, or, at the very least, connected. We formalize the notions of connectivity and (weak) convexity for monochromatic components, and say that a voting rule is connected/(weakly) convex if each of its monochromatic components is connected/(weakly) convex. We then investigate which of the classic voting rules have these properties. It turns out that while all voting rules that we consider are connected, convexity and even weak convexity are much more demanding properties. Our study of connectivity suggests a new notion of monotonicity, which may be of independent interest.

3.11 Graph Aggregation

Ulle Endriss (University of Amsterdam, NL)

Joint work of Endriss, Ulle; Grandi, Umberto

Suppose several agents each provide us with a directed graph on the same set of vertices. Graph aggregation is the problem of computing a single collective graph that best represents the information inherent in this profile of individual graphs. A procedure to perform this kind of aggregation is called collectively rational with respect to a given property if it is the case that, whenever every individual graph satisfies the property in question, then so does the collective graph the procedure is going to return. We set up a formal framework

for analysing collective rationality in graph aggregation and discuss several possibility and impossibility results.

3.12 Manipulation Under Voting Rule Uncertainty

Gábor Erdélyi (Universität Siegen, DE)

Joint work of Elkind, Edith; Erdélyi, Gábor;
Main reference E. Elkind, G. Erdélyi, "Manipulation Under Voting Rule Uncertainty," in V. Conitzer and M. Winikoff, (eds.), Proc. of the 11th Int'l Joint Conf. on Autonomous Agents and Multi-Agent Systems (AAMAS). IFAAMAS, 2012.

An important research topic in the field of computational social choice is the complexity of various forms of dishonest behavior, such as manipulation, control, and bribery. While much of the work on this topic assumes that the cheating party has full information about the election, recently there have been a number of attempts to gauge the complexity of non-truthful behavior under uncertainty about the voters' preferences. In this paper, we analyze the complexity of (coalitional) manipulation for the setting where there is uncertainty about the voting rule: the manipulator(s) know that the election will be conducted using a voting rule from a given list, and need to select their votes so as to succeed no matter which voting rule will eventually be chosen. We identify a large class of voting rules such that arbitrary combinations of rules from this class are easy to manipulate; in particular, we show that this is the case for single-voter manipulation and essentially all easy-to-manipulate voting rules, and for coalitional manipulation and k-approval. While a combination of a hard-to-manipulate rule with an easy-to-manipulate one is usually hard to manipulate—we prove this in the context of coalitional manipulation for several combinations of prominent voting rules—we also provide counterexamples showing that this is not always the case.

3.13 Exploring and Exploiting Clone Structures in Elections

Piotr Faliszewski (AGH University of Science and Technology Krakow, PL)

Joint work of Elkind, Edith; Faliszewski, Piotr; Slinko, Arkadii
Main reference E. Elkind, P. Faliszewski, A. Slinko, "Clone Structures in Voters' Preference," in Proc. of 13th ACM Conf. on Electronic Commerce, *to appear*.

In election, a clone set is a subset of candidates ranked consecutively by all voters. A clone structure of a given election is a family of all its clone sets. In this talk we will consider the following issues: Given an election and some beliefs as to which clone sets are a result of cloning, how to reconstruct the most likely original election? How to reconstruct the most likely election that ensures some given candidate's victory? If the election was originally single-peaked (or single-crossing), is it possible to discover this single-peakedness (single-crossingness) while "decloning" as few candidates as possible? To answer these questions, we will explore the landscape of possible clone structures in elections.

3.14 The Common Structure of Aggregation Paradoxes (and how to avoid them)

Umberto Grandi (University of Amsterdam, NL)

In this talk I will analyse some of the classical paradoxes in Social Choice Theory (namely, the Condorcet paradox, the discursive dilemma, the Ostrogorski paradox and the multiple election paradox) using a general framework for the study of aggregation problems called binary aggregation with integrity constraints. I will provide a definition of paradox that is general enough to account for the four cases mentioned, and identify a common structure in the syntactic properties of the rationality assumptions that lie behind such paradoxes. I will conclude by introducing an aggregation procedure that avoids paradoxical situations for any given rationality assumption called the average voter rule. I investigate its axiomatic properties and the computational complexity of both the problem of winner determination and strategic manipulation.

3.15 Pareto Optimality in Coalition Formation

Paul Harrenstein (TU München, DE)

Joint work of Aziz, Haris; Brandt, Felix; Harrenstein, Paul
Main reference H. Aziz, F. Brandt, P. Harrenstein, "Pareto optimality in coalition formation," in G. Persiano, (ed.), Proc. of the 4th Int'l Symp. on Algorithmic Game Theory (SAGT), LNCS, vol. 6982, pp. 93–104. Springer-Verlag, 2011.
URL http://dx.doi.org/10.1007/978-3-642-24829-0_10

A minimal requirement on allocative efficiency in the social sciences is Pareto optimality. In this paper, we identify a close structural connection between Pareto optimality and perfection that has various algorithmic consequences for coalition formation. Based on this insight, we formulate the Preference Refinement Algorithm (PRA) which computes an individually rational and Pareto optimal outcome in hedonic coalition formation games or any other discrete allocation setting. Our approach also leads to various results for specific classes of hedonic games. In particular, we show that computing and verifying Pareto optimal partitions in general hedonic games, anonymous games, three-cyclic games, room-roommate games and B-hedonic games is intractable while both problems are tractable for roommate games, W-hedonic games, and house allocation with existing tenants.

3.16 Search versus Decision for Election Manipulation Problems

Lane A. Hemaspaandra (University of Rochester, US)

Joint work of Hemaspaandra, Edith; Hemaspaandra, Lane A.; Menton, Curtis

Most theoretical definitions about the complexity of manipulating elections focus on the decision problem of recognizing which instances can be successfully manipulated, rather

than the search problem of finding the successful manipulative actions. Since the latter is a far more natural goal for manipulators, that definitional focus may be misguided if these two complexities can differ. Our main result is that they probably do differ: If integer factoring is hard, then for election manipulation, election bribery, and some types of election control, there are election systems for which recognizing which instances can be successfully manipulated is in polynomial time but producing the successful manipulations cannot be done in polynomial time.

3.17 A Simple Bargaining Mechanism That Induces Truth-Telling

Marc Kilgour (Wilfrid Laurier University, CA)

Joint work of Kilgour, Marc; Brams, Steven J.; Kaplan, Todd R.;
Main reference D. M. Kilgour, S. J. Brams, T. R. Kaplan, "Three procedures for inducing honesty in bargaining," in Proc. of 13th Conf. on Theoretical Aspects of Rationality and Knowledge (TARK'11), pp. 170–176, ACM, 2011.
URL http://dx.doi.org/10.1145/2000378.2000398

No bargaining mechanism can induce bargainers to report their reservation prices (bottom lines) truthfully. Several mechanisms that come close to achieving perfect efficiency are reviewed, including a new 2-stage mechanism that induces two bargainers to report truthfully in a 1st stage. If these prices criss-cross, the referee reports that they overlap, and the bargainers proceed to make offers in a 2nd stage. The average of the 2nd-stage offers becomes the settlement if both offers fall into the overlap interval; if only one offer falls into this interval, it is the settlement, but is implemented with probability $\frac{1}{2}$; if neither offer falls into the interval, there is no settlement. Thus, if the bargainers reach the 2nd stage, they know their reservation prices overlap even if they fail to reach a settlement, possibly motivating them to try again.

3.18 N-Person Cake-Cutting: There May Be No Perfect Division

Christian Klamler (Universität Graz, AT)

Main reference S. J. Brams, M. A. Jones, C. Klamler, "N-Person Cake-Cutting: There May Be No Perfect Division," October 2011, available at SSRN.
URL http://dx.doi.org/10.2139/ssrn.1946993

A cake is a metaphor for a heterogeneous, divisible good, such as land.

Over the past fifteen years, a substantial literature on cake-cutting has sprung up. In particular, three properties of cake-cutting algorithms have been the focus of most of cake-cutting literature. Efficiency (also called Pareto-optimality) requires that there is no other division that gives players portions that they value at least as much and gives at least one player strictly more. Envy-freeness states that each player values its portion at least as much as that of every other player and, consequently, does not envy any other player. Finally, a division is considered to be equitable if each player values its portion exactly the same as everybody else values its portion, i.e., each player thinks that its portion is the same fraction of its perceived value of the entire cake. In this paper, we consider a division of a cake that

satisfies all three properties to be a perfect division. We give an example of a cake in which it is impossible to divide it among three players such that these three properties are satisfied, however many cuts are made. It turns out that two of the three properties can be satisfied by a 3-cut and a 4-cut division, which raises the question of whether the 3-cut division, which is not efficient, or the 4-cut division, which is not envy-free, is more desirable (a 2-cut division can at best satisfy either envy-freeness or equitability but not both). We prove that no perfect division exists for more than 4 cuts and for an extension of this example to more than three players.

3.19 Finding Extremal Voting Systems via Integer Linear Programming

Sascha Kurz (Universität Bayreuth, DE)

Main reference S. Kurz, "On the inverse power index problem," *to appear* in Optimization, 23 pages, 2012.
URL http://dx.doi.org/10.1080/02331934.2011.587008

Different types of yes/no voting systems are frequently studied in the literature. Using integer linear programming we determine extremal, according to a given criterion, voting systems.

As examples we consider voting systems

- whose Shapley-Shubik vector has minimal distance to a given power distribution;
- whose Public Good Index maximally violate local monotonicity;
- which are farthest away from weighted voting games with respect to a recently introduced hierarchy of simple games.

We present the general underlying ideas and computational results for instances where exhaustive enumeration of all voting systems is infeasible.

3.20 Judgment Aggregation Rules Based on Minimization

Jérôme Lang (Université Paris-Dauphine, FR)

Joint work of Lang, Jérôme; Pigozzi, Gabriella; Slavkovik, Marija; van der Torre, Leon
Main reference J. Lang, G. Pigozzi, M. Slavkovik, L. van der Torre, "Judgment aggregation rules based on minimization," in Proc. of 13th Conf. on Theoretical Aspects of Rationality and Knowledge (TARK'11), pp. 238–246, ACM, 2011.
URL http://dx.doi.org/10.1145/2000378.2000407

Many voting rules are based on a minimization or maximization principle.

Likewise, in the field of logic-based knowledge representation and reasoning, many belief change or inconsistency handling operators make use of minimization.

Surprisingly, minimization has not played a major role in the field of judgment aggregation, in spite of its proximity to voting theory and logic-based knowledge representation and reasoning. Here we the study judgment aggregation rules based on minimization, and propose a classification of judgment aggregation rules based on some minimization or maximization principle. We distinguish four families of rules. While most of these rules are new, a few ones correspond to rules that have been defined elsewhere.

We study the inclusion relationships among these rules, and analyze them with respect to the common judgment aggregation properties.

3.21 Social Distance Games

Kate Larson (University of Waterloo, CA)

Joint work of Larson, Kate; Branzei, Simina
Main reference S. Branzei, K. Larson, "Social Distance Games," in Proc. of the 22nd Int'l Joint Conf. on Artificial Intelligence (IJCAI'11), pp. 91–96, IJCAI/AAAI, 2011.
URL http://ijcai.org/papers11/Papers/IJCAI11-027.pdf

In this paper we introduce and analyze social distance games, a family of non-transferable utility coalitional games where an agent's utility is a measure of closeness to the other members of the coalition. We study both social welfare maximisation and stability in these games using a graph theoretic perspective.

We use the stability gap to investigate the welfare of stable coalition structures, and propose two new solution concepts with improved welfare guarantees. We argue that social distance games are both interesting in themselves, as well as in the context of social networks.

3.22 Convergence of Iterative Voting – Results & Problems

Omer Lev (The Hebrew University of Jerusalem, IL)

Joint work of Lev, Omer; Rosenschein, Jeffrey S.
Main reference O. Lev, J. S. Rosenschein, "Convergence of Iterative Voting," in Proc. of the 11th Int'l Joint Conf. on Autonomous Agents and Multiagent Systems (AAMAS'12), June 2012, Valencia, Spain.
URL ftp://ftp.cs.huji.ac.il/users/jeff/aamas12lev.pdf

In multiagent systems, social choice functions can help aggregate the distinct preferences that agents have over alternatives, enabling them to settle on a single choice. Despite the basic manipulability of all reasonable voting systems, it would still be desirable to find ways to reach a stable result, i.e., a situation where no agent would wish to change its vote. One possibility is an iterative process in which, after everyone initially votes, participants may change their votes, one voter at a time. This technique, explored in previous work, converges to a Nash equilibrium when Plurality voting is used, along with a tie-breaking rule that chooses a winner according to a linear order of preferences over candidates.

In this work, we both consider limitations of the iterative voting method, as well as expanding upon it. We demonstrate the significance of tie-breaking rules, showing that when using a general tie-breaking rule, no scoring rule (nor Maximin) needs to iteratively converge. However, using a restricted tie-breaking rule (such as the linear order rule used in previous work) does not by itself ensure convergence. We demonstrate that many scoring rules (such as Borda) need not converge, regardless of the tie-breaking rule. On a more encouraging note, we prove that Iterative Veto does converge—but that voting rules "between" Plurality and Veto, k-approval rules, do not.

3.23 On Worst-Case Allocations in the Presence of Indivisible Goods

Evangelos Markakis (Athens University of Economics and Business, GR)

Joint work of Markakis, Evangelos; Psomas, Christos-Alexandros
Main reference E. Markakis, C.-A. Psomas, "On Worst-Case Allocations in the Presence of Indivisible Goods," in Proc. of the 7th Int'l Workshop on Internet and Network Economics (WINE'11), pp. 278–289, LNCS, vol. 7090, Springer, 2011.
URL http://dx.doi.org/10.1007/978-3-642-25510-6_24

We study a fair division problem, where a set of indivisible goods is to be allocated to a set of n agents. Each agent may have different preferences, represented by a valuation function that is a probability distribution on the set of goods. In the continuous case, where goods are infinitely divisible, it is well known that proportional allocations always exist, i.e., allocations where every agent receives a bundle of goods worth to him at least 1/n. In the presence of indivisible goods however, this is not the case and one would like to find worst case guarantees on the value that every agent can have. We focus on algorithmic and mechanism design aspects of this problem. In the work of [Hill, 1987], an explicit lower bound was identified, as a function of the number of agents and the maximum value of any agent for a single good, such that for any instance, there exists an allocation that provides at least this guarantee to every agent. The proof however did not imply an efficient algorithm for finding such allocations. Following upon the work of Hill, we first provide a slight strengthening of the guarantee we can make for every agent, as well as a polynomial time algorithm for computing such allocations. We then move to the design of truthful mechanisms. For deterministic mechanisms, we obtain a negative result showing that a truthful 2/3-approximation of these guarantees is impossible. We complement this by exhibiting a simple truthful algorithm that can achieve a constant approximation when the number of goods is bounded. Regarding randomized mechanisms, we also provide a negative result, showing that we cannot have truthful in expectation mechanisms under the restrictions that they are Pareto-efficient and satisfy certain symmetry requirements.

3.24 Approximate Judgement Aggregation

Ilan Nehama (The Hebrew University of Jerusalem, IL)

Joint work of Nehama, Ilan
Main reference I. Nehama, "Approximate Judgement Aggregation," Discussion Paper 574R, Center for the Study of Rationality, Hebrew University, Jerusalem, 2012.
URL http://www.ratio.huji.ac.il/dp_files/dp574R.pdf

In this paper we analyze judgement aggregation problems in which a group of agents independently votes on a set of complex propositions that has some interdependency constraint between them(e.g., transitivity when describing preferences). We consider the issue of judgement aggregation from the perspective of approximation. That is, we generalize the previous results by studying approximate judgement aggregation. We relax the main two constraints assumed in the current literature, Consistency and Independence and consider mechanisms that only approximately satisfy these constraints, that is, satisfy them up to a small portion of the inputs. The main question we raise is whether the relaxation of these notions significantly alters the class of satisfying aggregation mechanisms. The recent

works for preference aggregation of Kalai, Mossel, and Keller fit into this framework. The main result of this paper is that, as in the case of preference aggregation, in the case of a subclass of a natural class of aggregation problems termed 'truth-functional agendas', the set of satisfying aggregation mechanisms does not extend non-trivially when relaxing the constraints. Our proof techniques involve Boolean Fourier transform and analysis of voter influences for voting protocols.

The question we raise for Approximate Aggregation can be stated in terms of Property Testing. For instance, as a corollary from our result we get a generalization of the classic result for property testing of linearity of Boolean functions.

3.25 Optimal Voting Manipulation

Svetlana Obraztsova (St. Petersburg Electrotechnical University, RU)

Joint work of Obraztsova, Svetlana; Elkind, Edith;

Complexity of voting manipulation is a prominent research topic in computational social choice. In this talk the complexity of optimal manipulation, i.e., finding a manipulative vote that achieves the manipulator's goal yet deviates as little as possible from his true ranking, was discussed. This problem was studied for three natural notions of closeness, namely, swap distance, footrule distance, and maximum displacement distance, and a variety of voting rules, such as scoring rules, Bucklin, Copeland, and Maximin. For all three distances, poly-time algorithms for all scoring rules and Bucklin and hardness results for Copeland and Maximin were showed.

3.26 Applying Social Choice Rules for the Solution of the Multi-Dimensional Knapsack Problem

Ulrich Pferschy (Universität Graz, AT)

Joint work of Nussbaumer, Martin; Pferschy, Ulrich;

The multi-dimensional knapsack problem (MKP) considers a set of items, each of them with a profit and a d-dimensional weight vector, and asks for the selection of a subset of items with maximum total profit, such that the sum of weights in each dimension fulfills a capacity constraint implied by a d-dimensional capacity vector. This generalization of the standard knapsack problem (KP) with a single constraint is surprisingly difficult to solve in practice. Even relatively small benchmark instances with 500 items and 10 constraints still cannot be solved to proven optimality.

Many approaches tackling MKP make use of an ordering of items based on a generalization of the efficiency measure usually applied for KP. This measure simply calculates the profit to weight ratio for each item. However, the presence of multiple constraints requires an aggregation of the d weights for each item. Different approaches for the resulting efficiency coefficients were presented in the literature. The most successful among them is based on the optimal dual variables from the associated LP-relaxation.

In this contribution, we propose a different approach to obtain a valuation of each item. We consider each of the d weight dimensions as a voter who gives a preference relation on the set of items based only on the single constraint the voter is associated with. Then we use different voting rules to derive a complete ordering of items based on the aggregated preference profile of the d voters. This ordering is then used e.g. for greedy-type heuristics.

Computational experiments show that this new approach of applying social choice techniques for the solution of a classical combinatorial optimization problem produces reasonably good solutions and offers a highly welcome element of diversification for metaheuristic frameworks.

Squeaky wheel optimization (SWO) is a metaheuristic which was successfully applied to MKP. In particular, SWO turned out to be useful in reducing an MKP instance to a core, i.e. fixing some of the variables to 0 or 1 and leaving only a smaller instance for further treatment (e.g. by an ILP-solver). Since SWO is based on an initial ordering and the subsequent reordering of the item set, the above voting-based procedure is well suited for obtaining alternative initial orderings. Computational experiments show that the resulting cores compare favorably with those based on more involved LP-solution values.

3.27 Bribery in Voting with CP-nets

Francesca Rossi (University of Padova, IT)

Joint work of Mattei, Nicholas; Venable, Kristen Brent; Pini, Maria Silvia; Rossi, Francesca;
Main reference N. Mattei, F. Rossi, K. B. Venable, M. S. Pini, "Bribery in Voting Over Combinatorial Domains Is Easy," in Proc. of the 11th Int'l Joint Conf. on Autonomous Agents and Multiagent Systems (AAMAS'12), Extended Abstracft, June 2012, Valencia, Spain.

We investigate the computational complexity of finding optimal bribery schemes in voting domains where candidates are multi-issue decisions and agents' preferences are represented as CP-nets.

In this setting, voting can be structured as the combination of several decisions, or it can be a one-step process.

We consider both approaches, by studying voting rules such as sequential majority (SM), one-step plurality (OP), one-step veto (OV), and one-step k-approval (OK). We then consider several cost schemes for changing a vote of an agent in response to a briber's request, among which:

C_{EQUAL} (any amount of change costs the same),

C_{FLIP} (the cost is the number of flips),

C_{LEVEL} (the cost is the number of flips weighted by their position in the CP-net).

SM bribery is easy except when we use C_{EQUAL}. For OP and OV, bribery is always easy, except with C_{FLIP} or C_{LEVEL} when we can flip dependent variables. Bribery is easy also for OK when k is a power of 2.

3.28 Bribery in Path-Disruption Games

Jörg Rothe (Universität Düsseldorf, DE)

Joint work of Rey, Anja; Rothe, Jörg
Main reference A. Rey, J. Rothe, "Bribery in Path-Disruption Games," in Proc. of the 2nd Int'l Conf. on Algorithmic Decision Theory (ADT'11), LNCS, vol. 6992, pp. 247–261, Springer-Verlag, 2011.
URL http://dx.doi.org/10.1007/978-3-642-24873-3_19

Bachrach and Porat (AAMAS 2010) introduced path-disruption games. In these coalitional games, agents are placed on the vertices of a graph, and one or more adversaries want to travel from a source vertex to a target vertex. In order to prevent them from doing so, the agents can form coalitions, and a coalition wins if it succeeds in blocking all paths for the adversaries. In this paper, we introduce the notion of bribery for path-disruption games. We analyze the question of how hard it is to decide whether the adversaries can bribe some of the agents such that no coalition can be formed that blocks all paths for the adversaries. We show that this problem is NP-complete, even for a single adversary. For the case of multiple adversaries, we provide an upper bound by showing that the corresponding problem is in Σ_2^p, the second level of the polynomial hierarchy, and we suspect it is complete for this class.

3.29 Control Complexity in Bucklin and Fallback Voting: A Theoretical and Experimental Analysis

Lena Schend (Universität Düsseldorf, DE)

Joint work of Erdélyi, Gábor; Rothe, Jörg; Schend, Lena;
Main reference J. Rothe, L. Schend, "Control Complexity in Bucklin, Fallback, and Plurality Voting: An Experimental Approach," in Proc. of the 11th Int'l Symp. on Experimental Algorithms (SEA'12), LNCS, vol. 7276, pp. 356–368, Springer-Verlag, 2012.
URL http://dx.doi.org/10.1007/978-3-642-30850-5_31

In [1] we complete the study of control complexity in fallback voting (FV) initiated by Erdelyi and Rothe. FV displays the broadest resistance to control currently known to hold among natural voting systems with a P-time winner problem. We also prove that Bucklin voting (BV) behaves almost as good in terms of control resistance.

Complementary to these worst-case results, an experimental analysis for FV and BV has been made inspired by Walsh's empirical investigation of manipulation complexity. Our findings indicate that NP-hard control problems can often be solved effectively in practice. Moreover, our experiments allow a more fine-grained analysis and comparison across various control scenarios, vote distribution models, and voting systems.

References

1 G. Erdélyi, L. Piras, J. Rothe. *The Complexity of Voter Partition in Bucklin and Fallback Voting: Solving Three Open Problems.* Proc. AAMAS'11. IFAAMAS, pages 837–844, 2011.

3.30 On the Computation of Fully Proportional Representation

Arkadii Slinko (University of Auckland, NZ)

My talk will consist of two parts. Firstly, I will outline challenges that Computational Social Choice faces in case of multi-winner elections. There is no such thing as an ideal voting system and we must sacrifice something but what are the trade-offs?

In the second part I will dwell on some parameterized complexity results in relation to fully proportional representation methods of Chamberlin-Courant and Monroe (joint work with Nadja Betzler and Johannes Ulhmann).

3.31 The Structure, Efficacy and Manipulation of Double-Elimination Tournaments

Isabelle Stanton (University of California, Berkeley, US)

Joint work of Stanton, Isabelle; Vassilevska Williams, Virginia

A double-elimination (DE) tournament is a competition where no participant is eliminated until they have lost two matches. It is structured as two single-elimination tournaments: the winner bracket and the loser bracket. Players who lose once in the winner bracket are mapped to positions in the loser bracket, according to a mapping called the link function. Surprisingly, although the same structure of the winner and loser brackets is used universally, there is no standard definition of the link function. By investigating several design goals, we show that the functions used in practice are not optimal and propose a similar function that is optimal with respect to avoiding repeated match-ups. We empirically show that use of the new link function does not impact the ability of a DE tournament to select a strong winner. Given our definitions, we address the manipulability of DE tournaments. We show that they are vulnerable to manipulation by a coalition of players who can improve their chance of winning by throwing matches. We also discuss the computational complexity of manipulation by a tournament organizer (agenda control) in two settings: by changing the player seeding in the winner bracket, or by picking the mapping of losers to the loser bracket. We provide algorithms, hardness proofs, and we formulate open problems for future research. Finally, we empirically compare single and double-elimination tournaments in terms of the probability that the strongest player wins the tournament and show that this probability can be drastically higher in DE tournaments, confirming the intuition that DE tournaments are more robust than SE tournaments.

3.32 Dividing the indivisible: elicitaton free protocols for the allocation of indivisible goods

Toby Walsh (NICTA and University of New South Wales, Sydney, AU)

Joint work of Kalinowski, Thomas; Narodytska, Nina; Walsh, Toby; Xia, Lirong

We study in detail a simple sequential procedure for allocating a set of indivisible goods to multiple agents. Agents take turns to pick items according to a policy. For example, in the alternating policy, agents simply alternate who picks the next item. A similar procedure has been used by Harvard Business School to allocate courses to students. When agents behave truthfully, this sequential allocation procedure returns precisely the Pareto optimal allocations. Supposing agents behave truthfully is a strong assumption. Indeed, strategic behavior has been observed in students selecting courses at the Harvard Business School. We study therefore the impact of strategic behavior on the complete information extensive-form game of such sequential allocation procedures. We show that computing the subgame-perfect Nash equilibrium is PSPACE-hard in general, but takes only linear time with two agents. Finally we compute the optimal policies for two agents in different settings, including when agents behave strategically and when agents can give away items.

4 Rump Session

The first presentation in the rump session was by Marcel Ackermann, who talked about recent developments concerning the DBLP database and asked the seminar participants to share their opinions and experiences using DBLP. Dr. Ackermann was available for discussions in the evening of the same day, and many seminar participants used this opportunity to talk to him.

The talk of Dr. Ackermann was followed by two conference announcements: Vincent Merlin reminded the participants about the 11th Meeting of the Society for Social Choice and Welfare, to take place in New Delhi in August 2012, and Felix Brandt and Piotr Faliszewski gave a brief presentation about the Fourth International Workshop on Computational Social Choice, to be held in Krakow in September 2012.

The announcements were followed by 9 short research talks.

- Vangelis Markakis talked about approximation algorithms for maxsum and minmax procedures in the election of committees; he mentioned several conjectures about the lower and upper bounds for this problem.
- Toby Walsh introduced various prices (of manipulation, information or computation) in voting and suggested them as a means to compare voting rules.
- Andreas Darmann considered the problem of deciding whether a given spanning tree is popular (in the sense of a weak Condorcet criterion) given that agents have preferences over the edges of an undirected graph. Whereas it is possible to draw a sharp separation between polynomially solvable and computationally intractable instances, the computational complexity of the existence of a popular spanning tree is still open.
- Ioannis Cariagiannis talked about complexity issues in bribery problems under scoring rules with scoring vectors of the form $(s, t, 0, \ldots, 0)$. Results for plurality, 2-approval and 3-approval are known, but the general case remains open.

- Ulle Endriss asked whether opinion polls provide relevant information in elections. He argued that the answer is positive for the plurality rule; however, it is unclear whether this is also the case for other rules.
- Jérôme Lang suggested that the problem of selecting the social activity for the free afternoon in Dagstuhl can be viewed as a social choice problem, proposed a formal model for it, and mentioned several research questions that can be stated within this model. He invited the participants of the seminar to contact him if they are interested in working on this problem. As a result, 5 seminar participants (including Jerome himself) and one external co-author wrote a paper about this problem that was submitted to COMSOC'12.
- Edith Elkind talked about open problems regarding the complexity of finding a safe strategic vote, as defined in the COMSOC'08 paper of Slinko and White. While the complexity of this problem has been resolved for a large class of scoring rules (including Borda and k-approval) and the Bucklin rule, for Maximin and Copeland this question remains open. She has also mentioned the problem of finding the Condorcet dimension of a given profile (this notion was introduced in the IJCAI'11 paper by Elkind, Lang and Saffidine).
- Vincent Conitzer introduced a new measure of manipulability of a voting rule, which is based on comparing the benefits from submitting a non-truthful vote and those from being able to submit multiple truthful votes. He showed how to compute this measure for some simple voting rules; for others, the associated algorithmic question is open.
- Craig Boutilier talked about matching models for preference-sensitive group purchasing: How should buyers be assigned to vendors?

Participants

- Craig Boutilier
University of Toronto, CA
- Steven J. Brams
New York University, US
- Felix Brandt
TU München, DE
- Robert Bredereck
TU Berlin, DE
- Markus Brill
TU München, DE
- Ioannis Caragiannis
CTI & University of Patras, GR
- Jiehua Chen
TU Berlin, DE
- Yann Chevaleyre
Université Paris-Dauphine, FR
- Vincent Conitzer
Duke University, US
- Andreas Darmann
Universität Graz, AT
- Britta Dorn
Universität Tübingen, DE
- Daniel Eckert
Universität Graz, AT
- Edith Elkind
Nanyang TU – Singapore, SG
- Ulle Endriss
University of Amsterdam, NL
- Gábor Erdélyi
Universität Siegen, DE
- Piotr Faliszewski
AGH University of Science & Technology – Krakow, PL
- Felix Fischer
University of Cambridge, GB
- Umberto Grandi
University of Amsterdam, NL
- Paul Harrenstein
TU München, DE
- Edith Hemaspaandra
Rochester Institute of Technology, US
- Lane Hemaspaandra
University of Rochester, US
- Marc Kilgour
Wilfrid Laurier University, CA
- Christian Klamler
Universität Graz, AT
- Sascha Kurz
Universität Bayreuth, DE
- Jérôme Lang
Université Paris-Dauphine, FR
- Kate Larson
University of Waterloo, CA
- Omer Lev
The Hebrew University of Jerusalem, IL
- Vangelis Markakis
Athens University of Economics and Business, GR
- Nicolas Maudet
UPMC – Paris, FR
- Vincent Merlin
Caen University, FR
- Ilan Nehama
The Hebrew University of Jerusalem, IL
- Svetlana Obraztsova
St. Petersburg Electrotechnical University, RU
- Ulrich Pferschy
Universität Graz, AT
- Francesca Rossi
University of Padova, IT
- Jörg Rothe
Universität Düsseldorf, DE
- Lena Schend
Universität Düsseldorf, DE
- Arkadii Slinko
University of Auckland, NZ
- Isabelle Stanton
University of California – Berkeley, US
- Toby Walsh
NICTA – Kensington, AU
- Virginia Vassilevska Williams
Stanford University, US
- Gerhard Woeginger
TU Eindhoven, NL
- Michael Zuckerman
The Hebrew University of Jerusalem, IL

Report from Dagstuhl Seminar 12111

Normative Multi-Agent Systems

Edited by

Giulia Andrighetto[1], Guido Governatori[2], Pablo Noriega[3], and Leon van der Torre[4]

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 12111 "Normative Multi-Agent Systems". Normative systems are systems in the behavior of which norms play a role and which need normative concepts in order to be described or specified. A normative multi-agent system combines models for normative systems (dealing for example with obligations, permissions and prohibitions) with models for multi-agent systems. Norms have been proposed in multi-agent systems and computer science to deal with issues of coordination, security, electronic commerce and institutions, agent organization. However, due to the lack of a unified theory, many multi-agent system researchers are presently developing their own ad hoc concepts and applications. The aim of this Dagstuhl Seminar was to formulate a collective appraisal of the current perspectives in the field and the most promising venues for future activity. In particular, the seminar has been conceived for the writing of a volume titled "A Prospective view of Normative Multi Agent Systems" aimed to become a standard reference in the field and to provide guidelines for future research in normative multi-agent systems.

Seminar 11.–16. March, 2012 – hwww.dagstuhl.de/12111
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1 Executive Summary

Giulia Andrighetto
Guido Governatori
Pablo Noriega
Leon van der Torre

The multi-disciplinary workshop on Normative Multi Agents attracted leading international scholars from different research fields (e.g., theoretical computer science, programming languages, cognitive sciences and social sciences).

The workshop was organised as follows: the organisers identified several relevant areas of research covering a wide and comprehensive spectrum of topics in the filed of Normative Agents. For each area, a prominent researcher was appointed as chair for the area. In the

months preceding the workshop the chairs collected material from the participants. During the first day they presented an overview of the areas they were in charge with special emphasis on some open questions and direction for future research.

The participants were divided in groups corresponding to the areas (due to some last minute cancellations some topics were under-represented and the scholars in those areas joined groups for closely related topics). Each group was allocated a morning session during which each member of the group had five minutes to provide an overview of their personal contribution to Normative Multi-Agents (plus some time for QA).

The format was well received by the participants and conducive to discussion. It gave them the opportunity to give very focused presentations while keeping the audience attention. The afternoon sessions, other the contrary, were dedicated to group work and group discussions. The aim of these sessions was to build consensus material of the specific topics and to identify fundamental research directions. The material is expected to be refined and to be articulated in chapters intended as a first step for the development for a road-map for this emerging area of computer-science with close interactions with other disciplines.

Results

During the seminar, participants split in seven working groups, centered around seven discussion themes. In the following paragraphs there is a summary of the discussion held by each working group.

Normative MAS: An Introduction. This working group first focused on three definitions and some related requirements for normative MAS. For each of such definitions, some guidelines for developing normative MAS have been proposed. Second, it has been discussed how to relate the concept of normative MAS to different conceptions of norms and how norms can be used within the systems. Finally, some specific issues that open research questions or that exhibit interesting overlaps with other disciplines have been identified.

Normative Consequence. This working group first provided a definition what deontic logic and normative reasoning is. Second, it discussed why normative reasoning is relevant for normative multi-agent systems and pointed out the advantages of formal methods in multi-agent systems. Finally, it focused on the specificity of normative reasoning in comparison to other kinds of reasoning.

Computational NorMAS. This working group considered normative systems from the computational perspective, proposing the following themes as challenging for the domain: 1) trade-offs in expressive power of the languages for representing deontic notions (such as norms, conflicts of norms, violations of norms, etc.); 2) complexity of algorithms required for a) implementing tools capable of analysing and verifying norms, b) implementing normative system platforms capable of monitoring norm violations and finally c) implementing agents capable of deliberating about norms.

Regulated MAS: Social Perspective. This working group addressed the problem of building normative multi-agent systems. It developed a static conceptual model through which a normative multi-agent system may be specified along with a dynamic conceptual model through which the operation of a normative system can be captured. A demonstration of how the proposed approach may be applied in prototypical applications of normative systems has been proposed.

Norm Compliance in MAS. This working group aimed to understand how norms regulate agent conduct and how norms impact on agent reasoning and behavior. Agents must be endowed with abilities to be able to reason about, process and otherwise manage norms in some appropriate fashion. In short, it demands that agent architectures are considered in terms of their ability to address these concerns, and that suitable architectures are developed.

(Social) Norm Dynamics. The working group aimed to identify the main steps in the dynamics of norms - i.e., generation, spreading, stabilization and evolution - as well as some of the relevant factors or determinants of such a process. The need for a deep understanding of these dynamics is becoming a compelling task for the NorMAS community due to the growing interest in open, evolving and flexible norm regulated and socio-technical systems. The working group pointed out that for a well-founded and innovative study of norms, it is necessary on the one hand to look at the cognitive mechanisms underlying the dynamics of norms and on the other hand to consider the role played by trust and cultural dimensions.

Norms and Simulation. This working group focused on the application of agent-based modeling and simulation to the issue of norm emergence, modification, and change. For the NorMAS community, agent-based simulations offer a platform to evaluate the behaviour of different models of norms and normative processes in a dynamic environment. Vice versa, the NorMAS community can supply (social) agent-based simulation studies with formal models of social concepts and mechanisms, especially those related to normative concepts, such as norms, roles, values, morals and conventions, and their transmission within a society.

The findings of the working groups were reported and discussed during the morning plenary sessions, and led to lively debate. During the seminar, each working group drafted a document presenting the main outputs achieved. Further work within the groups (by email correspondence) followed the end of the seminar, allowing finalizing the documents.

After a review process, the contributions of the working groups will be collected in a volume of the novel Dagstuhl Follow-up Series titled *A Prospective view of Normative–Multi Agent Systems*, aimed to become a standard reference in the field and to provide guidelines for future research in normative multi-agent systems.

In addition, *The Journal of Logic and Computation* and *Artificial Intelligence and Law* have agreed to publish special issues based on expanded and revised versions of the material presented at the seminar.

2 Table of Contents

3 Overview of Talks

3.1 Challenges in programming norm-aware agents

Natasha Alechina (University of Nottingham, GB)

There has recently been considerable work on programming frameworks for developing normative organisations. Such frameworks are often designed to inter-operate with existing BDI-based agent programming languages. However, programming norm-aware agents in conventional BDI-based agent programming languages remains difficult, as such languages typically lack support for deliberating about goals, obligations, prohibitions, sanctions and deadlines. These difficulties are compounded by the need to ensure that any normative agent programming framework remains tractable, i.e., deliberation about norms should be computationally feasible. In our opinion, this precludes the uses of approaches such as decision-theoretic scheduling to minimise sanctions or maximise the agent's utility (as this would require exponential computation).

The aim of this contribution is to identify challenges and advance the state of the art in programming norm-aware multiagent systems, by identifying key issues and questions in normative organisations and agent programming with priorities and deadlines.

3.2 Prescribing Norms Through Actions

Giulia Andrighetto (ISTC – CNR – Rome, IT)

Joint work of Andrighetto, Giulia; Castelfranchi, Cristiano

This work is aimed to claim that an understanding of the functioning of the normative competence requires a study of how norms are represented in the minds of individuals, the requisites that such representations must have, and what the mechanisms that allow a normative request to generate the corresponding mental representations are. After a brief overview of the debate in the study of norms, we will present a cognitive model of norms, and in particular we will focus on the role that Behavioral Implicit Communication (BIC) plays in the diffusion and stabilisation of social norms.

3.3 The Same Side of Two Coins? – A Survey on the usage of "Norms" and "Policies" across disciplines

Tina Balke (University of Surrey, GB)

Joint work of Balke, Tina; De Vos, Marina; Mileo, Alessandra; Schiller, Frank; Padget, Julian

"Norms" and "policies" are two terms in use across various areas of the computer science literature (multi-agent systems, security/privacy, web services, business applications, distributed/autonomic computing, decision support,...). However, the definition of these terms is

fuzzy, as is the identification of the purposes to which they are put. Furthermore, the terms are frequently used interchangeably, yet appear to refer to different concepts. Starting from their origins in social and political science, this paper aims to analyse systematically the usage of the terms "norms" and "policies" in computer science in general and multiagent and decision-support systems in particular. As a result of this analysis we aim to put forward for discussion our observations on overlaps and similarities in terminology, modeling and usage of these related concepts, and establish a more interdisciplinary perspective that may foster better concept and model reuse.

3.4 In what sense is deontic reasoning special?

Jan M. Broersen (Utrecht University, NL)

Intuitionistic logic is special in that is prescribes an alternative way to come from arbitrary premisses to entailed conclusions. The same holds for relevance logic and other alternatives to classic logic. I argue that deontic logic is not special in this sense. Deontic logic is the field aimed at designing formal systems for coming from deontic premisses to entailed deontic conclusions. And this is best studied by enriching languages with the appropriate structure. Deontic logic is special because this reasoning requires the modeling of many concepts: time, action, agents, intuitions, agency, etc.

3.5 Social Computing: A Software Engineering Perspective

Amit K. Chopra (University of Trento – Povo, IT)

The nature of applications is changing. Earlier they were logically-centralized; now they are becoming increasingly interaction-oriented. Social networks, social cloud, healthcare information systems, virtual organizations, and so on are evidence of the shift. In such applications, *autonomous* social actors (individuals or organizations) interact in order to exchange services and information. I refer to applications involving multiple autonomous actors as *social applications*.

Unfortunately, software engineering hasn't kept up with social applications. It remains rooted in a logically centralized perspective of systems dating back to its earliest days and continues to emphasize low-level control and data flow abstractions. In requirements engineering, for instance, the idea that specifications are of *machines*, that is, controllers, is firmly entrenched. Software architecture applies at the level of the internal decomposition of a machine into message-passing components. In other words, it helps us *realize* a machine as a physically distributed system. However, the machine-oriented worldview cannot account for social applications in a natural manner.

I understand *social computing* as the joint computation by multiple autonomous actors. By "joint", I refer simply to their interactions and the *social relationships* that come about from the interaction, not necessarily cooperation or any other form of logical centralization. In fact, each actor will maintain its own local view of the social relationships—there is no

centralized computer or knowledge base. The relationships themselves may take the form of commitments, trust, or some other suitable social norm. The purpose of the computation may be to loan a bicycle or a couch to a peer, to schedule a meeting or a party, to carry out a multiparty business transaction, to provide healthcare services, to schedule traffic in smart cities, to manage the distribution of electricity in smart grids, to build consensus on an issue via argumentation, or globally distributed software development itself—*anything* that would involve interaction among autonomous actors.

Clearly, we are already building social applications, even with current software engineering approaches. For example, online banking is a social application in which a customer interacts with one or more banks to carry out payments, deposits, and transfers. Social networks such as Facebook and LinkedIn facilitate interactions among their users. However, just because we can build social applications, it does not mean we are building them the right way. Right now, all these applications are built in a heavily centralized manner: banks provide all the computational infrastructure; so does Facebook. Users of these infrastructures are just that—*users*, no different from those of an elevator or an operating system. In other words, current software engineering produces only low-level technical solutions.

My vision of social computing instead embraces the social. It recognizes the autonomy of actors. Instead of control flow or message flow, it talks about the meanings of messages in terms of social relationships. Computation refers to the progression of social relationships as actors exchange messages, not to any actor's internal computations (although these too could be accounted for). The different aspects of my vision constitute a challenging research program. What form would specifications of social applications take? What would be the principles, abstractions, and methodologies for specifying social applications? On what basis would we say that an actor is behaving correctly in a social application? How would we help an actor reason about specifications of social applications with respect to its own goals and internal information systems? What kind of infrastructure would we need to run social applications? The answers to these questions and the realization of my vision will lead to a software engineering vastly more suited to social applications.

More details on social computing can be found in [1]. The idea of social computing is an elaboration of Munindar Singh's work on protocols and commitments in multiagent systems. To anyone wishing to learn more about the foundations of social computing, I highly recommend starting with [2].

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3.6 Control Automation to Reduce Costs of Control

Rob Christiaanse (TU Delft, NL)

Joint work of Christiaanse, Rob; Hulstijn, Joris

Abstract. Much compliance effort concerns adherence to contracts. Controls are added to the business process to make sure the other party will fulfill his part of the contract. Controls

have costs. In this paper we argue that fully automated controls help to lower control costs, because (i) they help to prevent misstatements (compliance by design) or (ii) they increase the quality of audit evidence and thereby reduce the audit risk and additional audit fees. The line of reasoning is illustrated by a case study of the implementation of automated controls on the procurement process for public transport services for the elderly and disabled. The case study suggests some open issues, which can be linked to concepts from Normative Multi Agent Systems.

3.7 Towards an Abstract Framework for Compliance: Preliminary Results

Silvano Colombo-Tosatto (University of Luxembourg, LU)

Joint work of Colombo-Tosatto, Silvano; El Kharbili, Marwane; Governatori, Guido; Kelsen, Pierre; Ma, Qin; van der Torre, Leendert

The present paper aims to provide an abstract framework to tackle the compliance problem. We first define the compliance problem and its elements such as processes and obligations. Secondly our abstract framework capable to efficiently deal with a fragment of the compliance problem is introduced. We provide the algorithms used in the framework along with the complexity results.

3.8 On the relationship between expectations, norms and commitments

Stephen Cranefield (University of Otago, NZ)

The concept of an agent expectation has been formalised by a number of researchers. A common understanding is that an expectation is a formula describing some future state of affairs, together with an active interest of the agent in tracking the value of the formula over time. At this informal level, there is a commonality with both norms and commitments: both involve expectations on future behaviour and, in general, they presuppose that some agent (or society as a whole) is interested in their fulfilment. However, while the concept of an expectation is related primarily to the temporal issue of whether a formula becomes true or false in the future, commitments and norms have additional social context, such as the debtor and creditor of a commitment and the sanction that may be associated with a norm. Commitments and instantiated norm instances are also created by different mechanisms and have different practical implications when fulfilled and violated.

This paper explores the relationship between expectations, norms and commitments and presents the argument that a logical account of expectations can be seen as representing a common core for logics of commitment and normative concepts. To make this concrete argument concrete we sketch out how this can be achieved for a particular choice of technlogies.

3.9 A Norm-Deliberation Process for Norm-Autonomous Agents

Natalia Criado (Polytechnic University of Valencia, ES)

Joint work of Criado, Natalia; Argente, Estafania; Dignum, Frank; Noriega, Pablo; Botti, Vicente

Norm-autonomous agents must be endowed with capabilities for making a decision about norm compliance. This paper proposes a new norm-deliberation process for allowing agents to make decisions about norm compliance autonomously.

3.10 Fuzzy Legal Interpretation

Celia da Costa Pereira (Université de Nice, FR)

Joint work of Boella, Guido; da Costa Pereira, Celia; Tettamanzi, Andrea; van der Torre, Leon; Villata, Serena

Legal interpretation is a mechanism from law allowing norms to be adapted to unforeseen situations. We focus on the role of interpretation in legal reasoning. A norm may be represented as a rule $b_1, ..., b_n => O$ such that l is the obligation linked to the norm. The degree associated to l depends on the degrees of truth of conditions b_i. These degrees depend in turn on the goal associated to the norm. We propose to define the fuzzy set $b'_i = f(b_i, g_j)$ where the value of b' increases or decreases according to the matching between b_i and the goal associated to norm j. The degree of matching depends on how concepts relevant to the norm are defined in a domain ontology.

3.11 Using Values in Normative Multi-Agent Systems

Gennaro Di Tosto (Utrecht University, NL)

Values can be intended as dispositions to choose one state of the world over another. Used to represent the motivational state of an agent, they can be useful to tackle issues related normative change, norm conflicts and policy making through social simulation. We present an example scenario intended to exemplify the behaviours we are interested in, to describe cultural groups as normative systems, and where the element of change is represented by the introduction of a new norm. Endowing agents with variables expressing what they value allows us to describe the direction of change in the proposed scenario.

3.12 Six Remarks on Normative Multiagent Systems

Frank Dignum (Utrecht University, NL)

1. **On the use and meaning of norms.** Although norms have been used in various ways and forms in CS (and MAS in particular) it is still unclear what it is that we try to incorporate in the normative systems that we build. Norms are very fuzzy and subtle instruments that have many aspects. Usually only a few aspects are picked up and implemented. However, it is unclear whether the result will live up to expectations, because the simplifications that are made prevent good predictions on the effect of the norms on the system. Thus I advocate to create a general framework for describing norms in a formal way in which we can include all the different aspects that are relevant in using norms. Because this is very complex (and possibly never concluded) the framework should be flexible and also allow for different techniques to be used to model different aspects of norms. Such a framework would allow people that actually want to use norms in a practical system to check which aspects of norms are important for their implementation and can check what are the consequences of including or excluding certain parts.
2. **On a computational view of norms.** In some sense this is a sequel of the first remark. When implementing norms in any system it is very important to check first which aspects of norms are relevant and important for the system. This should lead to a certain way of implementing the norms. Thus I do not believe that we can have a kind of "norm module" that could be added to a system. The big challenge is how norms can be added to a system that might already be built or is implemented in a certain software platform or according to a fixed architecture. How can these be extended to include norms, without having to start all over again? Can this be done or are normative systems so fundamentally different that we have to create different architectures, languages and platforms to cope with them? Can we characterise the main difficulties in connecting norms to other aspects of (MAS) systems? If so, we might still be able to automatize or support the connection (at least for some part).
3. **On collective norms.** When a norm is issued for a collective it has to be translated to some norms for the individuals that make up the collective. The question is what is the set of individual norms that will properly describe the collective norm. Or is this the same as collective intentions that cannot be defined in terms of individual intentions? If not, what are the exact relations between collective and individual norms? Another question (already being investigated in some of our papers) is the question who is responsible to fulfill the norm and who is responsible when a collective norm is violated. It might be clear that this depends on the structure of the collective. Is it a set of persons, a team, an organization,...How do the structural relations of the collective play a role in the collective norms?
4. **Norms and Groups.** Norms are not just imposed on members of a group, but also form a part of the identity of the group. One can say that a group of friends is tight, because they have a norm that whenever one of them is in trouble the others ought to help. Looking at the identifying role of norms for groups this also becomes part of the reason to comply or violate a norm. Complying to a group norm establishes group membership. In a similar way norms can identify roles within a group and thus determine whether persons can fulfill these roles. How does this influence the spreading and maintenance of norms? What does it mean for the violation and sanctioning of norms?

5. **Emergence of norms.** There has been some work on the emergence of norms, mainly in simulations. In order to determine whether a norm emerges, what should we measure? Can we see the difference between a norm emerging or a coincidental behavioral pattern a convention or something else? This raises the important question when we state that a system is a "normative system" (both artificial as natural systems). Can we pose some minimal requirements on when they can be normative? Should the agents in the system have some capability to have "moral judgements", should they contain value systems?
6. **Why are normative systems better?** Although we advocate norms as being essential elements for open systems it is not really clear where the added value of norms come in. As there seems not to be a standard way of implementing norms in systems it is difficult to predict how normative systems will behave. So, it is also not clear whether they will behave better in some way then systems that are designed without the explicit use of norms. If they are more flexible, what makes them more flexible? If they are more modular, what creates this modularity? And how would these properties reflect on the overall behavior of the normative systems? Can we say that norms provide added value when designing open systems? If so, what is the added value in the design exactly? I claim that we should be able to give precise answers to these questions if we want norms to be used by other people outside our community. It also leads to some research questions about implementing norms that have not been addressed in any systematic way. Nl. What are standard ways of implementing norms and normative behavior. How do norms relate to other design concepts for traditional (multi agent) systems and how should methodologies be adjusted to take them into account properly.

3.13 Formalizing Open Normative Systems Situated in Environment using Semantic Web Technologies

Nicoletta Fornara (Università della Svizzera italiana – Lugano, CH)

The study and analysis of the design and implementation process that brings to the realization of open interaction systems where autonomous heterogeneous components, like agents and humans, may interact in order to reach their goals is a crucial topic of research. This process involve the definition of various components: from the design of the data necessary to represent the state of the interaction, to the rules to describe the evolution of the state, to the norms for regulating the interactions, to the monitoring and enforcement component, to the mechanisms for the definition of the rules for the perception of the events and actions. Taking into account those characteristics, components, and required functionalities, relevant open challenges are: (i) How to design norms and institutions with the goal of reusing them in different applications? (ii) How to combine institutional models with studies on distributed event-based systems, like environments? (iii) What formal languages and architecture is it better to use for designing and implementing efficient and effective open interaction systems?

3.14 Position Paper

Dov M. Gabbay (King's College London, UK)

We view norms as metalevel rules on state of affairs and actions. We distinguish two types of rules:

1. Rules saying whether certain formulas should hold in the state.
2. Rules saying whether certain actions should or should not be taken in the state.

To be able to formalise this set up we need a language for states , a language for actions, a language for formulas which can be evaluated to hold or not hold in a state or on an action and an algorithm, telling us how to apply an action to a state to get new states.

The norms can be defined on top of that, as input output pairs (A, B) where A is a formula and B is a formula, to be evaluated on states and actions. A is the condition and B is the result of the norm.

The norm is violated in a state or action if A holds and B does not hold.

3.15 Bipolar argumentation frames and Contrary to Duty obligations Abstract (preliminary report of a research program)

Dov M. Gabbay (King's College London, UK)

In my papers [5, 3], I modelled the Chishom paradox and generaly Chicholm like sequences of contrary to duty obligations by using Reactive Kripke models [4]. Reactive Kripke frames have two types of arrows: ordinary single arrows $x \to y$ indicating accessibility relations and double arrows of the form $(u \to v) \twoheadrightarrow (x \to y)$, indicating reactive connections.

If the frame ordering is a tree, as it is in the models for contrary to duty obligations, the double arrow $(u \to v) \twoheadrightarrow (x \to y)$ can be uniquely represented by $v \twoheadrightarrow y$. We thus get a bipolar network where we interpret $\to$ as support and $\twoheadrightarrow$ as attack. Of course the same reactive graph can be manipulated in the Deontic way [5], when we read it as modelling contrary to duty obligations and it will be manipulated in the argumentation way [1, 2], when viewed as a bipolar network. The question arises , can we find a family of tree like graphs, (which do not sacrifice generality neither in the contrary to duty area nor in the bipolar argumentation area) for which the Deontic and the argumentation manipulations are the same. This paper shows that this is possible , and thus establishes a connection between the contrary to duty area and the bipolar argumentation area.

Note the following:

1. This connection with bipolar argumentation frames is made possible because of the modelling of contrary to duty obligation using reactive Kripke models. The connection between Reactivity and Bipolarity is more easy to see.
2. The way the game is played in each area is different. So we have here a wide scope for interaction and exchange of ideas between argumentation and contrary to duties. These include:

2a. Deontic like modelling and axiomatisations for bipolar argumentation.

2b. Argumentation semantics for contrary to duty paradoxes which can especially handle contrary to duty loops (a subject not even mentioned in the contrary to duty literature).
2c. The equational approach to contrary to duty, imported from the equational approach to argumentation.
2d. The fact that bipolar frames can be instantiated as contrary to duty obligation might shed some light on the polarised debate in the argumentation community on how to instantiate argumentation networks, see [7].
2e. Settle questions of how to model (what is) support in argumentation.
3. Doing Modal Logic in Bipolar Argumentation Theory (compare with [6]).

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3.16 Norms as Objectives: Revisiting Compliance Management in Mulit-agent systems

Aditya K. Ghose (University of Wollongong, AU)

Joint work of Ghose, Aditya K.; Savarimuthu, Bastin Tony Roy

This paper explores a hitherto largely ignored dimension to norms in multi-agent systems: the normative role played by optimization objectives. We introduce the notion of optimization norms which constrain agent behaviour in a manner that is significantly distinct from norms in the traditional sense. We argue that optimization norms underpin most other norms, and offer a richer representation of these. We outline a methodology for identifying the optimization norms that underpin other norms. We then dfine a notion of compliance for optimization norms, as well as a notion of consistency and inconsistency resolution. We

offer an algebraic formalization of valued optimization norms which allows us to explicitly reason about degrees of compliance and graded sanctions. We then outline an approach to decomposing and distributing sanctions among multiple agents in settings where there is joint responsibility.

3.17 Combining different perspectives on norms and agency

Max Knobbout (Utrecht University, NL)

Norms in Multiagent Systems generally allow for different modes of analysis. On one hand we can see them as constructs specified by some formal language denoting what ought (or ought not) to be the case. Such approaches generally do not answer what incentives the agents have to comply, nor do they answer how these norms can emerge. On the other hand we can see norms as the emerging coordination between interacting (rational) agents. This allows for a more game-theoretic oriented approach, where for example a norm can be seen as an equilibrium choice in a game that possesses multiple equilibria. This approach suffers from different problems; for example it does not specify where the preference from the agents come from. I believe that an important challenge for researchers in the field of norms and agency is to find the underlying connection between these different approaches (this is also the topic of my current research). This will hopefully allow us to get a better and more broader understanding of the current issues within this field of research.

3.18 Open Normative Environments

Henrique Lopes-Cardoso (University of Porto, PT)

Joint work of Lopes-Cardoso, Henrique; Oliveira, Eugenio

Open multi-agent systems relying on autonomy as an intrinsic property of agents cannot be addressed with constraining approaches, in which agent behavior is concerned. Moreover, in normative multi-agent systems autonomy is fully accommodated at the level of norms: agents being able to choose which norms to adopt. It is therefore important to develop appropriate infrastructures that assist software agents in two tasks: first, that of negotiating or selecting the norms that they deem more appropriate to govern their interactions; second, that of monitoring and enforcing the normative system thus created. From this perspective, an open normative environment is envisaged as one with an evolving normative space, whose norms apply if and when agents commit to a norm-governed relationship.

3.19 Norm generation from experience

Maite Lopez-Sanchez (University of Barcelona, ES)

Joint work of Morales, Javier; Lopez Sanchez, Maite; Esteva, Marc
Main reference J. Morales, M. Lopez-Sanchez, M. Esteva, "Using Experience to Generate New Regulations," in Proc. of the Int'l Joint Conf. on Artificial Intelligence (IJCAI'11), pp. 307–312, 2011.
URL http://ijcai.org/papers11/Papers/IJCAI11-061.pdf

Defining the norms for bright new organizations or Multi-Agent systems may not be a straightforward process, so the aim of this paper is to advance in the automatic generation of norms based on experience. If we understand norms in their broad sense of social conventions, a number of approaches, such as norm synthesis, norm agreement or norm emergence have been studied by the research community. Nevertheless, they present some limitations in terms of complexity or required domain knowledge that we aim at overcoming. Thus, we present a proposal for norm generation where a regulatory authority proposes new norms whenever conflicts arise. Proposed norms are continuously evaluated in terms of the compliance behavior of agents and their effects in the system. Therefore, agents can decide whether to comply or violate norms, and this may result in conflicts. We consider this information to be valuable when assigning a meaning to this effect. For instance, the fact that a norm that is being repeatedly violated and no conflicts have arisen can be interpreted as evidence against the necessity of the norm. This top-down proposal combined with the bottom-up evaluation closes the loop of the generation of norms, and leaves room for dynamic changes both in the system or the agents behaviour.

3.20 Norm Adaptation in MAS

Maite Lopez-Sanchez (University of Barcelona, ES)

Joint work of Campos, Jordi; Esteva, Marc; Lopez-Sanchez, Maite; Morales, Javier; Salamo, Maria
Main reference J. Campos, M. Esteva, M. Lopez-Sanchez, J. Morales, M. Salamo, "Organisational adaptation of multi-agent systems in a peer-to-peer scenario." Computing, 91(2):169–215, 2011
URL http://dx.doi.org/10.1007/s00607-010-0141-9

The overall structure of agent interactions in a Multi-Agent System (MAS) may emerge implicitly as a result of agent activities in Agent Centred MAS approaches (ACMAS) or may be explicitly designed in Organisation Centred MAS approaches (OCMAS). We consider the later to include an organization composed of a social structure, social conventions and organizational goals. Norms can be defined as social conventions that prescribe how agents should interact so to accomplish organizational goals. Nevertheless, at run time, changes in the environment or in the agent population may result in a decrease in goal accomplishment. Organisational dynamic adaptation has attracted a significant amount of research effort since it can improve system performance across changing situations, outweighing the overhead and costs associated with making dynamic changes. In particular, we claim that norm adaptation constitutes a relevant research topic despite the fact that far fewer approaches have tackled it. We envision norm adaptation as a goal driven process, and so, we advocate for acquiring knowledge about the relationship between norms and goal accomplishment at run time by using a machine learning approach. Furthermore, we argue the resulting adaptation mechanism should be robust enough so to be able to cope with different system

instabilities regardless of its origin: changes in system dynamics, agent population changes, or even existence of non-norm- compliant agents. And this may not necessarily require an explicit norm enforcement mechanism but a change in the norms that best compensate for current instabilities.

3.21 On the conceptual and logical foundations of moral agency

Emiliano Lorini (Paul Sabatier University – Toulouse, FR)

The aim of this work is to provide a logical analysis of moral agency. Although this concept has been extensively studied in social philosophy and in social sciences, it has been far less studied in the field of deontic logic and multiagent systems (MASs). We discuss different aspects of moral agency such as the distinction between desires and moral values and the concept of moral agent.

3.22 How to make existing logics for MAS and NorMAS

Emiliano Lorini (Paul Sabatier University – Toulouse, FR)

I propose an Ockhamist variant of Propositional Dynamic Logic PDL, called Ockhamist Propositional Dynamic Logic OPDL. I discuss the relationships between OPDL and existing logics of agency and cooperation used in the area of multi-agent systems such as CTL, PDL, STIT, Coalition Logic and ATL.

3.23 The Harmonious Triad of Social Norms, Complex Systems and Agent-based Simulation.

Samhar Mahmoud (King's College London, GB & PPM Group Univ. of Konstanz, DE)

At the advent of the social computing era, billions of devices are now (i) globally interconnected, (ii) environment-aware, and (iii) embedded in human society with the scope of improving quality of life. Together with the unstoppable increase in on-line communities and social networking, it seems that humans (and devices) are increasingly, and better, connected through virtual environments. The set of interactions between individuals in society results in complex community structure, captured by social networks. However, by virtue of frequent changes in the activity and communication patterns of individuals, their associated social and communication networks are subject to constant evolution. Moreover, due to the magnitude, openness and dynamism of on-line communities, centralised supervision of all possible interactions in real time becomes infeasible and computationally intractable. Social norms provide one potential solution for the regulation of such types of system. The use of social

norms brings several advantages since they are inexpensive for society (as there is no need for trained authorised individuals in supervising interactions), have adaptive capability (as norms are self-imposed and self-controlled, so they can rapidly adapt), are easy to implement (since it is in everyone's social interest to follow them). The main strength of social norms can be found in their decentralised nature: they emerge through the decentralised interactions of individuals within a collective, and are not imposed or designed by an authority, but by the individuals themselves. Despite their value, our understanding of such phenomena is limited. It is thus vitally important to investigate and understand complex systems and their interactions, in the context of different types of norms and different types of normative systems, in order to achieve appropriate adaptability and consequently efficient and effective self-organisation and self- regulation. Critically, the techniques of agent-based simulation provide a key means of developing this understanding in order that the dynamics of social norms can be leveraged in support of such self- regulation. Moreover, these techniques can potentially serve policy-makers and system designers to foresee the effects of specific environmental and social conigurations and react against failures.

3.24 Social And Customary Norms in Multi-Agent Systems

Eunate Mayor Villalba (GET – Toulouse, FR)

Abstract. In order to disentangle the real nature and dynamics of customs and its role within the legal system, the first issue pertains finding the proper way to study the de- velopment of such customary practices: is it a merely spontaneous dynamic process over which individuals have little control, and which depends basically on psycho-cognitive human characteristics, or is it a more complex phenomenon? The aim of this paper is to stimulate debate and foster the development of an interdisciplinary approach to social and customary norms.

Keywords: Social norms, Multi-Agent Systems, Customs, Learning

3.25 Culture and Norms

John McBreen (Wageningen University, NL)

We discuss how group dynamics are an essential part of social interaction that can add to the realism of models of the evolution of social norms. We discuss how relationships to others in a group context may affect one's willingness to emulate, forgive, reproach, oppose, admire etc. the adoption of new social norms by other group members. We also discuss how these group dynamics can differ across countries, and link this to the Hofstede Dimension of Culture.

3.26 Remarks on normative MAS from an institutional perspective

Pablo Noriega (IIIA – CSIC – Barcelona, ES)

This paper has two aims. First, it intended as an outline of the many aspects of normative MAS that become interesting when one sees a Normative MAS as a set of regulations that apply to a population of agents and the elements that support them. It takes an institutional perspective in the sense that the interest is on those aspects that are constitutive of normative MAS, regardless of any particular set of regulations, and regardless of the motivations, rationality or goals of participating agents. The perspective is institutional also in the narrower sense that it is not concerned with the same and similar issues when they are approached from an "organizational perspective" where the normative system presumes the existence of elements such as organizational goals, structure, allegiances and boundaries. The second aim is to use that broad view as a background that gives context to a few questions that might be significant for normative MAS and have been little explored in this community.

3.27 Interdependence of norms, reputation and groups

Mario Paolucci (ISTC – CNR – Rome, IT)

In this paper, I argue how norms and reputation can interact and concur to define groups which are needed to move from "delusional" norms and reputation to actual ones.

3.28 Conflict resolution techniques for normative reasoning

Xavier Parent (University of Luxembourg, LU)

Main reference X. Parent, "Moral particularism in the light of deontic logic." Artificial Intelligence and Law, 19, pp. 75–98, 2011.
URL https://parent.gforge.uni.lu/

Conflicts resolution techniques have been developed in the context of the study of non-monotonic reasoning. We argue they are not suitable to model normative reasoning because of the need to distinguish between norm violation and exception to a norm. A medical example is use to substantiate this point further. It highlights the role of backwards reasoning in the normative domain.

3.29 An Argumentation-based Approach to Trust

Simon Parsons (Brooklyn College, US)

Joint work of Parsons, Simon; McBurney, Peter; Sklar, Elizabeth; Tang, Yuqing
Main reference Y. Tang, K. Cai, P. McBurney, E. Sklar, S. Parsons, "Using argumentation to reason about trust and belief," Journal of Logic and Computation, to appear.

Trust is a mechanism for managing the uncertainty about autonomous entities and the information they store, and so can play an important role in any decentralized system. As a result, trust has been widely studied in multiagent systems and related fields such as the semantic web. Here we introduce a formal system of argumentation that can be used to reason using information about trust. This system is described as a set of graphs, which makes it possible to combine our approach with conventional representations of trust between individuals where the relationships between individuals are given in the form of a graph. The resulting system can easily relate the grounds of an argument to the agent that supplied the information, and can be used as the basis to compute Dungian notions of acceptability that take trust into account.

3.30 The Use and Meaning of Norms in MAS: A Conceptual View

Antonino Rotolo (University of Bologna, IT)

In this paper we discuss the role of norms in MAS. We first argue that the most fruitful way to define norms in this setting is not state what norms are, but what they do or are expected to do. Then, we identify some normative paradigms that MAS can adopt, including those inspired by morality, social norms, and the law. In particular, we argue that the legal paradigm offers a number challenges (and an opportunity) for normative MAS. We finally show that any comprehensive view of normative MAS must be tested against the following research questions: developing (a) generative models of norms; (b) norm change models of norms; and (c) compliance, application and sanction models of norms.

3.31 Norm learning - research issues and opportunities

Bastin Tony Roy Savarimuthu (University of Otago, NZ)

Joint work of Savarimuthu, Bastin Tony Roy; Cranefield, Stephen; Verhagen, Harko

Several simulation-based works in Normative multi-agent systems (NorMAS) have investigated how software agents learn norms that exist in an agent society. However, there are limitations to the research works on norm learning. This position paper aims at discussing these limitations and the research questions that need to be addressed to overcome these limitations. This paper also briefly discusses the suitability of virtual environments such as multi-player games and SecondLife as domains to explore these research questions.

3.32 Towards mining norms in open source software repositories

Bastin Tony Roy Savarimuthu (University of Otago, NZ)

Joint work of Savarimuthu, Bastin Tony Roy; Dam, Hoa Khanh

The concept of norms has attracted a lot of interest in various disciplines including computer science since it facilitates collaboration and cooperation of individuals in societies. Extracting norms from computer-mediated human interactions is gaining popularity since huge volume of data is available from which norms can be extracted or "mined". The emerging open source communities offer exciting new application opportunities for norms mining since such communities involve collaboration and cooperation among developers from different geographical regions, background and cultures. Mining norms from open source projects however has not received much attention from the normative multi-agent system community. Therefore, our position paper addresses this issue by discussing the opportunities and the challenges presented by this domain for the study of norms. It provides a brief description of existing technologies in mining software repositories (MSR) that can be leveraged. In addition, it highlights the motivations for the study of normative behaviour in open source software development from the data available in various software repositories. On this basis, it lays out the main research questions and open challenges in mining norms from these repositories.

3.33 Common Semantics and Complexity - An NMAS Research Agenda Proposal

Fernando Schapachnik (University of Buenos Aires, AR)

Joint work of Mera, Sergio; Schapachnik, Fernando

This short article sketches a proposal for an NMAS research agenda for the upcoming years. The salient topics are finding common families of formalisms that allow for easy comparison of deontic proposals and considering not only their expressiveness but also their complexity.

3.34 A Normative Basis for Trust

Munindar Singh (North Carolina State University, US)

We consider open settings wherein multiple autonomous parties interact. Such settings bring out the problem of decision-making: How can each party decide on how it should engage the others?

Trust is a key ingredient in such decision making. But this leads to another question: How can each party determine how much trust to place in another autonomous party? To be an effective basis for decision making, the estimation of trust must incorporate (1) the

interaction being considered by the first party (i.e., the task or transaction), (2) the social or organizational relationships, and (3) the relevant context.

3.35 Governance in Sociotechnical Systems

Munindar Singh (North Carolina State University, US)

We address the challenge of administering sociotechnical systems, which inherently involve a combination of software systems, people, and organizations. Such systems have a variety of stakeholders, each in essence autonomous. Traditional architectural approaches assume that stakeholder concerns are fixed in advance and addressed out-of-band with respect to the system. In contrast, sociotechnical systems of interest have long lifetimes with changing stakeholders and needs. We propose addressing stakeholders' needs during the operation of the system, thus supporting flexibility despite change. Our approach is based on norms among stakeholders; the norms are streamlined through a formal notion of organizations. We demonstrate our approach on a large sociotechnical system we are building as part of the Ocean Observatories Initiative.

3.36 Actions and Obligations: merging the internal and the external perspective

Paolo Turrini (University of Luxembourg, LU)

When an individual or a group of individuals is confronted with a number of possible choices, often the question arises of what that individual *should* do. Traditionally, the formal study of terms such as should, must, ought to, may etc. has been dealt with by deontic logic, a branch of modal logic that analyzes the structure of normative concepts. In the history of deontic logic two perspective have been taken in modelling these type of concepts:

- In the first, norms assume an *internal* or *utilitarian* character: actions that are obligatory for a player (or a group of players) are those that are best for the player itself (or, in a general sense, meet the preferences of some players).
- In the second, norms assume an *external* or *systemic* character: choices are judged against predetermined interests, specified from outside the system.

We briefly describe the two views on norms and we show a two-steps example where the two views converge at first, but radically differ later. We believe that a challenge for deontic logic is to understand the relations among the two perspectives and, possibly, to suggest a choice among the two.

3.37 Group Norms

Wamberto Vasconcelos (University of Aberdeen, GB)

Group norms address groups of individuals, affecting their joint behaviours, arising in many situations; *e.g.*, an obligation on the sales team to meet once a week, a prohibition on gatherings of more than x people, or a permission for a group visit to a building. This document makes a case for the importance of representing and processing such norms, raises issues which should be investigated, and sketches how research on group norms could connect coordination mechanisms and normative reasoning.

3.38 Putting the agent back together again - needs for integrating social and behavioural sciences for agent-based social simulation

Harko Verhagen (Stockholm University, SE)

Joint work of Verhagen, Harko; Elsenbroich, Corinna

Agent-based modelling has had great success in modelling normative behaviour. Its success is due to agent-based modelling being able to tackle the problem of normative behaviour at the heart by reconstructing the micro macro link, generating macro phenomena from micro specifications. The starting point for models of normative behaviour has so far been an individualist agent, i.e. an agent has its own goals and behaves according to them with social behaviour as an emergent phenomenon. The BDI architecture on which most models are based is a strongly individualist architecture. An agent is defined over its individual beliefs, desires and intentions and any social behaviour results either by emergence (Epstein 2001), by deterrence (Axelrod 1986) or by explicitly defining a set of obligations an agent has to follow, transforming the BDI into the BOID (Broersen et al. 2000, 2001). The most advanced models of normative behaviour to date, those based on the EmiL-a architecture transcend the individualist nature of an agent to some extent by incorporating both perception of norms and reasoning with norms into the agent via the so called normative board. Now the agents are able to have a normative interface with the world rather than just a factual one as is the case in the BOID agent. Still, desires and intentions of the agent are defined individualistically, with normative knowledge evaluated according to these desires and intentions. But what if the agent was not quite as individualistic? What if agents have an active interest in social behaviour, in sharing goals, in cooperating? And how do we integrate emotions into these frameworks or open up for glass-box cognitive models to replace the black box of BDI? And what about emotions? We advocate work on these issues to improve the agent simulation models such that: a) Models will no longer analyse whether social behaviour is possible but what kind of social behaviour might emerge. b) Models give up a long-standing paradigm of atomism. c) Models can no longer be purely behavioural as agents need to understand their own intentions and goals and those of other agents. d) Models of human agency need to address the social, psychological and emotional aspects simultaneously. In the following we will describe we-intentions as an alternative to the I-intentions of homo economicus followed by a description of an agent architecture encompassing the components outlined above. We will conclude by pointing to a set of challenges.

3.39 Data Licensing in the Web of Data: open challenges

Serena Villata (INRIA Sophia Antipolis, FR)

Joint work of Villata, Serena; Gandon, Fabien

A common assumption in the Web is that the publicly avail- able data, e.g., photos, blog posts, videos, can be reused without restric- tions. However, this is not always true, even when the licensing terms are not specified. Consuming Linked Open Data includes the fact that the data consumer has to know the terms under which the data is re- leased. The licensing terms in the Web of Data are specified by means of machine-readable expressions, such as additional triples added to the RDF documents stating the license under which the data is available. We highlight the future trends in data licensing and the possible connections with normative multiagent systems.

3.40 Argumentation and Norms

Serena Villata (INRIA Sophia Antipolis, FR)

Joint work of Villata, Serena; Antonino Rotolo; Nir Oren; Leendert van der Torre

Norms and argumentation are two research areas which are becoming more and more connected over the last decade, in the legal field, in knowledge representation, ethics, or linguistics, and most recently, in agreement technologies in computer science. Norms are used to set the space of legal agreements (or commitments) and argumentation is used to choose among the possible agreements. Moreover, we may consider norms set not only the scope of possible legal agreements, but also the way we can choose among these possible agreements. Existing works, same of them mentioned above, on norms and argumentation can be categorized into two different classes, namely (i) arguing about norms, and (ii) norms about argumentation. The former includes the greater part of existing works in the area of norms and argumentation, such as approaches which aim at resolving conflicts and dilemmas, looking in particular at how norms interact with other norms, arguing about norm interpretation and dynamics, arguing about norm adoption, acceptance and generation, representing norm negotiation, and arguing about contracts. In spite of all the existing literature on these topics, several challenges have still to be addressed and resolved. For instance, the introduction of frameworks where the individuals can discuss about the merits and the effects of the norms to be adopted in the society, or the proposal of reacher preference models to detect and reason about norm interactions are fundamental steps to approach the two research areas. The latter, instead, includes a smaller set of existing works, and it aims at addressing the challenges about dialogue and debate protocols, reasoning about epistemic norms, and enforcement models of the burden of proof. For instance, the introduction of new techniques to verify whether a virtual agent complies with an epistemic norm, or the development of tools able to support the judging entities and the lawyers to enforce the burden of proof are further challenges for agreement technologies.

3.41 Visualizing Normative Reasoning

Leon van der Torre (University of Luxembourg, LU)

Successful reasoning formalisms in artificial intelligence such as Bayesian networks, causal networks, belief revision, dependence networks, CP-nets, Dung's abstract argumentation theory, come with intuitive and simple visualizations. Traditionally deontic logic has been associated with preference orders, which have an intuitive visualization. With the rise of candidates for new standards for normative reasoning, the need emerges to have new visualizations.

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Report from Dagstuhl Seminar 12121

Applications of Combinatorial Topology to Computer Science

Edited by

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Abstract

This report documents the program of Dagstuhl Seminar 12121 "Applications of Combinatorial Topology to Computer Science". The seminar brought together researchers working on applications of combinatorial topology to various fields of computer science. The goal was to foster communication across these fields by providing researchers in each field the opportunity to explain their research programs to the others. The fields covered included distributed computing, persistent homology, semantics of concurrency, and sensor networks.

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1 Executive Summary

Lisbeth Fajstrup
Dmitry Feichtner-Kozlov
Maurice Herlihy

In recent years, concepts and techniques adapted from combinatorial and algebraic topology have led to a variety of promising new results in several areas of Computer Science, including distributed computing, sensor networks, semantics of concurrency, robotics, and vision.

The recent Dagstuhl seminar *Applications of Combinatorial Topology to Computer Science* (12121), brought together researchers in these fields, both to share ideas and experiences, and to establish the basis for a common research community. Because of differences in terminology and academic culture, it is often difficult for researchers in one area to become aware of work in other areas that may rely on similar mathematical techniques, sometimes resulting in duplication of effort. This Dagstuhl seminar provided a valuable opportunity to bring together researchers in both computer science and mathematics who share a common interest in emerging applications of combinatorial topology.

2 Table of Contents

3 Overview of Talks

3.1 Evasion paths in mobile sensor networks

Henry Adams (Stanford University, US)

Imagine that disk-shaped sensors wander in a planar domain. A sensor can't measure its location but does know when it overlaps a nearby sensor. We say that an evasion path exists in this sensor network if a moving evader can avoid detection. A theorem of Vin de Silva and Robert Ghrist gives a necessary condition, depending only on the time-varying connectivity graph of the sensor network, for an evasion path to exist. Can we sharpen this theorem? We'll consider examples that show the existence of an evasion path depends not only on the network's connectivity data but also on its embedding.

3.2 An equivariance theorem with applications to renaming

Armando Castañeda (IRISA / INSA – Rennes, FR)

Joint work of Castañeda, Armando; Herlihy, Maurice; Rajsbaum, Sergio

In the *M-renaming* task, each of $n+1$ processes is issued a unique name taken from a large namespace, and after coordinating with one another, each chooses a unique name taken from a (much smaller) namespace of size M. Processes are *asynchronous* (there is no bound on their relative speeds), and potentially *faulty* (any proper subset may halt without warning). Assuming processes communicate through a shared read- write memory, for which values of M can we devise a protocol that ensures that all non-faulty processes choose unique names?

To rule out trivial solutions, we require that any such protocol be *anonymous*: informally stated, in any execution, the name a process chooses can depend only on the name it was originally issued and how its protocol steps are interleaved with the others.

This problem was first proposed by Attiya et al. [1], who provided a protocol for $M = 2n+1$, and showed that there is no protocol for $M = n+2$. Later, Herlihy and Shavit [6] used chain complexes, a construct borrowed from Algebraic Topology, to show impossibility for $M = 2n$. Unfortunately, this proof, and its later refinements [2, 6, 7], had a flaw: because of a calculation error, the proof did not apply to certain dimensions satisfying a number-theoretic property described below. Castañeda and Rajsbaum [3] provided a new proof based on combinatorial properties of black-and-white simplicial colorings, and were able to show that in these dimensions, and only for them, protocols do exist for $M = 2n$. Nevertheless, this later proof was highly specialized for the weak symmetry breaking task, a task equivalent to renaming with $M = 2n$, so it was difficult to compare it directly to earlier proofs, either for renaming, or for other distributed problems. In the *weak symmetry breaking* task [4, 6], each of $n+1$ processes chooses a binary output value, 0 or 1, such that there is no execution in which the $n+1$ processes choose the same value.

In this talk we present an algebraic topology theorem that captures the impossibility of the renaming task. While this theorem requires more mathematical machinery than the specialized combinatorial arguments used by Castañeda and Rajsbaum, the chain complex formalism is significantly more general. While earlier work has focused on protocols for an

asynchronous model where all processes but one may fail ("wait-free" protocols), the chain complex formalism applies to any model where one can compute the connectivity of the "protocol complexes" associated with that model. This approach has also proved broadly applicable to a range of other problems in Distributed Computing [5, 7]. In this way, we incorporate the renaming task in a broader framework of distributed problems. The second contribution is to point out where the flaw is in previous renaming lower bound proofs [6, 7].

As in earlier work [5, 7], the existence (or not) of a protocol is equivalent to the existence of a certain kind of chain map between certain chain complexes. Here, we replace the *ad-hoc* conditions used by prior work [6, 7] to capture the informal notion of anonymity with the well-established mathematical notion of *equivariance*. We prove a purely topological theorem characterizing when there exists an equivariant map between the chain complexes of an n-simplex and the chain complexes of an annulus. The desired map exists in dimension n if and only if $n+1$ is not a prime power. These are exactly the dimensions for which renaming is possible for $M = 2n$ [3].

In a more precisely way, the theorem is the following. Let σ^n be the simplex $\{P_0, \ldots, P_n\}$. For brevity, let σ^n denote the complex containing σ^n and all its faces. Let $\mathcal{S}_n$ be the symmetric group of order $n+1$. Clearly, $\mathcal{C}(\sigma^n)$ is an $\mathcal{S}_n$-chain complex: for each $\pi \in \mathcal{S}_n$, $\pi(\langle P_0 P_1 \ldots P_j \rangle) = \langle \pi(P_0)\pi(P_1)\ldots\pi(P_j)\rangle$. Now consider the following annulus $\mathcal{A}^n$ defined as follows. Each vertex has the form (P_i, b_i), where $P_i \in \sigma^n$ and v_i is 0 or 1. A set of vertexes $\{(P_0, v_0), \ldots, (P_j, v_j)\}$ defines a simplex of $\mathcal{A}^n$ if the P_i are distinct, and if $j = n$ then the b_i are not all 0 or all 1. Clearly, $\mathcal{C}(\mathcal{A}^n)$ is a $\mathcal{S}_n$-chain complex: for each $\pi \in \mathcal{S}_n$, $\pi(\langle (P_0, b_0)\ldots(P_j, b_j)\rangle) = \langle(\pi(P_0), b_0)\ldots(\pi(P_j), b_j)\rangle$.

▶ **Theorem 1.** *There exists a non-trivial $\mathcal{S}_n$-equivariant chain map*

$$a : \mathcal{C}(\sigma^n) \to \mathcal{C}(\mathcal{A}^n)$$

if and only if $n+1$ is not a prime power.

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3.3 Persistence based signatures for compact metric spaces

Frederic Chazal (INRIA Saclay – Orsay, FR)

Joint work of Chazal, Frederic; de Silva, Vin; Oudot, Steve
URL http://geometrica.saclay.inria.fr/team/Fred.Chazal/papers/RipsCompactTalk.pdf

We introduce a family of signatures for compact metric spaces, possibly endowed with real valued functions, based on the persistence diagrams of suitable filtrations built on top of these spaces. We prove the stability of these signatures with respect to the Gromov-Hausdorff metric. We illustrate their use through an application in shape classification.

3.4 Lower bounds on multiple sensor estimation

Frederick R. Cohen (University of Rochester, US)

Joint work of Moran, Bill; Cochran, Doug; Suvarova, Sofia; Howard, Stephen; Taylor, Tom
Main reference In preparation

This summary represents joint work with Bill Moran, Doug Cochran, Sofia Suvarova, Stephen Howard, and Tom Taylor.

Given sensor reports of counts of agents, a typical classical problem is to try to deduce the total number of agents reported by the sensors. One standard method is given by "inclusion-exclusion" as well as the Bonferroni inequalities. The main focus here is to refine techniques to provide estimates of minimum total numbers.

The new input here is the use of topology and geometry to give some estimates.

1. With natural assumptions concerning the sensor regions, methods are given for minimum counts via topology.
2. Three features are an introduction of
   a. a universal solution,
   b. topological methods to give criteria for whether "atoms are represented", and
   c. an infinite polytope which has an action of an integral lattice with some describable vertices and which gives a potential list of vertices for testing of minima.

Specific examples arise from a hexagonal tesselation of the plane and the introduction of a universal polytope with data concerning the structure of some of the vertices.

3.5 Why so persistent?

Herbert Edelsbrunner (IST Austria – Klosterneuburg, AT)

[Abstract omitted.] Herbert Edelsbrunner gave a survey talk about his work on proteins with E.P. Mücke and C.J.A. Delfinado, persistence with D. Letscher and A. Zomorodian, and stability with D. Cohen-Steiner, J. Harer, and D. Morozov.

3.6 Ditopology: A short tutorial

Lisbeth Fajstrup (Aalborg University, DK)

3.6.1 Introduction

The objects of ditopology are d-spaces, topological spaces with a selected set of *directed* paths. Such spaces provide a geometric model for the most powerful model of concurrent computing, Higher Dimensional Automata [3]. Dipaths model executions and paths which are directed homotopic model equivalent executions.

3.6.2 Definitions

▶ **Definition 1.** A pair $(X, \vec{P})$, where X is a topological space and $\vec{P} \subset X^I$ is a set of paths, is a d-space if

- $\vec{P}$ contains all constant paths.
- $\vec{P}$ is closed under concatenation.
- For $\gamma \in \vec{P}$ and $\alpha : I \to I$ non-decreasing, $\gamma \circ \alpha \in \vec{P}$.

For $p, q \in X$, the set of directed paths $\vec{P}(X)(p, q)$ is a topological space with the compact-open topology.

The trace space is the quotient space $\vec{T}(X)(p, q) = \vec{P}(X)(p, q)/R$ where R is the relation generated by non-decreasing reparametrization. See [1].

▶ **Definition 2.** A trace $\sigma \in \vec{T}(X)(p', p)$ induces maps $\sigma^* : \vec{T}(X)(p, q) \to \vec{T}(X)(p', q)$ and $\sigma_* : \vec{T}(X)(r, p') \to \vec{T}(X)(r, p)$ by concatenation $\sigma^*([\gamma]) = [\gamma \circ \sigma]$ and $\sigma_*([\mu]) = [\sigma \circ \mu]$.

The directed topology of X is the (ordinary) topology of $\vec{T}(X)(p, q)$ for all pairs of points p, q, and of the induced maps.

▶ **Definition 3.** The fundamental category of a d-space $(X, \vec{P})$ has objects all points of X. The morphisms from p to q are $\vec{\pi}_1(X)(p, q)$, the directed homotopy classes of dipaths from p to q.

In other words: The morphisms are the connected components of $\vec{T}(X)(p, q)$. There are no inverses, so the dihomotopy classes and concatenation gives rise to a fundamental groupoid; not a group.

3.6.3 Examples

Prominent examples of d-spaces are built from cubes I^n with the coordinate wise order or as subsets of cubes:

▶ **Example 1.** The geometric model of a Higher Dimensional Automaton is a the geometric realization of a cubical complex. This gives rise to a d-space, where the directed paths in a cube are paths which increase in all coordinates. The space $\vec{P}$ is obtained by concatenation and non-decreasing reparametrization of d-paths in cubes.

▶ **Example 2.** In Dijkstra's PV-model, n processes share some resources $R_1, \ldots, R_l$, which allow the access of a finite number $k_1, \ldots, k_l$ of processes. Each process is modelled as a directed graph Γ_i. The geometric model of the concurrent execution is the product $Y = \Gamma_1 \times \cdots \times \Gamma_n$ representing the joint progress of each process. A subset of the product,

the forbidden region, is removed – the points corresponding to states where more than k_i processes access resource R_i.

In the simpler case when processes neither loop nor branch, Γ_i is an interval and the concurrent model is a cube $[0,1]^n$. The forbidden region is a union of n-rectangles. When $k_j \geq n$ there is no conflict at R_j. When $k_i \leq n-1$, and at least k_i+1 processes want access to R_i, the forbidden rectangle is $\times_{j=1}^{n} J_j$ where $J_j =]a_j^i, b_j^i[$ if the process j wants access to R_i at time a_j^i and releases R_i at time b_j^i and $J_j = [0,1]$ else. It is a generalized cylinder.

▶ **Example 3.** Dipaths may be homotopy equivalent but not dihomotopy equivalent:

Let X be $I^3 \setminus F$ where $F = R_1 \cup R_2 \cup R_3$ $R_1 =]1/7, 2/7[\times]1/7, 2/7[\times[0,1]$, $R_2 =]5/7, 6/7[\times]5/7, 6/7[\times[0,1]$, $R_3 =]3/7, 4/7[\times]1/7, 6/7[\times]1/4, 3/4[$. The piecewise linear directed paths γ_1 through $(0,0,0)$, $(1/7, 2/7, 0)$, $(1, 2/7, 0)$, $(1,1,1)$ and γ_2 through $(0,0,0)$, $(1/7, 2/7, 1)$, $(1, 2/7, 1)$, $(1,1,1)$ are homotopy equivalent, but not dihomotopy equivalent, since a homotopy between them will include a path whose second coordinate either passes $2/7$ before $1/7$ (to get over R_1, then under R_3) or it passes $6/7$ before $5/7$ (to get over R_3 then under R_2).

3.6.4 Calculations

When $X = I^n \setminus F$ and F is the union of a finite set of rectangles, Raussen's algorithm [5] provides a prod-simplicial model of the trace space. This has been implemented and there is a preliminary version of an extension to the case with loops [2]. The connected components of the trace space are calculated and used for static analysis. Moreover, calculation of higher homology is being implemented by M.Juda with the coreduction technique of M.Mrozek and B. Batko [4].

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3.7 Random manifolds and random simplicial complexes

Michael Farber (University of Warwick, GB)

In the talk I described the construction of random closed smooth manifolds arising as configuration spaces of linkages with random bar lengths. I also stated and explained theorems of M. Farber, T. Kappeler, C. Mazza, and C. Dombry on the asymptotic values of

Betti number of these random manifolds. In the second part of the talk I considered the Linial-Meshulam model of random simplicial complexes. I stated a recent joint result with A. Costa stating that in certain range of the probability parameter p a random complex can be made aspherical by puncturing all contained in it tetrahedral; the obtained punctured complex satisfied the Whitehead conjecture, a.a.s.

3.8 Combinatorial algebraic topology

Dmitry Feichtner-Kozlov (Universität Bremen, DE)

Combinatorial Algebraic Topology is concerned with computing algebraic invariants for combinatorial complexes with combinatorial means, and more generally to study properties of such complexes.

A number of applications in theoretical computer science (in particular, recently in theoretical distributed computing) use such combinatorial complexes, and the methods of combinatorial algebraic topology turn out to be quite useful in this context.

This talk is a survey, in part following my textbook, and is aimed at computer scientists as well as interested mathematicians working in related areas.

3.9 Some research notes on G-invariant persistent homology

Patrizio Frosini (University of Bologna, IT)

In this talk we would like to illustrate a current research about the problem of adapting Persistent Homology, in order to obtain a theory that is invariant with respect to a given subgroup G of the group of all the homeomorphisms from a compact topological space to itself. This research is motivated both by applications in shape comparison and by the need of mathematical tools to compute lower bounds for the natural pseudo-distance associated with the group G.

3.10 Some elements on Static Analysis and Geometry

Eric Goubault (CEA LIST and Ecole Polytechnique, France)

[Abstract omitted.] Eric Goubault's talk began with a tour of semantics/static analysis of sequential programs. He then described techniques for geometric analysis of concurrent programs and the inherent difficulties in analysis due to the interleaving semantics.

3.11 Introduction to combinatorial topology and distributed computing

Maurice Herlihy (Brown University – Providence, US)

This talk describes how simplicial complexes can be used to describe many kinds of distributed computing.

3.12 Torsion in computations

Anil N. Hirani (Univ. of Illinois – Urbana, US)

The absence of relative torsion in a simplicial complex leads to a polynomial time algorithm for finding smallest chains homologous to a given chain. This seems to be the first appearance of torsion in computations. I will give a brief exposition of what torsion is and how it is related to the constraint polyhedron of linear programming. Then I will describe a few variants of the problem and show an application to finding least spanning area surface of a knot. This is joint work with T. Dey, N. Dunfield, and B. Krishnamoorthy.

3.13 CAPD::RedHom – Homology software based on reduction algorithms

Mateusz Juda (Jagiellonian University – Krakow, PL)

URL http://redhom.ii.uj.edu.pl/

In the talk I presented CAPD::RedHom software (http://redhom.ii.uj.edu.pl/) – a software for efficient computation of the homology of sets.

As an input we use cubical, simplicial, or in some cases CW complexes. The software uses geometric and algebraic reduction to speed up classical Smith diagonalization or even the diagonalization is not required. During the talk we discussed following methods:

- acyclic subspace construction,
- elementary reductions and coreductions,
- discrete Morse theory.

The presentation contained also numerical experiments, comparison with other packages, and latest results for huge data sets.

3.14 Spectral methods in probabilistic topology

Matthew Kahle (Ohio State University, US)

There has been quite a bit of interest in recent years in the study of the expected topological properties of various kinds of random spaces. Dunfield and Thurston constructed random 3-manifolds from random walks on mapping class groups. Linial and Meshulam introduced the study of random simplicial complexes with independent faces, providing higher-dimensional analogues of Erdos-Renyi random graphs.

Some of my recent work has focused on using spectral methods to prove theorems about random simplicial complexes. These methods depend on theorems of Ballman and Swiatkowski, and of Zuk, and the main idea goes back to foundational work of Garland, where he introduced the notion of p-adic curvature.

In joint work with Hoffman and Paquette, we found a sharp threshold for Property (T) of the fundamental group of random 2-complexes. This work requires new results for the spectral gap of random graphs near the connectivity threshold. Using similar techniques, I was recently able to show that with high probability, a random d-dimensional flag complex has nontrivial homology only in middle degree.

This most recent result helps make measure-theoretic sense of the fact that so many complexes arising in combinatorics have homology concentrated in a small number of degrees.

3.15 Distributed computing mishmash: the operational perspective

Petr Kuznetsov (TU Berlin, DE)

Joint work of Gafni, Eli; Kuznetsov, Petr

One difficulty in addressing computability questions in distributed computing is the huge diversity of existing models of distributed systems, abstractions for distributed programming, and complexity metrics, with no apparent connection. In particular, the computational power of a model depends on synchrony assumptions, communications primitives, and (possibly non-uniform) patterns in which processes may fail.

In this talk, we focus on a large class of shared-memory adversarial models. In these models, processes communicate via reading and writing in the shared memory and their failure patterns are described as a set system on the set of process subsets. In every run of the model, the set of correct processes must belong to the set system.

We overview a set of recent (operational) simulations that allow reducing the question of colorless task solvability given an arbitrary adversary to a similar question in the more studied and better understood wait-free model. We speculate how topological methods can be used to extend these results to more general classes of distributed computing problems.

3.16 Persistence for shape comparison

Claudia Landi (University of Modena e Reggio Emilio, IT)

Main reference S. Biasotti, L. De Floriani, B. Falcidieno, P. Frosini, D. Giorgi, C. Landi, L. Papaleo, M. Spagnolo, "Describing shapes by geometrical- topological properties of real functions," ACM Computing Surveys, Vol 40, No. 4, Article No. 12, pp. 1–87, 2008.
URL http://dx.doi.org/10.1145/1391729.1391731

Persistence is a theory for Topological Data Analysis based on analyzing the scale at which topological features of a topological space appear and disappear along a filtration of the space itself. As such, it is particularly suited for handling qualitative rather than quantitative information about the studied space. Moreover, persistence deals with noise consistently, in that noisy data do not need to be smoothed out in advance. Last but not least, it is modular, meaning that different filtrations give insights from different perspectives on the space under study.

For all these reasons persistence turns out to be a well-suited tool for shape comparison, i.e. the task of assessing similarity between digital shapes.

In particular, persistence provides a shape descriptor, the persistence diagram, and a distance between these diagrams, the bottleneck distance. Thus the similarity between two shapes, represented by spaces endowed by functions, is measured by the bottleneck distance between the corresponding persistence diagrams.

Persistence diagrams are very concise descriptors, consisting of finitely many points of the plane. Moreover, the bottleneck distance between persistence diagrams is stable in the sense that small changes in the filtration imply small changes in the bottleneck distance. Finally, the bottleneck distance between persistence diagrams bounds from below the natural pseudo-distance between the original shapes.

3.17 Random methods in discrete topology: Discrete Morse functions and the complicatedness of triangulations

Frank H. Lutz (TU Berlin, DE)

We introduce a measure for the *complicatedness* of triangulations. For this, we define the *discrete Morse spectrum* of a simplicial complex as the distribution of discrete Morse vectors that are obtained by choosing free faces for collapses and critical faces uniformly at random. The complicatedness then is the expected number of critical cells.

It is hopeless to compute the discrete Morse spectrum for larger complexes, but it can easily be approximated by random experiments. In particular, the concept works well for manifolds and allows to compute optimal discrete Morse vectors in many cases. For example, we showed collapsibility of a nontrivial 5-manifold with f-vector $(5013, 72300, 290944, 495912, 383136, 110880)$.

3.18 Topology of random complexes

Roy Meshulam (Technion – Haifa, IL)

Joint work of Aronshtam, Lior; Linial, Nathan; Luczak, Tomasz; Meshulam, Roy; Wallach, Nathan

Let Y be a random d-dimensional subcomplex of the $(n-1)$-simplex S obtained by starting with the full $(d-1)$-dimensional skeleton of S and then adding each d-simplex independently with probability p.

For $d = 1$ this coincides with the Erdos-Renyi model $G(n,p)$ of random graphs, and the topology of Y in $G(n,p)$ is thoroughly understood. We'll survey some recent work on the topology of Y for $d > 1$, where much less is known. In particular, we'll discuss results concerning:

1. The threshold probability for vanishing of the $(d-1)$-dimensional homology of Y (Joint work with N. Linial and with N. Wallach).
2. The threshold probabilities for the vanishing of the d-dimensional homology of Y and for the d-collapsibility of Y (Joint work with L. Aronshtam, N. Linial and T. Luczak).

3.19 Homology and robustness of levelsets

Dmitriy Morozov (Stanford University, US)

Given a function $f\colon X \to R$ on a topological space, we consider its levelsets and their homology groups. We quantify the robustness of the homology classes under perturbations of f using well groups, and we show how to read the ranks of these groups from the extended persistence diagram. The special case $X = R^3$ has ramifications in the fields of medical imaging and scientific visualization.

3.20 Impossibility of set agreement and renaming

Ami Paz (Technion – Haifa, IL)

We present new proofs for two impossibility results for wait-free computation in asynchronous shared-memory systems, with only read / write operations. The results apply to two fundamental problems for n processes:

- $(n-1)$-set agreement, and
- renaming with a rank-based algorithm, when n is a prime power.

Both proofs are purely combinatorial and rely on simple counting arguments, and on results about the structure of restricted executions.

3.21 Locality and checkability in wait-free computing

Sergio Rajsbaum (Universidad Nacional Autonoma – Mexico, MX)

Main reference P. Fraigniaud, S. Rajsbaum, C. Travers, "Locality and Checkability in Wait-Free Computing," in Proc. of 25th Int'l Symp. on Distributed Computing (DISC'11), LNCS, Vol. 6950, pp. 333-347, Springer, 2011.
URL http://dx.doi.org/10.1007/978-3-642-24100-0_34

Given a task $T = (I, O, \Delta)$ and a black box protocol that claims to solve it, a distributed *checker* tries to find out whether the result of an execution is correct. Each process p_i gets as input (s_i, t_i), the i-th entries of an input-output pair $(s, t) \in I \times O$ produced by the black box, that is supposedly correct, i.e., $t \in \Delta(s)$. In a DISC 2011 paper we introduced AND-checkers, namely after communicating wait-free with the other processes, each process must output either "yes" or "no", with the following interpretation: every process says "yes" if and only if $t \in \Delta(s)$. We showed that there are many tasks that are AND-checkable. Yet, important tasks such as consensus and set agreement, are not.

In a new paper we generalize the AND-checker notion as a pair (E, D), respectively called the *encoder* and the *decoder*. The encoder E is a *wait-free distributed* protocol that takes as input a pair $(s, t) \in I \times O$, where each process p_i receives as input a pair (s_i, t_i), communicates with the others, and eventually returns an output value $u_i \in U$, where U is the range of E. The decoder D is a *centralized* algorithm that takes as input any multiset S of values from U output by the processes, and returns either "yes" or "no." For every pair $(s, t) \in I \times O$, it is required that $t \in \Delta(s)$ if and only if $D(E(s, t)) =$ "yes".

We show that every task has a *parsimonious* checker, based on a set U, independent of the task, and of small size. Tasks that are more difficult to check require a set U of larger size. We show that, for every task T on n processes, there exists a checker with range of size at most $n + 1$. The main result is a tight bound on the size $|U|$ of the encoder's range enabling every task on n processes to be checked. As a consequence, a classification of tasks in terms of their checkability difficulty is provided. We thus explain why consensus and set agreement are not AND-checkable: a range of three values is necessary to check consensus, while for k-set agreement the range of values needed depends on k.

3.22 Directed algebraic topology – with an eye to concurrency theory

Martin Raussen (Aalborg University, DK)

Higher-Dimensional Automata (HDA) are a framework for concurrency theory generalizing mutual exclusion using semaphores. These models consist of a geometric space (given combinatorially as a pre-cubical complex) with preferred directions, a so-called d-space. The space models the allowable (non-forbidden) states of all program counters. Not all continuous paths in that space are allowed; only so-called d-paths through the interleaving states, progressing with time.

A 1-parameter family of such d-paths (preserving the time constraint) is called a *dihomotopy*. Dihomotopic d-paths represent schedules that will always give the same result for a concurrent calculation. Therefore it is relevant to study d-paths up to dihomotopy; likewise

to study d-spaces and d-maps between them (preserving d-paths) up to the dihomotopy relation.

Algebraic Topology offers a rich kit of insights, methods and tools to handle continuous geometric spaces (and their combinatorial counterparts) up to homotopy; in particular translating questions of a geometric flavor into algebraic problems that can solve the question or prove non-existence/unsolvability. We try to add a toolbox to the discipline taking explicit care of directedness. The algebra gets more complicated, since d-paths most often are not invertible.

Therefore, group theoretic constructions (like the fundamental group) have to be replaced by categorical constructions (like the fundamental category).

In general, one would like to get hold on properties of the space of all d-paths (or traces, i.e., d-paths up to directed reparametrization) in a d-space. One would like to calculate the number of components, to describe the homotopy types or at least some topological invariants of these components. For that purpose, we have constructed at least for simple HDA an algorithmic method yielding a description of the space of all d-paths (schedules) in such an automaton between given start and end points – as a *simplicial complex*. In principle, it is therefore possible to calculate invariants by known (computer) algorithms. In praxis, these complexes tend to be huge, and this is why we work on

- smaller representations yielding the same homotopy type,
- adaptations that work well when directed loops are part of the model, and
- general results concerning, e.g., the (higher) connectivity of the resulting spaces of d-paths.

At least formally, there are relations to *multidimensional persistence* to understand and to develop. These arise when the start and end point of a computation (schedule) are allowed to vary. Hence, one needs to understand, at what thresholds and how the trace spaces change under variations at end points. The goal is to subdivide the state space (or rather, its square) into a number of *components*: Trace spaces with end points in the same component should be homotopy equivalent to each other.

Moreover, we would like to explore relations to the methods from combinatorial algebraic topology used in *distributed computing*. This involves modeling further communication primitives and associated HDA. Moreover, one would need to compare d-spaces and their schedules for a variety of (live/dead) processors participating in the solution of a task.

3.23 A spectral sequence for parallelized persistence

Mikael Vejdemo-Johansson (University of St Andrews, GB)

Joint work of Vejdemo-Johansson, Mikael; Skraba, Primoz; Lipsky, David
Main reference D. Lipsky, P. Skraba, M. Vejdemo-Johansson, "A spectral sequence for parallelized persistence," arXiv:1112.1245v1 [cs.CG]
URL http://arXiv.org/abs/1112.1245v1

We describe a spectral sequence approach to a parallel algorithm to compute persistent homology. The spectral sequence of the double complex C_{**} with $C_{ij} = \bigoplus_{\sigma \in \mathcal{N}(\mathcal{U})_j} C_i \bigcap_{k \in \sigma} U_k$, where $\mathcal{U} = \{U_j\}$ is a covering of $\mathbb{X}$, will converge to the homology $H_*\mathbb{X}$ of the total space.

We are able to describe all higher differentials in the spectral sequence, and to adapt the computation to persistence modules, which we hope will yield parallelizable algorithms for computing persistent homology.

3.24 Directed paths in d-simplicial complexes

Krzysztof Ziemianski (University of Warsaw, PL)

Main reference K.Ziemiański, "A cubical model for path spaces in d-simplicial complexes," Topology and its Applications, vol. 159, issue 8, pp. 2127–2145. 2012.
URL http://dx.doi.org/10.1016/j.topol.2012.02.005

A d-simplicial complex is a simplicial complex equipped with a suitable relation on the set of its vertices which allows one to define a d-structure on its geometric realization. Given a d-simplicial complex $\vec{K}$ and two of its vertices v and w I will construct a cubical complex $CT(\vec{K})$ which is homotopy equivalent (under some mild conditions) to the space of directed paths on $|\vec{K}|$ from v to w. This construction gives the minimal functorial model for spaces of directed paths. Then, I will present a similar construction for cubical complexes; in this case the model for directed paths is a CW-complex which has a structure of permutohedral complex.

4 Panel Discussions

4.1 Persistent homology

Herbert Edelsbrunner and Dmitriy Morozov served on a panel for a discussion about persistent homology and its history.

Participants

- Henry Adams
Stanford University, US
- Sergio Cabello
University of Ljubljana, SI
- Armando Castaneda
IRISA / INSA - Rennes, FR
- Bernadette Charron-Bost
Ecole Polytechnique – Palaiseau, FR
- Frederic Chazal
INRIA Saclay – Orsay, FR
- Frederick R. Cohen
University of Rochester, US
- Armindo Emanuel Costa
University of Warwick, GB
- Carole Delporte
University Paris-Diderot, FR
- Jean-Marie Droz
Universität Bremen, DE
- Herbert Edelsbrunner
IST Austria – Klosterneuburg, AT
- Ulrich Fahrenberg
IRISA / INSA – Rennes, FR
- Lisbeth Fajstrup
Aalborg University, DK
- Michael Farber
University of Warwick, GB
- Hugues Fauconnier
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- Eva-Maria Feichtner
Universität Bremen, DE
- Dmitry Feichtner-Kozlov
Universität Bremen, DE
- Pierre Fraigniaud
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- Patrizio Frosini
University of Bologna, IT
- Eric Goubault
Centre d'Etudes Nucleaires de Saclay, FR
- Tobias Heindel
CEA – Gif sur Yvette, FR
- Maurice Herlihy
Brown Univ. – Providence, US
- Anil N. Hirani
Univ. of Illinois – Urbana, US
- Marc Jeanmougin
ENS - Paris, FR
- Mateusz Juda
Jagiellonian Univ. – Krakow, PL
- Matthew Kahle
Ohio State University, US
- Petr Kuznetsov
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- Claudia Landi
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- Frank H. Lutz
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- Facundo Memoli
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- Roy Meshulam
Technion – Haifa, IL
- Alessia Milani
Université Bordeaux, FR
- Samuel Mimram
Commissariat a l'Energie Atomique – Gif-sur-Yvette, FR
- Dmitriy Morozov
Stanford University, US
- Thomas Nowak
TU Wien, AT
- Ami Paz
Technion – Haifa, IL
- Sergio Rajsbaum
Universidad Nacional Autonoma – Mexico, MX
- Martin Raussen
Aalborg University, DK
- Srivatsan Ravi
TU Berlin, DE
- Matthieu Roy
LAAS – Toulouse, FR
- Primoz Skraba
Jozef Stefan Institute – Ljubljana, SI
- Christine Tasson
University Paris-Diderot, FR
- Corentin Travers
Université Bordeaux, FR
- Mikael Vejdemo-Johansson
University of St Andrews, GB
- Peter Widmayer
ETH Zürich, CH
- Krzysztof Ziemianski
University of Warsaw, PL

Report from Dagstuhl Seminar 12131

Open Models as a Foundation of Future Enterprise Systems

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 12131 "Open Models as a Foundation of Future Enterprise Systems". Research on open models introduces a new model of collaboration among researchers, developers, and prospective users of reference enterprise models—leading to the prospect of shaping future enterprise systems. This seminar brought together researchers and practitioners with expertise in a broad range of fields including conceptual modelling, model-driven engineering, enterprise systems, software architectures, and modelling tool development. The seminar mixed short presentations on the attendees' perspectives on open models with keynote presentations and working groups on selected research issues. Topics discussed include the shape of future enterprise systems amalgamated with open reference enterprise models, business domains to be addressed in first open models, requirements towards a technical infrastructure as well as organisational issues of open model initiatives. The seminar's discussions benefitted from the different perspectives of attendees on the common topic, raised important new questions on open models, and brought to light overlooked aspects important to future research activities.

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1 Executive Summary

Ulrich Frank
Andreas Oberweis
Matti Rossi
Robert B. France
Stefan Strecker

To effectively support business operations and managerial decision-making, future enterprise systems require an elaborate conceptual foundation that promotes a tight mutual alignment of information systems and the business. Enterprise models provide such a foundation. They integrate conceptual models of an information system (e. g. an object model) with models of the surrounding action system (e. g. business process models or strategy models). Thereby, they relax the notorious cultural chasm between business and IT experts and provide a versatile instrument for the conjoint development of large-scale, mission-critical enterprise systems and for analyzing and (re-) designing the corporation.

However, the development of comprehensive enterprise models requires efforts, expertise, and resources beyond the capabilities of even large corporations. Therefore, the development and dissemination of reference enterprise models that can be adapted to a wide range of companies is a pivotal success factor. Enterprise models are usually specified by domain-specific modelling languages (DSML). The development and evaluation of reference enterprise models and corresponding DSML is an attractive scientific challenge. It corresponds to the development of theories: Reference models and DSML are linguistic constructions (on different levels of abstraction) that come with the claim for general validity or suitability respectively—not just for one particular occurrence but for an entire class of organizations.

They integrate and consolidate contributions from several scientific disciplines such as Computer Science, Information Systems, and Management Science. Both, reference models and DSML provide a reification of an attractive vision: Higher quality of software systems at lower cost. It is the complexity of modern organizations and the diversity of involved perspectives that renders the development of reference enterprise models and corresponding DSML a particular research challenge. Inspired by the remarkable results of the free/open source movement, recent work on reference enterprise models has resulted in the notion of open reference enterprise models (open models for short). Research into open models does not only address the feasibility issue. Furthermore, it introduces a new model of collaboration among researchers, developers, and prospective users of reference enterprise models—leading to the prospect of shaping future enterprise systems. Recent initiatives on joint, collaborative modeling of open licensed conceptual models, thus, provide a new, innovative model for research on reference enterprise models that served as the starting point to this Dagstuhl seminar. It links to research on collaborative modeling, modeling tool development, model management, models@run.time, enterprise systems, and model-driven engineering.

This Dagstuhl seminar was aimed at bringing together a multi-disciplinary group of academic and industry researchers from the disciplines of Wirtschaftsinformatik, Computer Science, Information Systems, and Software Engineering, specifically those working in Requirements Analysis, Conceptual Modelling, and Enterprise Modelling to foster our understanding of how to develop, evaluate, disseminate, and promote the use of open reference enterprise models. The primary emphasis of the seminar was to determine the present state-of-the-art in this multi-disciplinary research field, and to establish a research

agenda for future work towards solving theoretical and practical challenges related to the development of open reference enterprise models. The following overview describes more particular questions/objectives and related achievements:

1. **What are key characteristics of future ES?** The analysis of this question started with assumptions about relevant changes to be expected for the use of future ES. On the one hand, it was commonly expected that in many industries there will be a growing need for adapting the ES quickly to changing demands, e. g. to benefit from sudden opportunities or to build effective protection against threats. On the other hand, it was assumed that a growing number of managers will have received professional training in sophisticated uses of information systems. As a consequence, it was concluded that future ES should not only be based on an elaborate conceptual foundation but should also make this foundation, e. g. an enterprise model, accessible to prospective users—on various levels of abstraction and detail. This would not only empower users to perform more advanced analyses, but also to modify the ES to a certain extent by applying changes to certain parts of the underlying conceptual model. From a software engineering perspective such a conception of future ES creates the challenge to allow for using models at run time—and to synchronize models and code. It was concluded that programming languages which allow for an arbitrary number of abstraction layers provide a promising approach to address this challenge.
2. **What is a promising strategy for the development of a common modeling platform?** A platform for enterprise modeling needs to integrate an extensible set of DSML editors. Also, it should support the specification of DSML and the development of corresponding model editors. Furthermore, it should enable model analysis and support the use of models at run time. The participants agreed that there is no environment available that would satisfy all these demands. At the same time, developing such an environment would require a substantial amount of resources and would take years. During that time, the intended modeling activities would be compromised, since they lacked the required tool platform. Therefore, it was concluded that only an evolutionary approach to developing a common modeling platform is a realistic option. It should start with existing modeling tools that are gradually extended or replaced with more advanced systems.
3. **What are key features to be offered by a repository to integrate contributions from a wide range of participants?** Since a common modeling environment cannot be expected at the beginning of an open model initiative, there is need to integrate contributions (models, meta models etc.) from various sources. That puts emphasis on a versatile repository that allows handling a wide range of representations on a level of semantics that enables model integration and various forms of retrieval and analysis. A working group focused on a corresponding architecture and presented an elaborate proposal.
4. **What are appropriate guidelines to establishing and sustaining initiatives and corresponding processes of collaborative modeling of open models?** Apart from incentives, discussions centered on organisational issues involving considerations of the economics of open models and success factors related to community aspects, procedural aspects, stakeholder aspects and infrastructure aspects. A life-cycle and a maturity model were proposed together with an initial process model aimed at guiding the steps to establish and sustain open model initiatives. The concluding plenary discussions corroborated the need for a guided and concerted division of labor.

A joint publication by the organizers is currently in preparation to reflect the seminar's key results. It is to appear in 2013.

2 Table of Contents

3 Overview of Contributions

3.1 Abstract

Jörg Becker (Universität Münster, DE)

So far, reference models (valid for a specific group of companies, built to be reused) have not found the attention in practice as we – as researchers – had wanted them to be used. There may be some reasons for that: 1 There are few 2 The ones that are in place are poor 3 The ones who want to use them do not know that there are some in place 4 Reference models are not useful. My own experience with many companies shows: 4 does not hold true (Working with companies and using reference models has very helpful). 1 and 2 hold true partly (we have to work on better reference models!) 3 holds true → Here, the open model initiative can help! So it's worth working on opening reference models to companies. The work in Dagstuhl was fruitful, inspiring, and bringing the idea of open models forward. We worked on modeling languages, content of reference models, abstraction, meta-modeling, scientific foundation, and how bringing the idea of open models to life.

3.2 The Model Driven Enterprise

Tony Clark (Middlesex University, GB)

Organisations increasingly rely on a distributed collection of heterogeneous systems, find themselves required to comply with a range of dynamically changing regulations, all within a business context that produces events, opportunities and demands using a variety of digital formats and modes. Furthermore, the choice of IT systems that can be used by organisations to replace manual systems and to implement business processes increases and also changes on a regular basis making it difficult and risky to commit to one particular technology choice. Modelling technology has advanced in the last 20 years or so to the point where it is possible to describe complex data, transformations and processes in a technology independent way. Modelling techniques such as transformations, models@RunTime, version control, team working and code generation make it possible to envision a situation where an organisation can encode its business as a collection of technology independent models and to run entirely from the models. This situation is attractive for a collection of reasons. Firstly, it reduces the risk of committing to technology platforms that either change regularly or may not be the optimal choice, since the same models can be made to target different technologies. Secondly, domain-specific modelling techniques can be used to being the representation of an organisation within the grasp of people whose expertise is not technology. In particular domain-specific techniques can provide different views of an organisation for different roles within the company, for example allowing the CEO to view progress, successes and failures at the IT level in terms of the goals of the organisation. Finally, modelling is based on abstraction and thereby allows otherwise highly complex technology to be expressed at an appropriate level of detail. In order to realise the Model Driven Enterprise, it is necessary to address a number of research challenges: when viewed as an engine, what are the key

features of an organisation, for example goals, directives, processes, information, roles etc?; what languages should be provided for modelling the enterprise?; what techniques can be used to manage the models within an enterprise? how can the context of an organisation be modelled?; how can organisational models be compared and migrated?

3.3 Open Models @ Runtime

Patrick Delfmann (Universität Münster, DE)

One challenge in establishing a comprehensive support for open reference models and open reference modeling is to provide corresponding methodical and tool support for an overall reference model lifecycle. Such a lifecycle comprises the construction of a reference model, its adoption and adaptation by enterprises, and its use and refinement by enterprises. Furthermore, experiences made in using (potentially adapted) reference models should be integrated into the original reference model in order to consider special requirements coming from particular business players. A new lifecycle of reference modeling can start as soon as the special requirements are integrated into the original model. To establish such a support, an according methodology or platform has to provide mechanisms supporting preferably every step of the modeling lifecycle. One great challenge for the Open Model Initiative will be to establish a corresponding open model platform. Since full support will be a future goal, our working group proposes to set up a tool stepwise, beginning with the possibility to understandand share reference models. The next levels could incorporate manipulation of models, followed by collaboration and transformation tools, modeling language definition and manipulation tools, and model processing tools including variant management, transformation, monitoring, refinement, and re-integration.

3.4 From Model-driven to Model-Integrating Software Development

Gregor Engels (Universität Paderborn, DE)

During the last two decades, the usage of models as a relevant step within software development has been advocated. Unfortunately, this had not lead to an industrial success, as the additional burden of erecting und maintaining models and at the same time the increased market and budget pressure hindered software development teams to invest in such a model-driven development. Therefore, we started a novel research initiative to integrate models and code into a coherent unit, called MoCo. This implies that any information is only represented once, i. e., in case of a flexible notation as a model and in case of an efficient notation as code. During runtime of a software system consisting of MoCos, it may change its state. This means that pieces of code which need an update are re-transformed into a model representation, while models which appear to be stable are compiled into efficient code. This approach of using MoCos is nowadays already present in process-driven service-oriented architectures, when processes are expressed as business process models and business logic as application services. What is missing here, is an on-the-fly transition between model and code and back again. The research described here in conducted in close cooperation with J. Ebert, University of Koblenz.

3.5 The Open Models Initiative as a Platform for the Implementation of Modelling Methods: The Case of the SeMFIS Project

Hans-Georg Fill (Universität Wien, AT)

One vision of an Open Models Initiative is to support the sharing of know-how on the implementation of modelling methods. For this purpose several requirements have to be met in regard to the description of a modelling method, its design in terms of a particular meta modelling approach and its technical realization using a concrete implementation platform. In the paper at hand we will discuss these requirements and show how they were realized in the context of the Semantic-based Modelling Framework for Information Systems (SeMFIS) project. SeMFIS provides a set of model types, algorithms and services for managing semantic aspects of conceptual models about information systems and has been realized using the ADOxx meta modelling platform and the Protégé ontology management toolkit. Subsequently we derive a set of general guidelines for other Open Models projects based on these insights.

3.6 Multi-Level Modelling

Ulrich Frank (Universität Duisburg-Essen, DE)

In recent years, the idea of domain-specific modeling languages has raised remarkable attention. This is for good rashes. DSML provide reconstructions of domain-specific technical languages. They promise to promote modeling productivity and the quality of models. However, a close look at DSML shows that there are frequent differences in the use of domain-specific terms. This poses a serious challenge to reusing DSML. The approach I presented addresses this challenge. On a higher level of abstraction a generic DSML serves to represent textbook knowledge that is applicable to a wide range of domains. The level below serves to represent organization specific instantiations of concepts defined with a corresponding generic DSML. The differentiation of multiple levels of models – and modeling languages respectively – promises to overcome the conflict between a high range of reuse (which recommends a low level of semantics, but promotes economies of scale) and a high benefit of reuse in a particular case (which recommends concepts that fit the specific requirements of a particular domain). In addition to that, it is also suited to foster integration: If two organizations do not succeed in specifying a common schema on the type level, because the conceptual diversity is too big, they can still go for common concepts on a higher (meta) level, thereby allowing for integration at least on this higher level. To give an example: Two companies that deal with clearly different types of products (e.g. software and industrial components) could still define common meta types of products which then could be instantiated into specific types. The prospects of multi-level modeling are contrasted by substantial challenges which are mainly related to restrictions of prevalent programming languages: To build corresponding model editors one would need a language that is not restricted to two levels of abstraction (such as "class" and "instance"). In recent years a number of (meta) programming languages have emerged that allow for overcoming this restriction be providing an arbitrary number of meta levels. They form a promising foundation for future research on multi-level modeling and corresponding tools.

3.7 Hub Services as a Use Case for Open Enterprise Models

Andreas Hess (Capgemini München, DE)

Technology trends like mobility and the availability of public cloud services support new business activities in market-facing units, close to clients or in cooperation with collaborators from other enterprises that can co-exist together based on a loose-coupled, stateless consumption of "services" on demand. As a result, future Enterprise Systems might have the characteristics of an Enterprise Integration Hub that supports dynamic interactions between collaborators inside and outside of the enterprise using application services that are provided by the involved enterprises, are acquired in the cloud or are created using services of the hub. To enable this interaction these hubs will make use of models that describe information and its exchange, offered and consumed services including choreography as well as orchestration of services and associated business rules. Because of the dynamics of the interaction and the affiliation of the collaborators to different enterprises these models necessarily need to be open. To effectively support the collaboration the services of the integration hubs will cover social network like functionality, the creation and provisioning of data and meta data including model management plus the acquisition, creation and usage of services on demand. Because of their characteristics the integration hubs can serve as catalyzers for the development of open enterprise models: They request the existence of models for their operation and offer the environment needed for the development of such models as open content at the same time.

3.8 The ADOxx® Metamodelling Platform: Functional Requirements

Dimitris Karagiannis (Universität Wien, AT)

Enterprise models have the potential to act as a conceptual foundation for enabling mutual alignment between information systems and business. Hence the use, development, and evaluation of modelling methods is not only (a) an attractive scientific challenge, but also (b) a business goal to achieve efficient model-based development for future enterprise systems. Modelling method tool support requires and relies on available IT-infrastructure and a conceptual backbone, like a $meta^2$ concept. This concept evolved to a mature approach for developing, aligning, using and evaluating hybrid modelling methods for enterprise applications. The functional capability of the underlying metamodelling platform is a critical success factor for both(a) working on scientific issues and (b) realising future enterprise solutions. The first part of this paper focuses on: (a) the core elements of a metamodelling platform and (b) the nature and origin of its functional requirements. The second part is concerned with three basic observations. First, technological trends such as—but not limited to: (a) web-applications, (b)collaboration and social software, (c) adaptability and personalisation of software, (d) mobile devices and third party interaction, (e) semantics and (f) cloud computing as well as very large data sets that need to be taken into consideration. Second, concrete user scenarios from industrial and research projects in the domain of business and IT modelling. Third, the maturity of existing metamodelling platforms as

commercial as well as open source/use software. The third part describes how ADOxx®—a metamodelling development and configuration platform for the implementation of modelling methods can be applied. The ADOxx® platform supports: (1) modelling languages by inheriting modelling concepts from a metamodel to define syntax, semantics and notation,(2) modelling mechanisms and algorithms by providing generic platform functionality that can be used or adapted, scripting possibilities, integration and interaction with third party add-ons, as well as (3) modelling procedures by combining model types as part of the modelling language, and scripts as part of the mechanisms and algorithms to support the sequence of modelling. The paper concludes with an evaluation of ADOxx® applications, which are realized on the Open Model Initiative (www.openmodels.at), and the outlook on future functionality.

3.9 Feedback on seminar topic

Mogens Kuehn-Pedersen (Copenhagen Business School, DK)

The seminar revealed a general expectation that modelling Future Enterprise Systems entailed new open modelling processes that would heed cross-company developments and mobility supported by multiplicity of platforms. Common select, domain specific semantics would be supported by numerous technologies including intelligent agents design, standards and tools. Practice would increasingly benefit from application of open models as shared data become a precondition for operational effectiveness and innovative improvements.

3.10 Structured design of a modeling language

Marc Lankhorst (Novay – Enschede, NL)

Joint work of Lankhorst, Marc; Proper, Erik; Jonkers, Henk
Main reference M.M. Lankhorst, H.A. Proper, and H. Jonkers, "The Anatomy of the ArchiMate Language," IJISMD 1.1 (2010): 1–32. Web. 29 Mar. 2012.
URL http://www.novay.nl/publicaties/the-anatomy-of-the-archimate-language/64893

In current business practice, an integrated approach to business and IT is indispensable. In many enterprises, however, such an integrated view of the entire enterprise is still far from reality. To deal with these challenges, an integrated view of the enterprise is needed, enabling impact/change analysis covering all relevant aspects. This need sparked the development of the ArchiMate language, which was developed with the explicit intention of becoming an open standard, and as such has been designed such that it is extendable while still maintaining a clear and orthogonal structure. This article is concerned with documenting some of the key structures and design principles underlying the ArchiMate language. ArchiMate is designed as an architecture description language (ADL) for enterprise architectures. Developing such a language comes with many challenges. The design principles of the ArchiMate language aim to tackle these challenges. The modelling concepts of ArchiMate were derived in a stepwise process, applying these principles and successively refining high-level, abstract concepts to obtain concepts relevant for enterprise architects. In this, we make a distinction between

concepts needed to model domains in general, the modelling of dynamic systems, and the modelling of enterprise architecture specific elements. This approach helps to, on the one hand, base our language on established conceptual modeling approaches, and on the other hand realize a concrete and usable language. Moreover, this backbone structure allows for extensions of the language by refining the higher-level structure for specific domains and/or users, which then become an integral part of the language, not just something that is grafted on as an afterthought.

3.11 Abstract

Sina Lehrmann (TU Dresden, DE)

The brain storming session and the group work revealed a categorization of reference models according to differing purposes. Corresponding to the viewpoint categorization within the Archimate Specification reference models could be differentiated in reference models for the purposes designing, deciding and informing.

- Designing: Reference models serve as a blueprint for a good solution. Enterprises could adopt the offered design solution for similar problems.
- Deciding: Reference models provide decision support by pointing out different alternatives, parameters, experiences etc. In general these models areconstructed inductively. The Open Model Initiative could support the construction and evolution of this kind of reference models by gathering and generalizing experiences from different sources.
- Informing: Reference models could promote the reverse direction of communication by announcing publicly that certain enterprise systems are aligned to it. E.g.reference models could act as a means for certification, which could be used asa marketing instrument in turn. To provide the standard or regulation as are ference model improves transparency and facilitate the negotiation of reasonable regulations. The Open Model Initiative could be the independent and reliable third party.

  Particularly the last category for reference models contains innovative research ideas.

3.12 Challenges for Open Reference Models

Peter Loos (Universität Saarbrücken, DE)

Conceptual models play an important role in all phases of information systems life cycle, e.g. business engineering, IS development and ERP customizing. To reduce the effort and improve the fault-prone process of modeling user requirements, reference models as blue prints for enterprise-specific models are regarded as an appropriated means. Hence, a reference model is generic for a certain type of companies or organisations according to their typological characteristics, e.g. industry domain and company size. Since reference models represent a common body of knowledge it is suitable that they are available as open models. Openness refers to public availability as well as open development, e.g. in a crowd-sourced

manner. First collections of reference models in the form of reference model catalogs exist (e.g. rmk.iwi.uni-sb.de). More challenging is the development of open models. Organizing collaborative development processes and finding appropriated tools and platforms for the design of open models can be based on the experiences with and can adopt techniques from the field of open source software. However, there are some specific challenges concerning open models: (1) Contrary to open source software the appropriate level of model abstraction is not clear. If the model it to detailed, it might be too specific to use it as a blue print, while a coarse-grained model provides only marginal support. (2) Furthermore, there are only limited means for quality measurements and quality assurance of conceptual models. However, for conceptual models high quality is crucial since flaws in the requirements specification lead to expensive delay in software development or ERP customizing. (3) The development process of reference models can differ from the development process of software code. While conceptual models are usually constructed in a deductive way (collecting requirements, formalize them and describe them by means of a model language) like software code, reference models can also be derived in an inductive way. Comparable to process mining approaches, where process models are derived from event logs of process instances, reference model can be mined by analyzing various enterprise-specific conceptual models (reference model mining). A combined deductive and inductive approach for developing is assumed to foster the quality of open reference models.

3.13 Open Models for Business Information Systems Development

Andreas Oberweis (KIT – Karlsruhe Institute of Technology, DE)

Main reference F. Schönthaler, G. Vossen, A. Oberweis, T. Karle, "Business Processes for Business Communities. Modeling Languages, Methods, Tools," Springer-Verlag, 2012
URL http://www.horus.biz/public-space.html

The open models concept provides promising opportunities to improve the development of future business information systems. Open models allow a better alignment of information systems to user needs due to more intensive user participation in the design phase. Furthermore open models support a more open discussion of functional and non-functional requirements for business information systems than traditional requirements engineering concepts.

A key research objective in the field of open modeling is developing constructive and analytical methods to guarantee the quality of open models. Languages for open models should provide mechanisms for consistently refining and coarsening models since different user groups might require different levels of model granularity. Another important challenge in the field of open models is efficient maintenance of large sets of open models in repositories. A query language is required for effectively finding models in possibly distributed repositories. Another open issue is the question whether integrated models, including e.g. descriptions of activities, objects and roles, are preferable to more separate models for different aspects of information systems. A practical question of constructing open models is about who should build open models, and how modelers, especially experienced practitioners, can be motivated to participate in open modeling efforts. Collaborative modeling activities must be effectively supported.

Horus is a set of languages, methods and software tools for information systems modeling. Horus especially supports modeling processes within business communities. It integrates

concepts of typical social software systems in order to collaboratively develop different types of models in an open process. Horus includes simulation and analysis tools for community based evaluation and improvement of models. Reference models are provided in public spaces to improve productivity and quality of modeling processes. Horus can be downloaded from http://www.horus.biz/public-space.html.

3.14 Coherent Modelling Landscape

Erik Proper (Radboud University Nijmegen, NL)

Currently, models produced during one stage of the transformation process (such as an ArchiMate model) quite often have to be re-drawn, or even re-modelled, in some other language in a later stage of the process (such as a BPMN or a UML model). This leads to unnecessary delays and costs during a transformation process, and basicially constitutes a major disinvestment. The coherence (and automatic transformations) between different models is hampered due to the inherent disconnectedness of the modelling languages used, such as BPMN, UML, ArchiMate, et cetera. With "inherent disconnectedness" I refer to the fact that the meta-models underlying these languages have (from their designs) no formal connections. At the same, time an actor used in e.g. an ArchiMate model will re-appear as an actor in a BPMN model, while this latter model may also provide more details of the business process used in the original ArchiMate model. Of course it is possible to provide a mapping from (relavant parts of) an ArchiMate model to a BPMN model. However: A better integration of the meta-models would make such transformations more easy. A BPMN model provides a detailed view of the actual process and the roles of the actors involved, than what an ArchiMate model would. Therefore, one would expect the BPMN meta-model to be a specialisation of (part of) the ArchiMate meta-model as well. Regretfully, this is not the case at present, but might be strived for by the standardisation bodies. Even more, the needed transformations between e. g. (a relevant part of) an ArchiMate model towards/backwards a BPMN model could we standardised and become part of the body of standards (e. g. supporting boundaryless information flow at the level of models). This would ensure the portability of these transformations between different modelling tools in use by organisations. Both of these require an active role of the standardisation organisations such as the OMG and The Open Group, as well as their core members to take their responsibility in this. One might argue that the problem of coherence between models can be solved easily by creating one integrated modelling language. Essentially UML already provides such a language focusing at the level of software applications and their direct usage environment, while ArchiMate provides such a language focussed at the representation of enterprise architectures over different levels of abstraction (from technology via applications to the business level). The operative word here is "focussed". When designing a modelling language, one selects different modelling constructs to express the models. As argued in two earlier papers (1, 2), the modelling concepts included in a modelling language should really provide a real utility in relation to the purpose/focus of the language. Depending on the stage of an enterprise transformation, the aspects of the enterprise one focusses on, etc, different sets of modelling concepts are necessary. Therefore, a single unified modelling language will be hard to create, and even harder to use. In that sense we are likely to end up with several more focussed

languages, with their own added value. At the same time, this does not have to mean that we cannot have coherence between the different models. For example, within a single enterprise transformation, one may use:

- e3Value to model the position of the enterprise in a value web
- DEMO to elaborate the essential transactions between the enterprise and its environment as well as the essential internal workings of the enterprise
- ArchiMate to elaborate the enterprise architecture towards IT support for the enterprise's activities, and
- BPMN and UML to refine things even further to the level of specific applications and business processes.

These are all valid reasons for using the distinctive modelling languages. At the same time, it is only fair to expect to be able to trace the relations between:

- value exchanges between the enterprise and other actors in a value web (e3Value),
- the transactions between these actors operationalising these value exchanges and the essential processed needed to realise them (DEMO),
- the implementation of these essentual transactions and processes in terms of tangible actors, applications and IT, in terms of an enterprise architecture (ArchiMate),
- the actual realisation of these artefacts in applications and business processes (BPMN and UML).

In other words, a coherent modelling landscape is called for. To really be able to do so, requires these models to be interrelated, and eventually, the meta-models of the underlying modelling languages. The most basic way of realising this is to at least use persistant naming of actors, processes, etc, accross the different models. However, to explicitly express the fact that a specific value exchange (e3Value) is implemented using a number of transactions (DEMO), requires additional relations matching the two meta-models. The most practical way to proceed at the moment would be to apply a disciplined naming convention for the concepts used. A practical way of doing this would be the use of a domain model of the different domain concepts used accross the specific e3Value, DEMO, ArchiMate, etc, models, and a consequent use of the (names of these) concepts accross the models. Actually, creating such a domain model may also help modellers in the creation of more specific models such as value models and process models, since they can then start from a thorough understanding of the domain. A more ambitious approach would also require more advanced modelling tools, in which meta-models of different modelling languages are positioned in a hierarchy in such a way that models can also be mutually related and essentially be re-interpreted in terms of more specific meta-models. In the past, dome some initial work has been done in this regard.

3.15 Future Enterprise Systems in Business Ecosystems

Mirja Pulkkinen (University of Jyväskylä, FI)

As maybe the most challenging features, adaptability and flexibility are expected of future enterprise systems for modifiability in quick responses to changes in the business environment and thus changing needs of the business these systems support. Among the facets of an envisioned future of enterprise systems are ecosystems, where several enterprises, in conjoined

efforts, participate in provisioning business services. Besides interlinked, interoperable information systems, another trend is the provisioning of services is to an extent migrating into the computing cloud. Cloud services allow for evolving ecosystem participation by business partners and customers. The flexible, enhanced ICT capabilities are in future even more a business enabler, with the potential to meet the market needs quickly and precisely. Reference models are an expedient for the design and maintenance of these capabilities. Within an ecosystem, a common understanding of the systems, the business services and the processes to provision the services must exist for the information system supported co-operation. Open reference models (ORM) contribute essentially to the collaboration, both in intra-organizational settings and in inter-enterprise constellations, when design models for interoperable systems are created and interfaces designed. Reference models or model elements have different origins and audiences. There are differences in the modeling languages and disciplines in communicating them. A research avenue is opened here to explore the support for the collaborative construction, maintenance and use of open reference models. This is an effort across different communities of practice among the stakeholders either in a single enterprise, their reference groups like professional communities, or further, in the business ecosystems at a broader scale. Different contexts and goals of the diverse communities present both a challenge, and a potential driver for open reference models: there are common, reusable but also community specific features with existing models and modeling methods. However, the modeling and different aspects of it (languages and the overarching communication between the communities of practice with their specific linguistic practices) presents a challenge. The combination of IS design and methodology knowledge, and the knowledge on the linguistic behavior and communication in communities of practice is a possibility to meet the challenge.

3.16 Faithful Models of Discrete Dynamic Systems

Wolfgang Reisig (HU Berlin, DE)

This talk focuses on models of discrete, dynamic systems rather than datamodels. I start with the fundamental observation that the choice of the level of abstraction is fundamental for a modeler (whereas a programming lan-guage fixesthe level of detail for a programmer). We identify four requirements that a good modeling technique should fulfill: 1. Free choice of the level of abstraction: A good modeling language allows the modeler maximal freedom to chose the level of abstraction. 2. Faithful models: A model is faithful if—on the chosen level of abstraction—the elementary system items and operations correspond bijectively to the elementary model items and elementary model operations; the composed system items and operations correspond bijectively to model compositions; and the system states and steps correspond bijectively to model states and steps. In a faithful model, every property expressible on the chosen level of abstraction corresponds to a property of the model. Systematic refinement, i.e. steps to more detailed levels of abstraction, should ideally yield faithful models again. A modeler may "open up" his model until a distinguished detail level of abstraction has been reached. 3. Minimal infrastructure: Each model of dynamic systems assumes some kind of infrastructure ("Operating system") that guarantees runs to continue, if possible. Assumptions about the effect of the environment should be made

explicit and kept to a minimum. Implicit assumptions about the infrastructure are the source of most mismatches of models. 4. All this in one formalism: Is it possible to squeeze the above assumptions into one formalism? In fact, this can be achieved on the basis of Tarski structures, sig-algebras and Gurevich's Abstract State Machines.

3.17 The Business of Open Models

Dirk Riehle (Universität Erlangen-Nürnberg, DE)

Main reference The Business of Open Models (Blog entry)
URL http://dirkriehle.com/2012/03/27/the-business-of-open-models/

For open models to be sustainable, they'll need a business model. My suggestion is to create developer foundations like Apache or Eclipse for this.

3.18 Abstract

Matti Rossi (Aalto University, FI)

I see OMI as on important possibility for changing how enterprise systems are developed and deployed. For this kind of idea to become widespread, several obstacles need to be overcome. First there needs to be a demand for the models and a critical mass of models to start with, when these are available, there needs to be a community working with the models in the repository. Repository itself and tools for using it are needed also. Finally there needs to be use cases and tools to support those use cases in the OMI site. I believe that industry specific ES reference models could be a good starting point. This could provide a platform for an ecosystem of new ES and individual services to be build and for companies within the industry to use.

3.19 Open Models: Community-driven Collaboration to Promote Development and Dissemination of Reference Models

Stefan Strecker (FernUniversität in Hagen, DE)

Main reference U. Frank, S. Strecker, "Open Reference Models – Community-driven Collaboration to Promote Development and Dissemination of Reference Models," in: Enterprise Modelling and Information Systems Architectures: An International Journal, Vol. 2, No. 2, November 2007, pp. 32–41.

Reference models constitute a reification of a promising vision: Higher quality of information systems at less cost through reuse of confirmed domain knowledge and systems design. Paradoxically, however, development and, in particular, reuse of reference models has been ratherlimited both in practice and academia. The Open Model movement draws on analogies to free and open source software development to overcome the present barriers to the

development and adoption of reference models. It has been reasoned that ancommunity effort involving participants from academia and industry promises to leverage complementary know-how and resources to create a win-win situation for those who contribute domain knowledge as well as those who contribute modelling know-how. It has, however, become clear over the past few years – and first attempts to establish open model initiatives – that the Open Model conception requires a convincing (i.e. elaborate) kernel of models, modelling languages and tools in order to provide incentives for third parties to join in and to reach a critical mass. The Dagstuhl seminar on Open Models as a Foundation of Future Enterprise Systems not only underlined the necessity of such a kernel but also pointed at very attractive applications of open reference models in the context of next-generation enterprise systems.

3.20 Science and art of conceptual modelling / Pragmatism for Open Models: Codesign + Pattern + Storyboarding

Bernhard Thalheim (Universität Kiel, DE)

Science and art of conceptual modelling

Conceptual models are one of the main instruments for information systems development. A large body of knowledge has been developed in the past and resulted in sophisticated modelling techniques and languages. It needs however a combination, compilation, systematisation, and a general art (in the sense of the book series "The art of programming" by D.E. Knuth). At the same time, most of the notions of conceptual modelling must be clarified: what is a model, what is a concept; what is the use and value of a model; which community of practice acts; ... The talks survey our results on the definition of the notion of a "model" as an artifact with specific characteristics and qualifying propoerties, of "to model" as primitive or composite acts or activities, and of "modelling" as a systematic art or science, of concepts, of intention, of purpose as the main driving force, of (added) value of a model, of roles and plays of members from a community of practice, etc. It continues the theory of conceptual modelling in the Handbook of Conceptual Modelling.

Pragmatism for Open Models: Codesign + Pattern + Storyboarding

The codesign approach to conceptual modelling covers structuring, functionality, distribution and interactivity specification for large information systems specification and realisation. This approach has been certified to be on SPICE level 3. The codesign methodology might thus serve as a starting point for an integration of models which are concentrating on covering complete enterprise models. It uses the experience we have gained by our industrial schema library. Abstraction is an essential feature for the development of an open model library. One kind of abstraction—beside the meta-(meta-(meta-))-level abstraction—is generalisation abstraction. It can be based on pattern, i. e. generic solutions to basic and composite modelling problems. At the same time, models are for use and deployment. Therefore, they are bound to deployment and development stories. These stories can be modelled as storyboards.

3.21 Stakeholder-specific Modeling

Michael zur Mühlen (Stevens Institute of Technology, US)

Models serve multiple purposes: They provide a shareable conceptualization of some subject matter that can be shared among stakeholders. They can replicate or explain a phenomenon, or they can predict, guide and constrain future phenomena. In the first two cases, the process of modeling may prove to be as significant as the resulting model. Collaborative modeling creates a shared understanding of same problem (or solution) space. Consensus in this area requires understandable methods, tools and design processes. But: Stakeholders should be able to retain their specific interests that guide, constrain, and predict need to be understood and interpreted in a uniform fashion. In this area, models may be more important than the process of their creation. It is important for the conceptual modeling community to recognize these use case differences and to focus differently, depending on the area of application.

4 Working Groups

Five working groups discussed pertinent research issues in the vicinity of the seminar's scope. The four working groups were:

1. **Future Enterprise Systems**: Gregor Engels, Andreas Oberweis, Eric Proper, Mirja Pulkinnen, Stefan Strecker, Bernhard Thalheim.
2. **Modelling domains and purposes**: Jörg Becker, Marc Lankhorst, Sina Lehrmann, Peter Loos, Erik Proper, Mirja Pulkkinen.
3. **Technical Infrastructure and tools**: Dimitris Karagiannis, Andreas Oberweis, Florian Matthes, Wolfgang Reisig, Dirk Riehle, Matti Rossi.
4. **Organisation**: Hans-Georg Fill, Dirk Riehle, Mogens Kühn Pedersen, Michael zur Mühlen.
5. **Open Models @ Runtime**: Tony Clark, Patrick Delfmann, Jörg Desel, Werner Esswein, Robert France, Ulrich Frank, Andreas Hess.

5 Open Problems

Open research issues and practical problems will be discussed in a joint publication by the organizers to appear in 2013.

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