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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 14201

Horn Formulas, Directed Hypergraphs, Lattices and Closure Systems: Related Formalisms and Applications

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 14201 “Horn formulas, directed hypergraphs, lattices and closure systems: related formalisms and applications”. The seminar brought together researchers working in various areas of mathematics and computer science, mostly in algebra, logic, data base theory, artificial intelligence and data mining. A key objective of the seminar has been to bring together a critical mass of researchers and to provide a platform for personal contacts and scientific interchange between the different disciplines in an atmosphere that will stimulate collaboration and lead to new partnerships. The goal was to crystallize the main research directions and to disseminate challenging open problems across the different research areas.

Seminar May 11–16, 2014 – <http://www.dagstuhl.de/14201>

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1 Executive Summary

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Giuseppe F. Italiano

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György Turán

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Brief Introduction to the Topic

The Dagstuhl Seminar 14201 on “Horn formulas, directed hypergraphs, lattices and closure systems: related formalisms and applications” was motivated by the growing recognition in the respective research communities that theoretical research and applications of the areas would benefit from increasing the interaction between these fields of research.



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Horn formulas, directed hypergraphs, lattices and closure systems: related formalisms and applications, *Dagstuhl Reports*, Vol. 4, Issue 5, pp. 1–26

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These areas deal with very closely related concepts, but have traditionally been studied within logic, algebra, combinatorics, database theory and artificial intelligence using different techniques and often exploring similar questions with somewhat different emphasis corresponding to the particular area. One of the basic results, the existence of GD-basis, was discovered independently and has different proofs in several areas, such as database theory, the theory of implicational systems and computational learning theory.

The principal objective of the seminar was, as formulated in the seminar announcement, to “bring together a critical mass of researchers and to provide a platform for personal contacts and scientific interchange between the different disciplines in an atmosphere that will stimulate collaboration and lead to new partnerships”. In particular, it was hoped that the invitation of a large number of young researchers who would then become familiar with the related research in all the topics discussed, will contribute to the fruitful study of these areas as a more unified discipline in the next generation. Another, related, objective was to help crystallize the main research directions and to disseminate challenging open problems across the different research areas.

Organization of the Seminar and Activities

The seminar brought together 40 participants working in various areas of mathematics and computer science, mostly in algebra, logic, data base theory, artificial intelligence and data mining. In order to establish the common ground for the discussion and use of terminology, the organizers planned five tutorial talks that were scheduled in the first two days of the seminar. There were the following:

- Endre Boros, in Horn Boolean functions
- Leonid Libkin, in Data Bases
- Marcel Wild, in Closure Systems
- Karell Bertet, in Implicational systems and Concept Analysis
- Georgio Ausiello, in Directed Hypergraphs

It is worth mentioning that two of the tutorial presenters, Endre Boros and Georgio Ausiello, are editors-in-chief of two leading journals that often publish papers associated with the topic of the seminar: Applied Discrete Mathematics and Theoretical Computer Science, respectively. Most other talks of the seminar were related to one or more of these big themes, and they were loosely grouped into sections of presentations in order to stimulate the discussion during regular sessions of the seminar, as well as the break time and follow-up informal meetings. The following grouping gives an approximation to the various topics reflected in the presentations:

- Closures: Duquenne, Wild, Rudolph, Khardon
- Implicational systems: Wild, Adaricheva, Bertet
- Databases: Petit, Libkin
- Directed hypergraphs: Berczi, Nanni, Turán, Ausiello
- Concept Analysis: Obiedkov, Napoli, Kuznetsov
- Horn formulas: Arias, Kučera, Stasi, Čepék
- Applications : Arias, Balcazar, Nation, Bertet
- Knowledge representation: Khardon, Marquis, Sloan
- Constraints: Tamaki
- Probability: Istrate, Balcazar
- Satisfiability: Kleine Büning, Kullmann, Wild

There was a relatively large group of participants attending the seminar without giving a presentation, many of them formed an active audience that initiated discussions and informal meetings. There were several young participants, who associated themselves with one or two presenters, some of them were co-authors in presented results. In some presentations, the participants touched the rare topics which remarkably found active response from the audience. For example, U. Nanni mentioned application of hypergraphs in the modeling of E-Learning. This seems to open a new connection to the theory Knowledge Spaces that were not previously considered by the organizers as the direction of common interests with the current seminar. S. Tamaki presented the overview of recent developments in constraint satisfiability, the topic of the separate Dagstuhl seminar in 2012, which is also familiar to a number of participants of the current seminar. This gave a nice connection to the earlier collective effort of researchers approaching a common research problem with different tools. On Wednesday most participants took part in the countryside walk, the venue of informal exchange of news and views. It was followed by a dinner and a session on open problems. 17 open problems were presented by the participants, some of them referring to the topics of presentations, several young participants introducing new topics. On Thursday night many informal groups were gathering in the after-dinner discussions. During the work of the whole seminar participants took advantage of open access to the comprehensive library, in particular, checking the collection of books authored by participants of the seminar.

Concluding Remarks

We believe that the seminar was very successful in bringing together a critical mass of researchers from different communities and in providing a platform for personal contacts and scientific interchange between the participants. Due to its highly interdisciplinary nature, in order to stimulate collaborations and to foster possible interactions between different research communities, the organizers decided to schedule talks and discussions not only grouped according to topics but also so as to provide a vivid mix of different research questions and results. In particular, the first two days started with introductory talks (tutorials and surveys) delivered by leading experts, while the rest of the seminar included talks presenting current research and applications as well as problem sessions aimed at identifying core research problems coming from the different fields. Besides presentations, the program offered room for open discussions and informal working groups. As a major outcome, a special issue of the journal *Theoretical Computer Science*, co-edited by the organizers, will be devoted to the themes of the seminar. We hope this could serve as a reference material for future interdisciplinary research in the field. Schloss Dagstuhl and its staff provided a very convenient and stimulating environment. The seminar participants appreciated the cordial atmosphere which improved mutual understanding and inspiration. The organizers of this seminar wish to thank all those who helped to make the seminar a fruitful research experience.

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3 Overview of Talks

3.1 Effective bases of closure systems

Kira V. Adaricheva (Yeshiva University – New York, US)

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Joint work of Adaricheva, Kira V.; Nation, James B.

Main reference K. V. Adaricheva, J. B. Nation, “On implicational bases of closure systems with unique critical sets,” *Discrete Applied Mathematics*, Vol. 162, pp. 51–69, 2014.

URL <http://dx.doi.org/10.1016/j.dam.2013.08.033>

In this talk the overview is presented of recent results inspired by the study of closure systems with unique critical sets. Many of these results, however, are of a more general nature. Among those is the statement that every optimum basis of a finite closure system, in D. Maier’s sense, is also right-side optimum. This connects the results given in D. Maier [5] and G. Ausiello et al. in [3], in different frameworks of closure systems.

We introduce the K-basis of a closure system, which is a refinement of the canonical basis of V. Duquenne and J.L. Guigues [4], and discuss a polynomial algorithm to obtain it.

Then we focus on closure systems with unique critical sets, and some subclasses of these where the K-basis is unique. A further refinement in the form of the E-basis is possible for closure systems without D-cycles. The latter basis was first introduced in K. Adaricheva et al. [2], in the family of the ordered direct bases.

One of the main achievements is to demonstrate a polynomial algorithm to recognize the D-relation from a K-basis. Consequently, closure systems without D-cycles can be effectively recognized. While the E-basis achieves an optimum in one of its parts, the optimization of the others is an NP- complete problem. New results are obtained in finding the optimum bases in some classes of convex geometries, K. Adaricheva [1].

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- 3 G. Ausiello, A. D’Atri and D. Saccá, *Minimal representation of directed hypergraphs*, *Journal on computing* **15** (1986), 418–431.
- 4 J. L. Guigues and V. Duquenne, *Familles minimales d’implications informatives résultant d’une tables de données binaires*, *Math. Sci. Hum.* **95** (1986), 5–18.
- 5 D. Maier, *Minimum covers in the relational database model*, *JACM* **27** (1980), 664–674.

3.2 Query learning of Horn implications: complexity and connections to the GD-basis

Marta Arias (UPC – Barcelona, ES)

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Joint work of Arias, Marta; Balcázar, Jose Luis; Tirnauca, Cristina

Main reference M. Arias, J.L. Balcázar, “Construction and learnability of canonical Horn formulas,” *Machine Learning Journal*, Vol. 85(3):273–297, 2011.

URL <http://dx.doi.org/10.1007/s10994-011-5248-5>

In this talk we will review our results on the connections between learning Horn formulas and a minimal representation of Horn implications (the Guigue-Duquenne basis or GD-basis).

The talk will cover a review of known upper and lower bounds on the complexity of learning these formulas by presenting a well-known algorithm and the notion of certificates. Then, we will introduce a new learning model based on closure queries which we think captures the essence of the difficulty of learning Horn implications. This is joint work with José L. Balcázar and Cristina Tirnauca.

3.3 Logical entailment among partial implications

Jose Luis Balcazar (UPC – Barcelona, ES)

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Joint work of Balcázar, Jose Luis; Atserias, Albert

Main reference J. L. Balcázar, “Redundancy, Deduction Schemes, and Minimum-Size Bases for Association Rules,” *Logical Methods in Computer Science*, 6(2:4), 2010.

URL [http://dx.doi.org/10.2168/LMCS-6\(2:4\)2010](http://dx.doi.org/10.2168/LMCS-6(2:4)2010)

Relaxed implication connectives are a relatively natural concept. Probabilistic versions defined by resorting to thresholding conditional probability have been proposed in different research communities. Luxemburger introduces them as ‘partial implications’; the association rules of the data mining world are partial implications that impose the additional condition that the consequent is a single propositional variable.

One gets easily a logic language of partial implications. For that language, we review known syntactic characterizations of one formula entailing another, and of two formulas entailing another, as well as the handling of additional classical implications, as described in the paper linked to by the following DOI: [http://dx.doi.org/10.2168/LMCS-6\(2:4\)2010](http://dx.doi.org/10.2168/LMCS-6(2:4)2010).

We report as well on our latest developments towards a full characterization of entailment among partial implications, from arbitrary sets of premises. This progress is obtained, essentially, by recasting the entailment property in the form of a linear program and reasoning on its dual. This part is joint work (unpublished for the time being) with Albert Atserias.

3.4 From digraphs to dypergraphs: paths and arborescences

Kristof Bercezi (Eötvös Lorand University – Budapest, HU)


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Directed hypergraphs can be defined in many ways. We consider the following definition: a directed hypergraph (or dypergraph for short) is a pair $H = (V, E)$ where V is a finite ground set, E is a family of hyperedges (subsets of V), and each hyperedge e has a designated node called the head of e , while other nodes in e are called tails. A path is an alternating sequence $v_1, e_1, v_2, e_2, \dots, e_k, v_{k+1}$, where v_i is a tail node of e_i and v_{i+1} is the head of e_i . A node v is said to be weakly reachable from another node u if there is a path from u to v . The reason for calling this reachability condition ‘weak’ is that in some applications a different notion of reachability is used. However, an advantage of the present definition is that analogues of Menger’s theorems extend naturally.

In this talk, we show how to extend Menger’s theorem to dypergraphs. A method for ‘cropping’ dyperedges is also presented, giving a powerful tool for handling rooted edge-connectivity problems in dypergraphs.

3.5 Closure lattices and implication bases

Karell Bertet (*University of La Rochelle, FR*)

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Formal Concept Analysis (FCA) [14] allows to analyze and extract information from a context – i. e. a binary table – where implicit knowledge between data can be represented either by a concept lattice or implications. In data mining, various symbolic methods stemming from FCA have been studied for (un)supervised classification, association rules extraction and frequent pattern extraction. These methods focus on relevant concepts, closures, or implicational rules and their minimal generators. Implications are also linked to minimal functional dependencies in databases. In logic area, implicational system corresponds to the set of representation of Horn clauses of a logic formula, and the closed set lattice is composed of all the true subsets of variables. A closure lattice can also be used as the hierarchical scheme of an ontology. More recently, extensions to more complex data were also proposed as pattern structures in [13], i. e. when there exists a Galois connexion between objects and their space of description. Let us cite extensions to histograms description of objects [25], or logical space description [9]. Thus, implicit knowledge can be extracted from any closure system as contexts, but also implications systems, pattern structures.

The first reference book on lattice theory is due to Birkhoff in 1940 [4], where the lattice structure is introduced as an algebraic structure provided with two operators: the lower and upper bounds. However, in recent works [20, 6], Monjardet establishes that the algebraic lattice structure appeared for the first time in the works of Dedekind in 1900 as the *dualgruppe* term, and then with several forms and terminologies between 1928 and 1936 in the works of Merge, Klein, Blind, Birkhoff, Öre or Von Neuman. Monjardet also mentions that lattices appeared for the first time in 1847 in its Boolean form in the works of Boole on the algebra of logic, then in the works of Pierce in 1880. The lattice term was proposed by Birkhoff during the first symposium on lattices in 1938, while Merge proposed the *System von Dingern* term, and Öre the *structure* term.

In [8, 1], the lattice is defined as an ordered structure (i. e. transitive, antisymmetric and reflexive) defined by the existence of particular elements called upper and lower bounds. The notion of irreducible elements [1, 19] of a lattice allow the conception of compact representations of lattices from which it is possible to reconstruct them. The fundamental result of lattice theory, stemming from [1], establishes the bijection between any lattice and the Galois lattice defined from its binary table of irreducible elements. A direct consequence is the existence of bijective links between lattices, reduced contexts (via the table) and a set of implicational rules (via the canonical (direct) basis):

1. Any complete lattice is the concept lattice of its binary table; Any reduced context is isomorphic to the irreducible table of its concept lattice.
2. Any complete lattice is isomorphic to the closed set lattice of its canonical (direct) basis of implicational rules; Any implicational system on its canonical (direct) form is isomorphic to the canonical (direct) basis of its closed set lattice.

In [1], the authors introduce the Galois lattice term, while the Galois connexion term was defined by Ore in 1944 in [23]. This fundamental bijection is a consequence of the property of a closure operator of any Galois connexion, and can therefore be extended to a closed set lattice [7] and to the very rich closure systems, i. e. sets systems provided with a closure operator. Indeed, we find closure operators in numerous domains, whether in logic, in databases, in combinatoric, or even in data analysis

The concept lattice was introduced in the 1990s by Wille within the framework of the Formal Concepts Analysis (FCA), with a reference book dated 1999 [14]. A concept lattice is a graph defined from a binary data (or context) object \times attributes. This lattice composed of concepts connected by the generalization/specialisation relation supplies a very intuitive representation of the data. FCA is a knowledge representation approach whose use is increasing this last decade in various domains of computer science, such as data mining, knowledge representation, databases or information retrieval. Indeed, the technological improvements enable to use these structures for large data in these domains though they are exponential in space/time (worst case), and make the development of a large number of applications possible. The need for efficient algorithms to manipulate these structures is a major challenge.

Generation problems of these objects stemming from lattice theory belong to the more general class of problems having an input of size n , and an output of size N bounded by 2^n :

- The closed set lattice and the canonical (direct) basis of a closure system on a set S have a size bounded by $2^{|S|}$ in the worst case.
- The canonical (direct) basis and the minimal generators of a lattice (X, \leq) have a size bounded by $2^{|X|}$ in the worst case.

For this class of problems, a classical worst-case analysis makes them exponential, thus NP-complete. However, a more precise estimation can be obtained from output-sensitive analysis where the time complexity per element – i. e. one implication or one closed set – is estimated either by the amortized complexity or the delay complexity. A polynomial delay algorithm is then an algorithm with a delay cost bounded by a polynomial. In lattice theory, generation problems with an exponential output are mainly resolved:

Closed set lattice generation from a closure system: Polynomial delay problem

Numerous polynomial delay algorithms have been proposed in the literature [21, 12, 5, 15, 22]. Ganter's NextClosure [12] is the reference algorithm that computes the closures lexicographically ordered (which can then be ordered to form the lattice) while Bordat's algorithm [5] is the first algorithm that computes directly the Hasse diagram of the lattice.

Canonical direct basis generation from a closure system: Open problem

Let us cite the algorithm of Mannila in [18], where the canonical direct basis is generated with an exponential time per implication in the worst case. It is based on the generation of all minimal transverses, a problem known to be an open problem (there actually exists a quasi-polynomial algorithm to solve it). More generally, the canonical direct basis can be obtained from the closed set lattice of the closure system, with the generation of all closed set as an additional cost, thus an exponential delay complexity. In the particular case where the closure system is an implicational system, there exist specific algorithms, always with the same exponential delay complexity. The algorithms described in [27] and [3] compute an intermediate but larger implicational system of exponential size in the worst case. The algorithm with the best known complexity, in logic area, is due to Fredman and Khachiyan ([11]). It generates one implication with a quasi-polynomial time and has been modified in [17] to solve this problem with a first step in deterministic polynomial time, followed by $O(\log^2 |S|)$ non deterministic steps.

Canonical direct basis generation from a lattice: Polynomial amortized problem

In the area of data mining the algorithm of Taouil and Bastide in [26] generates the canonical direct basis with an exponential complexity per implication. The incremental algorithm of Pfaltz [24] and Jen algorithm [10] both compute the minimal generators – i. e. premises of the canonical direct basis – of a lattice with the same complexity. However, in logic area, the algorithm attributed to Ibaraki et al. ([16]) computes an implication in polynomial time with a set of closures as input. The algorithm in [2] is similar to those in [16]. It computes the dependency graph of a lattice, and then extracts the canonical direct basis from this graph.

Equivalent notions such as lattices (or closed set lattices), closure systems, closure operators (or dual closure operators), (pure) Horn functions have been studied by different authors in different domains (topology, lattice theory, hypergraph theory, choice functions, relational databases, data mining and concept analysis, artificial intelligence and expert systems, knowledge spaces, logic and logic programming, theorem proving...). It is not surprising that one finds the same notions, results or algorithms under various names. One can also find many original results or algorithms only known in a specific domain. It would be very profitable to increase (or create) the communications between the various domains that use the same (or equivalent) notions and tools.

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3.6 Horn functions: a combinatorial view

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Joint work of Boros, Endre; Čepek, Ondřej; Crama, Yves; Gruber, Arifan; Hammer, Peter L.; Kogan, Alexander; Kučera, Petr

Main reference E. Boros, “Horn Functions,” in Y. Crama and P.L. Hammer, eds., “Boolean Functions: Theory, Algorithms, and Applications”, Cambridge University Press, 2011.

In this talk basic properties of Horn functions and their representations are surveyed. Horn functions are viewed as 0-1 valued real functions, and representations in terms of their implicants (implicates) are considered. The space of implicants and implicates are viewed as abstract sets, in which consensus and resolution provides some order. We recalled results about decomposability of the Horn minimization problem in terms of exclusive sets and components. We provided constructive descriptions via forward chaining and syntactical properties for such exclusive families of implicants.

These properties provided the bases for the efficient (polynomial delay) generation of ALL prime implicants/implicates of a Horn DNF/CNF (equivalent to generating the direct implication basis of an implication system).

We also recalled an associated graph, the so called implication graph of a Horn function, and showed that the structure of this graph provides additional exclusive subfamilies of exclusive sets. Based on such exclusive sets and the resulting decomposition ideas, one can simplify Horn minimization and also can simplify the proof of correctness of some hardness results.

Finally, we recalled recent hardness results about Horn DNF/CNF minimization and Horn literal minimization, namely that unless $P=NP$, one cannot approximate within a factor of $2^{\log^{1-o(1)} n}$ the term/literal minimum of a Horn DNF (and the same applies to clause/literal minimum Horn CNF-s), even if the input is restricted to ‘short’ cubic Horn DNF/CNF-s.

This talk was based on joint research with O. Čepek, Y. Crama, A. Gruber, P. L. Hammer, A. Kogan, and P. Kučera.

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3.7 Shortest CNF representations of Horn functions: complexity issues, decomposition schemes, and lower bounds

Ondřej Čepek (Charles University – Prague, CZ)

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Joint work of Boros, Endre; Čepek, Ondřej; Kogan, Alex; Kučera, Petr; Savický, Petr

Main reference E. Boros, O. Čepek, A. Kogan, P. Kučera, “Exclusive and essential sets of implicates of Boolean functions,” Discrete Applied Mathematics, Vol. 158, Issue 2, pp. 81–96, 2010.

URL <http://dx.doi.org/10.1016/j.dam.2009.08.012>

Finding a shortest CNF representation of a given Horn function is a problem with many practical applications in artificial intelligence (knowledge compression) and other areas of computer science. In this talk we briefly survey complexity results known for this problem and then concentrate on the relationships between CNF representations of Horn functions and certain sets of implicates of these functions. We introduce two definitions of sets of implicates which are both based on the properties of resolution. The first type of sets, called exclusive sets of implicates, is shown to have a functional property useful for decompositions which allow to reduce the minimization problem to smaller subCNFs. The second type of sets, called essential sets of implicates, has an orthogonality property, which implies that every CNF representation and every essential set must intersect. This property leads to

interesting lower bounds on the CNF size. Given the topic of the Dagstuhl seminar, it would be interesting to see whether concepts similar to exclusive and essential sets of implicates were studied in the context of directed hypergraphs or closure systems.

3.8 Some variations on lexicographic enumeration of closed subsets and canonical bases of implications

Vincent Duquenne (UPMC – Paris, FR)

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Since their promotion in 1984 [3], many efforts have been done to overtake the so-called NextCLOSURE algorithms, which are applying natural lexicographic enumeration [7]. More than going faster (who cares getting more than 105/s on a 200E laptop?), a hidden motivation could have been to try escaping their simplicity . . . These attempts have been partly successful to scan through intents (closed subsets) with some costs. For the canonical basis of implications based on pseudo-intents [2, 4] the fees are a bit higher and more than often – if not always – involve an exponential explosion in memory [5, 6]. Here we come back to mere lexicographic enumeration with some specific tricks to speed up the process, which can be adapted to other related objects. Hence with a special dedication to ecologically minded users, we will try to give some visions of what could be next in doing with boosted basic algorithms.


Keywords: closure operator, lattice, combinatorial exhaustive enumeration, NextCLOSURE, (quasi / pseudo) intents, canonical basis of implications.

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3.9 Random Horn satisfiability. Some (old) results and some new(er) surprises.

Gabriel Istrate (West University of Timisoara, RO)

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We will overview results on thresholds in random versions of satisfiability, applications to random tree automata emptiness, and the way random Horn satisfiability is important in a classification (similar in spirit to Schaefer's dichotomy theorem) of thresholds of generalized satisfiability problems in a model based on clausal formulas. We will also discuss the connection of this classification to recently investigated the problem of random mixed Horn satisfiability.

The talk is based on several papers, some of them authored solely, one of them in cooperation with Cristopher Moore and Moshe Vardi, as well as some unpublished results.

3.10 GFODDs – a representation and calculus for structured functions over possible worlds

Roni Khardon (Tufts University, US)

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Joint work of Khardon, Roni; Saket, Joshi; Kersting, Kristian; Wang, Chenggang; Schermerhorn, Paul; Scheutz, Matthias; Raghavan, Aswin; Fern, Alan; Tadepalli, Prasad

URL http://www.cs.tufts.edu/research/ml/index.php?op=res_full&id=5

The Generalized first order decision diagrams (GFODD) representation, captures numerical generalizations of first order logic where truth values are generalized to real values and logical quantifiers are generalized to aggregation functions over such values. GFODDs can be seen as expressions representing functions over possible worlds (interpretations) and can therefore represent probability functions, value functions etc. A calculus of expressions allows us to perform operations over the functions they represent and perform inference in this way. A heuristic, using reasoning from examples, allows us to implement inference reasonably efficiently and therefore support complex patterns of inference. The talk will give an overview of this work motivating the representation, discussing complexity, explaining heuristics, and illustrating our main application in solving structured Markov decision problems.

Based on joint work in multiple papers with Saket Joshi, Kristian Kersting, Chenggang Wang, Paul Schermerhorn, Matthias Scheutz, Aswin Raghavan, Alan Fern, Prasad Tadepalli.

A complexity based treatment can be found in [1]. For other papers please see our project site (see URL above) for online versions of the papers.

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<http://www.cs.tufts.edu/~roni/PUB/aaai2014gfcomplexity.pdf>

3.11 Closed Sets in Relational Data

Roni Khardon (Tufts University, US)

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Joint work of Khardon, Roni; Garriga, Gemma ; De Raedt, Luc

Main reference G. C. Carriga, R. Khardon, L. De Raedt, “Mining closed patterns in relational, graph and network data,” *Annals of Mathematics and Artificial Intelligence*, 69(4):315–342, 2013.

URL <http://dx.doi.org/10.1007/s10472-012-9324-8>

In this talk I reviewed our work from IJCAI 2007 and AMAI 2013 that investigates semantic properties of closed sets in multi-relational datasets, and the implications for algorithmic properties. Prior literature has multiple definitions for the notions of occurrence of a pattern and the notion of closure relative to such occurrences. Our work shows that these implicit choices are important because they yield dramatically different properties, resulting closed sets, and algorithms.

Based on joint work with Gemma Garriga and Luc De Raedt.

Note: Given the strong interest and focus on closed sets in the workshop I added this second brief talk to complement the discussion.

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3.12 Expressive Power of Quantified Horn Formulas

Hans Kleine Büning (Universität Paderborn, DE)

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Joint work of Kleine Büning, Hans; Bubeck, Uwe; Zhao, Xishun

In this talk we give an overview of the expressive power of quantified Horn formulas and related quantified Boolean formulas. Additionally, we present the computational complexities of the satisfiability problem for various classes and the structure of satisfying models. These are Skolem functions for the existential quantifiers satisfying the formula. Another application is the linear time transformation of propositional formulas into satisfiability equivalent formulas in CNF by means of existentially quantified CNF formulas with free variables where the bounded part of the clauses are 2-Horn clauses.

Based on joint work with Uwe Bubeck and Xishun Zhao.

3.13 Hydras: Complexity on general graphs and a subclass of trees

Petr Kučera (Charles University – Prague, CZ)

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Main reference P. Kučera, “Hydras: Complexity on general graphs and a subclass of trees,” in Proc. of the Int’l Symp. on Artificial Intelligence and Mathematics (ISAIM’14), 2014.

URL http://www.cs.uic.edu/pub/Isaim2014/WebPreferences/ISAIM2014_Boolean_Kucera.pdf

Hydra formulas were introduced in [1]. A hydra formula is a Horn formula consisting of definite Horn clauses of size 3 specified by a set of bodies of size 2, and containing clauses formed by these bodies and all possible heads. A hydra formula can be specified by the undirected graph formed by the bodies occurring in the formula. The minimal formula size for hydras is then called the hydra number of the underlying graph. In this paper we aim to answer some open questions regarding complexity of determining the hydra number of a graph which were left open in [1]. In particular we show that the problem of checking, whether a graph $G = (V, E)$ is single-headed, i. e. whether the hydra number of G is equal to the number of edges, is NP-complete. We also consider hydra number of trees and we describe a family of trees for which the hydra number can be determined in polynomial time.

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3.14 Good SAT representations of boolean functions, with applications to XORs

Oliver Kullmann (Swansea University, GB)

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Joint work of Kullmann, Oliver; Gwynne, Matthew

Main reference M. Gwynne, O. Kullmann, “On SAT representations of XOR constraints,” in Proc. of the 8th Int’l Conf. on Language and Automata Theory and Applications (LATA’14), LNCS, Vol. 8370, pp. 409–420, Springer, 2014.

URL http://dx.doi.org/10.1007/978-3-319-04921-2_33

URL <http://www.cs.swan.ac.uk/csoliver/papers.html#DAGSTUHL2014a>

An approach towards measuring the quality of SAT representation is outlined, via various ‘hardness measurements’. The application to XOR-constraints is considered, showing that there is no polysize ‘good’ representation in general, while finding such a “good” representation is fixed-parameter tractable in the number of constraints. ‘Good’ here means ‘UR-representation’, that is, every partial instantiation to the variables of the boolean function represented, which destroys all satisfying assignments, is recognised by unit-clause propagation. We consider also stronger positive results, using unit-propagation completeness.

3.15 On Complexity of Computing Concept Lattices, Implication Bases and Dualization

Sergei O. Kuznetsov (NRU Higher School of Economics – Moscow, RU)

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Joint work of Kuznetsov, Sergei O.; Babin, Mikhail A.; Obiedkov, Sergei A.

Main reference M. A. Babin, S. O. Kuznetsov, “Computing premises of a minimal cover of functional dependencies is intractable,” *Discrete Applied Mathematics*, Vol. 161, Issue 6, pp. 742–749, 2013.

URL <http://dx.doi.org/10.1016/j.dam.2012.10.026>

Most important computation problems of lattices and related implication systems are discussed: computing a concept lattice from context (i. e., computing a lattice from the sets of its irreducible elements), computing cardinality-minimal implication base (i. e., minimum Horn theory or minimum cover of functional dependencies) related to the lattice. Learning from positive and negative examples in a concept lattice is shown to be equivalent to a dualization problem on a lattice given implicitly by the ordered set of its irreducible elements. Efficient lazy classification is proposed as an alternative to the direct usage of implications as classification rules. The positive results are shown to be extendible to lattices of arbitrary closed descriptions.

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3.16 Databases and lattice theory

Leonid Libkin (University of Edinburgh, GB)

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In this talk we surveyed recent database applications that used lattice-theoretic techniques, specifically the lattice of graph cores ordered by homomorphisms between them. We explained why these are important in the study of conjunctive queries, and concentrated on two applications: approximation of queries by efficient ones, and evaluation of queries over databases with incomplete information.

3.17 Knowledge compilation and Horn formulae

Pierre Marquis (Artois University – Lens, FR)

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Main reference P. Marquis, “Existential Closures for Knowledge Compilation,” in Proc. of the 22nd Int’l Joint Conference on Artificial Intelligence (IJCAI’11), pp. 996–1001, IJCAI/AAAI, 2011.

URL <https://www.aaai.org/ocs/index.php/IJCAI/IJCAI11/paper/view/3026/>

In this talk I will focus on the concept of disjunctive closure of the language of (renamable) Horn CNF formulae, i. e., the class of existentially quantified disjunctions of (renamable) propositional Horn CNF formulae. I will analyze the corresponding languages L along the lines of the knowledge compilation map, i. e. I will make precise the queries and transformations of interest feasible in polynomial time (and those which are not unless $P = NP$) when the input is in L and I will also compare the succinctness of L with those of other propositional languages.

3.18 Directed hypergraphs: a leverage to investigate properties of Petri nets, workflow nets, and more

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Joint work of Alimonti, Paola; Feuerstein, Esteban; Laura, Luigi; Nanni, Umberto

Main reference P. Alimonti, E. Feuerstein, L. Laura, U. Nanni, “Linear time analysis of properties of conflict-free and general Petri nets,” Theoretical Computer Science, Vol. 412, Issues 4–5, pp. 320–338, 2011.

URL <http://dx.doi.org/10.1016/j.tcs.2010.09.030>

Petri nets have been introduced in 1962 by Carl Adam Petri to model the dynamic properties of a concurrent system, and have enjoyed a wide success, with application in a number of realms – far beyond computing. A Petri net is a 4-tuple $\langle P, T, A, M_0 \rangle$ where: P is the set of places, T is the set of transitions, A is the set of arcs (from places to transitions, or vice-versa, i. e., $\langle P, T, A \rangle$ is a bipartite graph), and M_0 is the initial marking which can be expressed as a function from places to natural numbers; you can figure out the marking of a net as a distribution of “tokens” over the places. The marking of a Petri net, representing the state of the net, can evolve from the initial state by firing transitions. Most problems on Petri nets (a bit less expressive than Turing machines) are decidable, although with high computational complexity. We introduce the notion of T-path within Petri nets, and adopt

directed hypergraphs in order to determine structural properties of nets. In particular, we study the relationships between T-paths and firable sequences of transitions. Let us consider a Petri net P , with initial marking M_0 , and the set of places with a positive marking in M_0 , i. e., $P_0 = \{p \mid M_0(p) > 0\}$. It can be shown that the existence of a T-path from any subset of P_0 to a transition t is a necessary condition for the potential firability of t and, furthermore: (a) if P is a Conflict Free Petri net, this is also a sufficient condition, (b) if P is a general Petri net, t is potentially firable “by augmentation” of the initial marking (i. e., by increasing the number of tokens in P_0). For the class of Conflict-Free nets (CFPN), using the notion of T-path, we show that there exist simple algorithms requiring linear space and time for the following problems: (a) determining the set of firable transitions, (b) determining the set of reachable places, (c) determining the set of live transitions, (d) deciding the boundedness of the net. All these problems, untractable on general Petri nets, have been solved previously in CF-nets by matrix operations in quadratic time in several papers by Howell, Rosier, Yen.

Given a Petri net and a marking M , the well-known coverability problem consists in finding a reachable marking M' such that $M' \geq M$. We introduce a relaxed form of this problem: we say that a marking M is “coverable by augmentation” if it is coverable from an augmented marking M_0+ of the initial marking M_0 : $M_0+ \geq M_0$ and, for any place p , $M_0+(p) = 0$ if $M_0(p) = 0$. The coverability problem is known to be EXPSPACE-hard [Rackoff, 1978]; we solve the relaxed problem of coverability by augmentation in linear time in general Petri nets.

Workflow nets are the results of adopting Petri nets for modeling Workflow Management [van der Aalst, 1997]. This seminal approach has boosted the adoption of these structures within the context of Business Process Management, with impact on methodologies with high industrial relevance (UML, BPMN). We show as adopting the notion of augmented marking allow us to investigate properties of Workflow nets.

More recent applications of directed hypergraphs in the context of eLearning show that it is possible to build personalized learning paths in linear time within a collection of learning components: this solution tackle the problem of managing and reusing learning objects stored in huge repositories where they have been accumulated in the range of millions.

3.19 Formal Concept Analysis, Variations and Applications

Amedeo Napoli (LORIA & INRIA Nancy, FR)

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In Formal Concept Analysis (FCA [8]), the formalization of a classification problem relies on a formal context $K = (G, M, I)$ where G is a set of objects, M a set of attributes and $I \subseteq G \times M$ a binary relation describing links between objects and attributes. Then a formal concept corresponds to a maximal set of objects – the extent – associated with a maximal set of attributes – the intent. Formal concepts are ordered within a complete lattice thanks to a subsumption relation based on extent inclusion.

The standard FCA formalism can be extended to deal with relational and complex data. Relational Concept Analysis (RCA [12]) is able to take into account relational data, i. e. relations between objects while the basic data structure in FCA relies on object and attribute relationships. Pattern Structures [7] provide an extension of Formal Concept Analysis for dealing with complex data such as numbers, intervals, sequences, trees and graphs. Pattern

Structures are based on a triple $(G, (D, \sqcap), \delta)$, where G is a set of objects, (D, \sqcap) is a semi-lattice of descriptions, and δ is a mapping associating an object with a description. The similarity operation \sqcap induces a subsumption relation in (D, \sqcap) such as $c \sqcap d = c$ iff $c \sqsubseteq d$. In addition, a similarity between objects based on the closeness of attribute values can be considered and formalized as a tolerance relation, i. e. reflexive and symmetric [9].

In this presentation, we will introduce basic elements on Formal Concept Analysis (FCA), Relational Concept Analysis and Pattern Structures. Then we will discuss the capabilities of RCA and Pattern Structures in various applications. RCA is used in text mining while Pattern Structures are used in situations involving real-world data for dealing with numbers and intervals [11, 10], with strings and sequences [3], for discovering functional dependencies [2, 1], for information retrieval [5] and for ontology engineering [6, 4]. Actually, FCA, RCA and Pattern Structures are become an efficient and well-founded mathematical support for knowledge discovery in real-world applications.

Keywords: Formal Concept Analysis, pattern structures, relational concept analysis, classification, knowledge discovery, complex data mining.

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3.20 Mathematical Methods for Analyzing Genomic Data

James B. Nation (University of Hawaii at Manoa, US)

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Joint work of Nation, James B.; Adarichev, Vyacheslav; Adaricheva, Kira; Okimoto, Gordon; Wenska, Tom; Zeinalzadeh, Ashkan

In this talk we show that reductions based on the singular value decomposition can be combined with order-theoretic methods to produce a useful analysis of biological data for cancer patients. An iterated rank-one decomposition of matrices for gene expression, microRNA expression, and methylation loci identifies a genetic signature for a particular type of cancer. The signature can be correlated with clinical data, with the goal of guiding detection, classification and treatment of cancers.

This method is applied to find a signal based on the expression of five microRNA that is a predictor for survival (response to treatment) of patients with ovarian cancer. In a related study, an order-theoretic method is applied to immunological data from brain tumor patients to again find a predictor for response to treatment.

This is based on joint work with Vyacheslav Adarichev, Kira Adaricheva, Gordon Okimoto, Tom Wenska and Ashkan Zeinalzadeh.

3.21 Enumeration of minimal dominating sets of a graph and related notions

Lhouari Nourine (University Blaise Pascal – Aubiere, FR)

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Joint work of Kante, Mamadou Moustapha; Limouzy, Vincent; Mary, Arnaud; Nourine, Lhouari

Main reference M. M. Kanté, V. Limouzy, A. Mary, L. Nourine, “On the Enumeration of Minimal Dominating Sets and Related Notions,” . arXiv:1407.2053v1 [cs.DM], 2014.

URL <http://arxiv.org/abs/1407.2053v1>

We consider the problem of enumerating (inclusion-wise) minimal dominating sets in graphs. The enumeration of minimal dominating sets of graphs is closely related to the well-known

transversal hypergraph problem in hypergraphs, which consists in enumerating the set of minimal transversals (or hitting sets) of a hypergraph. It is well known that the set of minimal dominating sets of a graph is in bijection with the set of minimal transversals of its *closed neighbourhood hypergraph*. We show that the problem of enumerating minimal transversals of a hypergraph can be polynomially reduced to the enumeration of minimal dominating sets of co-bipartite graph, and therefore they are equivalent.

We also formulate the enumeration of minimal dominating sets of a graph as the enumeration of i-keys of some implicational system, where a set is a i-key if its i-closure is the set of vertices of the graph. Whenever the implicational system is direct then i-keys correspond to classical notion of keys.

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3.22 Parameterized Ceteris Paribus Preferences over Atomic Conjunctions

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Main reference S. Obiedkov, “Modeling ceteris paribus preferences in formal concept analysis,” in Proc. of the 11th Int’l Conf. on Formal Concept Analysis (ICFCA’13), LNCS, Vol. 7880, pp. 188–202, Springer, 2013.

URL http://dx.doi.org/10.1007/978-3-642-38317-5_12

We consider a propositional language for describing parameterised ceteris paribus preferences [4] over atomic conjunctions. Such preferences are only required to hold when the alternatives being compared agree on a specified subset of propositional variables. We propose an approach based on formal concept analysis [1] to learning preferences from data by showing that ceteris paribus preferences valid in a particular model correspond to implications of a special formal context derived from this model. Regarding the expressivity of the language in question, we show that a parameterised preference statement is equivalent to a conjunction of an exponential number of classical, non-parameterized, ceteris paribus statements [3]. Next, we present an inference system for parameterized statements and prove that the problem of checking the semantic consequence relation for such statements is coNP-complete. Finally, we adapt a polynomial-time algorithm for abduction using Horn clauses represented by their characteristic models [2] to the problem of determining preferences over new alternatives from preferences over given alternatives (with ceteris paribus preferences as the underlying model).

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3.23 RQL: a Query Language for Implications

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Main reference B. Chardin, E. Coquery, B. Gouriou, M. Pailloux, J.-M. Petit, “Query Rewriting for Rule Mining in Databases,” in Proc. of the Languages for Data Mining and Machine Learning Workshop (LML’13), pp. 1–16, 2013.

URL <http://liris.cnrs.fr/publis/?id=6311>

RQL is a concrete SQL-like language derived from a well-founded logical query language, called SafeRL, allowing to express a wide variety of rules to be satisfied against the data. RQL extends and generalizes functional dependencies in databases to new and unexpected implications easily expressed with a SQL-like language. In this setting, every rule mining problem turns out to be seen as a query processing problem. We provide a query rewriting technique and a constructive proof of the main query equivalence theorem, leading to an efficient query processing technique. From a practical point of view, we show how a tight integration of RQL can be performed on top of any DataBase Management Systems. The approach has been implemented and experimented on different datasets (<http://rql.insa-lyon.fr>).

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3.24 On the Succinctness of Closure Operator Representations

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Main reference S. Rudolph, “On the Succinctness of Closure Operator Representations,” in Proc. of the 12th Int’l Conf. on Formal Concept Analysis (ICFCA’14), LNCS, Vol. 8478, pp. 15–36, Springer, 2014.

URL http://dx.doi.org/10.1007/978-3-319-07248-7_2

It is widely known that closure operators on finite sets can be represented by sets of implications (also known as inclusion dependencies) as well as by formal contexts. In this paper, we consider these two representation types, as well as generalizations of them:

extended implications and context families. We discuss the mutual succinctness of these four representations and the tractability of certain operations used to compare and modify closure operators.

3.25 The hydra number of a graph

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Joint work of Sloan, Robert H.; Stasi, Despina; Turán, György

Main reference R. H. Sloan, D. Stasi, G. Turán, “Hydras: Directed hypergraphs and horn formulas,” in Proc. of the 38th Int’l Workshop on Graph-Theoretic Concepts in Computer Science (WG’12), LNCS, Vol. 7551, pp. 237–248, Springer, 2012.

URL http://dx.doi.org/10.1007/978-3-642-34611-8_25

We consider a graph parameter, the hydra number, arising from a restricted version of Horn minimization. The hydra number of a graph $G=(V,E)$ is the minimum number of hyperarcs of the form $(u,v)\rightarrow w$ required in a directed hypergraph $H=(V,F)$, such that for every pair (u,v) , the set of vertices reachable in H from u,v is the entire vertex set V if (u,v) is an edge in E , and it is u,v otherwise. Here reachability is defined by the standard forward chaining or marking algorithm. Various bounds are given for the hydra number. We show that the hydra number of a graph can be upper bounded by the number of edges plus the path cover number of its line graph, and this is a sharp bound for some graphs. On the other hand, we construct graphs with hydra number equal to the number of edges, but having arbitrarily large path cover number. We also give a lower bound for trees which is sharp for spider trees.

3.26 The Complexity of Robust Satisfiability of the Constraint Satisfaction Problem (Survey)

Suguru Tamaki (Kyoto University, JP)

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In the Constraint Satisfaction Problem (CSP), an instance consists of a set of variables and a set of relations, and the objective is to find an assignment of values to the variables that satisfies all the constraints. In Max-CSP, the objective is to find an assignment that satisfies as many constraints as possible. Robust satisfiability of CSP is the notion between (standard) CSP and Max-CSP.

A CSP instance is $(1 - \epsilon)$ -satisfiable if some assignment satisfies at least a $(1 - \epsilon)$ -fraction of constraints. For a class C of instances of CSP, an approximation algorithm is robust if there exists $f : [0, 1] \rightarrow [0, \infty)$, where $\lim_{\epsilon \rightarrow 0} f(\epsilon) = 0$, such that for every $\epsilon \geq 0$ and every $(1 - \epsilon)$ -satisfiable instance of C , the algorithm outputs an assignment that satisfies at least a $(1 - f(\epsilon))$ -fraction of constraints.

Since robust satisfiability of CSP is NP-hard in general, we are naturally interested in tractable subclasses of CSP. A constraint language Γ is a set of relations over some domain. Then a subclass of CSP, denoted by $\text{CSP}(\Gamma)$, is defined as a set of CSP instances with relations from Γ .

The complexity classification problem of robust satisfiability of $\text{CSP}(\Gamma)$ for each Γ was initiated by Zwick, and people have continued the study to reach the ultimate goal, i. e., the complete classification of constraint languages with respect to polynomial time robust approximability. Finally, Barto and Kozik complete the classification for CSP with finite domains.

In this talk, I will give an overview on the complexity of robust satisfiability of CSP. This talk is in part based on joint work with Gábor Kun, Ryan O'Donnell, Yuichi Yoshida, and Yuan Zhou.

3.27 Some combinatorial problems for directed hypergraphs

György Turán (University of Illinois – Chicago, US)

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We consider directed hypergraphs with size-3 edges of the form $a, b \rightarrow c$, and discuss some extremal and probabilistic problems corresponding to analogous problems for graphs.

How many edges can a directed hypergraph on n vertices have if it doesn't contain two edges of the form $a, b \rightarrow c$ and $c, d \rightarrow e$? It is shown that the maximum is given by the following directed hypergraph: divide the vertices into two parts A and B , and include all triples $a, b \rightarrow c$ with $a, b \in A$ and $c \in B$, choosing sizes to maximize the number of edges. The similar problem for triples $a, b \rightarrow c$ and $b, c \rightarrow d$ is solved only asymptotically.

We also discuss a question about random directed hypergraphs. where every edge is included with probability p . Given a directed hypergraph, a pair (u, v) is good, if forward chaining started from u and v marks every vertex. The probability of having at least one good pair changes from almost 0 to almost 1 over the interval between $1/n \ln n$ and $\ln \ln n / n \ln n$. The probability of every pair being good changes from almost 0 to almost 1 around $\ln n / n$. The question of how the number of good pairs grows in between is open.

We also mention an $n / \ln n$ approximation algorithm for the minimization of Horn formulas in the Steiner version, where it is allowed to introduce new variables in a restricted manner. The algorithm is based on covering bipartite graphs with bicliques.

Joint works with Amitava Bhattacharya, Bhaskar DasGupta, Marina Langlois, Dhruv Mubayi, Despina Stasi and Robert Sloan.

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JA4AI – Judgment Aggregation for Artificial Intelligence

Edited by

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Abstract

This report documents the programme and the outcomes of Dagstuhl Seminar 14202 on “Judgment Aggregation for Artificial Intelligence”. Judgment aggregation is a new group decision-making theory that lies in the intersection of logic and social choice; it studies how to reach group decisions on several logically interconnected issues by aggregation of individual judgments. Until recently research in judgment aggregation was dominated by its originating context of philosophy, political science and law. Presently, however we are witnessing increasing work in judgment aggregation from researchers in computer science. Since researchers from such diverse disciplinary backgrounds working on judgment aggregation each publish within their own discipline with virtually no cross-discipline cooperation on concrete projects, it is essential that they are given an opportunity to connect to each other and become aware of the workings of the other side. This seminar has provided such an opportunity.

Seminar May 12–15, 2014 – <http://www.dagstuhl.de/14202>

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1 Executive Summary


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Judgment aggregation is a group decision-making theory, developed in the last decade, that studies how to reach group decisions on logically interconnected issues by aggregation of individual decisions on those issues. The interest of computer science in group reasoning and decision-making theories is driven by the increase of distribution of information and computation as features of various Internet-based services that dominate the information technology market.



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JA4AI – Judgment Aggregation for Artificial Intelligence, *Dagstuhl Reports*, Vol. 4, Issue 5, pp. 27–39

Editors: Franz Dietrich, Ulle Endriss, Davide Grossi, Gabriella Pigozzi, and Marija Slavkovic



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Judgment aggregation studies collective decision-making as a process whereby individual opinions concerning the acceptance or rejection of a set of issues are aggregated into one collective judgment. The problem is for the aggregation process to preserve, in a non-trivial way, some ‘rational’ aspects of the individual to-be-aggregated stances like, in particular, logical consistency. A wealth of results have highlighted how the rationality of a collective decision may clash with other desirable properties of a process of aggregation one may wish to require (*e.g.*, anonymity of the voters, independence of the aggregated issues, to mention a few).

Judgment aggregation research, originally studied in law, was propelled into other disciplines with its establishment as a separate discipline from preference aggregation in the early 2000’s. The first half of the decade was marked by studies of aggregation properties that cannot be jointly satisfied by one aggregation function, usually referred to as ‘impossibility results’. These studies were mostly conducted by researchers from political science, law, economics, mathematics, and philosophy. The second half of the decade witnessed an increase of interest in judgment aggregation of researchers from artificial intelligence (AI), specifically knowledge representation and reasoning (KR), and multi-agent systems (MAS).

Research on judgment aggregation, from the computer scientific perspective, has splintered in many directions, with scholars pursuing very different lines of research: judgment aggregation and logic, judgment aggregation and complexity theory, judgment aggregation and relations to preference aggregation, judgment aggregation and belief merging, judgment aggregation and argumentation, to mention a few. At the same time work in judgment aggregation has diversified in non-computer science disciplines: judgment aggregation and deliberation, judgment aggregation and strategic voting, judgment aggregation and probabilistic opinion pooling, to mention a few. Despite the common research thread, having so many disciplines involved make it difficult to keep track of the research advancements across all domains.

The goal of this Dagstuhl seminar was to give researchers across the contributing disciplines an integrated overview of the current research and interests in judgment aggregation and of its emerging trends, and by doing this, to kick-start a lasting interdisciplinary network bridging the computer science/humanities divide in the field. To accomplish this goal, we structured the seminar around four types of events:

- Invited tutorials – three invited overview talks aimed to introduce the interdisciplinary audience to the origins and advancements of judgment aggregation in law, political science and computer science.
- Contributed talks – fourteen contributed talks of thirty minutes each.
- Networking sessions – two free networking sessions.
- Rump session – open to all participants to present new ideas.

The topics of the invited talks were chosen so as to give a foundation of the disciplines in which judgment aggregation originated and was formalised, as well as to motivate the interest of judgment aggregation for computer science. Although we expected that all of the participants would be familiar with at least one of these foundational topics, we also expected them to be unfamiliar with at least one as well. The tutorial lectures aimed to homogenise the background knowledge in judgment aggregation among the participants.

The contributed talks aimed to introduce the community with the recent work of the speakers. We accommodated fourteen talks, possibly compromising on the length of the talk itself in the interest of allowing space for questions. We are happy to observe that there was a lively debate after each of the talks, which we expect shall contribute towards advancement of each of the presented works.

Given the short period of three days and prior Dagstuhl experience of the organisers, we decided to not structure the networking session and simply allow for a time for the participants to talk to each other and get to know about each other's work and interests. The enthusiastic discussions following the contributed talks typically continued into the networking sessions.

The rump session was free for a last-minute sign up to all participants. Each interested person was given a five-minute time slot to present an idea that emerged during the seminar or a work in progress. A third of the participants took this opportunity to present. This was a very lively and well received part of the seminar. In retrospect, a similar session would have been well received also at the beginning of the seminar, giving the participants more time to discuss the presented ideas.

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Overview of Talks


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3 Invited Tutorials

3.1 Judgment Aggregation on Common Law Courts

Lewis A. Kornhauser (New York University, US)

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Common law courts develop legal rules through the adjudication of specific controversies by collegial courts. These courts decide the case before them but, also, develop over time a complex of legal rules, structured around doctrine. The process of rule emergence differs across common law legal systems. In the majoritarian process of the United States, the court aggregates judgments across both doctrinal issues and case outcomes. As is well-known, these two aggregations may, and sometimes do, conflict. How should a court resolve this conflict? A common law process naturally suggests itself to a common law court; that process proceeds incrementally. It considers the context, the dispute in which the conflict arises, and balances the reasons that weigh in favour of each procedure.

3.2 Judgment Aggregation and Social Choice Theory

Christian List (London School of Economics, UK)

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This talk provided an introductory review of the theory of judgment aggregation in relation to three classic impossibility findings from social choice theory: Arrow's impossibility theorem about pairwise independent aggregation, the Gibbard-Satterthwaite theorem about non-manipulable aggregation, and Sen's theorem about respecting rights. The talk introduced the paradoxes of majority voting that originally motivated the field, and proceeded to show how some of the well-known problems of social choice theory re-emerge in the context of judgment aggregation. The aim was to familiarise participants whose background is in computer science with the theory of judgment aggregation and its broader social-choice-theoretic context.

3.3 Judgment Aggregation and Artificial Intelligence

Jérôme Lang (University Paris Dauphine, FR)

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This talk provided an overview of the possible interest of Artificial Intelligence in judgment aggregation and vice versa, as well as an overview of work in judgment aggregation done from the computer science perspective. Judgment aggregation can be seen as having in its crux the problem of resolving inconsistencies: between individual majorities, as well as between the judgment set supported by the majority and the logic relation among the issues on which the judgments are cast. A significant part of the research in Artificial Intelligence and logic is about resolving inconsistencies (of various kinds): nonmonotonic reasoning, belief revision and belief merging, reasoning about action and change, paraconsistency, inconsistency debugging,

etc. Applying judgment aggregation to various fields of AI (and beyond) makes sense to problems where aggregating information may lead to conflicts that we have to resolve, such as argumentation, situation assessment in multiagent systems, crowdsourcing and collective annotation of linguistic resources, merging ontologies etc. While the interest in judgment aggregation from the perspective of law, economics, political science and mathematics is focused on identifying inconsistencies among properties of judgement aggregation functions and characterisation of functions, from a computer science perspective, the focus is more on the engineering aspects of judgment aggregation, namely how can judgments be aggregated, how computationally efficient and scalable are the methods used for this purpose.

4 Overview of Talks

4.1 Judgment Aggregation in Multi-Agent Argumentation

Edmond Awad (Masdar Institute – Abu Dhabi, AE)

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Joint work of Awad Edmond, Richard Booth, Fernando Tohmé, Iyad Rahwan

Given a set of conflicting arguments, there can exist multiple plausible opinions about which arguments should be accepted, rejected, or deemed undecided. We study the problem of how multiple such judgments can be aggregated. We define the problem by adapting various classical social- choice-theoretic properties for the argumentation domain. We show that while argument-wise plurality voting satisfies many properties, it fails to guarantee the collective rationality of the outcome, and struggles with ties. We then show more general results, proving multiple impossibility results on the existence of any good aggregation operator. Moreover, we study whether restricting the domain of argument-wise plurality voting to classical semantics allows us to escape the impossibility result. Finally, we list graph-theoretic restrictions under which argument-wise plurality rule does produce collectively rational outcomes. In addition to identifying fundamental barriers to collective argument evaluation, our results open up the door for a new research agenda for the argumentation and computational social choice communities.

4.2 Complexity of Manipulation, Bribery, and Control in Judgment Aggregation for Premise-Based Quota Rules

Dorothea Baumeister (Heinrich-Heine-Universität Düsseldorf, DE)

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Joint work of Baumeister, Dorothea; Erdélyi, Gábor; Erdélyi, Olivia; Rothe, Jörg

Main reference D. Baumeister, G. Erdélyi, O. J. Erdélyi, J. Rothe, “Computational Aspects of Manipulation and Control in Judgment Aggregation,” in Proc. of the 3rd Int’l Conf. on Algorithmic Decision Theory, LNCS, Vol. 8176, pp. 71–85, Springer, 2013.

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Endriss et al. [1] initiated the complexity-theoretic study of problems related to judgment aggregation. We extend their results for manipulating two specific judgment aggregation procedures to a whole class of such procedures, namely to uniform premise-based quota rules. In addition, we consider incomplete judgment sets and the notions of top-respecting

and closeness-respecting preferences introduced by Dietrich and List [2]. This complements previous work on the complexity of manipulation in judgment aggregation that focused on Hamming-distance-induced preferences only, which we also study here. Furthermore, inspired by work on bribery and control in voting [3] we introduce and study the closely related issues of bribery and control in judgment aggregation.

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4.3 Binary Aggregation by Selection of the Most Representative Voter

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Joint work of Grandi, Umberto; Endriss, Ulle

Main reference U. Endriss, U. Grandi, “Binary Aggregation by Selection of the Most Representative Voter,” in *Proc. of the 28th AAAI Conf. on Artificial Intelligence (AAAI’14)*, pp. 668–674, AAAI Press, 2014.

URL <http://www.aaai.org/ocs/index.php/AAAI/AAAI14/paper/view/8272>

In binary aggregation, each member of a group expresses yes/no choices regarding several correlated issues and we need to decide on a collective choice that accurately reflects the views of the group. A good collective choice will minimise the distance to each of the individual choices, but using such a distance-based aggregation rule is computationally intractable. Instead, we explore a class of low complexity aggregation rules that select the most representative voter in any given situation and return that voter’s choice as the outcome.

4.4 Model-Theoretic and Universal-Algebraic Accounts of Aggregation

Frederik S. Herzberg (Universität Bielefeld, DE)

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Main reference F. Herzberg, “Aggregating infinitely many probability measures,” *Theory and Decision*, published online March 2014.

URL <http://dx.doi.org/10.1007/s11238-014-9424-5>

This paper explores the recent use of model theory and universal algebra in the theories of judgement aggregation and probabilistic opinion pooling. We review the model-theoretic approach to judgement aggregation and its potential for applications. Aggregators satisfying Arrovian responsiveness axioms on sufficiently rich agendas turn out to be restricted ultraproduct constructions, generalising an earlier result by Lauwers and van Liedekerke [1]. Ultraproduct constructions are also useful in the extension of McConway’s theory of probabilistic opinion pooling [2] to the case of infinite profiles of probability measures. Dietrich and List [3] have proposed a theory of propositional-attitude aggregation, which unifies both

judgement aggregation and probabilistic opinion pooling. We prove a one-to-one correspondence between aggregators satisfying Arrovian responsiveness axioms (on sufficiently rich agendas) and MV-algebra homomorphisms.

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4.5 Two Theories of Logical Aggregation: On the Links between Belief Merging and Judgment Aggregation

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Joint work of Everaere, Patricia; Konieczny, Sébastien; Marquis, Pierre

Main reference P. Everaere, S. Konieczny, P. Marquis, “Counting votes for aggregating judgments,” in *Proc. of the 2014 International Conf. on Autonomous Agents and Multi-agent Systems (AAMAS’14)*, pp. 1177–1184, Int’l Foundation for Autonomous Agents and Multiagent Systems, 2014.

URL <http://dl.acm.org/citation.cfm?id=2617388.2617436>

There are two theories of aggregation of logical formulas. The first one, merging, has been developed in AI as an extension of belief revision. The second one, judgment aggregation, has been introduced by works in political philosophy and social choice theory. In this work we investigate the links between these two theories both in the general case and in the fully informed case (where the agenda contains all the possible interpretations). This allows us to illustrate the correspondences or incompatibilities between the rationality properties proposed in these two theories.

4.6 A Collective Argument Dilemma as Judgement Aggregation

Yixi Li (Sun Yat-sen University – Guangzhou, CN)

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The legal provisions always show various degrees of acceptability. Despite the difficulty of describing the acceptability of a legal provision, it is commonly agreed that a legal provision is unacceptable if it is against some rules. We have described a Legislative Dilemma where neither of two contradictory behaviours leads to a breach of a legal provision. In other words, if one behaviour is the purpose of a legal provision, the justification of the other contradictory behaviour means the unacceptability of this legal provision.

4.7 The max-min Method for Judgment Aggregation

Xavier Mora (Autonomous University of Barcelona, ES)

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Joint work of Mora, Xavier; Camps, Rosa; Saumell, Laia

Main reference R. Camps, X. Mora, L. Saumell, “A general method for deciding about logically constrained issues,” *Annals of Mathematics and Artificial Intelligence*, 64(1):39–72, 2012.

URL <http://dx.doi.org/10.1007/s10472-012-9292-z>

We discussed the general method of judgment aggregation that we introduced in [1]. This method can be seen as a maximin procedure for revising a system of (collective) degrees of belief in accordance with the existing logical constraints and for arriving at a decision that complies with these constraints. We looked at the main idea of this method, its advantages and limitations, and its application to a variety of examples (some of which are dealt with in [2]).

The main idea of the revision procedure is using the logical constraints in all possible ways to derive belief on every issue. This is done in accordance with the so-called peiorem principle. Belief is derived separately in favour and against each issue. Decisions are taken by the balance of belief.

The advantages of this method include: a quite general character, ability to deal with incomplete information, respect for consistent majority decisions, respect for unanimity on an issue, a property of monotonicity, decisions are robust under small perturbations, decisions have a quantified degree of confidence.

Its limitations are concerned with: complexity depending on the constraints, constraints must be checked for a certain condition to guarantee that decisions are unquestionable.

Its applications include: preferential voting, preferential-approval voting, other social-choice procedures, aggregation of equivalence relations (cluster analysis).

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4.8 Complexity of Optimal Lobbying in Threshold Aggregation

Ilan Nehama (The Hebrew University of Jerusalem, IL)

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Main reference I. Nehama, “Complexity of optimal lobbying in threshold aggregation,” in *Proc. of the 2013 Int’l Conf. on Autonomous Agents and Multi-agent Systems*, pp. 1197–1198, Int’l Foundation for Autonomous Agents and Multiagent Systems, 2013.

URL <http://dl.acm.org/citation.cfm?id=2485140>

Optimal Lobbying is the problem a lobbyist or a campaign manager faces in a full-information voting scenario of a multi-issue referendum when trying to influence the result. The Lobby is faced with a profile that specifies for each voter and each issue whether the voter approves or rejects the issue, and seeks to find the smallest set of voters it must influence to change their vote, for a desired outcome to be obtained. This computational problem also describes problems arising in other scenarios of aggregating complex opinions, such as principal-agents incentives scheme in a complex combinatorial problem, and bribery and manipulation

in Truth-Functional Judgement Aggregation. We study the computational complexity of Optimal Lobbying when the issues are aggregated using an anonymous monotone function and the family of desired outcomes is an upward-closed family. We analyse this problem with regard to two parameters: the minimal number of supporters needed to pass an issue, and the size of the maximal minterm of the desired set. We show that for the extreme values of the parameters, the problem is tractable, and provide algorithms. On the other hand, we prove intractability of the problem for the non-extremal values, which are common values for the parameters.

4.9 Weighing Experts, Weighing Sources: The Diversity Value

Klaus Nehring (University of California – Davis, US)

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Joint work of Nehring, Klaus; Guerdjikova, Ani

A decision maker has to come up with an aggregate judgment based on the individual opinions submitted by a set of information sources. Provided that the decision maker is committed to an aggregation rule expressed as a weighted average, how should he determine the weight assigned to each source? We consider this problem, when the decision maker has an assessment of the reliability of each subset of sources given by a reliability function. Reliability functions are assumed to have the properties of diversity functions in the sense of Nehring and Puppe (2002). In particular, non-additive reliability functions capture perceptions of similarity between sources. We propose a rule called the Diversity value, which associates with each reliability function a (set of) weight vector(s). The Diversity value selects those weights which best approximate the relative reliability of sources in the sense of a generalised Kullback-Leibler distance. Notably, the Diversity value obeys the Similarity Principle which requires that larger weights should be assigned to sources which are viewed as more distinct. We provide an axiomatisation of the Diversity value. We discuss its aggregation properties and show that a version of the No-Show Paradox and violations of Reinforcement are typical features of the model.

4.10 The Median Rule in Judgement Aggregation

Marcus Pivato (Trent University, CA)

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Joint work of Pivato, Marcus; Nehring, Klaus

Let K be a set of logically interconnected propositions or “issues”. A “view” is an assignment of a truth-value to each issue in K . However, not all views are admissible; some may violate the logical relationships between the different issues in K . A “judgement aggregation rule” is a function which takes a collection of admissible views as input, and produces an admissible view as output.

As is well-known, the “majority” rule (which simply agrees with the majority on each issue) often yields logically inconsistent views. This raises the question: which (consistent) judgement aggregation rule is the “best approximation” of the majority view? We propose

that the “median rule” fits this description. The median rule chooses the admissible view which minimizes the average Hamming distance to the views of the voters. In the special case of preference aggregation, it becomes the Kemeny rule.

We axiomatically characterise the median rule as the only judgement aggregation rule satisfying three axioms: Extended Supermajority Efficiency, Reinforcement, and Upper Hemicontinuity. “Supermajority efficiency” means (roughly) that the rule tries to agree with the majority view in as many issues as possible; furthermore, if it can only agree with a majority in one out of two issues, it will choose the larger majority. “Extended supermajority efficiency” extends this principle to the case where the rule is applied to solve many aggregation problems simultaneously. “Reinforcement” means that, if two subpopulations independently choose the same view using the rule, then the combined population should also choose this view using this rule. “Upper hemicontinuity” means that the outcome is invariant under small perturbations; equivalently, it means that an outcome reflecting the will of an “overwhelming majority” of voters cannot be changed by a small minority.

After precisely stating the above result, we discussed some other axiomatic characterisations of the median rule, and other judgement aggregation rules which generalise it.

4.11 Modelling Collective Rationality in Non-Classical Logics. A Possibility Result

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Main reference D. Porello, “A proof-theoretical view of collective rationality,” in Proc. of the 23rd Int’l Joint Conf. on Artificial Intelligence (IJCAI’13), pp. 317–323, AAAI Press, 2013.

URL <http://dl.acm.org/citation.cfm?id=2540128.2540175>

The notion of collective rationality in judgment aggregation is mainly modelled by means of classical propositional logic. In this work, we adapt the model of judgment aggregation in order to account for a number of definitions of collective rationality grounded on a number of non-classical logics. We extend therefore the map of possibility and impossibility results in judgement aggregation to non-classical logics. In particular, we show that there are logics for which the majority rule always returns rational outcomes. Finally, we discuss how the choice of a logic determines the epistemic commitments that we expect from collective agents and we argue in favour of a weaker non-classical view of collective rationality.

4.12 Unanimity Overruled: Majority Voting and the Burden of History

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

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Sequential majority voting over interconnected binary propositions can lead to the overruling of unanimous consensus. We characterise, within the general framework of judgement aggregation, under what circumstances this happens for some sequence of the voting process. It turns out that the class of aggregation spaces for which this difficulty arises is very large, including the aggregation of preference orderings over at least four alternatives, the

aggregation of equivalence relations over at least four objects, resource allocation problems, and most committee selection problems.

We also ask whether it is possible to design respect for unanimity by choosing appropriate decision sequences. Remarkably, while this is not possible in general, it can be accomplished in interesting special cases. Adapting and generalising a classic result by Shepsle and Weingast, we show that respect for unanimity can indeed be thus guaranteed in case of the aggregation of weak orderings, strict orderings and equivalence relations.

4.13 Pre-Vote Negotiations

Paolo Turrini (Imperial College London, GB)

Joint work of Grandi, Umberto; Grossi, Davide; Turrini, Paolo

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Main reference U. Grandi, D. Grossi, P. Turrini, “Pre-vote negotiations and binary voting with constraints,” arXiv:1404.5433v1 [cs.GT], 2014.

URL <http://arxiv.org/abs/1404.5433v1>

This talk was about voting games on possibly interconnected issues, where voters might hold a principled opinion about a subset of the issues at stake while willing to strike deals on the remaining ones, and can influence one another before casting their ballots in order to obtain an individually more favourable outcome. The authors analyse voters’ rational behaviour in a two-phase game, allowing players to undergo a negotiation phase before their vote, and showing under what conditions undesirable equilibria can be removed as an effect of the pre-vote phase.

4.14 Universal and Symmetric Scoring Rules for Binary Relations

William S. Zwicker (Union College – Schenectady, US)

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Are Plurality voting, the Kemeny rule, Approval voting, and the Borda Mean Dichotomy rule actually all versions of the same voting rule? Yes, in a sense. We consider functions F that assign real number scoring weights $F(R_1, R_2)$ to pairs of binary relations on a finite set A of alternatives, serving as symmetric measures of similarity between R_1 and R_2 . Any such F induces a symmetric binary relational scoring rule F – a highly abstract form of aggregation rule that allows arbitrary binary relations as ballots R_1 and as aggregated outcomes R_2 . The resulting level of generality is surprisingly effective. By restricting the classes of relations allowed as ballots and elections outcomes, F yields scoring rules of a more familiar and concrete kind. The symmetric assignment FH, for example, arises from an inner product in a simple and natural way, and restrictions of the induced scoring rule script-FH yield all the aforementioned familiar voting rules. Moreover, the inner product formulation yields a Euclidean form of distance rationalisation for script-FH, resulting in a universal distance rationalisation for all concrete scoring rules obtained as restrictions.

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The Future of Refactoring

Edited by

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 14211 on “The Future of Refactoring.” Over the past decade, refactoring has become firmly established as an essential part of industrial software development. At the same time, academic interest in refactoring has grown at a fast pace, resulting in a large body of literature on many different aspects of refactoring. The aim of this seminar was to provide a forum for refactoring researchers and practitioners to discuss what has been achieved, get to know each others’ work, and plan future collaboration. This report presents abstracts of the participants’ talks and summaries of breakout sessions, and introduces some joint projects that were started as a result of the seminar.

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1 Executive Summary

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The Dagstuhl seminar on “The Future of Refactoring” brought together 41 researchers and practitioners from academia and industry working on different aspects of refactoring. Participants had the opportunity to introduce their own work both in short plenary talks and more detailed presentations during breakout sessions, with daily keynote talks by eminent refactoring researchers providing historical background. Given the rapid growth of the field over the past decade, special emphasis was put on providing opportunities for researchers with similar interests to meet and survey the state of the art, identify open problems and research opportunities, and jointly chart the future of refactoring research.

We believe the seminar achieved its goal of providing a forum for in-depth discussion of recent research in the area, and of fostering collaboration. In particular, it kickstarted several collaborative projects, among them a book on refactoring tools, a special journal issue on refactoring and a survey article on refactoring research over the last decade.



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The Future of Refactoring, *Dagstuhl Reports*, Vol. 4, Issue 5, pp. 40–67

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Research Context

Modern software is rarely written from scratch. Instead, it usually incorporates code from previous systems, and is itself reincarnated in other programs. Modern software is also not static. Instead, it constantly changes as bugs are fixed and features added, and usually these changes are performed by more than one programmer, and not necessarily by the original authors of the code.

Refactoring is a technique for supporting this highly dynamic software life cycle. At its most basic, refactoring is the process of improving the internal structure of an existing piece of code without altering its external behavior. It can be used for cleaning up legacy code, for program understanding, and as a preparation for bug fixes or for adding new features. While any behavior-preserving change to a program can be considered a refactoring, many particularly useful and frequently recurring refactoring operations have been identified and catalogued. Over the past decade, popular development environments have started providing automated support for performing common refactorings, making the process of refactoring less tedious and error-prone.

Based on the accumulated experience with refactorings both in practical applications and in research, this seminar aimed to identify open problems and challenges and to foster collaboration between researchers and between academia and industry to address these issues and actively shape the future of refactoring.

Seminar Format

Given the large number of participants, the standard conference format with one in-depth talk per participant would have been impractical. Instead, we decided to split up the schedule: during the first three days, the mornings were allocated to plenary sessions. Each day began with a keynote by a distinguished speaker with decades of experience with refactoring, in which they presented their perspective on refactoring. The rest of the morning was allocated to “lightning talks” where each participant was given a 7-minute presentation slot for providing a quick, high-level overview of their work without getting bogged down in detail, followed by a few minutes for questions. While this format was not easy for the speakers, everyone rose to the challenge, and reactions from both presenters and audience were broadly positive.

Monday afternoon was given over to four parallel breakout sessions organized along thematic lines: novel domains for refactoring, user experience in refactoring, refactoring tools and meta-tools, and refactoring in education. While participants appreciated the opportunity for more in-depth presentations and discussion, this format had the unfortunate but inevitable drawback that several talks were held in parallel, and not everyone was able to attend all the talks they were interested in.

Tuesday afternoon had an industry panel, followed by another round of breakout sessions. Discussion and exchange continued in an informal setting during Wednesday afternoon’s excursion to Mettlach.

On Thursday morning, we had another keynote followed by a final round of breakout sessions. While the focus of the breakout sessions on Monday and Tuesday had been on surveying recent work and getting an overview of the state of the art, Thursday’s sessions were aimed at gathering together the threads, and identifying common themes, open problems and research opportunities.

The outcome of these group discussions were then briefly presented in a plenary on Thursday afternoon, and opportunities for collaborative projects were identified. Specifically,

the following projects were discussed and planned in group discussions on Thursday afternoon:

- a book on refactoring tools;
- a special issue of IEEE Software on refactoring;
- a survey paper on refactoring research in the last decade;
- an informal working group on the place of refactoring in the Computer Science curriculum.

Friday morning saw a final plenary discussion, summarizing the project discussions of Thursday afternoon and ending with a retrospective session on which aspects of the seminar are worth keeping for the future, what needs to change, and what still puzzles us.

We hired George Platts, a professional artist, to facilitate games he designed and tangential thinking activities to help the participants develop a sense of scientific community. During each of the five days of the Seminar, George ran 30-minute games sessions at the beginning of the day which doubled as times for announcements to be given and daily reports to be delivered. In the early afternoon, we had a 30-minute game session to energize participants for the afternoon's workshops. For the rest of the time in his 'studio', he has been playing music, showing short films, facilitating drawing and painting activities, composing sound composition for all participants to perform.

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3 Perspective Talks

3.1 The Birth of Refactoring – A Personal Perspective

William G. Griswold (University of California – San Diego, US)

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Joint work of Griswold, William G.; Notkin, David; Bowdidge, Robert W.

Software Refactoring was invented in the late 1980's at two institutions – the University of Illinois by Bill Opdyke and Ralph Johnson, and the University of Washington by myself and David Notkin. In this talk I revisit the surprising events at the birth of refactoring – what we called meaning-preserving restructuring – at the University of Washington. I'll talk about how the ideas came about, and the research agenda and results that emerged. In the course of the presentation, I'll highlight several lessons for researchers seeking high impact in their work.

3.2 Concerns in Refactoring

Bill Opdyke (JP Morgan Chase – Chicago, US)

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What are the four key reasons why software developers might be reluctant to refactor their code even if they think refactoring is, at least in the abstract, a good idea? How might one effectively address those concerns? These four concerns, and the means for addressing them, have applicability far beyond refactoring. In this talk, I discussed these lessons learned in a refactoring context and how they subsequently helped me as an architect and in other roles.

3.3 Two Decades of Refactoring Tools

Don Roberts (University of Evansville, US)

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Joint work of Brant, John; Roberts, Don

We released the first industrial refactoring tool for Smalltalk 20 years ago this month. In this talk, we will present the history of the Refactoring Browser along with the other tools that we have developed to solve rewriting problems. The tools have been used to replace a database layer in a commercial application. We have also developed a process that, along with our rewriting tool, allows us to migrate existing systems between languages while not sacrificing development time. We will also present what we've learned about how end-users interact with refactoring tools.

3.4 Refactoring using Type Constraints

Frank Tip (University of Waterloo, CA)

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Joint work of Tip, Frank; Fuhrer, Robert; Kiežun, Adam; Ernst, Michael; Balaban, Ittai; De Sutter, Bjorn

Type constraints express subtype relationships between the types of program expressions, for example, those relationships that are required for type correctness. Type constraints were originally proposed as a convenient framework for solving type checking and type inference problems. This work shows how type constraints can be used as the basis for practical refactoring tools. In our approach, a set of type constraints is derived from a type-correct program P . The main insight behind our work is the fact that P constitutes just one solution to this constraint system, and that alternative solutions may exist that correspond to refactored versions of P . We show how a number of refactorings for manipulating types and class hierarchies can be expressed naturally using type constraints. Several refactorings in the standard distribution of Eclipse are based on our work.

4 Lightning Talks

4.1 Teaching Refactoring

Andrew P. Black (Portland State University, US)

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Joint work of Black, Andrew P.; Noble, James; Bruce, Kim B.

Main reference A. P. Black, K. B. Bruce, Michael Homer, J. Noble, “Grace: the absence of (inessential) difficulty,” in Proc. of the 2012 ACM Int’l Symp. on New Ideas, New Paradigms, and Reflections on Programming and Software (Onward’12), pp. 85–98, ACM, 2012.

URL <http://dx.doi.org/10.1145/2384592.2384601>

I’m engaged in designing Grace, a new programming language for teaching object-oriented programming. We hope that Grace will be used for teaching object-oriented concepts, testing, debugging, design, and refactoring. Our motivation is to have a language with low ‘accidental’ complexity, so that students can focus on the essential complexity of the task.

I have questions, not answers. How should one introduce refactoring to novices? If we teach ‘red—green—refactor’, what are the important refactorings? What about the refactorings that are no-ops in our language, such as abstract instance variable? Should refactoring be taught early, or late? I would like to discuss these questions with the group.

4.2 Retrofitting Parallelism through Refactoring

Danny Dig (Oregon State University, US)

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Main reference D. Dig, “A Refactoring Approach to Parallelism,” IEEE Software 28(1):12–22, 2011.


URL <http://dx.doi.org/10.1109/MS.2011.1>

In the multicore era, programmers have to work harder to introduce parallelism for performance or to enable new applications and services not possible before. In this talk I present

our ever-growing toolset of interactive refactorings for adding parallelism into sequential programs. This toolset is grounded on empirical studies that shed light into the practice of using, misusing, underusing, or abusing parallel libraries. Our refactoring toolset supports refactorings from three domains: adding thread-safety, improving throughput, and scalability. Empirical evaluation shows that our toolset is useful: (i) it dramatically reduces the burden of analyzing and changing code, (ii) it is fast so it can be used interactively, (iii) it correctly applies transformations that open-source developers applied incompletely, and (iv) users prefer the improved quality of the changed code. I muse on lessons that can be learned as we move onto automated refactoring for mobile apps.

4.3 Refactoring for Usability of Web Applications

Alejandra Garrido (University of La Plata, AR)

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Joint work of Garrido, Alejandra; Rossi, Gustavo

Refactoring represents an essential activity in today's software lifecycle and a powerful technique against software decay. Software decay, however, is not only about code becoming legacy, but it is also about systems becoming less usable compared to competitor solutions. We propose refactoring to progressively and systematically improve the external quality of an existing web application, like usability and accessibility. The transformations can be applied at the model level (the navigation, presentation or process model) or at the implementation level. We created a framework where refactorings can also be applied at the client-side, as DOM changes, which allows for personalization. We are now working on the automatic detection of bad usability smells from user interaction logs.

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4.4 Automated Behavioral Testing of Refactoring Engines

Rohit Gheyi (*Universidade Federal – Campina Grande, BR*)

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Joint work of Soares, Gustavo; Gheyi, Rohit; Massoni, Tiago

Main reference G. Soares, R. Gheyi, T. Massoni, “Automated behavioral testing of refactoring engines,” *IEEE Transactions on Software Engineering*, 39(2):147–162, 2013.

URL <http://dx.doi.org/10.1109/TSE.2012.19>

Proving refactoring sound with respect to a formal semantics is considered a challenge. In practice, developers write test cases to check their refactoring implementations. However, it is difficult and time consuming to have a good test suite since it requires complex inputs (programs) and an oracle to check whether it is possible to apply the transformation. In this talk, I discuss the challenges of automated testing of refactoring engines. Moreover, I present our current technique that detected more than 200 bugs related to compilation errors, behavioral changes and overly strong conditions in the best refactoring engines (Eclipse, NetBeans and JRRT) [1].

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4.5 Refactoring Refactoring History

Shinpei Hayashi (*Tokyo Institute of Technology, JP*)

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Joint work of Hayashi, Shinpei; Omori, Takayuki; Zenmyo, Teruyoshi; Maruyama, Katsuhisa; Saeki, Motoshi

Main reference S. Hayashi, T. Omori, T. Zenmyo, K. Maruyama, M. Saeki, “Refactoring Edit History of Source Code,” in *Proc. of the 28th IEEE Int’l Conf. on Software Maintenance (ICSM’12)*, pp. 617–620, IEEE, 2012.

URL <http://dx.doi.org/10.1109/ICSM.2012.6405336>

In this talk, we present a concept for refactoring an edit history of source code in a refactoring process and a technique for its automation. The aim of our history refactoring is to improve the clarity and usefulness of the history without changing its overall effect. We have defined primitive history refactorings including their preconditions and procedures, and large refactorings composed of these primitives. Our tool enables developers to pursue some useful applications using history refactorings such as task level commit from an entangled edit history in an floss refactoring process, and support for reviewing the difference obtained from tangled edits.

4.6 Refactoring Spreadsheets

Felienne Hermans (TU Delft, NL)

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Joint work of Hermans, Felienne; Dig, Danny

URL <http://www.felienne.com/BumbleBee>

Spreadsheets are code! They are just as complex, used for similar purposes and suffer from similar problems like a long life span and lack of documentation. Therefore, we can apply methods from software engineering to spreadsheets to address those problems.

For refactoring, we propose a tool called BumbleBee that can refactor spreadsheet formulas, which the user can define themselves in a little language.

4.7 Awareness of Refactoring Tools

Emerson Murphy-Hill (North Carolina State University, US)

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Main reference E. R. Murphy-Hill, “Continuous Social Screencasting to Facilitate Software Tool Discovery,” in Proc. of the 34th Int’l Conf. on Software Engineering (ICSE’12), pp. 1317–1320, IEEE, 2012; pre-print available from author’s webpage.

URL <http://dx.doi.org/10.1109/ICSE.2012.6227090>

URL <http://people.engr.ncsu.edu/ermurph3/papers/icseNIER12.pdf>

One of the main challenges developers face when using refactoring tools is not even knowing that the refactoring tools are there. This lack of awareness is a problem because programmers, without tools, are otherwise refactoring manually, which is both slow and error-prone. In this talk, I discuss the causes of lack of awareness among programmers, existing solutions, and some open questions.

4.8 Agile Software Assessment

Oscar M. Nierstrasz (Universität Bern, CH)

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Modern IDEs are largely code-centric, and do not support developers well in understanding the software systems they need to develop, maintain and refactor. We believe that developers need a flexible environment of “meta-tools” that can be easily adapted to the project at hand, to query, browse, debug and monitor software systems and the ecosystems they belong to.

4.9 Wrangler – Writing Refactorings Made Easy

Huiqing Li (University of Kent, GB)

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Joint work of Li, Huiqing; Thompson, Simon

Main reference S. J. Thompson, “Refactoring tools for functional languages,” *Journal of Functional Programming*, 23(3):293–350, 2013.

URL <http://dx.doi.org/10.1017/S0956796813000117>

URL <https://github.com/RefactoringTools/wrangler>

This talk and demo shows a framework built into Wrangler – a refactoring and code inspection tool for Erlang programs – that allows users to define for themselves refactorings that suit their needs. With this framework, elementary refactorings are defined using a template- and rule-based program transformation and analysis API; composite refactorings are scripted using a high-level domain-specific language (DSL). User-defined refactorings, both elementary and composite, are fully integrated into Wrangler and so can be previewed, applied interactively and ‘undone’.

4.10 Proof Improving Refactoring

Francesco Logozzo (Microsoft Research – Redmond, US)

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Main reference P. Cousot, R. Cousot, F. Logozzo, M. Barnett, “An abstract interpretation framework for refactoring with application to extract methods with contracts,” in *Proc. of the 27th Annual ACM SIGPLAN Conf. on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA’12)*, pp. 213–232, ACM, 2012.

URL <http://dx.doi.org/10.1145/2384616.2384633>

URL <http://research.microsoft.com/apps/pubs/default.aspx?id=170382>

Traditional refactoring modifies the program source while preserving the concrete semantics of the program. Proof-improving refactoring, on the other hand, aims at preserving or improving the proof of correctness of a program, i.e., its abstract semantics. In the talk I presented three examples of proof-improving refactoring. The first one is useful to make code-bases ready for automatic program verification. Starting from an un-annotated code base, we automatically insert CodeContracts (preconditions, postconditions, and object invariants). The inferred contracts are sound, in that no good execution is removed, only bad ones. The injected contracts enable a modular correctness proof of the program. The second example are automated code repairs. Starting from the alarms of a sound static analyzer, we propose a set of program transformations to fix bug in the programs and/or to let its correctness proof succeed. Finally, the last example is an abstract interpretation framework for refactoring. We instantiate it to a new refactoring: extract method with contracts. In addition to extracting the method, we endow it con preconditions and postconditions which satisfy some constraints, namely to be a valid, general, and complete. The extract method with contracts guarantee that the proof of correctness of the program proceeds even when the refactoring is applied.

4.11 Usage Contracts

Kim Mens (UCL, Belgium)

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Joint work of K. Mens, A. Lozano and A. Kellens

Developers often encode design knowledge through structural regularities such as API usage protocols, coding idioms and naming conventions. As these regularities express how the source code should be structured, they provide vital information for developers (re)using that code. Adherence to such regularities tends to deteriorate over time when they are not documented and checked explicitly. Our uContracts tool and approach allows to codify and verify such regularities as ‘usage contracts’. The contracts are expressed in an internal domain-specific language that is close to the host programming language, the tool is tightly integrated with the development environment and provides immediate feedback during development when contracts get breached, but the tool is not coercive and allows the developer to decide if, when and how to correct the broken contracts (the tool just highlights the errors and warnings in the integrated development environment). In spirit, the approach is very akin to unit testing, except that we do not test behaviour, but rather verify program structure. The tool, of which some screenshots can be found below, was prototyped in the Pharo dialect of the Smalltalk programming language.

4.12 Domain-Specific Model Refactoring

Tom Mens (University of Mons, Belgium)

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Model-driven software engineering is becoming an established discipline. In this presentation we present the challenge of providing generic support for domain-specific model refactoring. While refactoring tools and technology are well established for programming languages, it is much less the case for (software) modeling languages. For domain-specific modeling languages (DSMLs), there is even no or very little refactoring support. In this presentation, we provide a case study in which we are developing a domain-specific modelling language (DSML) for developing executable models of applications that use gestural interactions (hand movements) to control virtual objects in a 3D environment. We explain the need for refactoring such models, and the need for dealing with different notions of “behaviour preservation”. We illustrate how one can provide generic support for domain-specific models, using the AtomPM transformation tool (<https://www.youtube.com/watch?v=iBbdpmpwn6M>, <http://syriani.cs.ua.edu/atopm/atopm.htm>), that combines graph transformation technology with the use of a concrete visual model syntax. Preservation of desirable model properties can be verified using the most appropriate formalism (e.g. model checkers for verifying temporal properties; OCL checkers for verifying structural properties; or any other tool that may be more appropriate for expressing and verifying the property of interest).

4.13 Detection and Correction of Anti-Patterns

Naouel Moha

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Anti-patterns are design problems that come from “poor” recurring design choices. They may hinder development and maintenance of systems by making them hard for software engineers to change and evolve. A semi-automatic detection and correction are thus key factors to ease the maintenance and evolution stages. Several techniques and tools have been proposed in the literature both for the detection and correction of anti-patterns in object-oriented systems. However, works in service-based systems are still in their infancy despite their importance. In this seminar, I presented a novel and innovative approach supported by a framework for detecting antipatterns in service-based systems. For the correction, we are still investigating some techniques for correcting service-based antipatterns.

4.14 Can we Mine and Reapply Refactoring Strategies?

Francisco Javier Perez Garcia

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I believe reuse is the single most beneficial strategy in software engineering and it can be fostered by harnessing today’s wide available data and extensive collaborative software development environment. In this context, I want to propose a challenge. Can we mine and reuse successful complex refactoring strategies? In the past I have developed a technique to compute refactoring plans – complex refactoring sequences – from refactoring strategies for correcting bad smells, using automated planning. The future challenge I present involves studying: how to analyse software projects’ history to identify refactoring patterns that were successful in the past for removing bad smells; and how to collect and represent these strategies so they can be automatically re-applied in other projects.

4.15 Refactoring with Synthesis

Veselin Raychev (ETH Zürich, CH)

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Joint work of Raychev, Veselin; Schäfer, Max; Sridharan, Manu; Vechev, Martin

Main reference V. Raychev, M. Schäfer, M. Sridharan, M. Vechev, “Refactoring with synthesis,” in Proc. of the 28th Annual ACM SIGPLAN Conf. on Object-Oriented Programming, Systems, Languages, and Applications (OOPSLA’13), pp. 339–354, ACM, 2013.

URL <http://dx.doi.org/10.1145/2509136.2509544>

Modern IDEs provide a fixed set of supported refactorings listed in a menu, which limits the possible use cases and additionally leads to poor discoverability of the available refactoring tools. In this talk, I show a new approach “Refactoring with Synthesis”, where the user demonstrates an edit on a piece of code and then a refactoring engine synthesizes a sequence of existing refactorings that perform the task demonstrated by the user task on the entire project.

I present an Eclipse plug-in that operates as “Refactoring without Names”: the programmer first indicates the start of a code refactoring phase; then she performs some of the desired code changes manually; and finally, she asks the tool to complete the refactoring. Our system completes the refactoring by first extracting the difference between the starting program and the modified version, and then synthesizing a sequence of refactorings that achieves (at least) the desired changes.

I show how our approach extends the capabilities of current refactorings: with only minimal user input, the synthesizer was able to quickly discover complex refactoring sequences for several challenging realistic examples. Then, I discuss the concept of local refactorings that we introduce, and how it helps synthesize sequences in an extensible and scalable way.

4.16 Identifying Overly Strong Conditions in Refactoring Implementations

Gustavo Soares (Universidade Federal – Campina Grande, BR)

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Joint work of Soares, Gustavo; Mongiovi, Melina; Gheyi, Rohit
Main reference G. Soares, M. Mongiovi, R. Gheyi, “Identifying overly strong conditions in refactoring implementations,” in Proc. of the 27th Int’l Conf. on Software Maintenance (ICSM’11), pp. 173–182, IEEE, 2011.
URL <http://dx.doi.org/10.1109/ICSM.2011.6080784>

Each refactoring implementation must check a number of conditions to guarantee behavior preservation. However, specifying and checking them are difficult. Sometimes refactoring tool developers may define overly strong conditions that prevent useful behavior-preserving transformations to be performed. We propose an approach for identifying overly strong conditions in refactoring implementations. We automatically generate a number of programs as test inputs for refactoring implementations. Then, we apply the same refactoring to each test input using two different implementations, and compare both results. We use Safe Refactor to evaluate whether a transformation preserves behavior. We evaluated our approach in 10 kinds of refactorings for Java implemented by three tools: Eclipse and Netbeans, and the JastAdd Refactoring Tool (JRRT). In a sample of 42,774 transformations, we identified 17 and 7 kinds of overly strong conditions in Eclipse and JRRT, respectively.

4.17 The History of C++ Refactoring (for Eclipse CDT)

Peter Sommerlad (Hochschule für Technik – Rapperswil, Switzerland)

In this talk I present the history of refactoring support within Eclipse-based IDEs. While C++ was the first language addressed by Bill Opdyke that coined the term Refactoring, it was a long way to get working Refactoring support within an IDE. IFS Institute for Software contributed over almost a decade now to Eclipse and provided infrastructure and plug-ins for better refactoring and code transformation support of C++ code.

The presentation gives a historical overview and shows some of the challenges that need to be addressed when building a refactoring plug-in for C++ in Eclipse CDT. For example, testing refactorings can be tough when formatting details make test cases inadvertently fail, or when interaction with a wizard makes using a refactoring unbearable. For the

latter, instead of a “Change Function Signature” refactoring with usability problems, the author invented “Toggle Function Definition” quick-refactoring that eases the manual burden of changing a function signature in C++. Another example is interactive guidance for modernizing C++ code to conform to new standard versions or ridding it from bad practices like macros implemented through the refactoring engine.

The talk concludes with an overview of the lessons learned over the many years, such as “automate refactoring tests”.

4.18 A Brief History of Eclipse-based Refactorings by HSR

Peter Sommerlad (Hochschule für Technik – Rapperswil, Switzerland)


This Lightning Talk gives an overview of the many attempts to create Refactoring plug-ins for Eclipse-based IDEs by IFS Institute for Software students for many different languages, some succeeded and some failed.

The failures happened because of technology, student quality but also for political reasons. The only languages for which we can sustain supporting the refactoring tooling today are C++ and Scala. Our first attempt at Ruby refactoring succeeded technology wise, but failed in the end for political reasons, as well as PHP refactoring which was overtaken by Zend Studio. Parts of our Python refactorings still seem to live within PyDev. With our Groovy Refactoring we were among the first to provide cross-language rename refactoring, but due to lack of financing and personnel we abandoned supporting it. Javascript Refactoring failed for all of the above reasons and because to make it useful it must support the conventions of the JS framework du jour.

One of the lessons learned that even with very good student project results, it still requires work to productize a new refactoring plug-in. When that happens and it gets integrated into “the official IDE” like it happened with the Scala-IDE, then results will be used.

4.19 Extract+Move=Bug

Volker Stolz (University of Oslo, NO)

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Extracting a chunk of code and moving it to a more suitable class to reduce coupling may change the behaviour of the code. A possible solution (apart from reasoning on the code) is to add assertions specific to the extract&move refactoring which track the information necessary to decide (at runtime) whether the behaviour has changed with respect to the old code. We use a search-based, heuristic approach to identify candidates for the refactoring, and evaluate it on the Eclipse JDT UI-project. Existing unit tests provide the necessary coverage.

4.20 Why Should I Trust Your Refactoring Tool?

Simon J. Thompson (University of Kent, GB)

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Joint work of Thompson, Simon J.; Li, Huiqing; Sultana, Nikolai.

A common question for refactoring tool builders is one of trust. While there are many social, organisational and psychological aspects to this, there are two technical aspects too.

The first is of strength of the assurance: do we test, or do we try to prove correctness in some sense? Secondly, do we aim to verify the results if a single refactoring, or the refactoring itself: that is, verifying it for all possible invocations.

Work has been done by us and others on this, and I survey that and conclude with two suggestions: full verifying a refactoring tool for a formally-verified language, CakeML; and using SMT solving automatically to verify the results of refactorings – initially for Haskell.

4.21 To the Cloud and Back: Automated Inter-Address Space Component Migration to Support Software Evolution

Eli Tilevich (Virginia Polytechnic Institute – Blacksburg, US)

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Joint work of Kwon, Young-Woo; Tilevich, Eli

Main reference Y.-W. Kwon, E. Tilevich, “Cloud refactoring: automated transitioning to cloud-based services,” *Automated Software Engineering*, 21(3):345–372, 2014.

URL <http://dx.doi.org/10.1007/s10515-013-0136-9>

The modern computing landscape is increasingly mobile and distributed, characterized by rapidly evolving hardware platforms and network technologies. As a particular example, mobile software designed yesterday will have to run on mobile hardware to be designed tomorrow. Adapting modern software applications for changing execution environments, hardware setups, and user requirements often requires moving software components across address spaces. To facilitate these non-trivial program transformations, this lightning talk introduces two refactoring techniques: Cloud Refactoring and Component Insourcing. Cloud Refactoring renders a portion of an application’s functionality remotely accessible as a Web service, including migrating to the cloud the functionality to be accessed as remote cloud-based services, re-targeting the client code accordingly, and handling the faults raised while invoking the services. Component Insourcing moves a remotely accessed component into its client’s address space, replacing accesses through a middleware interface with those through local method calls. This talk highlights how these refactoring techniques can facilitate the process of evolving modern software and outlines some of their implementation challenges.

4.22 Automated Decomposition of Software Modules

Mohsen Vakilian (University of Illinois – Urbana, US)

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Joint work of Vakilian, Mohsen; Sauciuc, Raluca; Morgenthaler, J. David; Mirrokni, Vahab

Main reference M. Vakilian, R. Sauciuc, J. D. Morgenthaler, V. Mirrokni, “Automated Decomposition of Build Targets,” Technical Report, 2014.

URL <http://hdl.handle.net/2142/47551>

Large software is often organized as a set of interdependent modules. As the software evolves, the cost of managing the dependencies between the modules tends to grow. A common dependency problem is underutilized modules. An underutilized module is one whose dependents need only a small part of it. Underutilized modules increase the cost of building, testing, and deploying software. Thus, programmers often manually decompose modules. However, decomposing underutilized targets manually is tedious. We propose a greedy algorithm that proposes effective module decompositions by analyzing both intra-module and inter-module dependencies. We implemented the algorithm and evaluated it at Google. The results show that the algorithm is efficient and the decompositions that it proposes significantly reduce the cost of testing.

4.23 Complexity of Maintenance – Refactoring for the Reproducible Evaluation of Design Choices

Jurgen Vinju (CWI – Amsterdam, NL)

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Joint work of Hills, Mark; Klint, Paul; Vinju, Jurgen

Main reference M. Hills, P. Klint, J. J. Vinju, “A case of visitor versus interpreter pattern,” in Proc. of the 49th Int’l Conf. on Objects, Models, Components and Patterns (TOOLS’11), LNCS, Vol. 6705, pp. 228–243, Springer, 2011; pre-print available from author’s webpage.

URL http://dx.doi.org/10.1007/978-3-642-21952-8_17

URL <http://homepages.cwi.nl/~jurgenv/papers/TOOLS2011.pdf>

This lightning talk had two messages. The first is the existence of Rascal, a meta programming language designed to cover the requirements for both source code analysis and transformation. Refactoring requires them both. Rascal emphasizes programming over specification, is based on powerful pattern matching and substitution primitives and relational calculus.

The second message was that refactoring tools can also be used to research trade-offs in design choices. We report on the creation of an ad-hoc refactoring from the Visitor design pattern to the Interpreter design pattern [1]. Using this refactoring we could create two versions of a complex system which differ only in this single design choice: isolating it from all other factors on code quality. We then experimented by executing maintenance scenarios on both systems and measuring the complexity of analyzing and transforming the source code manually. The manual tasks were recorded as “meta-programs” as well. We found out that Visitor is better, surprisingly, even in cases where in theory Interpreter should be better.

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5 Demonstrations

5.1 IDEs are Ecosystems

Andrew P. Black (Portland State University, US)

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Joint work of Vainsencher, Daniel; Black, Andrew P.

Main reference D. Vainsencher, A. P. Black, “A pattern language for extensible program representation,” Transactions on Pattern Languages of Programming 1, LNCS, Vol. 5770, pp. 1–47, Springer, 2009.

URL http://dx.doi.org/10.1007/978-3-642-10832-7_1

For many years, implementors of multiple view programming environments have sought a single code model that would form a suitable basis for all of the program analyses and tools that might be applied to the code. They have been unsuccessful. The consequences are a tendency to build monolithic, single- purpose tools, each of which implements its own specialized analyses and optimized representation. This restricts the availability of the analyses, and also limits the reusability of the representation by other tools. Unintegrated tools also produce inconsistent views, which reduce the value of multiple views.

This talk is an advertisement for a paper that describes a set of architectural patterns that allow a single, minimal representation of program code to be extended as required to support new tools and program analyses, while still maintaining a simple and uniform interface to program properties. The patterns address efficiency, correctness and the integration of multiple analyses and tools in a modular fashion.

5.2 Tools for Retrofitting Parallelism

Danny Dig (Oregon State University, US)

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Main reference D. Dig, “A Refactoring Approach to Parallelism,” IEEE Software 28(1):12–22, 2011.

URL <http://dx.doi.org/10.1109/MS.2011.1>

In the multicore era, programmers have to work harder to introduce parallelism for performance or to enable new applications and services not possible before. In this talk I present our ever-growing toolset of interactive refactorings for adding parallelism into sequential programs. This toolset is grounded on empirical studies that shed light into the practice of using, misusing, underusing, or abusing parallel libraries. Our refactoring toolset supports refactorings from three domains: adding thread-safety, improving throughput, and scalability. Empirical evaluation shows that our toolset is useful: (i) it dramatically reduces the burden of analyzing and changing code, (ii) it is fast so it can be used interactively, (iii) it correctly applies transformations that open-source developers applied incompletely, and (iv) users prefer the improved quality of the changed code. I muse on lessons that can be learned as we move onto automated refactoring for mobile apps.

5.3 Tools for Refactoring of Web Applications

Alejandra Garrido (University of La Plata, AR)

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Joint work of Garrido, Alejandra; Firmenich, Sergio; Grigera, Julián; Rossi, Gustavo

Refactoring can be applied to improve external quality attributes of web applications, and thus provides the ideal context to incite developers to experiment new interface metaphors, and keep them or discard them after usage testing or client feedback. We have extended a tool for web application modeling to support refactoring in a model-driven approach. We have also developed a framework that allows for refactoring on the client-side. This makes it possible to have different views of the same application, customized for and by users, depending on their experience, preferences, or accessibility issues. We are currently developing a tool to automatically detect bad usability smells from user interaction logs.

References

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- 3 Julian Grigera, A. Garrido and J.M. Rivero. *A Tool for Detecting Bad Usability Smells in an Automatic Way*. Int. Conf. On Web Engineering (ICWE 2014). Demo and poster track. Toulouse, France. July, 2014.

5.4 WitchDoctor: IDE Support for Real-Time Auto-Completion of Refactorings

William G. Griswold (University of California – San Diego, US)

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© William G. Griswold

Joint work of Foster, Stephen R; Lerner, Sorin; Griswold, William G.;

Main reference S. R. Foster, W. G. Griswold, S. Lerner, “WitchDoctor: IDE support for real-time auto-completion of refactorings,” in Proc. of the 34th Int’l Conf. on Software Engineering (ICSE’12), pp. 222–232, IEEE, 2012.

URL <http://dx.doi.org/10.1109/ICSE.2012.6227191>

Integrated Development Environments (IDEs) have come to perform a wide variety of tasks on behalf of the programmer, refactoring being a classic example. These operations have undeniable benefits, yet their large (and growing) number poses a cognitive scalability problem. Our main contribution is WitchDoctor – a system that can detect, on the fly, when a programmer is hand-coding a refactoring. The system can then complete the refactoring in the background and propose it to the user long before the user can complete it. This implies a number of technical challenges. The algorithm must be 1) highly efficient, 2) handle unparseable programs, 3) tolerate the variety of ways programmers may perform a given refactoring, 4) use the IDE’s proven and familiar refactoring engine to perform the refactoring, even though the the refactoring has already begun, and 5) support the wide range of refactorings present in modern IDEs. Our techniques for overcoming these challenges are the technical contributions of this paper. We evaluate WitchDoctor’s design and implementation by simulating over 5,000 refactoring operations across three open-source

projects. The simulated user is faster and more efficient than an average human user, yet WitchDoctor can detect more than 90% of refactoring operations as they are being performed – and can complete over a third of refactorings before the simulated user does. All the while, WitchDoctor remains robust in the face of non-parseable programs and unpredictable refactoring scenarios. We also show that WitchDoctor is efficient enough to perform computation on a keystroke-by-keystroke basis, adding an average overhead of only 15 milliseconds per keystroke.

5.5 REdiffs: Refactoring-aware Difference Viewer for Java

Shinpei Hayashi (Tokyo Institute of Technology, JP)

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Joint work of Hayashi, Shinpei; Thangthumachit, Sirinut; Saeki, Motoshi

Main reference S. Hayashi, S. Thangthumachit, M. Saeki, “REdiffs: Refactoring-Aware Difference Viewer for Java,” in Proc. of the 20th Working Conf. on Reverse Engineering (WCRE’13), pp. 487–488, IEEE, 2013.

URL <http://dx.doi.org/10.1109/WCRE.2013.6671331>

Comparing and understanding differences between old and new versions of source code are necessary in various software development situations. However, if changes are tangled with refactorings in a single revision, then the resulting source code differences are more complicated. We propose an interactive difference viewer which enables us to separate refactoring effects from source code differences for improving the understandability of the differences.

5.6 Refactoring via Pretty-Printing

Jongwook Kim (University of Texas – Austin, US)

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We demonstrate a new refactoring engine called Relativistic Reflective Refactoring that uses a projection or pretty-printer technology based on Simonyi’s Intentional Programming. Using main-memory databases to encode containment and inheritance relationships among program elements (like classes, methods, fields, and interfaces), we can encode the changes made by refactorings within the database itself, and not modifying existing program ASTs. By displaying the contents of the database through ASTs, we can emulate many different and classical refactorings and design patterns without using “program transformation” technologies.

5.7 Interactive Quick Fix

Emerson Murphy-Hill (North Carolina State University, US)

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Joint work of Song, Yoonki; Barik, Titus; Johnson, Brittany; Murphy-Hill, Emerson
URL <https://www.youtube.com/watch?v=y4BhIF0mMZg>

Quick fixes are a great way to fix problems when the number of possible solutions are easily enumerable. However, when this is not the case, they fail to adequately support the programmer. In this demo, I talk about our approach called Interactive Quick Fix, which allows a developer to benefit from the structured help of tools yet still explore the full design space of the solution.

5.8 Cloud Refactoring

Eli Tilevich (Virginia Polytechnic Institute – Blacksburg, US)

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Joint work of Kwon, Young-Woo; Tilevich, Eli
Main reference Y.-W. Kwon, E. Tilevich, “Cloud refactoring: automated transitioning to cloud-based services,” *Automated Software Engineering*, 21(3):345–372, 2013.
URL <http://dx.doi.org/10.1007/s10515-013-0136-9>

We demonstrate a set of Cloud Refactoring techniques, which we have implemented as automated, IDE- assisted program transformations that render a portion of an application’s functionality accessible remotely as a Web service. In particular, we show how a programmer can extract services, add fault tolerance functionality, and adapt client code to invoke cloud services via refactoring transformations integrated with a modern IDE. The running example refactors a bioinformatics application to use a remote sequence alignment service.

5.9 A Universal Type Qualifier Inference System

Mohsen Vakilian (University of Illinois – Urbana, US)

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Joint work of Vakilian, Mohsen; Phaosawasdi, Amarin; Johnson, Ralph E.

Type qualifiers augment an existing type system to check more properties, such as safety against null dereferences and SQL injections. To get the benefits of type qualifiers, programmers have to add type qualifiers to the source code. Realizing the burden of manually adding type qualifiers to existing code, researchers have proposed inference systems for each type qualifier system. Each of these inference systems operates in the batch mode, gives little control to the programmer, and is limited to a single type qualifier system. A combination of two concepts, compositional refactoring and speculative analysis, enabled us to develop the first universal type qualifier inference system called Cascade. Cascade is an interactive system that achieves universality by repeatedly invoking the checker for a given type qualifier system and proposing a composition of changes to fix the errors reported by the checker.

5.10 Rascal for Experimenting with New Intermediate Formats for Source Code Analysis

Jurgen Vinju (CWI – Amsterdam, NL)

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© Jurgen Vinju

Joint work of Klint, Paul; Van der Storm, Tijs; Vinju, Jurgen

Main reference P. Klint, T. van der Storm, J. J. Vinju, “Rascal: A Domain Specific Language for Source Code Analysis and Manipulation,” in Proc. of the 9th IEEE Int’l Working Conf. on Source Code Analysis and Manipulation (SCAM’09), pp. 168–177, IEEE, 2009; pre-print available from author’s webpage.

URL <http://dx.doi.org/10.1109/SCAM.2009.28>

URL <http://homepages.cwi.nl/~jurgenv/papers/SCAM-2009.pdf>

In this live coding demonstration we demonstrate the power of Rascal as a language to introduce new intermediate representations, extracting these from source code, then analyzing them. Models of source code in Rascal are all represented as immutable data: terms in many-sorted algebras, parse trees over context-free grammars, sets, relations, maps, etc.

As an example we translated Java to the Object Flow Language [Tonella] and then extracted an over-approximated object flow graph from this as a binary relation. Then we visualize this graph by exporting a graphviz dot graph.

We claim that experimenting with new representations and new source code extractors and new analysis requires hardly any boilerplate using the Rascal language, which makes it more fun and more effective to explore new ideas in refactoring.

5.11 How Can We Do Better than Search and Replace?

Jan Wloka (IBM Research GmbH – Zürich, CH)

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When using a refactoring tool to automate incremental design improvements in mixed-language programs you can get the impression that current tools are very limited in how refactoring targets can be selected and when a refactoring can be applied. The tool expects a single program element as target, e.g. a method declaration, before it tries to find and change all referencing elements in the program. The resolution of declaration-reference bindings is difficult and it is often impossible for a program analysis to determine whether a certain change preserves program behavior.

Future refactoring tools can overcome these limitations by enabling their users to provide (non-determinable) declaration-reference bindings. Developers would use the tool to change declaring program elements and their bindings separately. The developer would specify a search term and a substitution template in a unified pattern language, and the tool would search, preview and then consistently refactor all matching bindings in the different programming language files. The refactoring tool would know how to match and refactor the individual elements of each programming language with the unified search and substitution template provided by the developer.

The use of syntax trees for each supported language would allow for context-dependent matches and substitutions and introduce fewer programming errors than textual search-and-replace. Even if possibly not behavior preserving, refactorings automated by such a tool would enable developers to perform vast and complex changes in a consistent way, and automated tests would catch unintended behavioral changes.

Until such a refactoring tool is available, developers will continue to change mixed-language programs with search-and-replace in their favorite editor.

6 Working Groups

6.1 User Experience Breakout: Dimensions of Refactoring

Emerson Murphy-Hill (North Carolina State University, US)

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URL <https://docs.google.com/document/d/1GmEtQWz4xUnBdpDucfJV0fnUMaIVmWxIzPEWfnNJUlw/edit>

The user experience breakout group (about 10 people, including Emerson) brainstormed “dimensions of refactoring”. Later, Oscar and Jurgen pulled Emerson aside to augment those dimensions with some Oscar came up with based on the industry panel. The results are in the linked Google Doc. Figure 1 shows the dimensions visualized by Emerson, Friedrich, Jurgen, and Oscar.

6.2 User Experience Breakout: The Future of Refactoring

Emerson Murphy-Hill (North Carolina State University, US)

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URL <https://docs.google.com/document/d/1xHqizIEjVZaYxsTfTFVv1IEjyPkt9slcds-KYVvZPH8/edit>

The user experience refactoring group met to discuss the future of refactoring. We discussed current problems, solutions, and future opportunities. The results are in the linked Google Doc.

6.3 Plenary Discussion on Refactoring in Education, Corpora and Benchmarks

Thompson, Simon J.

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© Simon J. Thompson

URL <https://docs.google.com/document/d/1q3E1n6tJbX7W-V0jtgObpoR8P37JL2ja8rj4yC2cFQ/edit?usp=sharing>

In a plenary discussion, the seminar talked about the various roles of refactoring in higher education, and the roles of corpora and benchmarks in refactoring research.

6.4 Novel Applications of Refactoring Breakout

Bill Opdyke (JP Morgan Chase – Chicago, US)

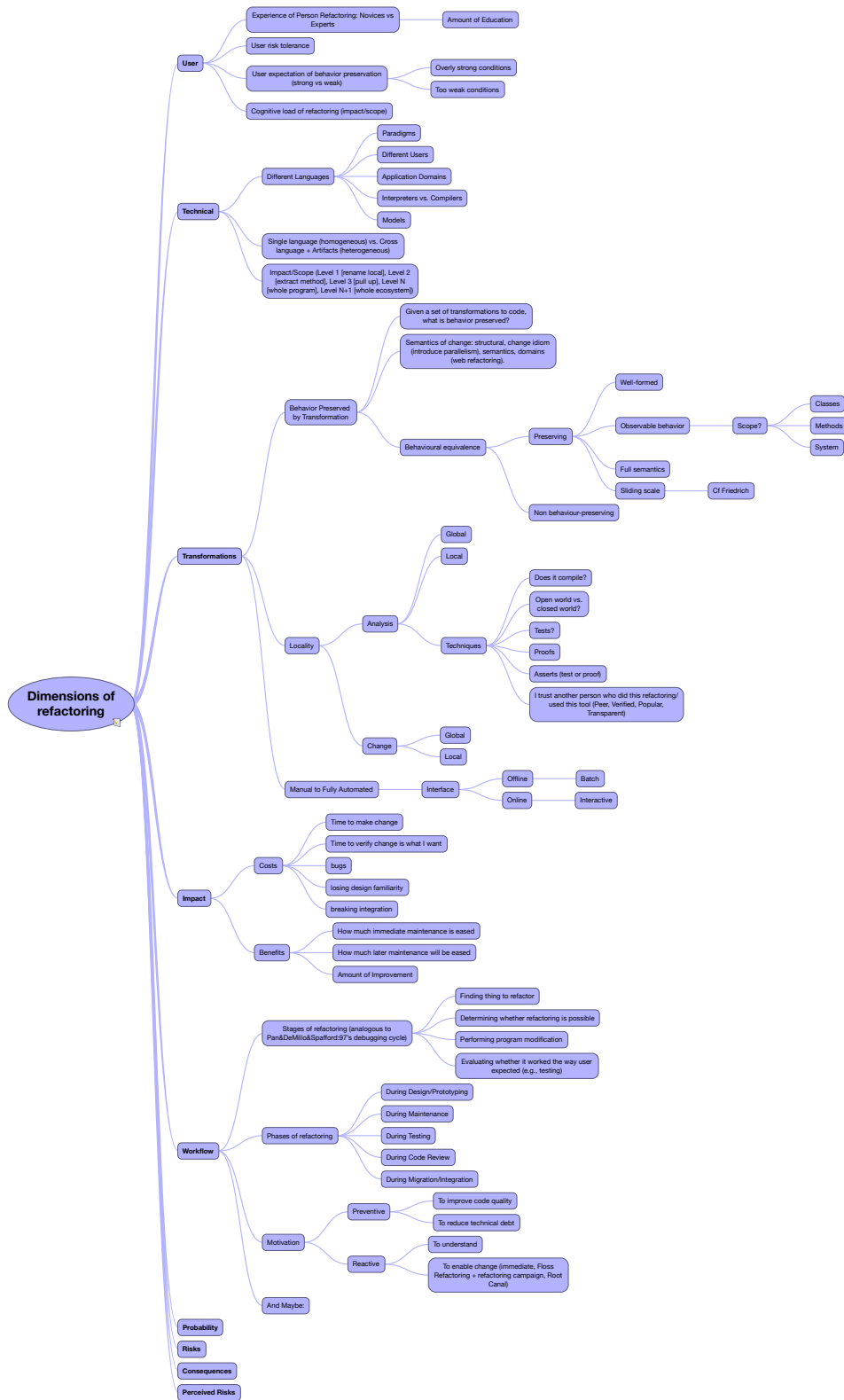
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URL https://drive.google.com/folderview?id=0B7DV-T4_2mpKcXNYb0VJR3NqN28&usp=sharing

During the discussion breakout session, the “Novel Applications of Refactoring” participants listed several opportunity areas (problems/ challenges and open issues):

- How to introduce refactoring to children.
- Teaching that you don’t need to have it right the first time.



■ Figure 1 Dimensions of Refactoring.

- Refactoring (in the mobile area), tailored to environments with special constraints (e.g., security, screen space, battery power, efficiency, latency, data usage, network connectivity, preferences, heterogeneity).
- Use of resources more efficiently (green computing).
- Refactoring to distribute resources on the cloud.
- Refactoring of big data.
- Expressing refactorings as goals to non-expert developers or users.
- Globalization, internationalization (cultural awareness, use of color and fonts, other factors).
- How to transfer insights of basic refactoring research to new domains.

The breakout group noted several existing solutions:

- Self-adaptation and self-healing to handle dynamic user of resources.
- Software product lines for internationalization.
- Refactoring for accessibility.

The breakout group also noted several works in progress:

- Refactoring for improving user responsiveness on mobile devices (extracting long running – blocking u/p computation from the UI event to asynchronous task).
- Annotation refactoring (before and after examples).
- Record and replay of web macros.
- Finding bad usability smells (as part of solving limitations of systems with respect to internationalization).

6.5 Refactoring Tools and Meta-Tools

Max Schäfer (Semmler Ltd., Oxford, UK)

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The group discussed open problems in refactoring tools, existing solutions and work in progress, and ideas for approaching the open problems. It was agreed that the main problem facing authors of refactoring tools is the great complexity of real-world languages and code bases. Moreover, languages continue to evolve and thus become more complex. At the same time, commercial tool vendors seem to have little interest in improving existing refactoring tools. On the research side, many participants found that there was too little exchange and collaboration between, thus leading people to solve the same problems over and over again. This shows the importance of broad-based seminars such as this one.

7 Industry Roundtable

We held one industry panel, moderated by Bill Griswold, and attended by Robert Bowdidge, Loius Wasserman, Don Roberts, John Brant, Ira Baxter, and Bill Opdyke. Panelists were asked: “Tell us one surprising fact about industry refactoring that you’d like academics to know.”

Here are some issues that came out during the session:

Refactoring Process

- Why? (what’s the trigger?)
- When? (on-the fly Agile, post facto re-architecting, etc.)
- Scope? (small scale, system-wide, etc.)
- How? (tools and techniques, meaning-preserving or not)
- Who? (everybody, specialists, etc.)

Critical Analysis

- Surprising fact(s)
- Barriers to adoption
- Skill set required to perform refactoring (and how common that skill set is)
- How important to the on-going success of the software
- How related or compared to re-development and other maintenance

Participants

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Geometric Modeling

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Abstract

This report documents the program and the outcomes of Dagstuhl Seminar 14221 “Geometric Modeling”. This is the 9th Dagstuhl seminar on “Geometric Modeling”, and the seminar was attended by 44 leading researchers coming from 3 continents and 20 countries. A total of 45 presentations were grouped together into 12 lecture sessions and 3 perspective working group sessions. There was also ample time for stimulating and fruitful person to person and group discussions in the harmonic Dagstuhl atmosphere.

Seminar May 25–30, 2014 – <http://www.dagstuhl.de/14221>

1998 ACM Subject Classification I.3.5 Computational Geometry and Object Modeling

Keywords and phrases Geometric modeling, material modeling, locally refinable splines, isogeometric analysis, mesh processing, algebraic methods

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1 Executive Summary

Falai Chen

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The 9th Dagstuhl seminar was attended by 44 leading researchers coming from 3 continents and 20 countries. A total of 45 presentations were grouped together into 12 lecture sessions and 3 perspective working group sessions. There was also ample time for stimulating and fruitful person to person and group discussions in the harmonic Dagstuhl atmosphere. Dagstuhl seminars on Geometric Modelling are among the most interdisciplinary events within Geometric Modelling. The reason is the seminar format and the generous numbers of targeted invitation to leading researchers across the different research communities addressing Geometric Modelling. Geometric Modeling is the branch of Computer Science concerned with the acquisition, representation, modeling and analysis of 3-dimensional and higher dimensional geometry. The evolution of IT-technology with Cloud Computing and the big data challenge, and novel manufacturing technologies such as 3D printing and layered manufacturing, as well as the introduction of Isogeometric Analysis drive a need for increased innovation within Geometric Modeling. The Dagstuhl seminars on Geometric Modelling are one of the main driving forces facilitating such innovation.



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Geometric Modeling, *Dagstuhl Reports*, Vol. 4, Issue 5, pp. 68–94

Editors: Falai Chen, Tor Dokken, Thomas A. Grandine and Stefanie Hahmann



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The twelve lecture sessions covered a wide range of topics:

- Geometric modelling, analysis and computations;
- Methods in approximate algebraic geometry and implicitization;
- Mesh processing both related to triangulations and isogeometric analysis;
- Optimization and Isogeometric Analysis;
- Splines over triangulations and locally refinable splines;
- Material modelling and reverse engineering;
- Funding opportunities for Geometric Modelling within Horizon 2020.

The three perspective working groups have each written a short document reporting on approach and result of the session. The perspective working group on subdivision addressed the state of the art and the future research challenges of subdivisions. The group on 3D printing approached the challenges from the current wide media coverage of 3D printing and challenges experienced by industry using 3D printing. The group on modeling of material microstructures was approaching the topic from additive manufacturing, and the challenges faced by the geometric modelling community to support modeling and representation of such material structures in variety of applications. As with all previous Dagstuhl Seminars on Geometric Modeling, the conference proceedings will be published, the 2014 proceedings as a special issue of the Elsevier Journal Graphical Models. A special event during the conference was the John Gregory Memorial Award honoring Elaine Cohen, Jörg Peters and Ulrich Reif. This award is presented every three years at Dagstuhl and honors fundamental contributions to the field of geometric modeling. The organizers thank all the attendees for their contributions and extend special thanks to the team of Schloss Dagstuhl for helping to make this seminar a success. As always, we enjoyed the warm atmosphere of the Schloss, which supports both formal presentations as well as informal exchanges of ideas.

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3 Overview of Talks

3.1 Numerical methods for implicitization

Oliver Barrowclough (SINTEF IKT Applied Mathematics – Oslo, NO)

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Main reference O. J. D. Barrowclough, “Numerical methods for implicitization and their applications,” in T. Dokken and G. Muntingh, eds., *SAGA – Advances in Shapes, Geometry, and Algebra – Geometry and Computing*, Vol. 10, Springer, 2014; to appear.

A long standing problem in computer aided geometric design has been the robustness of intersection algorithms. Geometries resulting from intersections often lack watertightness and have incorrect topology, requiring costly repair procedures to be applied prior to analysis or manufacturing. One technique that can support the robustness and consistency of geometric computations is implicitization. In this talk we present some recent approaches to computing implicitizations numerically. This includes both exact methods for low degree curves, and approximate methods, which are better suited to higher degree surfaces and envelopes.

3.2 Biharmonic fields and mesh completion

Pere Brunet (UPC – Barcelona, ES)

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We discuss biharmonic fields which approximate signed distance fields. We conclude that biharmonic field approximation can be a powerful tool for mesh completion in general and complex cases. We present an adaptive, multigrid algorithm to extrapolate signed distance fields. By defining a volume mask in a closed region bounding the area that must be repaired, the algorithm computes a signed distance field in well-defined regions and uses it as an over-determined boundary condition constraint for the biharmonic field computation in the complementary regions. We discuss this approximation in practical examples in the case of raw triangular meshes resulting from laser scan acquisitions which require massive hole repair. We conclude that the proposed algorithm is robust and general, being able to deal with complex topological cases.

3.3 Properties of Matrix Representations of Rational Bézier Curves and Surfaces

Laurent Busé (INRIA Sophia Antipolis – Méditerranée, FR)

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Main reference L. Busé, “Implicit matrix representations of rational Bézier curves and surfaces,” *Computer Aided Design*, Vol. 46, pp. 14–24, 2014; pre-print available at HAL.

URL <http://dx.doi.org/10.1016/j.cad.2013.08.014>

URL <http://hal.inria.fr/hal-00847802>

Matrix-based implicit representations of rational Bézier curves and surfaces in the 3-dimensional space have been extensively developed during the last fifteen years by many

authors. They have a lot of interesting properties, so that they can be considered as representations on their own. One of their well-known advantage is that they adapt geometric problems, such as intersection problems, to the powerful tools of numerical linear algebra, as the singular value decomposition.

In this talk, we will focus on the behavior of these matrix representations with respect to numerical computations. We will also show that a distance-like function can be defined from a matrix representation.

3.4 Some Problems on Splines over T-meshes

Falai Chen (University of Science & Technology of China – Anhui, CN)

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Joint work of Chen, Falai; Deng Jiansong; Li, Xin

Main reference J. Deng, F. Chen, X. Li, C. Hu, W. Tong, Z. Yang, Y. Feng, “Polynomial splines over hierarchical T-meshes,” *Graphical Models*, 74(4):76–86. 2008.

URL <http://dx.doi.org/10.1016/j.gmod.2008.03.001>

In this talk, I will summarize some recent advances on splines over T-meshes, including dimension calculation, basis construction and applications in geometric modeling and isogeometric analysis. I will then put forward some further research problems.

3.5 Direct Isosurface Visualization for Hex-based High Order Geometry and Attributes

Elaine Cohen (University of Utah, US)

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With the increasing use of hexahedral based high order trivariate representations, there is increasing need for accurate visualization methods for both the geometry and any related attributes and simulation results. This talk discusses one such approach.

3.6 Challenges from IsoGeometric Analysis to CAGD—Experiences from the TERRIFIC project

Tor Dokken (SINTEF IKT Applied Mathematics – Oslo, NO)

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Main reference T. Dokken, T. Lyche, K. F. Pettersen, “Polynomial splines over locally refined box-partitions,” *Computer Aided Geometric Design*, 30(3):331–356, 2013.

URL <http://dx.doi.org/10.1016/j.cagd.2012.12.005>


URL <http://www.terrific-project.eu>

The TERRIFIC-project (funded under EUs Factories of the Future program, 2011-2014) ends in August 2014, www.terrific-project.eu. TERRIFIC aims at significant improvement of the interoperability of computational tools for the design, analysis and optimization of functional products. An isogeometric approach is applied for selected manufacturing application

areas (cars, trains, aircraft) and for computer-aided machining. The talk illustrated the achievements of TERRIFIC illustrated by the TERRIFIC demonstrator part, and addressed the many open challenges still remaining to be solved before IsoGeometric Analysis can be deployed to industry on a broad scale.

3.7 Precise Continuous Contact Motion Analysis for Freeform Geometry

Gershon Elber (Technion – Haifa, IL)

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Joint work of Gershon Elber; Yongjoon Kim; Myung Soo Kim; Michael Baron; Helmut Pottmann


This work presents an efficient algorithm for generating a continuous and precise contact motion between geometric models bounded by piecewise polynomial C^1 -continuous parametric B-spline curves and surfaces.

The contact configurations are characterized algebraically. We will start by discussing simpler cases of curves' contact in the plane, only to continue and considered a CNC tool (cylinder)-freeform surface contact in multi-axis machining context. Hyper osculating circles are considered along with double tangency contacts, in the case of tool-surface analysis.

We strive to ensure the topology of the reconstructed solution and we demonstrate the effectiveness of the proposed approach using several examples of both 2D curve-curve contacts and 3D tool-surface contacts in 5-axis machining scenarios.

3.8 Sparse Approximate Implicitization

Ioannis Z. Emiris (National Kapodistrian University of Athens, GR)

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Main reference I. Z. Emiris, T. Kalinka, C. Konaxis, T. Luu Ba, "Sparse implicitization by interpolation: Characterizing non-exactness, and an application to computing discriminants," *Computer-Aided Design – Special Issue on Solid and Physical Modeling 2012*, 45(2):252–261, 2013.

URL <http://dx.doi.org/10.1016/j.cad.2012.10.008>

We reduce implicitization of parametric (hyper)surfaces to computing the kernel of a square (or rectangular) numeric matrix. Our algorithm works in the presence of base-points. It relies on predicting the monomial support of the implicit equation by developing tools in sparse elimination theory. In particular, by predicting the Newton polytope of the sparse resultant, we obtain (a superset of) the Newton polytope of the implicit equation, hence all monomials in the implicit equation. This theory allows us to exploit any sparseness in the parametric polynomials as well as in the implicit equation [1]. We can moreover characterize the cases of higher-dimensional kernel [2]: in particular, the predicted implicit polytope is the Minkowski sum of the true implicit polytope and an extraneous polytope; in this case, the implicit equation is the GCD of a number of polynomials.

The method is easy to implement (already developed in Maple), can approximate the exact equation by using a smaller support, and should be generalizable to parameterizations in the Bernstein basis. Certain operations on the surface, such as point membership and sidedness of a query point, can be reduced to matrix operations without computing the

implicit equation, namely rank drop and sign of determinant, respectively. Our current work focuses on exploiting the generalized Vandermonde structure of the matrix and on improving numerical stability by controlling point (over)sampling on the surface, e.g. by using Chebyshev points rather than complex roots of unity, which have proven the best choice so far.

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3.9 Geometric Variations of the Lane-Riesenfeld Algorithm

Ron Goldman (Rice University, US)

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Joint work of Dyn, Nira; Goldman, Ron; Levin, David

The Lane-Riesenfeld algorithm is a classical subdivision procedure for generating uniform B-spline curves and surfaces. Here we discuss some geometric variations of this classical subdivision procedure. Instead of treating each component of a curve or surface independently, we treat the control polygons as geometric entities, where the components do not have independent geometric meanings. The split and averaging paradigm of the Lane-Riesenfeld algorithm is mimicked, but midpoint averaging is replaced by geometric averaging. We discuss what is currently known and not known about the convergence, continuity, and smoothness of such geometric Lane-Riesenfeld algorithms.

3.10 The Geometry of Colour Space

Jens Gravesen (Technical University of Denmark – Lyngby, DK)

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The space of colours is a fascinating space. It is a real vector space, but no matter what inner product you put on the space the resulting euclidean distance does not corresponds to human perception of difference between colours.

In applications that involve searching through images it is important to have a good notion of distance between colours. And in the textile industry it is important to be able to determine if residues of old dye have a visible effect on the current colour.

In 1945 MacAdam performed the first experiments on colour matching and found the MacAdam ellipses which are often interpreted as defining the metric tensor (or first fundamental form) at the centres of the ellipses. A fundamental question is whether it is possible to define colour coordinates such that the euclidean distance in these coordinates corresponds to human perception. Put another way, can we find an isometry to euclidean space or what is the curvature of the space colours?

I will report on a simple approach that solves the practical problem but also formulate a purely geometric question of which I only have the answer in the one dimensional case.

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3.11 Efficient computation of NURBS components interfaces

Stefanie Hahmann (INRIA Grenoble Rhône-Alpes, FR)

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Joint work of François Jourdes, Georges-Pierre Bonneau, Stefanie Hahmann, Jean-Claude Léon, François Faure
Main reference F. Jourdes, G.-P. Bonneau, S. Hahmann, J.-C. Léon, F. Faure, “Computation of components’ interfaces in highly complex assemblies,” *Computer-Aided Design*, 46(Jan. 2014):170–178, 2014; pre-print available at HAL.

URL <http://dx.doi.org/10.1016/j.cad.2013.08.029>

URL <http://hal.inria.fr/hal-00854926>

The preparation of CAD models from complex assemblies for simulation purposes is a very time-consuming and tedious process, since many tasks are still completed manually. Herein, the detection and extraction of geometric interfaces between components of the assembly is of central importance not only for the simulation objectives but also for all necessary shape transformations such as idealizations or detail removals. It is a repetitive task in particular when complex assemblies have to be dealt with. This talk presents a method to rapidly and fully automatically generate a precise geometric description of interfaces in generic B-Rep CAD models. The approach combines an efficient GPU ray-casting technique commonly used in computer graphics with a graph-based curve extraction algorithm. Not only is it able to detect a large number of interfaces efficiently, but it also provides an accurate NURBS geometry of the interfaces, that can be stored in a plain STEP file for further downstream treatment. We demonstrate our approach on examples from aeronautics and automotive industry.

3.12 Generalized Lane-Riesenfeld Algorithms

Kai Hormann (University of Lugano, CH)

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Joint work of Cashman, Thomas J.; Hormann, Kai; Reif, Ulrich
Main reference T. J. Cashman, K. Hormann, U. Reif, “Generalized Lane-Riesenfeld Algorithms,” *Computer Aided Geometric Design*, 30(4):398–409, 2013.


URL <http://dx.doi.org/10.1016/j.cagd.2013.02.001>

The Lane-Riesenfeld algorithm for generating uniform B-splines provides a prototype for subdivision algorithms that use a refine and smooth factorization to gain arbitrarily high smoothness through efficient local rules. In this paper we generalize this algorithm by maintaining the key property that the same operator is used to define the refine and each smoothing stage. For the Lane-Riesenfeld algorithm this operator samples a linear polynomial, and therefore the algorithm preserves only linear polynomials in the functional setting, and straight lines in the geometric setting. We present two new families of schemes that extend this

set of invariants: one which preserves cubic polynomials, and another which preserves circles. For both generalizations, as for the Lane-Riesenfeld algorithm, a greater number of smoothing stages gives smoother curves, and only local rules are required for an implementation.

3.13 Workshop: The Future Challenges of Subdivision

Kai Hormann (University of Lugano, CH)

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In this workshop, we reviewed the state of the art of subdivision methods for geometric modelling and tried to identify the future challenges for this field of research. We agreed that subdivision algorithms for curves are well understood by now, but that we still lack good schemes and analysis tools for surfaces. In particular, we believe that non-linear or geometric surface schemes should be developed and examined, as they have the potential to provide reproduction of basic shapes (cylinder, spheres, etc.) and C^2 -continuous and fair limit surfaces.

3.14 TDHB splines: The truncated and decoupled basis of hierarchical spline spaces

Bert Jüttler (University of Linz, AT)

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Joint work of Jüttler, Bert; Mokris, Dominik

Main reference D. Mokris, B. Jüttler, “TDHB-splines: The truncated decoupled basis of hierarchical tensor-product splines,” *Computer Aided Geometric Design*, 2014, in press.

URL <http://dx.doi.org/10.1016/j.cagd.2014.05.004>

We introduce a novel basis for multivariate hierarchical tensor-product spline spaces. Our construction combines the truncation mechanism with the idea of decoupling basis functions. While the first mechanism ensures the partition of unity property, which is essential for geometric modeling applications, the idea of decoupling allows us to obtain a richer set of basis functions than previous hierarchical approaches. Consequently, we can guarantee the completeness property of the novel basis for large classes of multi-level spline spaces. In particular, completeness is obtained for the multi-level spline spaces defined on T-meshes for hierarchical splines of (multi-) degree p (i) with single knots and p -adic refinement and (ii) with knots of multiplicity $m > (p + 1)/3$ and dyadic refinement (where each cell to be refined is subdivided into 2^n cells, with n being the number of variables) without any further restriction on the mesh configuration. Both classes (i,ii) include multivariate quadratic hierarchical tensor-splines with dyadic refinement.

3.15 Bounding Circular Arcs for a Dynamic Bounding Volume Hierarchy

Myung-Soo Kim (Seoul National University, KR)

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Joint work of Lee, Jaewook; Kim, Yong-Joon; Elber, Gershon

We consider the construction of dynamic bounding volume hierarchy (BVH) for planar freeform curves under deformation. For this purpose, we employ the Bounding Circular Arcs (BCA), originally proposed by Meek and Walton (JCAM 1995) for the purpose of proving the cubic convergence of their biarc approximation method. The BCA construction is compared with conventional bounding volumes, in particular, with fat arcs and spiral fat arcs. The effectiveness of the BCA-based approach is then demonstrated using a few test examples of geometric computing on planar freeform curves under deformation.

3.16 On the dimension of spline spaces on T-meshes and its applications to the refinement algorithms

Tae-Wan Kim (Seoul National University, KR)

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The spline representations using T-mesh as an underlying geometric structure has absorbed substantial interest among designers, engineers and researchers for the last decade. One of the fundamental requirements of the refinement technique is being able to generate nested sequence of spline spaces and spline basis functions generating these spline spaces. For example, the construction of hierarchical B-splines or LR B-splines provides feasible algorithms for generating spline basis functions. The dimension of spline space is used to ensure the completeness and linear independence of spline basis functions. In this talk we will discuss about the dimension of spline spaces for some classes of 2-dimensional and 3-dimensional T-meshes. In particular we will demonstrate how the results about the dimension of a spline space can be used to show the completeness of hierarchical B-splines. We will also discuss some alternative refinement techniques that essentially use a formula for the dimension of a spline space.


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3.17 From Quad Meshes to Quad Layouts

Leif Kobbelt (RWTH Aachen, DE)

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Joint work of Kobbelt, Leif; Marcel, Campen; David, Bommers

URL <http://www.graphics.rwth-aachen.de>


The conversion of raw geometric data (that typically comes in the form of unstructured triangle meshes) to high quality quad meshes is an important and challenging task. The complexity of the task results from the fact that quad mesh topologies are subject to global consistency requirements that cannot be dealt with by local constructions. This is why recent quad meshing techniques formulate the mesh generation process as a global optimization problem. By adding hard and soft constraints to this optimization, many desired properties such as structural simplicity, principal direction alignment, as well as injectivity can be guaranteed by construction. A, in some sense, extreme form of quad meshing is the computation of quad layouts, where a coarse segmentation of the input surface into essentially rectangular patches is sought which also satisfies global consistency and shape quality requirements. While being structurally related, both problems need to be addressed by fundamentally different approaches. In my talk I will present some of these approaches and demonstrate that they can generate high quality quad meshes and quad layouts with a high degree of automation but that they also allow the user to interactively control the results by setting boundary conditions accordingly.

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3.18 Rational bilinear quaternionic parametrization of Dupin cyclides

Rimvydas Krasauskas (Vilnius University, LT)


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Joint work of Olechnovic, Kliment; Krasauka, Rimvydas

Rational Bezier formulas with quaternion weights are introduced for parametrization of principal Dupin cyclide patches. Well-known geometric properties (Moebius invariance, offsetting, representation as a canal surface) and several new ones (Willmore energy, natural parametrizations) of Dupin cyclides can be derived using this quaternionic approach. An application example will be presented: surfaces for modeling voids and channels in large biomolecules.

3.19 Modeling with Ambient B-Splines

Nicole Lehmann (TU Darmstadt, DE)

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The talk introduces a new approach for the generation of C^k approximants of functions defined on closed submanifolds for arbitrary k in \mathbb{N} . In case a function on a surface resembles the three coordinates of a topologically equivalent surface in R^3 , we even obtain C^k -approximants of closed surfaces of arbitrary topology. The key idea of our method is a constant extension of the target function into the submanifold's ambient space. In case the reference submanifolds are embedded and C^2 , the usage of standard tensor product B-splines for the approximation of the extended function is straightforward. We obtain a C^k approximation of the target function by restricting the approximant to the reference submanifold. We illustrate our method by an easy example in R^2 and verify its practicality by application-oriented examples in R^3 . The usage of B-splines not only guarantees full approximation power but also allows a canonical access to adaptive refinement strategies.

3.20 Bijection-Lifting For Surface Mapping

Yaron Lipman (Weizmann Institute, IL)

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Joint work of Lipman, Yaron; Aigerman Noam; Poranne Roi

Main reference N. Aigerman, R. Poranne, Y. Lipman, "Lifted bijections for low distortion surface mappings," ACM Transactions on Graphics, 33(4:69), 12 pages, 2014; pre-print available at author's webpage.

URL <http://doi.acm.org/10.1145/2601097.2601158>

URL <http://www.wisdom.weizmann.ac.il/~noamaig/html/projects/lifted/lifted.pdf>

This work introduces an algorithm for computing low-distortion, bijective mappings between surface meshes. The algorithm receives as input a coarse set of corresponding pairs of points on the two surfaces, and follows three steps: (i) cutting the two meshes to disks in a consistent manner; (ii) jointly flattening the two disks via a novel formulation for minimizing isometric distortion while guaranteeing local injectivity (the flattenings can overlap, however); and (iii) computing a unique continuous bijection that is consistent with the flattenings. The construction of the algorithm stems from two novel observations: first, bijections between disk-type surfaces can be uniquely and efficiently represented via consistent locally injective flattenings that are allowed to be globally overlapping. This observation reduces the problem of computing bijective surface mappings to the task of computing locally injective flattenings, which is shown to be easier. Second, locally injective flattenings that minimize isometric distortion can be efficiently characterized and optimized in a convex framework. Experiments that map a wide baseline of pairs of surface meshes using the algorithm are demonstrated. They show the ability of the algorithm to produce high-quality continuous bijective mappings between pairs of surfaces of varying isometric distortion levels.

3.21 Compressed sensing and its application in geometry processing

Ligang Liu (University of Science & Technology of China – Anhui, CN)

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Joint work of Liu, Ligang; Yang, Zhouwang; Chen, Falai; Deng, Jiansong

Main reference R. Wang, Z. Yang, L. Liu, J. Deng, F. Chen, “Decoupling Noises and Features via Weighted l_1 -analysis Compressed Sensing,” ACM Transactions on Graphics, 33(2:18), 12 pages, 2014; pre-print and additional data available at author’s webpage.

URL <http://doi.acm.org/10.1145/2557449>

URL http://staff.ustc.edu.cn/~lgliu/Projects/2014_DecouplingNoise/default.htm

Compressed sensing (CS) and sparse representation have attracted considerable attention in areas of applied mathematics, computer science, and electrical engineering during the last few years. CS builds upon the fundamental fact that we can represent many signals using only a few non- zero coefficients in a suitable basis or dictionary. Nonlinear optimization can then enable recovery of such signals from very few measurements. We have demonstrated our recent works on geometry processing using sparse representation and sparse optimization.

3.22 Smooth Simplex Splines for the Powell-Sabin 12-split.

Tom Lyche (University of Oslo, NO)

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This is a dummy text. Simplex splines are the natural generalization of B-splines to the multivariate case. Recently a simplex spline basis for C^1 quadratics on the Powell-Sabin 12-split was constructed. This basis has all the usual properties of univariate B-splines. In this talk we present work in progress dealing with C^3 quintic polynomials on PS 12. This piecewise polynomial on one triangle can be combined with neighboring elements to form a C^2 representation on any triangulation. We give several Simplex spline bases for this element. These bases form a nonnegative partition of unity, satisfy a Marsden-like identity, and the restriction of each basis element to the boundary edges of the macro element reduces to a standard univariate quintic B-spline.

3.23 Similarities in parametric B-rep models: detection and applications

Geraldine Morin (ENSEEIH – Toulouse, FR)

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In this work, we identify and exploit the partial similarities within 3D objects represented by NURBS based B-rep models. Novel methods are introduced, on the one hand to detect the partial similarities [1], on the other hand to use these similarities for specific applications such as shape editing, compression and indexation of 3D objects [2, 3]. The number of 3D models available is increasing. To limit the time spent to create these models, the reuse and the adaptation of existing models becomes a prior choice. Thus, methods to ease storing, searching and exploiting these models are necessary. Partial similarities within 3D objects is


common: many objects are composed of similar patches up to an approximated rotation, translation or symmetry. In a first phase, we introduce an approach similar to the Hough Transform to detect the partial similarities within NURBS-BRep models. This approach identifies not only similar patches but also the transformations that connect them. Two proposed filtering techniques make this approach flexible and able to adapt to special features of BRep models: a face-based to general cases and a point-based to identify transformations within a single face. Additionally, through the classification of isometries in transformations analysis, our approach can distinguish the nature of similar patches of a model, that is, the patches similar up to an approximated rotation, translation or symmetry. Additionally, 3D model indexation requires a canonical orientation of these models; the symmetry within a 3D object is a good orientation reference, coherent with the human perception. Accordingly, we use the partial symmetries to align 3D models and so reinforce the robustness of indexation methods.

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3.24 Spline spaces on topological complexes

Bernard Mourrain (INRIA Sophia Antipolis – Méditerranée, FR)

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In geometric modeling and in applications such as isogeometric analysis, one is interested in the precise representation of geometric shapes and of functions on these shapes, Complex models made of simple pieces glued together according to a specific topology are often involved. We are interested in providing simple and efficient parametric representations of such models. Given a topological complex described by 2 dimensional cells and glueing relations along edges, we consider the space of piecewise polynomial functions on this complex with a given regularity across the edges. The regularity property across edges is specified by transition maps and C^k conditions through the composition with these transition maps. We describe constructions of such spline spaces over cell complexes with vertices of arbitrary, we analyse the dimension of the space of splines of bounded degree and some basis. Homological techniques used for planar subdivisions are extended to this context.

3.25 A Hermite interpolatory subdivision scheme for C^2 -quintics on the Powell-Sabin 12-split

Georg Muntingh (SINTEF IKT Applied Mathematics – Oslo, NO)

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Joint work of Lyche, Tom; Muntingh, Georg

Main reference T. Lyche, G. Muntingh, “A Hermite interpolatory subdivision scheme for C^2 -quintics on the Powell-Sabin 12-split,” *Computer Aided Geometric Design*, 2014, in press.

URL <http://dx.doi.org/10.1016/j.cagd.2014.03.004>

In order to construct a C^1 -quadratic spline over an arbitrary triangulation, one can split each triangle into 12 subtriangles, resulting in a finer triangulation known as the Powell-Sabin 12-split. It has been shown previously that the corresponding spline surface can be plotted quickly by means of a Hermite subdivision scheme. In this talk we introduce a nodal macro-element on the 12-split for the space of quintic splines that are locally C^3 and globally C^2 . For quickly evaluating any such spline, a Hermite subdivision scheme is derived, implemented, and tested in the computer algebra system Sage. Using the available first derivatives for Phong shading, visually appealing plots can be generated after just a couple of refinements.

3.26 Adaptive Refinement in Isogeometric Shape Optimization

Peter Noertoft (Technical University of Denmark – Lyngby, DK)

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Joint work of Noertoft, Peter; Dokken, Tor

Shape optimization deals with designing “best” shapes based on some notion of goodness. In engineering sciences, shape optimization problems are often constrained by partial differential equations (PDEs). In the context of PDE constrained shape optimization, isogeometric analysis is recent numerical methodology that provides a unified computational framework for designing shapes and solving PDEs. In this methodology, local refinement is crucial to ensure efficiency and accuracy of the method. This goes both for the geometric model to be optimized, and for the discretization on which the solution of the governing PDE is based. This talk presents some ongoing work on how to combine isogeometric shape optimization and local refinement through the use of Locally Refinable (LR) B-splines. The focus is on flow problems, where the governing PDE is the Navier-Stokes equations.

3.27 Isogeometric analysis at irregular points

Jörg Peters (University of Florida – Gainesville, US)

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Joint work of Peters, Jörg; Thien Nguyen; Kęstutis Karčiauskas

Main reference T. Nguyen, K. Karčiauskas, J. Peters, “A Comparative Study of Several Classical, Discrete Differential and Isogeometric Methods for Solving Poisson’s Equation on the Disk,” *Axioms*, 3(2):280–299, 2014; related pre-print available at arXiv.

URL <http://dx.doi.org/10.3390/axioms3020280>

URL <http://arxiv.org/abs/1406.4229v1>

The iso-geometric approach has to date not been analyzed at irregular points (a.k.a. extraordinary points or star points) where more or fewer than four tensor-product splines meet smoothly. Since the smooth joining of spline (surface) pieces is governed by geometric

continuity relations, it is natural to apply the concept of geometric continuity to constructing everywhere differentiable iso-geometric elements.

This presentation at the Dagstuhl workshop consisted of a comparative study by Thien Nguyen, Kęstutis Karčiauskas and Jörg Peters [1] of several classical, discrete differential and four (new) isogeometric methods and explained why geometrically continuous surface constructions yield iso-geometric elements that are differentiable also at irregular domain points [2].

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3.28 Interactive Spacetime Control of Deformable Objects

Konrad Polthier (FU Berlin, DE)

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Joint work of Hildebrandt, Klaus; Schulz, Christian; von Tycowicz, Christoph; Polthier, Konrad

Main reference K. Hildebrandt, C. Schulz, C. von Tycowicz, K. Polthier, “Interactive Spacetime Control of Deformable Objects,” *ACM Transactions on Graphics – SIGGRAPH 2012 Conference Proceedings*, 31(4:71), 8 pages, 2012.

URL <http://dx.doi.org/10.1145/2185520.2185567>

Creating motions of objects or characters that are physically plausible and follow an animator's intent is a key task in computer animation. The spacetime constraints paradigm is a valuable approach to this problem, but it suffers from high computational costs. Based on spacetime constraints, we propose a framework for controlling the motion of deformable objects that offers interactive response times. This is achieved by a model reduction of the underlying variational problem, which combines dimension reduction, multipoint linearization, and decoupling of ODEs. After a preprocess, the cost for creating or editing a motion is reduced to solving a number of one-dimensional spacetime problems, whose solutions are the wiggly splines introduced by Kass and Anderson [2008]. We achieve interactive response times through a new fast and robust numerical scheme for solving the one-dimensional problems that is based on a closed-form representation of the wiggly splines.

3.29 Interactive geometric modeling under nonlinear constraints

Helmut Pottmann (KAUST – Thuwal, SA)

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Joint work of Gomes, Alexandra; Jiang, Caigui; Pottmann, Helmut; Sun, Xiang; Tang, Chengcheng; Tomicic, Marko; Wallner, Johannes; Wang, Jun

Main reference C. Tang, X. Sun, A. Gomes, J. Wallner, H. Pottmann, “Form-finding with polyhedral meshes made simple,” *ACM Transactions on Graphics*, 33(4), 9 pages, 2014.

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Aiming at shape modeling systems which support the user to satisfy constraints implied by function and fabrication of the designed product, we present a computational framework for


handling nonlinear constraints within interactive geometric modeling tools. Our approach can be described as guided exploration of the constraint space whose algebraic structure is simplified by introducing auxiliary variables and ensuring that constraints are at most quadratic. Computationally, we perform a projection onto the constraint space which is biased towards low values of an appropriate energy which expresses desirable soft properties like fairness. Our main application is form-finding for polyhedral meshes, taking care of user-specified constraints like boundary interpolation, planarity of faces, statics, panel size and shape, enclosed volume and cost. Moreover, we present results on interactive design of freeform honeycomb structures, polyhedral patterns and developable B-spline surfaces.

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3.30 Rational Manifolds by Simple C_k Constructions

Hartmut Prautzsch (KIT – Karlsruher Institut für Technologie, DE)

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Commenting on known work by other authors, I will discuss a construction of piecewise rational free form G_k surfaces with linear rational transition functions. Albeit rational, these surfaces can be represented by integral splines over affine planes which are extended to homogenous splines over the space. Conversely from any integral splines over affine planes, we can easily obtain a rational spline manifold. In particular, spherical Bernstein-Bezier surfaces introduced by Alfeld et al in 1996 can be described in this way and we can derive their common Bézier representation. For odd degree, the common and the spherical Bézier representation by Alfeld et al. have a simple geometric relationship.

3.31 Geometric Modeling in the Cloud

Ewald Quak (Technical University – Tallinn, EE)

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This talk provided some information about two ongoing European projects which include the porting of geometric modeling approaches to Cloud computing environments.

One project is CloudFlow – Computational Cloud Services and Workflows for Agile Engineering – in the framework of Factories of the Future (FoF) that aims to ease the access to computationally demanding virtual product development and simulation tools, such as CAD, CAM, CAE, and make their use more affordable by providing them as engineering

Cloud services. CloudFlow (<http://www.eu-cloudflow.eu>) will organize two open calls to solicit application experiments to be run in the framework of CloudFlow, the first of which was published on 30 June, 2014.

The other project is IQmulus– A High-volume Fusion and Analysis Platform for Geospatial Point Clouds, Coverages and Volumetric Data Sets in the area of “Big Data” (<http://www.IQmulus.eu>). The IQmulus project addresses the integration of cutting edge computational approaches for data processing and visualization in Cloud infrastructures to make crucial information from large geospatial datasets available on time and to derive and visualize important knowledge for the relevant level of decision-making. IQmulus held its first scientific workshop processing Large Geospatial Data in July 2014 co-located with the Eurographics Symposium on Geometry Processing (SGP 2014).

3.32 SpiraLine: Interpolatory subdivision with log spirals

Jarek Rossignac (Georgia Institute of Technology, US)

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We propose a new interpolatory subdivision scheme that produces curves in two and three dimensions, which we call spiraLines. We argue that the fairness of the spiraLine and the predictability of its behavior during interactive editing compare favorably to those offered by several other schemes. SpiraLines may be used to model circles and logarithmic spirals exactly and have many other benefits: they have local control, they are surprisingly stable when inserting additional control points and when sliding a control point tangentially along the curve, their curvature is fairly continuous and does not exhibit the ringing effect that plagues the fourPoint subdivision curves, an adequate spiraLine approximation of a given curve may often be designed using fewer control points than other interpolating curve would require, and finally spiraLines provide a consistent treatment of closed-loop curves and of the subdivision of the end-segments in non-closed curves.

3.33 Isogeometric Analysis with box-splines: a preliminary study

Maria Lucia Sampoli (University of Siena, IT)

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B-spline and NURBS representations (with a tensor-product structure in 2D) are an effective tool originally developed in the context of geometric modeling, and they constitute the standard form of modern CAD software libraries.

Recently they have been successfully used in the so called *Isogeometric Analysis* to represent both geometry and physical fields for the solution of problems governed by partial differential equations. One of the main advantages of this new approach is the elimination of geometric-approximation error at even the coarsest level of refinement. In addition, the increased continuity of the NURBS basis has led to significant numerical advantages over traditional FEM methods.

On the other hand the tensor-product structure makes the modeling on rectangular regions a hard task, often accomplished by inserting unnatural singularities in the geometry

map. A way to overcome this problem is to consider triangular topologies, even if dealing with completely general triangulations is quite difficult, because only in few cases suitable bases for the corresponding spline spaces are available. Moreover, their extension to the trivariate setting is computationally prohibitive in practice. Aim of the current work is therefore to investigate on the usage of suitable splines on regular triangulations (in particular on regular three-directional meshes), which can be seen as the natural bivariate generalization of univariate B-splines and can be extended to higher dimensions. Then, they can be seen as an intermediate step between tensor product structures and general triangulations and can provide an interesting alternative to NURBS in IgA.

In this talk the first steps for the employments of box-splines in IgA will be discussed.

3.34 Mesh Denoising via L0 Minimization

Scott Schaefer (Texas A&M University – College Station, US)

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Joint work of He, Lei; Schaefer, Scott

Main reference L. He, S. Schaefer, “Mesh denoising via L_0 minimization,” ACM Transactions on Graphics – SIGGRAPH 2013 Conference Proceedings, 32(4:64), 8 pages, 2013.

URL <http://dx.doi.org/10.1145/2461912.2461965>

We present an algorithm for denoising triangulated models based on L_0 minimization. Our method maximizes the flat regions of the model and gradually removes noise while preserving sharp features. As part of this process, we build a discrete differential operator for arbitrary triangle meshes that is robust with respect to degenerate triangulations. We compare our method versus other anisotropic denoising algorithms and demonstrate that our method is more robust and produces good results even in the presence of high noise.

3.35 From Solid Modeling to Material Modeling

Vadim Shapiro (University of Wisconsin – Madison, US)

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Classical solid modeling techniques were designed to model curves, surfaces, and solids in support of traditional manufacturing. These techniques appear to be ill-suited for modeling of complex material structures, such as composites and random heterogeneous materials, that are increasingly important in modern manufacturing and engineering of materials. I will attempt to articulate some of the challenges in modeling of such material structures and speculate on possible approaches for addressing them.

3.36 Motorcycle Graph Enumeration from Quadrilateral Meshes for Reverse Engineering

Hiromasa Suzuki (University of Tokyo, JP)

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Joint work of Suzuki, Hiromasa; Gunpinar, Erkan; Moriguchi, Masaki; Ohtake, Yutaka

Main reference E. Gunpinar, M. Moriguchi, H. Suzuki, Y. Ohtake, "Motorcycle Graph Enumeration from Quadrilateral Meshes for Reverse Engineering," *Computer-Aided Design*, Vol. 55, pp. 64–80, Oct. 2014.

URL <http://dx.doi.org/10.1016/j.cad.2014.05.007>

Recently proposed quad-meshing techniques allow the generation of high-quality semiregular quadrilateral meshes. This paper outlines the generation of quadrilateral segments using such meshes. Quadrilateral segments are advantageous in reverse engineering because they do not require surface trimming or surface parameterization. The motorcycle graph algorithm of Eppstein et al. produces motorcycle graph of a given quadrilateral mesh consisting of quadrilateral segments. These graphs are preferable to base complexes, because the mesh can be represented with a smaller number of segments, as T-joints (where the intersection of two neighboring segments does not involve the whole edge or vertex) are allowed in quadrilateral segmentation. The proposed approach in this study enumerates all motorcycle graphs of a given quadrilateral mesh and optimum one for reverse engineering is then selected. Due to the high computational cost of enumerating all these graphs, the mesh is cut into several sub-meshes whose motorcycle graphs are enumerated separately. The optimum graph is then selected based on a cost function that produces low values for graphs whose edges trace a large number of highly curved regions in the model. By applying several successive enumeration steps for each sub-mesh, a motorcycle graph for the given mesh is found. We also outline a method for the extraction of feature curves (sets of highly curved edges) and their integration into the proposed algorithm. Quadrilateral segments generated using the proposed techniques are validated by B-spline surfaces.

3.37 Applying Geometric Constraints in Reverse Engineering

Tamas Varady (Budapest University of Technology and Economics, HU)

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This talk revisits and extends former work on reverse engineering with constraints; see [Benk et al. 2002]. Due to noisy data and the numerical nature of surface fitting, the majority of reconstructed CAD models need to be perfected to meet various engineering requirements in downstream applications. The surface elements must be accurately aligned and set to parallel, orthogonal, tangential, coaxial, and so on. This is hardly possible when surfaces are fitted individually, however, this can be accomplished when various groups of entities are fitted simultaneously while obeying a set of constraints.

This talk focuses on the automatic detection of likely geometric constraints and discusses the approximation of multiple point sets by solving large systems of equations. The proposed numerical method is capable to automatically disregard contradicting or over-determined constraints. The process can be significantly simplified by means of introducing the so-called auxiliary elements, which also help to set up global constraints for optimal orientation, best

matching grid, full or partial symmetries, etc. The method will be illustrated by several examples showing reconstructed objects without and with constraints.

3.38 Computing Stable and Compact Representation of Medial Axis

Wenping Wang (University of Hong Kong, HK)


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As a complete shape description, the medial axis of a geometric shape possesses a number of favorable properties—it encodes symmetry, local thickness and structural components of the shape it represents. Consequently, the medial axis has been studied extensively in shape modeling and analysis since its introduction by Blum in 1960's. However, the practical application of the medial axis is hindered by its notorious instability and lack of compact representation; that is, a primitive medial axis without proper processing is often represented as a dense discrete mesh with many spurious branches and a large number of vertices. In this talk I shall present some recent studies on computing stable and compact representations of the medial axes of 2D and 3D shapes. Specifically, techniques from mesh simplification, spline fitting, and optimal point sampling will be employed to compute a medial axis without spurious branches and represented by a small number of mesh vertices, while meeting specified approximation accuracy.

4 Working Groups

4.1 Workshop: 3D Printing

Ligang Liu and Ewald Quak

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Main reference L. Gilpin, “3D printing: 10 companies using it in ground-breaking ways,” Tech Republic, March 26, 2014.

URL <http://www.techrepublic.com/article/3d-printing-10-companies-using-it-in-ground-breaking-ways/>

3D printers have become popular in recent years and enable fabrication of custom objects for home users. The promise of moving creations from a virtual space into reality is truly tantalizing, and its applications go far beyond basic manufacturing and rapid prototyping. Many obstacles remain, however, for 3D printing to be practical and commonplace.

The workshop on 3D printing was organized by Ligang Liu (University of Science and Technology of China) and Ewald Quak (Tallinn University of Technology). It featured an introduction by Ewald Quak on some examples of the media attention 3D printing has found in recent times, and two presentations, one by Ligang Liu on Geometry Processing for 3D Printing and one by Gershon Elber (Technion) on Volumetric Modeling, both concerning some of the geometric challenges arising in 3D printing.

The lectures were followed by a general discussion on possible future activities of the scientific community represented at this Dagstuhl meeting in the area of 3D printing, like how 3D models need to be processed for the purpose of 3D printing and whether 3D printing forms a disruptive technology that will enable ordinary users, not just trained professionals, to generate, design and produce 3D models. Connections to another session at the meeting

concerning material sciences were pointed out as 3D printing not only involves geometric design but also issues like deformable models, structural analysis and material properties.

Some comments by T. Grandine (Boeing) on the industrial geometric issues faced by Boeing concerning 3D printing were given as “There are several groups at Boeing pursuing 3D printing technology. Boeing is already using 3D printing for 1000s of different parts. The emerging AMF standard (Additive Manufacturing Format) for 3D printing is seriously flawed in many of the same ways as STL. In particular, it is overly reliant on triangle meshes as a means of transmitting geometries to printers. There is a real opportunity for our geometric modeling community to get involved and offer meaningful alternatives to what is currently under discussion.”


Some of the recent works on computational techniques of 3D printing are included below and have received considerable attention for assisting users to generate desired manufacturable objects.

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4.2 Workshop: The Future Challenges of Subdivision


Kai Hormann

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In this workshop, we reviewed the state of the art of subdivision methods for geometric modelling and tried to identify the future challenges for this field of research. We agreed that subdivision algorithms for curves are well understood by now, but that we still lack good schemes and analysis tools for surfaces. In particular, we believe that non-linear or geometric surface schemes should be developed and examined, as they have the potential to provide reproduction of basic shapes (cylinder, spheres, etc.) and C^2 -continuous and fair limit surfaces.

4.3 Workshop: Modeling heterogeneous, multi-scale, and graded material structures and behaviors

Jarek Rossignac and Vadim Shapiro

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Novel additive manufacturing technologies provide support for producing parts and assemblies with a complex internal structure made of arbitrary compositions of increasingly small constituents of different materials. Rapid advances in natural sciences, in biomedical engineering, in material science and engineering, and in other emerging disciplines demand modeling and representation of heterogeneous, multi-scale, and graded structures. Although in principle, voxel-based representations could be used to represent such complex material compositions, they do not, by themselves, adequately support the design, editing, and analysis needs in most applications due to limited resolution, lack of analytic properties, lack of support for high-level design editing, and explosion in computational cost.

The workshop addresses the challenges that the Geometric Modeling research community must face in order to support modeling and representation of such material structures in variety of applications. It is also important to provide the Industry with the theoretical foundations and practical design and processing tools that are adequate for specifying the functional objectives and constraints, for generating automatically a detailed geometric model of the shape and of its internal structure that is independent of any particular manufacturing technology and that may vary through space, for editing the representation at different levels of detail, and for exporting it to specific analysis tools and specific manufacturing devices.

Here are examples of what we need to understand and develop:

- What physical and material properties and microstructures must be represented and at what scale of detail?

- What are the underlying principles for modeling multi-scale models and hierarchical material structures?
- To what extent it is possible to characterize physical properties of such structures by geometric computations?
- How to represent, at the high design level, the intended functionality and behavior of the entire assembly and the, possibly continuous, space varying distribution (gradation) of mechanical properties?
- How to model and visualize the responsive behavior of these structures, including those having more than one structural states (memory alloys) or those changing states (ceramics during baking)?
- How to specify, represent, analyze and visualize stochastic models defined by space varying distributions of density, shape, size, and orientation, material chunks?
- How to cope with the increased topological and computational complexity of materials with a periodic, although possibly irregular, internal structure that may follow prescribed contours?
- How to best support precise and local geometric queries needed for interactive visualization and analysis?
- What constructions and transformation are needed to effectively support modeling systems for such complex material structures?
- How does one architect a modeling system for design, simulation, and planning of such material structures?
- How to best incorporate the constraints imposed by the limitation of a particular manufacturing technology throughout the design phases, while preserving, as much as possible the integrity of the intentional specification model and its independent of a particular resolution or manufacturing technology?
- How to best design, visualize, and edit effective material properties and their gradation?
- How to extend, to these advanced material structures, the principles of dimensioning and tolerancing developed originally for mechanical assemblies, so that we can capture, visualize, and analyze the uncertainty in behavior resulting from variations in a particular manufacturing process?
- How to compare two different models and measure and visualize their differences, for example to identify equivalent parts or to compare the intended and the manufactured models?
- How to support the interactive design, simulation, and visualization of physical properties, behavior, shape, and structure and multiple levels of detail?

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