MATHEMATICAL LOGIC AT THE DEPARTMENT OF MATHEMATICS AT TU DARMSTADT

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The history of logic in Darmstadt goes back to 1874, when Ernst Schröder (1841-1902) was appointed as a professor at the Polytechnikum Darmstadt (1874-1876) which in 1877 became the TH Darmstadt. The precursor of the current research group in logic, however, started in the year 1970 when Rudolf Wille (1937-2017) founded the research group 'AG1: Allgemeine Algebra' ('Research Group 1: Universal Algebra') which was enlarged in 1971 with the appointments of Peter Burmeister (1941-2019) and Klaus Keimel (1939-2017) as new professors.[1] Later also Christian Herrmann (*1943), who had received his PhD under the supervision of Wille in 1972, became an apl. Professor in this group. Besides Universal Algebra, topics of AG1 were partial and topological algebraic structures, Discrete Mathematics, and Lattice Theory involving aspects of decidability and axiomatizability. Also in 1971, Peter Zahn (*1930) came to Darmstadt joining the research group of Detlef Laugwitz, where he received his Habilitation in 1973 and later became apl. Professor and after the retirement of Laugwitz member of the logic group working primarily on predicative foundations of mathematics influenced by Paul Lorenzen. In 1978, Bernhard Ganter (*1949), who had received his PhD under the direction of Rudolf Wille in 1974, joined the AG1 as Professor but moved in 1993 to the TU Dresden. Out of the AG1, the research group on *Formal Concept Analysis* emerged, which focused on graph-based logic systems for concept analysis in knowledge acquisition and processing applications (Burmeister, Ganter, Wille). This research is still being pursued in co-operation with the 'Ernst Schröder Zentrum für Begriffliche Wissensverarbeitung e.V.' which started in 1983 with Wille as its first speaker.

During the second half of the 1970s Darmstadt was one site of the multinational seminar on Dana Scott's continuous lattices whose activity resulted in the famous *Compendium of Continuous Lattices* published at Springer in 1980. The Darmstadt site was represented by Klaus Keimel and his student Gerhard Gierz who also worked on sheaf representations of ordered algebraic structures. Karl Heinrich Hofmann (*1932), another co-author of this volume, joined the Mathematics Department in Darmstadt in 1982.

Keimel was also the main contributor and organizer of the later edition *Continuous Lattices and Domains* which appeared in 2003 at Cambridge University Press. This was a strongly revised version which systematically treated also the more general case of domains, i.e. directed complete partial orders lacking a top element, which are of central importance in the denotational semantics of programming languages.

One may add here that Gerd Mitschke worked in Darmstadt during the first half of the 1970s and organized in Darmstadt one of the first informal meetings on λ-calculus (20-25 August

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[1]Logic has been also represented at the Computer Science Department, notably by Wolgang Bibel (*1938), one of the poineers of AI in Germany, who founded the research group of 'Intellektik' (1988-2004).

1973) gathering the few experts who initiated the renaissance of this subject including Henk Barendregt, Roger Hindley, Gordon Plotkin and Chris Wadsworth. Mitschke's work, however, was mainly syntactical and disjoint from the group of people interested in continuous lattices.

In 1995 Klaus Keimel, the newly appointed Thomas Streicher (*1958) and the aforementioned Christian Herrmann started the AG14 'Logik und mathematische Grundlagen der Informatik' ('Logic and the Mathematical Foundations of Computer Science') while the remaining AG1 focused on 'Universal Algebra' (later joined by Thomas Ihringer (1953-2015), who became apl. Professor in 1996) and 'Formal Concept Analysis' (Burmeister, Wille).
Martin Hofmann (1965-2018), who together with Streicher introduced the groupoid model for Martin-Löf type theory, worked in the AG14 as research assistant from 1995 to 1998 and received his habilitation in 1999 when he was already lecturer at the University of Edinburgh. He also joined the AG14 as a professor in the summer term 2001 before he moved to the Computer Science Department of Ludwig-Maximilians-Universität Munich. In this period starting with his habilitation work he developed his type-theory based approach to characterize computational complexity classes in a logical way.

Both the AG1 and the AG14 were re-united around 2003/2004 in connection with the new appointments of Martin Otto (*1961) in 2003 and - as successor of Rudolf Wille - Ulrich Kohlenbach (*1962) in 2004 and the research group was renamed in 'AG Logik'.

The logic group organized the Colloquium Logicum 2008 of the the DVMLG at TU Darmstadt with a special evening lecture by Professor Georg Kreisel in connection with his 85th birthday.

From 2010-2015, Martin Ziegler (*1968, now Professor at KAIST) joined the AG Logik. With Kohlenbach and Ziegler as PI's, the AG Logik took part in the Darmstadt-Tokyo PhD School on Mathematical Fluid Dynamics (2011-2016, DFG International Research Training Group 1529).

Since 2017, Kord Eickmeyer (*1979) has been a permanent lecturer in the logic group.

In 2021, Pascal Schweitzer, who had been appointed as professor in the 'AG Didactik' ('AG Didactics'), became also a co-member of the AG Logik given the close connection between his research and the area of Logic in Computer Science. Finally, in 2021, Anton Freund (*1990), who had been a postdoctoral researcher in Kohlenbach's research group, received a prestigious 'Emmy-Noether-Program' award from the German Science Foundation (DFG) and was appointed in October 2021 as 'Assistenzprofessor' ('assistant professor') in the AG Logik.

In recent years the research group AG Logik represents the subject area of Mathematical Logic viewed as an applied foundational discipline between mathematics and computer science. Research activities focus on the application of proof-theoretic, recursion-theoretic, categorical, algebraic and model-theoretic methods from mathematical logic to mathematics and computer science. Besides classical mathematical logic (represented by proof theory, computability theory and model theory) this involves proof mining, constructive type theory, categorical logic, universal algebra, domain and lattice theory, finite model theory and complexity theory. Within mathematics, a primary field of applications in the proof- and recursion-theoretic setting is the extraction of new information from proofs in areas of core mathematics (proof mining: Kohlenbach). The goal of this applied reorientation of proof theory is the use of proof-theoretic transformations such as appropriate functional interpretations for the analysis of prima facie noneffective proofs in mathematics for the purpose of extracting new results from given proofs. This concerns qualitative aspects such as generalizations of proofs (e.g.

from a linear Banach space setting to metric structures) and new uniformity results (independence of existence assertions from certain parameters) as well as quantitative aspects such as the extraction of explicit rates of convergence or - in cases where this is precluded - rates of metastability, oscillation bounds and other effective data from proofs. This novel proof mining approach, for which the logic group in Darmstadt is internationally recognized as the leading center, has been applied in many areas of (mostly nonlinear) analysis including approximation theory, fixed point theory, ergodic theory, abstract Cauchy problems, nonsmooth optimization, hyperbolic geometry, pursuit-evasion games.

Complementing this applied proof-theoretic research, also foundational goals are pursued such as the calibration of the proof-theoretic strength of mathematical theorems e.g. in combinatorics and concrete independence results (Freund). The proof-theoretic research is also connected to methods in categorical logic, constructive systems of set theory and type theory and homotopic type-theoretic foundations (Streicher) as well as dilators and ordinal notation systems (Freund).

The model-theoretic research of the logic group has close links to discrete mathematics (graphs and hypergraphs, Eickmeyer, Otto, Schweitzer) and algebra (group theory, Schweitzer).

Concerning Logic in Computer Science and the Mathematical Foundations of Computer Science, major activities revolve around issues of semantics. On the one hand, this involves the mathematical foundation of the semantics and the logic of programming languages (Streicher); on the other hand, logics and formal systems are investigated in the sense of model theoretic semantics, w.r.t. expressiveness and definability, with an emphasis on computational aspects (algorithmic and finite model theory, descriptive complexity: Eickmeyer, Otto, Schweitzer) as well as practical and theoretical aspects of the graph isomorphism problem and algorithmic symmetry detection (Schweitzer). Besides specific application domains in computer science, as, e.g., verification, data bases and knowledge representation, there is work on foundational issues in the areas of computability and complexity, as well as type theory and category theory (Streicher).

Overall, the logic group forms an internationally well connected cluster of expertise, with a characteristic emphasis on the connections that mathematical logic has to offer, both w.r.t. other areas within mathematics and w.r.t. the 'logic in computer science' spectrum.

Since the Logic Group was formed in its current form in 2004 many PhDs and habilitations have been completed. PhDs that have been finished are (with the supervisor/mentor mentioned in brackets):

- Julian Bitterlich (2019, Otto)
- Eyvind Martol Briseid (2009, Kohlenbach)
- Felix Canavoi (2018, Otto)
- Jaime Gaspar (2011, Kohlenbach)
- Alexander Kartzow (2011, Otto)
- Daniel Körnlein (2016, Kohlenbach)
- Angeliki Koutsoukou-Argyraki (2016, Kohlenbach)
- Alexander P. Kreuzer (2012, Kohlenbach)
- Peter Lietz (2004, Streicher)
- Tobias Löw (2006, Streicher)
- Carsten Rösnick (2014, Ziegler)
- Pavol Safarik (2013, Kohlenbach)

- Florian Steinberg (2016, Kohlenbach and Ziegler)
- Jonathan Weinberger (2021, Streicher)

Habilitations:

- Achim Blumensath (2008, Otto)
- Kord Eickmeyer (2020, Otto)
- Laurenţiu Leuştean (2009, Kohlenbach)
- Vassilis Gregoriades (2015, Kohlenbach)
- Sam Sanders (expected 2022, Kohlenbach)
- Matthias Schröder (2016, Streicher)
- Benno van den Berg (2011, Streicher)

The logic group conducted many research projects with external funding such as individual DFG projects in the areas of finite model theory (Blumensath, Otto), proof mining (Kohlenbach) and semantics (Keimel), participated in DFG-cooperation projects with e.g. Novosibirsk (Herrmann, Keimel, Kohlenbach, Streicher) and South Africa (Keimel, Kohlenbach, Streicher) and took part in the EU working group APPSEM II (Keimel, Kohlenbach, Streicher, Ziegler).

Current research projects are

- 'Continuous Order Transformations: A Bridge between Ordinal Analysis, Reverse Mathematics, and Combinatorics' (Emmy Noether Programme of DFG - German Research Foundation, Freund),
- 'Proof Mining in Convex Optimization and related areas' (DFG - German Research Foundation Project KO 1737/6-2, Kohlenbach),
- Next generation algorithms for grabbing and exploiting symmetry (ENGAGES, ERC Consolidator Grant, Schweitzer).

The Logic Group takes also part in the new Research Profile Theme 'Cognitive Science' of TU Darmstadt (Kohlenbach).