Greg Michaelson *Editor*

Mathematical Reasoning: The History and Impact of the DReaM Group

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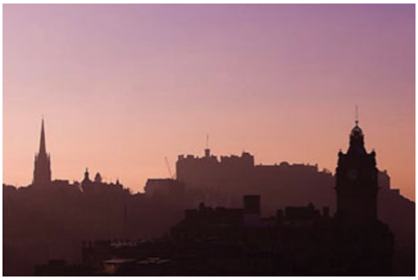
Foreword

AI, Automated Reasoning and Mathematics: DReaM

Edinburgh, one of the most beautiful cities of the world—Athens of the north—and the birthplace of Artificial Intelligence in Europe! Yes, this evokes fond memories of many pleasant visits, research exchanges, a sabbatical, and the close cooperation with Alan Bundy's research group over so many years.

Little did I know what was to come—let alone the meaning of the two letters A and I—when I came to England to study for an MSc in Computer Science at Essex University in 1972. But it was going to change my life, and all my plans, forever.

It was here that I learned for the first time that there are researchers who believe that computers can think, and that computers can have an almost human dialog about a children's blocks world. I also learned that computers can do mathematics—the queen of intellectual disciplines as I used to think as the highbrowed, newly graduated, math student I used to be—in the sense of proving novel mathematical theorems. So when Pat Hayes came from Edinburgh to become a lecturer for AI at Essex University and agreed to accept me as his PhD student, I turned down my chance to go to Oxford to be supervised by Dana Scott and stayed on: a decision I have never regretted—and it came in handy that I had a girlfriend who was doing politics at Essex in Colchester who later became my wife.



Edinburgh, Thou City Fair and High *Nisi Dominus Frustra, Psalm 127*

We learned in our AI courses that a system can do better than heuristic search, and I remember writing an essay on “What is wrong with GPS” (not the Global Positioning System, but Herb Simon’s General Problem Solver based on search by a single mechanism just like a resolution theorem proving system). Pat had written his Logician’s Folly paper,[1] and so, coming back to Germany after my PhD in 1976, I wanted to set up a research group for theorem proving, but not as a search-based resolution system—the still dominating paradigm at CADE. The new battle cry initiated by Carl Hewitt’s thesis at MIT, which hallmarked the paradigm change in AI research, was: knowledge based systems. So, our theorem proving system was still based on resolution, but it was to be guided by a supervisor, where the mathematical knowledge should be represented. We promised our funding agent, the DFG, two things: firstly that we could build a system that was not fundamentally characterised by blind search, mathematically expressed by the R-value (the ratio of the number of clauses in the final proof divided by the total number of clauses generated in the search space); and second, that the system would be by some order of magnitude stronger than any other system on the market, as it was *knowledge based.*

After many years of development, we could show that indeed this was possible, and for many years we had a friendly race with the then strongest system on the market by Larry Wos and his research group at Argonne National Lab, Chicago. This would work by sending each other problems we had solved and hoped that the other one could not do. So sometimes Larry would call in the middle of the night, unaware of the time difference between the continents: “Hey Siekmann, can you do this?” and then we had a week or two, to show that his theorem, indeed followed from the axioms he had also sent. By and by we knew the strength and weaknesses of the Argonne system pretty well and so we sent him a problem that was a real challenge for him, but not for us, for example, as we used a sorted logic among other special features. So our message “Hey, Larry, can you do this?” went to the other side of the Atlantic—but sooner or later his smart students found the trick and solved it as well. This went on for some years with our noses still up in the air, since our theorem prover could always do as well as theirs, but with a significantly better R-value.

But, the total amount of computation including the supervisor was expensive, and in one of the panel discussions Larry provoked us with something like this: “Look, Siekmann,[2] why don’t you discard your supervisor and replace it by the strongest and best system of the world, namely our system OTTER, let it find the proof and guide your base system smoothly to the proof with an R-value of exactly 1”. This was good thinking, in particular since our second promise to the DFG,

[1] Bruce Anderson and Pat Hayes. The logician’s folly, DCL Memo 54.University of Edinburgh. 1972.

[2] He always used my family name as opposed to the usual American custom of addressing a friend by his first name. This was to tease me with his quirky sense of humour that would take too long to explain here (for example, Larry was blind and sued Playboy Magazine for discriminating against the blind by not having any touch sensitive issues). We were really good friends, who respected each other very much.

the fundamental increase in strength, did not really come about: sometimes the pendulum swung to our side of the Atlantic but it always eventually swung back to the American side—the "knowledge base" revolution was never in sight. Also the guidance of the supervisor did not really work as we had hoped, and so by the end of the funding period we were somewhat disconcerted.

And this is the point where Alan Bundy and his ideas came to the rescue.[3]

His paper "A Science of Reasoning" impressed us deeply and left a lasting impression: could we not abandon the whole idea of the supervisor and build a system on very different principles that would come much closer to the way a human mathematician would prove a theorem? That is, to plan a proof at a more abstract level and then refine it down to the final syntactic logical proof?

Proof Planning was born!

Unusually enough, we were given a second chance by the DFG for another "Sonderforschungsbereich", which meant another 12 years of continuous funding, and this was spent on our new system OMEGA, which we considered our final word on the issue of theorem proving. Research was from now on dominated by the close collaboration and friendly competition with Alan's research group in Edinburgh: one of the most pleasant research periods in my academic life.

As a matter of principle, my PhD students had to spend at least half a year abroad, more often than not in Great Britain, and Edinburgh was their favourite spot. My late second wife, Erica Melis, even spent a whole year in beautiful Scotland with Alan Bundy's group and was full of enthusiasm not only about the wonderful countryside, but even more about the inspiring and open research atmosphere, the weekly discussion group, the blue notes, of which she wrote a few herself, and not least by Alan's advice and constructive criticism. And so, by and by, over the years to come, we had so many student exchanges that we jokingly applied to the Saarland Government to install a direct flight from Saarbrücken Airport to Edinburgh to accommodate for the exchanges. Well, there is still no direct flight and I missed many more flights and meetings in Edinburgh, because of the gruesome traffic conditions.

But it is not all work that springs to mind when I think of our visits to Edinburgh: the beautiful Firth of Forth (a tongue twisting pronunciation test for us non-natives); the walk up to Arthur's seat when you needed a break from work; relaxation during a stroll through Princes Street Gardens between the Old Town and the New Town (built in 1767 as J Strother Moore, an American working with Alan in Bernhard Meltzer's Meta-Mathematics Unit, noticed in awe); the Indian meal at Haymarket; and Erica's enthusiasm about the theatre scene during the Fringe Festival, where she took me often, sometimes more than once in a day. And the unforgettable olfactory bliss of malted barley from the city's breweries with scents of roasted malt from the North British Grain Distillery always reminding you that you are in Edinburgh. As a matter of fact, an Edinburger, as the natives are called in Auld Reekie, is no child of sadness: going out for evenings to have a beer somewhere at the Grassmarket (I must have been one of the few foreign members of CAMRA, the Campaign for

[3]Bundy, A.: A Science of Reasoning, pp. 178–198. MIT Press (1991).

Real Ale) or whisky tasting at the Scotch Malt Whisky Society in Queen Street—fond memories indeed. For many years we had a competition in our group, who has the smallest membership number of the Scotch Malt Whisky Society, and with now only an ϵ away from my eighties, I used to win until one day when we hired a new RA we could not believe it: he even had a significantly smaller number. This had to be celebrated with a special single cask whisky.

But it was the friendly intellectually inspiring atmosphere in Alan's research group that was the best experience: everyone was ready for a quick witticism about

Alan Bundy was appointed CBE in the 2012 New Year Honours for services to computing science almost anything, including ourselves. It was here that I learned the best biting British humour about the royal family, but we all fell silent when we saw the following photograph:

The Beat Generation; Jack Kerouac, On the Road; Allen Ginsberg's Howl and Burrough's "Naked Lunch"; and then the1968 student demonstrations in Berlin, London and Paris and now that: Alan Bundy in his cut in front of the queen shaking her hand and receiving the CBE!

Well—even Bob Dylan received the Nobel Prize.

But it was not just automated theorem proving, as this volume shows, but many more areas in AI where Alan and his students made lasting contributions and turned Edinburgh—the Lighthill Report not withstanding—back into one of the most influential and outstanding research sites for symbolic AI in the world: reconnoitring unexplored jungle, as Mateja put it. Or to phrase it using Alan's more sober and modest words:

> *My group has been characterised by its diversity of approaches to the representation of and reasoning with knowledge, including: deduction; meta-level reasoning; learning, especially of new reasoning methods; representation creation and change; as well as applications to problems as diverse as formal verification, analogical blending and computational creativity.*

Yes, Alan you were more dominant and present in our life here at Saarbrücken than you probably know!

Congratulations on your lifetime achievements!

Saarbrücken, Germany Jörg Siekmann
March 23, 2021

Preface

Overview

This timely and engaging collection constitutes a festschrift for the internationally leading DReaM Group (Discovery and Reasoning in Mathematics), founded and led by Alan Bundy, at the University of Edinburgh, from 1971 to the present. In many ways, of course, this book is also a festschrift for Alan himself, whose vision and leadership shine throughout.

Alan, with characteristic modesty, was adamant that the Group as a whole should be celebrated. Nonetheless, it is fundamental to acknowledge his pioneering roles, in both Mathematical Reasoning research, and in sustaining a cutting edge group driven by a strong ethos of mutually supportive inquisitiveness. Alan's contributions have been widely and deservedly recognised. Amongst other awards, he is an elected Fellow of The Royal Society (2012) and of The Royal Society of Edinburgh (1996), a Fellow of the Association for Computing Machinery (2014), and won the 2007 IJCAI Award for Research Excellence and Herbrand Award for Distinguished Contributions to Automated Deduction. In the 2012 New Year Honours, he was appointed CBE for services to Computing Science.

Under Alan's leadership, the DReaM Group enjoyed continuous funding from 1982 to 2019, from the United Kingdom Science and Engineering Research Council (SERC), and its successor, the Engineering and Physical Sciences Research Council (EPSRC). Unlike the more common time-limited, focused funding, this support was based on first Rolling, and then Platform, Grants, to underpin relevant research within a liberal interpretation of Mathematical Reasoning. This has enabled unparalleled support for exemplary activity, as is clear from the strength and diversity of the work presented here.

EPSRC ended funding for all Platform Grants in 2017, so we thought that was a good point at which to create a lasting record of the DReaM Group's contributions. However, as well as heralding the Group's substantial technical achievements, we also wished to highlight how these were nurtured by its constitution, so we asked contributors to present their achievements in wider personal and Group contexts.

Thus, where other festschrifts separate out scientific accounts from personal appreciations, we have sought to explicitly integrate the technical and the social.

In 2018, after Group discussion, I sent out a call to the DReaM email lists soliciting participation. All submissions were accepted, and the authors reviewed each other, with additional reviewers, acknowledged below. Thus, while I am formally the editor, this is very much a collective, Group endeavour.

Contents

The chapters are presented in a rough chronological order of the authors' first engagements with the DReaM Group.

In Chap. 1, Alan Bundy provides a thorough account of the Group's genesis and progress, highlighting key research themes and achievements. This chapter strongly situates the rest of the book.

In Chap. 2, J Strother Moore recounts his impressions of the environment in which the DReaM group first developed, in the Metamathematics Unit and the Department of Machine Intelligence and Perception, in the early 1970s.

In Chap. 3, Toby Walsh surveys his participation in the elaboration and formalisation of the key DReaM approach of proof planning, and of the core rewrite technique of rippling.

In Chap. 4, Paul Jackson explores systematic techniques for dynamically presenting proofs to varying degrees of detail, to aid accessibility and comprehension.

In Chap. 5, Jacques D. Fleuriot discusses the application of proof planning to nonstandard analysis, and fusing mechanical discovery and proof for effective geometric reasoning.

In Chap. 6, Gudmund Grov, Andrew Ireland, and Maria Teresa Llano describe reasoned modelling for system design, where the ideas of proof plans are extended to incorporate patterns of formal modelling.

In Chap. 7, Mateja Jamnik discusses the formalisation and automation of diagrammatic reasoning, and how best to choose representations for optimal human understanding.

Finally, in Chap. 8, Fiona McNeill explores how reasoning about failure, another central DReaM technique, can be applied to matching and integrating ontologies.

Edinburgh, UK Greg Michaelson

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- Jörg Siekmann, for his heartfelt foreword, which ably sets the tone for the rest of the book.

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