AUSTRALIAN RESEARCH COUNCIL
ARC Future Fellowships
Proposal for funding commencing in 2014

FT

PROJECT ID: FT140100048

First Investigator: Dr Serge Gaspers

Admin Org: The University of New South Wales

Total number of sheets contained in this Proposal: 55

CERTIFICATION

Certification by the Deputy/Pro Vice-Chancellor (Research) or their delegate or equivalent in the Administering Organisation

I certify that—

- I have read, understood and complied with the ARC *Future Fellowships Funding Rules for funding commencing in 2014*, and to the best of my knowledge all details provided in this Proposal form and in any supporting documentation are true and complete in accordance with these Funding Rules.
- Proper enquiries have been made and I am satisfied that the Participants and the organisations listed in this Proposal meet the requirements specified in the ARC *Future Fellowships Funding Rules for funding commencing in 2014*. I will notify the ARC if there are changes to any named Participant or organisation after the submission of this Proposal.
- To the best of my knowledge, all Conflicts of Interest relating to parties involved in or associated with this Proposal have been disclosed to this Administering Organisation, and, if the Proposal is successful, I agree to manage all Conflicts of Interest relating to this Proposal in accordance with the *Australian Code for the Responsible Conduct of Research (2007)*.
- I have obtained the agreement, attested to by written evidence, of all the relevant Participants and organisations necessary to allow the Project to proceed. This written evidence has been retained and will be provided to the ARC if requested.
- This Proposal is not substantially aimed at understanding or treating a human disease or health condition (as per the ARC definition of Medical and Dental Research located on the ARC website).
- This Proposal does not duplicate Commonwealth-funded research including that undertaken in a Commonwealth-funded Research Centre.
- If this Proposal is successful, I am prepared to have the Project carried out as set out in this Proposal and agree to abide by the terms and conditions of the ARC *Future Fellowships Funding Rules for funding commencing in 2014* and the ARC *Future Fellowships Funding Agreement for funding commencing in 2014*.
- The Project can be accommodated within the general facilities in this organisation and, if applicable, within the facilities of other relevant organisations specified in this Proposal, and sufficient working and office space is available for any proposed additional staff.
- All funds for this Project will only be spent for the purpose for which they are provided.
- The Project will not be permitted to commence until appropriate ethical clearance(s) has/have been obtained and all statutory requirements have been met.
- I consent, on behalf of all the parties, to this Proposal being referred to third parties, who will remain anonymous, for assessment purposes.
- To the best of my knowledge, the Privacy Notice appearing at the top of this form has been drawn to the attention of all the Participants whose personal details have been provided at the Personnel section.

PART A - Administrative Summary (FT140100048)

A1. If this proposal is successful, which organisation will it be administered by?

Administering Organisation Name

The University of New South Wales

A2. Proposal Title

(Provide a short descriptive title of no more than 150 characters (20 words). Avoid the use of acronyms, quotation marks and upper case characters.)

Algorithms for hard graph problems based on auxiliary data

A3. Person Participant Summary

	Person number	Family name	First name	Current organisation
1	1	Gaspers	Serge	National ICT Australia, The University of New South Wales

	Relevant organisation for this proposal	Role
1	The University of New South Wales	Future Fellowship - Level 1

A4. Organisation Participant Summary

	Organisation number	Short name	Name	Role
1	1	UNSW	The University of New South Wales	Administering Organisation

A5. Summary of Proposal

(In no more than 750 characters (approx 100 words) of plain language, summarise aims, significance and expected outcomes.)

When solving computational problems, algorithms usually access only the data that is absolutely necessary to define the problem. Often, however, much more data is readily available. Especially for important or slowly evolving data, such as road networks, social graphs, company rankings, or molecules, more and more auxiliary data becomes available through computational processes, sensors, and simple user entries. This auxiliary data can greatly speed up an algorithm and improve its accuracy. The project will design improved algorithms that harness auxiliary data to solve selected high-impact NP-hard graph problems, and will build a new empowering theory to discern when auxiliary data can be used to improve algorithms.

A6. Summary of Project for Public Release

(In no more than 350 characters (approx 50 words), please provide a two-sentence descriptor of the purpose and expected outcome of the project which is suitable for media or other publicity material. Do not duplicate or simply truncate the 'Summary of Proposal'.)

A new enabling theory will be developed to discern when auxiliary data can be harnessed to improve the running time and accuracy of algorithms for NP-hard computational problems. The theory will be underpinned by designing faster and more accurate algorithms for high-impact problems related to economics, network security, and graph preprocessing.

A7. Impact Statement

(In no more than 500 characters (approx 75 words), please outline the intended impact of the project. Refer to the Instructions to Applicants for further information.)

The computational problems considered in this project have very high exposure, attracting thousands of citations and a Nobel Prize (Roth and Shapley, 2012). Due to their exponential nature, faster algorithms are paramount to enhance their practical tractability. The theoretical framework will spur further interest in such multivariate algorithms, quantify how valuable auxiliary data is for computational tasks, and give a roadmap to practitioners for solving other NP-hard problems.

PART B - Classifications and other statistical information (FT140100048)

B1. Strategic Research Priorities

Does this proposal fall within one of the Strategic Research Priorities?

(Refer to the Selection Criteria described under Section 4.3 of the Future Fellowships Funding Rules for funding commencing in 2014.)

Strategic Research Priority Selected

Yes

Select which of the Strategic Research Priorities the proposal falls within, and one or more of the relevant Priority Goals for the designated Strategic Research Priority.

	Strategic Research Priority Area	Strategic Research Priority Goal
1	Lifting productivity and economic growth	Deliver skills for the new economy

B2. Does the proposed project increase national research capacity?

National Research Capacity

Yes

B3. Does the proposed project target one or more areas of national significance in disciplinary or interdisciplinary research as outlined in subsection 4.3.2.b of the Future Fellowships Funding Rules for funding commencing in 2014?

	Targeted Research Area
1	Pattern recognition and data mining

B4. Field of Research (FOR)

	Field of Research (FOR)	Field of Research (FOR) Percent
1	080201 - Analysis of Algorithms and Complexity	80
2	080202 - Applied Discrete Mathematics	15
3	010303 - Optimisation	5

B5. Socio-Economic Objective (SEO-08)

	Socio Economic Objective (SEO)	Socio Economic Objective (SEO) Percent
1	970108 - Expanding Knowledge in the Information and Computing Sciences	60
2	890201 - Application Software Packages (excl. Computer Games)	20
3	970101 - Expanding Knowledge in the Mathematical Sciences	20

B6. Keywords

	Keywords
1	algorithms
2	computational complexity
3	parameterized complexity

B7. If the proposed research involves international collaboration, please specify the country/ies involved.

	International Collaboration Country Name
1	Norway
2	Germany
3	Poland

B8. If the proposed research involves collaboration with other organisations, please specify those organisations.

	Organisation
1	University of Bergen, Norway
2	University of Warsaw
3	Berlin University of Technology
4	Charles Darwin University
5	The University of Newcastle
6	The University of Sydney
7	National ICT Australia

C1. Details on your career and opportunities for research over the last 5 years.

(Please attach a PDF detailing your career and opportunities over the last 5 years (2 pages maximum). Refer to the Instructions to Applicants for further information.)

Attached PDF

i) *The number of years since you graduated with your highest educational qualification.*

I obtained a PhD in computer science 5 years ago (December 2008).

ii) *The research opportunities that you have had in the context of your employment situation, the research component of your employment conditions, and any unemployment or part-time employment you may have had.*

Over the last 5 years I have been employed full-time as a postdoctoral scholar or research fellow without interruption. All positions have been research-only positions with a minimal administrative load.

- 06/2012 - 05/2015. ARC DECRA Fellow at the University of New South Wales, Sydney, Australia.
- 10/2010 - 05/2012. Postdoc at the Vienna University of Technology, Vienna, Austria.
- 09/2009 - 09/2010. Postdoc at the University of Chile, Santiago, Chile.
- 01/2009 - 08/2009. Postdoc at the University of Montpellier 2, Montpellier, France.

iii) *Whether you are a research-only, teaching and research, teaching-only, teaching and administration, research and administration, or administration-only academic, giving any additional information (for example, part-time status) needed to understand your situation. Give an indication of what percentage of time you have spent over the last five years in those roles.*

I have been a research-only academic over the last five years.

iv) *Any career interruptions you have had for childbirth, carers responsibility, misadventure, or debilitating illness.*

I have not had any career interruptions.

v) *The research mentoring and research facilities available to you.*

I collaborate frequently with Prof. Toby Walsh, who mentors me and has given me advice on issues related to research and supervision of students. Prof. Maurice Pagnucco, the Head of School of our department, has been very helpful in career advice and related matters. UNSW also offers formal research and supervision training where I have participated this year and I am planning to continue participation. In my research field, I have tight connections with some of the leading figures, such as Michael R. Fellows and Fedor V. Fomin, with whom I often discuss research directions and opportunities.

vi) *Any other aspects of your career or opportunities for research that are relevant to assessment and that have not been detailed elsewhere in this Proposal (for example, any circumstances that may have slowed down your research and publications) or affected the time you have had to conduct and publish your research.*

No other aspects have affected my career or opportunities for research.

C2. Recent significant publications (2009 onwards)

(Please attach a PDF with a list of your recent significant publications. Use asterisks to identify publications relevant to this Proposal. Include books and book chapters, refereed journal articles and refereed conference papers (20 pages maximum).)

Attached PDF

Preliminary remarks. Co-authors are always listed in alphabetical order; this is standard in my field of research. ERA ranks are taken from the ERA 2010 Ranked Journal List and CORE ranks from the CORE 2013 Conference Ranking Exercise.

1 Scholarly books

∗ **[1]** Serge Gaspers. *Exponential time algorithms: structures, measures, and bounds*. VDM Verlag Dr. Mueller e.K., ISBN 978-3-639-21825-1, 216 pages, 2010.

2 Scholarly book chapters

∗ **[2]** Serge Gaspers and Stefan Szeider. *Backdoors to Satisfaction*. In Hans L. Bodlaender, Rodney G. Downey, Fedor V. Fomin, Dániel Marx (editors), *The Multivariate Algorithmic Revolution and Beyond: Essays Dedicated to Michael R. Fellows on the Occasion of His 60th Birthday*, Springer LNCS 7370, pp. 287-317, 2012.

∗ **[3]** Michael R. Fellows, Serge Gaspers, and Frances A. Rosamond. *Multivariate complexity theory*. Chapter 13 in Edward K. Blum and Alfred V. Aho (editors), *Computer Science: The Hardware, Software and Heart of It*, pp. 269-293, Springer, 2011.

3 Refereed journal articles

∗ **[4]** Martin Fürer, Serge Gaspers, and Shiva Prasad Kasiviswanathan. *An Exponential Time 2-Approximation Algorithm for Bandwidth*. Theoretical Computer Science, special issue on Exact & Parameterized Computation – Moderately Exponential & Parameterized Approximation. In press, accepted 03/2013 (ERA rank: A).

∗ **[5]** Daniel Binkele-Raible, Henning Fernau, Serge Gaspers, and Mathieu Liedloff. *Exact and Parameterized Algorithms for Max Internal Spanning Tree*. Algorithmica 65(1): 95–128, 2013 (ERA rank: A*).

∗ **[6]** Fedor V. Fomin, Serge Gaspers, Saket Saurabh, and Stéphan Thomassé. *A linear vertex kernel for Maximum Internal Spanning Tree*. Journal of Computer and System Sciences 79(1): 1–6, 2013 (ERA rank: A*).

∗ **[7]** Serge Gaspers and Matthias Mnich. *Feedback Vertex Sets in Tournaments*. Journal of Graph Theory 72(1): 72–89, 2013 (ERA rank: A).

∗ **[8]** Serge Gaspers and Mathieu Liedloff. *A Branch-and-Reduce Algorithm for Finding a Minimum Independent Dominating Set*. Discrete Mathematics & Theoretical Computer Science 14(1): 29–42, 2012 (ERA rank: B).

∗ **[9]** Michael R. Fellows, Serge Gaspers, and Frances A. Rosamond. *Parameterizing by the Number of Numbers*. Theory of Computing Systems 50(4): 675–693, 2012 (ERA rank: C).

∗ **[10]** Serge Gaspers, Dieter Kratsch, and Mathieu Liedloff. *On independent sets and bicliques in graphs*. Algorithmica 62(3): 637–658, 2012 (ERA rank: A*).

∗ **[11]** Serge Gaspers and Gregory B. Sorkin. *A universally fastest algorithm for Max 2-Sat, Max 2-CSP, and everything in between*. Journal of Computer and System Sciences 78(1): 305–335, 2012 (ERA rank: A*).

∗ **[12]** Stéphane Bessy, Fedor V. Fomin, Serge Gaspers, Christophe Paul, Anthony Perez, Saket Saurabh, and Stéphan Thomassé. *Kernels for Feedback Arc Set in tournaments*. Journal of Computer and System Sciences, 77(6): 1071–1078, 2011 (ERA rank: A*).

∗ **[13]** Daniel Binkele-Raible, Henning Fernau, Serge Gaspers, and Mathieu Liedloff. *Exact exponential-time algorithms for finding bicliques*. Information Processing Letters, 111(2): 64–67, 2010 (ERA rank: B).

∗ **[14]** Fedor V. Fomin, Serge Gaspers, Petr Golovach, Dieter Kratsch, and Saket Saurabh. *Parameterized algorithm for Eternal Vertex Cover*. Information Processing Letters, 110(16): 702–706, 2010 (ERA rank: B).

[15] Serge Gaspers, Margaret-Ellen Messinger, Paweł Prałat, and Richard J. Nowakowski. *Parallel cleaning of a network with brushes*. Discrete Applied Mathematics, 158(5): 467–478, 2010 (ERA rank: A).

∗ **[16]** Fedor V. Fomin, Serge Gaspers, Dieter Kratsch, Mathieu Liedloff, and Saket Saurabh. *Iterative compression and exact algorithms*. Theoretical Computer Science, 411(7–9): 1045–1053, 2010 (ERA rank: A).

∗ **[17]** Serge Gaspers, Dieter Kratsch, Mathieu Liedloff, and Ioan Todinca. *Exponential time algorithms for the Minimum Dominating Set problem on some graph classes*. ACM Transactions on Algorithms, 6(1):9:1–21, 2009 (ERA rank: A).

∗ **[18]** Fedor V. Fomin, Serge Gaspers, Saket Saurabh, and Alexey A. Stepanov. *On two techniques of combining branching and treewidth*. Algorithmica, 54(2): 181–207, 2009 (ERA rank: A*).

∗ **[19]** Serge Gaspers, Margaret-Ellen Messinger, Richard J. Nowakowski, and Paweł Prałat. *Clean the graph before you draw it!* Information Processing Letters, 109(10): 463–467, 2009 (ERA rank: B).

4 Refereed conference papers

∗ **[20]** Fabrizio Frati, Serge Gaspers, Joachim Gudmundsson, and Luke Mathieson. *Augmenting Graphs to Minimize the Diameter*. Proceedings of the 24th Annual International Symposium on Algorithms and Computation (ISAAC 2013). In press, accepted 08/2013 (CORE rank: A).

∗ **[21]** René van Bevern, Michael R. Fellows, Serge Gaspers, and Frances A. Rosamond. *Myhill-Nerode Methods for Hypergraphs*. Proceedings of the 24th Annual International Symposium on Algorithms and Computation (ISAAC 2013). In press, accepted 08/2013 (CORE rank: A).

∗ **[22]** Serge Gaspers and Stefan Szeider. *Strong Backdoors to Bounded Treewidth SAT*. Proceedings of the 54th Annual IEEE Symposium on Foundations of Computer Science (FOCS 2013). IEEE Computer Society, pp. 489–498, 2013 (CORE rank: A*).

∗ **[23]** Geoffrey Chu, Serge Gaspers, Nina Narodytska, Andreas Schutt, and Toby Walsh. *On the complexity of global scheduling constraints under structural restrictions*. Proceedings of the 23rd International Joint Conference on Artificial Intelligence (IJCAI 2013). AAAI Press / IJCAI, pp. 503–509, 2013 (CORE rank: A*).

∗ **[24]** Haris Aziz, Serge Gaspers, Nicholas Mattei, Nina Narodytska, and Toby Walsh. *Ties Matter: Complexity of Manipulation when Tie-breaking with a Random Vote*. Proceedings of the 27th AAAI Conference on Artificial Intelligence (AAAI 2013). AAAI Press, 2013 (CORE rank: A*).

∗ **[25]** Serge Gaspers, Victor Naroditskiy, Nina Narodytska, and Toby Walsh. *Possible and Necessary Winner Problem in Social Polls (Extended Abstract)*. Proceedings of the 12th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2013). IFAAMAS, pp. 1131–1132, 2013 (CORE rank: A*).

∗ **[26]** Serge Gaspers, Thomas Kalinowski, Nina Narodytska, and Toby Walsh. *Coalitional Manipulation for Schulze's Rule*. Proceedings of the 12th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2013). IFAAMAS, pp. 431–438, 2013 (CORE rank: A*).

∗ **[27]** Serge Gaspers, Sebastian Ordyniak, M. S. Ramanujan, Saket Saurabh, and Stefan Szeider. *Backdoors to q-Horn*. Proceedings of the 30th International Symposium on Theoretical Aspects of Computer Science (STACS 2013), LIPIcs 20, pp. 67–79, 2013 (CORE rank: B).

∗ **[28]** Serge Gaspers and Stefan Szeider. *Backdoors to Acyclic SAT*. Proceedings of the 39th International Colloquium on Automata, Languages and Programming (ICALP 2012), Springer LNCS 7391, pp. 363–374, 2012 (CORE rank: A).

∗ **[29]** Serge Gaspers and Stefan Szeider. *Strong Backdoors to Nested Satisfiability*. Proceedings of the 15th International Conference on Theory and Applications of Satisfiability Testing (SAT 2012), Springer LNCS 7317, pp. 72–85, 2012 (CORE rank: A).

∗ **[30]** Serge Gaspers, Mikko Koivisto, Mathieu Liedloff, Sebastian Ordyniak, and Stefan Szeider. *On Finding Optimal Polytrees*. Proceedings of the 26th AAAI Conference on Artificial Intelligence (AAAI 2012), AAAI Press, pp. 750–756, 2012 (CORE rank: A*).

∗ **[31]** Serge Gaspers, Eun Jung Kim, Sebastian Ordyniak, Saket Saurabh, and Stefan Szeider. *Don't Be Strict in Local Search!* Proceedings of the 26th AAAI Conference on Artificial Intelligence (AAAI 2012), AAAI Press, pp. 486–492, 2012 (CORE rank: A).

∗ **[32]** Fedor V. Fomin, Serge Gaspers, Petr Golovach, Karol Suchan, Stefan Szeider, Erik Jan van Leeuwen, Martin Vatshelle, and Yngve Villanger. *k-Gap Interval Graphs*. Proceedings of the 10th Latin American Theoretical Informatics Symposium (LATIN 2012), Springer LNCS 7256, 350–361, 2012 (CORE rank: B).

∗ **[33]** Serge Gaspers and Stefan Szeider. *The parameterized complexity of local consistency*. Proceedings of the 17th International Conference on Principles and Practice of Constraint Programming (CP 2011), Springer LNCS 6876, 302–316, 2011 (CORE rank: A).

∗ **[34]** Serge Gaspers, Mathieu Liedloff, Maya J. Stein, and Karol Suchan. *Complexity of Splits Reconstruction for low-degree trees*. Proceedings of the 37th International Workshop on Graph-Theoretic Concepts in Computer Science (WG 2011), Springer LNCS 6986, 167–178, 2011 (CORE rank: A).

∗ **[35]** Serge Gaspers and Stefan Szeider. *Kernels for global constraints*. Proceedings of the 22nd International Joint Conference on Artificial Intelligence (IJCAI 2011), IJCAI/AAAI, 540–545, 2011 (CORE rank: A*).

∗ **[36]** Michael R. Fellows, Serge Gaspers, and Frances A. Rosamond. *Parameterizing by the number of numbers*. Proceedings of the 5th International Symposium on Parameterized and Exact Computation (IPEC 2010, formerly IWPEC), Springer LNCS 6478, 123–134, 2010 (CORE rank: B).

∗ **[37]** Serge Gaspers and Matthias Mnich. *Feedback Vertex Sets in tournaments*. Proceedings of the 18th Annual European Symposium on Algorithms (ESA 2010), Springer LNCS 6346, 267–277, 2010 (CORE rank: A).

∗ **[38]** Stéphane Bessy, Fedor V. Fomin, Serge Gaspers, Christophe Paul, Anthony Perez, Saket Saurabh, and Stéphan Thomassé. *Kernels for Feedback Arc Set in tournaments*. Proceedings of the 29th IARCS Annual Conference on Foundations of Software Technology and Theoretical Computer Science (FST & TCS 2009), LIPIcs 4, 37–47, 2009 (CORE rank: B).

∗ **[39]** Fedor V. Fomin, Serge Gaspers, Saket Saurabh, and Stéphan Thomassé. *A linear vertex kernel for Maximum Internal Spanning Tree*. Proceedings of the 20th International Symposium on Algorithms and Computation (ISAAC 2009), Springer LNCS 5878, 275–282, 2009 (CORE rank: A).

∗ **[40]** Martin Fürer, Serge Gaspers, and Shiva P. Kasiviswanathan. *An exponential time 2-approximation algorithm for Bandwidth*. Proceedings of the 4th International Workshop on Parameterized and Exact Computation (IWPEC 2009), Springer LNCS 5917, 173–184, 2009 (CORE rank: B).

∗ **[41]** Henning Fernau, Serge Gaspers, and Daniel Raible. *Exact and parameterized algorithms for Max Internal Spanning Tree*. Proceedings of the 35th International Workshop on Graph-Theoretic Concepts in Computer Science (WG 2009), Springer LNCS 5911, 100–111, 2009 (CORE rank: A).

∗ **[42]** Henning Fernau, Serge Gaspers, Dieter Kratsch, Mathieu Liedloff, and Daniel Raible. *Exact exponential-time algorithms for finding bicliques in a graph*. Proceedings of the 8th Cologne-Twente Workshop on Graphs and Combinatorial Optimization (CTW 2009), 205–209. Ecole Polytechnique and CNAM, 2009 (CORE rank: C).

∗ **[43]** Serge Gaspers and Gregory B. Sorkin. *A universally fastest algorithm for Max 2-Sat, Max 2-CSP, and everything in between*. Proceedings of the 20th Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2009), 606–615. SIAM, 2009 (CORE rank: A*).

5 Other publications

Videos

[44] Haris Aziz, Serge Gaspers, Nicholas Mattei, Nina Narodytska, and Toby Walsh. *Algorithmic Decision Theory @ NICTA*. AAAI-13 Video Competition and IJCAI 2013 Video Competition. Received the IJCAI 2013 Most Educational Video Award.

Scientific newsletters

∗ **[45]** Serge Gaspers. *Measure & conquer for parameterized branching algorithms*. Parameterized Complexity News: Newsletter of the Parameterized Complexity Community, September 2009.

C3. Ten career-best publications

(Please attach a PDF of your recent significant publications (5 pages maximum). Refer to the Instructions to Applicants for further information.)

Attached PDF

Ten career-best publications

∗ **1.** Serge Gaspers and Stefan Szeider. *Strong Backdoors to Bounded Treewidth SAT*. Proceedings of the 54th Annual IEEE Symposium on Foundations of Computer Science (FOCS 2013). IEEE Computer Society, pp. 489–498, 2013 (CORE rank: A*).

[ARC DE120101761] Greatly extends the class of known polynomial-time solvable Satisfiability instances along two orthogonal parameters, backdoor size and treewidth, by a complex algorithm based on new and deep mathematical results.

∗ **2.** Fedor V. Fomin, Serge Gaspers, Artem V. Pyatkin, and Igor Razgon. *On the Minimum Feedback Vertex Set problem: exact and enumeration algorithms*. Algorithmica, 52(2): 293–307, 2008 (ERA rank: A*).

Faster algorithm for a problem where brute-force seemed the best possible for a long time. Innovative technique to bound extremal vertex sets in graphs. $54 + 49$ citations. [1] [2]

∗ **3.** Serge Gaspers and Gregory B. Sorkin. *A universally fastest algorithm for Max 2-Sat, Max 2-CSP, and everything in between*. Journal of Computer and System Sciences 78(1): 305–335, 2012 (ERA rank: A*).

Fastest known algorithm for a very well-studied problem. Innovative use and improvement of known analysis techniques. 24 citations.

∗ **4.** Fedor V. Fomin, Serge Gaspers, Saket Saurabh, and Alexey A. Stepanov. *On two techniques of combining branching and treewidth*. Algorithmica, 54(2): 181–207, 2009 (ERA rank: A*).

New techniques for the design and analysis of exponential time algorithms, and new bounds on the treewidth of graphs. $48 + 14$ citations.

∗ **5.** Fedor V. Fomin, Serge Gaspers, Saket Saurabh, and Stéphan Thomassé. *A linear vertex kernel for Maximum Internal Spanning Tree*. Journal of Computer and System Sciences 79(1): 1–6, 2013 (ERA rank: A*).

A preprocessing algorithm that generalizes the very successful crown reduction rule and which holds the current record for the kernel size; see `http://fpt.wikidot.com/fpt-races`

∗ **6.** Serge Gaspers, Dieter Kratsch, and Mathieu Liedloff. *On independent sets and bicliques in graphs*. Algorithmica 62(3): 637–658, 2012 (ERA rank: A*).

Our tight bound on the number of bicliques improves on a famous result. The algorithm counting maximal independent sets is the first of its kind and currently fastest. 30 citations.

∗ **7.** Serge Gaspers, Dieter Kratsch, Mathieu Liedloff, and Ioan Todinca. *Exponential time algorithms for the Minimum Dominating Set problem on some graph classes*. ACM Transactions on Algorithms, 6(1):9:1–21, 2009 (ERA rank: A).

New treewidth bounds for several graph classes lead to faster algorithms for Dominating Set on these classes. $10 + 11$ citations.

[1] All citations are based on my Google Scholar profile (02 Nov 2013).

[2] $x + y$ citations stands for x citations for this paper and y citations for the corresponding conference version.

∗ **8.** Serge Gaspers and Stefan Szeider. *Backdoors to Acyclic SAT*. Proceedings of the 39th International Colloquium on Automata, Languages and Programming (ICALP 2012), Springer LNCS 7391, pp. 363–374, 2012 (CORE rank: A).

[ARC DE120101761] The paper spurs new interest in backdoor sets, using deep theoretical results in an ingenious way.

∗ **9.** Serge Gaspers and Stefan Szeider. *Kernels for global constraints*. Proceedings of the 22nd International Joint Conference on Artificial Intelligence (IJCAI 2011), IJCAI/AAAI, pp. 540–545, 2011 (CORE rank: A*).

Initiates the study of kernelization as a rigorous analysis of proprocessing in the practically very relevant area of global constraints.

∗ **10.** Serge Gaspers, Thomas Kalinowski, Nina Narodytska, and Toby Walsh. *Coalitional Manipulation for Schulze's Rule*. Proceedings of the 12th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2013). IFAAMAS, pp. 431–438, 2013 (CORE rank: A*).

[ARC DE120101761] Reveals a disadvantage of a very widely used voting rule: we describe an advanced polynomial time algorithm for a coalition of voters to "game" an election.

C4. A statement on your most significant contributions to the research field of this Proposal.

(Please attach a PDF of your most significant contributions to the research field of this Proposal (3 pages maximum). Refer to the Instructions to Applicants for further information.)

Attached PDF

The main field of research of this proposal is Computation Theory and Mathematics (FOR 0802), and more specifically, the Analysis of Algorithms and Complexity (FOR 080201).

Most of my research deals with algorithms for NP-hard computational problems. NP-hard problems are a very large class of problems occurring in all kinds of application domains for which no polynomial time algorithms are known. Since it is believed that no NP-hard problem has a polynomial-time algorithm [1], the running times of these algorithms have a super-polynomial dependency on the instance-size or some other parameter of the input. Due to their exponential nature, faster algorithms for NP-hard problems often make the difference between not being able to solve an instance at all (because the running time would easily exceed the age of the universe) versus solving it in a few seconds, with hardware issues being very negligible.

1 Backdoors to Satisfaction

My most significant contribution to Algorithms and Complexity has been my work on backdoors, which aims at explaining fast running times of SAT solvers. In the Satisfiability problem (SAT), the input is a propositional formula in conjunctive normal form, and the question is whether there is an assignment to the variables for which the formula evaluates to TRUE. SAT is probably the most well-known and well-studied NP-hard problem. Nevertheless, the problem is not well understood: practitioners solve very large real-world instances, while theoreticians had been unable to explain why this is possible. Backdoors bring us one step closer to understand why practical solvers work so fast. They provide a way to enlarge classes of instances that can be solved efficiently. The idea is to fix a base-class $\mathcal{C}$ of polynomial-time solvable formulas, and find a set B of variables such that each assignment to these variables reduces the formula to a formula in $\mathcal{C}$. The set B is then called a strong $\mathcal{C}$-backdoor. Other notions of backdoors include weak backdoors (at least one assignment to B reduces the formula to a satisfiable formula in $\mathcal{C}$) and deletion backdoors (removing the variables in B gives a formula in $\mathcal{C}$). Once an algorithm has detected a small backdoor of the input formula, the backdoor can be used to determine the satisfiability of the formula. The exponential dependency of the running time is then reduced from the total number of variables to the size of the backdoor. Detecting small backdoors efficiently is therefore one way to explain that formulas with small backdoors can be solved fast.

My recent papers on backdoor detection include FPT algorithms to find small backdoors to the base classes q-Horn (STACS 2013 [27]), acyclic (ICALP 2012 [28]), Nested (SAT 2012 [29]), and bounded treewidth formulas (FOCS 2013 [22]). Stefan Szeider and I extensively survey parameterized complexity results for problems related to backdoors in a survey which appeared in the 2012 Festschrift honouring Michael R. Fellows on the occasion of his 60th birthday [2] (cited 22 times [2]). This work has been partially supported by an ARC DECRA award. The highlight of this work is an FPT approximation algorithm for detecting backdoors to the class of formulas whose incidence graphs have bounded treewidth. Our backdoor detection algorithm relies on Graph Minor theory, which is often called the deepest theory in discrete mathematics. It should be noted that strong backdoors are much more powerful than deletion backdoors – in addition to the backdoor variables B, we have that for each assignment to B, the clauses satisfied by this assignment are also removed from the incidence graph. This makes the detection of strong backdoors much more challenging, and we developed completely new extensions of Graph Minor tools to tackle these complications. The main result is a quadratic time algorithm [3] for solving any SAT instance that has a constant-size strong backdoor to the class of formulas with bounded treewidth. This work also extends to generalisations of SAT, such as the counting version #SAT (determine the number of satisfying assignments) and Max-SAT (determine a maximum-weight set of clauses that can be satisfied).

FOCS is the top conference in Theoretical Computer Science (tied with STOC), and ICALP is the flagship conference of the European Association for Theoretical Computer Science. Both conferences are extremely competitive, publishing only a small fraction of the best work in Theoretical Computer Science. Further evidence of the community recognition of this work is my invited talk on backdoors at the First Symposium on Structure in Hard Combinatorial Problems (Vienna, Austria, May 2013).

The present proposal is a natural extension of the backdoor approach, where the backdoor can be viewed as additional data, which is first computed, and then exploited to solve the Satisfiability problem.

[1] Proving or refuting this belief would solve one of the famous Millennium Problems by the Clay Mathematics Institute, endowed with one million dollars each: `http://www.claymath.org/millennium/`.

[2] All citations are based on my Google Scholar profile (accessed 02 Nov 2013).

[3] This algorithm will appear in an upcoming journal paper. The FOCS 2013 paper contains a cubic-time algorithm.

2 Exponential time algorithms

Exponential time algorithms aim at designing algorithms for NP-hard problems that are provably faster than brute-force. These are parameterized algorithms where the parameter of interest is related to the instance size, such as the number of vertices for graph problems.

Dieter Kratsch introduced me to the world of exponential time algorithms – and research in general – during my Master studies. In the first year (2004), I implemented a state-of-the-art algorithm for the Dominating Set problem, compared it experimentally against the brute-force algorithm, and suggested heuristics which greatly improved the running times. The second year (2005) was oriented more towards theory and research: I surveyed the current techniques to design and analyse exponential time algorithms, and I designed faster algorithms for several problems (subgraph and hitting set problems).

Fedor V. Fomin was my PhD supervisor (2006–2008). Under his guidance, and in collaboration with other colleagues, I designed faster exponential time algorithms for basic graph problems, such as Feedback Vertex Set ([IWPEC 2006] and [Algorithmica 2008] cited 49+53 times [4]) and the problem of counting proper colourings of a graph ([COCOON 2007] and [18] cited 7+48 times). We developed a new algorithmic technique of combining branching algorithms with treewidth based algorithms ([ISAAC 2006] and [18] cited 14+48 times and received the ISAAC 2006 best student paper award), and transferred the technique of iterative compression to the field of exponential time algorithms ([MFCS 2008] and [16] cited 14 times). Our bounds on the treewidth of sparse graphs, that we needed for the former technique, are used for the analysis of several subsequent exponential and parameterized algorithms. Iterative compression was later been used by Dom *et al.* (J. Discrete Algorithms, 2010) to design an exponential time algorithm for finding minimum feedback vertex sets in tournaments, which was later improved in my work with Matthias Mnich [7,37] (cited 15 times).

Fomin and Kratsch are the authors of the recent textbook “Exact Exponential Algorithms” (2010), which is the standard reference in the field. The Measure and Conquer method that they developed with Fabrizio Grandoni has a very big impact on the analysis of branching algorithms. I contributed to the work on Measure and Conquer by devising novel measures to track the progress an algorithm makes during its execution. In joint work with Henning Fernau and Daniel Binkele-Raible, I illustrated that the Measure and Conquer technique is also relevant for algorithms where the parameter is not related to the instance size [5,41] (cited 17 times).

My most important work in exponential time algorithms is joint with Gregory B. Sorkin. We designed the currently fastest polynomial space algorithm for Max 2-SAT ([11,43] cited 24 times). With the insight that it is sometimes an advantage to replace several 2-SAT clauses by one 2-CSP clause, we left the 2-SAT space and designed an algorithm that works for Max 2-SAT, Max 2-CSP, and mixed instances. The analysis of the algorithm is a very clean and general application of the Measure and Conquer technique. For the first time, we show how to optimize the measure using convex programming, whereas all previous methods used quasi-convex programming at best. Most subsequent papers using the Measure and Conquer technique rely on our method. This work appeared in the proceedings of SODA 2009, the top conference in Algorithms.

This work demonstrates both my ability to invent new methods and techniques, and capacity to devise long and complicated proofs, yet present them in an accessible way. These skills, and my experience in the design and analysis of graph algorithms, will be necessary for the proposed project.

3 Kernelization

Kernelization is a rigorous study of preprocessing algorithms. For a parameterized problem, the goal is to preprocess a given instance I with parameter k in polynomial time into an equivalent instance I' with parameter k' of the same parameterized problem such that $|I'| \leq f(k)$ for some function f. We refer to the function f has the size of the kernel.

For the Feedback Arc Set in Tournaments problem, we obtained the first kernel with a linear number of vertices, which is still the best known kernel [12,38] (cited 24 times). Later work [5] builds on the methods introduced in this paper to find small kernels for other problems.

For the Maximum Internal Spanning Tree problem, we obtained the first kernel with a linear number of vertices [6,39] (cited 14 times). This is still the smallest known kernel, and was obtained by generalising the beautiful crown

[4] $x + y$ citations stands for x citations for the journal version and y citations for the corresponding conference version.

[5] Christophe Paul, Anthony Perez, Stphan Thomass: Conflict Packing Yields Linear Vertex-Kernels for k-FAST, k-dense RTI and a Related Problem. Proc. of MFCS 2011: 497-507

reduction rule, a classic preprocessing rule that is often taught in introductory parameterized complexity courses and used to illustrate more complex data reduction rules.

Finally, in an IJCAI 2011 publication with Stefan Szeider, we introduced kernelization to the field of global constraints, which is known for heavily relying on preprocessing algorithms in practice [35] (cited 9 times).

Since kernelization is one of the main algorithm design techniques in parameterized complexity, my experience in this topic is a valuable asset.

4 Parameterizations

My contributions to the art of problem parameterization have been twofold.

First, a new parameterization of multiple interval graphs was proposed in [32]. Considering the total number of gaps in a multiple interval representation was motivated by work on global constraints in constraint programming, where this parameter arises naturally [35] (cited 9 times). This work provided new tractability results for multiple interval graphs, which occur naturally in scheduling, storage, and bioinformatics.

Second, the study of the Number-of-Numbers parameterization, which considers the number of distinct integers in the input as a parameter, was initiated in [9,36] (cited 11 times). This work was motivated by prior work on a problem in combinatorial chemistry where the number of distinct weights of relevant atoms is naturally bounded [34]. It has been widely adapted by the parameterized complexity community.

Since the present project is heavily based on problem parameterizations with a primary and a secondary parameter, a certain affinity and taste of problem parameterizations is necessary to carry out the project.

5 Combinatorics for algorithm design

My work in algorithm design and analysis is strongly related to combinatorics. New combinatorial tools for the analysis of algorithms are often versatile and fit many settings. The upper bounds on the treewidth of graphs [17,18] (cited 11+10 and 14+48 times) and on extremal vertex sets in graphs [7,10,37] (cited 15, 30, and 53 times) have directly influenced the running time analyses of algorithms which I developed and algorithms designed by others.

For this project, a good understanding of various combinatorial structures in instances, and their influence on running times, is necessary, and will contribute to the success of this project.

6 Computational social choice

My previous work on preference aggregation and the complexity of computing manipulating behaviour by self-interested agents [24,25,26], prepares me well for questions related to stable assignments that are addressed in this project.

In [26], we uncovered a disadvantage of widely-used voting rule, called the Schulze method (Debian, Ubuntu, Gentoo, Software in the Public Interest, etc.). Namely, we showed that there is a polynomial time algorithm which allows a coalition of agents to game an election by misreporting their preferences. This gives an edge to the Ranked Pairs method over the Schulze method, since it satisfies all the desirable properties of the Schulze method, but computing a coalitional manipulation is NP-hard. In [24], we showed that the selection of the tie-breaking method can influence the complexity of computing a manipulation, and we came up with tie-breaking rules which make it significantly more difficult for a coalition of voters to game an election.

7 Conclusion

My previous work demonstrates extensive skills and experience in several aspects that will lead this project to a success: develop new, influential concepts; understand, use, and develop deep and technical mathematical tools; integrate societal and game-theoretic aspects; produce influential research with a compelling presentation having a strong impact in my research field and beyond (my papers are also cited in the areas of wireless networks, signal processing, error correction and localisation, crowdsourcing, computational biology, and planning).

C5. A statement detailing the evidence of your capacity to conduct high quality, innovative research and evidence of your national and/or international research standing.

(Please attach a PDF detailing the evidence of your capacity to conduct high quality, innovative research and evidence of your national and/or international research standing (3 pages maximum). Refer to the Instructions to Applicants for further information.)

1 Publications

In my main areas of research, conferences are the primary publication venues. Several of my papers have been published in the most prestigious conferences in Theoretical Computer Science, such as FOCS, SODA, ICALP, and ESA, and leading Artificial Intelligence conferences, AAAI, IJCAI, and AAMAS. A paper at ISAAC 2006 (CORE rank: A) received the best student paper award. The ERA 2010 and CORE 2013 ranks of my publications (since 2006) are summarised as follows.

Since 2006		
Rank	Journals	Conferences
A*	7	9
A	5	14
B	4	8
C	1	1

Since 2009		
Rank	Journals	Conferences
A*	6	9
A	5	9
B	4	5
C	1	1

Over 70 % of my publications are published in A/A*-rated venues. Co-authors are listed in alphabetical order in all my publications.

2 Citations

My Google Scholar profile (November 2013) lists 19 articles with at least 10 citations, including 9 articles with more than 20 citations. My **h-index** is 14 and my **g-index** is 21.

3 Invitations

I participate regularly in invitation-only workshops such as Dagstuhl seminars, the Workshop on Kernelization, and the Treewidth Workshop, where only the most active, internationally visible, and accomplished or promising researchers are invited.

- Dagstuhl Seminar 13331 on Exponential Algorithms: Algorithms and Complexity Beyond Polynomial Time. Schloss Dagstuhl, Germany, August 11–16, 2013.
- First Symposium on Structure in Hard Combinatorial Problems, Vienna, Austria, May 16–18, 2013.
- WorKer 2013, the 5th Workshop on Kernelization, Warsaw, Poland, April 10-12, 2013.
- Dagstuhl Seminar 12241 on Data Reduction and Problem Kernels. Schloss Dagstuhl, Germany, June 10–15, 2012.
- Treewidth Workshop, Bergen, Norway, May 19–20, 2011.
- Dagstuhl Seminar 10441 on the Exact Complexity of NP-hard problems. Schloss Dagstuhl, Germany, October 31 – November 5, 2010.
- Dagstuhl Seminar 08431 on Moderately Exponential Time Algorithms. Schloss Dagstuhl, Germany, October 19–24, 2008.
- Dagstuhl Seminar 07211 on Exact, Approximative, Robust and Certifying Algorithms on Particular Graph Classes. Schloss Dagstuhl, Germany, May 20–25, 2007.

Furthermore, I have co-authored two invited book chapters [2,3]. The first one gives a basic introduction to the field of parameterized complexity in a book edited by Edward K. Blum and Alfred V. Aho, which covers most major facets of the computer science curriculum. The second one surveys recent results in a more specific topic, the parameterized complexity of backdoor detection, a topic where I contributed to several of the recent major advances. I also presented this work in an **invited talk** at the First Symposium on Structure in Hard Combinatorial Problems (Vienna, Austria, May 2013). Moreover, I wrote an invited article in the Parameterized Complexity Newsletter about work on Measure and Conquer for parameterized algorithms.

I have given seminar talks at Charles Darwin Univ., Australia (1), Dalhousie Univ., Canada (1), IBM Watson Research Center, USA (1), NICTA (2), Pennsylvania State Univ., USA (1), Ryerson Univ., Canada (1), The Institute of Mathematical Sciences, Chennai, India (1), The Univ. of Newcastle, Australia (1), Univ. Adolfo Ibañez, Chile (1), Univ. Bordeaux I, France (1), Univ. de Chile, Chile (4), Univ. d'Orléans, France (1), Univ. i Bergen, Norway (6), Univ. Montpellier 2, France (2), Univ. Nacional de San Antonio Abad del Cusco, Peru (1), Univ. of Sydney, Australia (1), and the Univ. of Toronto, Canada (1).

4 Awards and grants

My currently most prestigious award is a DECRA 2012 award from the Australian Research Council. I was awarded a UNSW Vice-Chancellor's postdoctoral research fellowship, but had to decline it to take up the DECRA instead.

- 2012 NICTA / UNSW Collaborative Research Project on the Computational Complexity of Resource Allocation Problems (with Toby Walsh)
- 2012 Discovery Early Career Researcher Award (DECRA) from the Australian Research Council for the project Solving intractable problems: from practice to theory and back, A$ 375,000 (3 years)
- 2012 Vice-Chancellor's Postdoctoral Research Fellowship at The University of New South Wales, Australia (declined to take up the DECRA instead)
- 2008 L. Meltzers Høyskolefond research grant, 28 000 NOK
- 2007 L. Meltzers Høyskolefond research grant, 28 000 NOK
- 2006 Best Student Paper Award ISAAC 2006
- 2005 Scholarship from the French government (6 months) for the research training of excellent students, 4602 EUR

5 Service and Community

Algorithms Group At The University of New South Wales, I am leading the Algorithms Group, which I created in 2013.

Program Committee I served on the Program Committees of

- IPEC 2013, the 8th International Symposium on Parameterized and Exact Computation (Sophia Antipolis, France),
- AAAI 2013, the 27th AAAI Conference on Artificial Intelligence (Bellevue, Washington, USA),
- IJCAI 2013, the 23rd International Joint Conference on Artificial Intelligence (Beijing, China), and
- IPEC 2010, the 5th International Symposium on Parameterized and Exact Computation (Chennai, India).

Organization I am/was on the Organizing Committee of

- PCCR 2014, the 2nd Workshop on Parameterized Complexity of Computational Reasoning (Vienna, Austria), and
- WorKer 2011, the 3rd Workshop on Kernelization (Vienna, Austria).

I contributed to the organization and local arrangements of WG 2005 (Metz, France), WG 2006 (Bergen, Norway), and WG 2009 (Montpellier, France), the 31st, 32nd, and 35th Workshop on Graph-Theoretic Concepts in Computer Science.

Journal reviews I have reviewed papers for ACM Transactions on Algorithms, Algorithmica, Discrete Applied Mathematics, Discrete Mathematics, Discrete Mathematics & Theoretical Computer Science, Discrete Optimization, Graphs and Combinatorics, Information and Computation, Information Processing Letters, Integers, International Journal of Computer Mathematics, Journal of Combinatorial Mathematics and Combinatorial Computing, Journal of Combinatorial Optimization, Journal of Computer and System Sciences, Journal of Discrete Algorithms, Mathematical Programming, SIAM Journal on Discrete Mathematics, Theoretical Computer Science, and Theory of Computing Systems.

Conference reviews I have reviewed submissions for ADT, CIAC, COCOON, COMSOC, ESA, ICALP, ICTCS, IPCO, IPEC / IWPEC, LATIN, MFCS, SAT, SoCS, SODA, SOFSEM, STACS, SWAT, TAMC, WADS, and WG.

Grant reviews I have reviewed grant proposals for the Australian Research Council and the Czech Science Foundation.

Web I contribute regularly to the research-level Question-Answer site Theoretical Computer Science - Stack Exchange, and occasionally to the Parameterized Complexity Community Wiki and Wikipedia.

C6. A statement detailing the evidence of your capacity to build collaborations across industry and/or research institutions and/or with other disciplines.

(Please attach a PDF detailing the evidence of your capacity to build collaborations across industry and/or research institutions and/or with other disciplines (1 page maximum). Refer to the Instructions to Applicants for further information.)

1 Collaboration with industry and research institutions

From July 2007 until September 2007, I collaborated with Gregory B. Sorkin at the **IBM T.J. Watson Research Center** in Yorktown, New York, USA. My research visit was funded by the Norwegian Research Council, and I retained all Intellectual Property rights during my stay at IBM. Our work on an algorithm for Max 2-Sat and Max 2-CSP was finalized when Gregory Sorkin visited me at the University of Bergen in April 2008, which we published at SODA 2009 and the Journal of Computer and System Sciences in 2012.

Under an Indo-Austrian Science and Technology Cooperation programme between the Indian Department of Science & Technology and the Austrian Science Fund, I visited Saket Saurabh at **The Institute of Mathematical Sciences**, Chennai, India, in January 2012 to collaborate on local search algorithms, which were published at AAAI 2012.

My Collaborative Research Project with Toby Walsh at **NICTA** funds our joint work on Resource Allocation problems, and includes two NICTA researchers and two PhD students. The project started in August 2012 and is expected to continue for the length of the associated PhD projects.

2 Multi-disciplinary projects

Discrete Mathematics Research in algorithm design and analysis is closely related to discrete mathematics. As such, I have extensively collaborated with mathematicians. Some of this work was non-algorithmic and purely mathematical. For example, when I visited Richard J. Nowakowski from November until December 2007, we investigated questions around graph searching with Paweł Prałat and Margaret-Ellen Messinger, and produced an article for the Discrete Applied Mathematics journal. I have also been employed for one year (2009–2010) as a postdoctoral researcher in the Center for Mathematical Modeling at the University of Santiago, Chile.

Combinatorial chemistry Within the area of quantitative structure-activity relationship, several structural measures, such as the Wiener index, of chemical graphs were identified that quantitatively correlate with a well defined process, such as chemical activity or reactivity. Together with one mathematician (Maya Stein, who usually works on infinite graphs) and two computer scientists, we studied a problem arising in this area where given one molecule, one wishes to find other molecules that have a similar Wiener index as the first molecule, with the hope that these molecules will then have similar properties.

Artificial Intelligence Since late 2010, I have been interacting extensively with researchers in Artificial Intelligence (AI), such as Stefan Szeider and Toby Walsh. During my postdoc in Vienna, Austria, I was a member of the knowledge-based systems group, and I am currently affiliated with UNSW's Artificial Intelligence group. Since 2011, I have co-authored 7 papers that appeared at A* ranked AI conferences (IJCAI, AAAI, and AAMAS), and 2 at more specialised A ranked conferences (SAT and CP).

D1. Please upload a Project Description as detailed in the Instructions to Applicants in no more than eight A4 pages and in the required format

Attached PDF

1 Project title

Algorithms for hard graph problems based on auxiliary data.

2 Background

Modelling The theoretical study of computational problems is motivated by real-world applications where a core problem is identified which captures the main difficulty and all irrelevant information about the real-world application is ignored or abstracted away. The resulting computational problems are often versatile and fit many real-world settings. Moreover, they usually capture the essence and the most difficult part of the real-world problem.

Example 1. *For example, the Feedback Vertex Set problem takes as input a graph G and an integer k, and the question is whether it is possible to remove k vertices from G such that the resulting graph is cycle-free. This well-studied problem models various real-world applications. For example, the graph may model processes which use resources, and an arc from one process to another models that the first process is waiting for a resource currently used by the second process. A cycle in this graph then represents a deadlock, and to recover from the deadlock, one would like to make a minimum number of processes release their resources so that the graph becomes cycle-free. But the problem has also important applications in VLSI chip design, genome assembly, database systems, etc.*

The afore-mentioned abstraction has proven very useful. Indeed, it is often the case that new applications identify core problems which turn out to be equal or slight variants of well-studied basic computational problems.

Intractability Unfortunately, many of these computational problems, such as the Feedback Vertex Set problem, turn out to be computationally intractable (NP-hard) [35], with the fastest known algorithms being super-polynomial in the size of the input. NP-hardness is one of the most fundamental complexity theoretical notions expressing computational intractability [35]. Although NP-hard problems frequently arise in practice (e.g., folding proteins, scheduling aircraft landings, or designing faster microprocessors) and have been attacked from many algorithmic angles [17, 26, 32, 42, 55, 56, 59, 70], no polynomial time algorithm exists to date for any NP-hard problem. Among experts, it is widely believed that NP-hard problems cannot be solved in polynomial time [36]; a proof of this conjecture would solve the famous P *versus* NP question, one of the deepest and most difficult problems in mathematics and science.[1]

There are several well-known approaches to cope with NP-hardness, such as heuristics, approximation algorithms, and parameterized complexity. In *parameterized complexity* [17, 21, 26, 59], there is a parameter associated with each instance and the aim is to design algorithms that are fast whenever the parameter is small compared to the overall input size. The parameterized complexity community has a strong focus on the practicality of the technique, which is also one of the reasons why it has been successfully used in many other areas such as computational biology and Artificial Intelligence. The field has articulated a much richer interaction between the theory of computation and practical applications than most other theoretical fields. An exciting frontier, for example, is using carefully targeted parameterized algorithms as subroutines to speed-up established heuristics for hard computational problems, as surveyed in [20].

Enrich the modelling to increase tractability The rationale behind this project is that when modelling a problem, there is often information about the instance, which, although not crucial for the validity or optimality of a solution, can be used to drastically speed up the running time of an algorithm. Most current methods would just ignore this additional information; however, due to the inherent exponential character of NP-hard problems, harnessing or ignoring auxiliary data easily makes the difference between finding a solution in a few seconds or not at all.

Example 2. *Suppose one would like to monitor and secure an optical network. One problem that arises naturally in this domain is the Vertex Cover problem. A vertex cover of a graph is a set of vertices S such that each edge of the graph is incident to at least one vertex of S. In network security, monitoring devices are placed on nodes in the network that form a vertex cover (or a weak vertex cover) [12, 24, 25], and minimizing the number of devices reduces cost, enery, and processing time. The location of waivelength converters in the optical network might be of no relevance for this specific task. However, since waivelength converters form a feedback vertex set of the network [48], an algorithm can utilize the information about the location of waivelength converters to find a smallest vertex cover. Indeed, the proposal will outline a simple algorithm for Vertex Cover that uses a small feedback vertex as auxiliary data.*

The additional information can have several origins.

[1] see the Millennium Problems by the Clay Mathematics Institute, endowed with one million dollars each: `http://www.claymath.org/millennium/`

- It can be a previous solution that the algorithm is supposed to improve. In this case, the input contains a candidate solution, and the task is to find a better solution. There are various scenarios where a previous solution exists.
  - One scenario is that the previous solution was obtained by heuristic or approximate methods.
  - Another scenario is that it used to be an optimal solution, but the data has slightly changed, so that repairing the solution led to a sub-optimal solution.
  - Finally, there are algorithmic techniques, such as *iterative compression* and *local search* algorithms, which find optimal or locally optimal solutions by iteratively improving initial solutions.
- It can be a solution to a different problem. Such a solution can have various origins.
  - One scenario is that the solution has emerged in the instance naturally or by necessity. For example, a part of an optical network that became saturated necessitated an additional waivelength converter.
  - It can also be a solution that has previously been computed. This is especially relevant when dealing with important or central datasets, such as road maps, genomes, and social network graphs, for which a range of problems need to be solved.
- It can be statistical information about the data, which gives information about some parameters of the problem. For example, if the diameter of most social network graphs is small, it makes sense to design algorithms which are optimized for small diameter graphs when dealing with social networks.

Since this project considers NP-hard problems, for which no polynomial-time algorithms are known, algorithmic advances are the only viable alternative to increase their tractability. I will study approaches giving algorithmic improvements that are at least exponential in the instance size or some other relevant parameter.

Parameterized Complexity This work falls naturally within the area of *parameterized complexity*, which is my main research area. Here, the basic insight is that in many situations, a problem's computational complexity is governed by more than just the input size. Therefore, the definition of a parameterized problem includes a parameter k, which is a secondary measurement of problem instances or computational objectives. Any given problem can be parameterized in various ways; a few generic parameters are the size of a solution, the treewidth of the input graph, and the length of the shortest cycle of the input graph. A problem is *fixed-parameter tractable* (FPT) if there is a computable function f and a polynomial function poly, such that the problem can be solved in time $f(k) \cdot \mathsf{poly}(n)$, where n is the input size and k is the parameter. This is in contrast to running times of the form $n^{f(k)}$ that are polynomial for every fixed k, but where the degree of the polynomial grows with k. For FPT problems, the exponential explosion of the running time is instead restricted to the parameter. Once a parameterized problem is shown to be FPT, the next objective is to optimize the running time by decreasing the functions $f(k)$ and $\mathsf{poly}(n)$ in the running time. This makes for an efficient algorithm whenever the parameter is small and provides a fine-grained notion of the complexity of NP-hard problems.

The positive FPT toolkit for designing and analysing parameterized algorithms includes techniques such as iterative compression [29], colour coding [2, 38], Measure & Conquer [7], kernelization [10, 27, 50], and many others.

This positive toolkit is contrasted with a negative toolkit [16], involving hardness results for parameterized intractability classes. Showing that a parameterized problem is W[1]-hard is the basic evidence for parameterized *in*tractability. However, even when a parameterized problem is W[1]-hard, this does not mean that parameterized complexity was unsuccessful for this problem. Instead, it means that other parameterizations of the problem should be investigated in order to focus the origin of the intractability.

3 Aims and approach

I will first state the overall aims of the project, outline the approach, and present more specific aims. Then, I will review concrete methodologies that have already been developed and state how they will be extended, complemented, and combined. Finally, a timeline will be presented.

3.1 Overall aims

A new theoretical framework will be developed to provide the tools to rigorously tell when auxiliary data can be used for algorithmic speed-ups. The standard way to make use of additional data in parameterized complexity, has been to aggregate parameters by taking the sum of the original parameter and a parameter of the additional data. While this approach has its merits for attacking problems that are W[1]-hard with the original parameter and FPT with the aggregate parameter, it is ill-suited for problems that are already fixed-parameter tractable with the original parameter. The new framework will give a much more precise picture about the usefulness of the additional data. The main goal of the project is to identify overarching properties of parameterized problems and auxiliary data, where the auxiliary data helps solve the problems significantly faster. As a complementary goal, I will identify classes of problems and additional data, where the additional data does not help solve the problem significantly faster.

3.2 Approach: secondary parameter

The formal setup of the new theoretical framework developed in this project is as follows. Consider a parameterized problem (k, ℓ)-Π which has a primary parameter k and a secondary parameter ℓ. As usual in parameterized complexity, the main objective is to design algorithms that are efficient whenever the primary parameter k is small. The *secondary parameter* ℓ would typically be a function of the auxiliary data in our setting.

Example 3. *As an example, consider the (sol,fvs)-*VERTEX COVER *problem.*

(sol,fvs)-VERTEX COVER	
Input:	*A graph $G = (V, E)$, an integer k, and a feedback vertex set X of G*
Primary parameter:	k
Secondary parameter:	$\ell = \|X\|$
Question:	*Does G have a vertex cover of size k?*

Recall that a set of vertices S is a vertex cover *of a graph G if each edge of G has at least one endpoint in S, and a* feedback vertex set *of G if the graph obtained by removing S from G is acyclic.*

The main question is how useful the auxiliary information is. Denoting by k-Π the parameterized problem where the secondary parameter is ignored, several scenarios can be imagined.

1. The k-Π problem is W[1]-hard, but (k, ℓ)-Π is FPT whenever ℓ is upper bounded by a function of k. This is the typical scenario that has been investigated in parameterized complexity by augmenting parameters and considering the parameter $k + \ell$ instead of k.

2. The k-Π problem is FPT and a known algorithm solves it in time $f(k) \cdot n^{O(1)}$. Moreover, one can design an algorithm that runs in time $f'(k) \cdot n^{O(1)}$, where $f'(k) = o(f(k))$, for all instances (I, k, ℓ) with $\ell < l(I, k)$. This case corresponds to another scenario where the additional information is useful since it helps to speed up algorithmic running times.

3. The k-Π problem is FPT and a known algorithm solves it in time $f(k) \cdot n^{O(1)}$. Moreover, any algorithm that runs in time $f'(k) \cdot n^{O(1)}$, where $f'(k) = o(f(k))$, for all instances (I, k, ℓ) with $\ell < u(I, k)$, would lead to an algorithm for k-Π on arbitrary instances with running time $f''(k) \cdot n^{O(1)}$ where $f''(k) = o(f(k))$. In this case the auxiliary information is not useful. Results of this type will be obtained by parameterized reductions.

In Points 2 and 3, the functions $l(I, k)$ and $u(I, k)$ lower and upper bound the threshold of when the auxiliary information ceases to be useful.

Let us get back to the (sol,fvs)-VERTEX COVER problem, which is FPT and has an algorithm with running time $1.2738^k \cdot n^{O(1)}$ [14]. Now, if $\ell < \log_2 1.2737 \cdot k \approx 0.3491 \cdot k$, then a tree decomposition of G of width $\ell + 1$ can be computed in linear time [9], and a known tree decomposition based algorithm can be used to solve the problem in $2^\ell \cdot n^{O(1)} = 1.2737^k \cdot n^{O(1)}$ time. On the other hand, any instance (G, k) of sol-VERTEX COVER can be reduced to an instance (G', k', X') of (sol,fvs)-VERTEX COVER in polynomial time with $G' = G$, $k' = k$, and $\ell' = |X'| \leq 2k$ as follows. In polynomial time, compute a 2-approximation S for VERTEX COVER [58]. The set S is a vertex cover of G, and the approximation algorithm guarantees that G has no vertex cover of size less than $|S|/2$. Thus, if $|S| > 2k$, the algorithm returns NO, and if $|S| \leq k$, the algorithm returns YES. Otherwise, set $X' = S$ and return the instance (G', k', X'), since any vertex cover is also a feedback vertex set.

In conclusion, this shows that a feedback vertex set of size ℓ is useful to check whether a graph has a vertex cover of size k when $\ell < \log_2 1.2737$, and that it is not useful when $\ell \geq 2k$.

This project will investigate a range of two-parameter problems and aims at developing meta-theorems giving general criteria of when the secondary parameter or the auxiliary data is useful.

3.3 Specific aims

Treewidth Treewidth has become an important tool in algorithm design. Whole algorithms or subroutines are based on the treewidth approach, where, first a decomposition of the input graph is computed where the overlap between the different parts of the decomposition is bounded, and this decomposition is then used to solve the problem quickly.

A *tree decomposition* of a graph $G = (V, E)$ is a pair $(T, \{X_i : i \in I\})$ where T is a tree on the vertex set I, and for each node $i \in I$, there is a *bag* $X_i \subseteq V$ which is a subset of the vertices of G such that for each edge $e \in E$, there is at least one bag X_i with $e \subseteq X_i$, and for each vertex $v \in V$, the nodes of T associated with bags containing v form a non-empty (connected) subtree of T. The *width* of a tree decomposition is then the size of its largest bag minus one, and the *treewidth* of G is the smallest width of any tree decomposition of G. Treewidth is the most well-known graph decomposition measure, and it has been very successful since the class of graphs with bounded treewidth is a rich class of graphs and many computational graph problems become FPT with parameter treewidth.

Treewidth has a strong connection to the work of Robertson and Seymour who proved the graph minor theorem in a series of twenty papers from 1983 [65] to 2004 [66]. On the other hand, tree decompositions are also frequently used in practice (e.g., [46]) since they capture and exploit graph structure.

The bottleneck of the treewidth approach is usually the computation of a tree decomposition with smallest width, which takes $k^{O(k^3)}n$ time for a graph on n vertices with treewidth k using Bodlaender's algorithm [9]. Unfortunately, tree decompositions are not naturally found or observed in the real world. Since they serve as a way to exploit the structure of instances and can be reused for solving many problems on the same dataset, the project will speed up Boadlaender's famous algorithm. In a similar vein, other recent work [11] concerned the design of approximation algorithms for treewidth that are faster than Bodlaender's algorithm (see also [19, 49, 62, 64]).

Meta-theorems In algorithmic research, a meta-theorem is a theorem giving a complexity or algorithmic result for many computational problems at once. Basic graph problems (vertex cover, feedback vertex set, dominating set) will be bi-parameterized and analysed as in the previous section with the goal of finding common properties explaining why the auxiliary data is useful or not useful, and tackle many problems with the same secondary parameter at once. Courcelle's theorem is one such famous example for the parameter *treewidth*. It states that every graph property definable in monadic second-order logic can be decided in linear time on graphs of bounded treewidth. The meta-theorems resulting from this project will be similarly based on logic and on relationships between parameters.

Stable Matching The Stable Matching With Couples problem is a computational problem to assign residents to hospitals respecting their preferences. The input is a set of hospitals and a set of residents; each hospital has a capacity and a preference over the residents, which is an ordering of residents from most preferred to least preferred; each resident is either single or coupled with another resident; a single resident has a preference over the hospitals, and a couple has a joint preference over pairs of hospitals. The task is to find a stable matching if one exists. A *matching* is an assignment of residents to hospitals not exceeding the hospital's capacity. A matching is *stable* if there is no resident and hospital that are unmatched, but would prefer each other over their current match, and there is no couple of residents (r_1, r_2) and pair of hospitals (h_1, h_2) such that r_1 is not matched to h_1 or r_2 is not matched to h_2 but all of $(r_1, r_2), h_1, h_2$ weakly prefer that r_1 is matched to h_1 and r_2 is matched to h_2.

The Stable Matching With Couples problem is NP-complete [67], but polynomial-time solvable if there are no couples [34]. The algorithms that are currently in use (see, e.g., [68]) take couples into account and are believed to work well in practice because the number of couples is usually small compared to the overall number of residents. However, they are not guaranteed to find a stable matching if one exists. Moreover, the problem is W[1]-hard parameterized by the number of couples [53]. Marx and Schlotter [53] also studied the local search problem where, given a stable matching, a larger stable matching is sought in the k-step neighbourhood and they showed that it is FPT parameterized by $k + c$, where c is the number of couples in the instance. The main drawback of this algorithm is that the initial stable matching is hard to find, and no stable matching may exist.

In contrast, this project will design FPT and FPT approximation [13, 15, 18, 52] algorithms for minimizing the number of blocking pairs in a matching, or a function taking into account how "badly" each blocking pair wants to deviate. The parameters will be combinations of the number of candidates, the number of allowed blocking pairs, the number of allowed unmatched residents, the length of the longest preference list (maximum degree of the graph), and the size of the local search step. In particular, it will be interesting to see whether the local search algorithm of Marx and Schlotter [53] can be extended to matchings where a small number of blocking pairs is allowed. I will also consider other notions of stability, as in [3].

The resulting algorithms will be implemented, made openly available, and tested on data that is openly available through PrefLib [54], and data obtained from associations such as the National Resident Matching Program in the

United States [57], the Foundation Programme in the United Kingdom [61], the Postgraduate Medical Council of Victoria [60], and the Health Education & Training Institute in New South Wales [44].

3.4 Connection to existing work

The remainder of this section relates this research to previous work and approaches, it is clarified in how far the proposed project goes beyond what has been done before, and how the project will integrate into existing work.

Cross parameterization In cross-parameterization, a computational problem is parameterized by the size of the solution to another problem, or, more generally, by the value of the objective function of another problem. For example, one may parameterize the HAMILTONIAN CYCLE problem by the size of a smallest vertex cover. A *Hamiltonian cycle* of a graph is a 2-regular (all vertices have degree 2) connected subgraph spanning all the vertices of the graph, i.e., a tour in the graph visiting each vertex exactly once. From the point of view of fixed-parameter tractability, it makes no difference whether the parameter is the size of an unknown smallest vertex cover or the size of some (not necessarily smallest) vertex cover provided in the input, since a smallest vertex cover can be found in FPT time.

vc-HAMILTONIAN CYCLE	
Input:	A graph $G = (V, E)$, and a vertex cover C of G
Parameter:	$k = \|C\|$
Question:	Does G have a Hamiltonian cycle?

The vc-HAMILTONIAN CYCLE can easily be preprocessed in polynomial time to an instance with $2k$ vertices, which can then be solved by a $O(1.657^{|V|})$ time algorithm for HAMILTONIAN CYCLE [8].

I will informally call parameters, such as the size of a vertex cover, a *minimization parameter*, as being a parameter that one would usually minimize. By contrast, parameters that correspond to the objective function of a maximization problem, are called *maximization parameter*, for instance the size of a clique. This is neither a formal nor a rigorous definition, and some parameters can even play the role of both a minimization and a maximization parameter. I consider several issues in this context, primarily targeted at investigating if and how one can generalize results for variants where a certificate for the parameter is provided in the input.

- For a minimization parameter (such as the size of a vertex cover), where one can compute a minimum certificate (a smallest vertex cover) in FPT time, the complexity of both variants is the same. Here, the main issue is whether the computation of the certificate will slow down the algorithm. One very important parameter in this context is the treewidth of a graph, for which this project sets out to design a faster algorithm.
- For minimization parameters where merely an FPT approximation algorithm is known, i.e., an FPT algorithm computing a value that is within some function of the optimum value, one can compute a certificate whose value is bounded by a function of the parameter. In this case, I conjecture that the problem variant where the input includes a minimum certificate is not easier from a complexity point of view, unless the solution to the problem at hand is very tightly linked to the value of the parameter. What this tight link exactly is will be worked out during the project.
- For maximization parameters, it is crucial that either the input includes a large certificate (as opposed to *some* certificate), or that one can be computed efficiently. These parameters have been explored very little in the parameterized complexity literature. The project will initialize a study of symmetry-breaking algorithms with respect to maximization parameters. For example, large cliques in graphs have been exploited by practitioners as a symmetry-breaking tool for graph coloring [41, 51].

This topic is related to recent work on the complexity ecology of parameters, which has already laid some of the ground work [45, 23]. The project will make use of the insights that have already been developed, especially the maps of graph parameters detailing known relations between graph parameters. It will significantly enrich the current approaches by exploring in how far additional information and parameters can make the problems not only fixed-parameter tractable, but also whether the running times can be improved given the additional information and parameters. In most past work, a problem that was already shown FPT was usually not augmented with more parameters and additional data. In contrast, this project will investigate when speed-ups can be achieved by this augmentation, in the spirit of recent work by Abu-Khzam [1].

Iterative compression Iterative compression is a well-known technique [29, 43] for designing parameterized algorithms for minimization problems, which was developed by Reed et al. [63]. It is based on so-called *compression algorithms*, which, given an instance and a solution of size $k + 1$, determine whether there is a solution of size k. The compression algorithm is then iteratively applied to completely solve the problem. Typically, an instance is constructed iteratively, for example by starting from an empty graph and adding one vertex at a time, and at each step a (not necessarily optimal) solution is obtained from the previous solution by a small local modification. The compression algorithm then needs to check whether there is a smaller solution.

In general, the compression algorithm receives a solution for a smaller instance and is to the determine a solution for the larger instance. This solution to the smaller instance is the auxiliary information that the algorithm receives, and it can speed up the algorithm considerably. However, sometimes the auxiliary information does not seem useful and our attempts to use iterative compression fail to result in faster algorithms. However, no previous theory has been able to rule out the usefulness of iterative compression for specific problems. The technique of iterative compression will be revisited in the new framework, which will help determine for which problems iterative compression is useful.

Changing data Another setting where solutions to other problems arise naturally is when the data changes over time. Dynamic algorithms have access to solutions of previous versions of the data and are required to update the previous solutions to fit the new version of the data. Parameterized dynamic algorithms have been pioneered (yet unpublished work) by the Parameterized Complexity Research Unit (PCRU) at Charles Darwin University. In collaboration with the PCRU, I will use the proposed theoretical framework to determine when a dynamic algorithm should rely on the previous solution and when it is more efficient to find a new solution from scratch.

Local search Local search is a well-known algorithmic technique where the goal is to start from a candidate solution and check whether there is a better solution at distance at most k, for a parameter k. In the context of my current DECRA project [38], I showed that k-step local search can become tractable when the algorithm is allowed to look for better solutions that are at distance more than k, although both k-step local search is intractable, and finding a globally optimum solution is intractable. This illustrates that computational problems can become harder when the auxiliary data restricts the search space of an algorithm. Therefore, this project will focus on so-called permissive local search procedures for the Stable Matching with Couples problem where an algorithm can report a failure when there is no better solution in the k-step neighbourhood of the given candidate solution, but is allowed to find a better solution at any distance from the given candidate solution.

Solving one problem for the sake of solving another The backdoor approach for Satisfiability, which features prominently in my DECRA project, is one example of solving one problem for the sake of solving another one. A central task in Computer Science is to decide whether a given CNF formula is satisfiable. The backdoor approach is, for a fixed class of polynomial-time solvable formulas $\mathcal{C}$, to find a small set of variables such that each assignment to these variables reduces the formula to a formula in $\mathcal{C}$ [40]. Once such a backdoor B is found, the Satisfiability problem can be reduced to solving $2^{|B|}$ formulas in $\mathcal{C}$.

The treewidth approach is another approach where first a tree decomposition is computed, which can then be used to solve a range of other problems; similar for rankwidth and other graph width measures.

These are two well-studied approaches relying on solutions to other problems, which have become standard tools in algorithm design. This project will open up a much larger set of meaningful approaches to exploiting structure in solving NP-hard problems.

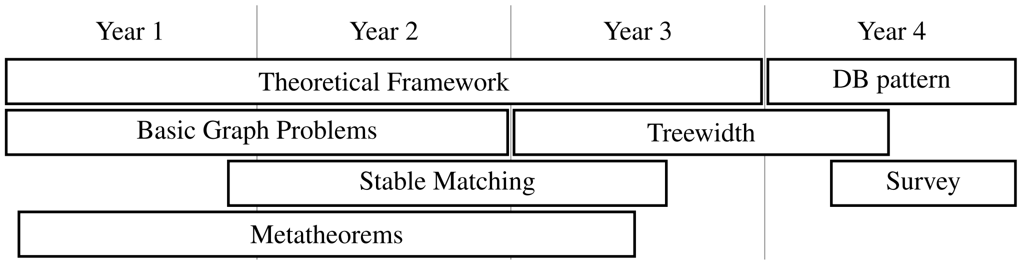
In the context of the Stable Matching With Couples problem, one approach will be to first compute resident types such that all residents of the same type have a similar preference over the hospitals. If the number of types is relatively small compared to the number of residents, because of hospital reputations and locations, an algorithm can then be tailored to run fast when the number of resident types is small. For determining the types, again external information about published hospital rankings and geographical information is likely to make this task easier. On the other hand, hospitals are also expected to have a quite uniform ranking over a small number of classes of residents, classes representing the specialities of the residents and within one class, rankings are expected to be heavily influenced by the reputation of medical schools and academic results and achievements.

3.5 Timeline

Work on the theoretical framework starts right away in Year 1 with basic graph problems providing initial guidance to the development of the framework and metatheorems. The graph problems are selected from application domains such as network security, wireless networks, and computational biology, thereby providing an initial seed for other research projects targeting these areas specifically. A solid version of the theoretical framework is available towards the end of the first year, but it is continually adapted and extended during Years 1–3, in particular when applying it to cross parameterization (Year 1), changing data (Year 1), iterative compression (Year 2), local search (Year 2), and solving one problem for the sake of solving another problem (Year 3).

At the end of Year 1, the data for the Stable Matching problem is acquired, and the initial framework is used to design and analyse algorithms for the Stable Matching problem. The implementation of these algorithms is done in Years 2-3, where a dedicated workstation is needed for testing (12 months). Concurrently, in Year 3, a Treewidth algorithm is designed and analysed (18 months). In Year 4, a collaboration with the database research group at UNSW leverages the framework to preprocess databases of graphs to identify small frequently occurring patterns with small treewidth.

At regular intervals, publications are prepared and presented at conferences and workshops. A survey on the work in this project will round it off in Year 4.



4 Significance and innovation

The significance and innovation of the project is demonstrated along three key points.

First, this research program will develop a new algorithmic theory for efficiently making use of auxiliary data. The proposed framework, along with algorithms for specific problems and classes of problems, will give a roadmap of how one could go about solving a problem for a specific instance. Instead of trying to solve a challenging instance directly, one would first try to solve simpler problems, exactly or approximately, whose solutions give structural information about the instance and help solving the challenging problem much easier, faster, and more accurately.

Second, the project sets out to design faster algorithms for very high-impact problems. One problem is to compute optimal tree decompositions for graphs. The current fastest algorithm for this task is Bodlaender's famous $k^{O(k^3)}n$ time algorithm [9], which has been cited 1,131 times, mainly because it is often used as a first step to solve other graph problems. Another problem for which faster and more accurate algorithms will be designed is the Stable Matching With Couples problem. Previous works on stable matchings received thousands of citations and Alvin E. Roth and Lloyd S. Shapley were awarded the Nobel Prize in Economics 2012 "for the theory of stable allocations and the practice of market design". The topic is a current issue in Australia, where a national intern allocation procedure is heavily promoted, since the current state-based systems suffer from complications due to inter-state movements of medical interns (see, for example, [47]).

Finally, a fully multivariate complexity theory has long been a major goal for the parameterized complexity community. In fact, classical complexity theory is inherently one-dimensional: running times are measured only in terms of instance size. Much of the success of parameterized complexity is attributed to the two-dimensional view of complexity and running times. This research will be another important step in the direction of a fully multivariate complexity theory.

5 Collaboration

The proposed project is centred around a core theoretical framework, with some specific high-profile computational problems. This framework is an ideal starting point around which other research projects focussing on specific application domains will be centred. It is expected that grants involving industries and Centres of Excellence will fund further research connected to the proposed project, for example with the Research Centre for Integrated Transport Innovation (rCITI) at UNSW, the Confederation of Postgraduate Medical Education Councils, and NICTA.

Within this project, the following existing collaborations with leading research groups will be strengthened through collaboration and bilateral research visits, where my visits are funded by the project and their visits are self-funded.

- Within The University of New South Wales, I am leading the recently created Algorithms group, enticing collaboration between algorithms-oriented researchers at UNSW.
- The Algorithms group at the University of Bergen (Norway) [5, 28, 29, 30, 31] is the most important hub for parameterized complexity research internationally. I will collaborate with this group on the iterative compression and local search aspects of the proposed research, especially with my former PhD supervisor, Fedor V. Fomin.
- The Parameterized Complexity Research Unit at Charles Darwin University (Australia) [6, 21, 22] is the major parameterized complexity research group in Australia, and is led by one of the founding fathers of the field, Michael R. Fellows. An extensive collaboration is expected on Changing Data and Cross Parameterization.
- I am a member of the Algorithmic Decision Theory group at NICTA [4, 37, 39], and I will continue my research within this group, in particular with Toby Walsh (AAAI Fellow). Particularly relevant for this project is the group's expertise on preference aggregation and game-theoretic aspects, such as stability and incentives of agents to misreport their true preferences.
- The Sydney Algorithms and Computing Theory group at the University of Sydney [33] is the largest algorithms group in Australia. The expertise of Joachim Gudmundsson (Future Fellow), Fabrizio Frati (DECRA Fellow), and Julian Mestre (DECRA Fellow) in approximation algorithms and algorithmic combinatorics will make for a fruitful collaboration on graph-related research of this project.

Moreover, new collaborations are expected with the following groups.

- The graph database research of UNSW's database research group preprocesses databases of graphs to identify small frequently occurring patterns. In many application domains, it turns out that restricting the pattern graphs to trees is already very useful, since this makes the Subgraph Isomorphism problem – to verify whether a pattern graph occurs in a host graph – significantly more tractable. Considering pattern graphs with bounded treewidth is an obvious extension which remains tractable [2], and this project will identify thresholds on the size, number, and treewidth of the pattern graphs where the preprocessing ceases to be useful.
- Ljiljana Brankovic is an expert in FPT approximation algorithms at the University of Newcastle, and I will collaborate with her on such algorithms for graph problems.
- The algorithms group at the University of Warsaw (Poland) is a new up-and-coming research group with expertise in all areas of parameterized complexity. I will collaborate with this group, notably with Marek Cygan and Marcin Pilipczuk on graph problems, and especially treewidth computation.
- Rolf Niedermeiers group at the Technical University of Berlin is a strong, established group, and I intend to collaborate with them on social choice aspects of this research.

6 Strategic research priorities and targeted priority areas

This project will develop the theory and algorithms for making efficient use of the big data resources a company may have access to. Faster and more accurate algorithms are essential for improved decision-making and planning, which will lift productivity and economic growth (strategic research priority) by providing the skills and tools needed to make use of big amounts of data. The project will increase national research capacity by retaining the Future Fellowship candidate and increasing collaboration within Australia and across the boarder. The project is relevant to the ARC Future Fellowship targeted research area "pattern recognition and data mining", especially the work on graph databases.

7 Communication of results

Conferences being the main publication venues in Computer Science, the dissemination and promotion of research outcomes is planned to be mainly through talks at international conferences and publications in conference proceedings (FOCS, STOC, ICALP, SODA, ESA, IPEC). Where appropriate, journal publications will complement the proceedings version. In particular, the work on stable matchings could be appropriate for a publication in a very broadly journal, such as Science. The produced papers will also be made available at open access repositories and my homepage. By participating in specialized workshops, collaboration with established researchers will be fostered, and my research results that are relevant to the workshop theme will be presented. Software and code will be made openly available in standard repositories and my homepage; an integration in larger software packages, such as Sage [69] seems possible.

D2. References

(Include a list of all references. Write a maximum of three A4 pages.)

Attached PDF

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[55] Zbigniew Michalewicz and David B. Fogel. *How to Solve It: Modern Heuristics*. Springer, 2004.

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[58] G. L. Nemhauser and L. E. Trotter, Jr. Properties of vertex packing and independence system polyhedra. *Math. Programming*, 6:48–61, 1974.

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[62] Bruce A. Reed. Finding approximate separators and computing tree width quickly. In *Proceedings of the 24th Annual ACM Symposium on Theory of Computing (STOC 1992)*, pages 221–228. ACM, 1992.

[63] Bruce A. Reed, Kaleigh Smith, and Adrian Vetta. Finding odd cycle transversals. *Operations Research Letters*, 32(4):299–301, 2004.

[64] Neil Robertson and P. D. Seymour. Graph minors. XIII. The disjoint paths problem. *Journal of Combinatorial Theory, Series B*, 63(1):65–110, 1995.

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[66] Neil Robertson and Paul D. Seymour. Graph minors. XX. Wagner's conjecture. *Journal of Combinatorial Theory, Series B*, 92(2):325–357, 2004.

[67] Eytan Ronn. NP-complete stable matching problems. *Journal of Algorithms*, 11(2):285–304, 1990.

[68] Alvin Roth and Elliott Peranson. The redesign of the matching market for american physicians: Some engineering aspects of economic design. *The American Economic Review*, 89(4):756–757, 1999.

[69] Sage (mathematics software). http://www.sagemath.org.

[70] Vijay V. Vazirani. *Approximation Algorithms*. Springer, 2001.

D3. Strategic Statement by the Administering Organisation

(Provide a Strategic Statement which outlines the alignment between the Future Fellowship Proposal and the Administering Organisation's research strengths (three pages maximum). The Strategic Statement must be signed by the Deputy Vice-Chancellor (Research), Chief Executive Officer or equivalent. Refer to the Instructions to Applicants for further information.)

D3 Strategic Statement by the Administering Organisation

ARC *Future Fellowships* Applicant Dr Serge Gaspers [FT140100048]

The University of New South Wales (UNSW), one of Australia's leading research intensive universities, fully supports the application by Dr Serge Gaspers for a *Future Fellowship* Level 1.

Dr Gaspers received a PhD from the University of Bergen, Norway, in 2008 and is now holds an ARC DECRA at UNSW. He is an expert in parameterized complexity, where he is particularly known for his work on backdoors for the Satisfiability problem, and in exponential-time algorithms, where his main contributions have been in the design and analysis of branching algorithms. He is very well recognised in his fields, which is evidenced by his publications in very selective conferences in Theoretical Computer Science (FOCS, ICALP, SODA, ESA) and Artificial Intelligence (IJCAI, AAAI, AAMAS), and by invited talks at the First Symposium on Structure in Hard Combinatorial Problems and various Dagstuhl seminars.

Dr Gaspers joined the School of Computer Science and Engineering in June 2012. He has formed the Algorithms group, and he has complemented the existing strengths in the School by a new, modern approach termed parameterized complexity. His knowledge and experience in algorithms and complexity has been a valued asset to the School. Indeed, using one algorithmic technique over another may make or break a whole research program, especially when dealing with computational problems with an exponential flavour for which Dr Gaspers is an expert.

UNSW recognises the increasing trend that more and more sciences are being looked at through the algorithmic lens, not only by empowering them through faster data processing, but also by lending a new perspective, with the view point that the likelihood of an evolving system to reach a target state is inversely proportional to the computational complexity of computing a transition from the original state to the target state. UNSW has an established, leading reputation in Computer Science in general and Artificial Intelligence more specifically, as evidenced by a rating of 4 (above world standard) in the ERA 2012 Report for *Information and Computing Sciences* (FoR 08) and ratings at or above world standard in 6 of the the FoR 08 4-digit codes (more than any other university) with: a rating of 5 (well above world standard) in *Computer Software* (0803); ratings of 4 (above world standard) in *Artificial Intelligence and Image Processing* (0801), *Distributed Computing* (0805) and *Information Systems* (0806); and, a rating of 3 (at world standard) *in Computation Theory and Mathematics* (0802) and *Library and Information Studies* (0807).

Accordingly, this candidate, and this Fellowship, is closely aligned with the UNSW Research Strengths[1] of *ICT, Robotics and Devices* and *Fundamental & Enabling Science*.

Contribution of the Future Fellow and Project to Building this Research Strength at UNSW

Building Strength

Dr Gaspers' research strengths are at the intersection of Algorithms and Artificial Intelligence, with his main background in Algorithms. Several of our Artificial Intelligence researchers, such as Prof Toby Walsh (AAAI Fellow), focus on very algorithmically oriented research, meaning that Dr Gaspers nicely complements the existing strengths in the School of Computer Science and Engineering. A significant research strength in parameterized complexity is currently emerging at UNSW, largely due to Dr Gaspers, who is supervising one PhD student and co-supervising another one, and is bringing new views and techniques into the School.

At the Vienna University of Technology, where Dr Gaspers was a postdoctoral researcher from 2010-2012, he was part of an algorithmically oriented research team within an Artificial Intelligence group. In this team, which was funded by a grant from the European Research Council, he designed algorithms for computational problems in several sub disciplines of Artificial Intelligence, such as Constraint Programming, Satisfiability, Bayesian Reasoning, and Local Search. There he laid the ground work for what would later become a very successful DECRA project executed at UNSW.

A Future Fellowship for Dr Gaspers will retain a strong expertise in discrete algorithms at UNSW, which is likely to be the seed for a larger algorithms group. Outside the School of Computer Science and Engineering, a potential collaboration of Dr Gaspers is with A/Prof Catherine Greenhill (President of the Combinatorial Mathematics Society of Australasia and June Griffith Fellow at the School of Mathematics and Statistics), Prof Igor Shparlinski (Fellow of the Australian Academy of Science and Fellow of the Australian Mathematical Society at the School of Mathematics and Statistics), and Prof Travis Waller (Evans & Peck Professor of Transport Innovation and Director of the Research Centre for Integrated Transportation Innovation), and he is already actively involved with the Optimisation research group at NICTA through a Collaborative Research Project.

Enhancing Collaboration
Dr Gaspers has an extensive group of collaborators and this Future Fellowship will give him the resources needed to maintain and further develop these collaborations through joint workshops, research visits, and regular meetings with researchers in Sydney.

He collaborates regularly with the Algorithmic Decision Theory group at NICTA, and he has started a collaboration on parameterized complexity with other non-UNSW researchers in Sydney: Joachim Gudmundsson, Fabrizio Frati, Julian Mestre (University of Sydney), and Luke Mathieson (Macquarie University).

Within Australia, he has extensively collaborated with Michael R. Fellows and Frances A. Rosamond from Charles Darwin University. They play a big role in shaping the field of parameterized complexity and Michael R. Fellows counts as a founding father of the field. Dr Gaspers is working on a new collaboration with Ljiljana Brankovic from the University of Newcastle.

Internationally, Dr Gaspers will maintain his collaborations via short research visits with leading research groups in parameterized computation at the University of Bergen (Norway) and the Vienna University of Technology (Austria). The algorithms group in Bergen has a long history of research excellence in parameterized complexity. In particular, Fedor V. Fomin (Dr Gaspers' former PhD supervisor) is leading a group at the forefront of many aspects of parameterized complexity, including kernelization and the theory of bidimensionality, which has received two grants (2.23 M€ and 1.69 M€) from the European Research Council (ERC). Stefan Szeider, another ERC grantee (1.42 M€), hosted Dr Gaspers as a postdoc at the Vienna University of Technology, which initiated a very successful ongoing collaboration. New collaborations are envisioned with the up-and-coming algorithms group in Warsaw (Poland) and Rolf Niedermeier's established group at the TU Berlin (Germany).

Contribution of the Future Fellow to UNSW Research Capacity and Staffing Profile

Key Staffing
Dr Gaspers is a DECRA recipient, currently employed at Level B. His publications in leading international conferences (FOCS, ICALP, IJCAI, AAAI, SODA, ESA, AAMAS) and journals (ACM Transactions on Algorithms, Journal of Computer and System Sciences, Algorithmica) show that he is internationally recognised as influential in expanding the knowledge of parameterized complexity, and he has significantly impacted his field through these contributions to research.

Dr Gaspers will be continuing his work with Prof Toby Walsh and the Algorithmic Decision Theory group. It is expected that he will be heading an independent research group with interactions with the database group led by A/Prof Raymond Wong, in particular concerning their work on graph databases where the Subgraph Isomorphism problem is prominently featured and parameterized complexity gives a means to make use of specific graph properties in various application domains to speed up queries. As mentioned above, other prospective interactions are with A/Prof Catherine, Prof Igor Shparlinski, and Prof Travis Waller.

Broader Staffing Profile
At UNSW, many research teams rely heavily on algorithms for their research programs. For example, the Research Centre for Integrated Transport Innovation designs and uses algorithms for planning multimodal transport infrastructure and operations. In a world with increasingly interconnected and automated data processing, algorithms become key to innovation. The existence of entire companies - Google, for example –

relies on a single algorithm. Research and innovation based on algorithmic advances is therefore well recognised at UNSW, and Dr Gaspers is a welcome addition to intensify these research strengths.

Opportunity benefit afforded by Fellowship
Dr Gaspers' current fixed-term contract comes to an end in June 2015. A Future Fellowship would guarantee the continuation of his very successful research career at UNSW, with the time and resources needed to continue establishing an internationally leading research group in parameterized complexity for the benefit of UNSW and Australia internationally.

UNSW Support for the Future Fellow

UNSW will commit to providing one APA for a local PhD candidate or one Tuition-Fee Scholarship to support an international candidate, subject to the student being competitive on the UNSW order of merit. Award of a TFS will require the stipend component to be provided by the Faculty/School or Supervisors funds and will therefore represent an additional UNSW cash contribution to that contained in Section E (Budget). It should be noted that since 2012, UNSW has significantly expanded its Tuition-Fee Scholarship program to increase the participation of exceptional international PhD students in our research mission with a concomitant increase in research capacity in strategic areas such as represented by this project. The School of CSE will also provide funding for a part-time research assistant of up to $20,000 for the duration of the Fellowship.

The University also assists its researchers in developing and maintaining pathways for their ongoing development. As such, UNSW has established several initiatives that provide research staff with professional support in planning and developing their careers. Formal performance appraisals are performed in all faculties and researchers are proactively mentored through an innovative Researcher Development Framework program.

UNSW will also provide support for IP protection and commercialisation through New South Innovations Pty Ltd (UNSW’s commercial arm) for any innovations which may arise from Dr Gaspers’ research program.

UNSW is committed to world-class research, actively encouraging its researchers to participate in a wide range of international research collaborations. Moreover, this extends to seizing the opportunity to attract and retain international researchers of the calibre of Dr Serge Gaspers, valuing their international reputation and their strong alignment with UNSW’s areas of research strength.

Integration of the Future Fellow into UNSW Research Activities after Fellowship

At the conclusion of the Fellowship, Dr Gaspers will be offered a further appointment for a minimum of 2 years in the School of Computer Science and Engineering, subject to performance and research output commensurate with the Fellowship. Given Dr Gaspers successful track record to date and this innovative Future Fellowship, conditional on budget constraints it is envisioned that Dr Gaspers will transition to a continuing position.

In closing, I reiterate UNSW’s strong support for the application by Dr Gaspers for a Future Fellowship in 2014 and welcome the opportunity provided by the Australian Research Council to promote and support research both for the benefit of Australia and the University.

Yours sincerely

Professor Les Field
Deputy Vice-Chancellor (Research)

[1] **UNSW Research Strengths** (http://www.dvcresearch.unsw.edu.au/strengths.html)
Biomedical Sciences; Business, Law & Economics; Contemporary Humanities & Creative Arts; Defence & Security; Fundamental & Enabling Science; ICT, Robotics & Devices; Next Generation Materials & Technologies; Social Policy, Government & Health Policy; Water, Environment, Sustainability.

D4. Medical and Dental Research Statement

(If applicable, in no more than 750 characters (approx. 100 words), please justify why this Project does not constitute Medical and Dental Research as defined on the ARC website. Refer to the Instructions to Applicants for further information.)

N/A

PART E - Project Cost (FT140100048)

E1. What is the proposed budget for your project?

(Please provide details of the budget proposed for your project.)

Proposal Funding Summary

Total requested budget: $711489

Year 1

Description	ARC	AdminOrg
Direct Cost	181064	2750
Personnel	143026	2750
FT1 (Dr Serge Gaspers)	143026	2750
Equipment	4895	0
Laptop (HP EliteBook 8570w)	4090	0
Tablet computer (Samsung Galaxy Note 10.1 32Gb 2014 Edition)	805	0
Travel	26743	0
Economy travel support (conference in Europe or North America STOC/FOCS/ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (conference in Europe or North America STOC/FOCS/ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (workshop in Europe WorKer/Treewidth/PCCR/Dagstuhl; 5 days; airfare $2,300; registration $200; accommodation $900; allowance $1,400)	4800	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit Darwin Fellows/Rosamond; 7 days; airfare $700; accommodation $1,848; allowance $995)	3543	0
Other	6400	0
Specialised books	2000	0
Publication costs	3000	0
Data acquisition (National Resident Matching Program)	1400	0

Year 2

Description	ARC	AdminOrg
Direct Cost	184053	7047
Personnel	143026	7047
FT1 (Dr Serge Gaspers)	143026	7047
Equipment	12402	0
High-performance workstation (Dell T7600 with 128 Gb RAM)	9400	0
Software license maintenance and upgrades	3002	0
Travel	25025	0
Economy travel support (conference in Europe or North America STOC/FOCS/ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0

Description	ARC	AdminOrg
Economy travel support (conference in Europe or North America STOC/FOCS/ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (workshop in Europe WorKer/Treewidth/PCCR/Dagstuhl; 5 days; airfare $2,300; registration $200; accommodation $900; allowance $1,400)	4800	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit Newcastle Brankovic; 5 days; rental car $400; accommodation $715; allowance $710)	1825	0
Other	3600	0
Specialised books	600	0
Publication costs	3000	0

Year 3

Description	ARC	AdminOrg
Direct Cost	176546	11337
Personnel	143026	11337
FT1 (Dr Serge Gaspers)	143026	11337
Equipment	4895	0
Laptop (HP EliteBook 8570w)	4090	0
Tablet computer (Samsung Galaxy Note 10.1 32Gb 2014 Edition)	805	0
Travel	25025	0
Economy travel support (conference in Europe or North America STOC/FOCS/ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (conference in Europe or North America STOC/FOCS/ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (workshop in Europe WorKer/Treewidth/PCCR/Dagstuhl; 5 days; airfare $2,300; registration $200; accommodation $900; allowance $1,400)	4800	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit Newcastle Brankovic; 5 days; rental car $400; accommodation $715; allowance $710)	1825	0
Other	3600	0
Specialised books	600	0
Publication costs	3000	0

Year 4

Description	ARC	AdminOrg
Direct Cost	169826	15633
Personnel	143026	15633
FT1 (Dr Serge Gaspers)	143026	15633
Travel	23200	0

Description	ARC	AdminOrg
Economy travel support (conference in Europe or North America STOC/FOCS/ ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (conference in Europe or North America STOC/FOCS/ ICALP/SODA/ESA/IPEC; 5 days; airfare $2,300; registration $600; accommodation $900; allowance $1,400)	5200	0
Economy travel support (workshop in Europe WorKer/Treewidth/PCCR/Dagstuhl; 5 days; airfare $2,300; registration $200; accommodation $900; allowance $1,400)	4800	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Economy travel support (research visit in Europe Fomin/Cygan/Niedermeier; 7 days; airfare $710; accommodation $1330; allowance $1,960)	4000	0
Other	3600	0
Specialised books	600	0
Publication costs	3000	0

PART F - Budget Justification (FT140100048)

F1. Justification of Future Fellowships non-salary funding

(Please provide a statement of no more than four A4 pages indicating how the organisation will use the non-salary funding of up to $50,000 per annum. This statement must fully justify in terms of need and cost, each budget item requested from the ARC using the same headings that are in the budget table.)

Equipment

Laptop A laptop will be used to work while travelling, providing access to information, email, read papers, and write longer notes. One laptop in the 1st year and one laptop in the 3rd year. The price is based on a quote for a HP EliteBook 8570w.

High-performance workstation A high-performance workstation will be used to run experiments for implementations of the assignment algorithms that will be designed. Since it is expected that some algorithms require exponential space (memory), a workstation with 128 Gb of memory will be needed to test the implementations in extreme circumstances. Moreover, it is expected that a trade-off will need to be made between time and space resource usage, which requires a dedicated workstation with large internal memory to fine-tune the parameters of this trade-off to varying memory capacities.

Software license maintenance and upgrades AMPL is a software package to formulate mathematical programs. It is used to optimize the measure in the Measure and Conquer analysis of exponential time algorithms and parameterized algorithms. A license renewal will be required during the 2nd year. Specification: one fixed user license with 3 years always current package ($ 1,565).

Maple is a general-purpose computer algebra system, supporting all kinds of mathematical manipulations to help in the analysis of algorithms. A license renewal will be required during the 2nd year. Specification: one academic single user licenses for Maple 16 ($ 1,437 each).

Tablet computer A touch-screen and stylus enabled Tablet computer will facilitate collaboration when doing research at UNSW and while travelling. It will be used to take digital hand-written notes during discussions and research talks, and to annotate articles. Organizing research notes electronically also makes for a more efficient working environment. One tablet computer in the 1st year and one tablet computer in the 3rd year. The price is based on a quote for a Samsung Galaxy Note 10.1” 32GB 2014 Edition. Tablet computers are not part of standard office equipment at the University of New South Wales.

Travel

Conferences Conferences are the main venues for the publication and dissemination of research results in the areas covered by the project proposal. Indeed, conferences are often regarded more important than journals for publication in computer science.

It is anticipated that the project outputs two conference papers of very high quality per year. The best conferences that are most relevant to this research are FOCS, STOC, ICALP, SODA, ESA, and IPEC, which are usually held in Europe or North America.

Economy airfares are estimated at $ 2,300 for these destinations, and conference registration fees at $ 600. The airfares are based on current prices from Expedia for travel to Paris and New York. The conference registration fees vary around $ 600; for example, the FOCS 2013 fee was 625 USD and the ICALP 2013 fee was 420 EUR. Accommodation and allowances are based on 5-day stays and are estimated using UNSW’s travel budget builder.

Workshops Dissemination is also one of the reasons to participate in workshops uniting experts of specialized research areas or bringing together experts of related areas. The other reason is to foster new collaboration and exchange research ideas.

In the context of this project I will attend one workshop per year, where the new concepts, ideas, and results of this project will be disseminated to experts in this domain, and new collaborations are fostered.

The costs for these workshops, which are usually held in Europe and North America, are the same as for conferences, except that the registration fees are estimated at $ 200.

Research visits Collaborations with leading experts in parameterized computation will be strengthened through research visits, where a few individuals spend about a week intensively on collaborative research, often leading to peaks of productivity.

One destination is the algorithms group at the University of Bergen (Norway). Many members of this group are internationally leading experts in several aspects of the proposed research, including Fedor V. Fomin, Pinar Heggernes, Daniel Lokshtanov, Saket Saurabh, and Jan Arne Telle. This group has a long history of research excellence in parameterized computation and graph problems.

The second destination is the algorithms group at the University of Warsaw (Poland), which has recently been strengthened by four young faculty members who are up and coming researchers with research strengths in the topic of this proposal, Marek Cygan, Marcin Kamiński, Marcin Pilipczuk, and Anna Zych.

The last overseas destination is Rolf Niedermeier's group at the Technical University of Berlin. This group has a strong expertise in both parameterized complexity and computational social choice, and is therefore very relevant for the proposed project.

Within Australia, I will visit the Parameterized Complexity Research Unit at Charles Darwin University (Australia). Michael R. Fellows counts as a founding father of the field of multivariate complexity; he and his wife and colleague Frances A. Rosamond play a very important role in shaping and guiding this area of research.

I will also visit Ljiljana Brankovic at the University of Newcastle, who is an expert in parameterized complexity, and especially parameterized approximation algorithms. Indeed, it is expected that large data sets cannot be handled by exact algorithms, which makes it necessary to consider parameterized approximation algorithms, where Ljiljana's expertise will be crucial.

Since overseas research visits will be combined with travels to workshops or conferences, regional airfares are sufficient to cover the transport ($ 710). The cost for an economy airfare to Darwin is estimated at $ 700, and the cost of a rental car to travel to Newcastle (7 days) is estimated at $ 400. Accommodation and allowances are based on UNSW's travel budget builder.

Other

Specialised books Specialized books on the relevant subjects provide encyclopaedic overviews and a clear and digested exposition of the material, helping to enhance the in-depth understanding of the subjects.
Specification: 10 books (including e-books) in the first year ($ 2,000), and 3 books in each subsequent year ($ 600). Examples of relevant books (not available at the UNSW library) are *Graph Theory* (2010) by Adrian Bondy and U.S.R. Murty, and *Parameterized Complexity Theory* (2010) by J. Flum and M. Grohe.

Publication costs This is the fee for one open-access journal publication per year. Springer's current fee is $ 3,000 for open-access publication at Algorithmica (similar for other journals).

Data acquisition Implementations of new stable assignment algorithms will be tested on practically very relevant data. Some of the data will be taken from the openly available PrefLib repository, developed and maintained by two colleagues at NICTA. The most relevant data will however be acquired from organisations such as the National Resident Matching Program (NRMP): anonymised preferences submitted by hospitals and residents in their annual assignment. The cost for this acquisition is a $ 200 charge for data requests and 8 hours of staff time ($ 150 per hour).

F2. Details of Administering Organisation contributions

(In no more than one A4 page provide an explanation of how the Administering Organisation's contributions will support the proposed project using the same headings that are in the budget table.)

Attached PDF

Personnel

The Administering Organisation contributes the gap between ARC and UNSW salary scales for a Level C researcher, and the use of infrastructure and facilities including libraries, computing facilities and office accommodation.

G1. Personal details

(The personal details will be filled out for you automatically. To update any of your personal details in this form, please update your profile accordingly and your details will update automatically in this form.)

Title

Doctor

Family Name

Gaspers

First Name

Serge

Person identifier

81441038

Role

Future Fellowship - Level 1

G2. Postal address

(The postal address will be filled out for you automatically. To update your postal address, please update your profile accordingly and your postal address will update automatically in this form.)

Postal Address Line 1

Computer Science and Engineering

Postal Address Line 2

UNSW, K17

Locality

Sydney

State

NSW

Postcode

2052

Country

Australia

G3. Are you a current member of the ARC or its selection or other advisory committees?

(This relates only to ARC College or Selection Advisory Committee members for National Competitive Grants Program funding schemes.)

Current Member of Advisory Committee

No

G4. Current Research Fellowship

Do you hold a current Research Fellowship?

(This includes all ARC Fellowships and Fellowships from other agencies.)

Hold Current Research Fellowship

Yes

Current fellowships held

	Fellowship Enumeration	Fellowship Name	Year Awarded	Expected Completion Date
1	Discovery Early Career Researcher Award	discoveryEarlyCareerResearcherAward	2012	31/05/2015

G5. Qualifications

	Degree/Award	Year	Discipline/Field	Organisation Name
1	PhD	2008	Computer Science	University of Bergen
2	Diplome d'Etudes Approfondies (Master)	2005	Computer Science	Paul Verlaine University, Metz
3	Maitrise	2004	Computer Science	Paul Verlaine University, Metz
4	Licence	2003	Computer Science	Paul Verlaine University, Metz
5	Diplome Universitaire de Technologie	2002	Computer Science	Centre Universitaire de Luxembourg

	Country
1	Norway
2	France
3	France
4	France
5	Luxembourg

G6. Which qualification is relevant to the Proposal for the Future Fellowship candidate for eligibility purposes?

Qualification relevant to Fellowship

phd

Date Awarded

16/12/2008

G7. Current and previous appointment(s)/position(s) – during the past 10 years

	Position	Organisation Name	Department	Year Appointed
1	Visiting researcher	National ICT Australia	Optimisation group	2012
2	ARC DECRA fellow	The University of New South Wales	School of Computer Science and Engineering	2012
3	Postdoctoral researcher	Vienna University of Technology	Institute of Information Systems	2010
4	Postdoctoral researcher	University of Montpellier 2	Laboratoire d'Informatique, de Robotique et de Microelectronique de Montpellier	2009
5	Postdoctoral researcher	University of Chile	Center for mathematical modeling	2009

	Continuity	Employment Kind	Current
1	Contract	Full Time	Yes
2	Contract	Full Time	Yes
3	Contract	Full Time	No
4	Contract	Full Time	No
5	Contract	Full Time	No

G8. Current salary

Classification

B

Salary (AUD gross)

98848

Status

Fixed Term

G9. Salary level justification

(In no more than 750 characters (approx 100 words), please provide justification of the Future Fellowships salary level requested in this Proposal.)

The Level 1 salary is higher than my current academic salary level.

G10. Citizenship/Residency Details

(Please note, that the Australian citizenship status as well as the list of countries that you have citizenship of is populated from your profile.)

Australian Citizen?

No

Countries of Citizenship

Luxembourg

Country of residence Name

Australia

Current Australian residency status

Temporary

G11. Organisational affiliation for eligibility purposes

(Will you hold an appointment at the Administering Organisation with effect on the date of the commencement of the Future Fellowship?)

Affiliation

Yes

G12. Has a successful eligibility exemption been granted by the ARC for this fellowship candidate?

	Pre-submission Issue Identifier
1	
2	

G13. Please name any Commonwealth-funded Research Centres that you will be associated with as at 1 July 2014.

(Please provide the name of the Centre/s along with an outline of the relationship between the proposed program of research and the Commonwealth-funded Centre/s in no more than 750 characters (approx 100 words) of plain language.)

I have a collaborative research project (CRP) with NICTA on Resource Allocation problems. I am the lead CI for UNSW and Toby Walsh is the lead CI for NICTA. That project is to use tools from game theory and parameterized complexity to study mechanisms for resource allocation, in particular fairness, envy-freeness, social welfare, and strategic behaviour. Therefore, the CRP is partially in the same research area, but the problems considered in the CRP are very different from those in this project.

G14. Detail the number of students you have supervised over the last five years

(In no more than 350 characters (approx 50 words) please provide the details of students that you have supervised over the last five years.)

Over the last 5 years, I have - co-supervised the PhD student Valentin Mayer-Eichberger (started in March 2013), - supervised (main supervisor) the PhD student Simon Mackenzie (started in August 2013), and - co-supervise the undergraduate student Jack (Jing Wu) Lian during a Taste of Research Summer Scholarship (November 2013 - February 2014).

G15. Are you an Indigenous Participant?

Indigenous Participant

No

PART I - Research Support (FT140100048)

I1. Research support for the Future Fellow

(Provide details of research funding (ARC and other agencies) for the years 2013 to 2017 inclusive. That is, list all projects/proposals/fellowships awarded or requests submitted involving the Future Fellow for funding. Please refer to the Instructions to Applicants for submission requirements (20 pages maximum).)

Attached PDF

Description (all named investigators on any proposal or grant/ project/ fellowship in which a participant is involved, project title, source of support, scheme and round)	**Same Research Area** (Yes/No)	**Support Status** (Requested/Current/Past)	**Proposal/ Project ID** (if applicable)	**2013** ($'000)	**2014** ($'000)	**2015** ($'000)	**2016** ($'000)	**2017** ($'000)
Dr Serge Gaspers, Algorithms for hard graph problems based on auxiliary data, ARC, Future Fellowship, 2014.	Yes	R	FT140100048		90	182	180	173
Dr Serge Gaspers, Prof Toby Walsh, Computational Complexity of Resource Allocation Problems, NICTA and UNSW, collaborative research project, 2012.	Yes	C		67	67			
Dr Serge Gaspers, Solving intractable problems: from practice to theory and back, ARC, Discovery Early Career Researcher Award, 2012.	Yes	C	DE120101761	125	125			

J1. For each participant on this Proposal, please attach a statement detailing progress for each Project/Award/Fellowship involving that participant who has been awarded funding for 2013 under the ARC Discovery Projects, Discovery Indigenous Researchers Development, Discovery Indigenous, Discovery Early Career Researcher Award, Linkage Projects schemes or any ARC Fellowship scheme.

	Project ID	First named investigator	Scheme	Statement
1	DE120101761	Dr Serge Gaspers	DECRA	

1 Timeline

The DECRA project ARC DE120101761 started effectively in June 2012 and will end in May 2015. This document reports on the progress as of November 2013.

2 Progress

Backdoors A backdoor of a SAT formula is a set of variables such that an assignment to these variables results in a formula that can be solved in polynomial time. Several variants of backdoors exist (weak/strong/deletion), and their size is a natural parameter in the context of parameterized complexity. For SAT formulas with small backdoor sets, it is reasonable to believe that they can be solved efficiently in practice. Namely when a solver branches on a superset of a backdoor, it can solve the remaining formula in polynomial time. In the context of this project, algorithms have been designed for detecting backdoors to the base classes of acyclic formulas (published in ICALP 2012), nested formulas (published in SAT 2012), q-Horn formulas (published in STACS 2013), and formulas whose incidence graphs have bounded treewidth (published in FOCS 2013).

Can theory learn from practice? There has been further progress related to this theme. A technical report is expected within the next few months.

Global constraints For global constraints related to scheduling, a new article has been accepted to IJCAI 2013 with algorithms and complexity results for various parameterizations and restrictions of the constraints.

Other CSP is polynomial-time solvable for instances whose hypertree width is upper bounded by a constant. However, from a parameterized view, finding a hypertree decomposition of width at most k is $W[2]$-hard with parameter k. We investigated whether a slightly larger parameter, the treewidth of the incidence graph, makes the problem fixed-parameter tractable. Our results (to appear at ISAAC 2013) suggest however that this is not the case.

Local search is often used in SAT solvers: the search for a solution is divided into many tasks that check whether there exists a solution in the local neighborhood of a given assignment. In a AAAI 2012 paper we showed that it can be a disadvantage if a SAT solver (or any other piece of software) focuses only on the local-search task at hand without considering the original problem.

3 Outlook

Backdoors The algorithms designed so far are very sophisticated and rely on deep theories. They nicely explain a good performance of SAT solvers on instances with a small backdoor set if we take the view that good solvers probably perform well on fixed-parameter tractable instances with small parameters. However, this intuition could be strengthened by designing simple algorithms that act in a way real-world SAT solvers do. The next step in this theme is therefore to try and design algorithms based on simple reduction rules and a randomized selection of variables to add to the backdoor.

Can theory learn from practice? Research on this theme with Gregory Sorkin will be written down in the next few months and we will aim at generalizing the developed techniques to other computational problems.

Global constraints Similar work will be done for other types of constraints, also taking into account the feedback from our recent paper.

K1. Other Agencies

Have you submitted or do you intend to submit a similar Proposal to any other agency?

Other Agency Submission

No

If Yes, please select one of the following:

Other Agency Name

Not applicable for this candidate

If Other is selected above, please enter the full name of the agency:

Not applicable for this candidate