CHRIS BARRETT

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PERSONAL PROFILE

I am a postdoctoral researcher with a research focus on (both pure and applied) category theory, type theory, and programming language theory. I am especially interested in bridging applied category theory and logical methods in order to develop a theory of effectful programming languages: for example, in understanding non-deterministic, probabilistic, differentiable, and quantum languages. Recent work has also focussed on using applied category theory to develop tools for (both classical and quantum) compilation. Finally, although I am newer to this field, I am also keen to apply tools from category theory to help develop foundations for the field of deep learning.

CURRENT AND PREVIOUS POSITIONS

University of Oxford
Post-Doctoral Researcher, Computer Science Oct 2023 – Present
Funded by Engineering and Physical Sciences Research Council (EPSRC)
Project Title: **Compilation and Verification of Quantum Software in the Noisy and Approximate Regime**
Supervisor: Dr. Aleks Kissinger

Like classical computers, quantum computers need compilers, which are tools that translate code written by a human into something the machine can run. Unlike classical computers, today's quantum computers have extremely limited computational resources and are highly susceptible to noise from the environment. Furthermore, it is often impractical or impossible to implement a computation exactly, meaning quantum compilers need to make certain approximations, which can yield further errors.

This project aims to use technology from e-graphs developed in my previous post-doctoral position, together with the ZX-calculus and recently developed tools from quantitative algebra to develop practical quantum compilers which are able to produce small quantum circuits, not only with error guarantees but also with benefits to size from allowing a small degree of error.

University of Birmingham
Post-Doctoral Researcher, Computer Science Oct 2022 - Nov 2023
Funded by Engineering and Physical Sciences Research Council (EPSRC)
Project Title: **Nominal String Diagrams**
Supervisor: Dr. Dan Ghica

As part of my responsibilities in this role, I have been involved in the preparation of a conference paper, expected to be submitted to Principles of Programming (POPL 2024), with my supervisor, Dr. Dan Ghica, and his new Ph.D. student, Aleksei Tiurin, whom I am also helping to supervise. I have also engaged in independent research, which has resulted in a second paper in preparation. Upon completion of this paper, I hope to eventually make the latter line of research the basis of a fellowship application. Additionally, I have given several talks (e.g., at CSL23 and as an invited speaker at the Oxford and Cambridge Theory seminars) on the topic of my Ph.D. thesis. Details of these works are included later in the C.V. As part of my development as an independent researcher, and looking to the longer-term, I am also building collaborations with a number of colleagues, both in Birmingham, Bath, and elsewhere, some of which I hope to result in eventual publications. These collaborations remain in the early stages, and further details are omitted here.

University of Bath
PhD, Computer Science 2018 – 2022
Funded by Engineering and Physical Sciences Research Council (EPSRC)
Thesis Title: **On the Simply-Typed Functional Machine Calculus: Categorical Semantics and Strong Normalisation**
Supervisor: Dr. Willem Heijltjes

The Functional Machine Calculus (FMC) was recently introduced as a generalisation of the lambda-calculus to include higher-order global state, probabilistic and non- deterministic choice, and input and output, while retaining confluence. The calculus can encode both the call-by-name and call-by-value semantics of these effects. This is enabled by two independent generalisations, both natural from the perspective of the FMC's operational semantics, which is given by a simple (multi-)stack machine.

The first generalisation decomposes the syntax of the lambda-calculus in a way that allows for sequential composition of terms and the encoding of reduction strategies. Specifically, there exist translations of the call-by-name and call-by-value lambda-calculus which preserve operational semantics. The second parameterizes application and abstraction in terms of 'locations' (corresponding to the multiple stacks of the machine), which gives a unification of the operational semantics, syntax, and reduction rules of the given effects with those of the lambda-calculus. The FMC further comes equipped with a simple type system which restricts and captures the behaviour of effects.

This thesis makes two main contributions, showing that two fundamental properties of the lambda-calculus are preserved by the FMC. The first is to show that the categorical semantics of the FMC (without considering the specifics of encoded effects), modulo an appropriate equational theory, is given by the free Cartesian closed category. The equational theory is validated by a notion of observational equivalence. The second contribution is a proof that typed FMC-terms are strongly normalising.

University of Bath
Teaching assistant 2018 – 2022

Teaching modules at masters and undergraduate level in the Computer Science department, including Foundations of Computation, Functional Programming and Analytical Mathematics for Applications. This included running seminars, often in a traditional lecture style, as well as running computer labs.

University of Newcastle
MMath Mathematics (First-class Honours) 2013-2017

University of Newcastle
Research Assistant Summer 2016

Implementing `simulated annealing' – a probabilistic technique for approximating the global optimum of a function – in MatLab for a project aiming to predict optimum historical settlement placements.

Scott Logic
Internship Summer 2015

Developing a real-time financial data visualisation application in JavaScript, using the d3 and react.js libraries, as a technology showcase for the company's own open-source d3fc library, which I also contributed to during the internship.

PUBLICATIONS AND PRESENTATIONS

Conference papers:

The Relational Machine Calculus, Chris Barrett, Daniel Castle, Willem Heijltjes
Logic in Computer Science (LICS) 2024

This paper presents the Relational Machine Calculus (RMC): a simple, foundational model of first-order relational programming. The core of the calculus is given by a decomposition of the first-order lambda-calculus which reveals a latent duality, concretely expressed by an involution on syntax. Semantically, this core fragment is sound and complete for string diagrams of Frobenius monoids. A corresponding symmetrization of beta-reduction gives rise to uni- fication as a reduction mechanism. By further including standard operations of Kleene algebra the RMC embeds a range of computational models: the first-order lambda-calculus, logic programming, and automata, among others.

These embeddings preserve operational semantics, which for the RMC is given by a generalisation of a standard stack machine for the lambda-calculus. The equational theory of the RMC (which supports reasoning about its operational semantics) is conservative over both the first-order lambda-calculus and Kleene algebra, and can be oriented to give a confluent reduction relation.

Functional Machine Calculus II: Semantics, Chris Barrett, Guy McCusker, Willem Heijltjes
Computer Science Logic (CSL), 2023

This publication is associated with, and contains early results from, my Ph.D. thesis. Additionally, my co-authors and I argue that the syntax of the FMC -- in which both effects and the lambda-calculus are realised using the same syntactic constructs -- is semantically natural, corresponding closely to the structure of a Scott-style domain theoretic semantics.

Presented by myself at Computer Science Logic (CSL 2023), and the New Ideas in Effects, Types and Sharing (NIETS 2022) workshop in Bath.

Journal papers:

A Subatomic Proof System for Decision Trees, Chris Barrett, Alessio Guglielmi
ACM Transactions on Computational Logic (TOCL), October 2022

In the first and second year of my Ph.D. I co-authored a paper with Alessio Guglielmi based on an independently developed, original idea of mine. In particular, I designed a deep inference proof system for propositional classical logic that integrates two languages for Boolean functions: standard conjunction-disjunction-negation and binary decision trees. The system exhibits remarkable proof-theoretical naturalness: the system consists of all and only the inference rules generated by the single, simple, linear scheme of the recently introduced subatomic logic. Thanks to this regularity, cuts are eliminated via a natural construction.

This work later influenced the development of ‘Decomposing Probabilistic Lambda-Calculi’, authored by Ugo Dal Lago, Giulio Guerrieri, Willem Heijltjes, which in turn began the line of research which led to the development of the FMC.

Presented by myself at Structures and Deduction (SD 2019), a workshop at Formal Structures for Computation and Deduction (FSCD 2019).

On the quantized dynamics of factorial languages, Chris Barrett, Evgenios T.A Kakariadis
Quarterly Journal of Mathematics, March 2018

For my masters' project I researched and wrote an introduction to Symbolic Dynamics, including some Haskell code to generate "follower set graphs" -- finite representations of certain spaces of infinite sequences. This code was used to falsify a conjecture and was part of my contribution to the above journal paper in mathematics. The work was awarded the Best MMath Project school prize.

Papers in Preparation:

Equivalence Hypergraphs, Chris Barrett, Dan Ghica, Aleksei Tiurin

The technique of equality saturation, based on a data-structure called e-graphs which compactly maintain equivalence classes of terms, has recently proved both powerful and practical in program optimisation, particularly for SMT solvers. We give a categorical semantics to these structures, called e-graphs, in terms of Cartesian categories enriched over a semilattice. We show how this semantics can be generalised to monoidal categories, which opens the door to new applications of e-graph techniques, from algebraic to monoidal theories. Finally, we present a sound and complete combinatorial representation of morphisms in such a category, based on a generalisation of hypergraphs which we call e-hypergraphs. They have the usual advantage that many of their structural equations are absorbed into a general notion of isomorphism.

Invited Talks:

On the Simply-Typed Functional Machine Calculus, Chris Barrett
Presentation of results from my thesis at the Oxford, Cambridge and Birmingham Theory Seminars, 2022-2023.

ADDITIONAL INFORMATION

Technical skills:

Self-taught programmer, with competence in C++, Python, JavaScript, Haskell, MatLab, R

Responsibilities:

Organiser for the University of Birmingham Theory Seminar, 2022-2023
Organiser for the University of Bath Mathematical Foundations Seminar, 2020-2022
Contributed to the peer-review process for various international conferences and workshops

Miscellaneous:

Received an acknowledgement on the publication `Higher-order causal theories are models of BV-logic', authored by Will Simmons and Aleks Kissinger. After reading some of their earlier work, I realised that it would be natural to extend their results from MLL to a lesser-known logic, BV. I invited them to the Bath Seminar, which I was hosting at the time, initiating an exchange of ideas which led to the above publication.

Extracurricular:

Volunteer with PsyCare UK, a charity that provides welfare services at music festivals, 2018-present