University of Wisconsin-Madison
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Charlie Murphy

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My research interests lie in formal methods, automated verification, synthesis and programming languages with a focus on logic and constraint-based methods and development of solvers for logical formulas.

Academics

Princeton University — Princeton, NJ
Ph.D. in Computer Science — Jan. 2023
M.A. in Computer Science — April 2018
Area: Automated Verification, Concurrency, Programming Languages, Formal Methods
Advisor: Zak Kincaid

Ohio University (Honors Tutorial College) — Athens, OH
B.S. in Computer Science — May 2016
Thesis title: *Examining the Effects of Key Point Detector and Descriptors on 3D Visual SLAM*
Advisor: David Chelberg

Work Experience

University of Wisconsin-Madison — Madison, WI
Post-Doctoral Research Associate for Loris D'Antoni — Feb. 2023-Present
Worked with Loris D'Antoni and Tom Reps to develop logic and constraint-based techniques for verification and synthesis within the Semantics-Guided Synthesis framework.

Amazon Web Services — New York, NY
Applied Science Intern — 7/20-9-20
Developed techniques to ensure correct runtime operation of distributed databases at scale with minimal memory, disk, and CPU overheads.

GrammaTech — Ithaca, NY
Research Intern — 6/18-8/18
Developed a technique to dynamically re-rank bug reports using user feedback, machine learning, and formal methods.

NOAA VizLab — Silver Springs, MD
Ernest F. Hollings Intern — 5/15-7/15
Developed NOAA WeatherView – A 3D Visualization system for education of global weather patterns.
https://www.nnvl.noaa.gov/weatherview/index.html

Ohio University — Athens, OH
Smart Health Lab — 5/14-5/16
National Science Foundation Research Experience for Undergraduates. Created and maintained database and visualization tools for analysis of physiological sensor data for prediction of hypoglycemia in patients with type 1 diabetes.

Ohio University — Athens, OH
Voinovich Research Assistant — 8/13-5/14
Performed data analysis of social networks / surveys for various educational and incarceration reform programs to determine the effectiveness of programs given level of involvement.

Works in Progress/Under Submission

Charlie Murphy, Loris D'Antoni, Tom Reps. Verifying Solutions to Semantics-Guided Synthesis Problems. Submitted to *PLDI'24*.
Abstract:

Semantics-Guided Synthesis (SemGuS) provides a framework to specify synthesis problems in a solver-agnostic and domain-agnostic way by allowing a user to provide both the syntax and semantics of the language in which the desired program should be synthesized. Because synthesis and verification are closely intertwined, the SemGuS framework raises the problem of how to *verify* programs in a solver and domain-agnostic way.

We prove that the problem of verifying whether a program is a valid solution to a SemGuS problem can be reduced to proving validity of a query in the μCLP calculus, a fixed-point logic that generalizes (co-)constrained-Horn clauses. Our encoding into μCLP allows us to further classify the SemGuS verification problems into ones that are

reducible to validity of (i) first-order-logic formulas, (ii) (co-)constrained-Horn clauses, and (iii) μCLP queries. Furthermore, our encoding shines light on some limitations of the SemGuS framework, such as its inability to model nondeterminism and reactive synthesis. We thus propose a modification to SemGuS that makes it more expressive, and for which verifying solutions is exactly equivalent to proving validity of a query in the μCLP calculus. Our implementation of SemGuS verifiers based on the above encoding can verify instances that were not even encodable in previous work.

Jiangyi Liu, Anvay Grover, Khangee Park, **Charlie Murphy**, Loris D'Antoni, Tom Reps. Synthesizing Semantics from Closed-Boxed Interpreters. *Work in Progress*.
Abstract:

It is necessary to know the formal semantics of a programming language when performing program verification or synthesis. In the Semantics-Guided Synthesis framework (SemGuS), for example, the user is required to provide a formal syntax and semantics of the language they want to synthesizes programs in, along with a logical specification of their program of interest. However, writing such a formal semantics is a challenging and error-prone task. In fact, most developers default to using interpreters to define their languages when programming. Here, we present an algorithm to automatically synthesize the semantics of a programming language given closed-box access to the syntax of a programming language and an interpreter for that language. This interpreter allows us to run programs and sub-programs and observe the output. We employ a Counterexample-Guided Synthesis (CEGIS) approach to synthesize a formal semantics in the form of Constrained-Horn Clauses (CHCs). We implement the algorithm in a tool called SemSynth. We evaluate SemSynth on a variety of benchmarks and show that it can successfully synthesize the semantics for many kinds of programming languages.

Charlie Murphy, Zachary Kincaid. Relational Verification via Weak Simulation. To be submitted to *OOPSLA'24*.
Abstract:

Distributed systems are notoriously hard to get right, even when based on existing protocols. We propose a novel method to automatically prove that message passing programs match an executable specification. The specification is a variant of relational Hoare logic based on weak simulation. Our technique, simulation synthesis, is the first to handle both infinite state programs and infinite state specifications. Simulation synthesis is based on the game semantics of weak simulation and synthesizes a winning strategy to the game induced by the relational verification query.

Charlie Murphy, Zachary Kincaid. Linear Arithmetic Satisfiability Via Fine-Grained Strategy Improvement. *Submitted to CAV'24*.
Abstract:

Checking satisfiability of formulae in the theory of linear rational arithmetic has far reaching applications, including program verification and synthesis. Many satisfiability solvers excel at proving and disproving satisfiability of quantifier free LRA formulas, but struggle with or are incapable of handling quantified formulae. Existing techniques for checking satisfiability of quantified LRA formulae require the formula first be converted to prenex normal form. Conversion to prenex normal form may alter the semantics of the original formula and introduce additional quantifier alternations. We present fine-grained strategy improvement—strategies for both quantifiers and connectives—which avoids conversion to prenex normal form. In addition to checking satisfiability, we provide a means of extracting a winning strategy that dictates exactly how the formula is proven sat or unsat. We experimentally evaluate our technique against existing methods and find it performs favorably on formulas with a greater number of quantifiers.

Publications

Charlie Murphy, Zachary Kincaid. Practical Algorithm for Structure Embedding. *VMCAI'19: 20th International Conference on Verification, Model Checking, and Abstract Interpretation*. Lisbon, Portugal. January 2019.

Charlie Murphy, Patrick Gray, Gordon Stewart. Verified Perceptron Convergence Theorem. *MAPL'17: The first ACM SIGPLAN Workshop on Machine Learning and Programming Languages*. Barcelona, Spain. June 2017.

Timothy Murphy. Examining the Effects of Key Point Detector and Descriptors on 3D Visual SLAM. Advisor David Chelberg. *Thesis Ohio University*. April 2016.

Timothy Murphy, David Chelberg. Development of a Robust Indoor 3D SLAM Algorithm. *Proceedings of Midstates*

Conference on Undergraduate Research in Computer Science and Mathematics. Wooster University. November 2014.

Presentations

Charlie Murphy. Relational verification via weak simulation. Advisor Zachary Kincaid. Readers: Aarti Gupta, Lennart Beringer. Examiners: Wyatt Llyod, Dave Walker. *Princeton University Final Public Oral*. January 2023.

Charlie Murphy. Relational verification via weak simulation. Advisor Zachary Kincaid. *Princeton University Pre-Final Public Oral*. April 2022.

Charlie Murphy. A Practical Algorithm for Structure Embedding. Advisor Zachary Kincaid. *Princeton University General Exam*. January 2018.

Timothy Murphy, Dan Pisut. New Web Interface for Real-Time-Visualization of NOAA Weather Data. American Meteorological Society. *32nd Conference on Environmental Information Processing Technologies*. January 2016.

Timothy Murphy. New Web Interface for Real-Time-Visualization of NOAA Atmosphere Model Data. *NOAA 2015 Science Symposium*. Silver Springs, MD. July 2015.

Timothy Murphy. Developing an Indoor 3D SLAM Algorithm. Ohio University. *Ohio University Student Expo*. April 2015

Timothy Murphy, Hannah Quillin. Towards the Quantified Self: Fitness Bands for Blood Glucose Prediction. Ohio University. *Ohio University Student Expo*. April 2015

Teaching

9/22-1/23	Assistant in Instruction. COS-516 - Automated Reasoning about Software, Princeton
9/22-1/23	Assistant in Instruction. COS-226 - Data Structures and Algorithms, Princeton
2/19-6/19	Lecturer. Mat-015C – Basic College Math, Prison Teaching Initiative
2/18-6/19	Assistant in Instruction. COS-226 – Data Structures and Algorithms, Princeton
9/17-1/18	Assistant in Instruction. COS-418 – Distributed Systems, Princeton
5/17-5/20	Course design. CS-103 – Intro to Computer Science, Prison Teaching Initiative

Service

20/23	Sub-reviewer ESOP'24
10/23	Sub-reviewer SOFSEM'24
11/20	POPL'21 Artifact Evaluation Committee
5/16-05/20	Princeton Computer Science Graduate Social Committee, Chair
9/17-9/19	Programming Languages Seminar, Organizer
8/17-9/19	Princeton Graduate Board Games, Treasurer
1/17-4/17	Graduate Student Faculty Recruiting Committee (Princeton Computer Science)
12/15	Hour of Code Event (Ohio University), Organizer
5/15-7/16	Ohio University Association of Computing Machinery (ACM), President
5/15-5/16	Bobcat Tabletop (Ohio University), Treasurer
12/14	Hour of Code Event (Ohio University), Organizer
5/14-5/15	Ohio University Association of Computing Machinery (ACM), Web Master

Honors

5/16	Honorable mention for best thesis. Ohio University Honors Tutorial College.
4/15	2nd Place presentation (Undergrad EECS). Ohio University Student Expo.
4/15	2nd Place presentation (Diabetes Institute). Ohio University Student Expo.
5/14	Ernest F. Hollings Scholarship. Class of 2014-2016.
5/13	Benjamin A. Gilman Scholarship Recipient (Ukraine).