APPLIED CATEGORY THEORY SCHOOL

Georgios Bakirtzis

Mon 21 Jan 2019

1 INTRODUCTION

During my doctoral studies, I have explored category theory for my own edification. I have no formal training in the field but have been self-learning using various resources. For example, I have read "Category Theory for the Sciences" by David Spivak.[1] and watched his lectures as presented in LambdaCon.[2] I have also been following closely some of the older and newer work of John Carlos Baez,[3] and have tried to understand "The Behavioral Approach to Open and Interconnected Systems" by Jan Willems—since I am familiar with control theory—with admittedly limited success.[4] In my own work, I have used graph-theory as a medium for capturing my models. I would like to be able to transform those graphs to models with properties that I can check over the graph, something that I believe is key to making the model useful.[5]

I am currently a PhD candidate on the computer engineering program at the University of Virginia, with affiliations with both the electrical and computer engineering department and the computer science department. My area of study is the

[1] i.e., https://mitpress.mit.edu/books/category-theory-sciences

[2] i.e., https://www.youtube.com/watch?v=IBeceQHz2x8&list=PLFTBfi-r3xj2jEpzoKl2koVLg1UrE9YL-

[3] e.g., https://arxiv.org/pdf/q-alg/9705009.pdf & https://arxiv.org/pdf/1704.02051.pdf

[4] i.e., http://homes.esat.kuleuven.be/%7Ejwillems/Articles/JournalArticles/2007.1.pdf

[5] e.g., https://arxiv.org/pdf/1712.01448.pdf

safety and security of cyber-physical systems, sometimes called hybrid systems. I am planning on graduating in late 2020 and am currently writing my dissertation proposal which I hope to base on category theory.

2 STATEMENT

Little work has been done to use category theory as a medium for the safety and security assessment of systems. A categorical view of hybrid systems exists, but to my knowledge it has not been used to assess a system's security or safety posture.[6] Some systems-theoretic work in formalizing responsive and formal design has been done, but that also does not get us closer to the power of category theory as a model and abstraction.[7] The way that category theory captures syntax and semantics is an appealing solution to capturing system specifications—with the eventual goal of verifying such a formal specification, which takes into account hazards, faults, accidents, attackers, as well as behavioral models of the systems.

Formal training on category theory will provide me with the tools to apply category theory in Leveson-style systems theory[8] to achieve safer and more secure cyber-physical systems. I posit that the use of category theory in my field is appropriate - and probably better than control theory - as it provides a notational and conceptual framework to think about requirements and can lead to formal specifications that reflect on the implementation (since most faults are introduced prior to the design phase).

My participation in this school will allow me to develop a fundamental framework to achieve my research goals. I hope to meet collaborators in system dynamics, system safety and security, and graph-based logical formalisms. Such contacts and communication would help me identify what excites me most in systems theory applications.

[6] e.g., http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.652.7966&rep=rep1&type=pdf

[7] i.e., https://ieeexplore.ieee.org/document/8369508

[8] i.e., https://mitpress.mit.edu/books/engineering-safer-world

3 PROJECT PREFERENCE

1. Toward a mathematical foundation for autopoiesis (David Spivak)
2. Complexity classes, computation, and Turing categories (Pieter Hofstra)
3. Traversal optics and profunctors (Bartosz Milewski)
4. Formal and experimental methods to reason about dialogue and discourse using categorical models of vector spaces (Mehrnoosh Sadrzadeh)
5. Partial evaluations, the bar construction, and second-order stochastic dominance (Tobias Fritz)
6. Simplifying quantum circuits using the ZX-calculus (Miriam Backens)

4 OXFORD

If funding is not provided by either my home institution or the Applied Category Theory school, I will explore other avenues for funding to come to Oxford.

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Georgios Bakirtzis

Researcher in cyber-physical system safety and security

May 2020 (expected)	PhD in computer engineering	University of Virginia
May 2015	BS in electrical engineering	Virginia Commonwealth University

Research

University of Virginia

2017–present

As a graduate research assistant to Prof. Cody H. Fleming (SYS), I currently

- develop a mission-centric requirements elicitation process,
- model and analyze complex systems to assure safe behavior,
- improve current hazard analysis techniques, and
- work in the general area of systems and control theory.

Virginia Commonwealth University

2015–present

As a graduate research assistant to Prof. Carl R. Elks (ECE), I currently

- design effective visualizations for cybersecurity,
- construct and analyze security models of cyber-physical systems,
- program tools for automated cybersecurity analysis,
- use formal languages to verify security properties, and
- work in the general area of dependable computing.

2013–15

As an undergraduate research assistant to Prof. Robert H. Klenke (ECE), I designed, programmed, and validated UAV flight control systems.

Scientific contributions

[in preparation]

G. Bakirtzis, B.T. Carter, C.H. Fleming, and C.R. Elks, "MISSION AWARE: Evidence-Based, Mission-Centric Cybersecurity Analysis", planning on submitting to SAFECOMP 2019

G. Bakirtzis, A.G. Collins, B.J. Simon, C.H. Fleming, and C.R. Elks, "CYBOK: Model-based Vulnerability Exploration & Analysis for Cyber-Physical Systems", submitted to IEEE DSN 2019

C.H. Fleming, C.R. Elks, G. Bakirtzis, S.C. Adams, B.T. Carter, A.G. Collins, P.A. Beling, and B.M. Horowitz, "Cyber-Physical Security Through Resiliency: A Systems Centric Approach for Facilitating Resilience in Cyber-Physical Systems", submitted to IEEE Computer Magazine

S.M. Gautham, G. Bakirtzis, M.T. Leccadito,
R.H. Klenke, C.R. Elks, "A Multilevel Cybersecurity
and Safety Monitor for Embedded Cyber-Physical Systems", TBD

[refereed conference]

G. Bakirtzis, B.J. Simon, C.H. Fleming, C.R. Elks, "Looking
for a Black Cat in a Dark Room: Security Visualization
for Cyber-Physical System Design and Analysis",
VizSec 2018, Proc. IEEE (2018)

B.T. Carter, C.H. Fleming, C.R. Elks, and G. Bakirtzis,
"Cyber-Physical Systems Modeling for Security
using SysML", CSER 2018, Proc. Springer (2018)

G. Bakirtzis, B.T. Carter, C.R. Elks, and C.H. Fleming,
"A Model-Based Approach to Security Analysis
for Cyber-Physical Systems", SysCon 2018, Proc. IEEE (2018)

B.T. Carter, G. Bakirtzis, C.R. Elks, and C.H. Fleming,
"A Systems Approach for Eliciting Mission-Centric
Security Requirements", SysCon 2018, Proc. IEEE (2018),
Best Student Paper Runner-up

G. Bakirtzis, B.T. Carter, C.R. Elks, and C.H. Fleming,
"Cyber Assurance Assessment using Systems and Control Theory",
2017 USENIX Security Poster Session (2017), VCU ECE Travel Award

A.V. Filippas, U. Hasni, A. Docef, G. Bakirtzis, A. Sunga, H. Nabi,
and A. French, "The Freshman Experience: A Modular Approach
to Experiential Learning", 2017 Zone II, Proc. ASEE (2017)

G. Bakirtzis, P.A. Beling, and C.R. Elks, "Toward Mission-Centric
Vulnerability Analysis for Critical Systems: Methodology
and Approach", 2016 NSRCI, Proc. Resilience Week (2016)

G.L. Ward, G. Bakirtzis, and R.H. Klenke, "A Modular Software Platform
for Unmanned Aerial Vehicle Autopilot Systems",
SciTech 2014, Proc. AIAA (2014)

[technical report]

B. Horowitz, P.A. Beling, C.H. Fleming, S. Adams, B.T. Carter,
T. Sherburne, C.R. Elks, G. Bakirtzis, F. Shull, and N.R. Mead,
"Cyber Security Requirements Methodology", SERC (2018)

B. Horowitz, P.A. Beling, C.H. Fleming, S. Adams, B.T. Carter, K. Vemuru, C.R. Elks, T. Bakker, K. Cios, G. Bakirtzis, A.G. Collins, N.R. Mead, and F. Shull, "Systems Aware Cybersecurity", SERC (2017)

C.R. Elks, G.M. Atkinson, T. Bakker, S. Gautham, R.D. Hite, F.E. Derenthal, and G. Bakirtzis, "Technologies for Enhancing Verifiability of Embedded I&C Systems in Nuclear Power: A Survey of Advanced FPGA and MEMs Technologies", EPRI (2015)

[invited talk] G. Bakirtzis, "Designing Secure Cyber-Physical Systems", Friday Forum, Virginia Commonwealth University (2017)

[open-source software] G. Bakirtzis, "A Vulnerability Assessment Tool for System Models", `cybok-cli`, DOI: 10.5281/zenodo.1313696 (2018)

G. Bakirtzis and B.J. Simon, "A GraphML Exporter for MagicDraw SysML", `graphml_export`, DOI: 10.5281/zenodo.1308914 (2018)

G. Bakirtzis and B.J. Simon, "A Security Dashboard for Analyzing CPS Designs", `security-analyst-dashboard`, DOI: 10.5281/zenodo.1318537 (2018)

[invited demo] G. Bakirtzis, "Automated Design-Phase Vulnerability Analysis", CSER (2018)

Teaching

University of Virginia

Fall 2017 I lectured a short course, *Model Sufficiency for Cybersecurity*, on modeling requirements, functional behaviors, and system architectures in SysML for Defense Intelligence Agency (DIA) analysts. (Enrollment: 10)

Virginia Commonwealth University

Fall 2018 As guest lecturer for *Signals and Systems II* I lectured on Markov chains and produced a corresponding homework assignment. (Enrollment: 46)

As teaching assistant for the graduate seminar *Systems-theoretic Cybersecurity*, I compiled a list of relevant seminal and current research publications and led weekly discussions. (Enrollment: 4)

Fall 2016 As codeveloper and lead teaching assistant for *Introduction to Engineering*, I designed homework assignments, laboratory exercises, and exam problems. I managed two graduate and five undergraduate teaching assistants and administered the course website. ¶ I received the School of Engineering Certificate of Scholarship for Outstanding Teaching Award Finalist and the ECE Graduate Student Teaching Assistant of the Year awards. (Enrollment: 87)

Fall 2015

As laboratory assistant for *Microcomputer Systems*, I restructured and rewrote all laboratory assignments, including the final project. I developed problem sets to improve the understanding of low-level instructions and their relation to higher level languages. (Enrollment: 56)

As teaching assistant for *Introduction to Microelectronics*, I introduced weekly recitation sessions where I lectured extra material. (Enrollment: 55)

Spring 2015

As lead teaching and laboratory assistant for *Electrical Circuits I*, I designed and ran laboratory exercises. I wrote and graded quizzes and a portion of the exams. I provided solutions to homework and test problems. (Enrollment: 141)

Fall 2014

As lead teaching assistant for *Signals and Systems II*, I conducted review sessions and held weekly office hours. I graded homework and a portion of the exams. I lectured two class sessions. (Enrollment: 31)

As teaching assistant for *Advanced Engineering Programming Using C/C++*, I ran weekly tutoring sessions. I formulated and applied grading criteria for homework assignments. (Enrollment: 55)

Spring 2014

As lead laboratory assistant for *Digital Logic Design*, I ran and graded laboratory exercises. I developed the laboratory policy, the grading rubric, two lab exercises, and the final design project. (Enrollment: 68)

Fall 2013

As teaching assistant for *Advanced Engineering Programming Using C/C++*, I ran multiple tutoring sessions each week. (Enrollment: 62)

Spring 2013

As teaching assistant for *Engineering Programming Using C*, I aided students during weekly help sessions and graded assignments. (Enrollment: 99)

Advising

Virginia Commonwealth University

2018

As on-demand mentor for Hyperloop at VCU—one of the twenty teams to advance to the final stage of the international Hyperloop competition—I advised on safety assessment and control system software design.

2018

I mentored capstone students Jasmine Norman and Tony Shin in designing and implementing a Vendor Managed Inventory (VMI) for Airline Hydraulics. I provided hands-on help with embedded system design and software engineering.

Service

Reviewer

2018

IEEE International Conference on Intelligent Transportation Systems (ITSC)
INCOSE Conference on Systems Engineering Research (CSER)

Graduate Student Advisory Board (GSAB)

2015–16 As founding chair of GSAB, I coordinated the board to resolve graduate students's concerns by communicating with the ECE department chair. I organized and led committees on social media engagement and engineering outreach.

Engineering Ambassadors

2013–15 As counselor, then activity leader, and finally event organizer I volunteered for several Virginia Commonwealth University K-12 educational programs.

Autonomous Robotics Group (ARG)

2013-15 As founding vice president of ARG I secured funds and managed a team that built and programmed a UAV to take part twice in the AUVSI SUAS competition.

Institute of Electrical and Electronics Engineers (IEEE)

2015 I was inducted in IEEE–HKN honor society.

2013–14 As student branch officer, I initiated a successful collaboration with HKN to acquire funds, attract new members, and organize joint volunteering outreach activities. I coordinated weekly tutoring sessions for most introductory electrical engineering courses. I created and administered the website of the Virginia Commonwealth University IEEE branch.

UNIVERSITY of VIRGINIA

SCHOOL of ENGINEERING & APPLIED SCIENCE

CODY FLEMING, ASSISTANT PROFESSOR

January 2019

To the Applied Category Theory School:

It is my pleasure to endorse **Giorgos Bakirtzis** for admission into your school. Before discussing his potential capability, I want to describe my relationship with Giorgos.

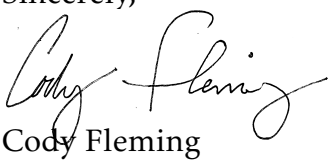
I have gotten to know Giorgos over the course of the past three years since I started working on a collaborative research project for security of cyber-physical systems. After about a year, he asked me to co-advise his PhD dissertation and went through a fairly significant effort to get me a courtesy appointment at his then-institution. He has since applied, and been accepted to, the University of Virginia. More than anything, I recall initially being struck by a kind of confidence and assertiveness; he jokingly refers to his Greek heritage as a possible reason. This project includes 5 PIs, several research scientists, 4 graduate students and 6 undergraduate students – in the context of this large group, Giorgos has stood out as a leader and is the most exceptional student I have known so far in terms of taking his own initiative. For the past 2 years I have met with Giorgos and another graduate student formally once per week, and informally even more often. Giorgos has **published 7 proceedings**, several of which have appeared in top conferences, and he has also won a **best student paper** award.

Giorgos is currently working in the broad area of safety and security of cyber-physical systems. The methodology we are developing spans several levels of abstraction, from very high level (and currently informal) descriptions of desired system behavior, all the way down to hardware and software components, and their interactions. These characteristics make Category Theory an attractive candidate for modeling and verifying many systems of interest. We have explored Category Theory together, but in a relatively informal setting. Giorgos would benefit significantly from an in-depth, concentrated treatment of the topic.

Given these Giorgos' experience, background, and future research goals – along with his diverse experience in several areas of engineering – I believe George is a very strong candidate for a position in your Applied Category Theory School program. He will not only benefit significantly from your program, but he will also contribute to our success as a school.

Please do not hesitate to ask any further questions about Mr. Bakirtzis.

Sincerely,



Cody Fleming

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