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RA12 Scalable Formal Methods in Robotics and Production

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CIIRC, CTU

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Robotics and Advanced Industrial Production
CZ.02.01.01/00/22_008/0004590

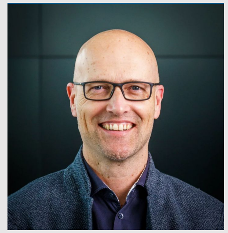
Structure

- Two groups
  - G12 - Faculty of Information Technology, CTU Prague
  - G14 - CIIRC

- RO 12.1: Scalable Symbolic Execution through Bounded Model Checking (G12, Ch. Kirsch)
- RO 12.2: Automated Reasoning for Industrial Applications (G14, M. Janota)
- RO 12.3: Reasoning about Configurable Systems (G14, M. Janota)
- RO 12.4 Graphs, parameters, and optimization for agents (G12, D. Knop)

G12

D. Knop (Ex TT)

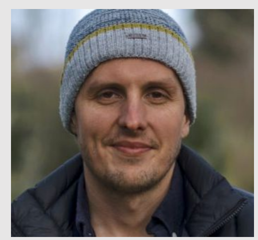


Ch. Kirsch (Ex TT)

G14

M. Janota (Ex TT)

J. Jakubův (PD)



J. Hůla (PD)

N. Antonov (PhD student)

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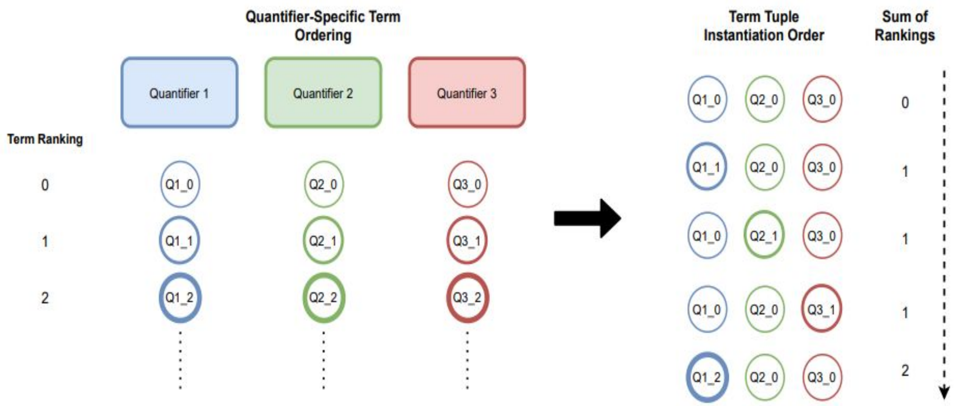
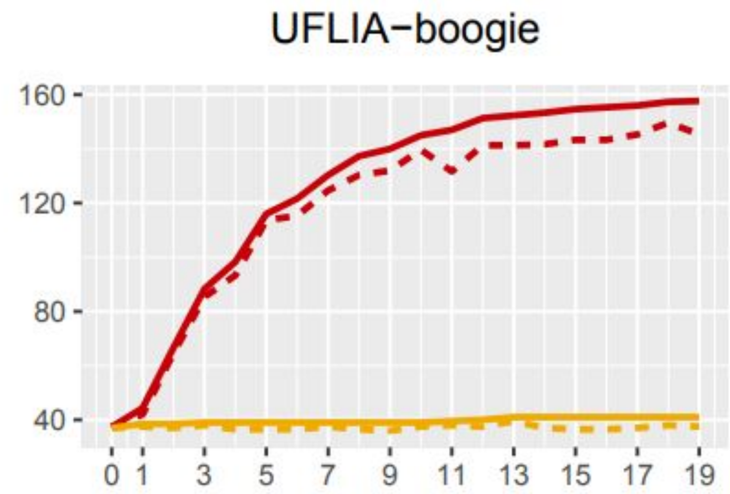
RO 12.2: Automated Reasoning for Industrial Applications





- Instantiating quantifier is a central problem in theorem proving (undecidable)
- We use machine learning to order candidates

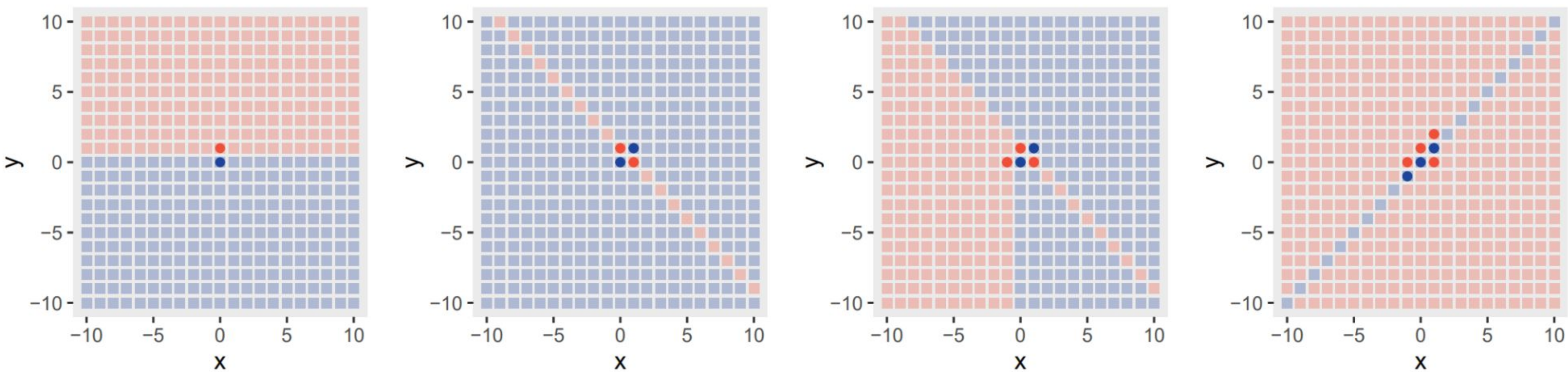
Towards Learning Quantifier Instantiation in SMT
M. Janota, J. Piepenbrock, B. Piotrowski *in* SAT 2022

RO 12.2: Automated Reasoning for Industrial Applications

- **Goals**
  - Make solvers more accessible to nonexpert users
  - Adapt to given set of problems and learn from past success and failure
  - Nontrivial counter-examples (eg bugs in a program)
- **Techniques used**
  - Incorporate ML techniques into solvers
  - Focus on specific types of problems
  - ML to create new objects
- **International collaboration**
  - Andrew Reynolds (U. of Iowa)
  - Vasco Manquinho (U. de Lisboa)
- **Cooperation with other RAs:**
  - **RA11:** Scheduling, discrete optimization and decision-making
  - **RO7.3**: Planning, scheduling and execution of tasks in the HRC workspace

RO 12.3: Reasoning about Configurable Systems

- Complex objects described as logical formulas
- Use learning within an SMT solver to synthesize and verify



Towards Learning Infinite SMT Models
M. Janota, B. Piotrowski, K. Chvalovský *in* SYNASC 2023

RO 12.3: Reasoning about Configurable Systems

- **Goals**
  - Enable reasoning about complex systems
  - Provide answers even for large-scale problems
- **Techniques used**
  - Synthesize specifications for submodules
  - Probabilistic answers
  - ML to identify likely scenarios
- **International collaboration**
  - Andrew Reynolds (U. of Iowa)
  - J. Fragoso (U. de Lisboa)
- **Cooperation with other RAs:**
  - **RO 7.2:** Interactive skill and task specification, learning

RO 12.1: Problem Statement and Vision

How do we make reasoning about correctness scalable to large software systems and accessible to non-experts?

At least 3 challenges:

1. Current reasoning technology works for hardware at scale but not software
2. Software engineering and formal methods communities do not intersect
3. Formal methods are hard, if not impossible to use for non-experts

Our vision:

1. Develop scalable tools that connect software development with state-of-the-art bit-precise solver technology
2. Provide benchmarks that foster innovation in formal methods

RO 12.1: State of the Art at CVUT: Rotor
github.com/cksystemsteaching/selfie

Rotor is a fast modelling tool for translating in linear time and space:

RISC-V binaries generated by production compilers

to

models that state-of-the art complete solvers can reason about

for

code analysis: is there program input such that an error occurs in finitely many steps?

code synthesis: is there an equivalent, faster implementation of some given code?

RO 12.1: Future of Rotor

Rotor is co-developed with colleagues at University of Freiburg, Germany, around Professor Armin Biere that are leading experts in bit-precise reasoning technology

Freiburg is working on new solver technology designed specifically for models generated by **Rotor**

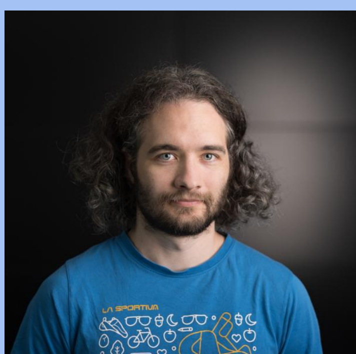
If future solvers scale, at least on some models, **Rotor** may become part of future software development tools and processes

RO12.4: Graphs, parameters, and optimization for agents


Ex TT




Postdoc



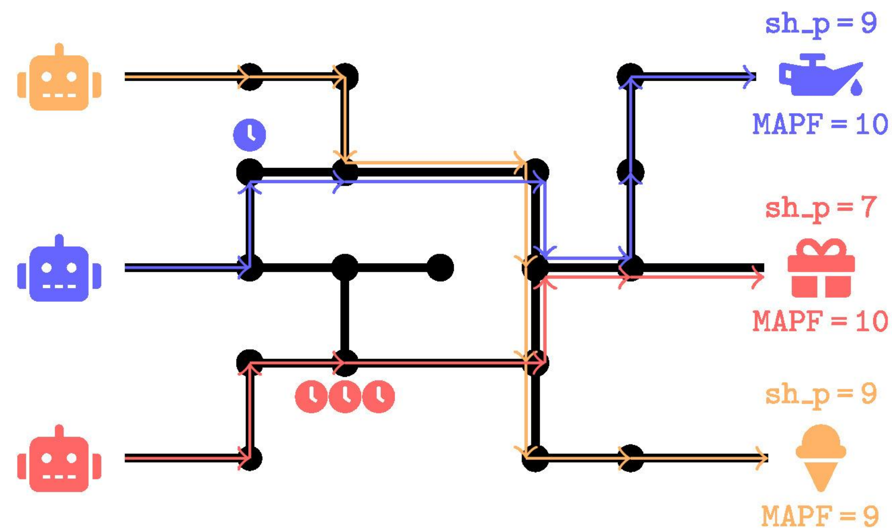

Ph.D. student

MSc

RO12.4: Graphs, parameters, and optimization for agents

MULTIAGENT PATHFINDING (MAPF)	
In:	An undirected graph G, a set of k robots, two lists $(s_1,\ldots,s_k)$ and $(t_1,\ldots,t_k)$ of initial and target vertices, and a makespan ℓ.
??:	Is there a non-colliding program for the robots such that each robot arrives to its target vertex in time at most ℓ?

- The problem is known to be NP-hard.
- We focus on the complexity of the problem if the underlying graph is restricted.
- We obtain multiple efficient (FPT) algorithms for various restrictions of the graph.
- The algorithmic results are accompanied with the matching hardness lowerbounds.



F. <u>Fioravantes</u>, D. <u>Knop</u>, J. M. Křišťan, N. <u>Melissinos</u>, M. <u>Opler</u>. *Exact Algorithms and Lowerbounds for Multiagent Pathfinding: Power of Treelike Topology*. AAAI '24.

RO12.4: Graphs, parameters, and optimization for agents

- **What we will aim for:**
  - Parameterized complexity and parameters in graphical optimization.
    - What are the most relevant parameters in practice? To which graph-theoretical parameters they relate?
    - For which parameters there is an efficient algorithm and for which (presumably) not?
  - Representation of elections
    - Recognition of 2D elections via reduction rules.
    - Connection between 2D profile and planar graph of possible voters.
  - Kernelization of IP in variable dimension.
  - Parameterized (in)tractability for total problems (TFNP)
- **International collaboration:**
  - Piotr Faliszewski, Andrzej Kaczmarczyk (AGH Kraków), Argyrios Deligkas, Eduard Eiben (RHUL), Robert Bredereck (TU Clausthal), Robert Ganian (TU Wien)
- **Cooperation with other RAs:**
  - Z. Hanzálek, P. Šůcha – RO 11.1: FPT algorithms in production scheduling
  - Z. Hanzálek, P. Šůcha, A. Novák – RO 11.2: FPT for stochastic optimization problems
  - more to come

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Thank you for your attention!

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