Formal Methods Supported by Symbolic Computation for Engineering Applications in Cloud Computing and Artificial Intelligence

Presentation of the Habilitation Thesis

Mădălina Eraşcu

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April 26th, 2024

Overview

Preamble
- Studies
- Career History & Research Projects

Presentation of the Research Contributions against State-of-the-art
- Formal Methods for Symbolic Computation
- Formal Methods for Cloud Computing
- Formal Methods for Data-intensive Applications
- (Formal methods in) Machine Learning
- Computer Science Education

Scientific and Professional Achievements
- Honors, Prizes, Scholarships
- Teaching
- Advising
- Comunity Service

Scientific and Professional Roadmap
- Envisaged Scientific and Professional Endeavors
- Upcoming Research in the Near Future

Outline

Outline

Studies

2008 – 2012 Johannes Kepler University Linz, Austria
PhD Studies in Technical Sciences
PhD Thesis: *Computational Logic and Quantifier Elimination Techniques for (Semi-)automatic Static Analysis and Synthesis of Algorithms”*
Scientific Coordinators: Tudor Jebelean and Hoon Hong

2006 – 2008 Johannes Kepler University Linz, Austria
Master Studies in Computer Science
Master Thesis: *Automated Formal Static Analysis and Retrieval of Source Code*
Scientific Coordinator: Tudor Jebelean

2002 – 2006 West University of Timișoara, Romania
Bachelor studies in Computer Science;
Bachelor Thesis: *XML Web Services using ADO.NET*
Scientific Coordinator: Florin Fortiș

1998 – 2002 “General Dragalina” High-School, Oravița, Romania
Informatics

Outline

Career History & Research Projects

2014 – 2016	West University of Timișoara, Romania Department of Computer Science	Associated Assistant
2014	West University of Timișoara, Romania Department of Computer Science	Post-doctoral Researcher

2014 HOST: High Performance Computing Service Centre. Funding: European Commission – FP7-REGPOT Programme. *Member*

2013	Johannes Kepler University, Linz, Austria Research Institute for Symbolic Computation	Post-doctoral Researcher

Career History & Research Projects

Since 2014 Institute e-Austria, Timișoara, Romania Researcher

2017 – 2018 Director (PI) of MANeUveR: Management Agency for Cloud Resources (`https://merascu.github.io/links/MANeUveR.html`). Funding: UEFISCDI. Budget: 475000 RON (approx. 102000 EUR). Competitive selection: 252 financed projects out of 2074 applications. *Principal Investigator*

2015 – 2017 DICE: Developing Data-Intensive Cloud Applications with Iterative Quality Enhancements. Funding: European Commission – H2020-ICT Programme. *In charge of WP3 DICE Verification from IeAT*

2014 – 2016 SPECS: Secure Provisioning of Cloud Services based on SLA Management. Funding: European Commission – FP7-ICT Programme. *In charge of WP2 - SLA Negotiation from IeAT*

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2016 – 2021 West University of Timișoara, Romania — Lecturer
Department of Computer Science

- 2016 – 2018 SC^2 Satisfiability Checking and Symbolic Computation - Bridging Two Communities to Solve Real Problems. Funding: European Commission – H2020-FETOPEN Programme
- 2016 – 2017 Matlib4Space - Prequalification of a Mathematical Library for Flight Software. Funding: European Space Agency.

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2017 – 2019 Continental Automotive Romania — Innovation Researcher
Advanced Driver Assistance Systems (ADAS) Department

Career History & Research Projects

Since 2021 | West University of Timișoara, Romania | Associate Professor
Department of Computer Science

2022 – 2024 Director (PI) of SAGE: A Symbiosis of Satisfiability Checking, Graph Neural Networks and Symbolic Computation (`https://merascu.github.io/links/SAGE.html`). Funding: UEFISCDI. Budget: 450000 RON (approx. 94000 EUR). Competitive selection: 162 financed projects out of 743 applications.

Since 2021 Member of COST Action CA20111: European Research Network on Formal Proofs (`https://europroofnet.github.io`). Also leader of WG3 - Program Verification between Oct 2022 - Sept 2023.

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Jan–May 2022 University of Rochester, USA Research Scholar
Simon Business School

Outline

Research interests

- Formal Methods, in particular Static Software Verification;

- Automated Reasoning , in particular First-Order Theorem Proving, SAT and SMT solving

- Symbolic Computation, in particular Polynomial Algebra.

with applications in Cloud Computing and Artificial Intelligence.

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Problem

Synthesize an Optimal Numerical algorithm for Solving $f(y) = x$

Solving $f(y) = x$

in: x - real number

ε - error bound

out: an interval I with width less than equal ε such that $y \in I \wedge f(y) = x$.

Numerical algorithm

Initialize I

while width(I) $> \varepsilon$

$I \leftarrow R(I, x)$

return I

Optimal

R such that the interval I shrinks fastest.

Synthesize

Find such R.

Problem

Synthesize an Optimal Numerical algorithm for Solving $y^2 = x$

Solving $y^2 = x$

in: x - real number

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out: an interval I with width less than equal ε such that $y \in I \wedge y^2 = x$.

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Motivation

Computing the square root of a given real number – fundamental operation.

Importance:

1. Numerical analysis
   Improve the convergence of an existing algorithm for computing the square root of a real number
2. Symbolic Computation
   - Demonstrate the power of symbolic methods over numerical methods
   - Advancing the state-of-the-art of quantifier elimination methods over reals
3. Theorem proving/algorithm synthesis
   (Semi-) automatic synthesis of optimal algorithms by combining in a novel way algebraic and logical methods

Publications:

M. Erascu and H. Hong, *The Secant-Newton Map is Optimal Among Contracting Quadratic Maps for Square Root Computation*, Journal of Reliable Computing 18 (2013), 73–81.

M. Erascu and H. Hoon, *Synthesis of Optimal Numerical Algorithms using Real Quantifier Elimination (Case Study: Square Root Computation)*, Proceedings of the 39th International Symposium on Symbolic and Algebraic Computation (ISSAC) (K. Nabeshima, K. Nagasaka, F. Winkler, and A. Szanto, eds.), ACM, 2014, pp. 162–169.

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Numerical Algorithms (Square Root)

Problem: solve $y^2 = x$

in: x - real number

ε - error bound

out: an interval I with width less than ε such that $y \in I \wedge y^2 = x$.

Algorithm schema: Interval refining

Initialize I

while width(I) $> \varepsilon$

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$I \leftarrow \left[L + \frac{x-L^2}{L+U}, U + \frac{x-U^2}{2U}\right]$ Secant-Newton Refining Map

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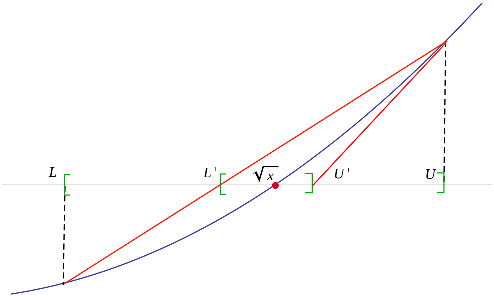

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return I

Is there any refinement map which is better than Secant-Newton?

Numerical Algorithms (Square Root) Synthesis

Problem: solve $y^2 = x$

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$$I \leftarrow \left[L + \frac{x + p_0 L^2 + p_1 LU + p_2 U^2}{p_3 L + p_4 U}, U + \frac{x + q_0 U^2 + q_1 UL + q_2 L^2}{q_3 U + q_4 L} \right]$$

Quadratic Refining Map

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Algorithm schema: Interval refining

$I \leftarrow [\min(1, x), \max(1, x)]$

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$$I \leftarrow \left[L + \frac{x+(-1)L^2+0LU+0U^2}{1L+1U}, U + \frac{x+(-1)U^2+0UL+0L^2}{2U+0L}\right]$$ Secant-Newton

return I

Numerical Algorithms (Square Root) Synthesis Optimal

$$L' = L + \frac{x + p_0 L^2 + p_1 LU + p_2 U^2}{p_3 L + p_4 U} \qquad U' = U + \frac{x + q_0 U^2 + q_1 UL + q_2 L^2}{q_3 U + q_4 L}$$

Subject to

$$Correctness(p,q) :\iff \forall_{\substack{L,U,x \\ 0<L\leq\sqrt{x}\leq U}} \; 0 < L' \leq \sqrt{x} \leq U'$$

$$Termination(p,q) :\iff \forall_{\substack{x \\ x>0}} \; \exists_{\substack{c \\ 1>c>0}} \; \forall_{\substack{L,U \\ 0<L\leq\sqrt{x}\leq U}} \; U' - L' \leq c\,(U-L)$$

$$QuadraticConv(p,q) :\iff \forall_{\substack{x \\ x>0}} \; \exists_{\substack{c \\ c>0}} \; \forall_{\substack{L,U \\ 0<L\leq\sqrt{x}\leq U}} \; U' - L' \leq c\,(U-L)^2$$

Minimize

$$E(p,q) = \sup_{\substack{L,U,x \\ 0<L\leq\sqrt{x}\leq U \\ L\neq U}} \frac{U'-L'}{U-L}$$

Standard numerical optimization methods cannot be applied because:

1. The objective function is itself the result of parametric optimization (sup).
2. The constraints are quantified formulas.
3. It turns out that there are infinitely many values of p and q with the same minimum.

Numerical Algorithms (Square Root) Synthesis Optimal

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Minimize

$$E(p,q) = \sup_{\substack{L,U,x \\ 0<L\leq\sqrt{x}\leq U \\ L\neq U}} \frac{U'-L'}{U-L}$$

Standard numerical optimization methods cannot be applied because:

1. The objective function is itself the result of parametric optimization (sup).
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3. It turns out that there are infinitely many values of p and q with the same minimum.

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Strategies:

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Numerical Algorithms (Square Root) Synthesis Optimal by QE

Dividing into Simpler QE Problems

1. $$-1 < p_2 \le 0 \;\wedge\; p_1 \le -2p_2 \;\wedge\; 1 + p_2 \le p_4 \le 2 \;\wedge$$
$$\underset{\substack{L,U,y\\0<L\le y\le U}}{\forall} (1 - p_1 - p_2 - p_4)L^2 + (p_1 + p_4)LU + p_2U^2 + y^2 > 0$$

2. $$0 < q_3 \le 2 \;\wedge$$
$$\underset{\substack{L,U,y\\0<L\le y\le U}}{\forall} y \le \frac{q_2L^2+(2+q_1-q_3)LU+(-1-q_1-q_2+q_3)U^2+y^2}{(2-q_3)L+q_3U}$$

3. $$0 < q_3 \le 2 \;\wedge$$
$$\underset{\substack{L,U\\0<L\le U}}{\forall} (-4 + 4q_2 + 4q_3 - q_3^2)L + (4 + 4q_1 + 4q_2 - 4q_3 + q_3^2)U \le 0$$

4. ...

Numerical Algorithms (Square Root) Synthesis Optimal by QE

QE manually

$$0 < q_3 \leq 2 \;\wedge\; \underset{\substack{L,U,y\\0<L\leq y\leq U}}{\forall} y \leq \frac{q_2 L^2 + (2+q_1-q_3)LU + (-1-q_1-q_2+q_3)U^2 + y^2}{(2-q_3)L + q_3 U}$$

$$\iff 0 < q_3 \leq 2 \wedge$$

$$\underset{\substack{L,U,y\\0<L\leq y\leq U}}{\forall} y^2 - ((2-q_3)L + q_3 U)y + q_2 L^2 + (2+q_1-q_3)LU + (-1-q_1-q_2+q_3)U^2 \geq 0$$

$$\iff 0 < q_3 \leq 2 \wedge$$

$$\underset{\substack{L,U\\0<L\leq U}}{\forall} -\left(\left(1-\frac{q_3}{2}\right)L + \frac{q_3}{2}U\right)^2 + q_2 L^2 + (2+q_1-q_3)LU + (-1-q_1-q_2+q_3)U^2 \geq 0$$

$\iff \ldots$ (by Mathematica/QEPCAD-B)

Numerical Algorithms (Square Root) Synthesis Optimal by QE

Main Result:

(a) $E(p,q) \geq \frac{1}{4}$ $\qquad \left(E(p^*,q^*) = \frac{1}{2},\ \text{where } p^*, q^* \text{ are for Secant-Newton}\right)$

(b) $E(p,q) = \frac{1}{4}$ iff

$$p_3 = q_3 = p_4 = q_4 = 1 \ \wedge \ p_2 = 0 \ \wedge \ q_0 = -\frac{3}{4} \ \wedge$$
$$p_0 + p_1 = -1 \ \wedge \ q_1 + q_2 = -\frac{1}{4} \ \wedge$$
$$-\frac{1}{2} \leq q_1 \leq p_1 \leq 0$$

In other words

$$L' = L + \frac{x - (1 + p_1)\,L^2 + p_1\,LU}{L + U}$$
$$U' = U + \frac{x - \frac{3}{4}U^2 + q_1\,UL - \left(\frac{1}{4} + q_1\right)L^2}{U + L}$$

where $-\frac{1}{2} \leq q_1 \leq p_1 \leq 0$

How much improvement?

	Secant-Newton Map $R^*(I,x)$	Synthesized Map $\tilde{R}(I,x)$	
Original	$\left[L+\frac{x-L^2}{L+U}, U+\frac{x-U^2}{2U}\right]$	$\left[L+\frac{x-L^2}{L+U}, U+\frac{x-\frac{3}{4}U^2-\frac{1}{2}LU+\frac{1}{4}L^2}{U+L}\right]$	
Rewritten	$\left[\frac{x+LU}{L+U}, \frac{x}{U+U}+\frac{1}{4}(U+U)\right]$	$\left[\frac{x+LU}{L+U}, \frac{x}{U+L}+\frac{1}{4}(U+L)\right]$	
# of ops.	9	9	The same
Convergence	Quadratic	Quadratic	The same
Lipschitz	$\frac{1}{2}$	$\frac{1}{4}$	Better
# of loop iters.	$\log_2 \frac{I_0}{\varepsilon}$	$\frac{\log_2 \frac{I_0}{\varepsilon}}{2}$	Better

Input: $x = 150$ $\quad \varepsilon = 10^{-5}$

How much improvement?

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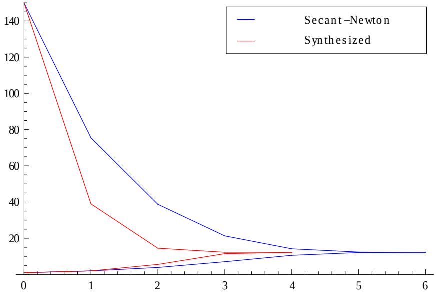

Outline

Security in Cloud

The main objective of the SPECS project was to provide an open source framework to easily build applications that offer services covered by Security SLAs, in an as-a-service fashion.

Security SLAs lifecycle:

- Negotiation and Renegotiation phases
- Enforcement (Implementation and Remediation phases)
- Monitoring

Publications:

V. Casola, A. De Benedictis, M. Erascu, M. Rak, and U. Villano.
A security sla-driven methodology to set-up security capabilities on top of cloud services. In *10th International Conference on Complex, Intelligent, and Software Intensive Systems, CISIS 2016, Fukuoka, Japan, July 6-8, 2016*, pages 549–554, 2016.

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Scalable optimal deployment in the cloud of component-based applications using optimization modulo theory, mathematical programming and symmetry breaking

Efficient methods to solve the Cloud resource allocation problem by combining exact (constraint programming, SMT solving) and approximate (greedy, metaheuristics) methods and symmetry breaking.

Publications:

M. Erascu, F. Micota, and D. Zaharie. Scalable optimal deployment in the cloud of component-based applications using optimization modulo theory, mathematical programming and symmetry breaking. *Journal of Logical and Algebraic Methods in Programming*, 121:100664, 2021.

Flavia Micota, Madalina Erascu, and Daniela Zaharie. Constraint satisfaction approaches in cloud resource selection for component based applications. In *14th IEEE International Conference on Intelligent Computer Communication and Processing, ICCP 2018, Cluj-Napoca, Romania, September 6-8, 2018*, pages 443–450, 2018.

Madalina Erascu, Flavia Zamfirache, and Daniela Zaharie. Influence of variables encoding and symmetry breaking on the performance of optimization modulo theories tools applied to cloud resource selection. In Gilles Barthe, Konstantin Korovin, Stephan Schulz, Martin Suda, Geoff Sutcliffe, and Margus Veanes, editors, *LPAR-22 Workshop and Short Paper Proceedings*, pages 1–14, 2018.

M. Erascu, F. Micota, and D. Zaharie. A Scalable Hybrid Approach for Applications Placement in the Cloud. In *Grid, Cloud High Performance Computing in Science (ROLCG), 2015 Conference*, pages 1–4, Oct 2015.

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Efficient methods to solve the Cloud resource allocation problem by combining exact (constraint programming, SMT solving) and approximate (greedy, metaheuristics) methods and symmetry breaking.

Publications:

M. Erascu, F. Micota, and D. Zaharie. Scalable optimal deployment in the cloud of component-based applications using optimization modulo theory, mathematical programming and symmetry breaking. *Journal of Logical and Algebraic Methods in Programming*, 121:100664, 2021.

Flavia Micota, Madalina Erascu, and Daniela Zaharie. Constraint satisfaction approaches in cloud resource selection for component based applications. In *14th IEEE International Conference on Intelligent Computer Communication and Processing, ICCP 2018, Cluj-Napoca, Romania, September 6-8, 2018*, pages 443–450, 2018.

Madalina Erascu, Flavia Zamfirache, and Daniela Zaharie. Influence of variables encoding and symmetry breaking on the performance of optimization modulo theories tools applied to cloud resource selection. In Gilles Barthe, Konstantin Korovin, Stephan Schulz, Martin Suda, Geoff Sutcliffe, and Margus Veanes, editors, *LPAR-22 Workshop and Short Paper Proceedings*, pages 1–14, 2018.

M. Erascu, F. Micota, and D. Zaharie. A Scalable Hybrid Approach for Applications Placement in the Cloud. In *Grid, Cloud High Performance Computing in Science (ROLCG), 2015 Conference*, pages 1–4, Oct 2015.

Motivation

Advent of Cloud computing $\rightsquigarrow$ loosely-coupled architecture $\rightsquigarrow$ DevOps paradigm $\rightsquigarrow$ application modeling $\rightsquigarrow$ optimal deployment

Benefits of optimal deployment:

1. the synthesis of deployment plans that are optimal by design
2. the integration of such deployment plans into the application modeling process, enables formal reasoning on a model of the deployed application.

Problem Specification

Automated deployment of component-based applications in the Cloud consists of:

1. selection of the computing resources,
2. distribution/assignment of the application components over the available computing resources,
3. its dynamic modification to cope with peaks of user requests.

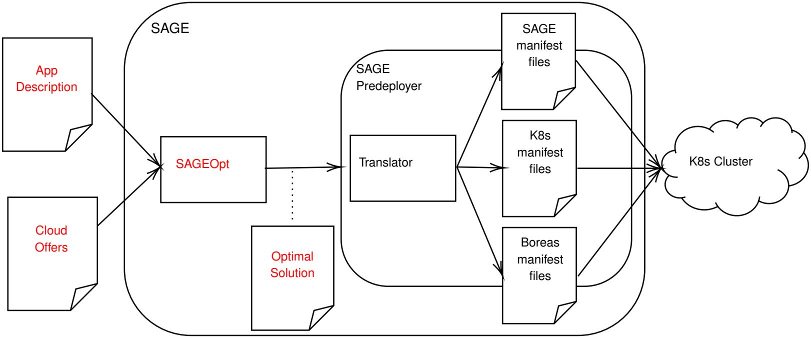
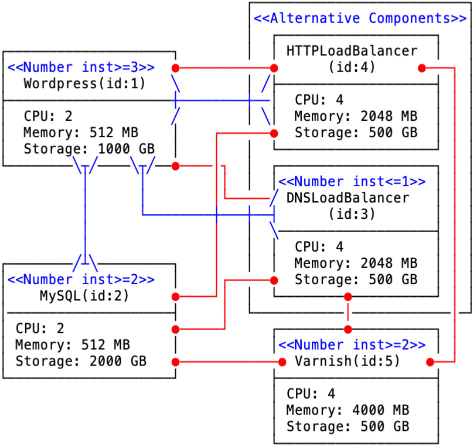


Figure: SAGE General Architecture

Case Study: Wordpress: Formalization

Wordpress (`www.wordpress.com`) is an open-source application frequently used in creating websites, blogs and web applications.



- DNSLoadBalancer requires at least 1 instance of Wordpress and can serve at most 7 such instances (*Require-Provide constraint*)
  $\sum_{k=1}^{M} a_{3k} \leq 7 \sum_{k=1}^{M} a_{1k}, \; k = \overline{1, M}$
- Only one type of balancer must be deployed (*Exclusive deployment constraint*). $a_{3k} + a_{4k} \leq 1, \; k = \overline{1, M}$
- Components are characterized in terms of their resource demand (i.e. in terms of CPU cores, RAM and storage capacity).
- ...

Cloud provider offers

Spot Instance Prices

Spot Instances | Defined Duration for Linux | Defined Duration for Windows

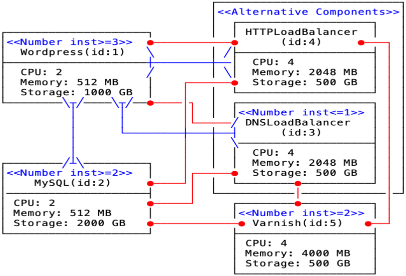
Region: EU (Ireland)

	Linux/UNIX Usage	Windows Usage
General Purpose - Current Generation		
t2.micro	$0.0038 per Hour	$0.0084 per Hour
t2.small	$0.0075 per Hour	$0.0165 per Hour
t2.medium	$0.015 per Hour	$0.033 per Hour
t2.large	$0.0302 per Hour	$0.0582 per Hour
t2.xlarge	$0.0605 per Hour	$0.1015 per Hour
t2.2xlarge	$0.121 per Hour	$0.183 per Hour
m3.medium	$0.0073 per Hour	$0.0633 per Hour
m3.large	$0.0306 per Hour	$0.1226 per Hour
m3.xlarge	$0.0612 per Hour	$0.2452 per Hour

Model	vCPU	CPU Credits / hour	Mem (GiB)	Storage
t2.nano	1	3	0.5	EBS-Only
t2.micro	1	6	1	EBS-Only
t2.small	1	12	2	EBS-Only
t2.medium	2	24	4	EBS-Only
t2.large	2	36	8	EBS-Only
t2.xlarge	4	54	16	EBS-Only
t2.2xlarge	8	81	32	EBS-Only

Remark: [snapshot from https://aws.amazon.com/ec2/] tens of thousands of price offers corresponding to different configurations and zones

Wordpress: Example Solution



- VM_1 (CPU:4, RAM: 30.5 GB, Storage: 1000 GB, Price: 0.0379 $/hour): Wordpress+MySQL
- VM_2 (CPU:4, RAM: 30.5 GB, Storage: 1000 GB, Price: 0.0379 $/hour): Wordpress+MySQL
- VM_3 (CPU:4, RAM: 7.5 GB, Storage: 2000 GB, Price: 0.021 $/hour): Varnish
- VM_4 (CPU:4, RAM: 7.5 GB, Storage: 2000 GB, Price: 0.021 $/hour): Varnish
- VM_5 (CPU:4, RAM: 7.5 GB, Storage: 2000 GB, Price: 0.021 $/hour): HTTPLoadBalancer
- VM_6 (CPU:4, RAM: 7.5 GB, Storage: 2000 GB, Price: 0.021 $/hour): Wordpress

Problem Formalization

General constraints

$$
\begin{array}{rll}
\textit{Basic allocation} & \sum\limits_{k=1}^{M} a_{ik} \geq 1 & \forall i = \overline{1, N} \\
\textit{Occupancy} & \sum\limits_{i=1}^{N} a_{ik} \geq 1 \Rightarrow v_k = 1 & \forall k = \overline{1, M} \\
\textit{Capacity} & \sum\limits_{i=1}^{N} a_{ik} \cdot R_i^h \leq F_{t_k}^h & \forall k = \overline{1, M}, \forall h = \overline{1, H} \\
\textit{Link} & v_k{=}1 \wedge t_k{=}o \Rightarrow \bigwedge\limits_{h=1}^{H} \left(r_k^h{=}F_{t_k}^h \right) \wedge p_k{=}P_{t_k} & \forall o = \overline{1, O},\ O \in \mathbb{N}^* \\
 & \sum_{i=1}^{N} a_{ik} = 0 \Rightarrow t_k = 0 & \forall k = \overline{1, M}
\end{array}
$$

where:

- $R_i^h \in \mathbb{N}^*$ is the hardware requirement of type h of the component i;
- $F_{t_k}^h \in \mathbb{N}^*$ is the hardware characteristic h of the VM of type t_k.

Problem Formalization (cont'd)

Application-specific constraints

Conflicts	$a_{ik} + a_{jk} \leq 1$	$\forall k = \overline{1, M}, \forall (i,j)\ \mathcal{R}_{ij} = 1$
Co-location	$a_{ik} = a_{jk}$	$\forall k = \overline{1, M}, \forall (i,j)\ \mathcal{D}_{ij} = 1$
Exclusive	*deployment*	
	$\mathcal{H}\left(\sum_{k=1}^{M} a_{i_1 k}\right) + \ldots + \mathcal{H}\left(\sum_{k=1}^{M} a_{i_q k}\right) = 1$	for fixed $q \in \{1, \ldots, N\}$
		$\mathcal{H}(u) = \begin{cases} 1 & u > 0 \\ 0 & u = 0 \end{cases}$
Require-	*Provide*	
	$n_{ij} \sum_{k=1}^{M} a_{ik} \leq m_{ij} \sum_{k=1}^{M} a_{jk}$	$\forall (i,j) \mathcal{Q}_{ij}(n_{ij}, m_{ij}) = 1$
	$0 \leq n \sum_{k=1}^{M} a_{jk} - \sum_{k=1}^{M} a_{ik} < n$	$n, n_{ij}, m_{ij} \in \mathbb{N}^*$

where:

- $\mathcal{R}_{ij} = 1$ if components i and j are in conflict (can not be placed in the same VM);
- $\mathcal{D}_{ij} = 1$ if components i and j must be co-located (must be placed in the same VM);
- $\mathcal{Q}_{ij}(n, m)$=1 if C_i requires at least n instances of C_j and C_j can serve at most m instances of C_i

Problem Formalization (cont'd)

Application-specific constraints

Full deployment $$\sum_{k=1}^{M}\left(a_{ik}+\mathcal{H}\left(\sum_{j,\mathcal{R}_{ij}=1} a_{jk}\right)\right)=\sum_{k=1}^{M} v_k$$

Deployment with *bounded number of instances*

$$\sum_{i\in\overline{C}}\sum_{k=1}^{M} a_{ik}\langle\mathrm{op}\rangle n \qquad |\overline{C}|\leq N,\ \langle\mathrm{op}\rangle\in\{=,\leq,\geq\}, n\in\mathbb{N}$$

Find:

- assignment matrix a with binary entries $a_{ik}\in\{0,1\}$ for $i=\overline{1,N}$, $k=\overline{1,M}$, which are interpreted as follows:

$$a_{ik}=\begin{cases}1 & \text{if } C_i \text{ is assigned to } V_k\\ 0 & \text{if } C_i \text{ is not assigned to } V_k.\end{cases}$$

- the type selection vector t with integer entries t_k for $k=\overline{1,M}$, representing the type (from a predefined set) of each VM leased.

Such that: the leasing price is minimal $\sum_{k=1}^{M} v_k\cdot p_k$

Characteristics of the problem

- Constrained optimization
- Linear programming: 0-1 + real/integer
- Related to bin packing but ...
  - ... the placement of items in bins is limited by constraints
  - ... the capacity of bins is not fixed (it depends on the offers)
  - ... the number of items is not known (it depends on the constraints on the number of instances)
  - ... the smallest price is not necessarily obtained by using the smallest number of bins
- NP-hard

Solution Approaches

1. Exact methods
   - Constrained Programming (CP)* °
     - Modelling language: MiniZinc (`https://www.minizinc.org`)
     - Solvers integrated with MiniZinc: Google OR-Tools, Gecode, Chuffed
   - Mathematical Programming (MP)**
     - Python CPLEX API
   - Satisfiability Modulo Theory (SMT)**
     - Python Z3 API
   - Advantage: provides an optimal solution
   - Drawback: significant computational time for large problems
2. Approximate methods
   - Population-based metaheuristic*
     - Evolutionary algorithm that uses only mutation operator
     - Advantage: always provides a (sub)optimal solution
     - Drawback: low success rate in case of larger instances

° B. David, "Constraint Optimization Approaches for Cloud Resource Provisioning," National Scientific Session of Mathematics and Informatics, November 25-27, 2021, Brasov, Romania.
* F. Micota, M. Eraşcu and D. Zaharie, "Constraint Satisfaction Approaches in Cloud Resource Selection for Component Based Applications," 2018 IEEE 14th International Conference on Intelligent Computer Communication and Processing (ICCP), Cluj-Napoca, Romania, 2018, pp. 443-450.
** M Eraşcu, F Micota, D Zaharie, "Scalable optimal deployment in the cloud of component-based applications using optimization modulo theory, mathematical programming and symmetry breaking", Journal of Logical and Algebraic Methods in Programming 121, 100664

Case Study: Wordpress (cont'd)

Solution:

- *assignment matrix* with elements $a_{ij} \in \{0, 1\}$

$$a_{ik} = \begin{cases} 1 & \text{if component } C_i \text{ is assigned to machine } V_k \\ 0 & \text{if component } C_i \text{ is not assigned to machine } V_k. \end{cases}$$

- *type selection vector t* with elements $t_k \in \mathbb{N}$ $(k = \overline{1, M})$ representing the type (from a predefined set) of each VM leased.

both fulfilling the application constraints and minimizing the leasing price.

For the case when the number of Wordpress instances is 3, we have:

- the assignment matrix

	V_1	V_2	V_3	V_4	V_5	V_6
Wordpress(C_1)	1	1	0	0	0	1
MySql(C_2)	1	1	0	0	0	0
DNSLoadBalancer(C_3)	0	0	0	0	0	0
HTTPLoadBalancer(C_4)	0	0	0	0	1	0
Varnish(C_5)	0	0	1	1	0	0

- the type vector: $t = [186, 186, 182, 182, 182, 182]$.

Case Study: Wordpress (cont'd)

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HTTPLoadBalancer(C_4)	0	0	0	0	1	0
Varnish(C_5)	0	0	1	1	0	0

- the type vector: $t = [186, 186, 182, 182, 182, 182]$.

Experimental Analysis I

Goals:

- study the scalability of state-of-the-art general CP, MP and SMT tools in solving COPs corresponding to the deployment of component-based applications in the Cloud
- effectiveness of various static symmetry breaking techniques in improving the computational time of solving these problems.
- the evaluation from two perspectives: number of VMs offers, respectively number of deployed instances of components.

#ins	#ofr=20	#ofr=40	#ofr=250	#ofr=500
Chuffed				
3	2.13	4.18	57.72	458.21
4	26.03	114.18	1974.16	-
5	638.26	2230.39	-	-
OR-Tools				
3	3.52	8.42	96.38	191.38
4	23.25	56.47	502.71	988.33
5	149.47	428.98	-	-
6	494.46	1174.36	-	-
IBM CPLEX				
3	9.81	-	-	-
4	124.68	-	-	-
5	452.32	-	-	-
6	737.89	-	-	-
Z3				
3	2.92	4.13	115.36	391.87
4	46.46	366.24	-	-

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Symmetries

- A symmetry is a bijection on decision variables (i.e. a, t) that preserves solutions and non-solutions.
- Symmetry often occurs because groups of objects within a matrix are indistinguishable. This leads to row/column symmetries.
- Two variables are indistinguishable if some symmetry interchanges their roles in all solutions and non-solutions (variable symmetry).
- Value symmetries can permute only the values of variables.
- A matrix has row/column symmetry iff all the rows/columns of one of its matrices are indistinguishable.
- A matrix has partial row/column symmetry iff strict subset(s) of the rows/columns are indistinguishable.

Partial row/column symmetry are more often encountered in Cloud deployment problems.

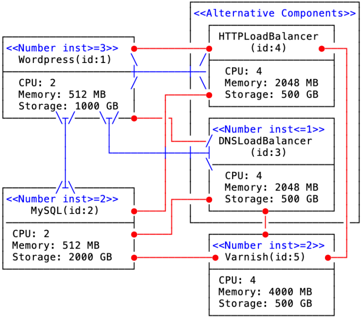
Symmetry Breaking: Column Symmetries

Ordering decreasing

- (L) the columns by the number of components for columns representing VMs of the same type:
$$\sum_{i=1}^{N} a_{ik} \geq \sum_{i=1}^{N} a_{i(k+1)}, \quad \forall k = \overline{1, N-1}$$
- (LX) the columns by lexicographic order for columns representing VMs of the same type
$$a_{\star k} \succ_{lex} a_{\star(k+1)}, \text{ where } a_{\star k} \text{ denotes the column } k.$$
- (PR) ordering decreasing the VMs by their characteristics (price, CPU, memory, storage)
$$P_1 \geq P_2 \geq ... \geq P_N, \quad \forall k = \overline{1, N}$$

Symmetry Breaking: Row Symmetries

(FV) pre-assigning, on separate VMs, the components composing the clique with maximum deployment size obtained from the conflict graph, i.e. the graph where the component instances are the nodes and the conflicts are the edges.

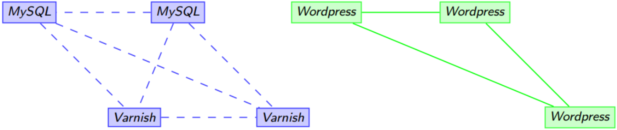


Example (**FV**: Wordpress with 3 Wordpress instances)

There are 3 cliques with maximum deployment size 4. Pick one:

- [2 *MySQL*, 2 *Varnish*]
- ~~[3 *Wordpress*, 1 *HTTPLoadBalancer*]~~
- ~~[3 *Wordpress*, 1 *DNSLoadBalancer*]~~

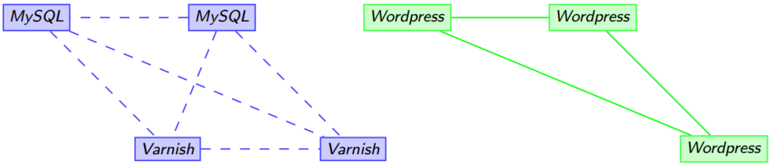
Examples of cliques



Symmetry Breaking: Row Symmetries (cont'd)

Example (**FV**: Wordpress with 3 Wordpress instances)

Clique with maximum deployment size 4: $[2 MySQL, 2 Varnish]$



	V_1	V_2	V_3	V_4	V_5	V_6
C_1	?	?	?	?	?	?
C_2	1	1	0	0	?	?
C_3	?	?	?	?	?	?
C_4	?	?	?	?	?	?
C_5	0	0	1	1	?	?

Symmetry Breaking: Finite combination of row and column symmetries

- FV, PR, L, LX,
- FVPR, FVL, FVLX, PRL, PRLX, LPR, LLX,
- FVPRL, FVPRLX, FVLPR, FVLLX, PRLLX, LPRLX,
- FVPRLLX, FVLPRLX

Example (PRLX (Wordpress with 3 Wordpress instances))

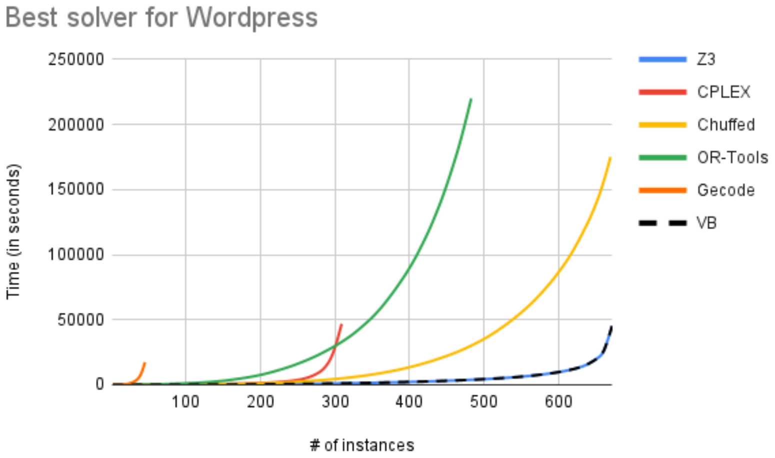
The assignment matrix:

	V_1	V_2	V_3	V_4	V_5	V_6
C_1	1	1	1	0	0	0
C_2	1	1	0	0	0	0
C_3	0	0	0	0	0	0
C_4	0	0	0	1	0	0
C_5	0	0	0	0	1	1

The price vector: $p = [379, 379, 210, 210, 210, 210]$.
Symmetry breakers:

$$
\begin{aligned}
&P_1 \geq P_2 \wedge \\
&P_1 = P_2 \Rightarrow a_{11} \geq a_{12} \wedge \\
&P_1 = P_2 \wedge a_{11} \geq a_{12} \Rightarrow a_{21} \geq a_{22} \wedge \\
&P_1 = P_2 \wedge a_{11} = a_{12} \Rightarrow a_{31} = a_{32} \wedge \\
&P_2 \geq P_3 \ \wedge \ldots
\end{aligned}
$$

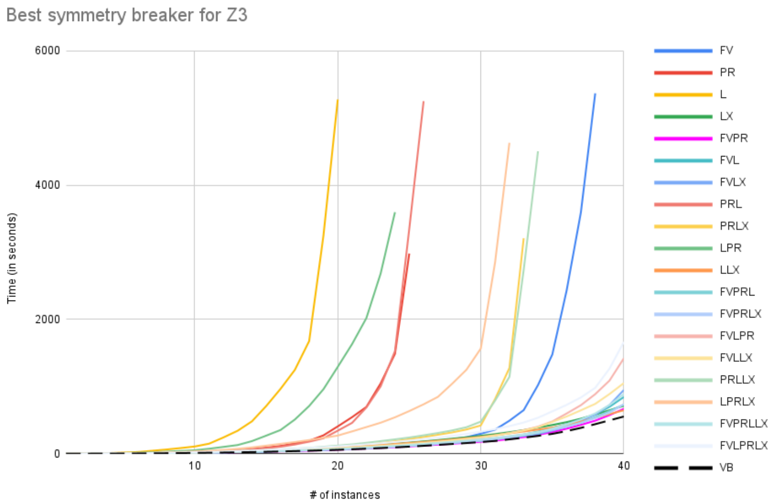
Experimental Results II



Symmetry Breaking: Row-Column Symmetries (cont'd)

Best symmetry breaker for Z3: FVPR

Remark: Combination of more than two symmetry breakers did not lead to better results although more symmetries are broken. This means that breaking more symmetries does not necessarily mean a computational improvement, since more more constraints are added.



Outline

Motivation

Software market switches to Big Data: popular technologies such as Spark, Storm, Hadoop, and NoSQL stimulates Big Data adoption.
DICE project (`http://www.dice-h2020.eu/`) aimed to define methods and tools for the data-aware *quality*-driven development of Date Intensive Applications (DIAs).
Prediction of quality properties of DIAs:

- Performance, reliability, *safety and liveness properties*
- Helpful early in the DIA design
- Assess the potential impact of architectural changes (iteratively)

Verification of data-intensive applications involves abstractions of systems with an infinite number of states. We have used both first-order logic formalisms (array-based systems) and temporal logics (CLTLoc) to verify safety and liveness properties of systems.

Publications:

M. M. Bersani, F. Marconi, M. Rossi, M. Erascu, and S. Ghilardi. Formal verification of data-intensive applications through model checking modulo theories. In *Proceedings of the 24th ACM SIGSOFT International SPIN Symposium on Model Checking of Software*, SPIN 2017, pages 98–101, New York, NY, USA, 2017. ACM.

M. M. Bersani, F. Marconi, M. Rossi, and M. Erascu. A tool for verification of big-data applications. In *Proceedings of the 2nd International Workshop on Quality-Aware DevOps, QUDOS@ISSTA 2016, Saarbrücken, Germany, July 21, 2016*, pages 44–45, 2016.

F. Marconi, M. M. Bersani, M. Erascu, and M. Rossi. Towards the formal verification of data-intensive applications through metric temporal logic. In *Formal Methods and Software Engineering - 18th International Conference on Formal Engineering Methods, ICFEM 2016, Tokyo, Japan, November 14-18, 2016, Proceedings*, pages 193–209, 2016.

Focus: Apache Storm technology

Apache Storm (`storm.apache.org`) technology – used in applications that need efficient processing of unbounded streams of data, such as event log monitoring, real-time data analytics and data normalization.

Applications that use Storm: Yahoo, Twitter, Spotify, The Weather Channel, etc.

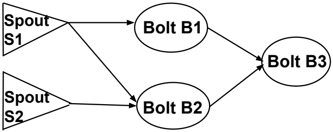
Key concepts:

- streams – infinite sequences of tuples that are processed by the application
- topologies – directed graphs
  - *nodes* represent operations performed over the application data
  - *edges* indicate how such operations are combined

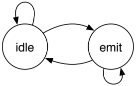
Types of nodes:

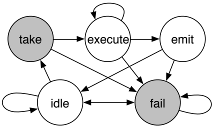
- *input nodes* bring information into the application from the environment: spouts
- *computational nodes* implement the logic of the application by processing information and producing a result: bolts

Example of Storm topology



Finite state automata describing the states of a spout (left) and bolt (right)





Features of the topology:

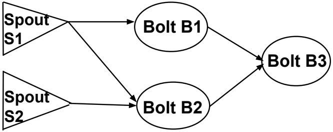
- parametric in the number of nodes and processes
- the number of nodes is known at design-time, hence fixed

Infinite-state model checking!

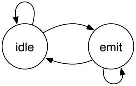
Suitable abstraction: ***array-based systems***. (Ghilardi et al.)

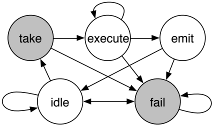
Safety verification of Storm topologies: given queue(s) bound(s) defined by the designer, “all bolt queues have a limited occupation level”.

Example of Storm topology



Finite state automata describing the states of a spout (left) and bolt (right)





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Array-based Systems

Formalizing an array-based system means specifying:

- the set of initial states
- the ordering of the actions (by means of a transition relation)
- the set of unsafe states (the negation of the formula we want to check)

Examples (Cubicle syntax):

- `init (i x) { T = 0.0 && B[i,x]=I && ... }` $\rightsquigarrow \forall_{i,x} \ldots$
- `transition spout_emit(i j)` $\rightsquigarrow \exists_{i,j} \ldots$

```
transition spout_emit(i j)
requires {Tsmin<Stime[i] && SubscribedBS[j,i]=True && ...}
 {
        L[l]:=case
        | l=j :  L[l]+1.0
        | _ :  L[l];
 }
```

- `unsafe(i) { L[i]>1.5 }` $\rightsquigarrow \exists_{i} \ldots$

Symbolic representation of array-based systems: *quantified first-order logic formulae*.
Verification of array-based systems: *decision procedure* based on backward reachability.
Termination of the decision procedure:

- the current set of reachable states has a non-empty intersection with the set of initial states (safety check) $\Rightarrow$ system is unsafe
- the current set has reached a fix-point (fix-point check) $\Rightarrow$ system is safe

Array-based Systems

Formalizing an array-based system means specifying:

- the set of initial states
- the ordering of the actions (by means of a transition relation)
- the set of unsafe states (the negation of the formula we want to check)

Examples (Cubicle syntax):

- `init (i x) { T = 0.0 && B[i,x]=I && ... }` $\rightsquigarrow \underset{i,x}{\forall} \ldots$
-

```
transition spout_emit(i j)
```
$\rightsquigarrow \underset{i,j}{\exists} \ldots$

```
requires {Tsmin<Stime[i] && SubscribedBS[j,i]=True && ...}
 {
       L[l]:=case
       | l=j :  L[l]+1.0
       | _ :  L[l];
 }
```

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Modeling assumptions

- Focus on the behavior of the queues of the bolts
- How time parameters of the topology affect the accumulation of tuples in the queues of the bolts
  - Time frequency the spouts send information to the subscribed bolts, i.e. *minimum time between two consecutive spout emits*
  - Tuples processing time for each bolt, i.e. *the time required by bolts to process a tuple (execution rate)*
- Spouts are considered sources of information; their queues are not represented
- Each bolt has one receiving queue and no sending queue
- Two approaches for abstracting the queues of the bolts:
  - each bolt has one receiving queue for each of its parallel instances (multiple queues) ($L[i, x]$)
  - one single receiving queue is shared among all its parallel instances (shared queues) ($L[i]$)
- Usage of discrete counters for queues size changes

Formalization and Verification

The formalization captures the topology behavior (subscription relation, current state, modeling assumptions) through transitions:

- discrete transitions change the state of the topology components or updating the size of the queues of the bolts but they do not modify the value of the global time T
- continuous transition changes the value of the global time T and, possibly, the states of some bolts when their processing has been terminated during the last δ time units

$$\underset{\delta}{\exists}\, 0 < \delta \wedge \mathit{CanTimeElapse} = \mathtt{true} \wedge$$
$$\underset{j,z}{\forall}\begin{pmatrix} T' & = T + \delta \\ P'[j,z] & = \textbf{if } (0 \leq P[j,z] - \delta) \textbf{then } P[j,z] - \delta \textbf{ else } 0 \\ B'[j,z] & \ldots \\ \mathit{CanTimeElapse}' & = \mathtt{false} \end{pmatrix}$$

Examples of transitions and their effect:

- $spout_{emit}(i,j)$: $L[j]$ increases ($SubscribedBS[j,i]$); emit time of the spout ($Stime$) is reset
- $bolt_{emit}(i,j)$: the state of $B[i]$ is changed into `idle` and $L[j]$ is incremented by 1
- $bolt_{take}(j,y)$: $L[j]$ is decreased by 1 and the percentage of tuple processing of the thread receiving the tuple ($P[j,y]$) is set to 1

Formalization and verification was performed in the same framework: MCMT (`http://users.mat.unimi.it/users/ghilardi/mcmt/`), respectively Cubicle (`http://cubicle.lri.fr/`).

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Challenges

- Nondeterministic updates

$$\exists_{x,y,i,j} \; \mathit{statechange} = \mathtt{true} \wedge$$
$$\forall_{l,k,z} \begin{pmatrix} \mathit{statechange}' = & \mathtt{false} \\ \dots & \\ B'[l,z] = & \textbf{if } (z = y \wedge l = j \wedge B[j,y] = \mathtt{E}) \\ & \textbf{then } (\mathtt{I} \textbf{ or } \mathtt{K}) \textbf{ else } B[l,z] \\ & \textbf{elseif } \dots \\ \mathit{CanTimeElapse}' = & \mathtt{true} \end{pmatrix}$$

- Reducing the dimension of the search space
  - spout states were left out; only the time elapsing to enable spout `emit` is considered
  - bolt queues have only one dimension (shared queue)

$$\exists_{i,j,x} \; Ts_{min} < \mathit{Stime}[i] \wedge \mathit{SubscribedBS}[j,i] = \mathtt{true} \wedge \dots$$
$$\forall_{l} \begin{pmatrix} L'[l] = \textbf{if } (l = j) \textbf{ then } L[l]+1 \textbf{ else } L[l] \\ \mathit{Stime}'[l] = \textbf{if } (l = i) \textbf{ then } 0 \textbf{ else } \mathit{Stime}[l] \\ \dots \end{pmatrix}$$

- Incorrect firing of transitions: the implemented backward reachability algorithm lacks the so-called *urgent transitions*.
  Our case: simulation of urgent transitions via flags; bolt emit and take are urgent wrt spout emits.
- Number of transitions limited by:
  - the emit state of a bolt is enforced if a bolt is ready to emit
  - state take omitted
  - restrict the reachability analysis only to one bolt (bolt 1) of the system

Experimental results

First attempt:

- $L[1] \geq 3$ and $Tsmin < 1$ – expected result: UNSAFE

  Trace: $Init \rightarrow time\_elapse \rightarrow setDoTake_{\texttt{False}} \rightarrow setDoEmit_{\texttt{False}} \rightarrow \mathbf{spout_{emit}} \rightarrow$
  $time\_elapse \rightarrow setDoTake_{\texttt{True}} \rightarrow setDoEmit_{\texttt{False}} \rightarrow$
  $\mathbf{bolt1_{take}} \rightarrow setDoTake_{\texttt{False}} \rightarrow setDoEmit_{\texttt{False}} \rightarrow \mathbf{spout_{emit}} \rightarrow$
  $time\_elapse \rightarrow setDoTake_{\texttt{False}} \rightarrow setDoEmit_{\texttt{False}} \rightarrow \mathbf{spout_{emit}} \rightarrow L[1] \geq 2$

- $L[1] \geq 3$ and $Tsmin \geq 1$ – expected result: SAFE

Result: the verification problems lead to memory exhaustion.

Second attempt:

- $L[1] \geq 2$ and $Tsmin < 1$ – obtained result: UNSAFE
- $L[1] \geq 2$ and $Tsmin \geq 1$ – expected result: SAFE

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Outline

Motivation

Rise of machine learning methods and their applicability in various domains:

- fake news detection
- autonomous driving

Publications:

Bashar Al Asaad and Madalina Erascu. A tool for fake news detection. In *20th International Symposium on Symbolic and Numeric Algorithms for Scientific Computing, SYNASC 2018, Timisoara, Romania, September 20-23, 2018*, pages 379–386, 2018.

A. Postovan and M. Erascu. Architecturing binarized neural networks for traffic sign recognition. In Lazaros Iliadis, Antonios Papaleonidas, Plamen Angelov, and Chrisina Jayne, editors, *Artificial Neural Networks and Machine Learning – ICANN 2023*, pages 87–98, Cham, 2023. Springer Nature Switzerland.

Architecturing Binarized Neural Networks for Traffic Sign Recognition

Traffic sign classification is an integral part of any vision system for autonomous driving.
Steps for traffic sign classification:

- isolating the traffic sign in a bounding box
- classifying the sign into a specific traffic class.

Well-know problem of the classifiers: the lack of robustness

Modified from https://deepdrive.berkeley.edu

Solution:

- probabilistic methods: traditionally used, have proven limitations
- logical methods: recently explored, scalability issues ⇝ our long time goal

Well-know limitation in autonomous driving: computationally limited and energy-constrained devices.

Solution: Binary neural network (BNN)[1] - a feedforward network where weights and activations are mainly binary.
Initially, we wanted to speed-up safety verification methods for BNNs (e.g. robustness) used in autonomous driving (e.g. traffic sign recognition) using symmetry breaking techniques. ⇝ **No public available pre-trained models!**

[1] Hubara, Itay, et al. "Binarized neural networks." Advances in neural information processing systems 29 (2016).

Problem Specification

The absence of BNN models specifically tailored for traffic sign recognition poses a significant gap and a unusual situation, knowing the benefits of BNNs.

These models should have high accuracy while amenable for formal verification.

Characteristics that count:

- Layers' type: convolution (Conv), sign (Sgn), max pooling (MP), batch normalization (BN), fully connected (FC)
- Number of parameters
- Sparsity
- Number of classes

Contributions

Methodology for obtaining a set of BNNs architectures with high accuracy but at the same time amenable for formal verification.

Datasets used: German Traffic Signs Recognition Benchmark (GTSRB), Belgium Traffic Signs, Chinese Traffic Signs

Bottom-up approach adopted:

1. Start with XNOR architectures
   - Lesson learned:
     - MP layer reduces the number of parameters but at the same time the accuracy
     - composition of Conv+Sgn layers learns well the features of traffic signs images but keeps the number of parameters high.
2. Experiment with BNN architectures: XNOR architecture with a BN layer after:
   - a MP layer
   - a Conv+Sgn layer
   - Lessons learned:
     - the BN layer is crucial after MP for accuracy
     - BN layer after Conv+Sgn might not yield substantial improvements in accuracy.

Contributions (cont'd)

3. Arrive at the architectures with the following characteristics:

# of Params	Input Dimension	Sparsity	# of Regions
905k-1.7M	2.7k-12k	0%	43

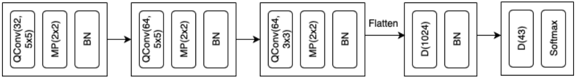

Figure: Architecture with Best Accuracy for GTSRB (96.45%) and Belgium (88.17%) dataset. Input: 64 px x 64 px

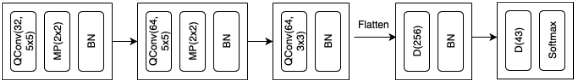

Figure: Architecture with Best Accuracy (83.9%) for Chinese dataset. Input: 48 px x 48 px

Outline

Research Context

West University of Timisoara, Romania, organizes and encourages participation at several IDPs that promote SCL.

The first author of the paper:

- attended a short IDP, University didactics and psychopedagogy (February and March 2020), comprising the following disciplines:
  - The Management of the Students Groups
  - Elaboration of the Didactic Materials
  - Modern Methods of Education
  - Curricular Design
- won a didactic incentive to further implement the SCL approach in the classroom:
  - design three activity plans and implement at least one of them
  - record a teaching activity

The acquired competencies were applied to the lecture and laboratory of an introductory course on Software Engineering, a new subject in her teaching portfolio whose results are presented in this paper.

Publications:

M. Erascu and V. Mladenovici. Transferring learning into the workplace: Evaluating a student-centered learning approach through computer science students' lens. In *Proceedings of the 14th International Conference on Computer Supported Education - Volume 2: CSEDU,*, pages 442–449. INSTICC, SciTePress, 2022.

Design and aim of the study and hypotheses

- quasi-experimental design including a pre-test and post-test to assess the transfer into the workplace of an SCL initiative
- More precisely, we evaluated the degree of the transfer into the workplace of an SCL approach into the context of teaching the Software Engineering subject for bachelor Computer Science students at West University of Timisoara, Romania.
- Hence, we evaluated the changes in students' perception of teaching quality and students' approaches to learning

We addressed the following questions:

Q1. Is there any progress in students' approaches to learning from the experimental group due to the learning transfer into the workplace of the SCL initiative implemented by their teacher?

Q2. Are there any statistically significant differences between the experimental and control group students regarding their approaches to learning?

Q3. Is the teacher's teaching that implemented the SCL initiative perceived as better by her students than students' perception of the teaching of her counterpart in the control group at the end of the semester?

Results and Discussion

Research Question 1. Is there any progress in students' approaches to learning from the experimental group due to the learning transfer into the workplace of the SCL initiative implemented by their teacher?

Student's approaches to study at the beginning, respectively at the end of the semester for students in the experimental group.

Group		Deep Learning Approach			Surface Learning Approach		
		Mean score	SD	N	Mean score	SD	N
Experimental	Before	2.72	0.66	52	2.44	0.68	52
	After	2.66	0.72	29	2.49	0.78	29
	Change	-.06			.05		
	t	.417			-.295		
	p	.678			.769		

Results and Discussion (cont'd)

Research Question 2. Are there any statistically significant differences between the experimental and control group students regarding their approaches to learning?

Comparison between experimental and control group before and after the end of semester regarding student's learning approaches.

Variables	Moment	Group						t	df	p
		Experimental			Control					
		N	M	SD	N	M	SD			
Deep Learning Approach	pre-test	52	2.72	0.66	26	2.74	0.54	-0.089	76	0.93
	post-test	29	2.66	0.72	19	2.89	0.66	-1.140	46	0.26
Surface Learning Approach	pre-test	52	2.44	0.68	26	2.60	0.65	-0.969	76	0.34
	post-test	29	2.49	0.78	19	2.79	0.73	-1.327	46	0.191

Results and Discussion (cont'd)

Research Question 3. Is the teacher's teaching that implemented the SCL initiative perceived as better by her students than students' perception of the teaching of her counterpart in the control group at the end of the semester?

ETCQ dimension scores for the experimental in comparison to the control group at the post-test moment.

ETCQ Scale (Group)	N	SD	Mean score	t	df	p	Change	d Cohen
Understand Fundam. Concepts								
Experim Grp	29	3.68	0.75	-1.252	426	0.217	Same	-
Ctrl Grp	19	3.97	0.86					
Relevance								
Experimental Grp	29	3.73	0.71	-0.178	46	0.859	Same	-
Control Grp	19	3.77	0.71					
Challenging Beliefs								
Experimental Grp	29	3.46	0.92	0.475	46	0.637	Same	-
Control Grp	19	3.34	0.70					
Active Learning								
Experimental Grp	29	4.21	0.56	1.891	27.76	0.069*	Better	0.58
Control Grp	19	3.79	0.87					
Teacher-Student Relationships								
Experimental Group	29	3.35	0.81	-2.065	46	0.045*	Worse	0.61
Control Grp	19	3.84	0.79					
Motivation								
Experimental Grp	29	3.41	0.92	-0.839	46	0.406	Same	-
Control Grp	19	3.63	0.81					
Organization								
Experimental Grp	29	3.45	1.01	-1.795	46	0.079*	Worse	0.53
Control Grp	19	3.96	0.90					
Flexibility								
Experimental Grp	29	3.92	0.82	-0.894	46	0.376	Same	-
Control Grp	19	4.15	0.95					
Assignments								
Experimental Grp	29	3.81	0.78	0.115	46	0.909	Same	-
Control Grp	19	3.79	0.61					

Outline

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Honors, Prizes, Scholarships

- Outstanding benchmark award for the traffic sign recognition benchmark (https://github.com/apostovan21/vnncomp2023) in the *Verification of Neural Networks Competition 2023* (https://sites.google.com/view/vnn2023) held in conjunction with the 6th Workshop on Formal Methods for ML-Enabled Autonomous Systems (FoMLAS'23) and affiliated with the 35th International Conference on Computer-Aided Verification (CAV'23).
- Participation and selection in the Demo Day in the ADRVest Accel (https://www.adrvestaccel.ro)
- The Fulbright-RAF Scholar Award in the field of Entrepreneurship & Entrepreneurial Studies for a semester-long fellowship (Spring 2022) in residence at University of Rochester, AIN Center for Entrepreneurship, USA.
- Didactic grant (https://cda.uvt.ro/granturididactice/) offered by West University of Timisoara aiming to support the implementation and innovation of the reflective-collaborative model of tools in teaching activities carried out within the Computer Science Department, West University of Timisoara (December 2020).
- BringITon2018 (http://bringiton.info.uaic.ro) mention award for *MANeUveR: Management Agency for Cloud Resources*; December 13-14, 2018. BringITon2018 is a workshop for promoting and capitalizing the interaction between computer science in academia and business environment.

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Teaching

- Exposing students to research earlier in their studies.
- Creating an entrepreneurial mindset: making students aware that there exists other career paths than being employed to a corporation with offices in Timisoara

2016 - present; West University of Timișoara Among typical courses like *Formal Languages and Automata Theory*, *Software Engineering*, I introduced formal methods courses (optional) for Bachelor and Master students (topics ranging from reasoning about programs to satisfiability checking, verification of neural networks). Other courses/activities: Bachelor Thesis preparation, coordination of internships for Bachelor students, Research Practice (Master students), Entrepreneurship Skills (for Computer Science Students and for all students of WUT through Complementary disciplines generating transversal competences).

2024, 2023; Strascheg Center of Entrepreneurship, University of Applied Sciences, Muenchen: Topics in Entrepreneruship (Research Basics and others needed during mentoring) during one week in the framework of Erasmus+ Teaching Mobility (Bachelor and Master level)

2019; Johannes Kepler University Linz, Austria: One week lecture on symbolic execution for program verification in the framework of Erasmus+ Teaching Mobility (Master and Undergraduate level)

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: Topics in Entrepreneruship (Research Basics and others needed during mentoring) during one week in the framework of Erasmus+ Teaching Mobility (Bachelor and Master level)

2019; Johannes Kepler University Linz, Austria:
: One week lecture on symbolic execution for program verification in the framework of Erasmus+ Teaching Mobility (Master and Undergraduate level)

2016; Universidad de Cantabria, Santander, Spain:
: One week lecture on quantifier elimination using cylindrical algebraic decomposition in the framework of Erasmus+ Teaching Mobility (Master level)

Outline

Advising (selected)

2022 – 2023 MSc thesis, Eduard Laitin: *Speeding Up the Deployment in the Cloud of Component-based Applications using Graph Neural Networks and SMT solving*. Paper accepted at IJCNN 2024.

2022 – 2023 MSc thesis, Vlad Luca: *SAGE - A Tool for Optimal Deployments in 'Kubernetes Clusters*. Paper accepted at IEEE CloudCom 2023.

2022 – 2023 MSc thesis, Andreea Postovan: *Binarized Neural Networks for Traffic Sign Recognition: Training and Verification*. Papers accepted at ICANN 2023 and FROM 2023. Benchmark award at VNN-COMP 2023.

2021 – 2022 Summer Practice and FMI Internship, Bogdan David: *Applications for the management of Cloud resources*; mention award at the Students Scientific Session "Traian Lalescu" at Transilvania University, November 25-27, 2022, Brasov; Paper accepted at SC-Square workshop 2022 affiliated to FLOC2022.

2020 – 2021 Summer Practice and BSc thesis, Andrei Iovescu: *Benchmark Problems for the Constraints Satisfaction Problems Repository*, 2020, honorable mention at International Student Conference StudMath-IT, November 26-27, 2020; Faculty of Exact Sciences, "Aurel Vlaicu" University of Arad.

2019 BSc thesis, Răzvan Meteş: *Evaluation of a Constrained Optimization Benchmark for Optimization Modulo Theory*; Paper accepted at SMT2019 workshop affiliated to SAT2019.

2018 BSc thesis, Al Asaad Bashar, *Detecting Fake News*; Paper accepted at NCA workshop affiliated to SYNASC 2018.

Outline

Comunity Service

- Invited Speaker

Oct 1-6, 2023	Dagstuhl Seminar 23401 on Automated mathematics: integrating proofs, algorithms and data, Schloss Dagstuhl – Leibniz-Zentrum für Informatik in Germany
Feb 13-18, 2022	Dagstuhl Seminar 22072 on New Perspectives in Symbolic Computation and Satisfiability Checking, Schloss Dagstuhl – Leibniz-Zentrum für Informatik in Germany
Sep 3-5, 2019	Working Formal Methods Symposium 2019, Timisoara, Romania

- PC Chair

2022	Int. Conference on Intelligent Computer Mathematics - Doctoral Programme

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Comunity Service (cont'd). Member of Program Committees

- 2024 20th Artificial Intelligence Applications and Innovations (AIAI 2024), Ionian University, Corfu, Greece; June 27-30, 2024.
- 2024 19th European Dependable Computing Conference, Student Forum Track, 8-11 April 2024, Leuven, Belgium
- 2024 30th International Conference on Tools and Algorithms for the Construction and Analysis of Systems (TACAS). April 6-13, 2024, Luxembourg Ville, Luxembourg.
- 2023,2024 International Conference on Artificial Neural Networks (ICANN).
- 2023, 2022, 2018, 2017, 2015 Int. Conference on Intelligent Computer Mathematics (CICM)
- 2024 – 2015 Int. Symposium on Symbolic and Numeric Algorithms for Scientific Computing, Logic and Programming Track (SYNASC)
- 2022 SC-square workshop, August 12, 2022, Haifa, Israel Part of IJCAR 22, at FLOC 2022
- 2022, 2020 International SPIN Symposium on Model Checking of Software
- 2019 Workshop on Microservices: Science and Engineering (MSE), affiliated with Technology of Object-Oriented Languages and Systems (TOOLS)
- 2018 The Sixth International Conference on Mining Intelligence and Knowledge Exploration (MIKE)
- 2018 Workshop on Microservices: Science and Engineering (MSE), affiliated with Software Technologies: Applications and Foundations (STAF)
- 2017 Workshop on Microservices: Science and Engineering (MSE), affiliated with 15th International Conference on Software Engineering and Formal Methods (SEFM)

Comunity Service

- Journal/Book Referee

  2017 Reviewer for International Journal of Grid and Utility Computing
  2017 External reviewer for Mathematics in Computer Science (Special Issue SYNASC 2016)

- Member of Organizing Committees

  Feb 8-9, 2023 Organizer of the meeting of WG3 (Program Verification) of EuroProofNet (`https://europroofnet.github.io`), West University of Timisoara, Romania
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- disseminate results at the intersection of formal methods, artificial intelligence, and real-world applications. *More quality less quantity!*
- submit grant proposals to the national agency UEFISCDI.
- reinvigorate the past collaborations and make new ones in order compete in consortia for European Commission funded projects

Serving the community

- organizing different kind of scientific events (conferences, workshops, project meetings)
- being part of conferences/journals program committees, as reviewer or chair.

Scientific and academic development of young fellows

- initiate scientific cooperation with potential future researchers early on their studies
- encourage PhD students to pursue a joint supervision scheme (e.g. UNITA alliance where West University is part of)
- encourage the formation of students spin-offs (introducing PhD level course on Technical Entrepreneurship and Innovation)

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Outline

Upcoming Research in the Near Future

Objective 1 Provide an understanding of what the *symmetries* and *similarities* are for the problems which we already studied, i.e resource management in the Cloud and (robustness) verification of binarized neural networks.

Objective 2 Develop methods for breaking the symmetries in and for learning templates* from the two problems enumerated above.

Objective 3 Invent theory and algorithms for:

- *abstracting* the symmetries of these case studies using the theory of invariant groups
- *learning problem templates* by formalizing the underlying problem as a graph analysis problem and using graph neural networks (GNNs) for solving it*

Objective 4 study the computational effectiveness of the newly developed symmetry breaking and similarity breaking techniques;

Objective 5 for ultimately, performing automatic solving of constraint satisfaction problems (CSP) at scale.

Objective 6 Safety Verification of Binarized Neural Networks**

* E. Laitin and M. Erascu, ”Fast and Exact Synthesis of Application Deployment Plans Using Graph Neural Networks and Satisfiability Modulo Theory”, accepted at 2024 International Joint Conference on Neural Networks (IJCNN).
** A. Postovan and M. Erascu. ”Benchmarking Local Robustness of High-Accuracy Binary Neural Networks for Enhanced Traffic Sign Recognition.” in Proceedings of FROM, EPTCS 389, 2023, pp. 120-130

Thank you!