Bachelor & Master Projects and Theses

Prof. Dr. Stefan Leue

Software and Systems Engineering

http://sen.uni-konstanz.de/

Summer Term 2024

software systems engineering

- **Members**
  - Prof. Dr. Stefan Leue {SL}
    - Email: Stefan.Leue@uni.kn, Room: PZ 902
  - Rafael Senn {RS}
    - Email: Raffael.Senn@uni.kn, Room: PZ 912
  - David Boetius {DB}
    - Email: David.Boetius@uni.kn, Room: PZ 912

Projects and Theses at the Chair

- **Our Objectives**
  - projects and theses close to ongoing research projects
  - links to practical and relevant applications
  - completion of project and theses within defined time limits (examination regulations / Prüfungsordnung)

- **What We Offer**
  - close and individual supervision
  - regular meetings and guidance
  - if possible and applicable, supervision in collaboration with external partners
    - research institutions
    - industry

Projects and Theses at the Chair

♦ Our Expectations

- **project** is typically a literature survey, problem statement or similar
  - leads to definition of thesis topic (not mandatory, but recommended)
  - project report: approx. 10-20 p.
- **thesis**
  - requires some own contribution
    - Bachelor: problem solution idea, critical literature survey, innovative case study, ...
    - Master: own problem solution concept, evolving an existing approach, algorithmic concept and implementation, revealing comparison with other approaches, ...
  - thesis document: approx. 30-50 p.

Scope and Duration of Projects/Theses

- **Project (Bachelor and Master)**
  - 1 semester
  - 9 ECTS (270h work)
- **Thesis (Bachelor)**
  - 3 months (1/2 Semester)
  - 12 ECTS (Thesis) + 3 ECTS (Colloquium) = 15 ECTS (450h work)
- **Thesis (Master)**
  - 6 Months (1 Semester)
  - 30 (Thesis + Colloquium) ECTS (900h work)

Dates

♦ **For BA/MA Projects and Theses, the Following Dates Apply**

Projekt	
Anmeldung	Abgabe bis
15.10. – 15.11.	15.01.
15.01. – 15.02.	15.04.
01.04. – 01.05.	30.06.
01.07. – 01.08.	30.09.

Abschlussarbeit		
Anmeldung	Bearbeitungsbeginn	Abgabe bis*
01.02. – 15.02.	01.03.	01.06.
01.05. – 15.05.	01.06.	01.09.
15.07. – 01.08.	15.08.	15.11.
15.10. – 02.11.	15.11.	01.03.

* ungefähre Angabe; der genaue Zeitpunkt wird vom ZPA festgelegt

Project Report / Thesis Structure

- **Typical Generic Structure:**
  1. Introduction
     - motivation of work, state of the art, related work, contributions
  2. Preliminaries
     - which facts / concepts / definitions / algorithms / approaches / methods does this work rely on ("standing on the shoulders of giants")
     - i.e., any technical information that is needed but not developed in the course of this report / thesis
  3. Approach
     - technical contribution of the thesis (concepts / definitions / algorithms / approaches / methods etc.)
  4. Implementation
     - software that has been implemented
  5. Evaluation
     - case studies, experiments, quantitative and qualitative assessment, etc.
  6. Conclusion
     - what has been accomplished
     - future research directions
  7. Bibliography

Formal Requirements

- **Before you start your work**
  - submit written proposal (≈ 1-2 pages) to **sen@uni-konstanz.de** containing
    - the *topic* you want to choose
    - how well you *match the prerequisites*
    - *schedule* for the project / thesis
      - what will be achieved at which point in time
        - requires a careful break-down of the project / thesis topic into subgoals
      - when will the project / thesis be officially registered

- **During your preparation of the project work / thesis**
  - regular consultation with your supervisor
    - approx. every 4 weeks

- **Deliverables**
  - project report to the supervisor
  - thesis
    - must be submitted to the examination office
    - in parallel: electronic copy (pdf) to supervisor
  - any models / code / data / binaries you created for the project
    - include in DVD attached to the thesis
    - in parallel: electronic copy to supervisor

Topic Areas for Projects and Theses

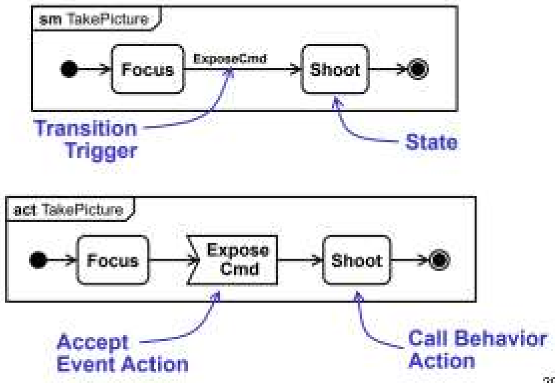
- **I. Safety Analysis, Causality, Real-Time Systems and Repair**
  - Causality Checking
  - Causality in DNNs
  - Functional Safety of Automotive Systems
  - QuantUM+: Model Based System Engineering, implementation of Causality Checking
  - TarTar: Analysis and Automated Repair of Timed Systems
    - synthesis of repairs using SMT technology
- **II. Legal Tech**
  - logical modeling and analysis of legal artefacts
  - understanding legal contracts using Natural Language Processing
- **III. Formal Verification and Repair for Machine Learning**
  - counterexample computation for DNNs
  - automated repair of DNNs
  - applications in health science

Topic Areas for Projects and Theses

- **I. Safety Analysis, Causality, Real-Time Systems and Repair**
  - Causality Checking
  - Causality in DNNs
  - Functional Safety of Automotive Systems
  - QuantUM+: Model Based System Engineering, implementation of Causality Checking
  - TarTar: Analysis and Automated Repair of Timed Systems
    - synthesis of repairs using SMT technology
- **II. Legal Tech**
  - logical modeling and analysis of legal artefacts
  - understanding legal contracts using Natural Language Processing
- **III. Formal Verification and Repair for Machine Learning**
  - counterexample computation for DNNs
  - automated repair of DNNs
  - applications in health science

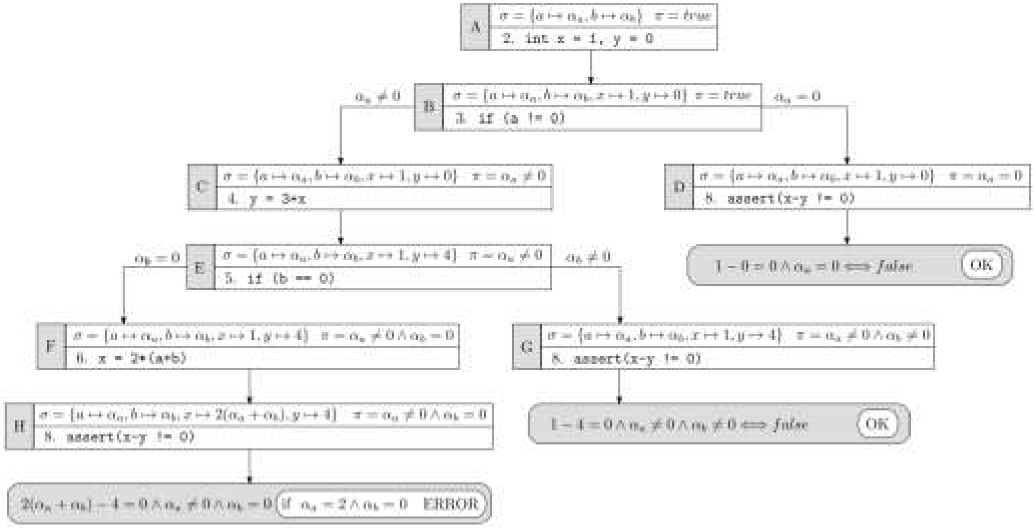
SysML v2 Dynamic Semantics [M] {SL}

- **Setting**
  - ongoing standardization of version 2 of the OMG SysML
    – https://www.omgsysml.org/SysML-2.htm
  - own meta-model and state-machine semantics independent from UML and SysML v. 1.x
- **Research Questions**
  - study and understanding of the state-machine semantics of SysML V2
    – https://github.com/Systems-Modeling/SysML-v2-Release/blob/master/doc/1-Kernel_Modeling_Language.pdf
  - study of the underlying "4D semantics" by Conrad Bock (NIST)
    – https://www.conradbock.org/bockonline.html
- **Goal**
  - devising a strategy for automated formal analysis of SysML V2 state machine models
  - prototype tool / case study
  - potential for link to QuantUM



excerpt from:
https://www.conradbock.org/omg/ad/2018-12-09.pdf

Causality Checking for Symbolic Execution [M] {SL}



- **Setting**
  - symbolic execution is the logical represenation of program execution paths
  - it is the foundation of many program analysis and testing methods, e.g., concolic testing, fuzzing, etc.
  - tools (examples)
    - KLEE, https://www.usenix.org/legacy/event/osdi08/tech/full_papers/cadar/cadar.pdf
    - SAGE, https://queue.acm.org/detail.cfm?id=2094081
- **Research Question**
  - study of the application of counterfactual causal analysis / Causality Checking to symbolic execution
- **Goal**
  - algorithm and tool developement, case study

Setting

- software model checkers analyze programming language code (often C code) instead of modeling languages
- tools
  - CPAChecker https://cpachecker.sosy-lab.org/
  - Ultimate https://www.ultimate-pa.org/

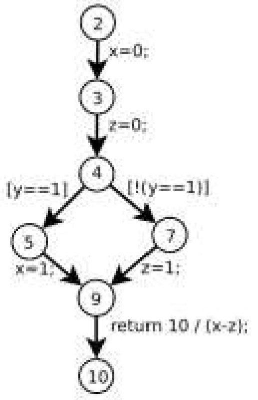
Research Question

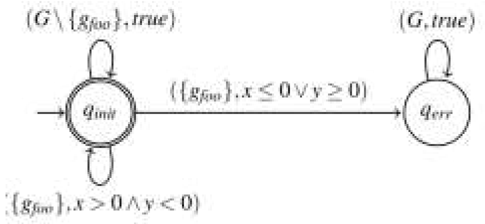
- how can the Causality Checking approach be conceptually applied to software model checking
  - interpretation of counterfactuality in counterexamples and non-faulty executions

Goal

- concept of Causality Checking for SMC
- prototypical tool development, case stucy

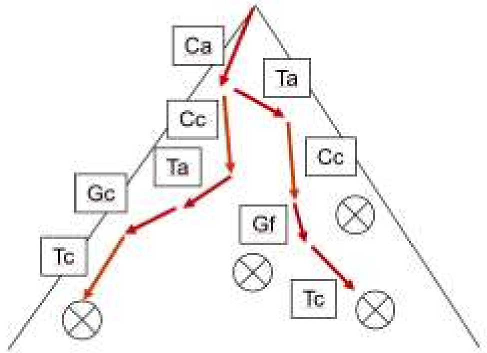
```
int foo(int y) {
  int x = 0;
  int z = 0;
  if (y == 1) {
    x = 1;
  } else {
    z = 1;
  }
  return 10 / (x - z);
}
```

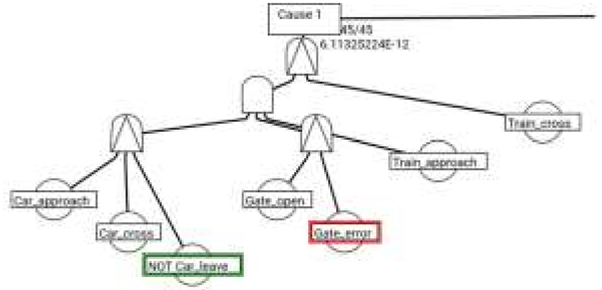


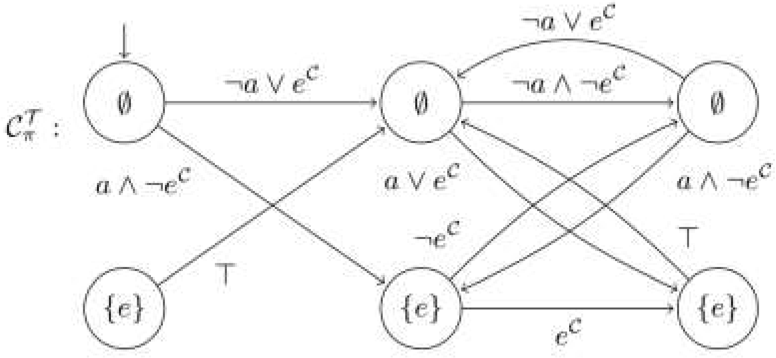


Causality Checking and Hyperproperties [B,M] {SL}

- **Setting**
  - Coenen et al. propose to use hyperproperties (properties of sets of traces) and Hyper LTL model checking to compute causalities
    - https://doi.org/10.1007/978-3-031-13185-1_20
    - https://doi.org/10.1007/978-3-031-19992-9_13
  - Causality Checking as implemented in QuantUM relies on simple explicit-state model checking
- **Research Objective**
  - comparison of the capabilities of both approaches to compute actual causes / counterfactual causal explanations
  - development of recommendations for a reconciliation of both approaches, if possible
  - case studies



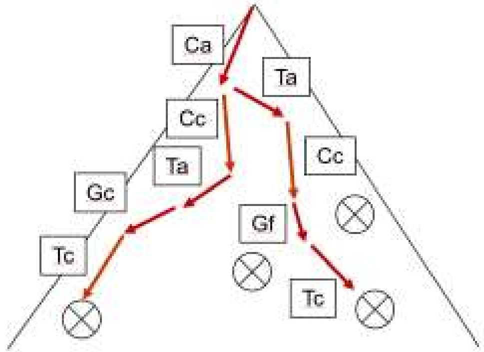


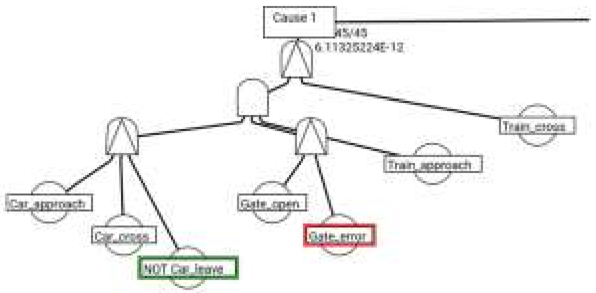


Symbolic Encoding of Causality Checking [M] {RS, SL}

Causality Checking

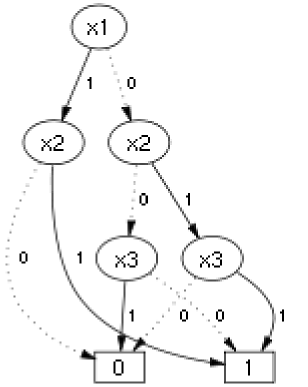
- computing ordered sequences of events in a system model as being causal for reaching a dangerous system state (e.g., car and train in the railroad crossing)
- currently relies on explicit state space search
- bottleneck
  - number of traces to be stored





Objective

- symbolic encoding of causality conditions using Binary Decision Diagrams (BDDs)
- computation of causes based on BDD libraries
- implementation in the QuantUM toolset



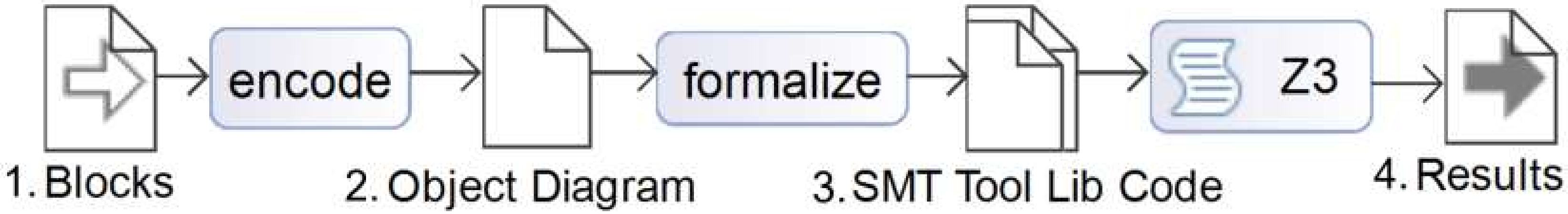
Literature

- F. Leitner-Fischer and S. Leue. 2013. Causality Checking for Complex System Models. In Proceedings of VMCAI 2012, pp. 248-267, LNCS, Volume 7737. Springer Verlag.

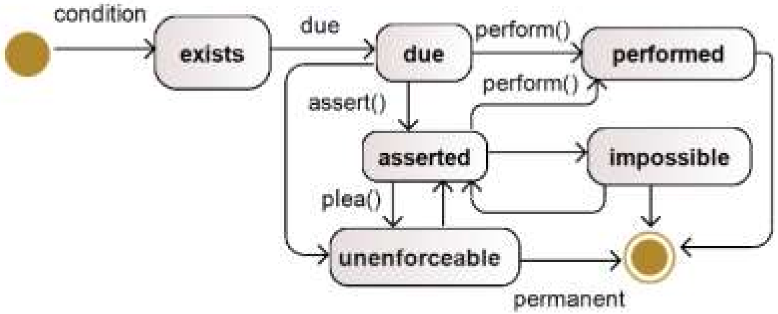
Topic Areas for Projects and Theses

- **I. Safety Analysis, Causality, Real-Time Systems and Repair**
  - Causality Checking
  - Causality in DNNs
  - Functional Safety of Automotive Systems
  - QuantUM+: Model Based System Engineering, implementation of Causality Checking
  - TarTar: Analysis and Automated Repair of Timed Systems
    - synthesis of repairs using SMT technology
- **II. Legal Tech**
  - logical modeling and analysis of legal artefacts
  - understanding legal contracts using Natural Language Processing
- **III. Formal Verification and Repair for Machine Learning**
  - counterexample computation for DNNs
  - automated repair of DNNs
  - applications in health science
- **IV. Centre for Human | Data | Science**

A State Machine Model for Contract Execution [B,M] {RS, SL}



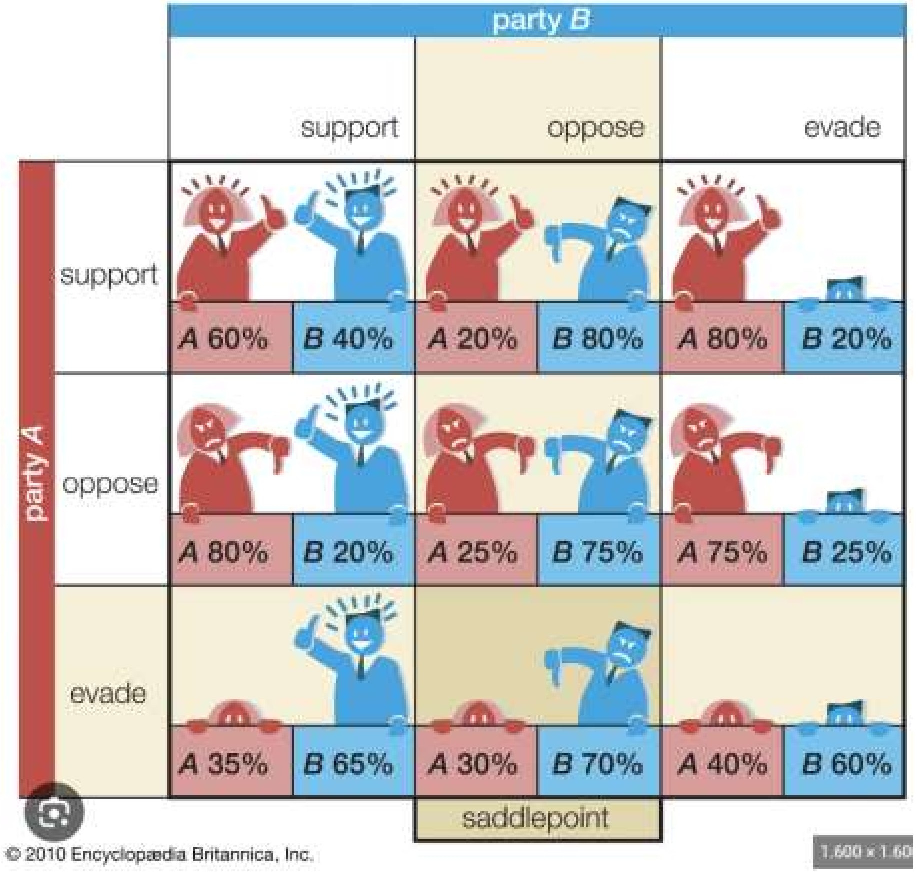
- **Legal Tech**
  - existing model of legal contract execution using strongest precondition semantics for claims
  - encoded as propositional logic
  - analyzed using SMT-solving / Contract Check



- **Goal**
  - deriving a concurrent state machine model for the contract execution
- **Context**
  - existing joint project with Prof. R. Wilhelmi, Department of Law
  - existing tool ContractCheck
- **Reading**
  - https://doi.org/10.1007/978-3-031-15077-7_1

Contract Execution and Game Theory [M] {RS, SL}

- **Legal Tech**
  - modeling of legal contracts
    - share purchase agreements
      - seller
      - purchaser
  - they "play a game"
    - satisfy / not satisfy claims
    - execution on time / delayed
    - ...
  - which moves put which player into an advantageous situation?
    - ⇒ **game theory**
  - possible extensions
    - quantifiable loss / risk



- **Objective**
  - formulate contract execution as two-party game

Testing Logic Encodings of Sales Contracts [B,M] {DB, SL}

- **Setting**
  - ContractCheck translates a Sales Purchase Agreement (SPA) into a logic encoding
  - Encoding knowledge and processes in logic bears the danger of producing a faulty encoding
- **Question**
  - How can we test an encoding in logic to gain confidence that it faithfully captures the encoded artefact?
    - Develop testing methods for gaining confidence in a logic encoding of an SPA
    - Important when encoding is provided automatically (e.g., by an ML model)
- **Possible Directions**
  - Compute a diverse set of satisfying assignments of the logic encoding
- **Literature**
  - https://doi.org/10.48550/arXiv.2212.03349 (ContractCheck)

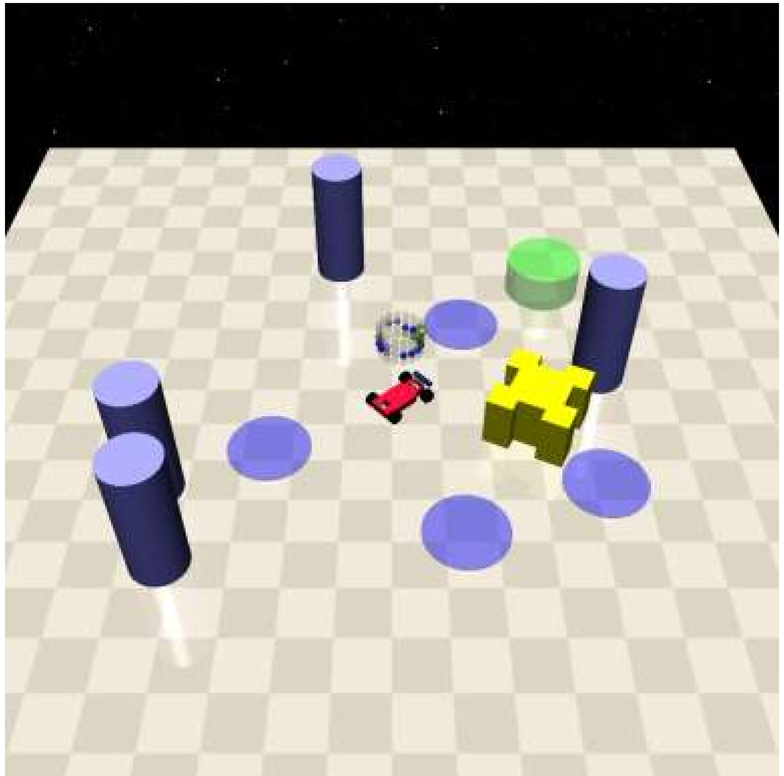
Generated by Midjourney

Topic Areas for Projects and Theses

- **I. Safety Analysis, Causality, Real-Time Systems and Repair**
  - Causality Checking
  - Causality in DNNs
  - Functional Safety of Automotive Systems
  - QuantUM+: Model Based System Engineering, implementation of Causality Checking
  - TarTar: Analysis and Automated Repair of Timed Systems
    - synthesis of repairs using SMT technology
- **II. Legal Tech**
  - logical modeling and analysis of legal artefacts
  - understanding legal contracts using Natural Language Processing
- **III. Formal Verification and Repair for Machine Learning**
  - NN repair for cyber-physical systems
  - verifying global specifications using cutting planes
  - faster NN repair
  - verification of Self-Driving cars

NN Repair for Cyber-Physical Systems [B,M] {DB, SL}

- **Setting**
  - Deep learning models can be embedded as controllers in safety-critical cyber-physical systems (autonomous driving, steering aircraft and spaceships).
  - Such systems require **safety guarantees**
- **Question**
  - Repair DNN controllers using SpecRepair and Safety Critics
  - Verification using JuliaReach, NNV, or others
- **Literature**
  - https://doi.org/10.1007/978-3-031-15077-7_5 (SpecRepair)
  - https://openreview.net/forum?id=iaO86DUuKi (Safety Critics)



From: https://github.com/PKU-Alignment/safety-gymnasium

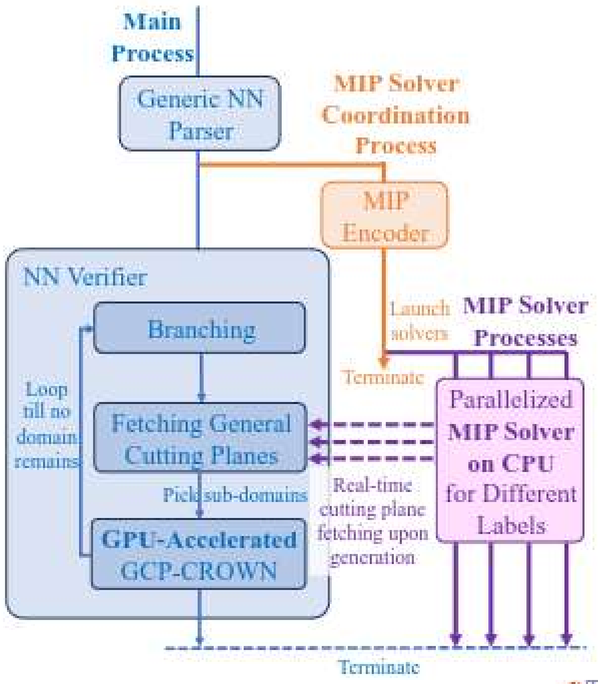
Verifying Global NN Specifications using Cutting Planes [B] {DB, SL}

Description

- Many desirable properties of NNs apply for the entire input region (global specifications)
- Current NN verifiers are targeted at local specifications
- Recent development in verifiers: cutting planes (GCP-CROWN)
- Cutting planes generalize the ReluDiff approach for verifying specific global specifications
- Can cutting planes verify general global specifications?

Tasks

- Formalize global specifications in GCP-CROWN
- How far does this scale?
- Comparison with ReluDiff

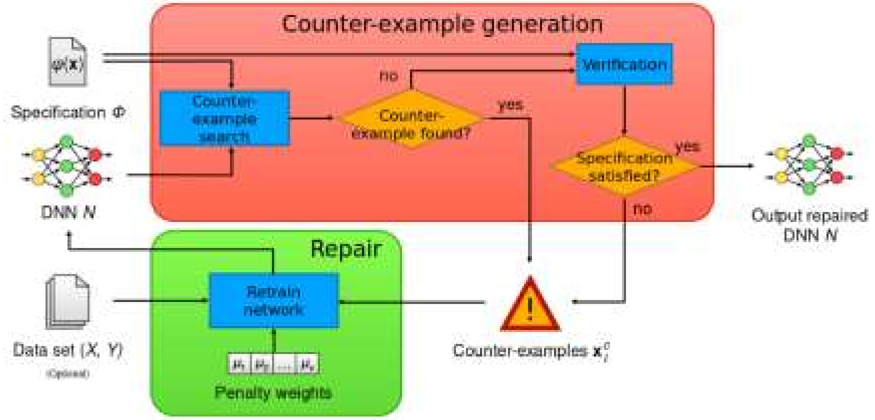


Literature

- https://arxiv.org/abs/2306.12495 (Global Specifications)
- https://papers.nips.cc/paper_files/paper/2022/hash/0b06c8673ebb453e5e468f7743d8f54e-Abstract-Conference.html (GCP-CROWN)
- https://dl.acm.org/doi/10.1145/3377811.3380337 (ReluDiff)

Faster Neural Network Repair [B, M] {DB, SL}

- **Setting**
  - SpecRepair uses piecewise-linear violation functions to quantify counterexample violations
  - These violation functions have certain drawbacks
    - Only gradient for the least-violated term is given for disjunction
    - Violation functions are not differentiable everywhere and, therefore, do not have a continuous gradient.
- **Question**
  - Are there different violation functions that can accelerate repair or improve network performance?
  - Can we learn violation functions and improve repair?
- **Literature**
  - https://doi.org/10.1007/978-3-031-15077-7_5 (SpecRepair)
  - http://proceedings.mlr.press/v97/fischer19a.html (DL2, has a different set of violation functions)



Verification of a Self-Driving Car [M] {DB, SL}

- **Motivation**
  - neural networks are applied in self-driving cars where mistakes are fatal
- **Identify Safety Constraints and Apply Them to the AI Training Procedure**
  - What safety constraints are important during driving?
  - can the neural network made safe by altering the training procedure?
  - develop a simulation of a self-driving car:
    - DeepDrive (https://deepdrive.io)
    - F1tenth (https://f1tenth.org)

- **Prerequisites**
  - machine learning models and training algorithms
  - interest in verification

Important

- **Own Ideas Welcome!**
  - if you have own ideas
    - topics not included in our catalog
    - modifications of proposed topics

    please talk to us!
      - topic finding is an iterative, deliberative process!

Interested? Contact...

- **... either one of us at any time!**
  - Prof. Dr. Stefan Leue
    - Email: Stefan.Leue@uni.kn
  - David Boetius
    - Email: David.Boetius@uni.kn
  - Raffael Senn
    - Email: Raffael.Senn@uni.kn
  - or: sen@uni-konstanz.de

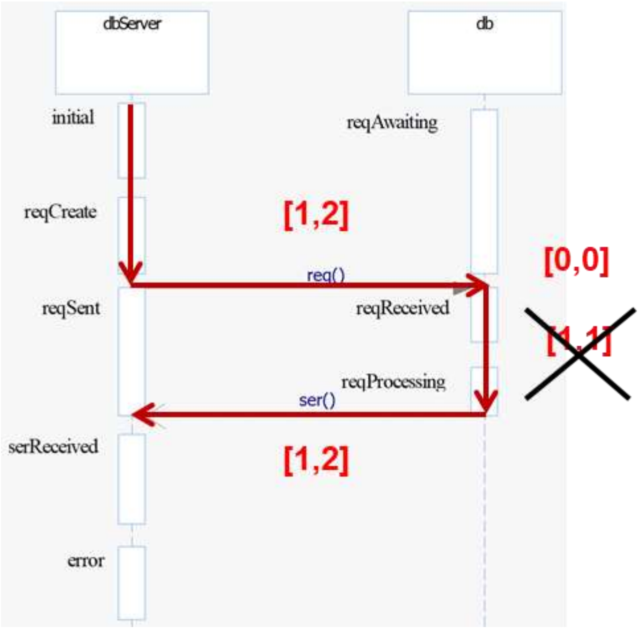
Questions

?

Causality Checking and Choice Functions

TA-Repair using k-normalized Zonegraphs [B,M] {RS, SL}

- **Setting**
  - Real-Time Systems can be modelled with Timed Automata (TA)
  - designing a TA which is correct w.r.t. some property is hard
  - TarTar can repair a faulty TA by removing a single counterexample.
    - This repair does not guarantee that the TA is correct



- **Objective**
  - Apply the repair computation of TarTar to a symbolic representation of the TA (k-normalized Zonegraph)
  - Experimentally implement the approach and compare it with state of the art methods
- **Literature**
  - M. Kölbl, S. Leue, and T. Wies. 2022. Automated Repair for Timed Systems. In Formal Methods in System Design, Springer Verlag.