Seminar *Trends in Computer-Aided Verification*

Introduction
Summer Semester 2021; April 14, 2021

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https://moves.rwth-aachen.de/teaching/ws-20-21/propro/

Software Modeling and Verification Chair | RWTH AACHEN UNIVERSITY

Outline

Formal Verification Methods

Formal verification methods

- Rigorous, mathematically based techniques for the specification, development and verification of software and hardware systems
- Aim at improving correctness, reliability and robustness of such systems

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Classifications

- According to design phase
  - specification, implementation, testing, ...
- According to specification formalism
  - source code, neural networks, Bayesian networks, fault trees, ...
- According to underlying mathematical theories
  - model checking, theorem proving, static analysis, ...

Areas Covered in this Seminar

Topic areas

- Robustness Analysis of Neural Networks
- Analysis of Bayesian Networks
- Synthesizing Quantitative Loop Invariants for Probabilistic Programs
- Formal Approaches to Systems Engineering

Outline

Goals

Aims of this seminar

- Independent understanding of a scientific topic
- Acquiring, reading and understanding scientific literature
  - given references sufficient in most cases
- Writing of your own report on this topic
  - far more that just a translation/rewording
  - usually an "extended subset" of original literature
    - "subset": present core ideas and omit too specific details (e.g., related work or optimisations)
    - "extended": more extensive explanations, examples, ...
    - discuss contents with supervisor!
- Oral presentation of your results
  - can be "proper subset" of report
  - generally: less (detailed) definitions/proofs and more examples

Requirements on Report

Your report

- Independent writing of a report of 12–15 pages
- First milestone: detailed outline
  - not: “1. Introduction/2. Main part/3. Conclusions”
  - rather: overview of structure (section headers, main definitions/theorems) and initial part of main section (one page)
- Complete set of references to all consulted literature
- Correct citation of important literature
- Plagiarism: taking text blocks (from literature or web) without source indication causes immediate exclusion from this seminar
- Font size 12pt with “standard” page layout
  - LaTeX template will be made available on seminar web page
- Language: German or English
- We expect the correct usage of spelling and grammar
  - $\geq$ 10 errors per page $\Longrightarrow$ abortion of correction

Requirements on Talk

Your talk

- Talk of 30 minutes
- Organised as Zoom meeting
- Focus your talk on the audience
- Descriptive slides:
  - $\leq$ 15 lines of text
  - use (base) colors in a useful manner
  - number your slides
- Language: German or English
- No spelling mistakes please!
- Finish in time. Overtime is bad
- Ask for questions
- Have backup slides ready for expected questions
- LaTeX/beamer template will be made available on seminar web page

Outline

Important Dates

Deadlines

- April 18: Topic preferences due
- May 10: Detailed outline due
- June 7: Full report due
- June 28: Presentation slides due
- July 13 (?): Seminar talks

Important

Missing a deadline causes immediate exclusion from the seminar

Selecting Your Topic

Procedure

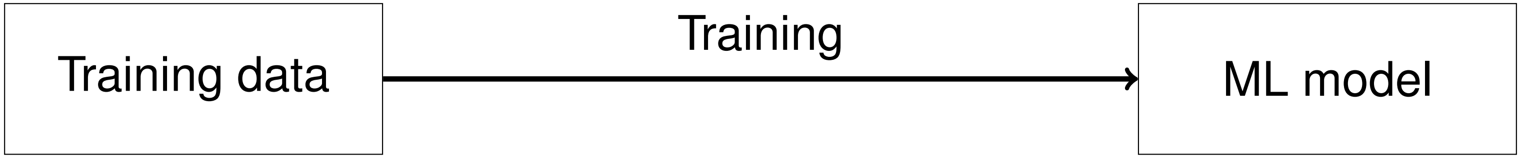
- Check out Foodle poll at `https://terminplaner.dfn.de/qhUSVZHyboDWZP63`
- Topics classified according to BSc/MSc level
- Please give at least three “Yes” votes ✓
- Preferably additional “Maybe” votes (✓)
- Give as comment:
  - preference of topics (if desired)
  - language of report and talk (English/German)
- **Fill form by Sunday, April 18**
- We do our best to find an adequate topic-student assignment
  - disclaimer: no guarantee for an optimal solution
- Assignment of topics and supervisors will be published on web site by mid next week

Withdrawal

- You have up to three weeks to refrain from participating in this seminar.
- Later cancellation (by you or by us) causes a not passed for this seminar and reduces your (three) possibilities by one.

Outline

Machine Learning



Machine Learning

Machine Learning

$$\text{Training data} \xrightarrow{\text{Training}} \text{ML model}$$

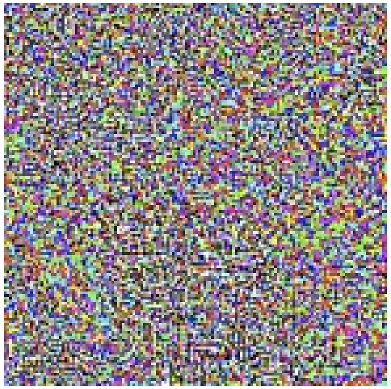
Machine Learning

$$\xrightarrow{\text{ML model}} \text{Prediction: Panda}$$

Inference

Adversarial Examples

$+\ 0.007 \cdot$



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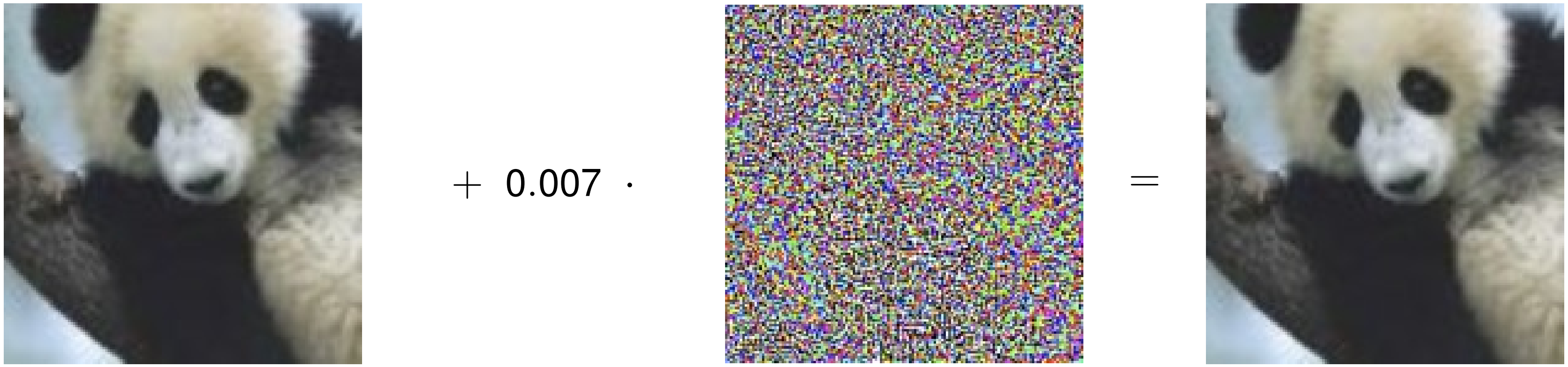
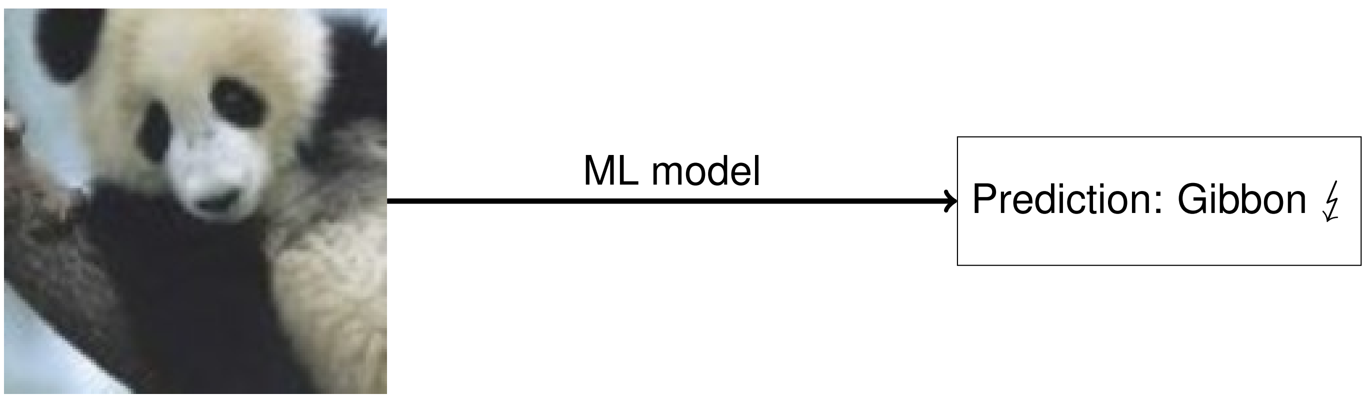
Adversarial Example [Goodfellow 2015]

Adversarial Examples



Adversarial Example [Goodfellow 2015]



Adversarial Attack

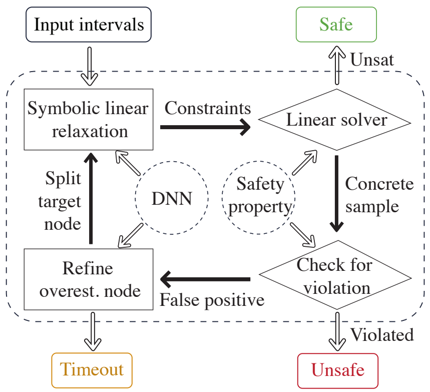
Questions

How to

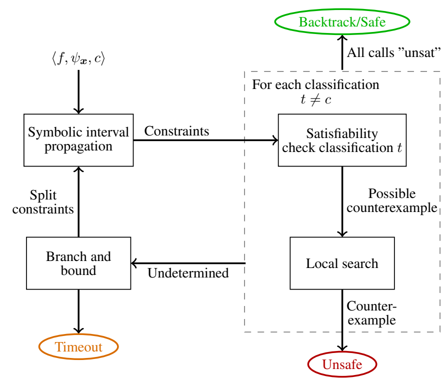
- find adversarial examples if they exist?
- prove that no adversarial examples exist?
- do so automatically?
- do so efficiently (avoid exponential runtime)?

Topics I

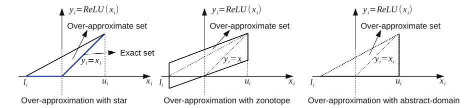
1. *Efficient Formal Safety Analysis of Neural Networks* (Wang et al.) (B/M)
   – Describes a toolkit for automatic verification
   – Uses symbolic propagation (tracking of dependencies)
   – Approximates piecewise linear activation functions



2. *Efficient Neural Network Verification via Adaptive Refinement and Adversarial Search* (Henriksen, Lomuscio) (M)
   – Describes an improved toolkit
   – Can also approximate non-linear functions (sigmoid, tanh)

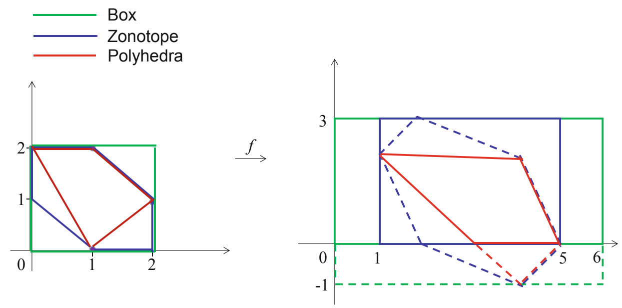


3. *Star-Based Reachability Analysis of Deep Neural Networks* (Tran et al.) (M)
   – Describes an alternative approach
   – No approximation is needed (sound and complete)
   – All (not just one) adversarial examples can be found

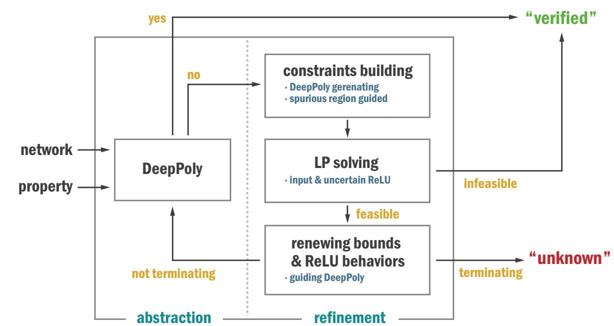


Topics II

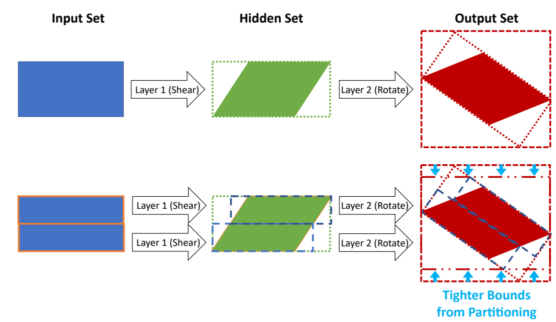
4. *Analyzing Deep Neural Networks with Symbolic Propagation: Towards Higher Precision and Faster Verification* (Li et al.) (B/M)
   - Systematic investigation of symbolic domains
   - Based on Abstract Interpretation and SMT methods



5. *Improving Neural Network Verification through Spurious Region Guided Refinement* (Yang et al.) (B/M)
   - Elimination of spurious adversarial examples by linear programming techniques
   - Based on DeepPoly framework



6. *Robustness Analysis of Neural Networks via Efficient Partitioning with Applications in Control Systems* (Everett, Habibi, How) (M)
   - Application of propagation and partitioning techniques to control systems

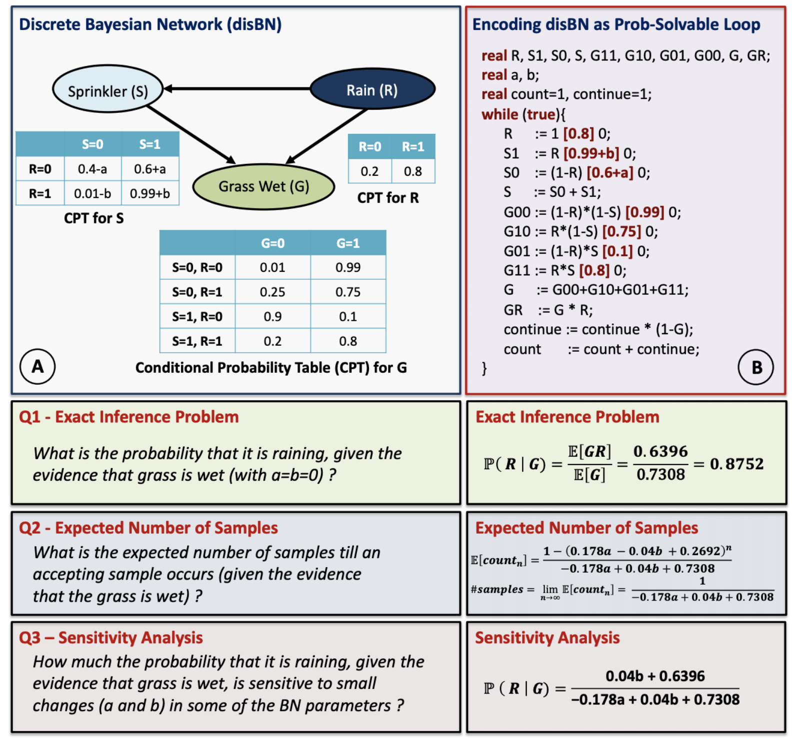


Outline

1. Analysis of Bayesian Networks via Prob-Solvable Loops

Ezio Bartocci, Laura Kovács, Miroslav Stankovic: *Analysis of Bayesian Networks via Prob-Solvable Loops.* ICTAC 2020 (B/M)

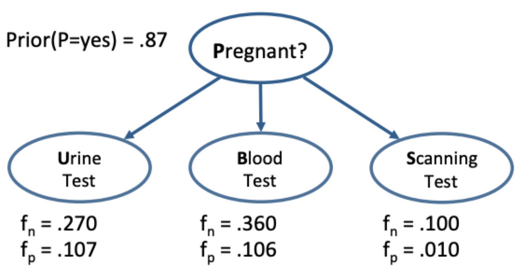
- Encoding the following types of BNs as Prob-solvable loops
  - *discrete BNs*
  - *Gaussian BNs*
  - *Dynamic BNs*
- Looking into the following problems
  - *exact inference*
  - *expected number of samples*
  - *sensitivity analysis*



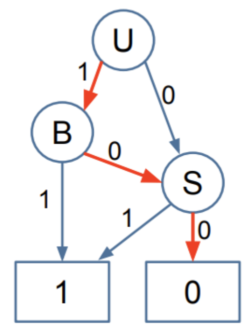
2. Formal Verification of Bayesian Network Classifiers

Andy Shih, Arthur Choi, Adnan Darwiche: *Formal Verification of Bayesian Network Classifiers.* PGM 2018 (B/M)

- Compiling Bayesian network classifiers into Ordered Decision Diagrams
- Verifying BN classifiers using ODDs
  - *monotonicity checking*
  - *finding irrelevant features*
  - *verifying classification robustness*
  - *verifying If-Then rules and decision independence*



(a) A naive Bayes classifier

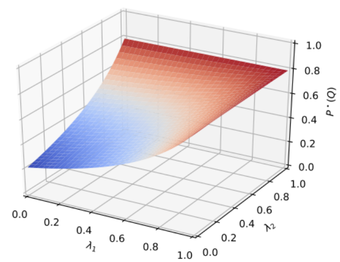


(b) An OBDD

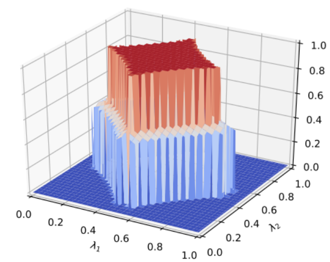
3. On the Relative Expressiveness of Bayesian and Neural Networks

Arthur Choi, Ruocheng Wang, Adnan Darwiche: *On the Relative Expressiveness of Bayesian and Neural Networks.* Int. J. Approx. Reason. 2019 (M)

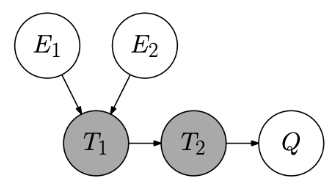
- Reviewing class of functions induced by neural and Bayesian networks
- Identifying the corresponding gap in expressiveness
- Proposing a new class of Bayesian networks, namely Testing Bayesian Networks
- Investigating expressiveness of TBNs



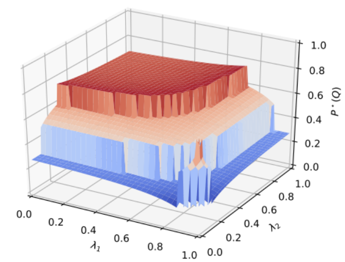
(a) BN function



(b) TBN function



(c) BN/TBN structure



(d) TBN function

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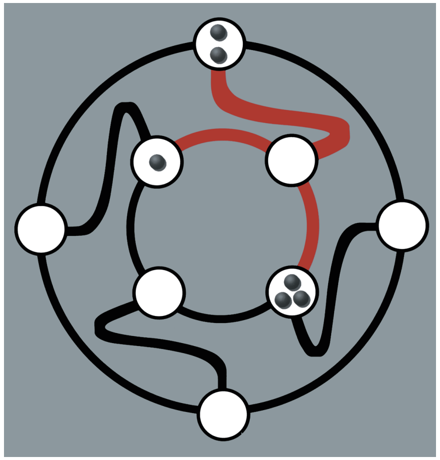
Outline

Quantitative Loop Invariants

- Reasoning about loops is the hardest task in (probabilistic) program verification.
- “Practical” approach: capture the loop effect by an invariant[a].
- But how to (automatically) find an appropriate loop invariant?
  1. Constraint solving-based numerical approach:
     Feng Y. *et al.*: *Finding Polynomial Loop Invariants for Probabilistic Programs*. ATVA 2017. (M)
  2. Martingale-based symbolic method:
     Barthe G. *et al.*: *Synthesizing Probabilistic Invariants via Doob’s Decomposition*. CAV 2016. (M)
  3. Moment-based approach by solving recurrences:
     Bartocci E. *et al.*: *Automatic Generation of Moment-Based Invariants for Prob-Solvable Loops*. ATVA 2019. (M)



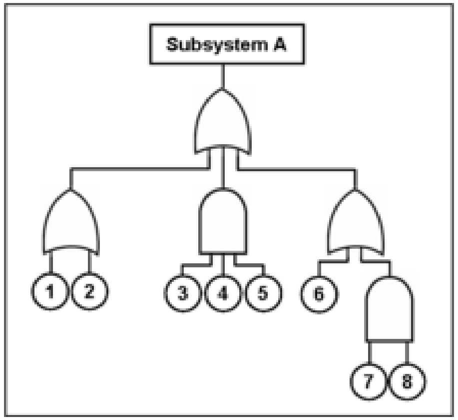
©A. McIver & C. Morgan, 2005

[a] A loop invariant is a property of a loop that is true before and after each iteration.

Outline

Formal Approaches to Systems Engineering

- Goal: ensure Reliability, Availability, Maintainability, and Security (RAMS) of (computer) systems
- Fault Trees as popular modelling formalism of RAMS-domain
- Use of formal methods to analyse fault trees
- Specifically: probabilistic model checking
- Doing this efficiently is a challenge
- Topics:
  1. Bäckström et al.: *Effective Static and Dynamic Fault Tree Analysis*. SAFECOMP 2016 (B)
     - presents efficient static and dynamic analyses of dynamic fault trees
  2. Kordy et al.: *Attack-Defense Trees*. J. Log. Comput. 24, 2014 (B)
     - surveys various usage scenarios and semantics for attack-defence scenarios for security applications
  3. Aslanyan et al.: *Quantitative Verification and Synthesis of Attack-Defence Scenarios*. CSF 2016 (B/M)
     - translates attack defence trees to two-player games to enable their stochastic analysis



Outline

Some Final Hints

Hints

- Take your time to understand your literature.
- Be proactive! Look for additional literature and information.
- Discuss the content of your report with other students.
- Be proactive! Contact your supervisor on time.
- Prepare the meeting(s) with your supervisor.
- Forget the idea that you can prepare a talk in a day or two.

We wish you success and look forward to an enjoyable and high-quality seminar!