Bounded Saturation Based CTL Model Checking

András Vörös, **Dániel Darvas**

Budapest University of Technology and Economics, Budapest, Hungary

Fault Tolerant Systems Research Group

Tamás Bartha

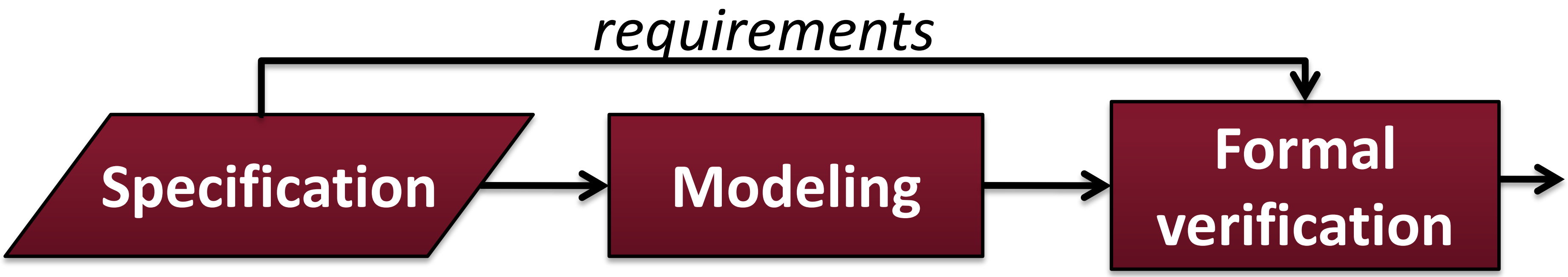
MTA SZTAKI, Budapest, Hungary

Computer and Automation Research Institute

Contents

Formal methods

- Safety critical and embedded systems
  - Railway, automotive industry, air transportation
  - Reliability is an important issue
- Design time analysis:



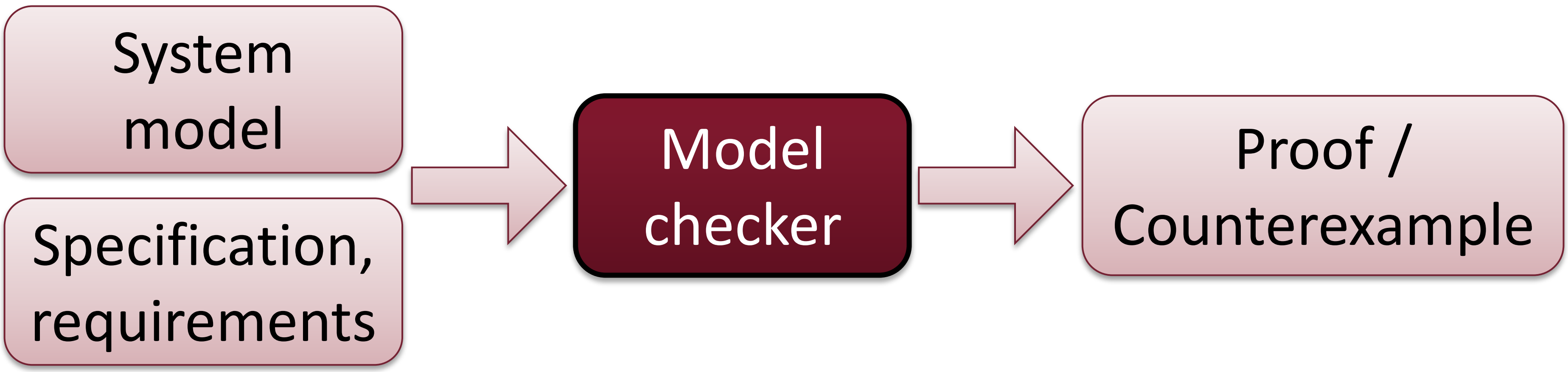
– Does my system work well?

– Does it provide services properly?

Mathematically sound answer

Model checking

- Automatic verification method



- Prerequisite:
  - Exploring and representing the reachable states
- Problem:
  - State space explosion
  - Time and space requirements

Saturation algorithm

- Efficient solution for:
  - State space generation
  - Model checking
- **Symbolic** algorithm
  - Encoding of states
  - **Special underlying data structures**
    - Multi-valued decision diagrams (MDDs)
- Special **iteration strategy**
  - Efficient for asynchronous models

Overview of the saturation workflow

Model of the system

Decomposition and ordering

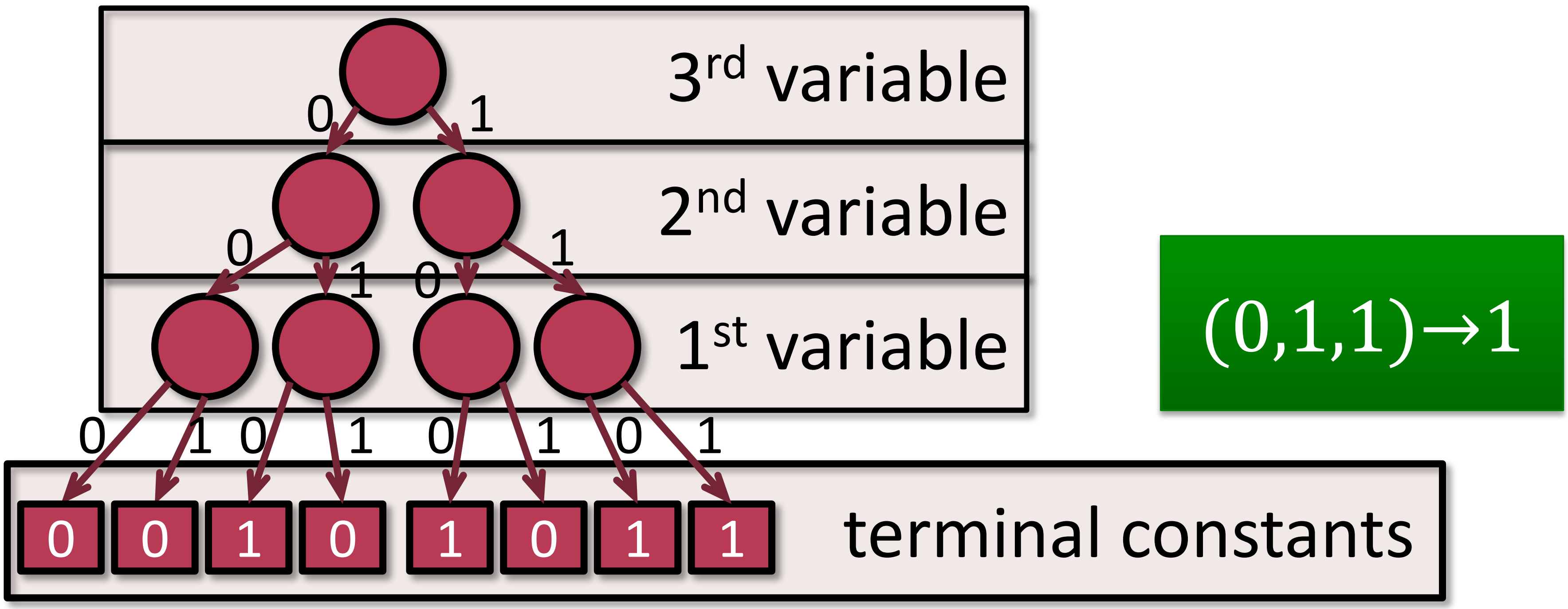
Saturation

State space exploring

Model checking

Multi-valued Decision Diagrams

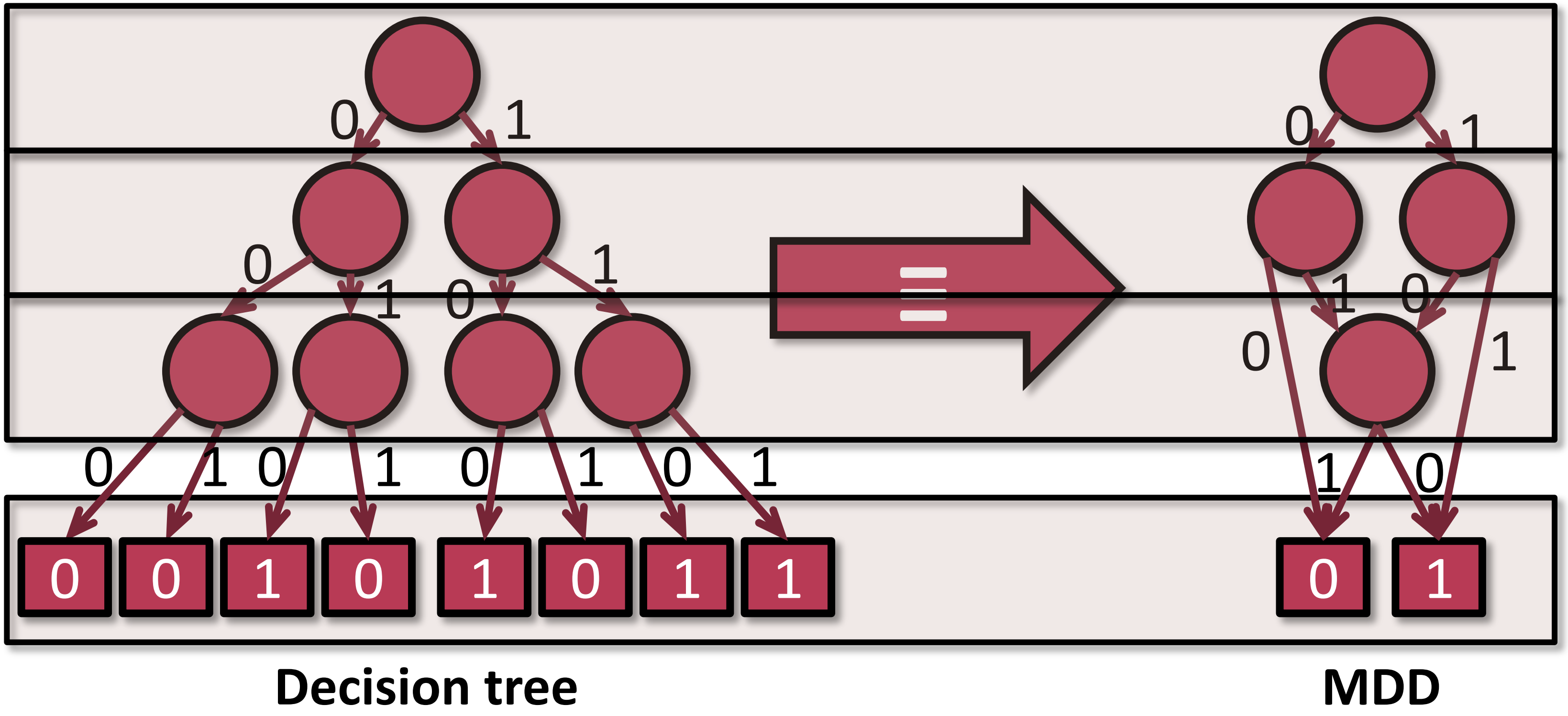
- Derived from **decision trees**
  - variables are ordered into levels



Decision tree

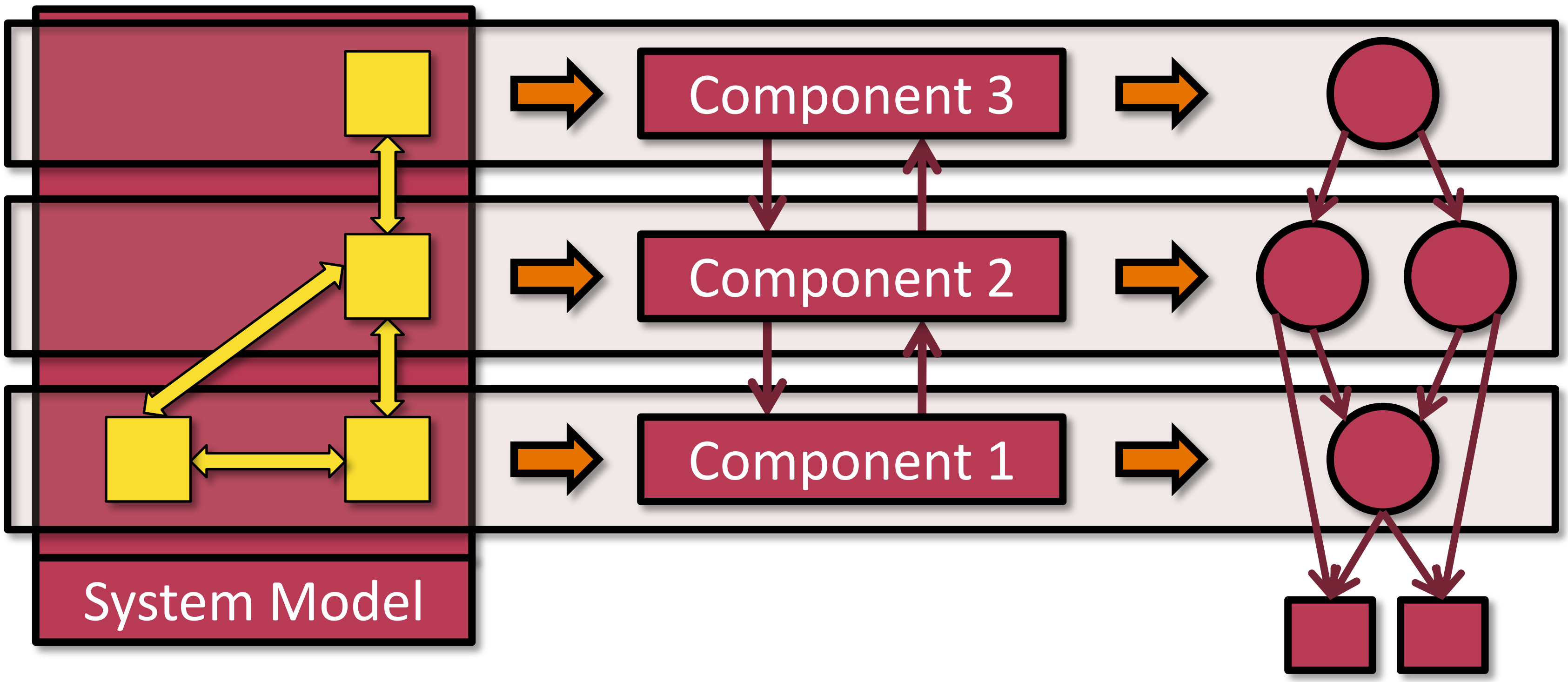
Multi-valued Decision Diagrams

- Derived from decision trees
  - variables are ordered into levels
- Special reduction rules
  - in a bottom-up fashion, applying reduction from level-to-levels
- **Compact representation** of multi valued functions



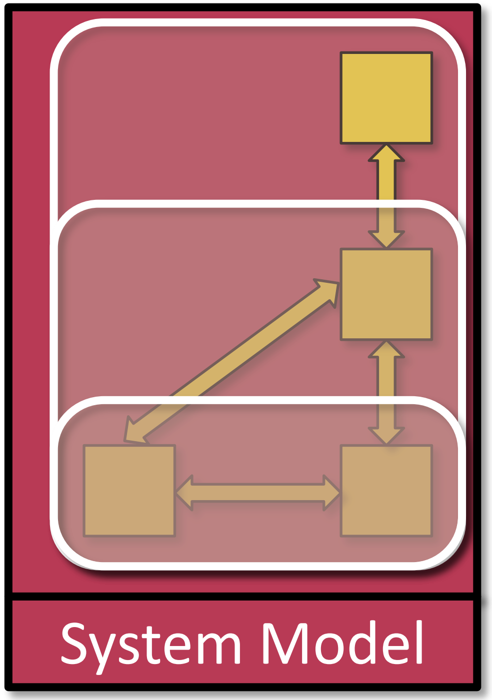
Symbolic algorithm

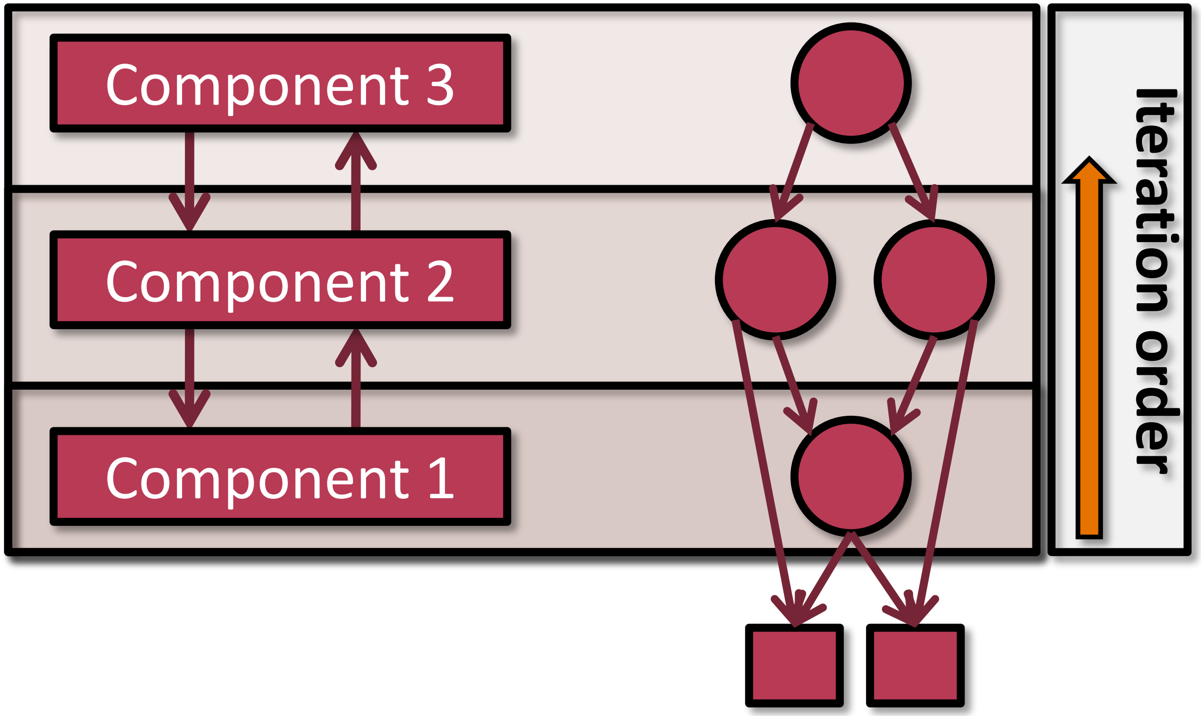
- Symbolic encoding instead of explicit state representation
  - Decomposition is needed
- Saturation uses componentwise encoding



Special iteration

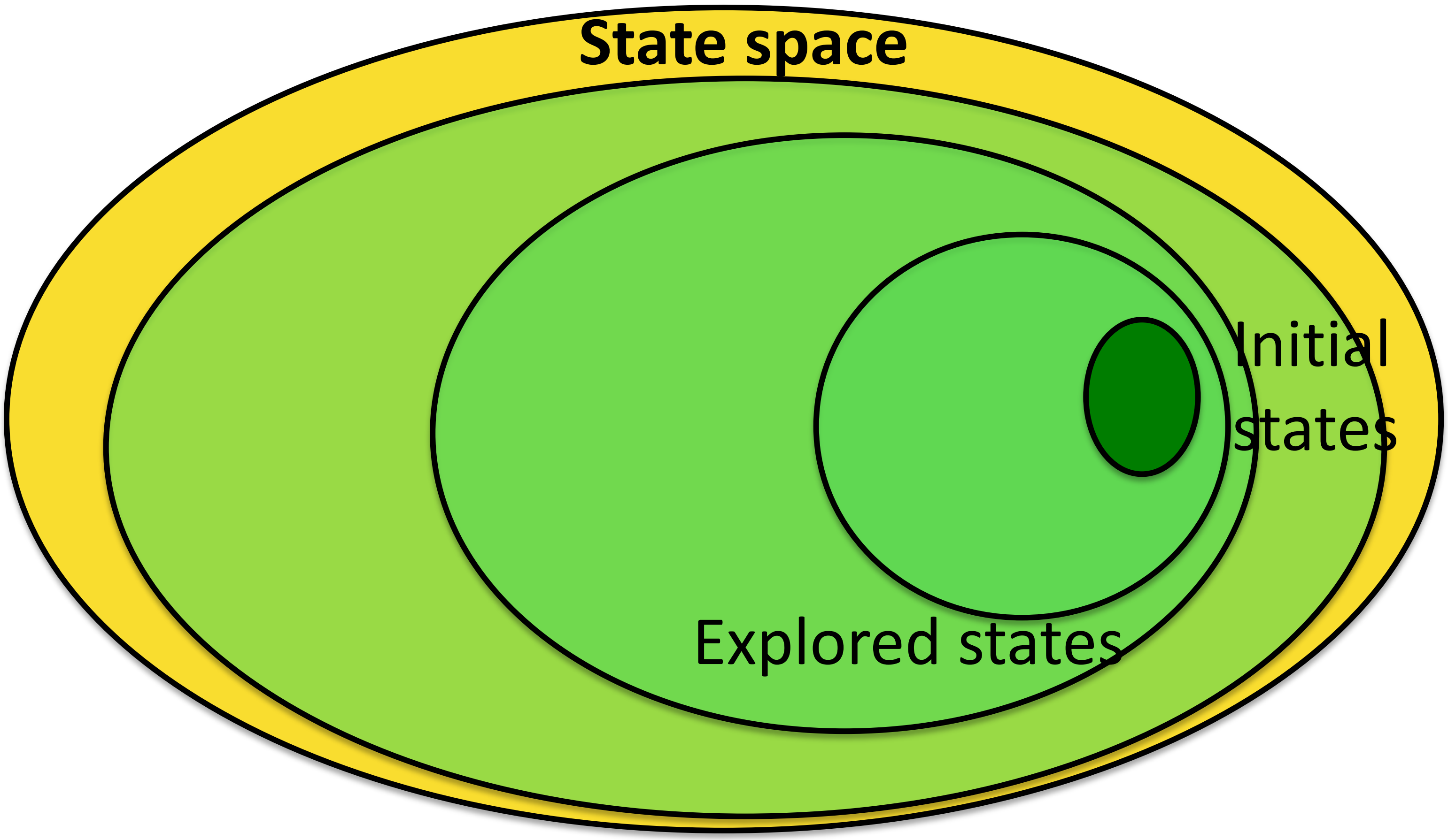
- Local exploration in a greedy manner
- Exploring global synchronization events if needed
- Uses the primarily defined order of the decision diagram variable encoding





Bounded saturation

Motivation for bounded model checking



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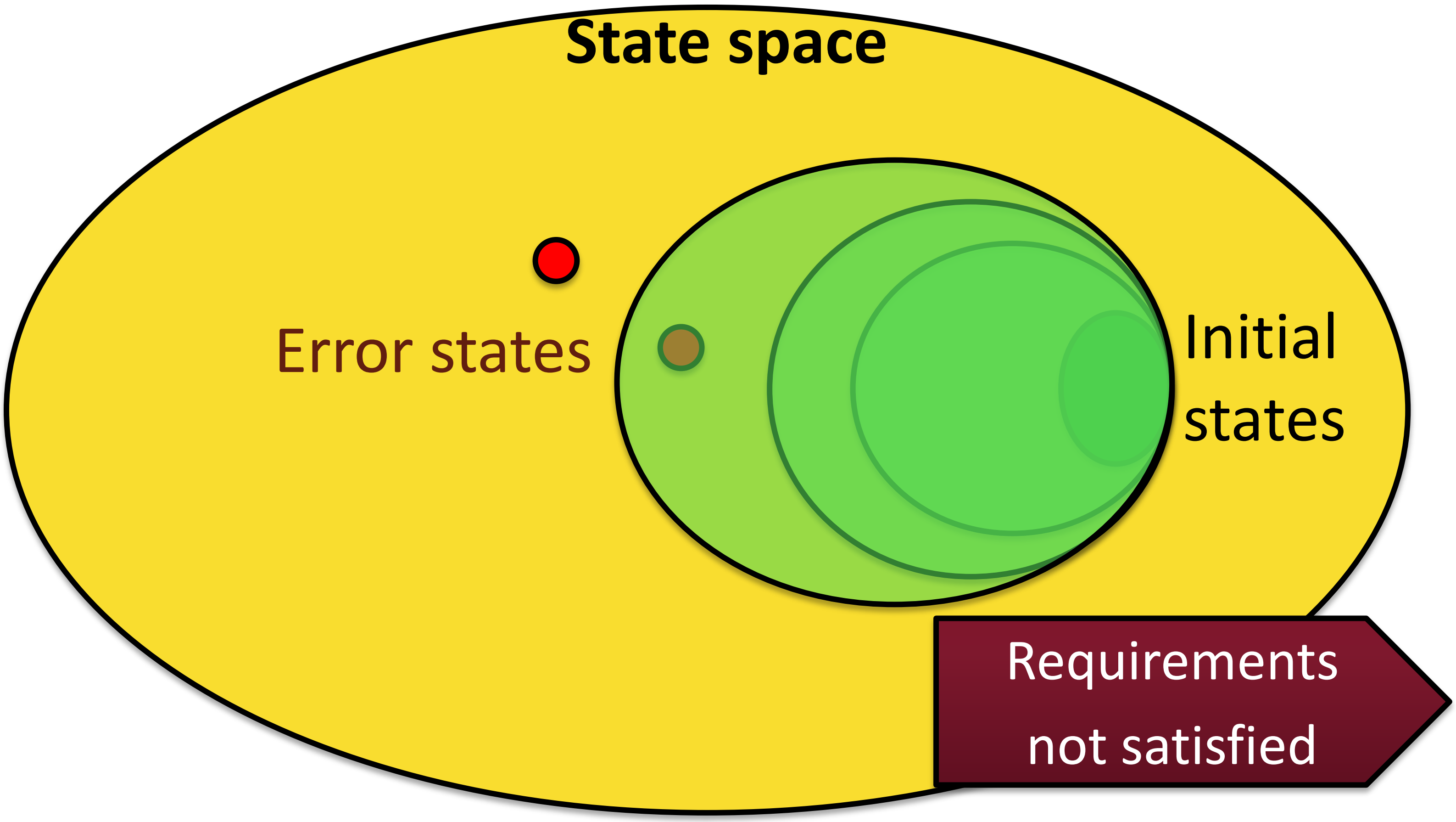
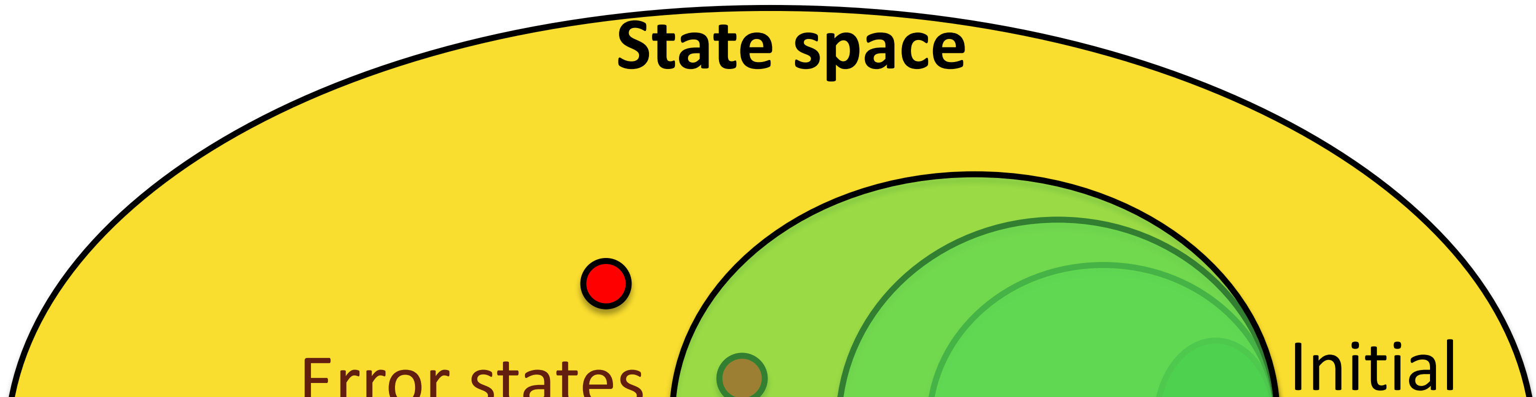


Motivation for bounded model checking



Bounded model checking (BMC)

- explores a *k*-bounded part of the state space (usually in a breadth first manner)
- examines the specification on this smaller part

Problems with Bounded Saturation

- Main problems with bounded saturation:
  - Saturation explores the state space in an irregular recursive order
    - ⇒ **Difficult to limit** the exploration
  - There is **no distance information** in the MDDs
    - ⇒ New data structure is needed

Problems with Bounded Saturation

- Main problems with bounded saturation:

Bounded number of iterations

Truncating the state space representation

New data structure:

Edge-valued decision diagrams (EDDs)

MDD based data structure enriched with distance information

Open questions before our work

- How can we ***implement*** a bounded state space exploration (BSSE) module?
  - In theory it needs *information about the state space*, but this is not available a priori.
- Can BSSE and a saturation based model checker ***work together***?
- Is there an efficient way for using ***exact bounds***?
- How can we use this method for model checking ***in practice***?

Truncating methods

- Two approach:

Exact truncating

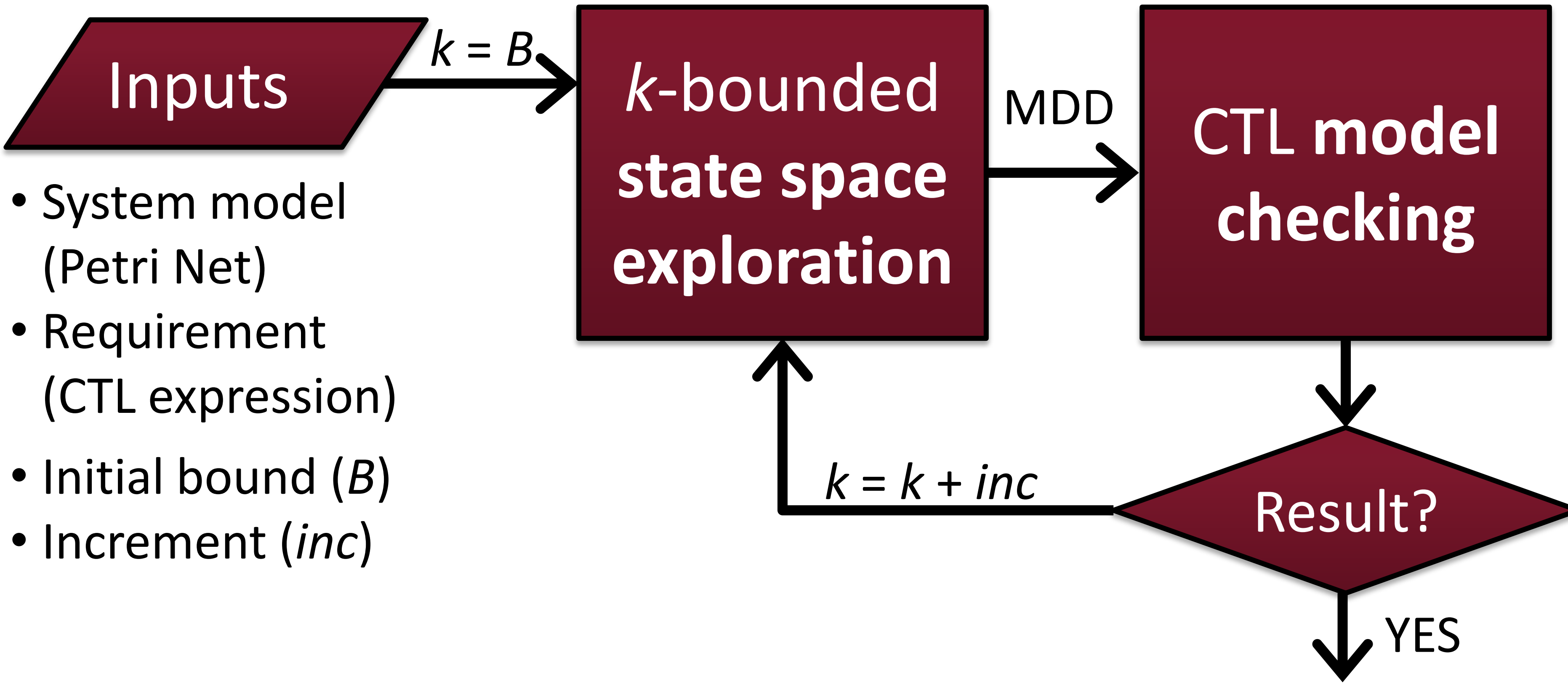
- exact *k*-bound
- less efficient originally
- in our work: **competitive (using caches)**

Approximate truncating

- only $k..k \cdot C$-bound
  (C: number of components)
- more efficient
  (as stated earlier)

Iterative BMC

- The necessary *k*-bound is not known a priori
- We use an **iterative algorithm**:



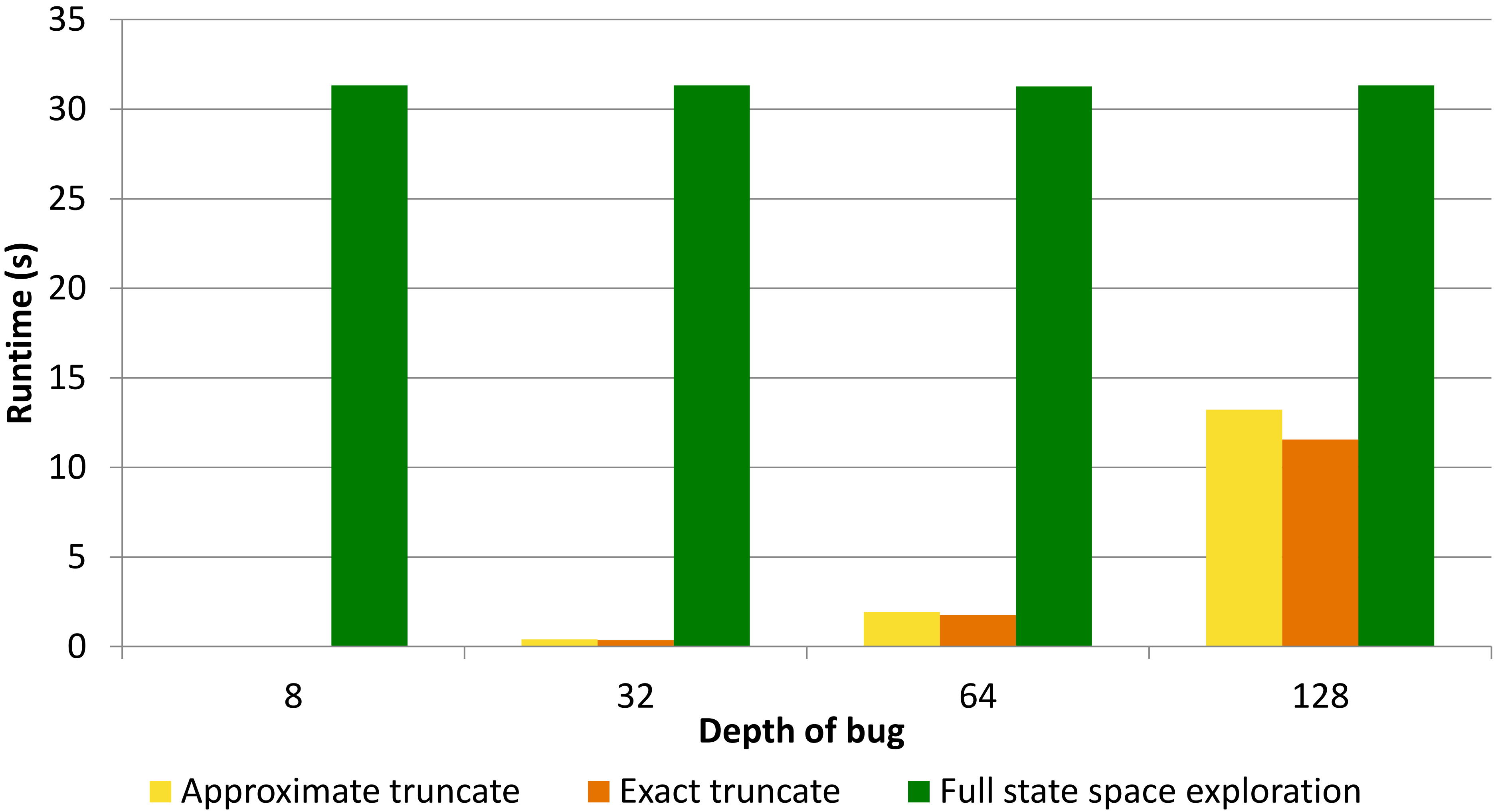
Efficiency problems

- Classical saturation based MC may explore and check some unreachable states needlessly
  - The answer is correct but could be more efficient
  - Work in progress (constrained saturation)
- Incremental building of the state space
  - The algorithm restarts state space exploration from the initial state
  - Future work

Measurements and conclusion

Measurements

- Scaling with **depth of „error state”**



Measurements

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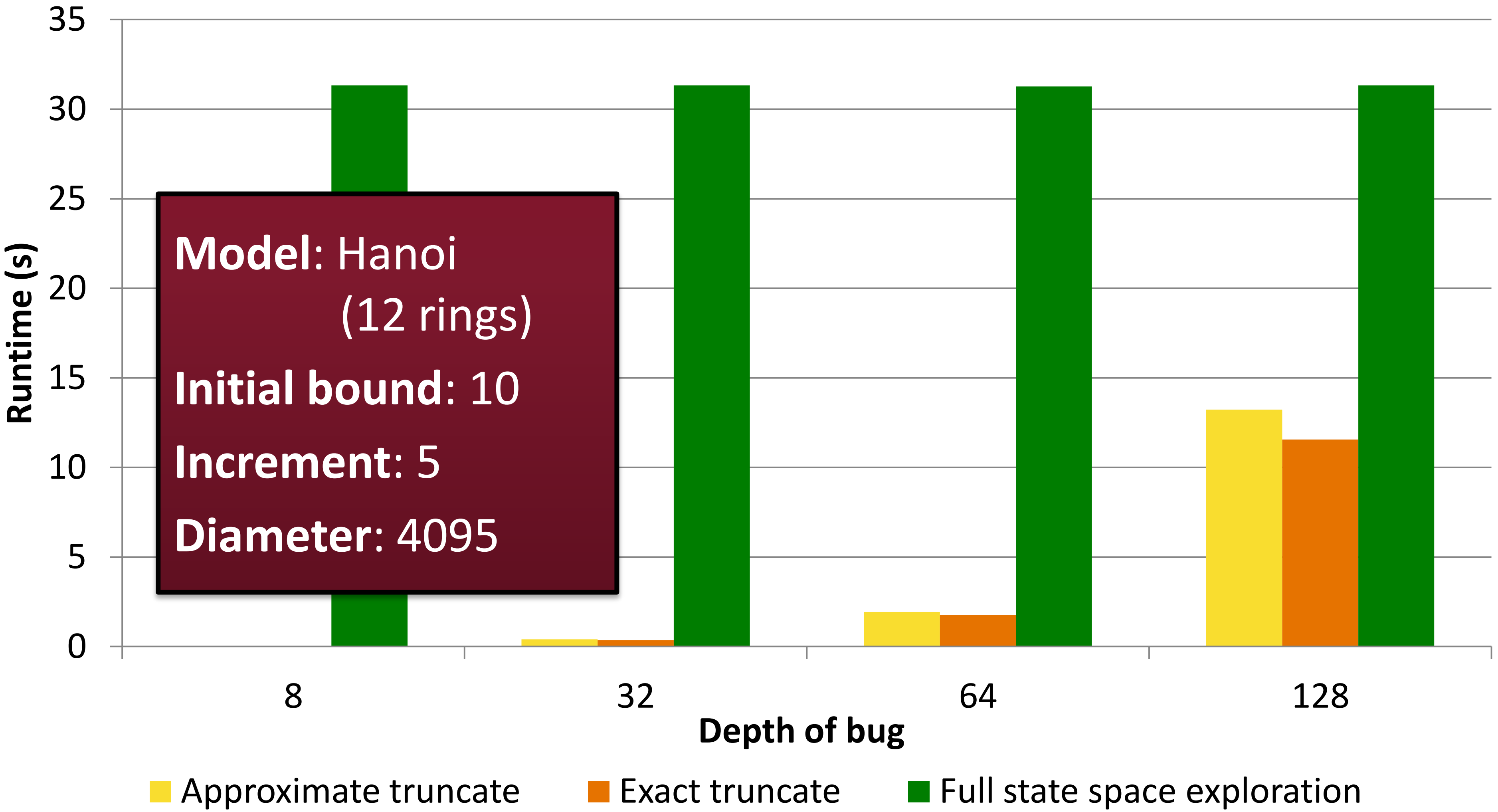
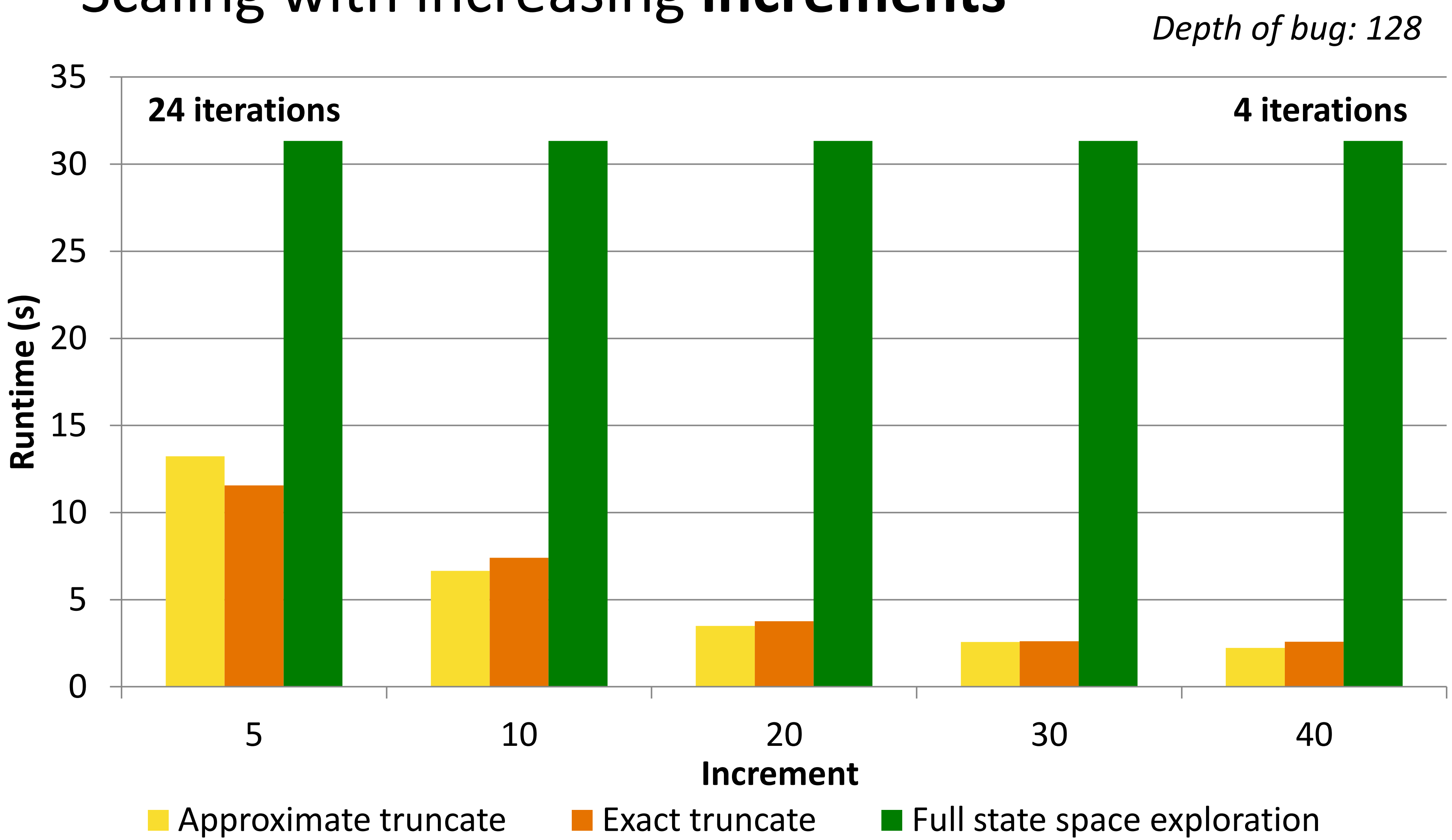


Measurements

- Scaling with increasing **increments**



Conclusion

- We have *implemented* a bounded model checker in our tool
  - Theoretical and practical improvements in the original bounded algorithm
- Saturation based bounded state space generation and classic MC *could work together*
- Efficient for ”*shallow bugs*”
- Efficiency is highly depending on the chosen *parameters*

Thank you for your attention!