# SAT Solver architectures

## Presentation at FMV, Linz

Mate Soos

Security Research Labs

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SECURITY RESEARCH LABS

# Motivations and goals

Motivations

- Architectural choices are not simple
- Rarely talked about, but matter a lot

Goals

- Present the different choices
- Shed light on their interactions

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# Outline

# SAT solvers

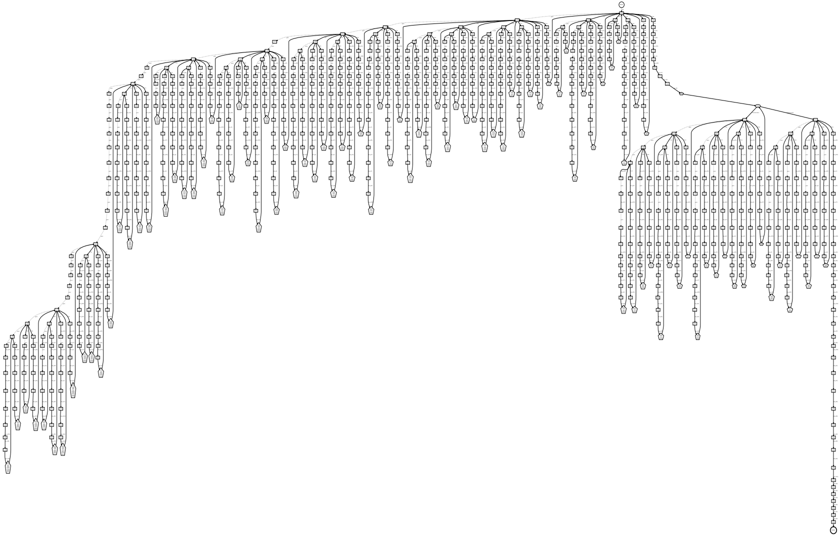
Input:

- CNF, an "`and` of `or`-s":
  $(x_1 \vee \neg x_3) \quad \wedge \quad (\neg x_2 \vee x_3) \quad \wedge \quad (x_1 \vee x_2)$
- Crypto-problem needs conversion
- E.g. $a \oplus bc \oplus d = 0$ needs internal var for $bc$

### Uses DPLL($\varphi$) algorithm

1. If (formula $\varphi$ trivial) return SAT/UNSAT
2. ret $\leftarrow$ DPLL($\varphi$ with $v \leftarrow$ `true`)
3. If (ret = SAT) return SAT
4. ret $\leftarrow$ DPLL($\varphi$ with $v \leftarrow$ `false`)
5. If (ret = SAT) return SAT
6. return UNSAT

# Example search tree



# Main challenges

Low-level constraints

- Efficient use of memory arch.: cache, page faults, etc.
- Must work well in multi-threaded: locks, semaphores, etc.
- Compiled code is of importance: compilation issues

High-level problems

- Highly theoretical approaches
- Complex interactions between algorithms
- Randomised algorithms
- No clear visual or statistical indicators

# Additional challenges

Cut-offs

- Some algos. can take *far* too long to finish
- Limit time... but solver must remain deterministic
- Make the best of time available

Validity (bugs)

- UNSAT is rarely proven — solution hard to check
- Internal state very large — infection hard to trace
- Problems very heterogeneous – hidden bugs

# Outline

# Elements to add

Main elements

- DPLL
- Branch literals
- Restarts
- Learnt clause cleaning
- Thread synchronisation

Simplification algos

- Equivalent literals
- Clause subsumption
- Variable elimination
- ...

# BCP

Must be efficient (70% of time)

- Bit stuffing, hand-rolled memory managers, etc.
- Prefetching, lazy algos
- Special treatment of small clauses

Completeness vs. speed

- Re-compute glues at propagation?
- Extended impl. graph?

# Learnt clauses&restarts

Options

- Geom./Luby rest. + clause activities: for packed problems
- Glue-based dyn rest. + glues: for large industrial problems
- Agility-based dyn rest. + glues: for both, but not perfect
- Outer-inner variations of above

Problems

- Important choice: cache behav., complexity of impl.
- Support multiple vs. speed
- Which to choose if multiple supported

# Scheduling of simplification algos.

In what order?

- They interact...
- Cannot try all combinations: $n!$
- Intuition/habits/experience

When?

- Once at start-up: e.g. XOR extraction
- Once every X conflicts: e.g. failed lit. probing
- If needed: SCC if new binary clauses
- AT every conflict: confl. minimisation

# Organising simplification algos.

Generally

- Some need occurrence lists: detach & reattach
- Some need to propagate w/o conflict analysis
- Some benefit from each other

In CryptoMiniSat

- Group 1: detached long clauses, occurrence lists
- Group 2: Simplified propagation, re-use of propagated values

# Multi-threaded / Distributed solving

Do something different (heterogeneity)

- Support multiple restarts/activities
- Range of magic constants → more testing

Do the same, faster (sharing)

- Forced var setting — redundancy check: O(1)
- Binary clauses — redundancy check: P
- Tertiary clauses — redundancy check: co-NP?
- Larger clauses — provably needed
- What else to share?

# Extra functionalities

Use solver as a

- Preprocessor
- Library for abstraction-refinement
- Multi-threaded and distributed variation of above
- Static analyser
- Dynamic analyser
- Accumulator of knowledge

# Outline

Context
- SAT Solvers
- Challenges

Architectures
- Main loop
- Simplification algos.
- Multi-threaded/distributed solving
- Extra functionalities

Conclusions

# Conclusions

- SAT solvers are complex
- Takes lots of time to write one
- Practise makes perfect
- But practise leads to habits
- Difficult to re-invent everything all the time