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Scalable SAT Solving on Demand

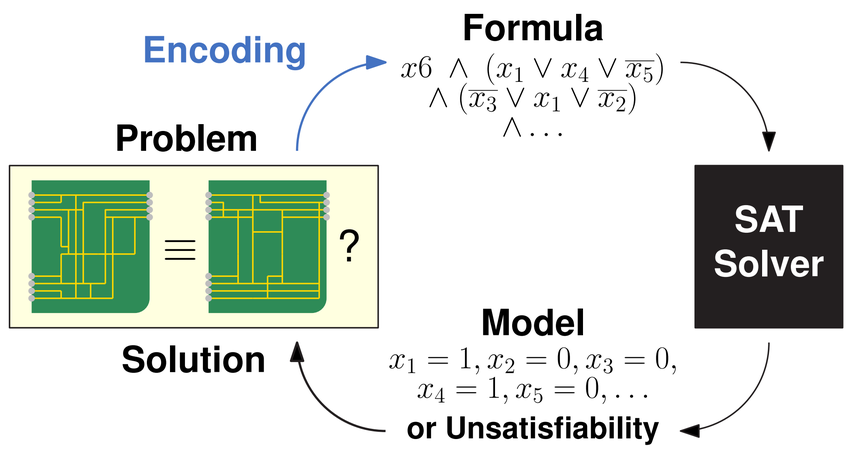
Dominik Schreiber and Peter Sanders • Highlights of Parallel Computing • Nantes, June 2024

0. Background

The Propositional Satisfiability Problem

Given a **propositional formula** F, assign a value (`true` or `false`) to each of its variables in such a way that F evaluates to `true`, or report that such an assignment ("model") does not exist.

— Solving Problems via SAT —



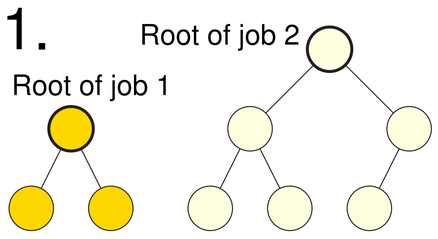
Applications: Software & hardware verification, electronic design, cryptography, theorem proving, scheduling, . . .

I. Decentralized Job Scheduling [1, 2, 3]

- Exploit **large clusters (1000 – 10 000 cores)** for SAT solving
- Substantially **reduce scheduling latencies** for interactive solving
- Combine job parallelism and parallel SAT solving

— Our Approach —

1.



Represent jobs as **binary trees** of processes

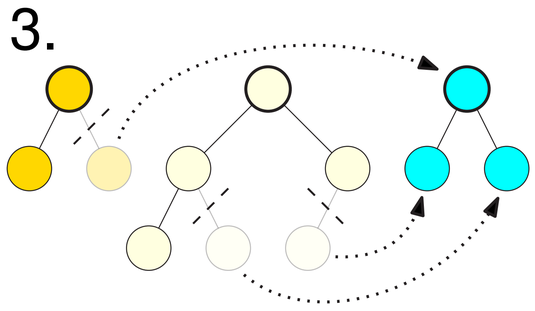
2.

Demand:	3	9	3
Priority:	1	2	8

Calculate fair job volumes

⇒ Volume: **2** **4** **3**

3.

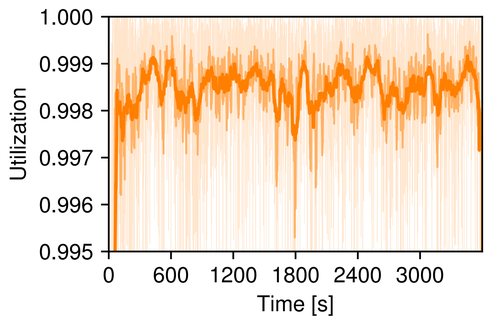


(Re-)assign processes to jobs according to fair volumes, using:

1. **Random walks** of requests
2. Guiding requests along distributed **routing tree** (better)
3. **Asynchronous prefix sums** for request-idle matching (best)

— Results —

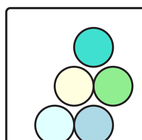
- Experiments at $\leq$ **6144 cores**
- Scheduling and resizing of jobs **within $\approx$ 10 milliseconds**
- **Near-optimal utilization**
  Right: moving avg. over 1/15/60 s
- Less than 10% of workers are rescheduled more than once



II. Distributed SAT Solving [2, 4]

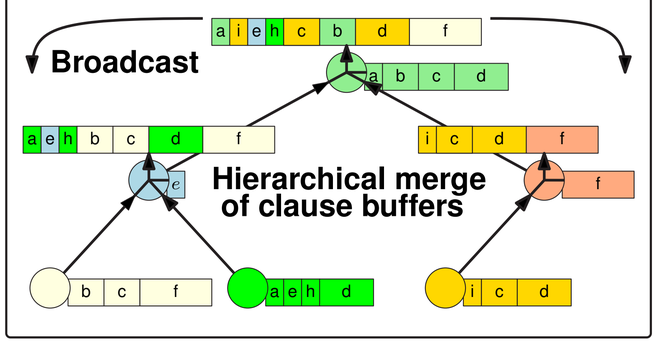
- Improve **scaling behavior** of distributed SAT solving
- Use flexible communication that supports **fluctuating resources**

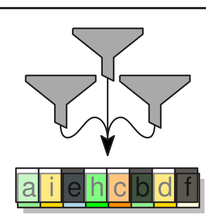
— Our Approach —



Portfolio approach [5]: Run diverse variants of sequential **CDCL solvers**, which produce useful **conflict clauses**

Clause sharing: Exchange **globally best distinct clauses** across solvers



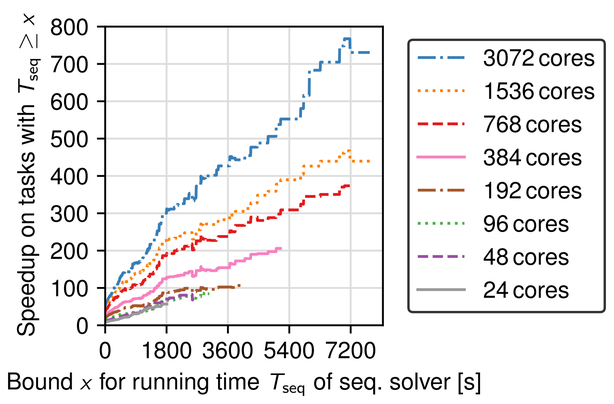


Clause sharing quality control via

– careful **steering** of sharing volume;
– exact **distributed filtering** of repeated / obsolete clauses;
– manipulating clause **quality scores** (LBD)

— Results —

- Speedups observed for **up to 3072 cores**, doubling prior speedups
- Clause sharing is demonstrably **main driver of scalability**
- Can conquer **previously infeasible instances**



III. The MALLOB Platform [3, 6]

- C++ UNIX application built on **MPI** featuring all of our contributions
- Winning system of **International SAT Competition** Cloud Tracks 2020–2023
- LGPL and MIT licensed code available

`github.com/domschrei/mallob`

— References —

[1] Peter Sanders and Dominik Schreiber. Decentralized online scheduling of malleable NP-hard jobs. In *Proc. Euro-Par*, pages 119–135. Springer, 2022.

[2] Dominik Schreiber and Peter Sanders. Scalable SAT solving in the cloud. In *Proc. SAT*, pages 518–534. Springer, 2021.

[3] Dominik Schreiber. *Scalable SAT Solving and its Application*. PhD thesis, Karlsruhe Institute of Technology, 2023.

[4] Dominik Schreiber and Peter Sanders. MALLOBSAT: Scalable SAT solving by clause sharing. *JAIR (to appear)*, 2024.

[5] Tomáš Balyo, Peter Sanders, and Carsten Sinz. Hordesat: A massively parallel portfolio SAT solver. In *Proc. SAT*, pages 156–172. Springer, 2015.

[6] Peter Sanders and Dominik Schreiber. Mallob: Scalable SAT solving on demand with decentralized job scheduling. *JOSS*, 7(76):4591, 2022.