Learned Clause Minimization in Parallel SAT Solvers

Pragmatics of SAT 2019

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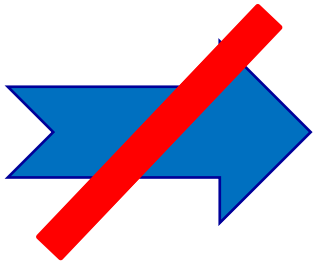
Background

(Learned) Clause Minimization in SC18

Solver	Author	CM/ LMC
MapleLCMDistChronoBT	Ryvchin et al.	✓
Maple_LCM_Scavel_fix2	Xu et al.	✓
Maple_CM	Luo et al.	✓
cms55-main-all4fixed	M. Soos	✓
Maple_CM_ordUIP	Luo et al.	✓
Maple_CM_Dist	Luo et al.	✓
cms55-main-all4fixed	M. Soos	✓
Maple_CM_ordUIP+	Luo et al.	✓
Maple_LCM_Scavel_200_fix2	Xu et al.	✓
cms55-main-all4fixed	M. Soos	✓

Top10 Main Track



Success was not transferred to parallel

Solver	Author	CM/ LMC
painless	Le Frioux et al.	✗
plingeling	A. Biere	✗
abcdsat	J. Chen	✓
cms55-parallel, 12 core	M. Soos	✓
cbpenelope	T. Sonobe	✗
ccspenelope	T. Sonobe	✗
syrup, 24 threads	Audemard et al.	✓
penelope_MDLC	Konan Tchinda et al.	✗
treengeling	A. Biere	✗
scalope	Konan Tchinda et al.	✗

Top10 Parallel Track

(Learned) Clause Minimization (LCM)

- Clause Minimization using Distillation[1] / Vivification[2]
- Applied at decision level zero

Clause $C = l_1 \lor l_2 \lor \ldots \lor l_i \lor \ldots \lor l_j \lor \ldots$

Iteratively propagate negations $\rightarrow$

<u>After</u> <u>propagating</u> $\neg l_1, \neg l_2, \ldots, \neg l_i$:

Case 1:
- l_j propagated to true
- C replaced by $l_1 \lor l_2 \lor \ldots \lor l_i \lor l_j$

Case 2:
- l_i propagated to false
- l_i removed from C

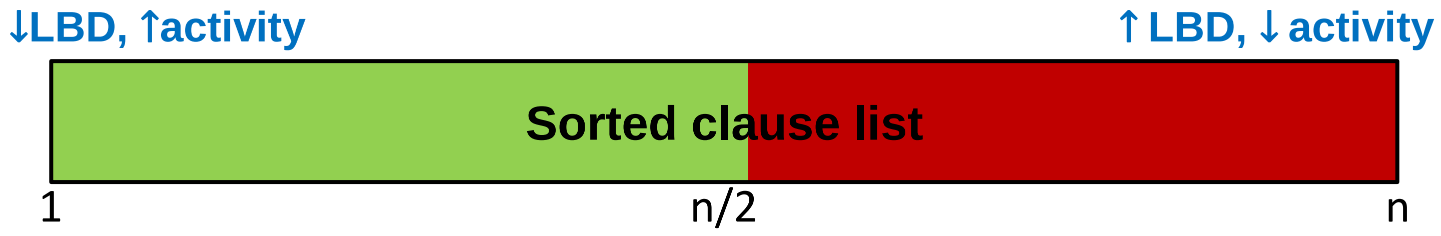
Case 3:
- Conflict detected
- C replaced by $l_1 \lor l_2 \lor \ldots \lor l_i$

- In this presentation: Minimization $\equiv$ Distillation/Vivification

LMC Approach [3]

Only apply CM to (in future) kept learned clauses

- Each clause minimized only once
- Reduction heuristic specifies which are kept
- Reduction example Glucose:



- low LBD, higher activity
→ keep and minimize

- high LBD, lower activity
→ remove

- Minimization triggered after a restart or decision tree is stashed

Parallel Clause Minimization

Heterogeneous vs. Homogenous

Heterogeneous minimization approach

Dedicate individual threads to minimization

- Examples:
    - CDCL solvers + One minimization thread [4][5]
    - Only part of solvers use minimization [6]
- Problems:
    - Not trivial for many cores
    - Introduces load balancing problem
    - Adds more magic parameters
- Finding good parameters expensive

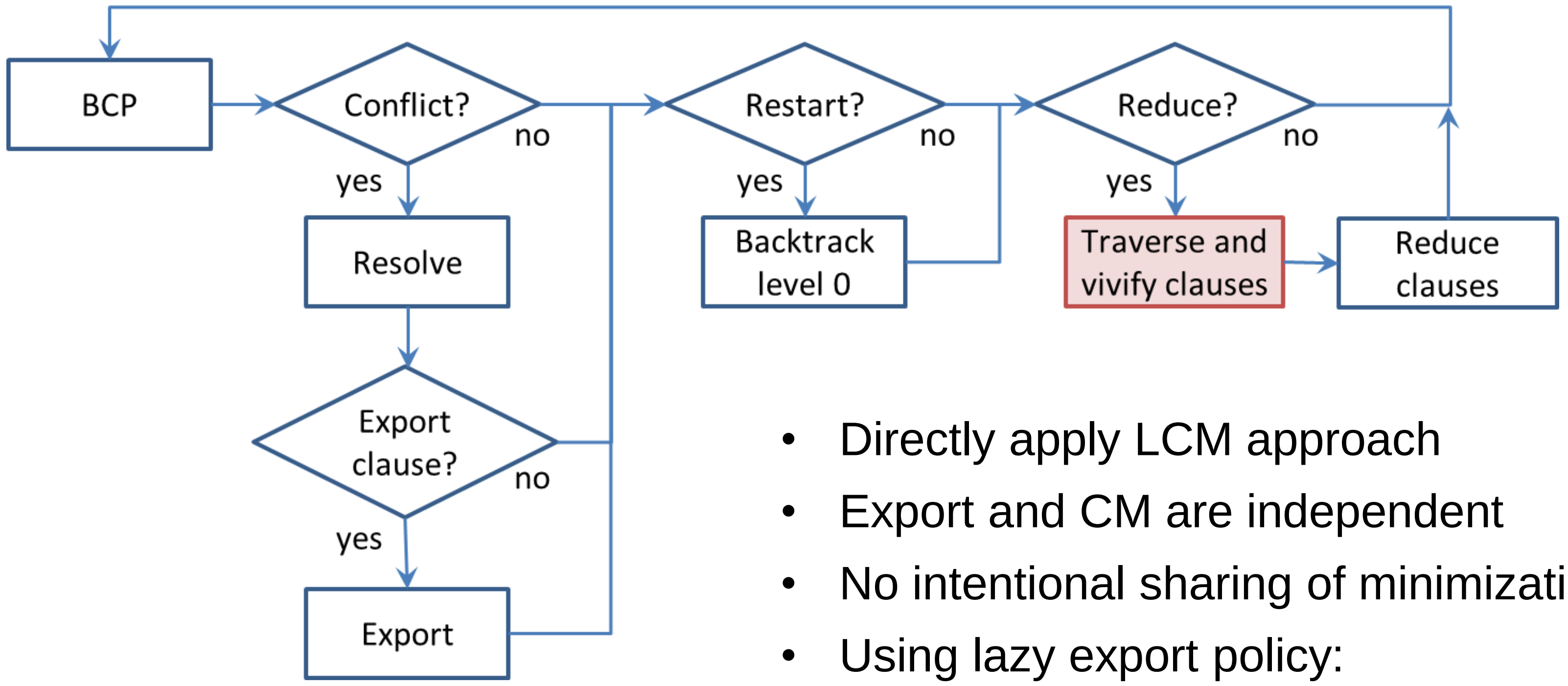
→ Discarded for future work

Heterogeneous vs. Homogenous

Homogenous minimization approach

- All solvers use same minimization approach
- Example: Minimize export clauses [7]
- Problems:
    - Balance minimization and BCP
    - How and if minimizations should be shared

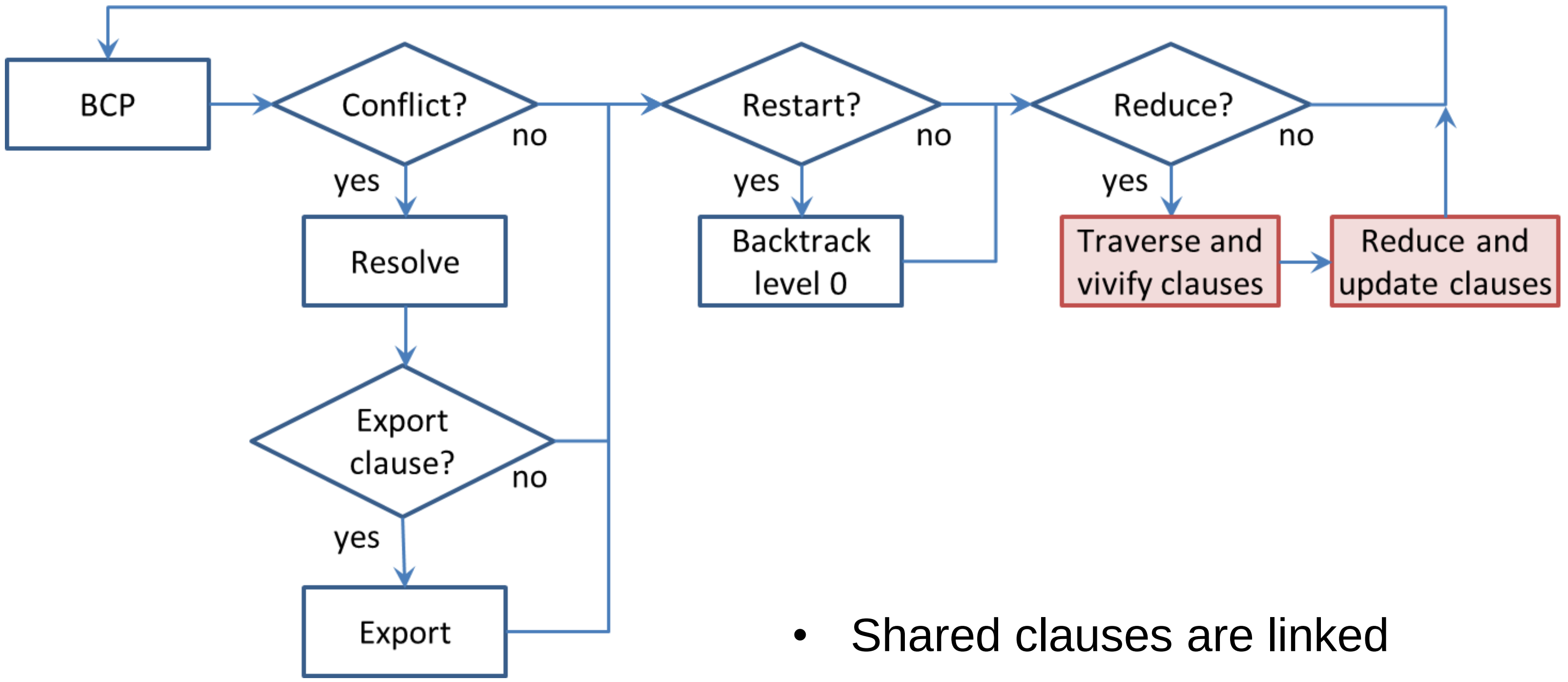
PCM – Private Clause Minimization



- Directly apply LCM approach
- Export and CM are independent
- No intentional sharing of minimizations
- Using lazy export policy:
  Minimized clauses might be shared

Implementation:
- LBD (≤ 5) cut
- Original version (no LBD cut) decreased performance
- Lazy export policy (two times used)

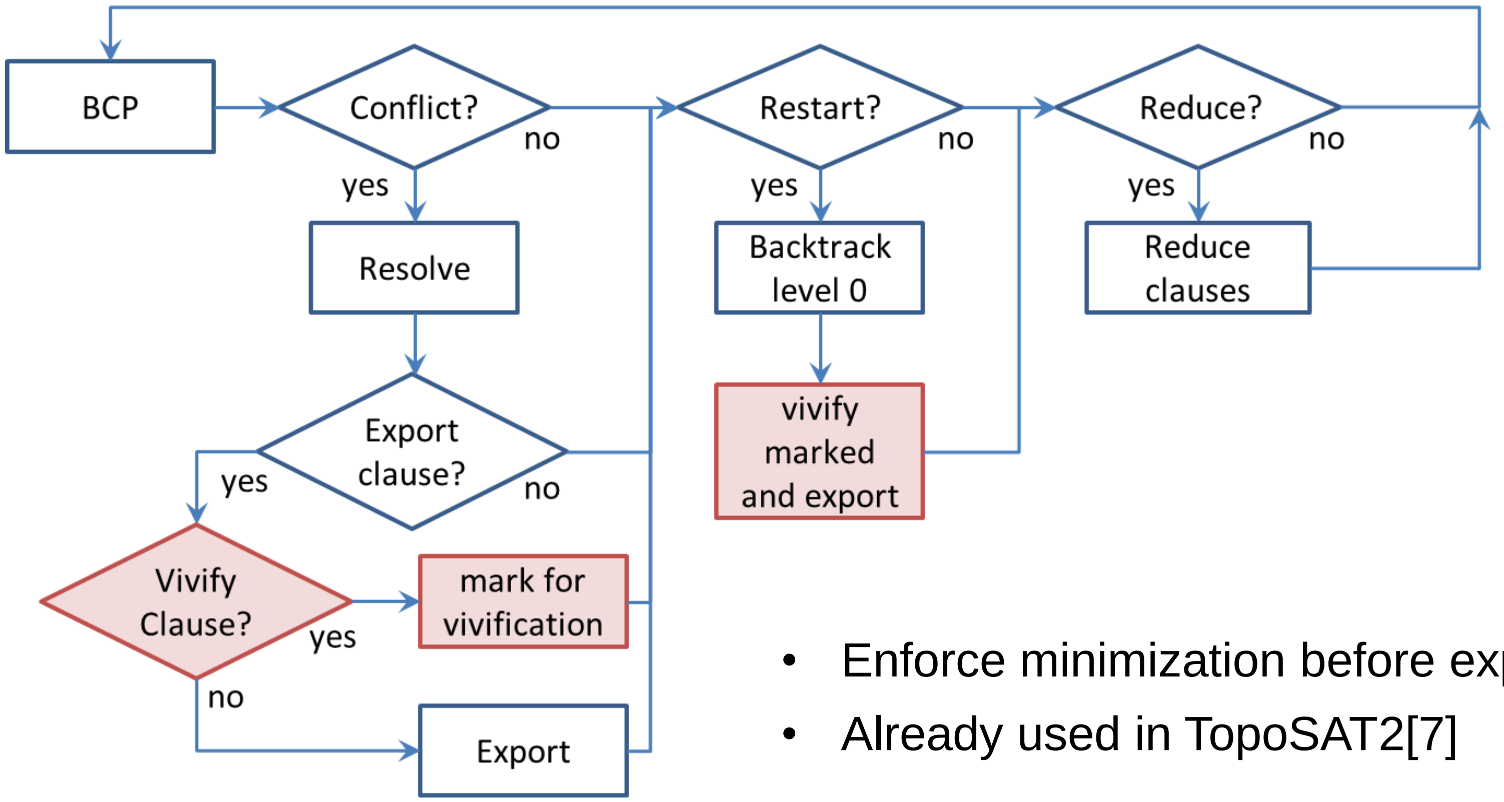
LPCM – Linked Private Clause Minimization



- Shared clauses are linked
- Minimizations shared via link

Implementation:
- LBD (≤ 5) cut
- Clause header contains pointer to memory chunk
- If minimized, chunk contains new clause

ECM – Export Clause Minimization



- Enforce minimization before export
- Already used in TopoSAT2[7]

Implementation:
- Lazy export policy (two times used)
- LBD (≤ 3 or ≤ 4) and length (≤ 30) cut
- Marked clauses are protected during reduction

Experiments

Test Set and Environment

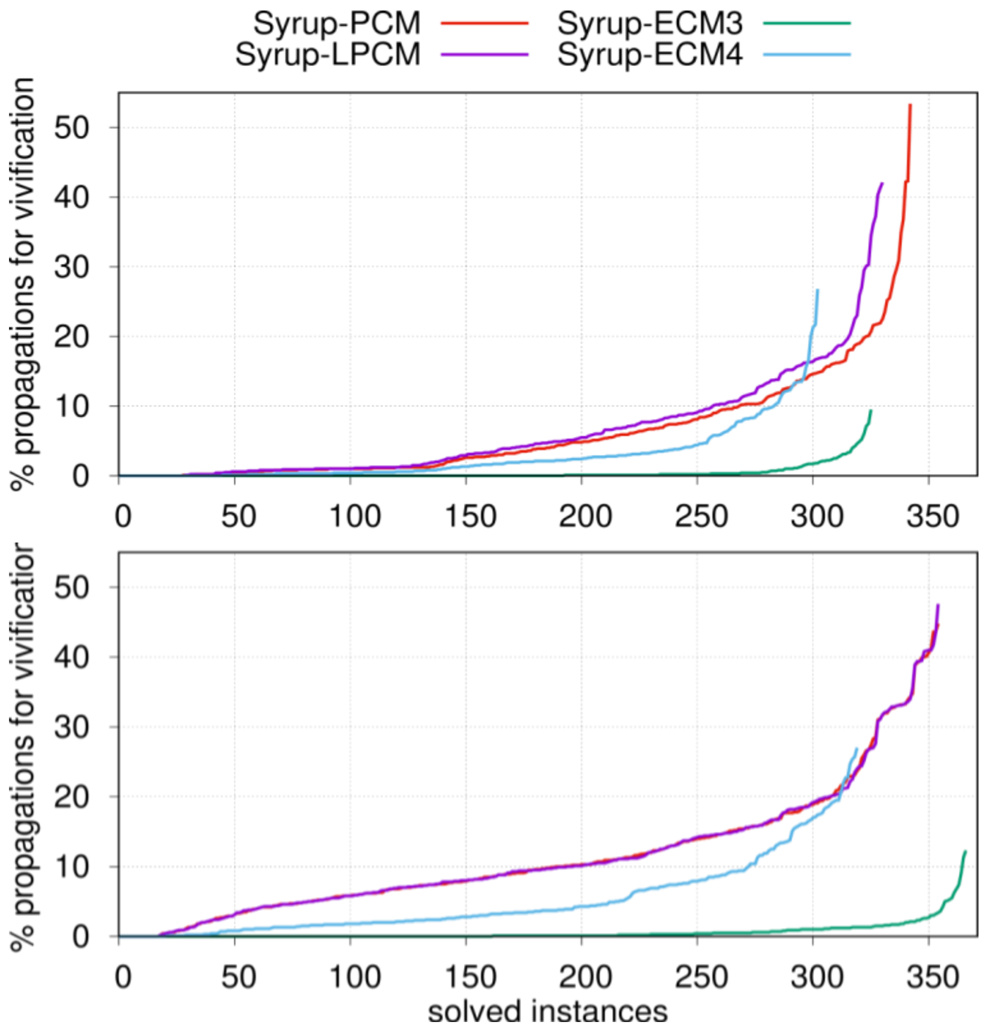
- SAT competition ‘16 application track, ’17 and ‘ 18 main track
- On Intel Xeon Phi 7250, 68 cores at 1.4 GHz with 96 GB RAM

- Maximum walltime of 15000 seconds
- Maximal 34 threads per solver
- Restrictions due to CPU frequency, cache and main memory

Vivification Overhead

SAT

UNSAT



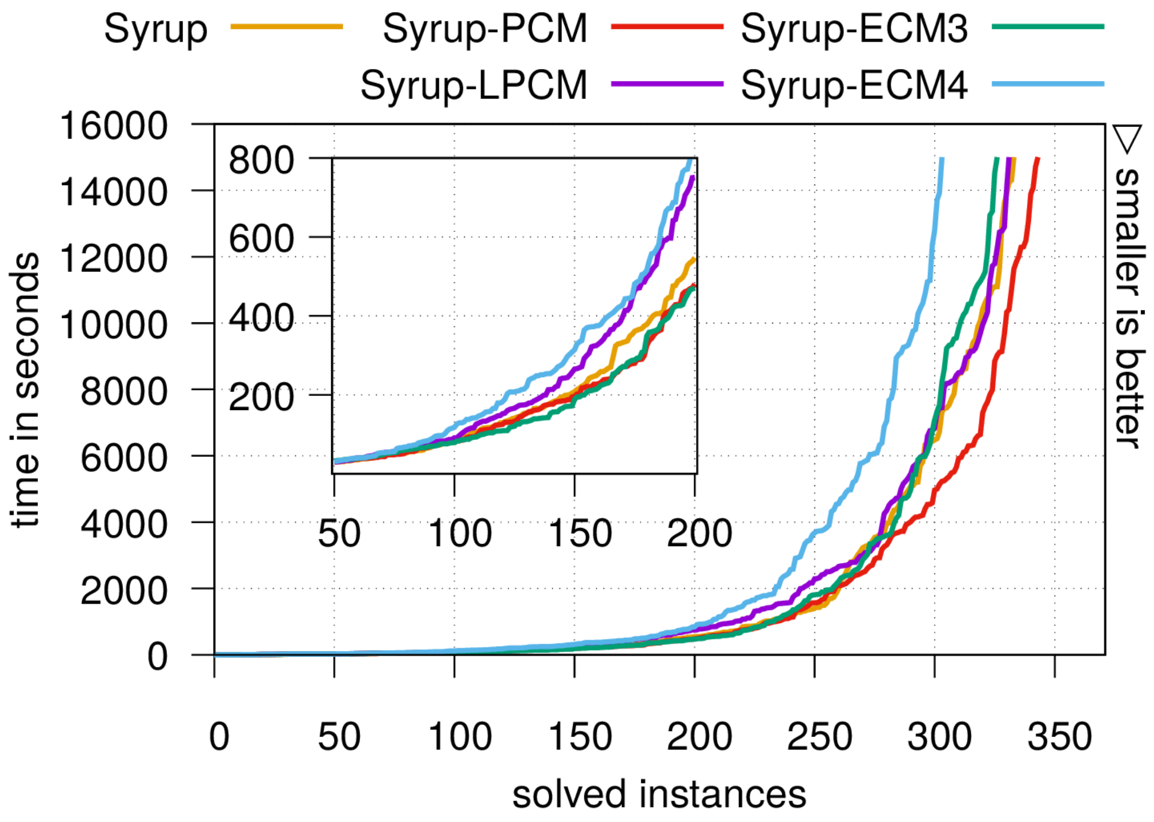
Propagation Overhead:

(L)PCM ≈ 10%
ECM3 ≈ 1%
ECM4 ≈ 4%
on average

Minimization success correlates with overhead:

(L)PCM ≈ 40%
ECM3 ≈ 6%
ECM4 ≈ 32%
on average

Syrup Runtime SAT



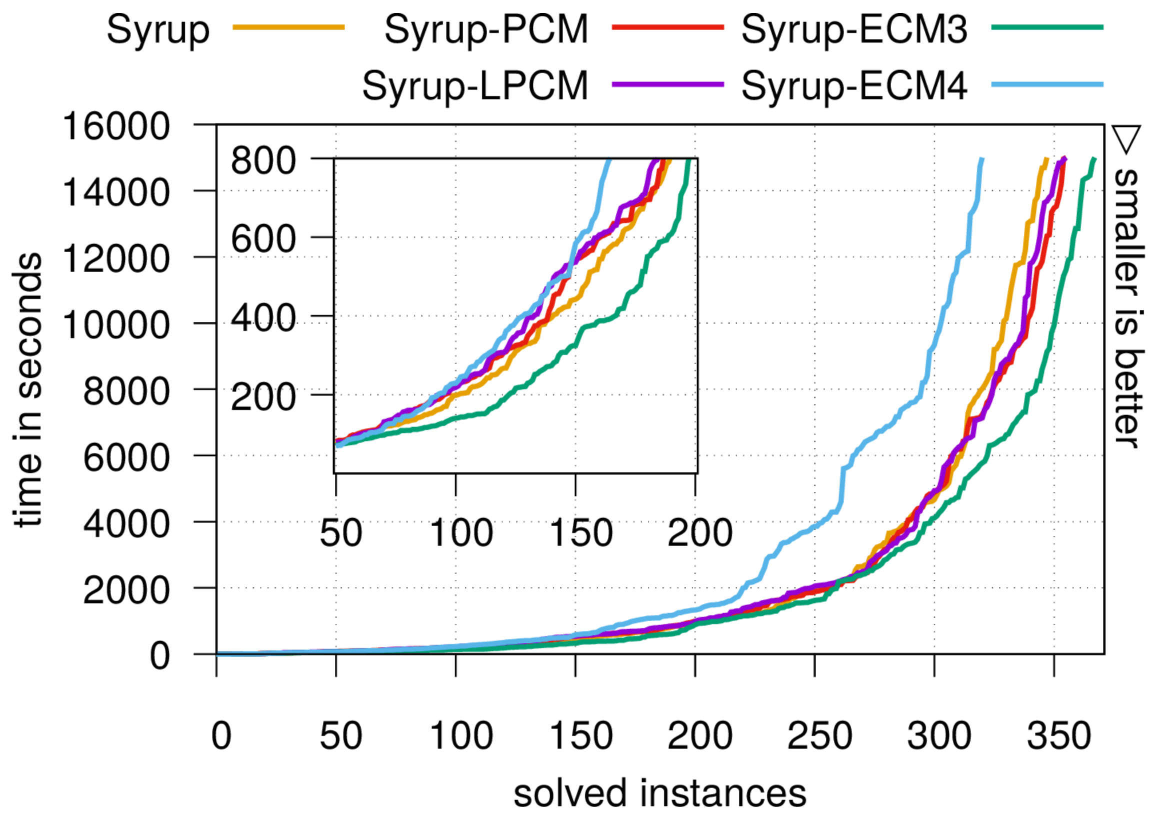
PCM increases SAT performance

Improvement to Syrup small for easy instances

Solved instances:

Syrup:	333
PCM:	**343**
LPCM:	331
ECM3:	326
ECM4:	302

Syrup Runtime UNSAT



Solved instances:

Syrup:	347
PCM:	355
LPCM:	355
ECM3:	**367**
ECM4:	321

- ECM increases overall UNSAT performance
- PCM, LPCM and ECM3 improve performance

Parallel CM Solver

TopoSAT2 – ECM

- Glucose 3.0 based ECM solver
- Direct clause export
- Copies of clauses are minimized and exported

→ Minimizations are not used by minimizing solver

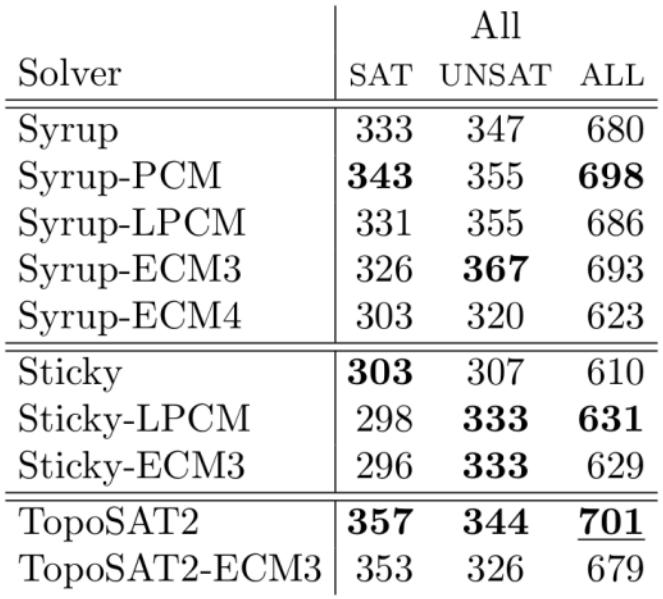
Sticky – LPCM, ECM

- Glucose 4.0 based solver with physical clause sharing
- No copy-sharing of clauses, only references are shared
- Adapted lazy clause sharing heuristic

SAT Competition Results

Results SC'16 (application track), SC'17, SC'18 (main track)

- Overall increase through nearly every CM approach
- Syrup-PCM nearly closed gap to Toposat2
- LPCM and ECM3 decrease SAT but increase solved UNSAT instances more



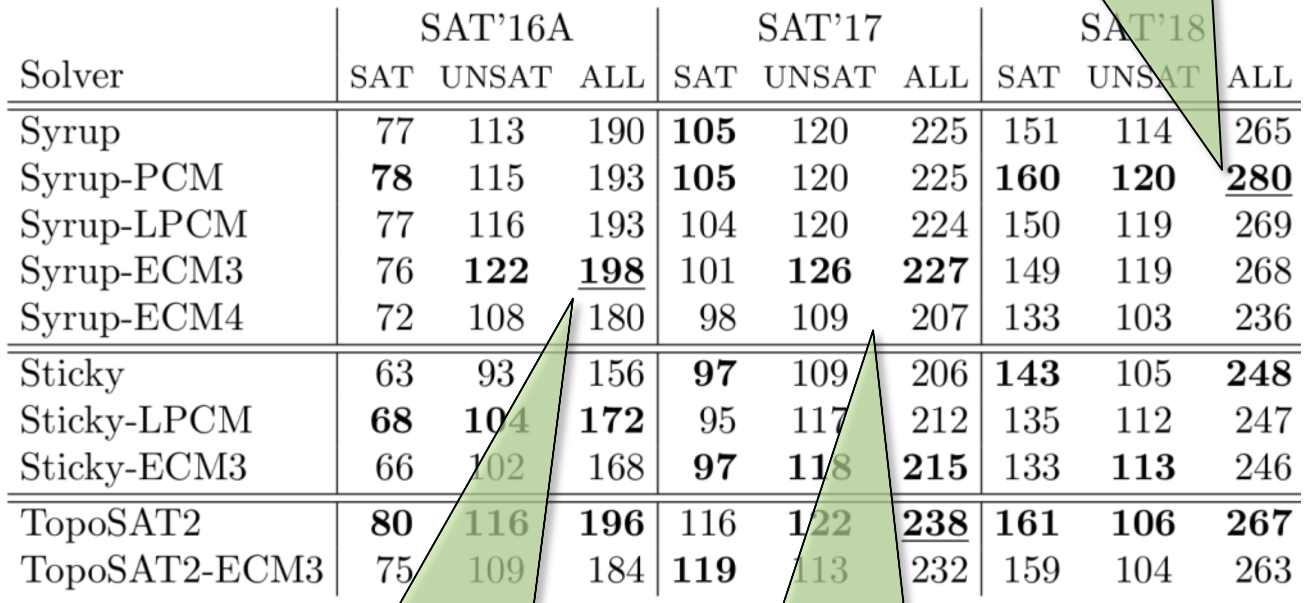
	All		
Solver	SAT	UNSAT	ALL
Syrup	333	347	680
Syrup-PCM	**343**	355	**698**
Syrup-LPCM	331	355	686
Syrup-ECM3	326	**367**	693
Syrup-ECM4	303	320	623
Sticky	**303**	307	610
Sticky-LPCM	298	**333**	**631**
Sticky-ECM3	296	**333**	629
TopoSAT2	**357**	**344**	**701**
TopoSAT2-ECM3	353	326	679

- TopoSAT2-ECM3 decrease:
  - No lazy export → missing activity filter for export → higher overhead
  - Minimizations not inserted in minimizing solver

SAT Competition Results

Single Competition Results

Syrup-PCM wins on SC’18 application track benchmarks



Solver	SAT'16A SAT	SAT'16A UNSAT	SAT'16A ALL	SAT'17 SAT	SAT'17 UNSAT	SAT'17 ALL	SAT'18 SAT	SAT'18 UNSAT	SAT'18 ALL
Syrup	77	113	190	**105**	120	225	151	114	265
Syrup-PCM	**78**	115	193	**105**	120	225	**160**	**120**	**280**
Syrup-LPCM	77	116	193	104	120	224	150	119	269
Syrup-ECM3	76	**122**	**198**	101	**126**	**227**	149	119	268
Syrup-ECM4	72	108	180	98	109	207	133	103	236
Sticky	63	93	156	**97**	109	206	**143**	105	**248**
Sticky-LPCM	**68**	**104**	**172**	95	117	212	135	112	247
Sticky-ECM3	66	102	168	**97**	**118**	**215**	133	**113**	246
TopoSAT2	**80**	**116**	**196**	116	**122**	**238**	**161**	**106**	**267**
TopoSAT2-ECM3	75	109	184	**119**	113	232	159	104	263

Syrup-ECM3 wins on SC’16 application track benchmarks

No real improvement on SC’17 benchmarks

Conclusion

- Homogeneous CM applicable for parallel solvers

  → Approaches solved 6 – 21 additional instances

- Sharing minimizations via link has no advantage

  → LPCM fewer solved instances than PCM

- More restrictive clause selection than in serial

  → ECM4 and TopoSAT2-ECM slow down
  → PCM/LPCM only succeed with LBD cut

- Prioritize:
  - Activity-based selection for SAT (PCM)
  - LBD-based selection for UNSAT (ECM)

References

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[3] Mao Luo, Chu-Min Li, Fan Xiao, Felip Many, and Zhipeng L. An effective learnt clause minimization approach for CDCL SAT solvers*, in IJCAI'17*

[4] Siert Wieringa and Keijo Heljanko. Concurrent clause strengthening, *in SAT'13*

[5] Michael Kaufmann, Stephan Kottler, Michael Kaufmann, and Stephan Kottler. SArTagnan – a parallel portfolio SAT solver with lockless physical clause sharing*, in POS'11*

[6] Gilles Audemard and Laurent Simon. Glucose and Syrup: Nine years in the SAT competitions, *in Proceedings of SAT Competition 2018*

[7] Thorsten Ehlers and Dirk Nowotka. Glucose hacks and TOPOSAT2 description, *in Proceedings of SAT Competition 2018*

Questions?

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