Revisiting Clause Exchange in Parallel SAT Solving

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SAT framework

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- Lots of solvers are of type *Conflict driven clause learning* (CDCL)

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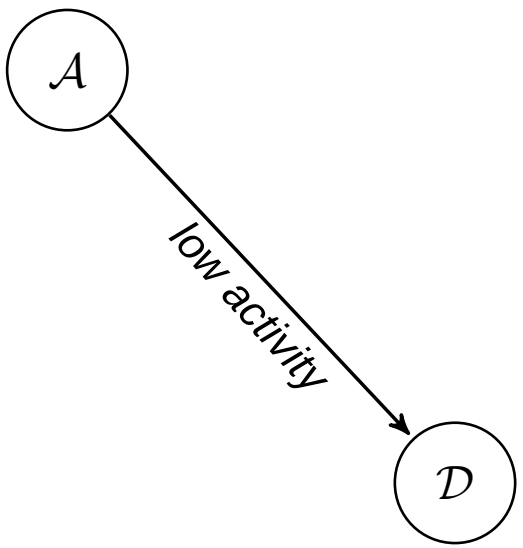
- CDCL creates one new clause at each conflict
- Restarts are quite frequent
- *Literal block distance* (*lbd*) provides a qualitative measure about learnt clauses (glucose)

Freezing learnt clauses

Classical learnt clause management

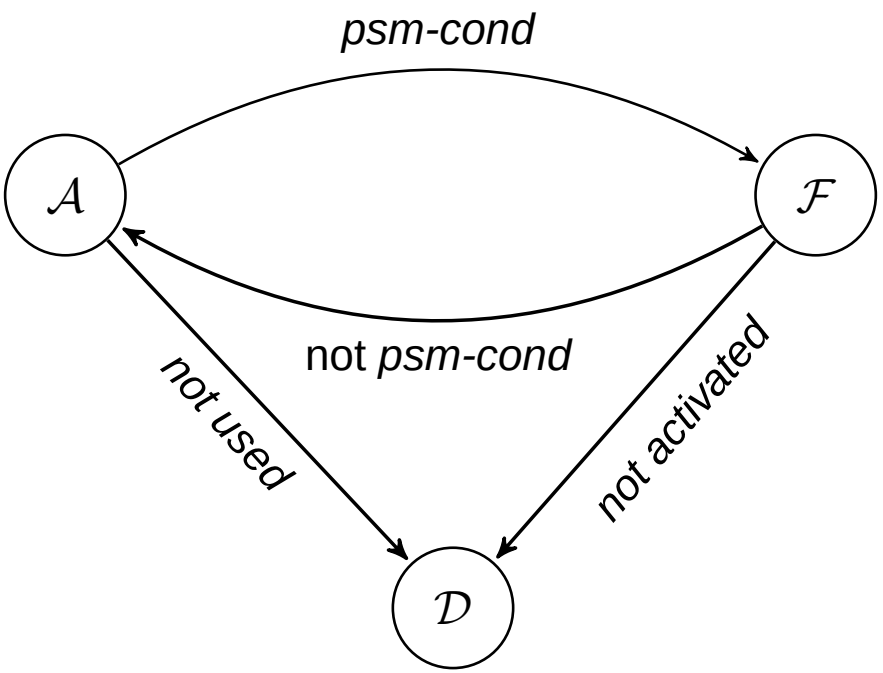
- $\mathcal{A}$: Set of active clauses (used in propagation)
- $\mathcal{D}$: Set of deleted clauses



Freezing learnt clauses

Freezing learnt clause management

- $\mathcal{A}$: Set of active clauses (used in propagation)
- $\mathcal{D}$: Set of deleted clauses
- $\mathcal{F}$: Set of frozen clauses



How can we solve SAT in parallel?

Two main approaches

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Divide and conquer

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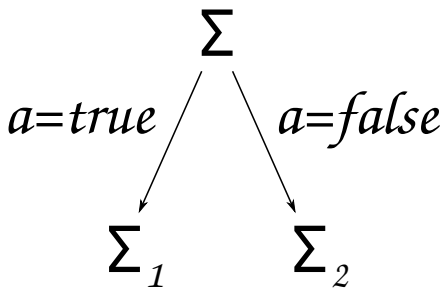

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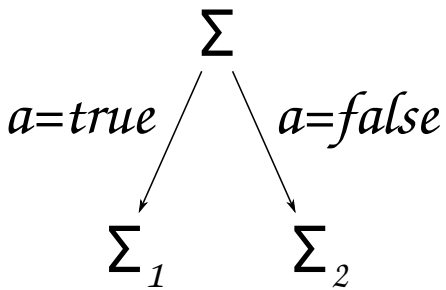

Portofolio

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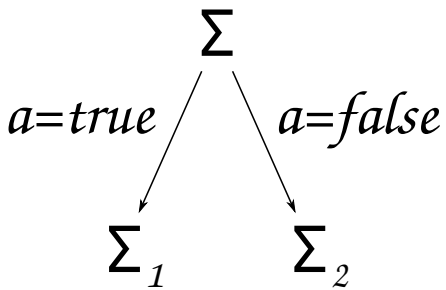
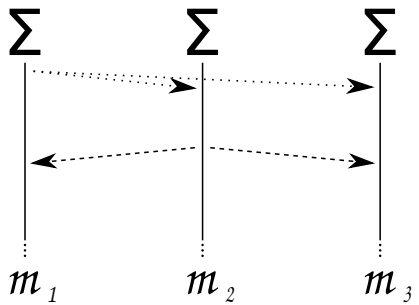


Portofolio



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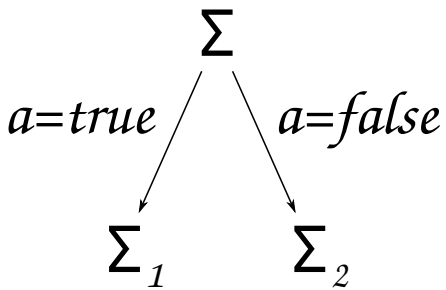

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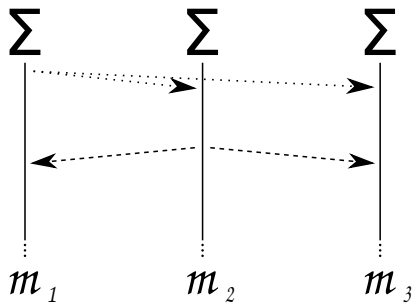

We will use the portofolio methodology

SAT competition 2011

ppfolio

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- run completely different state-of-the-art solvers in parallel

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Work needs to be done on communication

Good communication?

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To achieve good communication, we need to **maximize** the exchange of **useful** information, and **minimize** the **useless** information.

Communication in portofolio

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- Information = learnt clauses

Communication in portofolio

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- Information = learnt clauses
- What is a useful clause?

Communication in portofolio

Good communication

- Information = learnt clauses
- What is a useful clause?
- A useless clause is never used in propagation

New ratio

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- $\#\mathcal{I}_t - used(\mathcal{I}_t, t) - unused(\mathcal{I}_t, t)$ the number of clauses in the database that are neither used, nor deleted by thread t

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Usage ratio

$$\frac{\sum_{t=0}^{n} used(\mathcal{I}_t, t)}{\sum_{t=0}^{n} \#\mathcal{I}_t}$$

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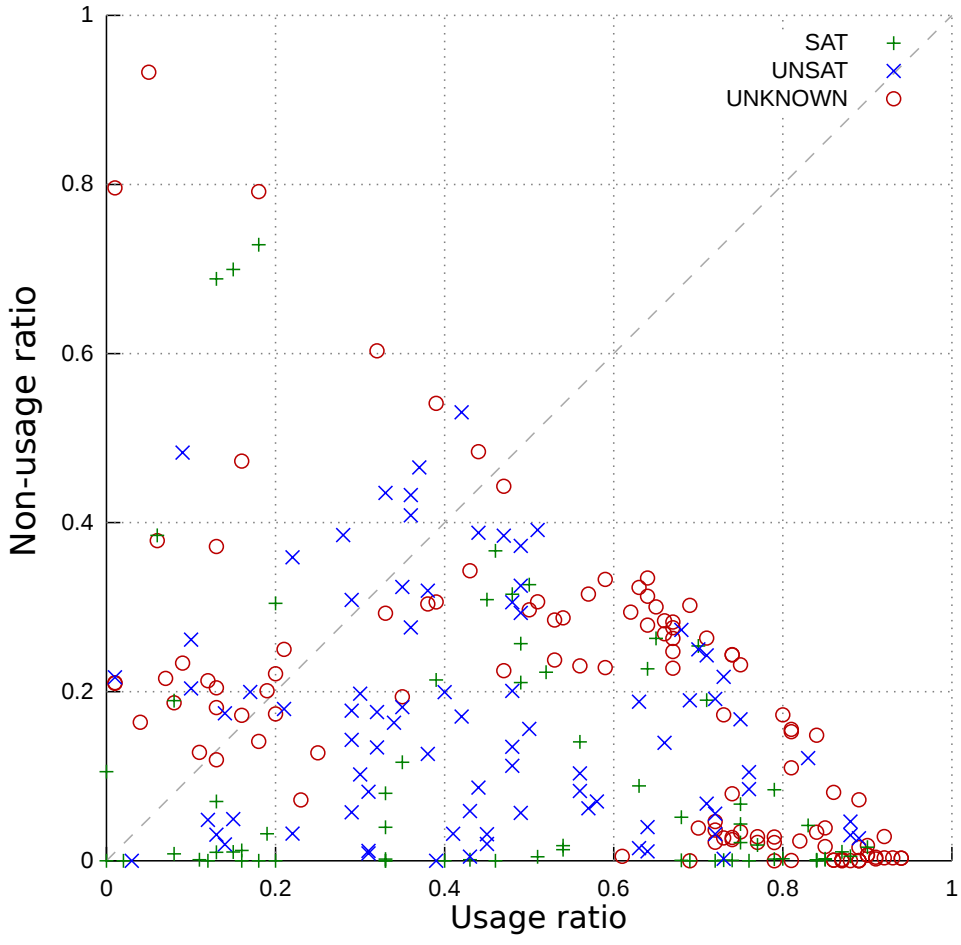
Non-usage ratio

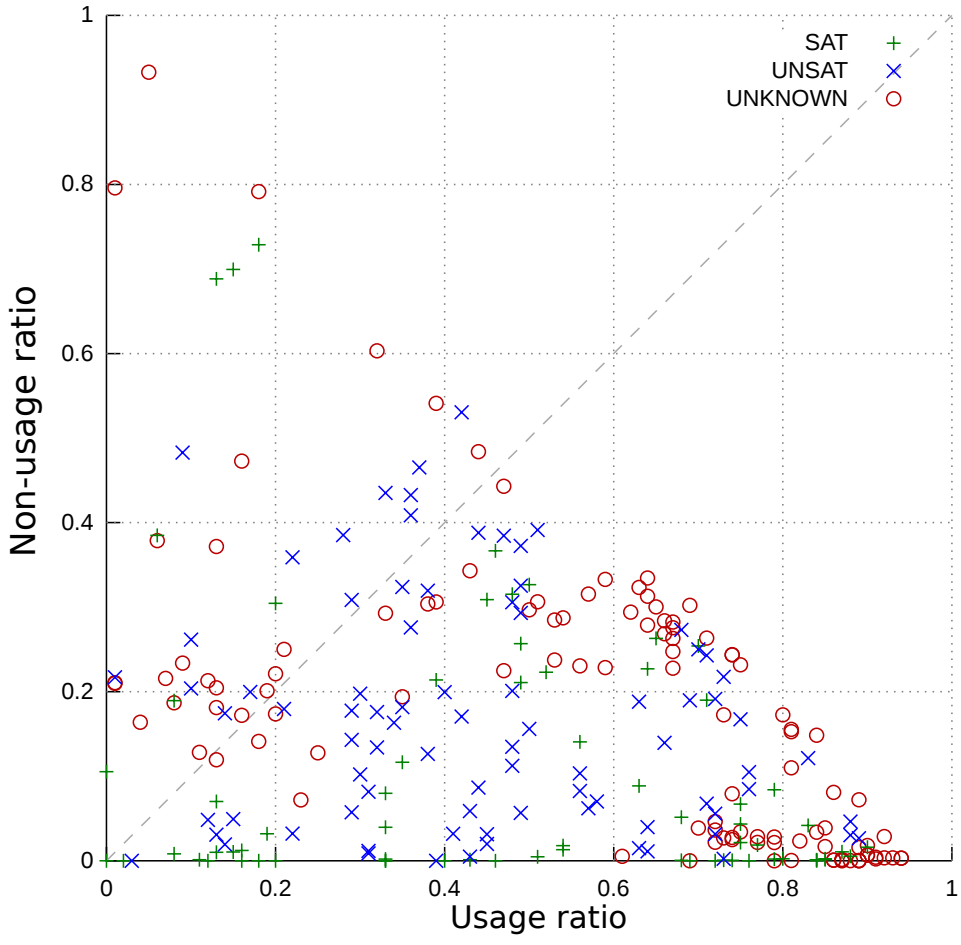
$$\frac{\sum_{t=0}^{n} unused(\mathcal{I}_t, t)}{\sum_{t=0}^{n} \#\mathcal{I}_t}$$

Classic manysat



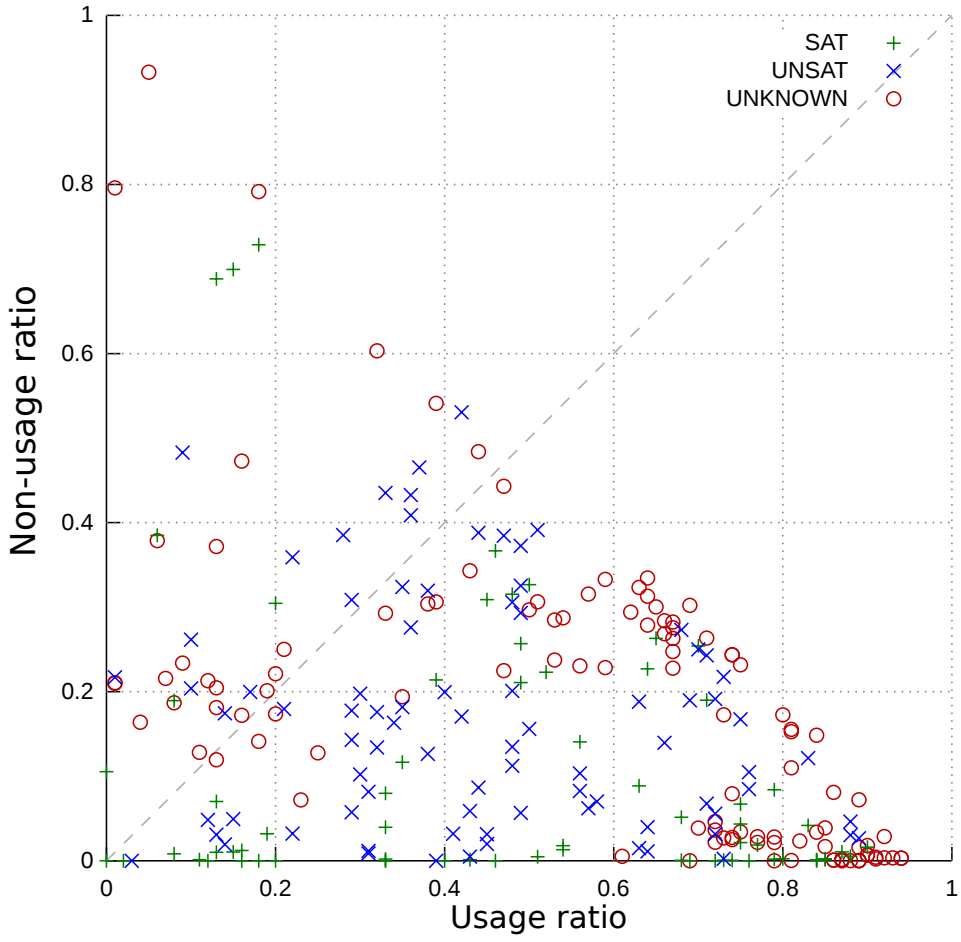
Classic manysat

- Ratio is good



Classic manysat

- Ratio is good
- A lot of imported clauses are not used but kept in memory



Challenges

Problems we must face

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Problems we must face

- Importation of duplicate information
- Imported clauses can be useless for the current search subspace
- Higher number of learnt clauses

Introducing PeneLoPe

We want to design a solver based on ManySat2.0 able to:

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Introducing PeneLoPe

We want to design a solver based on ManySat2.0 able to:

- handle all the learnt clauses
- communicate efficiently
- use every processor on the host

Freeze in parallel

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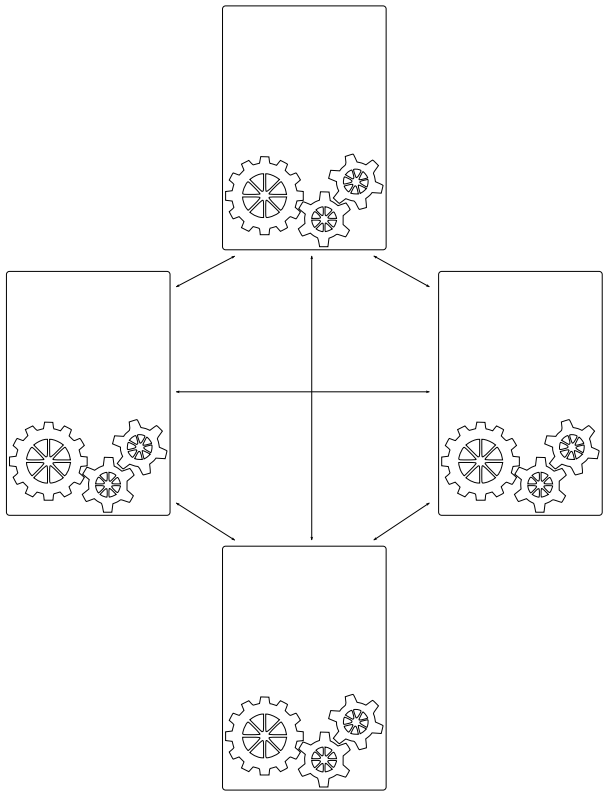
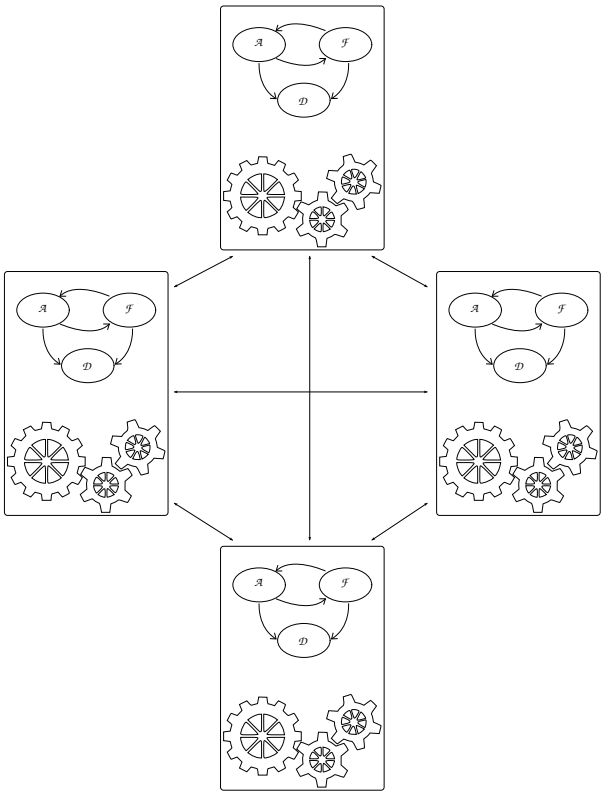


Freeze in parallel

- Each thread has its own sets



Import policy

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Import policy

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- No freeze

Affecting the ratio

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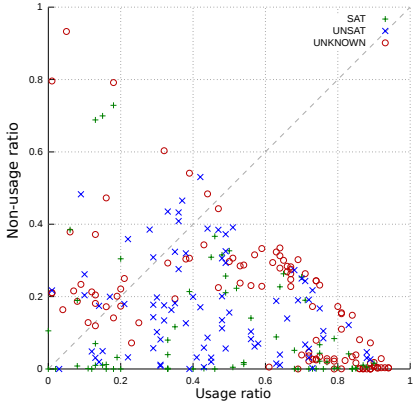

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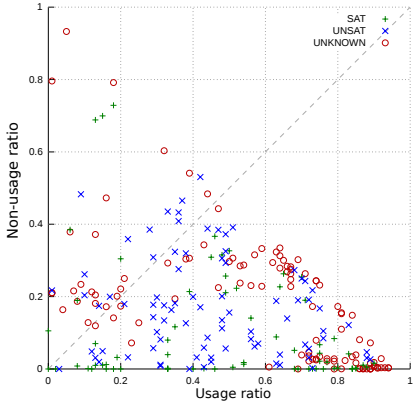
We could change the ratio by:

- Restart strategy



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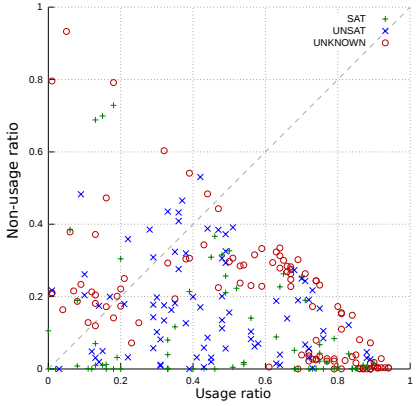

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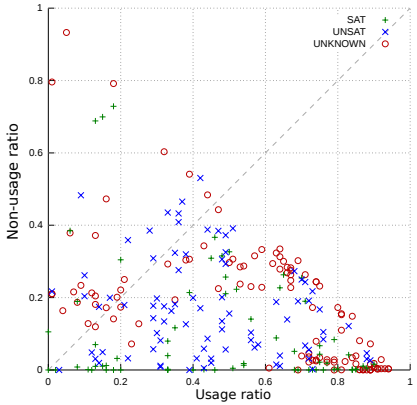

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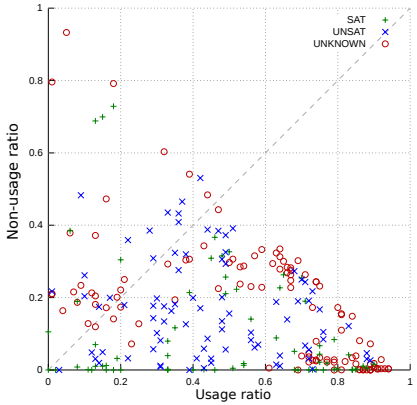

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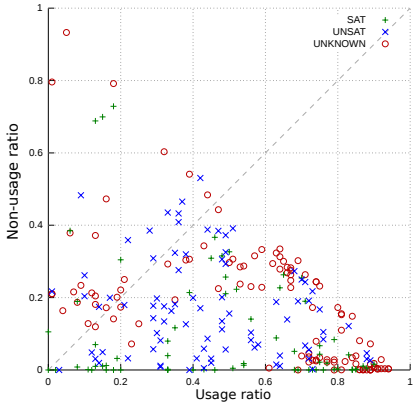

- Choosing what is exported
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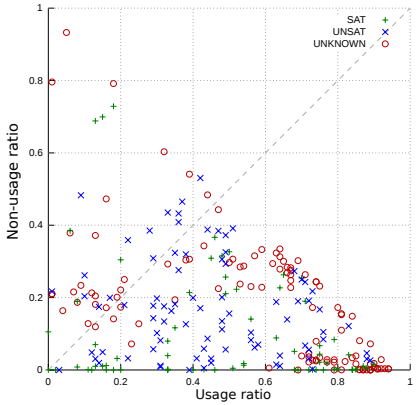

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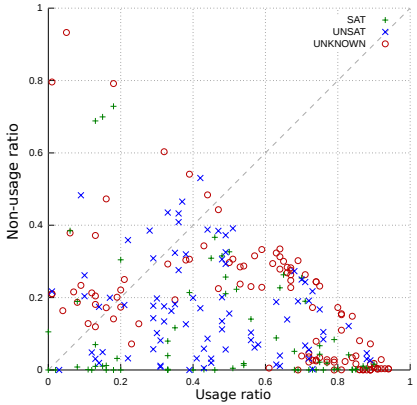

- Choosing what is exported
  - -Export every generated clauses
  - -Export clauses of size $\leq s$
  - -Export clauses with literal block distance $\leq l$

A closer look

SLN: size based export, luby restarts, no freeze at import
LLF: lbd based export, lbd restarts, freeze at import

instance	version	time	nb_i/nb_c	nb_i	nb_f	nb_u
hwmcc10-...	SLN	TO	1.34	7989	0%	35%
k50-eijkbs6669-tseitin	LLF	766	4.55	15299	10%	11%
AProVE07-21	SLN	10	1.06	83	0%	35%
	LLF	31	3.53	506	89%	9%

nb_c: number of conflicts (in thousands)
nb_i: number of imported learnt clauses (in thousands)
nb_f: the percentage of learnt clauses frozen at the import
nb_u: the percentage of used learnt clauses

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Manysat	95	93	188
PeneLoPe			

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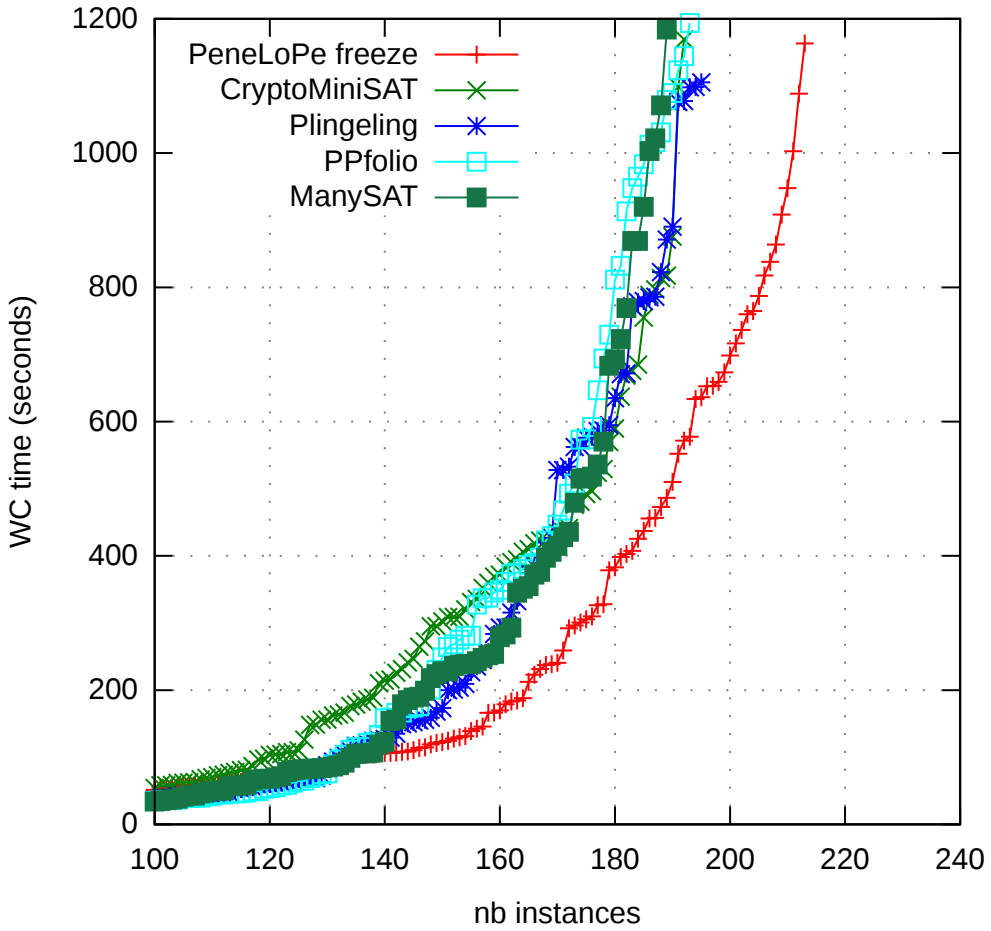
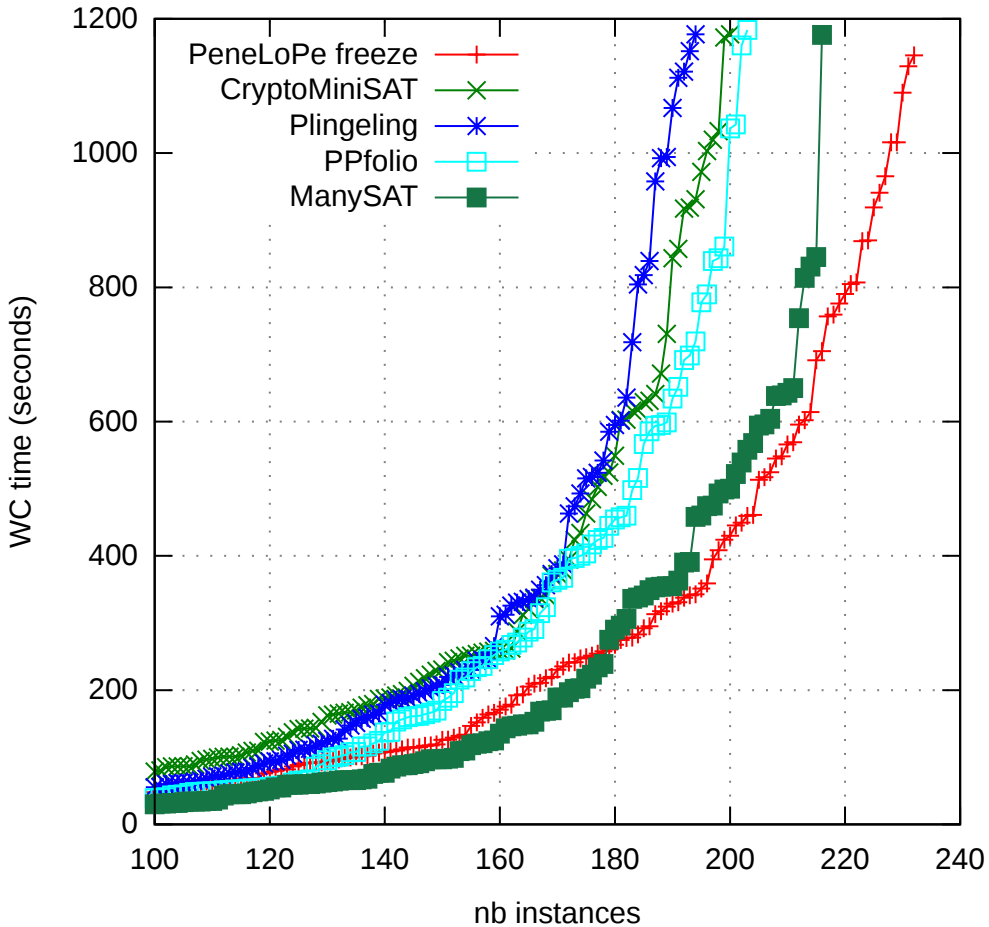
Comparison with other solvers (8 cores)



Scaling up to 32 cores



Conclusion

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- We need to pay attention to clause exchange technique
- The prototype is highly competitive
- We can expend the orthogonality of the threads by using different techniques for each thread

Thank you for your attention

Questions?

Some comparisons

psm used	export strategy	restart strategy	import strategy	#SAT	#UNSAT	#SAT + #UNSAT
✓	*lbd limit*	*lbd*	*no freeze*	94	111	**205**
✓	*lbd limit*	*lbd*	*freeze*	89	**113**	202
✓	*size limit*	*lbd*	*freeze*	93	107	200
✓	*size limit*	*lbd*	*no freeze*	89	107	196
✓	*size limit*	*luby*	*no freeze*	**97**	98	195
✓	*lbd limit*	*lbd*	*freeze all*	89	102	191
✓	*size limit*	*luby*	*freeze all*	96	92	188
✓	*unlimited*	*lbd*	*freeze*	86	102	188
✓	*size limit*	*luby*	*freeze*	92	96	188
✓	*lbd limit*	*luby*	*freeze*	91	97	188
manysat	-	-	-	95	93	188
✓	*lbd limit*	*luby*	*no freeze*	90	94	184
✓	*unlimited*	*luby*	*freeze*	91	92	183
	size limit	*luby*	*no freeze*	92	90	182
✓	*unlimited*	*luby*	*no freeze*	89	88	177
✓	*size = 1*	*lbd*	*freeze*	89	88	177

8 cores details

Solver	#SAT	#UNSAT	#SAT+#UNSAT
PeneLoPe *freeze*	97	**119**	**216**
PeneLoPe *no freeze*	96	**119**	215
plingeling	**99**	97	196
ppfolio	91	103	194
cryptominisat	89	104	193
ManySat	95	92	187

32 cores details

Solver	#SAT	#UNSAT	#SAT+#UNSAT
PeneLoPe *freeze*	104	127	**231**
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ManySat	105	111	216
ppfolio	**107**	97	204
cryptominisat	96	105	201
plingeling	100	95	195

Literal block distance

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Definition

Given a clause $\mathcal{C}$, and a partition of its literals into n subsets according to the current assignment, s.t. literals are partitioned w.r.t their decision level. The *lbd* of $\mathcal{C}$ is exactly n.

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lbd restarts

Avg_s is the average of *lbd* of the clauses created since the start of the process. Avg_{100} is the average of *lbd* over the last 100 created clauses. Restarts when $Avg_{100} \times \alpha \geq Avg_s$, $\alpha = 0.7$