

GP-SAT: a Framework for Parallel SAT Solving

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Université Paris Nanterre, France



MeFoSyLoMa – March 31, 2017

Context

How does it work?

- **Input** : a boolean logic formula
- **Output** : SAT (+ solution) or UNSAT

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- Theorem proving
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- Artificial intelligence
- **Model checking**
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SAT is **NP-complete** [Coo71]

CPU greedy + low memory consumption → parallelization.

My objective is to improve the parallelization of SAT solving.

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φ is a formula in **conjunctive normal form** (CNF).

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When is φ SAT?

- $\varphi = \text{true}$ iff $\forall \omega \in \varphi, \omega = \text{true}$
- $\omega = \text{true}$ iff $\exists l \in \omega, l = \text{true}$

Naive approach

$$\varphi = \omega_1 \wedge \omega_2 \wedge \omega_3 \wedge \omega_4 \wedge \omega_5 \wedge \omega_6$$

- $\omega_1 = \{x_1, x_2, x_3, x_4\}$
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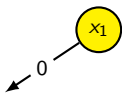
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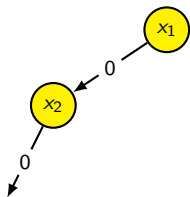
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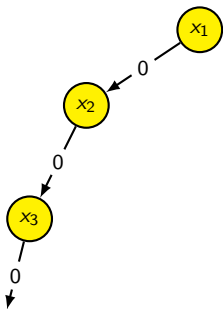
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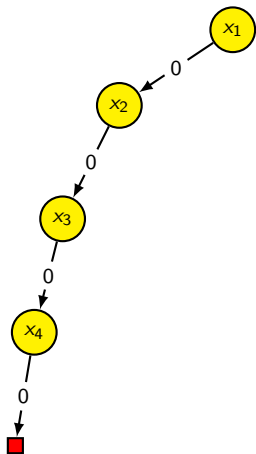
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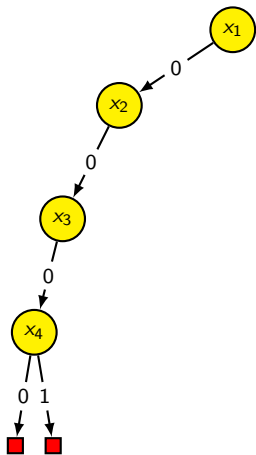
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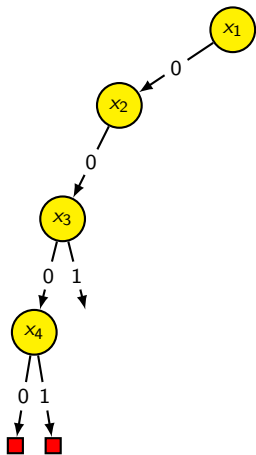
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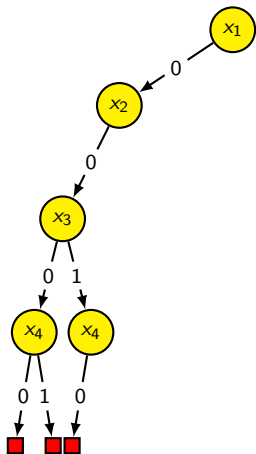
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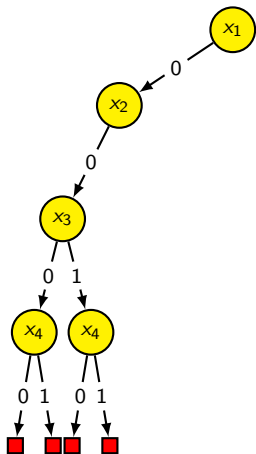
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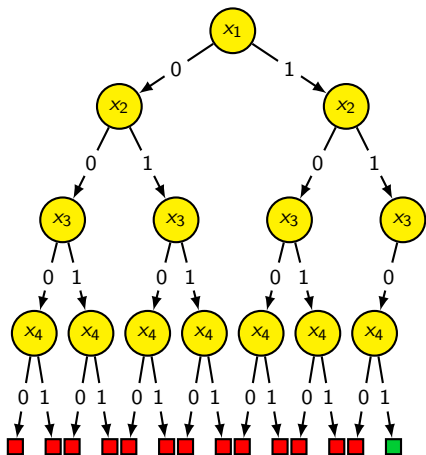
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Sequential Resolution

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- Davis, Putnam, Logemann, and Loveland (**DPLL**) [DP60, DLL62]
- Conflict Driven Clause Learning (**CDCL**) [MSS⁺99, ZMMM01]
 - Derived from DPLL

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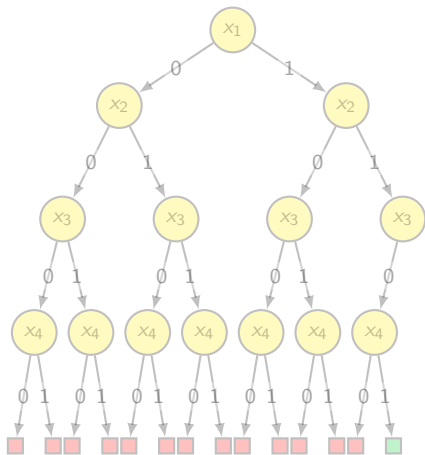
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Efficiency in practice

- Unit propagation
- Decision and polarity
- Clause learning
- Restart
- Preprocessing

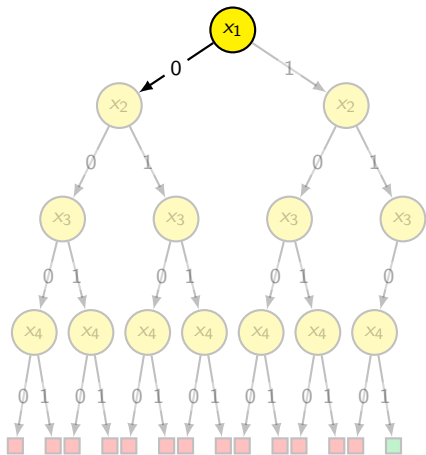
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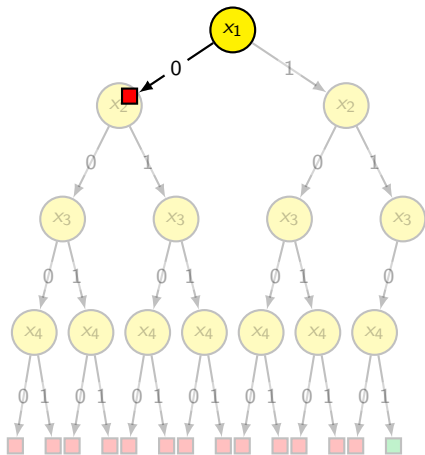
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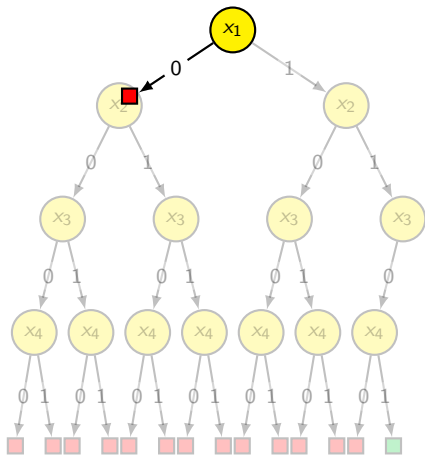
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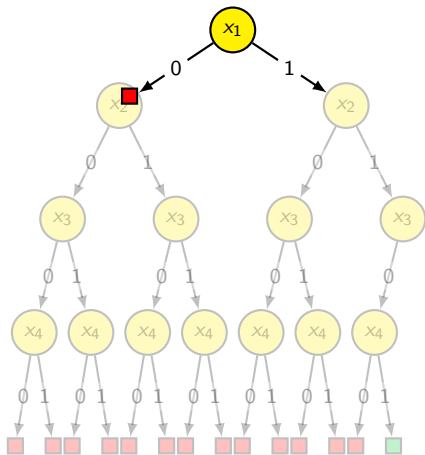
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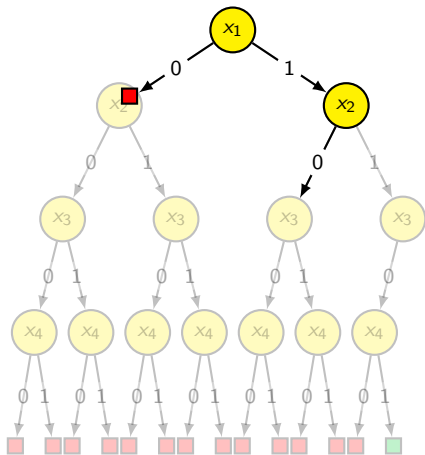
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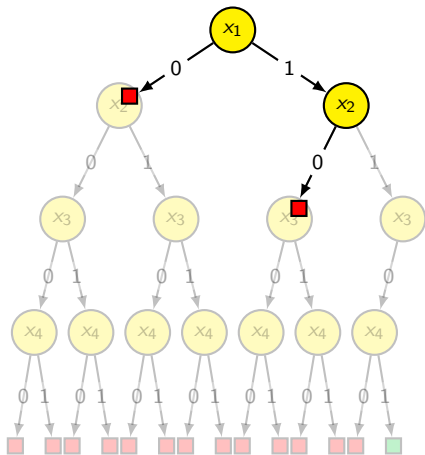
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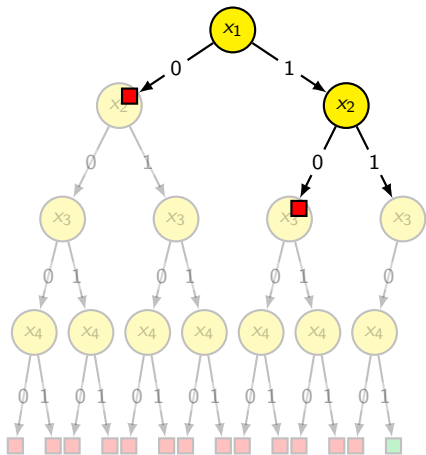
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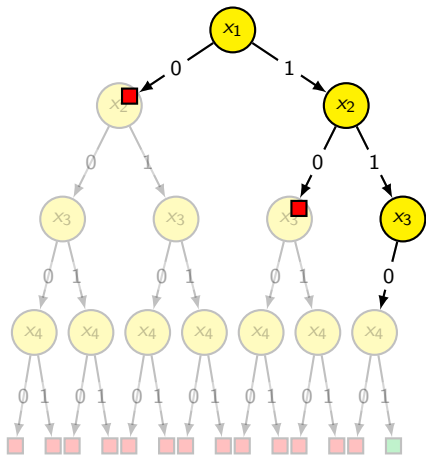
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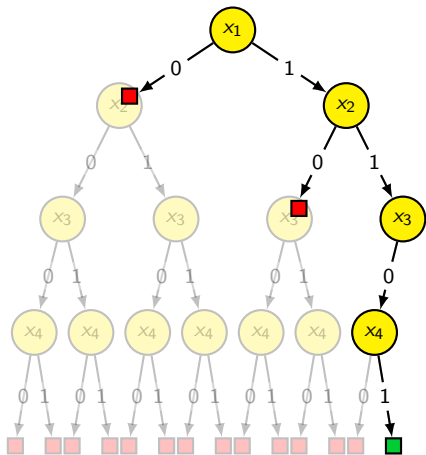
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Polarity

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- **Phase saving** [PD07]:
 - Each assignment is stored
 - The polarity used is the one stored
 - Functions as a cache

Parallel Resolution

Motivations

- Bigger and bigger instances
- No more faster CPU
- Multicore architectures

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State of the art solutions

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| Parallel propagation [HW12] | Formula decomposition [HMSW11] |

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SAT Competition 2016

| Rank | Name | Type |
|------|---------------------|------|
| 1 | treengeling | DC |
| 2 | plingeling | PF |
| 3 | cmsat5_run_parallel | PF |
| 4 | glucose-syrup | PF |
| 5 | cbpenelope | PF |
| 6 | csspenelope | PF |
| 7 | penelope_48 | PF |
| 8 | Priss | PF |
| 9 | tbParaGlueminisat | PF |
| 10 | gluco_par | PF |
| 11 | ampharos-sat | DC |

State of the art solutions



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worker: sequential solver + workflow

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Multiple workers competing on the entire search space [HJS09]

- Diversification and intensification

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| Worker search spaces | same | different |
| Scalable | no* | yes |
| Easy to implement | yes | no |

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Possible contributions:

There also exist **hybrid approaches** (more complex).

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- Choose workers allowed to communicate [LHJS12].

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Possible contributions:

Which clauses should be exchanged? And between which workers?

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Problem 3

- An implementation → single composition policy
- New heuristic × other mechanisms → difficult

Example of using GP-SAT

A **generic**, **modular**, and **efficient** framework to build parallel SAT solvers.

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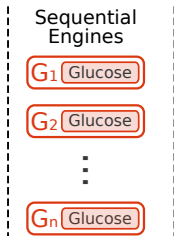
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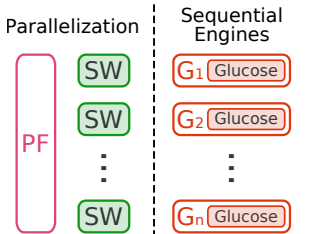
- glucose-syrup [AS14]
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Example of using GP-SAT

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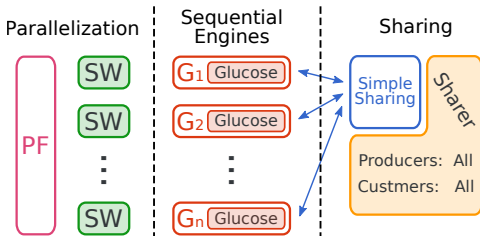
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Example of using GP-SAT

A **generic**, **modular**, and **efficient** framework to build parallel SAT solvers.

- glucose-syrup [AS14]
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 - All to all



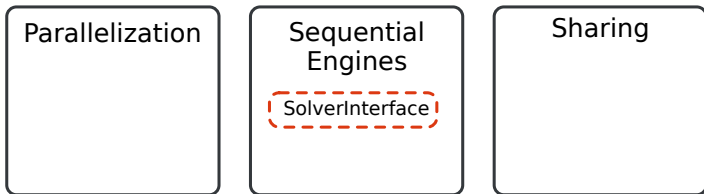
Architecture of GP-SAT

Parallelization

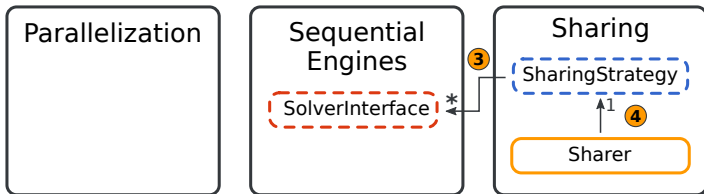
Sequential
Engines

Sharing

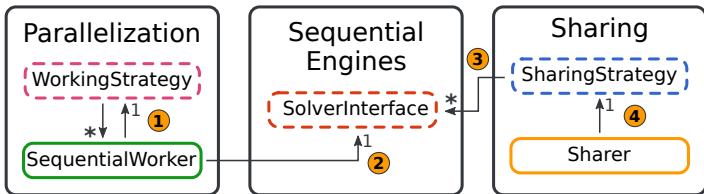
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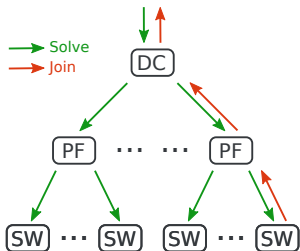
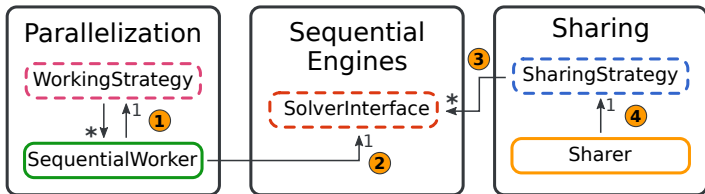
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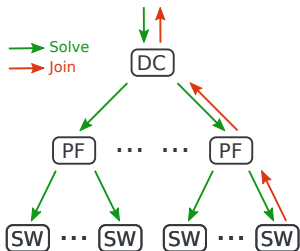
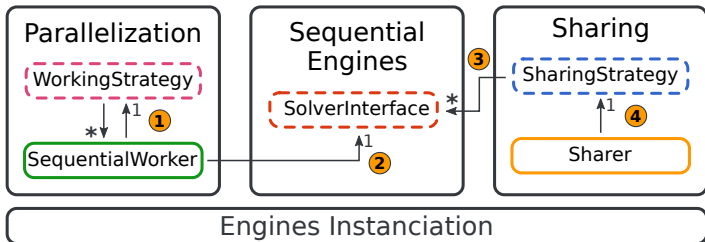


Architecture of GP-SAT



Exemple of a
Divide-and-Conquer of
Portfolio.

Architecture of GP-SAT



Exemple of a
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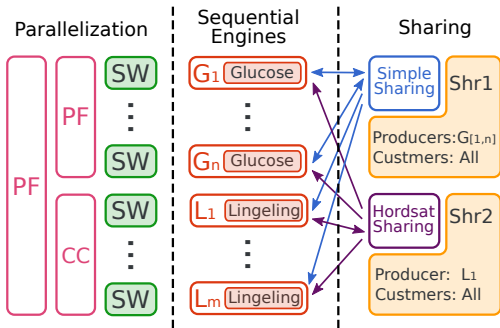
Others Implementations using GP-SAT

- Hordesat [BSS15]: Lingeling [Bie16] + Portfolio + special sharing.
- Treengeling [Bie16]: Lingeling + Cube-and-Conquer + simple sharing of units.

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Solver mixing all the strategies.



Experiments & Results

Parameters

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memory: 500 Go
#cores: 36
#instances: 100 (SAT Race 2015)
#run(s): 1
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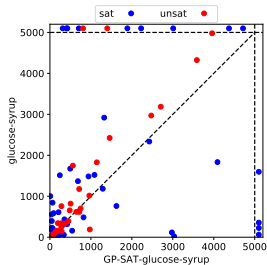
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|----------------|-----|-------|-----|
| glucose-syrup | 71 | 30 | 41 |
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Dots over the line are good ones.

Experiments & Results

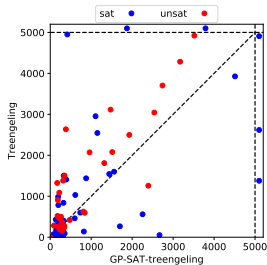
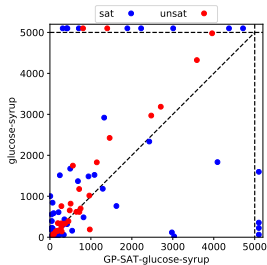
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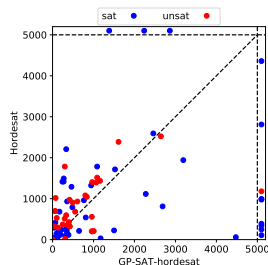
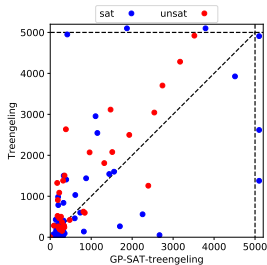
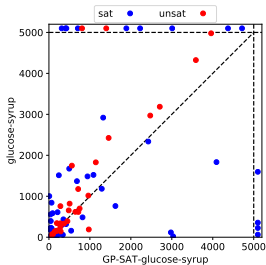
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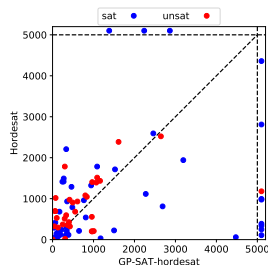
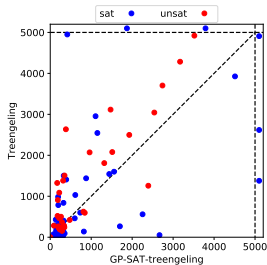
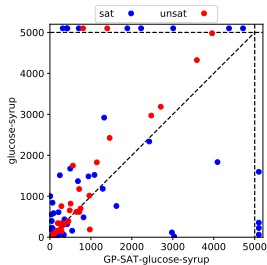
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Conclusion & Perspectives

- GP-SAT is **modular** and **generic**.
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- Bench with more instances (SAT Competition 2016).
- Toward a more generic architecture.
- **Implementing more strategies to test the architecture.**
- **Participating to the SAT Competition 2017.**
- **Use GP-SAT for our own contributions.**

Thank you!



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Clause Learning

Let $x_1 = 0$, $x_4 = 0$, $x_8 = 1$ be the reasons of a conflict.

$$\varphi \equiv \varphi \wedge \omega_{\text{learnt}}, \text{ where } \omega_{\text{learnt}} = \{x_1, x_4, \neg x_8\}$$

Problem

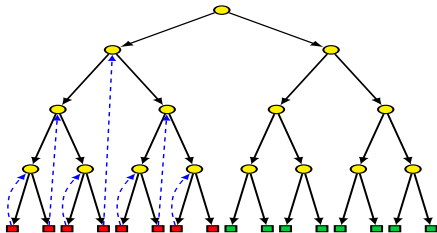
Too many clauses are learnt
→ not all of them can be kept.

Selection criteria

- Activity: keep clauses used for propagation/conflict resolution.
- Size: longer clauses are less used for propagation.
- **Literal Block Distance (LBD)** [AS09]:
 - number of decision level gathered by a clause.

Restart

Motivations



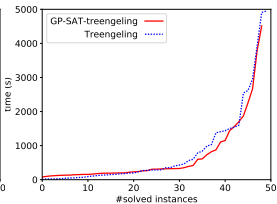
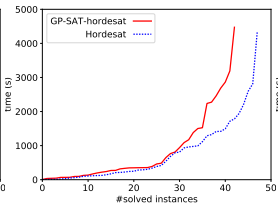
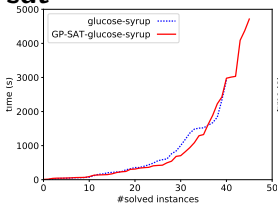
Escape from hard zones
(heavy-tailed) [BHvM09].

Strategies

- #conflicts: arithmetic, geometric, Luby progressions.
- Progress saving: prevents from softness.
- **Average LBD**: are we in a good region for learning?
- **SAT/UNSAT**: are we close to find a solution?

Cactus Plots

sat



unsat

