A New Variable Ordering for In-processing Bounded Variable Elimination in SAT Solvers

Shuolin Li[1],Chu-Min Li[1,2],Mao Luo[3],Jordi Coll[4],Djamal Habet[1],Felip Manyà[4]

[1]Aix Marseille Univ, Université de Toulon, CNRS, LIS, Marseille, France
[2]Université de Picardie Jules Verne, Amiens, France
[3]Hubei University of Technology, Wuhan, China
[4]Artificial Intelligence Research Institute, CSIC, Bellaterra, Spain

October 18, 2023

OUTLINE

Background

WHAT'S SAT?

- variable : $x_1, x_2, x_3, x_i \in \{0, 1\}$
- literal : $x_1, \overline{x}_1, x_2, \overline{x}_2, x_3, \overline{x}_3$
- clause : $(\overline{x}_1), (x_1 \vee x_2 \vee x_3), (\overline{x}_2), (x_2 \vee \overline{x}_3)$
- SAT formula : $(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)$

short : $\overline{x}_1 \wedge x_1 x_2 x_3 \wedge \overline{x}_2 \wedge x_2 \overline{x}_3$

$$\boxed{(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)}$$

WHAT'S SAT?

- variable : $x_1, x_2, x_3, x_i \in \{0, 1\}$
- literal : $x_1, \overline{x}_1, x_2, \overline{x}_2, x_3, \overline{x}_3$
- clause : $(\overline{x}_1), (x_1 \vee x_2 \vee x_3), (\overline{x}_2), (x_2 \vee \overline{x}_3)$
- SAT formula : $(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)$

short : $\overline{x}_1 \wedge x_1 x_2 x_3 \wedge \overline{x}_2 \wedge x_2 \overline{x}_3$

solving SAT: trying to find an assignment that satisfies all clauses in the formula.

$$\boxed{(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)}$$

WHAT'S SAT?

- variable : $x_1, x_2, x_3, x_i \in \{0, 1\}$
- literal : $x_1, \overline{x}_1, x_2, \overline{x}_2, x_3, \overline{x}_3$
- clause : $(\overline{x}_1), (x_1 \vee x_2 \vee x_3), (\overline{x}_2), (x_2 \vee \overline{x}_3)$
- SAT formula : $(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)$

  short : $\overline{x}_1 \wedge x_1 x_2 x_3 \wedge \overline{x}_2 \wedge x_2 \overline{x}_3$

solving SAT: trying to find an assignment that satisfies all clauses in the formula.

$\boxed{(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)}$ Unsatisfiable.

WHAT'S SAT?

- variable : $x_1, x_2, x_3, x_i \in \{0, 1\}$
- literal : $x_1, \overline{x}_1, x_2, \overline{x}_2, x_3, \overline{x}_3$
- clause : $(\overline{x}_1), (x_1 \vee x_2 \vee x_3), (\overline{x}_2), (x_2 \vee \overline{x}_3)$
- SAT formula : $(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)$

  short : $\overline{x}_1 \wedge x_1 x_2 x_3 \wedge \overline{x}_2 \wedge x_2 \overline{x}_3$

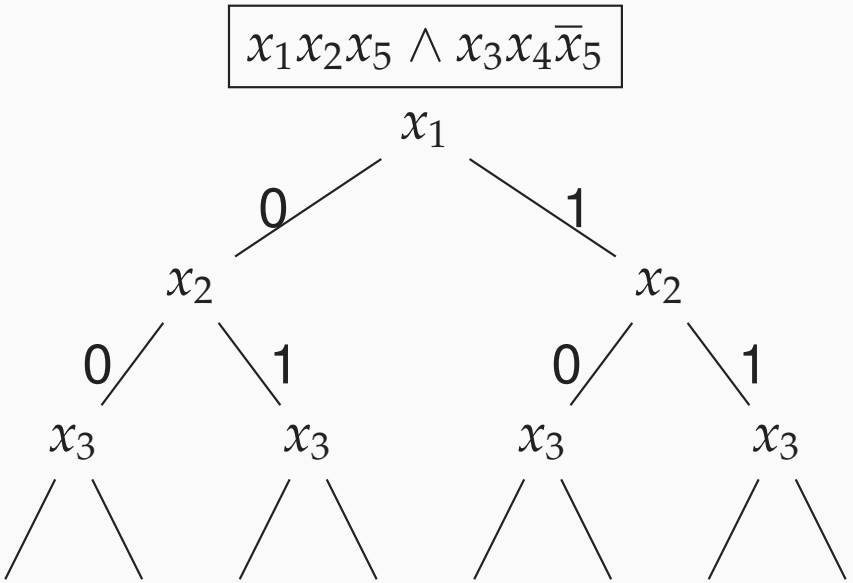
solving SAT: trying to find an assignment that satisfies all clauses in the formula.

$(\overline{x}_1) \wedge (x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)$ Unsatisfiable.

$(x_1 \vee x_2 \vee x_3) \wedge (\overline{x}_2) \wedge (x_2 \vee \overline{x}_3)$ Satisfiable.

How to Solve?

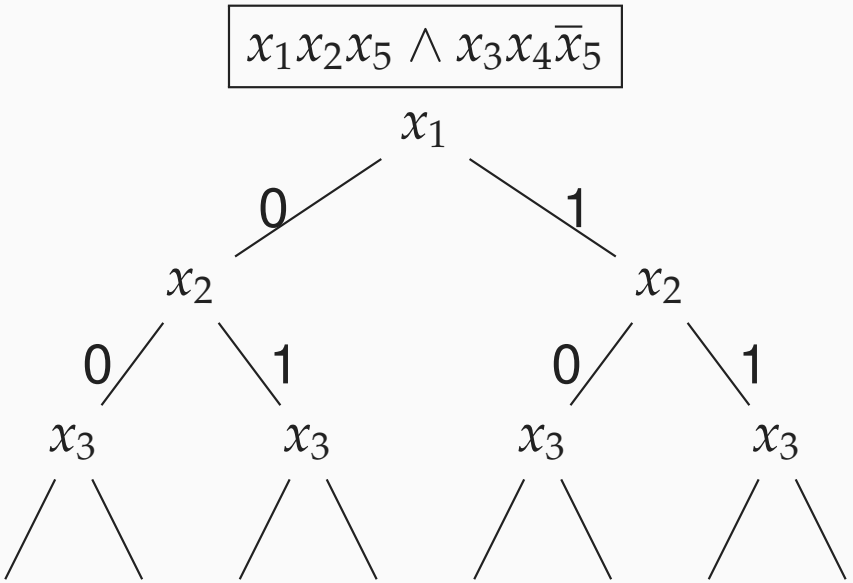
- Exhaustive Method



For a SAT formula with n variables, we need to check 2^n assignments at the worst case.

How to Solve?

- Exhaustive Method



For a SAT formula with n variables, we need to check 2^n assignments at the worst case.

That's too much!

How to Solve?

- Resolution Rule

$$(x \vee l_1 \vee l_2 \vee \ldots \vee l_n)$$
$$(\overline{x} \vee l'_1 \vee l'_2 \vee \ldots \vee l'_m)$$
$$\Downarrow$$
$$(l_1 \vee l_2 \vee \ldots \vee l_n \vee l'_1 \vee l'_2 \vee \ldots \vee l'_m)$$

How to Solve?

- Resolution Rule

$$(x \vee l_1 \vee l_2 \vee \ldots \vee l_n)$$
$$(\overline{x} \vee l'_1 \vee l'_2 \vee \ldots \vee l'_m)$$
$$\Downarrow$$
$$(l_1 \vee l_2 \vee \ldots \vee l_n \vee l'_1 \vee l'_2 \vee \ldots \vee l'_m)$$

Which variable should be resolved on first?

$$xx_1x_2 \wedge \overline{x}x_1x_2 \wedge \overline{x}_1x_3 \wedge \overline{x}_2x_4 \wedge \overline{x}_5x \wedge \overline{x}_6\overline{x} \wedge \overline{x}_3x_5x \wedge \overline{x}_4x_5x \wedge \overline{x}_3x_6\overline{x} \wedge \overline{x}_4x_6\overline{x}$$

Resolved on x_1: we get xx_2x_3, $\overline{x}x_2x_3$
Resolved on x_2: we get xx_1x_4, $\overline{x}x_1x_4$
Resolved on x_3: we get $\overline{x}_1x_5x$, $\overline{x}_1x_6\overline{x}$
...

Resolution driven by variable elimination

$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

Resolution driven by variable elimination

$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

$$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$$

Resolution driven by variable elimination

$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

$$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_3 x_4 \wedge \overline{x} x_3 x_4$$

Resolution driven by variable elimination

$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

$$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_3 x_4 \wedge \overline{x} x_3 x_4$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_4 x_5 x \wedge \overline{x}_4 x_6 \overline{x} \wedge x_4 x_5 x \wedge x_4 x_6 \overline{x}$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge x_5 x \wedge x_6 \overline{x}$$

$$\overline{x}_6 \overline{x} \wedge x_6 \overline{x} \wedge x$$

$$x \wedge \overline{x}$$

$\square$ Conflict happens.

Conflict: Clauses x and $\overline{x}$ can't be satisfied at the same time, a conflict happens.

Resolution driven by variable elimination

$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$

$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$

$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_3 x_4 \wedge \overline{x} x_3 x_4$

$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_4 x_5 x \wedge \overline{x}_4 x_6 \overline{x} \wedge x_4 x_5 x \wedge x_4 x_6 \overline{x}$

$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge x_5 x \wedge x_6 \overline{x}$

$\overline{x}_6 \overline{x} \wedge x_6 \overline{x} \wedge x$

$x \wedge \overline{x}$

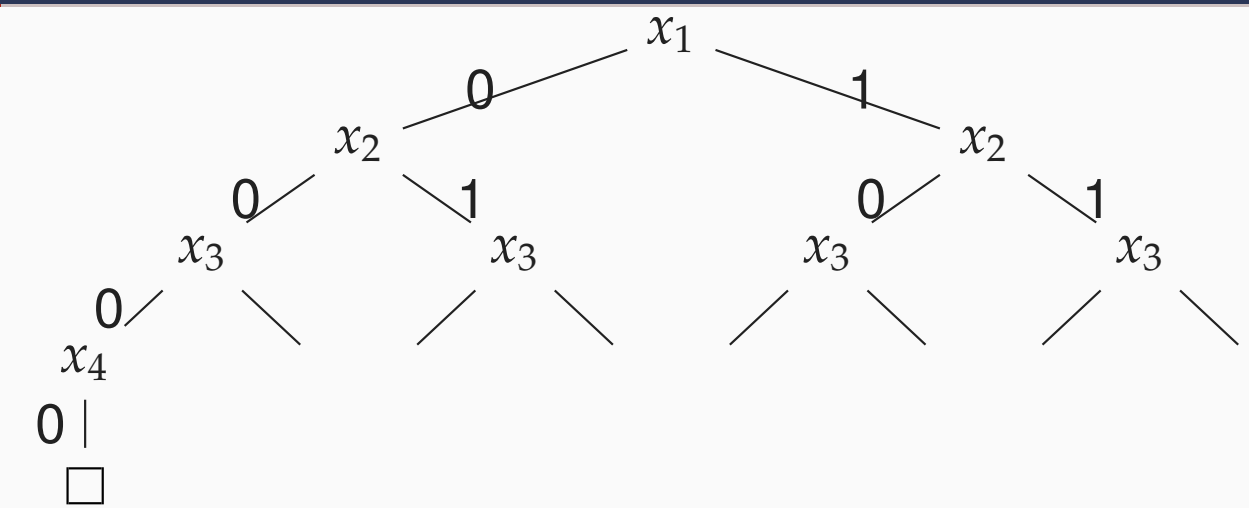
$\square$ Conflict happens.

Conflict: Clauses x and $\overline{x}$ can't be satisfied at the same time, a conflict happens.

If the original formula is unsatisfiable, we will absolutely get an empty clauses by doing resolution[Robinson, 1965].

RESOLUTION DRIVEN BY CONFLICT

$x_1x_2x_5 \wedge x_3x_4\overline{x}_5$

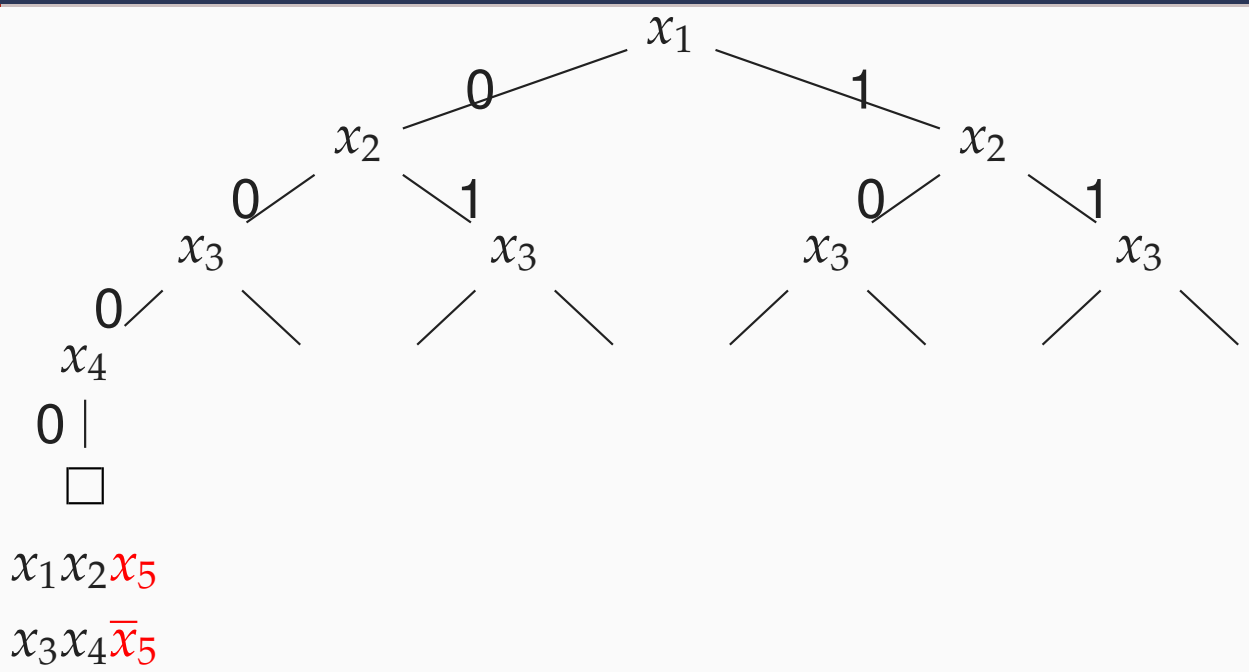


$x_1x_2x_5$

$x_3x_4\overline{x}_5$

RESOLUTION DRIVEN BY CONFLICT

$x_1x_2x_5 \wedge x_3x_4\overline{x}_5$



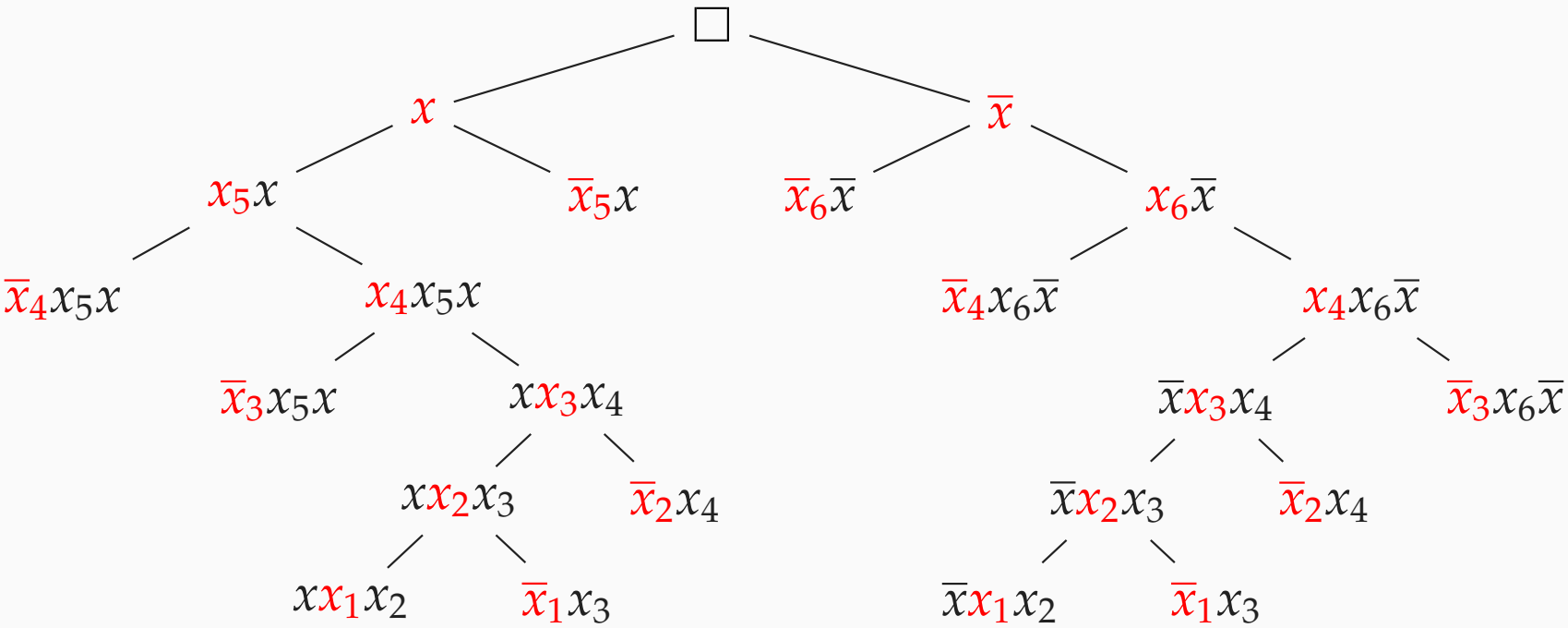
- **Conflict:** Clauses $x_1x_2x_5$ and $x_3x_4\overline{x}_5$ can't be satisfied at the same time, a conflict happens.
- **Conflict-Driven Clause Learning(CDCL):** By doing resolution with the two clauses $x_1x_2x_5$ and $x_3x_4\overline{x}_5$, a new clause $x_1x_2x_3x_4$ is produced and added to the formula. The new clause is learnt clause and this process called Conflict-Driven Clause Learning(CDCL).

Resolution Rule

Regular Resolution

Variables can be resolved on no more than once in any path of resolution tree.

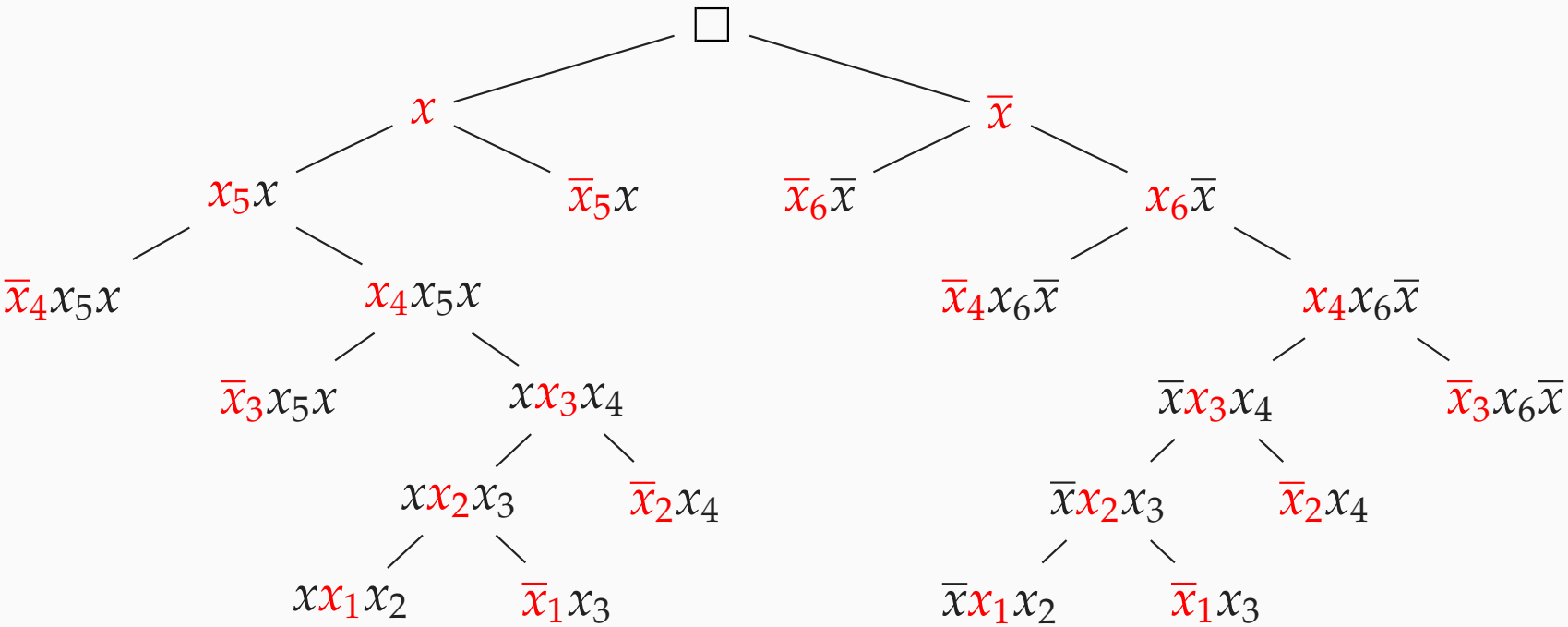
$$xx_1x_2 \wedge \overline{x}x_1x_2 \wedge \overline{x}_1x_3 \wedge \overline{x}_2x_4 \wedge \overline{x}_5x \wedge \overline{x}_6\overline{x} \wedge \overline{x}_3x_5x \wedge \overline{x}_4x_5x \wedge \overline{x}_3x_6\overline{x} \wedge \overline{x}_4x_6\overline{x}$$



11 resolution steps

Regular Resolution

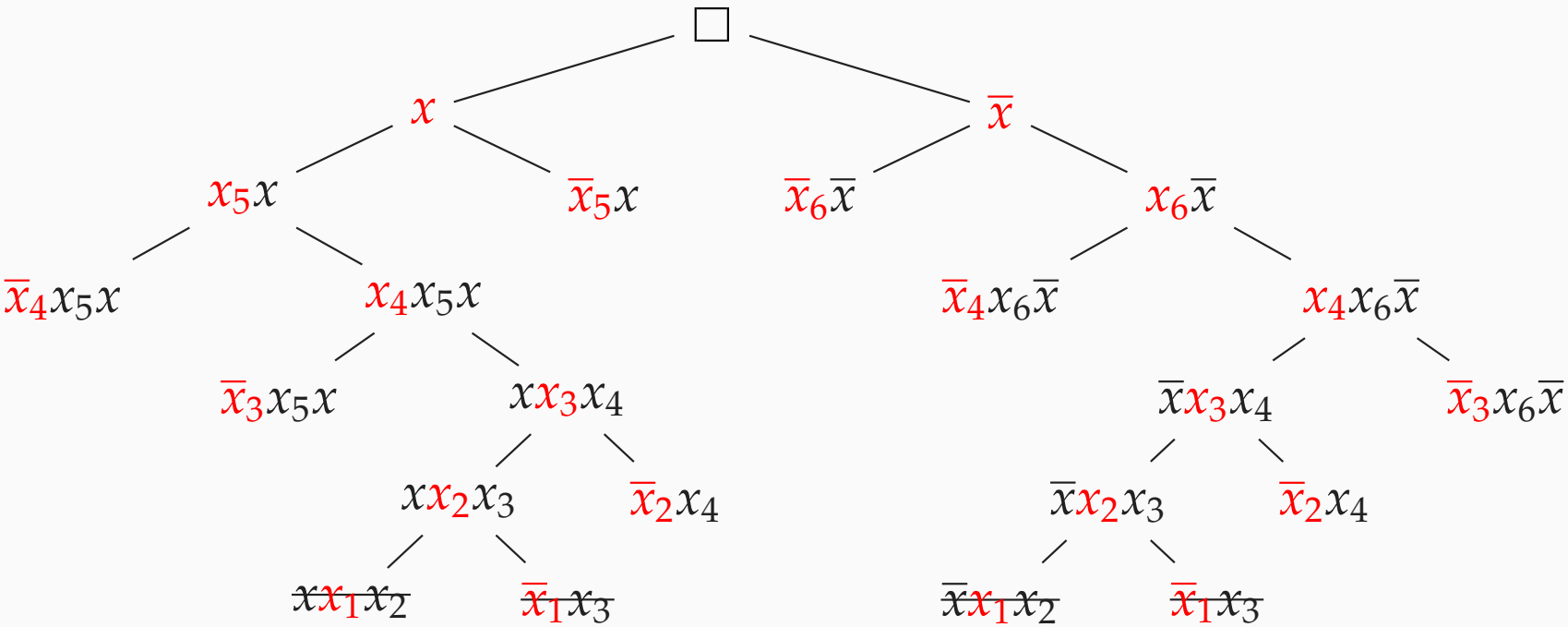
$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$



Regular Resolution

$$xx_1x_2 \wedge \overline{x}x_1x_2 \wedge \overline{x}_1x_3 \wedge \overline{x}_2x_4 \wedge \overline{x}_5x \wedge \overline{x}_6\overline{x} \wedge \overline{x}_3x_5x \wedge \overline{x}_4x_5x \wedge \overline{x}_3x_6\overline{x} \wedge \overline{x}_4x_6\overline{x}$$

$$\overline{x}_2x_4 \wedge \overline{x}_5x \wedge \overline{x}_6\overline{x} \wedge \overline{x}_3x_5x \wedge \overline{x}_4x_5x \wedge \overline{x}_3x_6\overline{x} \wedge \overline{x}_4x_6\overline{x} \wedge xx_2x_3 \wedge \overline{x}x_2x_3$$

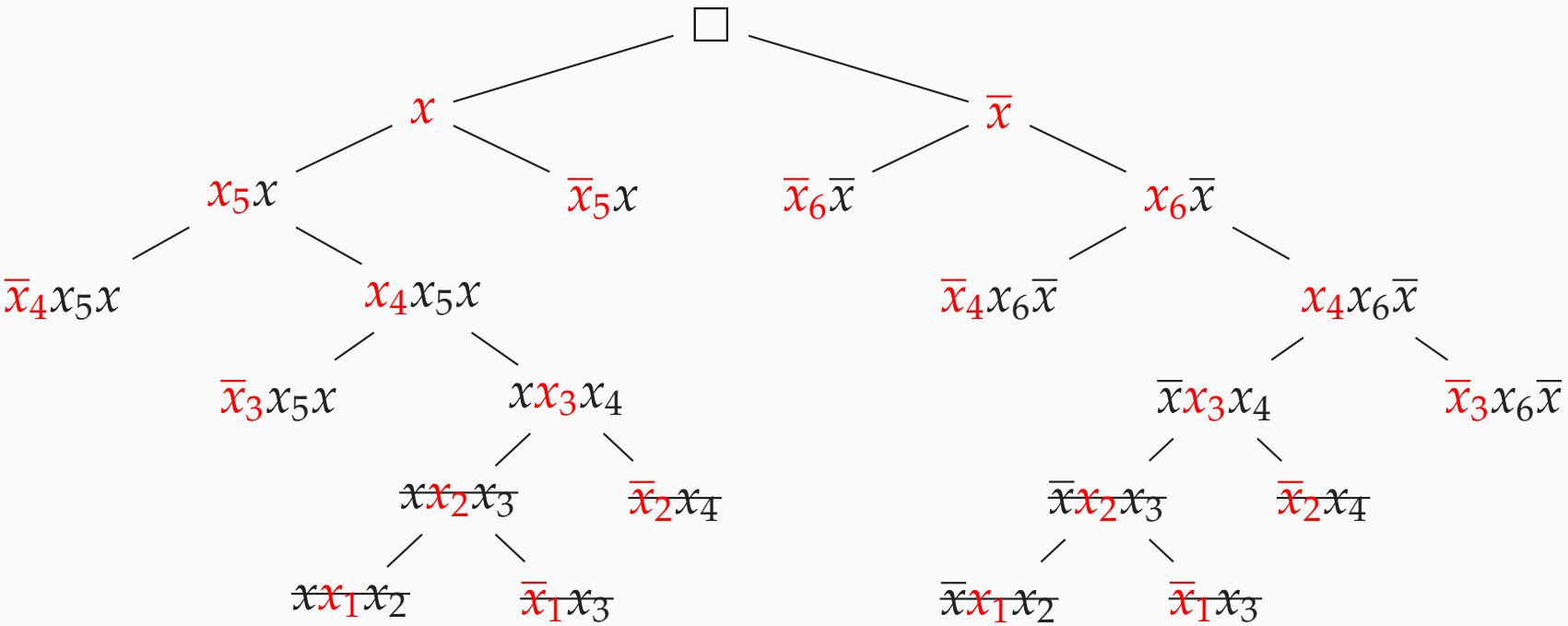


Regular Resolution

$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

$$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_3 x_4 \wedge \overline{x} x_3 x_4$$



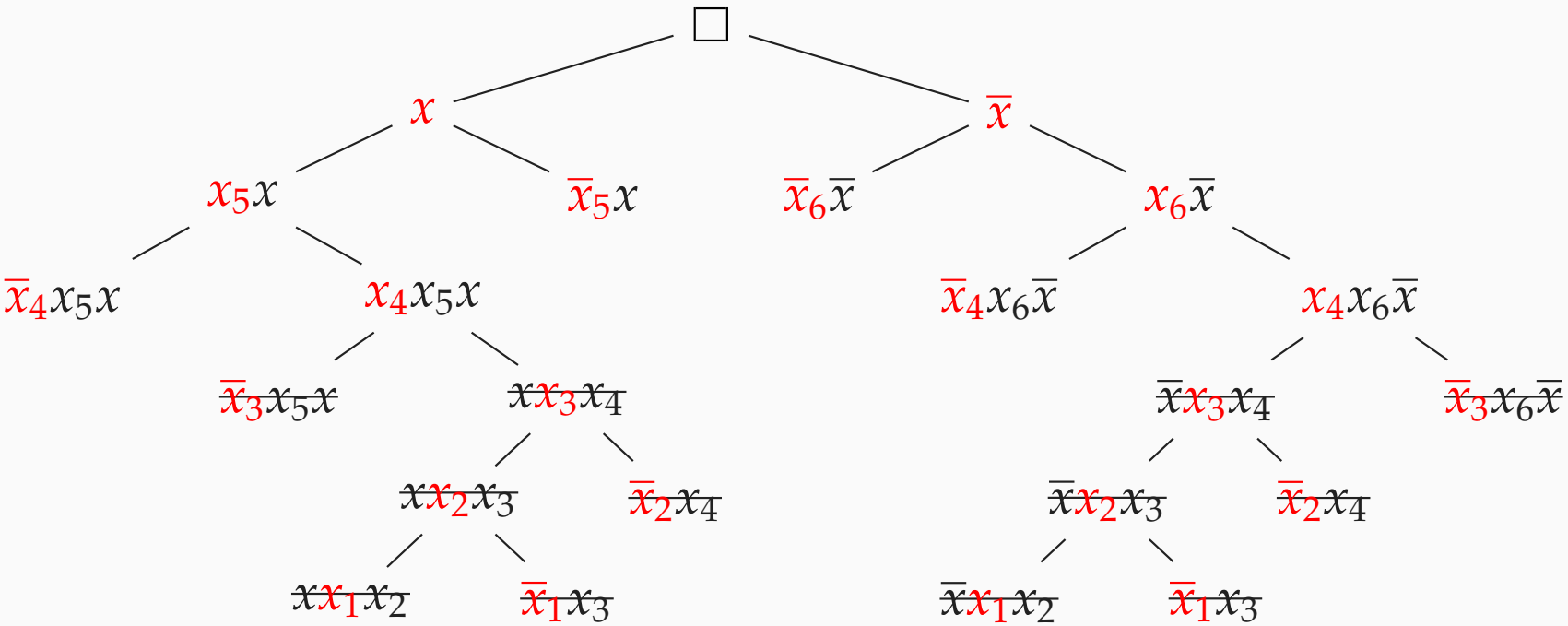
Regular Resolution

$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

$$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_3 x_4 \wedge \overline{x} x_3 x_4$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_4 x_5 x \wedge \overline{x}_4 x_6 \overline{x} \wedge x_4 x_5 x \wedge x_4 x_6 \overline{x}$$



Regular Resolution

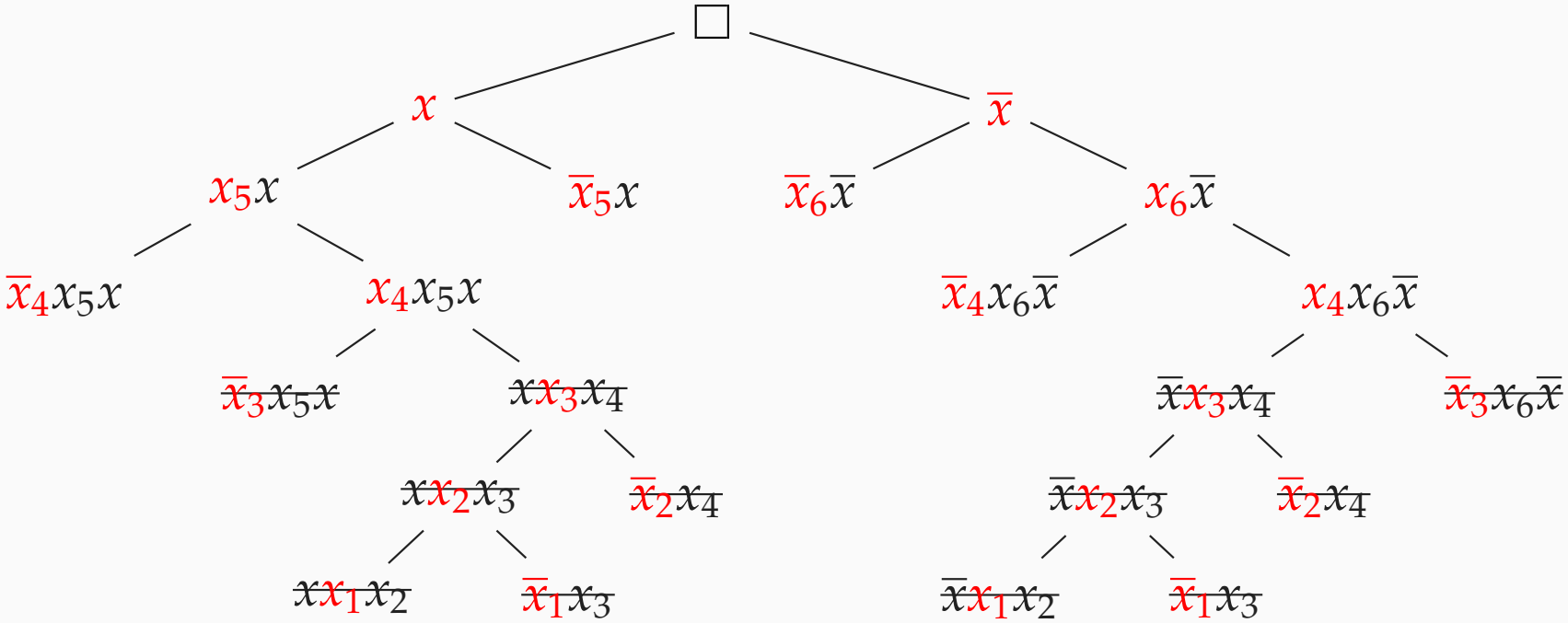
$$x x_1 x_2 \wedge \overline{x} x_1 x_2 \wedge \overline{x}_1 x_3 \wedge \overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x}$$

$$\overline{x}_2 x_4 \wedge \overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_2 x_3 \wedge \overline{x} x_2 x_3$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_3 x_5 x \wedge \overline{x}_4 x_5 x \wedge \overline{x}_3 x_6 \overline{x} \wedge \overline{x}_4 x_6 \overline{x} \wedge x x_3 x_4 \wedge \overline{x} x_3 x_4$$

$$\overline{x}_5 x \wedge \overline{x}_6 \overline{x} \wedge \overline{x}_4 x_5 x \wedge \overline{x}_4 x_6 \overline{x} \wedge x_4 x_5 x \wedge x_4 x_6 \overline{x}$$

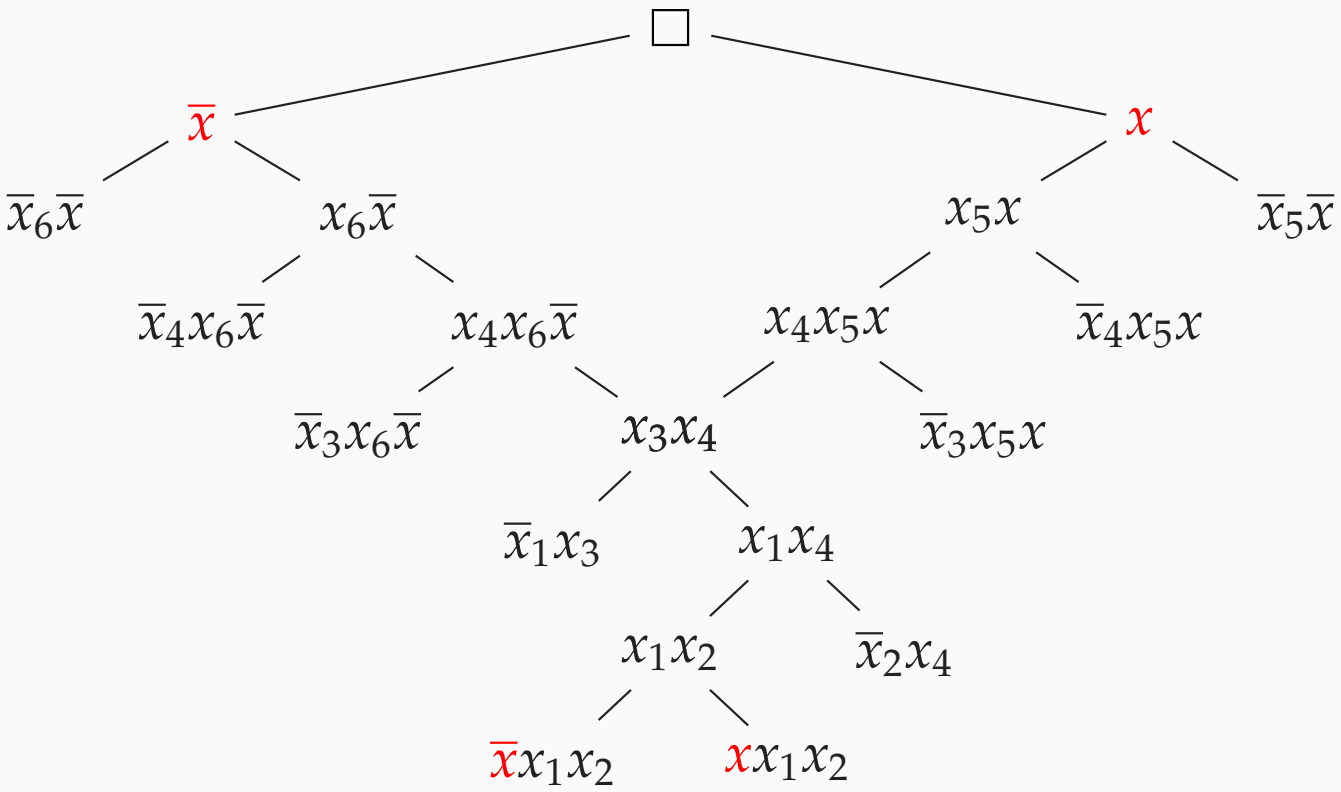
Regular resolution is use to eliminate variables and its clauses in formula. The formula is simplified.



General(Unrestrict) Resolution

Variables can be resolved on unlimited times.

$$xx_1x_2 \wedge \overline{x}x_1x_2 \wedge \overline{x}_1x_3 \wedge \overline{x}_2x_4 \wedge \overline{x}_5x \wedge \overline{x}_6\overline{x} \wedge \overline{x}_3x_5x \wedge \overline{x}_4x_5x \wedge \overline{x}_3x_6\overline{x} \wedge \overline{x}_4x_6\overline{x}$$

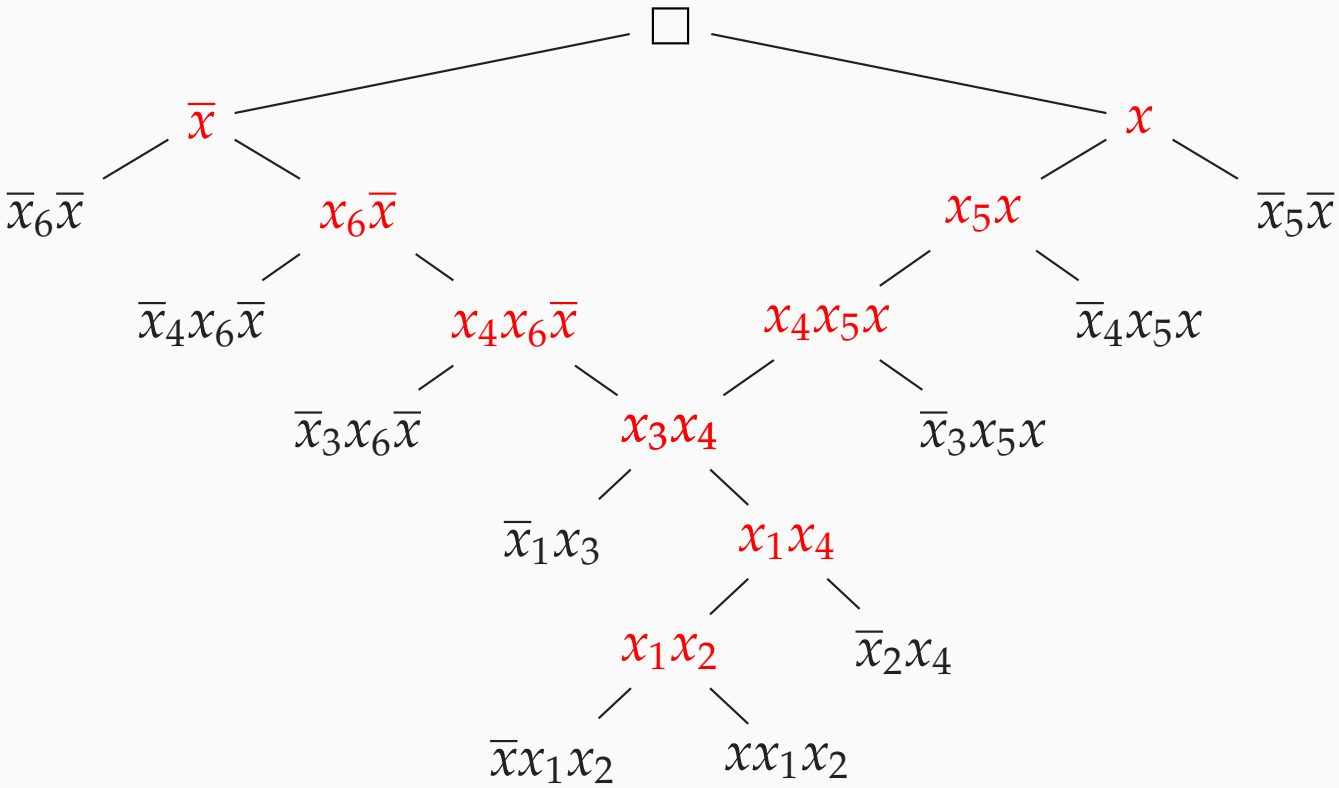


10 resolution steps

General resolution is exponentially stronger than regular resolution. [Huang and Yu, 1987; Goerdt, 1993]

General(Unrestrict) Resolution

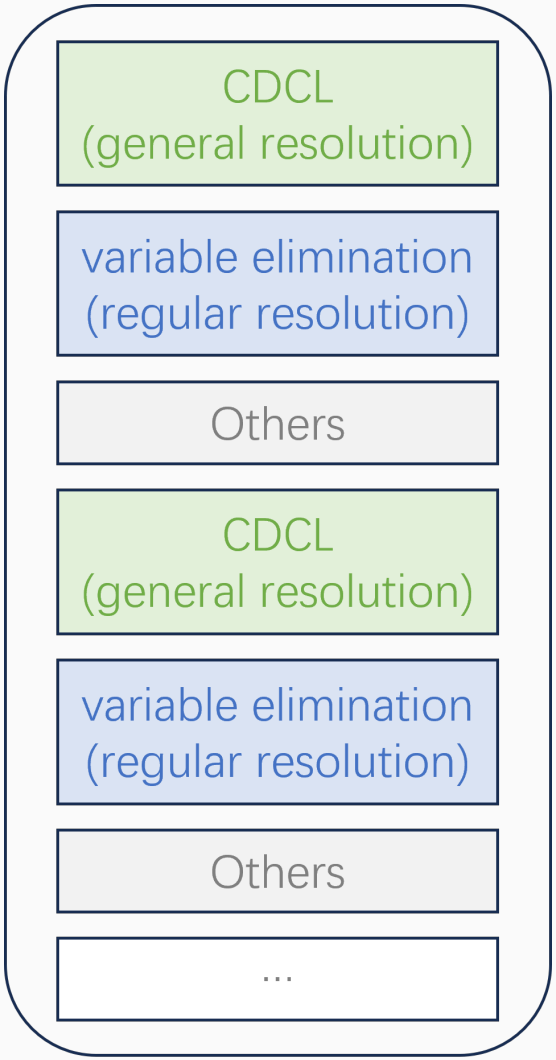
$$xx_1x_2 \wedge \overline{x}x_1x_2 \wedge \overline{x}_1x_3 \wedge \overline{x}_2x_4 \wedge \overline{x}_5x \wedge \overline{x}_6\overline{x} \wedge \overline{x}_3x_5x \wedge \overline{x}_4x_5x \wedge \overline{x}_3x_6\overline{x} \wedge \overline{x}_4x_6\overline{x}$$



General resolution is used to analyze conflicts and get learnt clauses, it's the basic of Conflict-Driven Clause Learning(CDCL), which is shown to be equivalent to general resolution under a few assumptions [Beame et al., 2003]

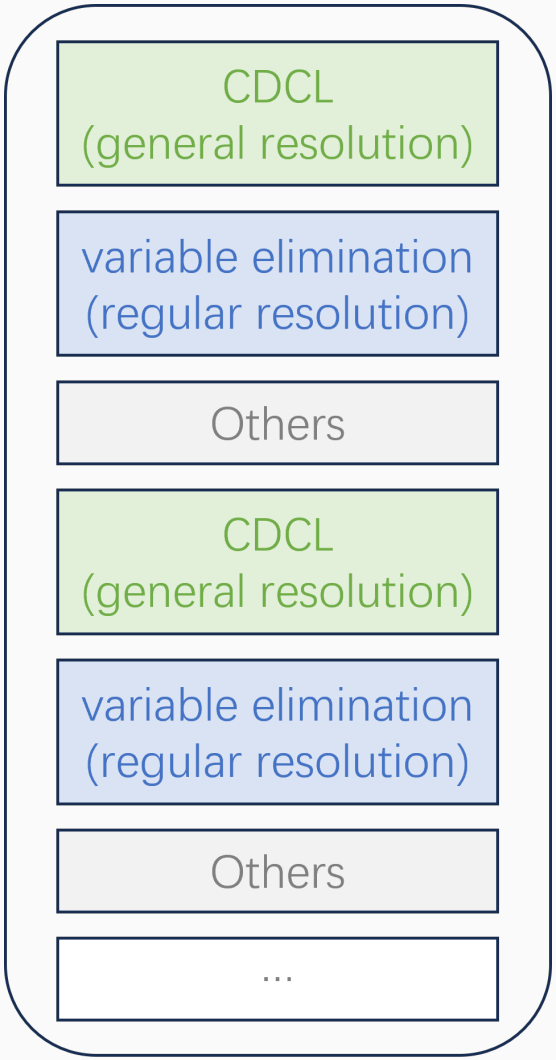
ESA and Experiments

Resolution Rule in SAT Solving



Cadical, Kissat, AMSAT

Resolution Rule in SAT Solving



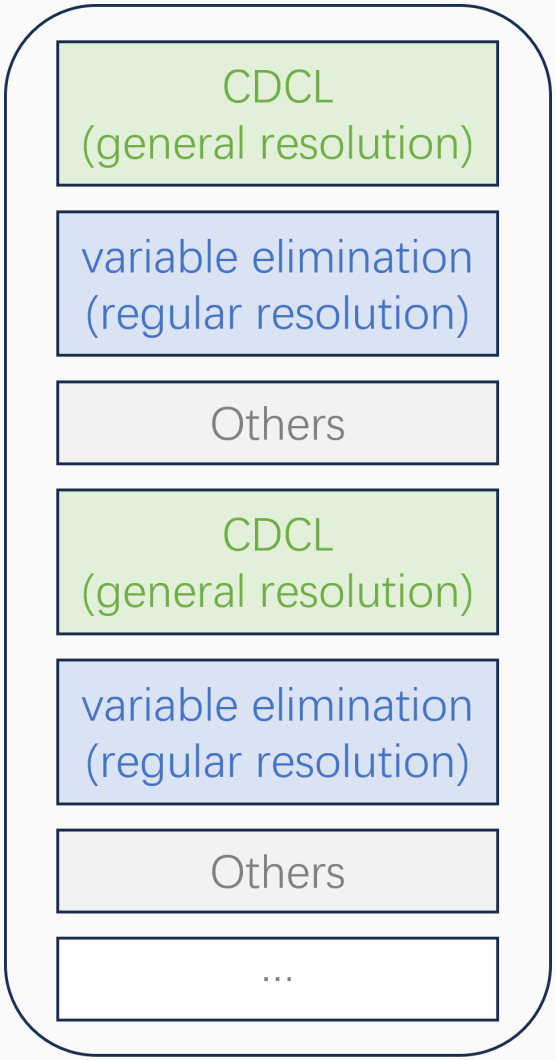
Cadical, Kissat, AMSAT

Which variable is eliminated first in Variable Elimination?

$$(x, l_1), (x, l_2) \quad (\overline{x}, l_3), (\overline{x}, l_4) \Rightarrow (l_1, l_3), (l_1, l_4) \quad (l_2, l_3), (l_2, l_4)$$

$$(y, l_1), (y, l_2), (y, l_3) \quad (\overline{y}, l_4), (\overline{y}, l_5), (\overline{y}, l_6) \Rightarrow (l_1, l_4), (l_1, l_5), (l_1, l_6) \quad (l_2, l_4), (l_2, l_5), (l_2, l_6) \quad (l_3, l_4), (l_3, l_5), (l_3, l_6)$$

Resolution Rule in SAT Solving

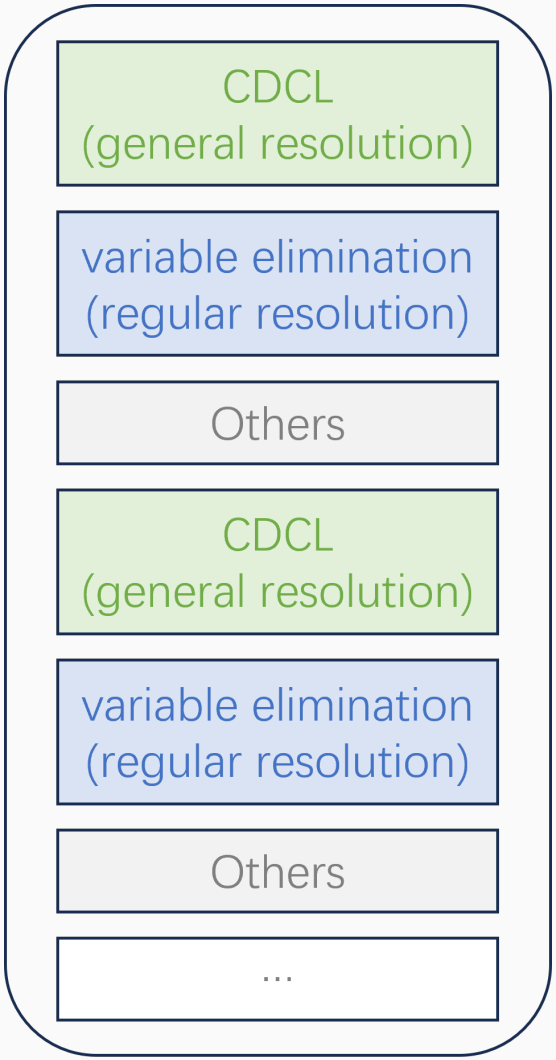


Cadical, Kissat, AMSAT

Which variable is eliminated first in Variable Elimination?

Variables occur less often in clauses.

Resolution Rule in SAT Solving



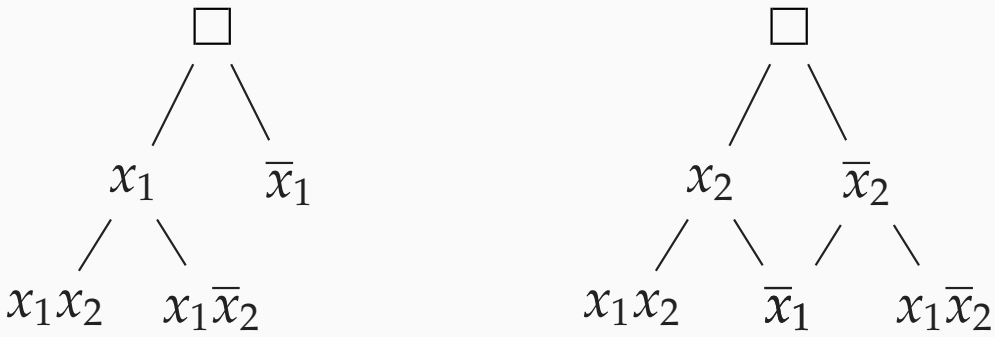
Cadical, Kissat, AMSAT

Which variable is eliminated first in Variable Elimination?

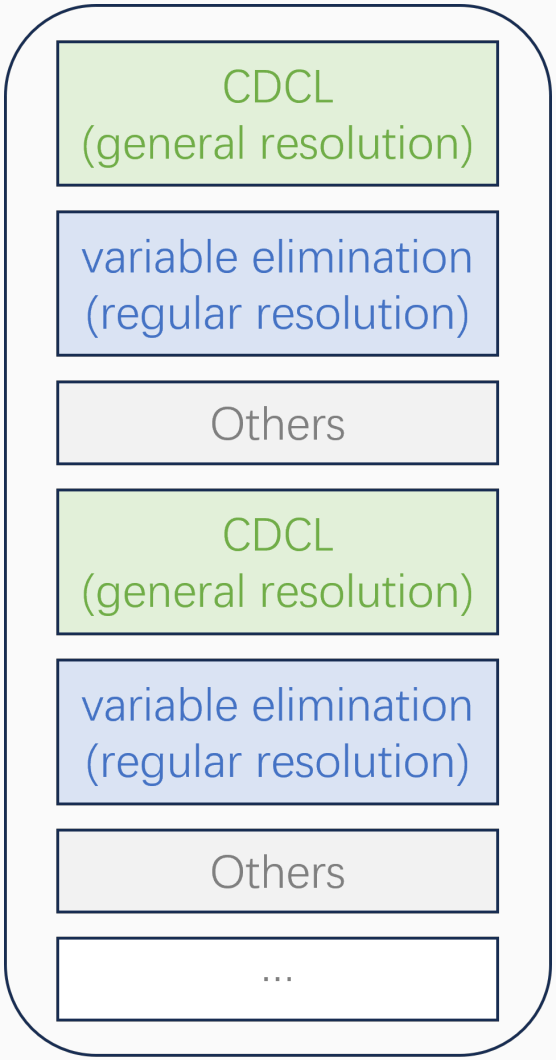
Variables occur less often in clauses.

Which variable is assigned first in CDCL?

$\overline{x}_1 \wedge x_1x_2 \wedge x_1\overline{x}_2$



Resolution Rule in SAT Solving



Cadical, Kissat, AMSAT

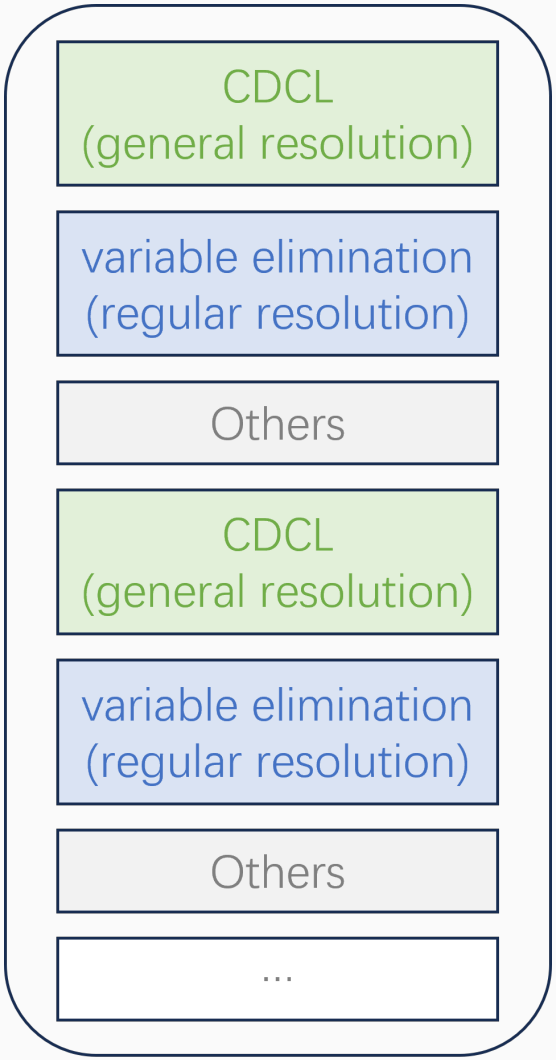
Which variable is eliminated first in Variable Elimination?

Variables occur less often in clauses.

Which variable is assigned first in CDCL?

Variables cause conflicts quickly. In implementation, they are variables occurs frequently in recent conflicts. This frequency is measured by a score called activity.

VARIABLES ELIMINATED SCHEDULED BY ACTIVITY



Cadical, Kissat, AMSAT

How to make variable elimination helpful to CDCL?

Eliminate variables with low activity, instead of variables occur in a small number of clauses.

- Eliminating those trivial variables simplifies formula, and helps the solver focus on searching in core fields.
- Keeping high activity variables also keeps their learnt clauses, those information is also helpful.

RESULTS

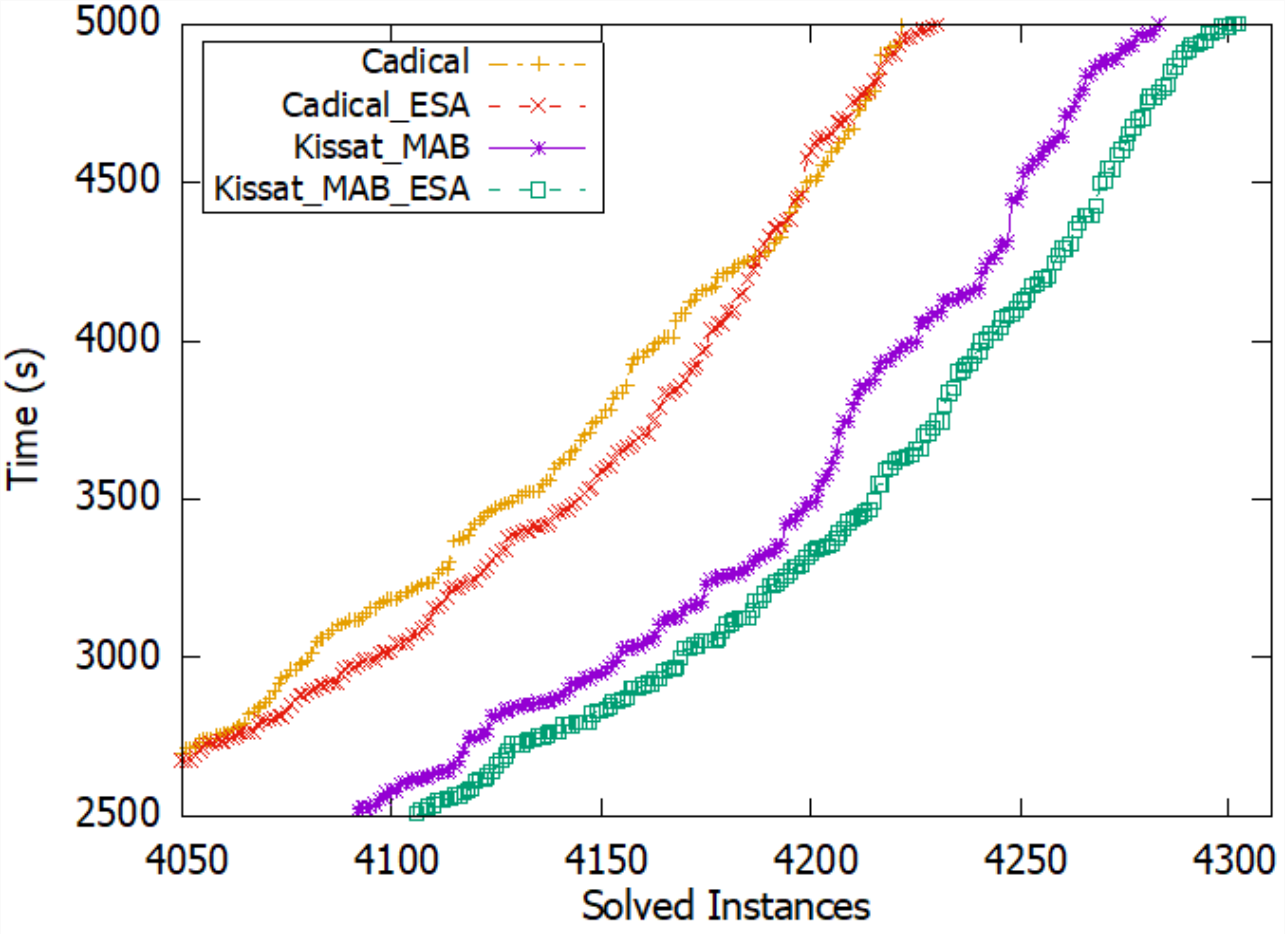


Figure 1: Cactus plots of different solvers. Each point (N, T) in a curve indicates the number N of instances solved within T secs by the corresponding solver.

Results

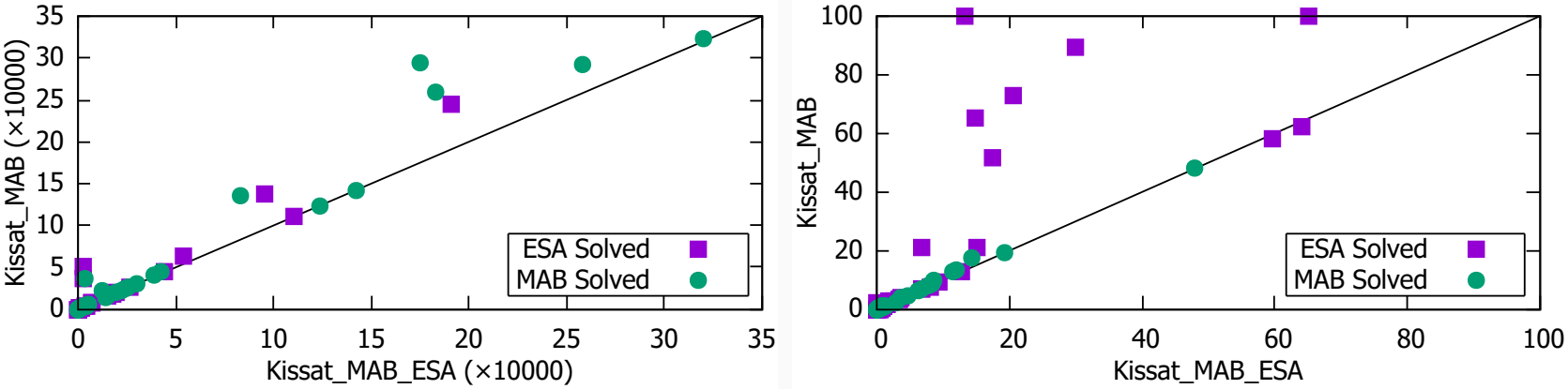


Figure 2: Scatter plot of the number of eliminated variables (left), and scatter plot of the number of learnt clauses lost per variable (right) by the 1st BVE of Kissat_MAB_ESA and Kissat_MAB.

The ESA ordering eliminates fewer variables, and loses fewer learnt clauses than Kissat_MAB when eliminating variables.

RESULTS

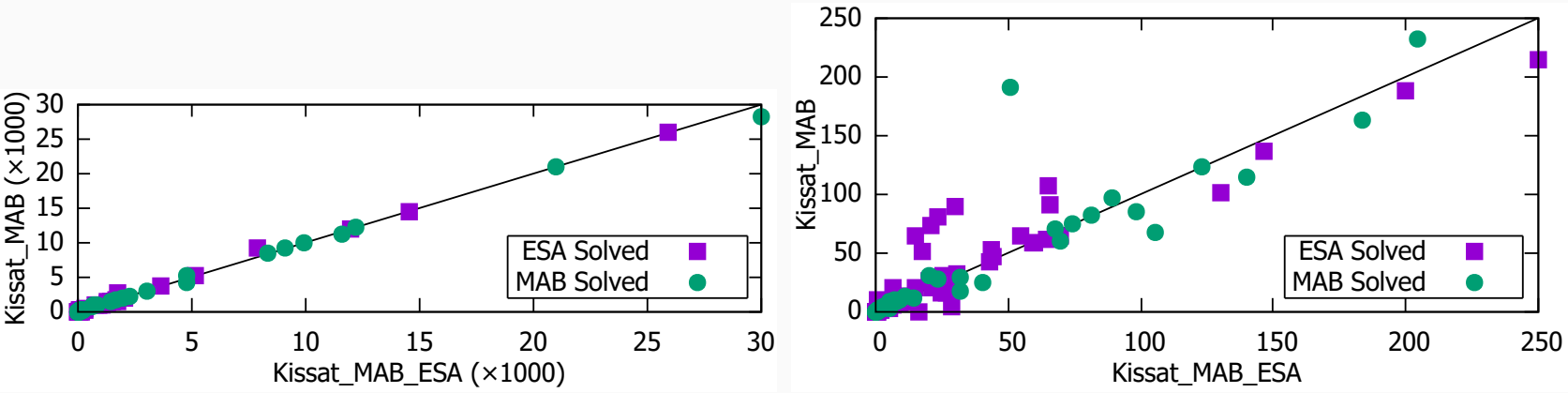


Figure 3: Scatter plot of the average number of eliminated variables per BVE call (left), and scatter plot of the average number of learnt clauses removed per variable among the first k BVE calls (right).

Kissat_MAB and Kissat_MAB_ESA eliminate roughly the same average number of variables per BVE call.
Removing learnt clauses will hurt the performance of solvers.

ESA APPLICATION IN COMPETITIONS

Anniversary Sequential Track

Winning Solvers

	Solver	Authors	PAR-2	Solved
1	Kissat-MAB-ESA	Shuolin Li, Jordi Coll, Chu-Min Li, Mao Luo, Djamal Habet, and Felip Manyà	2806.15	4029
2	Kissat-sc2022-bulky	Armin Biere and Mathias Fleury	2810.70	4038
3	eKissat-MAB-gb-db	Md Solimul Chowdhury	2829.88	4015

Anniversary Sequential Track UNSAT

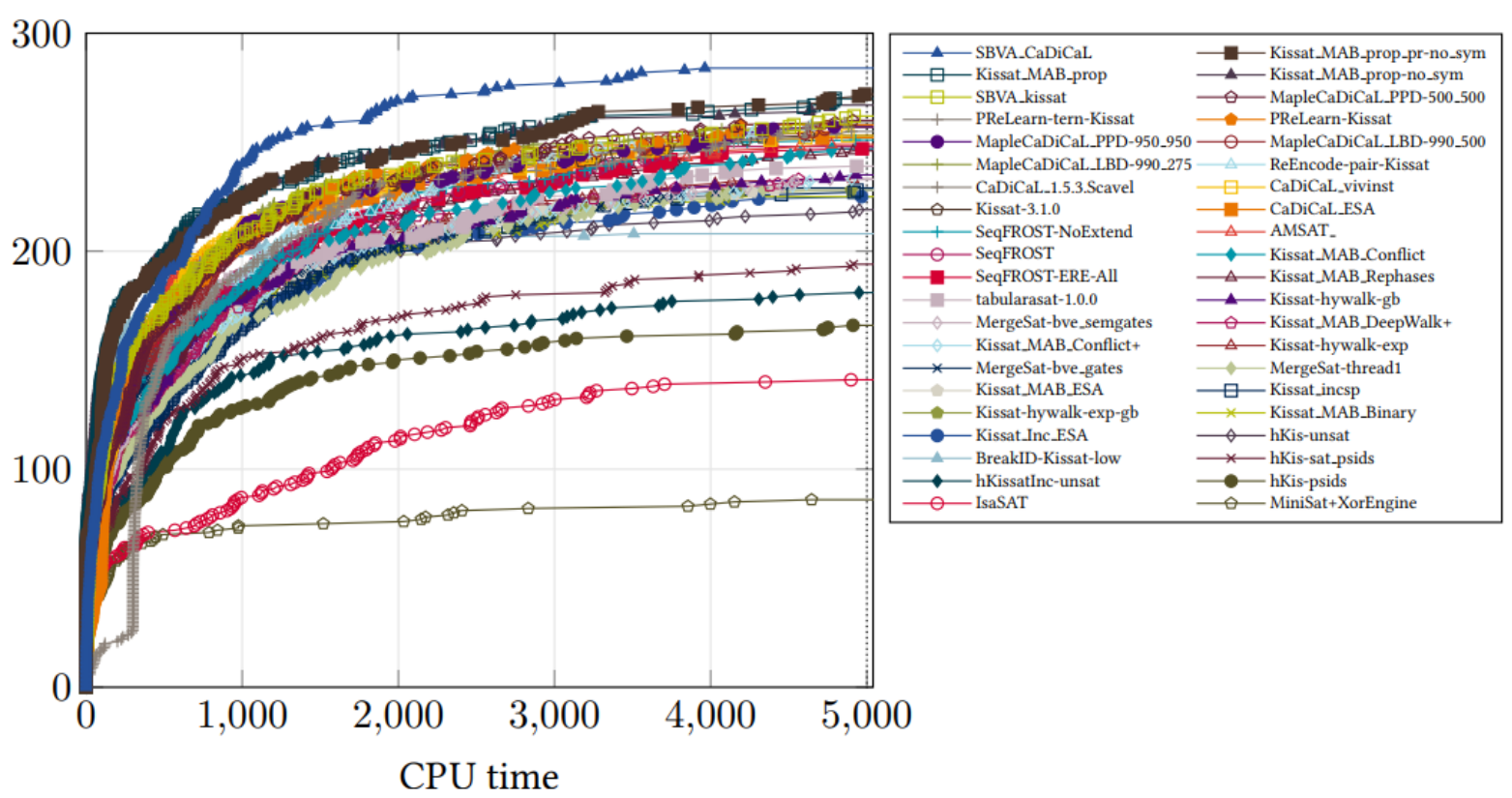
Winning Solvers

	Solver	Authors	PAR-2	Solved
1	hKis-unsat	Rodrigue Konan Tchinda and Clementin Tayou Djamegni	1071.99	2080
2	Kissat-MAB-ESA	Shuolin Li, Jordi Coll, Chu-Min Li, Mao Luo, Djamal Habet, and Felip Manyà	1093.82	2078
3	Kissat-sc2022-bulky	Armin Biere and Mathias Fleury	1115.26	2076

Kissat_MAB_ESA won the 1^{st} in Anniversary Track and 2^{nd} in Anniversary Unsat Track in SAT competition 2022.
Exploiting the difference between general resolution and regular resolution is useful.

ESA APPLICATION IN OTHER SOLVERS

AMSAT(Amiens Marseille SAT Solver) was submitted to SAT Competition 2023 and it outperformed all other Maple-based solvers. Variables activity is also used to choose learnt clauses to be deleted.



Notice most of these solvers are Cadical/Kissat based.

ESA APPLICATION IN OTHER SOLVERS

MaxCDCL equipped with ESA was submitted to MaxSAT Evolution 2023 and it ranked second in unweighted track.
Variables activity is also used in choosing learnt clauses to be deleted, learnt clauses vivification and failed literals detection.

Unweighted: 572 instances

Solver	#Solved	Time (Avg)
EvalMaxSAT (SCIP)	433	326.11
MaxCDCL (SCIP600, MaxHS900)	430	244.12
CASHWMAXSAT-CorePlus (SCIP)	428	401.84