TU WIEN TECHNISCHE UNIVERSITÄT WIEN

JOHANNES KEPLER UNIVERSITY LINZ

Open problems in interference and proofs for SAT solving

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Interference-based proofs

Reverse unit propagation (RUP) [Goldberg, Novikov '03]

a clause C is a RUP clause over a CNF formula F if $F \wedge \neg C$ leads to a conflict via unit propagation

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this is just reasoning without loss of generality!

Interpolants from interference-based proofs?

Mutation logic [Rebola, Suda ’18] [Rebola ’23]

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- Inferences are model-preserving
- Inferences depend only on specific clauses
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Craig interpolant [Craig '57]

$F \wedge G$ unsatisfiable $\Rightarrow$ $F \models P \models \neg G$ and $\mathrm{var}(P) \subseteq \mathrm{var}(F) \cap \mathrm{var}(G)$

Interpolants can be recursively computed in P-time from resolution proofs

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Theorem [Reckhow '75] [Krajícek, Pudlák '98] [Kiesl, Rebola, Heule '18] [Heule, Biere, '18]

Interpolants cannot be constructed from SR proofs in polynomial time unless RSA is insecure

Open problem 1 does this result still hold for interpolants in mutation logic?

Interference-based reasoning

Despite claims to the contrary [Philipp, Rebola ’16] [Rebola, Suda ’18] [Rebola ’23] interference-based clause introduction was not very used... until recently!

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Bounded Variable Addition (BVA) [Manthey, Heule, Biere ’12]

- Turn $F \lor Q$ into $(F \lor x) \land (Q \lor \bar{x})$
  - *forgotten by 2015, enormous resurgence in 2023*

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Encode "*C is an SR clause over F upon σ*" in a sub-solver

modest effect, enormous resurgence in 2023 *[Oliveras, Li, Wu, Chung, Ganesh '23]*

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Idea: splitting-based inprocessing

Perform SDCL/BVA over a subformula $G \subseteq F$, then identify clauses that can be brought back into F.

Can be proven sound in mutation logic, but not even in WSR

Similar problems in incremental solving [Fazekas, Biere, Scholl ’19]

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Open problem 2 How does entailment behaves across interference?

are we being artificially limited by how we think of redundancy/interference?

A critical history of proof formats for CDCL SAT

[Goldberg, Novikov ’03]

RUP

○

[Malik, Zhang ’03]

resolution

○

$$\dfrac{C \lor x \qquad D \lor \overline{x}}{C \lor D}$$

resolution

$$\dfrac{\dfrac{E_0}{A_0} \qquad E_1}{A_1}$$

$$\ddots$$

$$\dfrac{A_{n-1} \qquad E_n}{A_n}$$

RUP

propagate $\overline{A_n}$, check for conflict

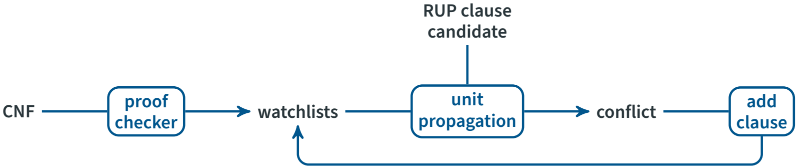
A critical history of proof formats for CDCL SAT

RUP

○

resolution

○



RUP clause candidate

CNF

proof checker

watchlists

unit propagation

conflict

add clause

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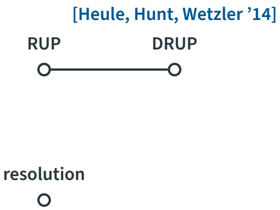
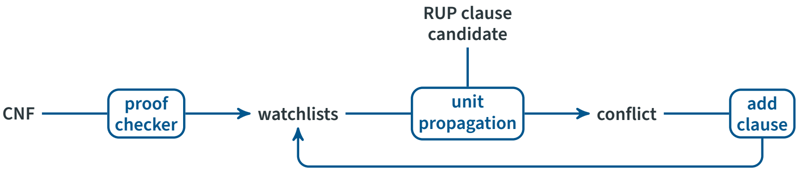


[Heule, Hunt, Wetzler ’14]

RUP

DRUP

resolution



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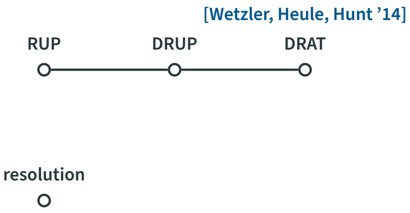


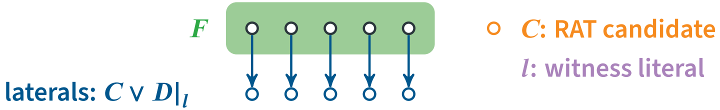
[Wetzler, Heule, Hunt ’14]

RUP

DRUP

DRAT

resolution



F

laterals: $C \lor D|_l$

C: RAT candidate

l: witness literal

i) laterals must be RUP

ii) $l \models C$

[Järvisalo, Heule, Biere ’12]

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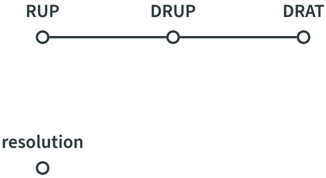
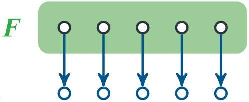




○ C: PR candidate

Q: witness cube

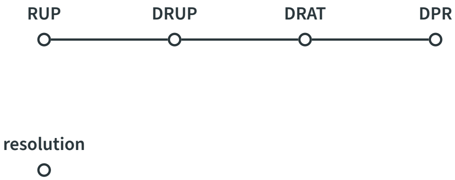
laterals: $C \lor D|_Q$

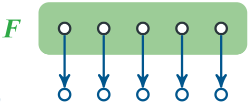
i) laterals must be RUP

ii) $Q \vDash C$

A critical history of proof formats for CDCL SAT

[Heule, Kiesl, Biere ’17]





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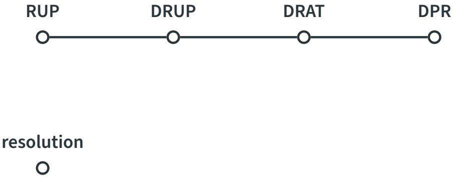
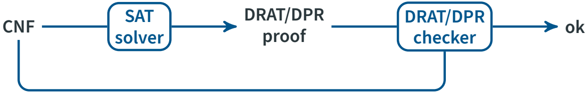

RUP
DRUP
DRAT
DPR
resolution


CNF
SAT solver
DRAT/DPR proof
DRAT/DPR checker
ok

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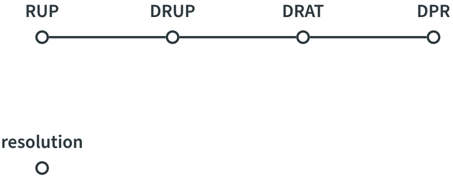

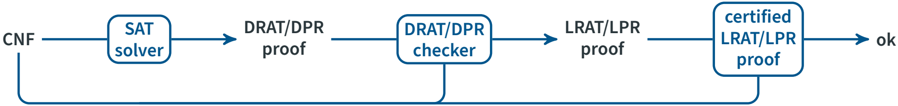

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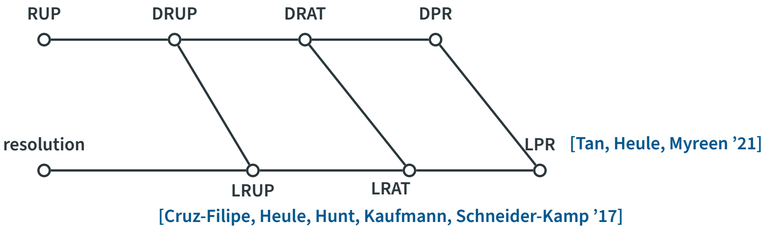
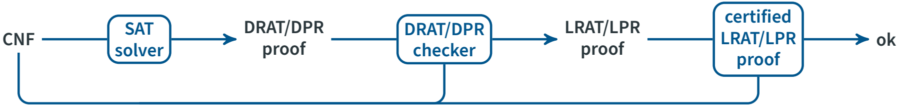


[Tan, Heule, Myreen '21]

[Cruz-Filipe, Heule, Hunt, Kaufmann, Schneider-Kamp '17]



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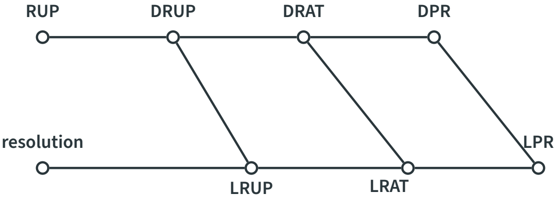
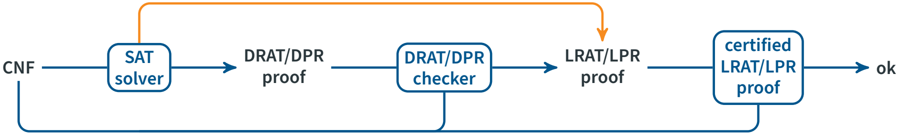


“There are several challenges regarding unsatisfiability proofs. How can one store resolution proofs using much less space on disk and using much less memory overhead?”
[Biere, Heule ’15]



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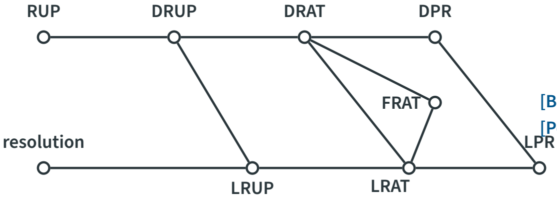

[Baek, Carneiro, Heule ’21]

[Pollitt, Fleury, Biere ’23]

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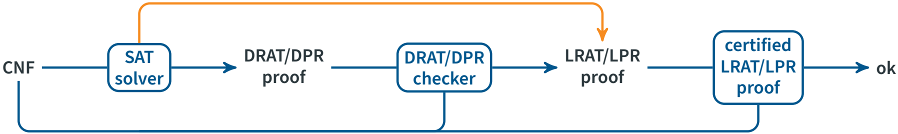

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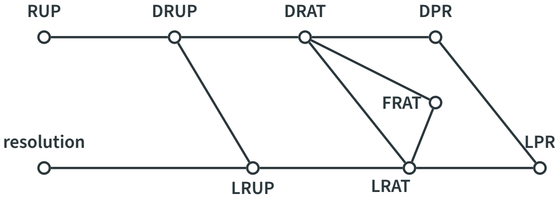

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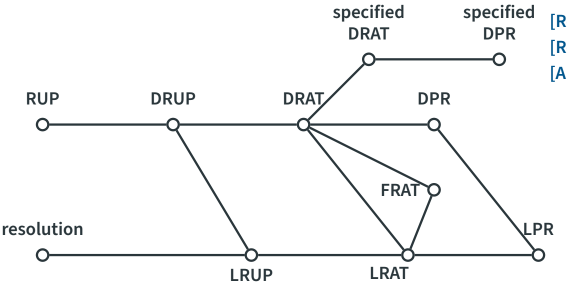

[Rebola-Pardo, Biere ’18]
[Rebola-Pardo, Cruz-Felipe ’18]
[Altmanninger, Rebola-Pardo ’20]

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Problem 1 checking if a clause is unit requires unit propagation

Problem 2 DRAT is non-monotonic, so skipping a deletion gives surprising results

Problem 3 the computational cost is the same (in our implementation, slightly lower)

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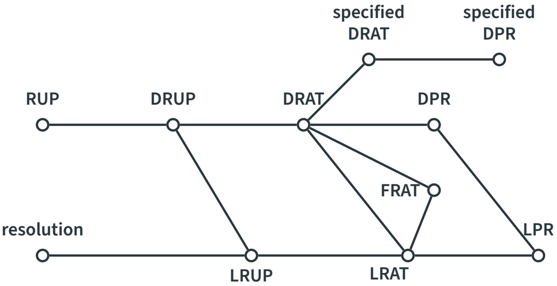

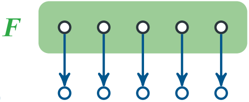

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Q: witness cube

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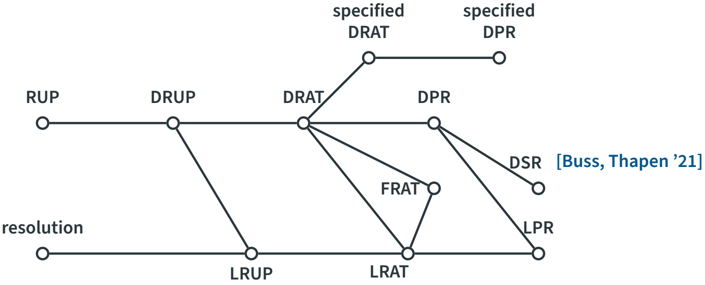

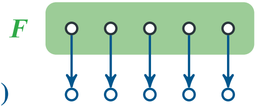

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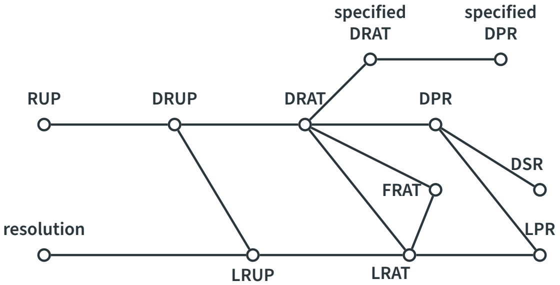

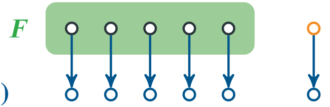

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[Gocht, Nordström ’21]
[Rebola-Pardo ’23]

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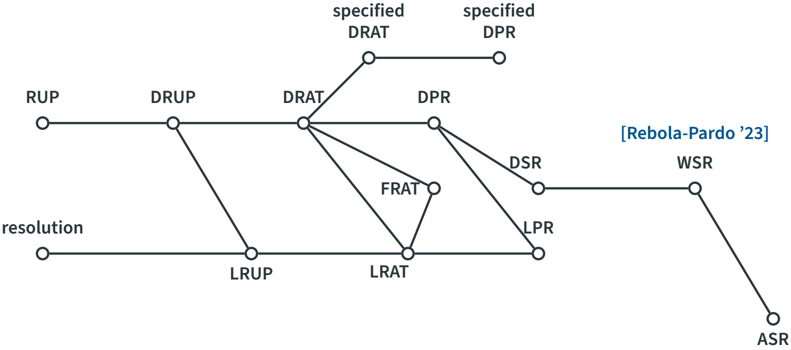

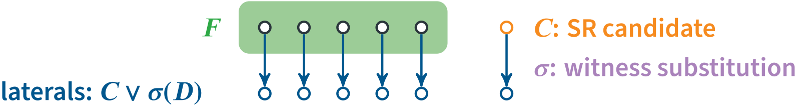

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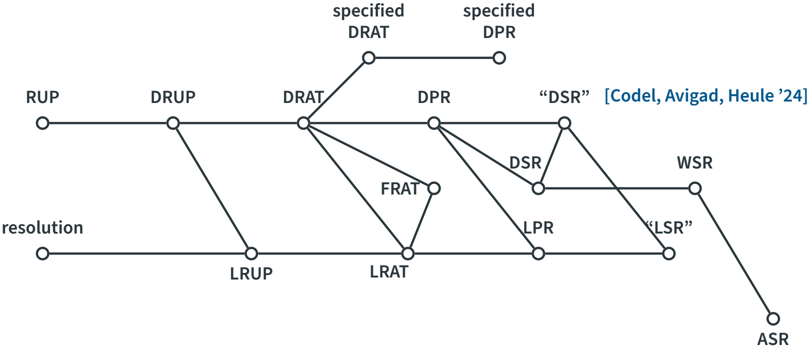

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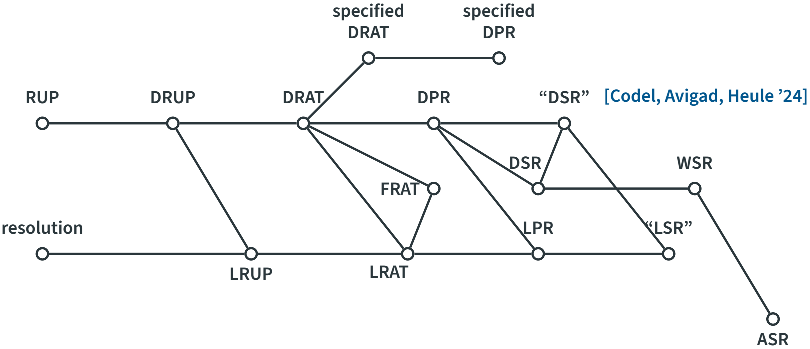
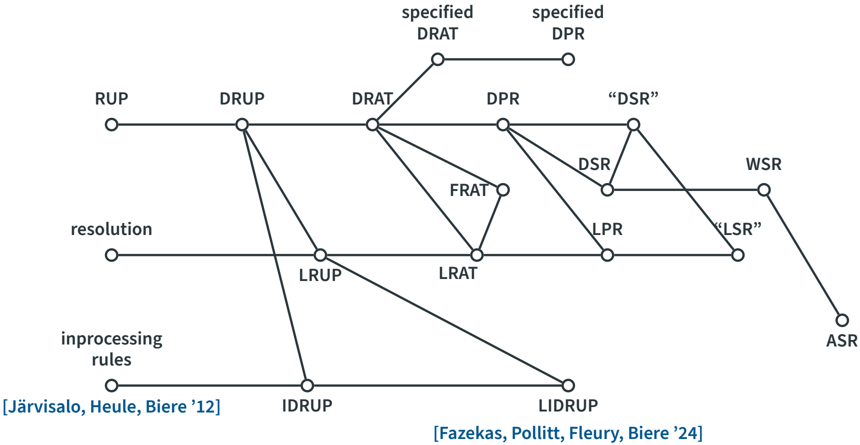


“Currently, our checkers assume that the witness σ satisfies the candidate clause C. However, the DSR and LSR formats can also express proofs where σ causes $C|_\sigma$ to be a tautology: the proof can simply map the pivot p to itself or to any other literal in the substitution portion. We plan to support this general case in the future.”

“At the moment, `dsr-trim` can only perform forwards checking, which means that it checks DSR proofs from start to finish and adds hints as it goes. (…) In practice, backwards checking can significantly reduce the size of proofs. Adding backwards checking to `dsr-trim` is ongoing work.” [Codel, Avigad, Heule ’24]

A critical history of proof formats for CDCL SAT



$$\frac{\varphi \wedge C\ [\rho]\ \sigma}{\varphi\ [\rho]\ \sigma \cdot (\omega : C)}\ \boxed{\flat} \qquad \frac{\varphi \wedge C\ [\rho]\ \sigma}{\varphi\ [\rho]\ \sigma}\ \boxed{\varnothing}$$

$\textsc{Weaken}^{+}$ $\qquad$ $\textsc{Drop}$

where $\boxed{\flat}$ is $\varphi \wedge C \equiv^{\omega}_{sat} \varphi$ and $\boxed{\varnothing}$ is $\varphi \models C$

Fig. 2. New weakening and dropping rules

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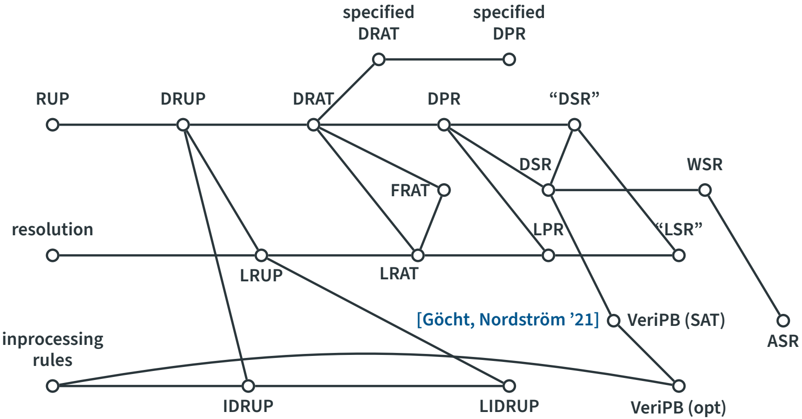
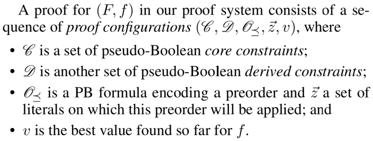


[Göcht, Nordström '21]

[Bogaerts, Gocht, McCreesh, Nordström '22]



A proof for (F, f) in our proof system consists of a sequence of *proof configurations* $(\mathscr{C}, \mathscr{D}, \mathscr{O}_{\preceq}, \vec{z}, v)$, where

- $\mathscr{C}$ is a set of pseudo-Boolean *core constraints*;
- $\mathscr{D}$ is another set of pseudo-Boolean *derived constraints*;
- $\mathscr{O}_{\preceq}$ is a PB formula encoding a preorder and $\vec{z}$ a set of literals on which this preorder will be applied; and
- v is the best value found so far for f.

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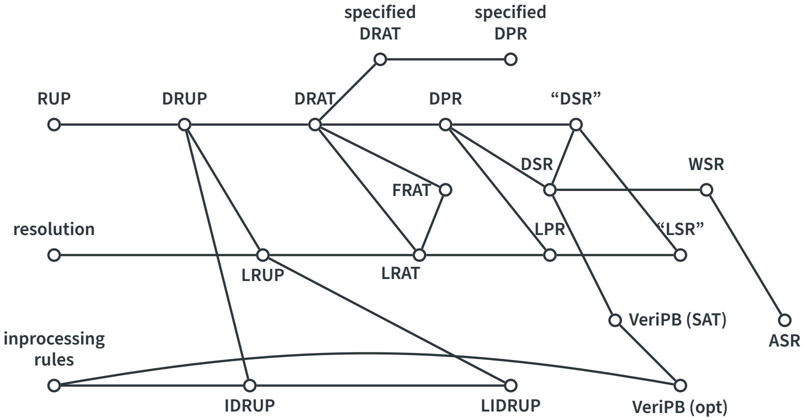

… plus binary vs text variants!

Proof formats: what do we need, what must go?

Open Problem 3 consolidating proof formats

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What do we certify? what counts as a “correct” proof? [yes, again]

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Open Problem 4 can we find a sensible framework unifying these ideas?