



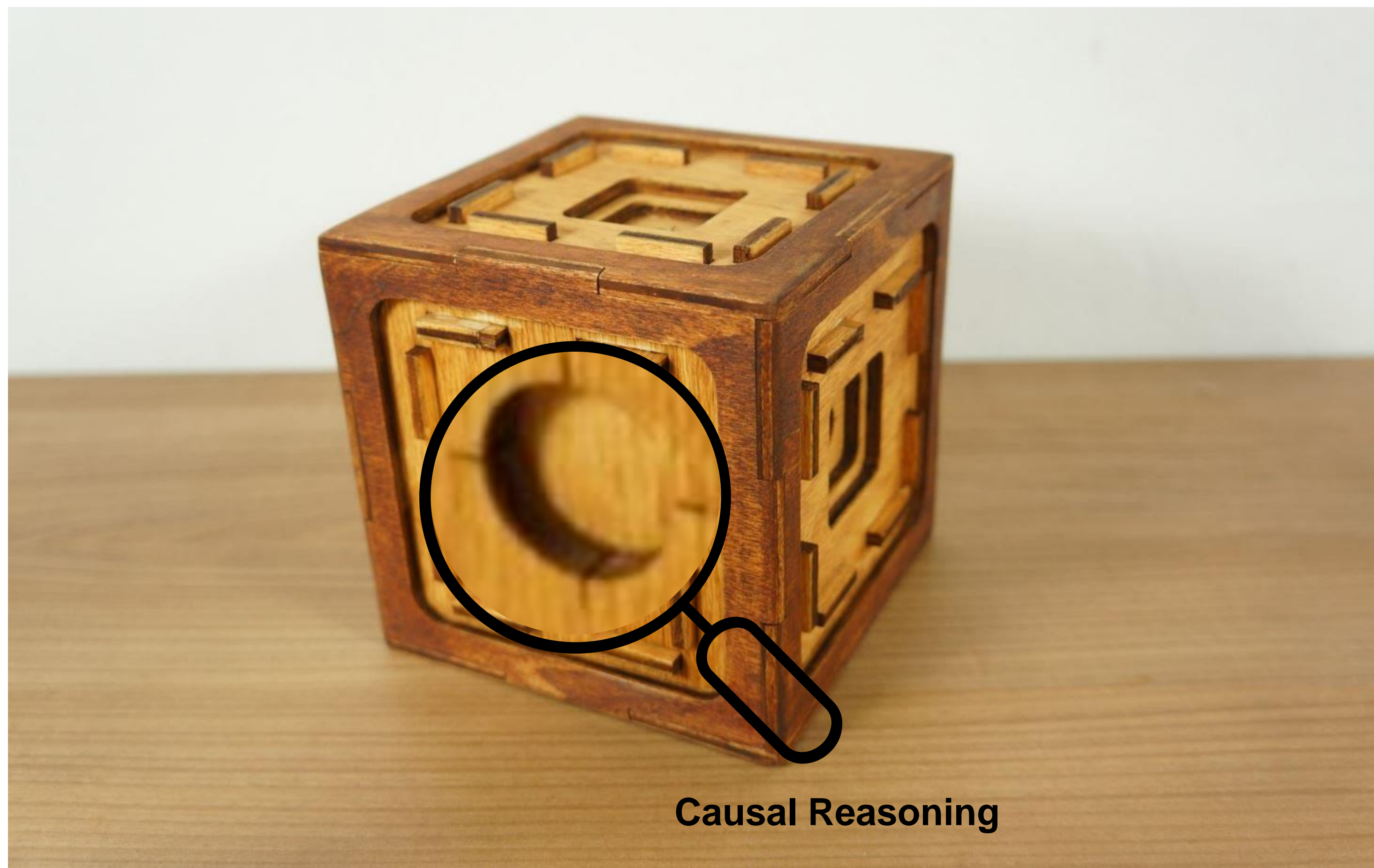
Explaining SAT Solving Using Causal Reasoning

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Joint work with Arijit Shaw, Teodora Baluta, Mate Soos, and Kuldeep S. Meel

SAT Solver



Causal Reasoning

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Do we really understand?

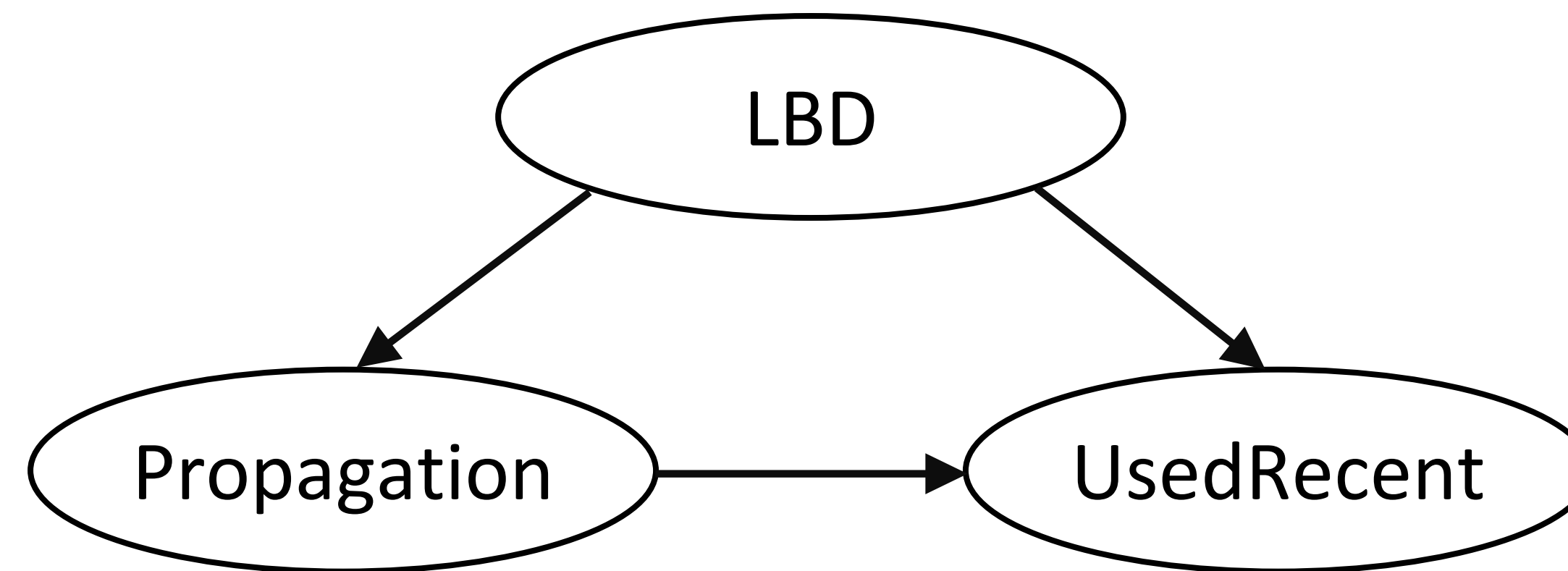
Literals blocks distance (LBD):
number of distinct decision levels of literals in a clause.

- Clauses with low LBD have greater utility.
- Small clause has greater utility.

Temperature



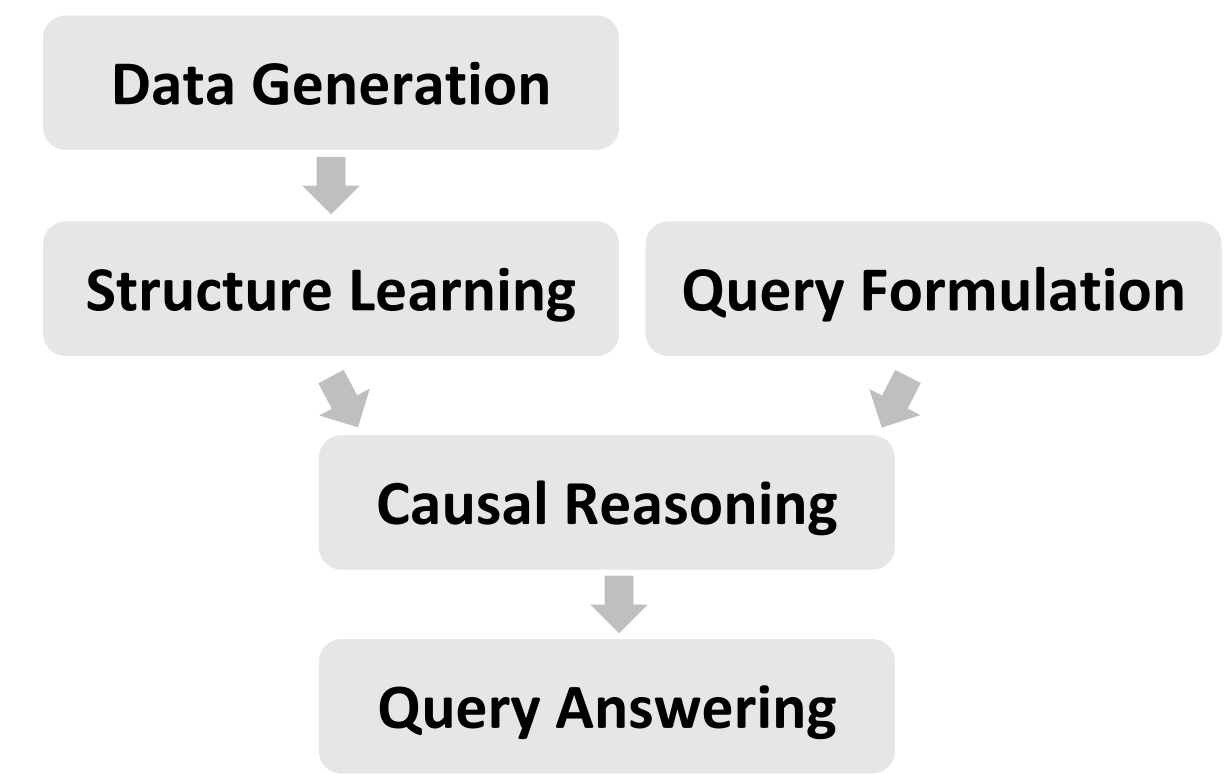
Causality in SAT Solver



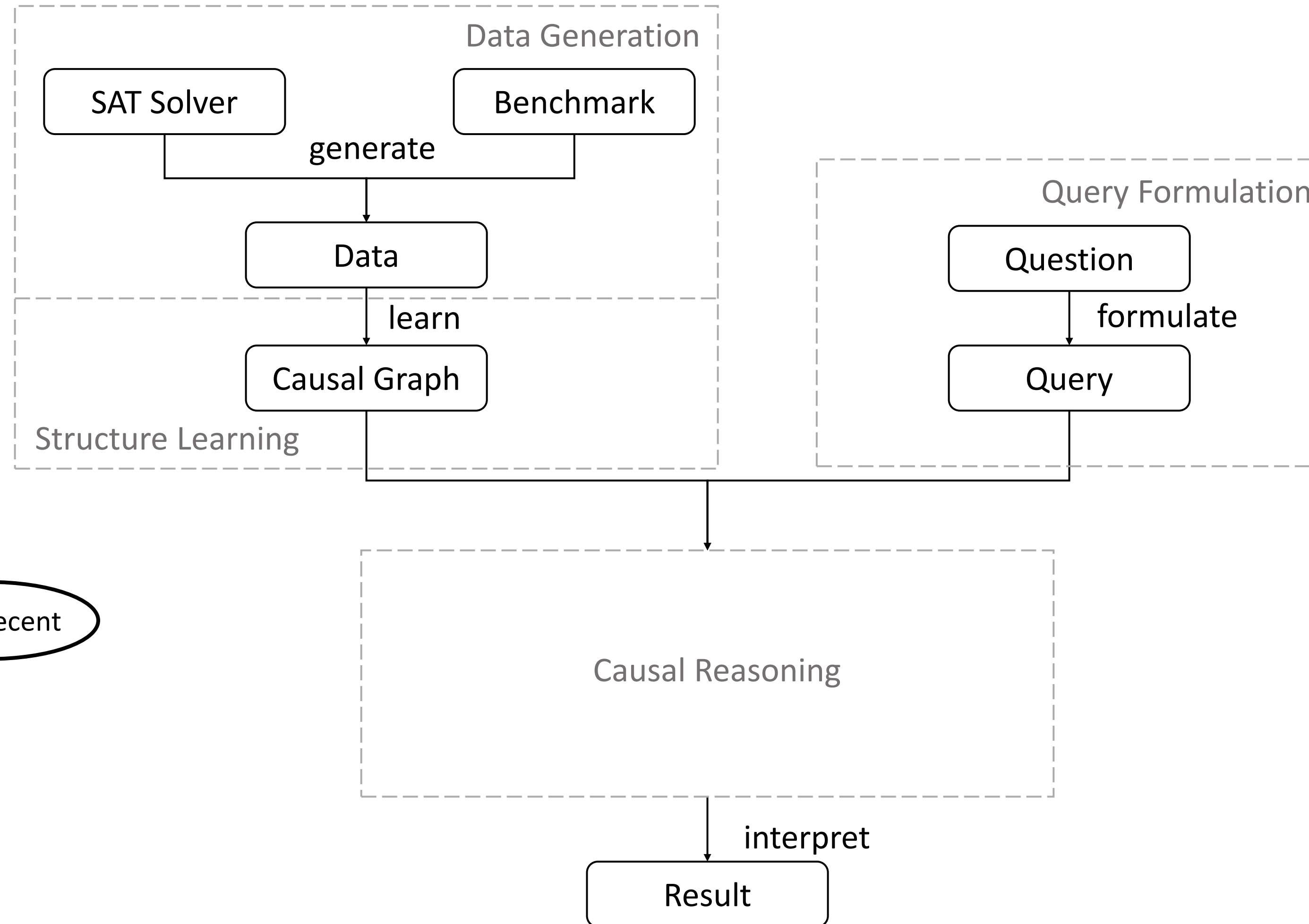
Propagation: the number of propagations the clause was involved.

UsedRecent: the number of conflicts since the clause was used in conflict analysis

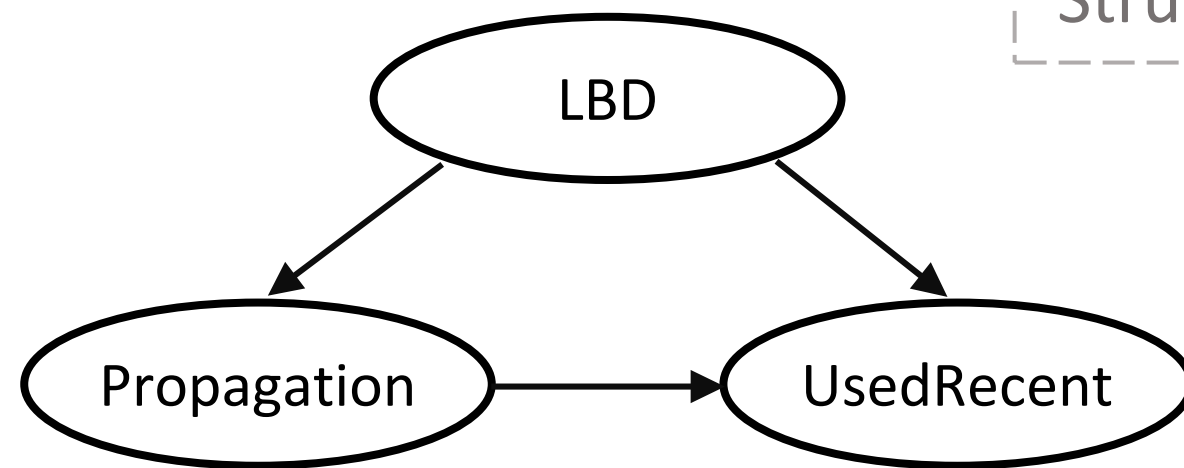
Approach Overview



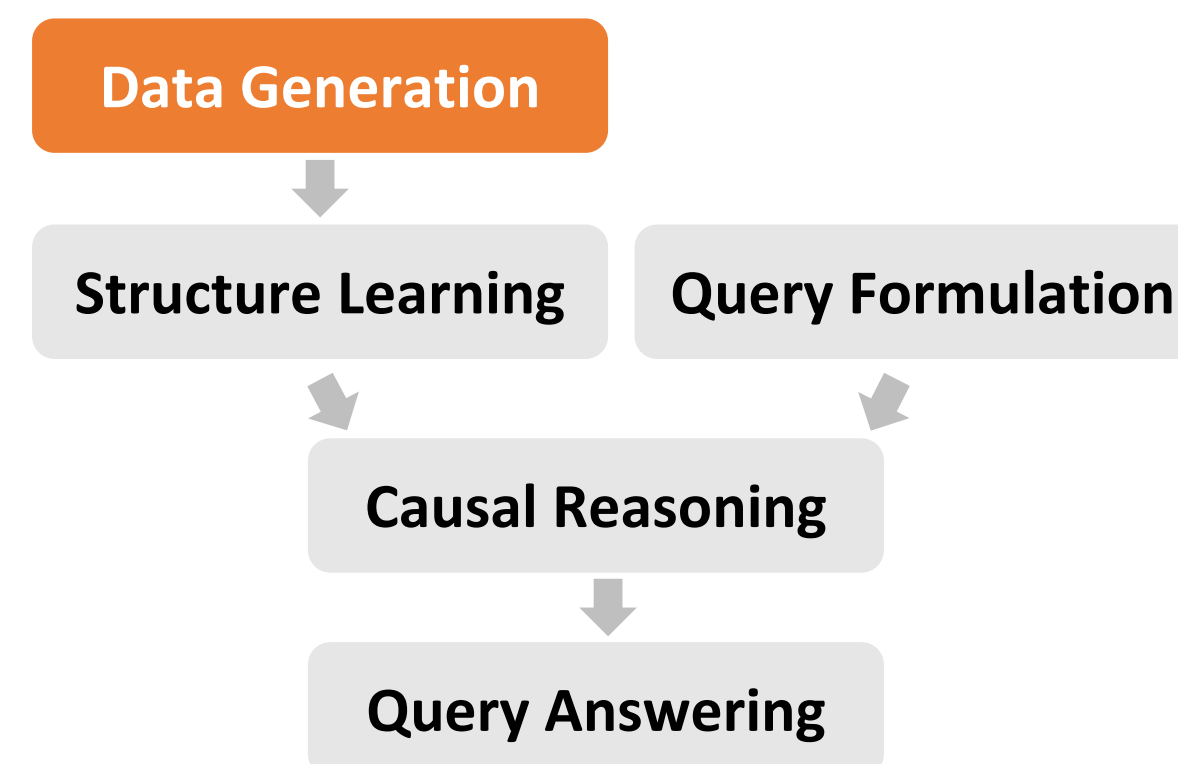
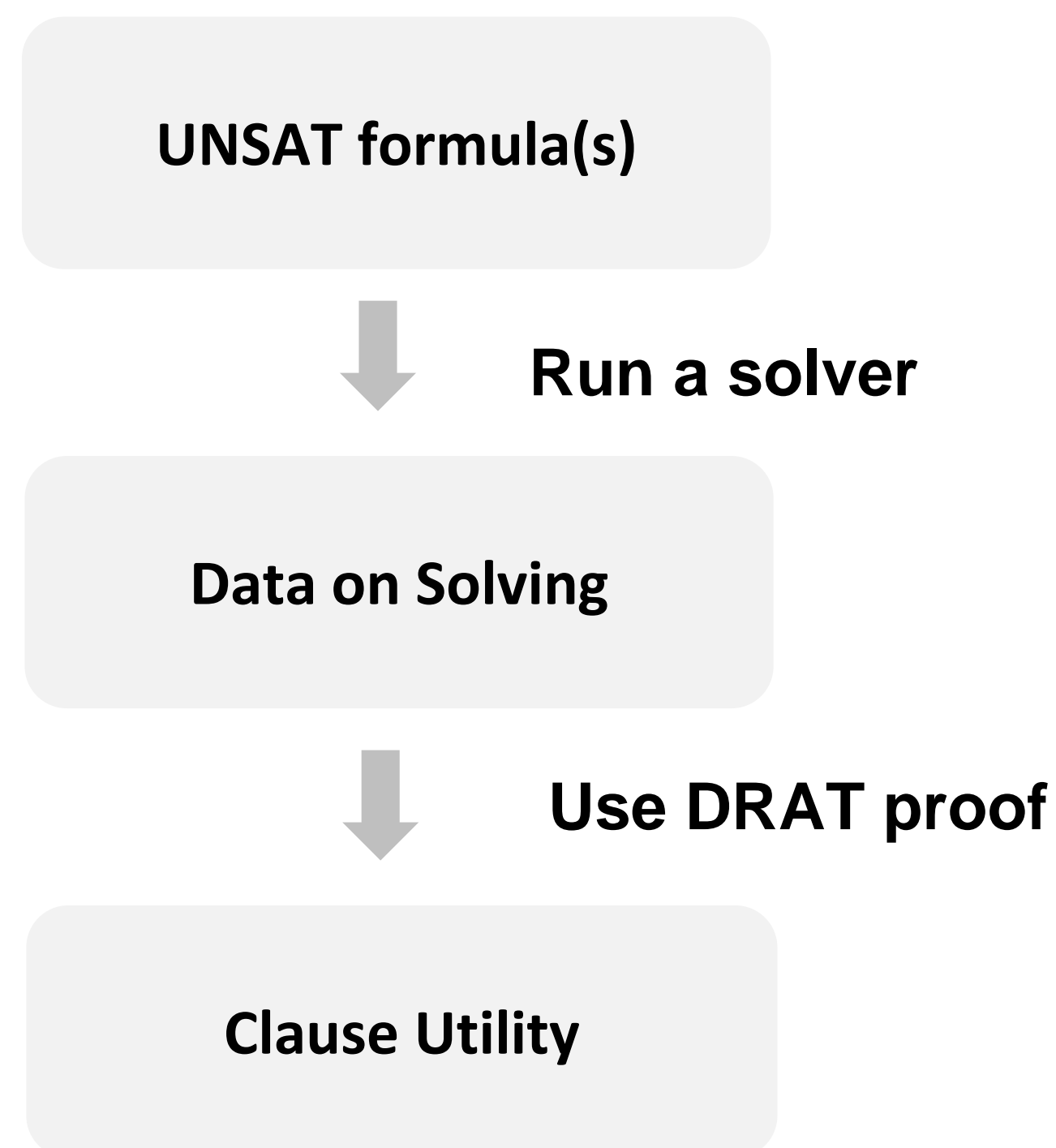
Which clause, with low or high LBD, has greater utility?



Branching	Size	LBD	Time	Utility
Maple	4	2	1000	10
VSIDS	7	3	10000	2
Maple	3	2	100	100



Data Generation



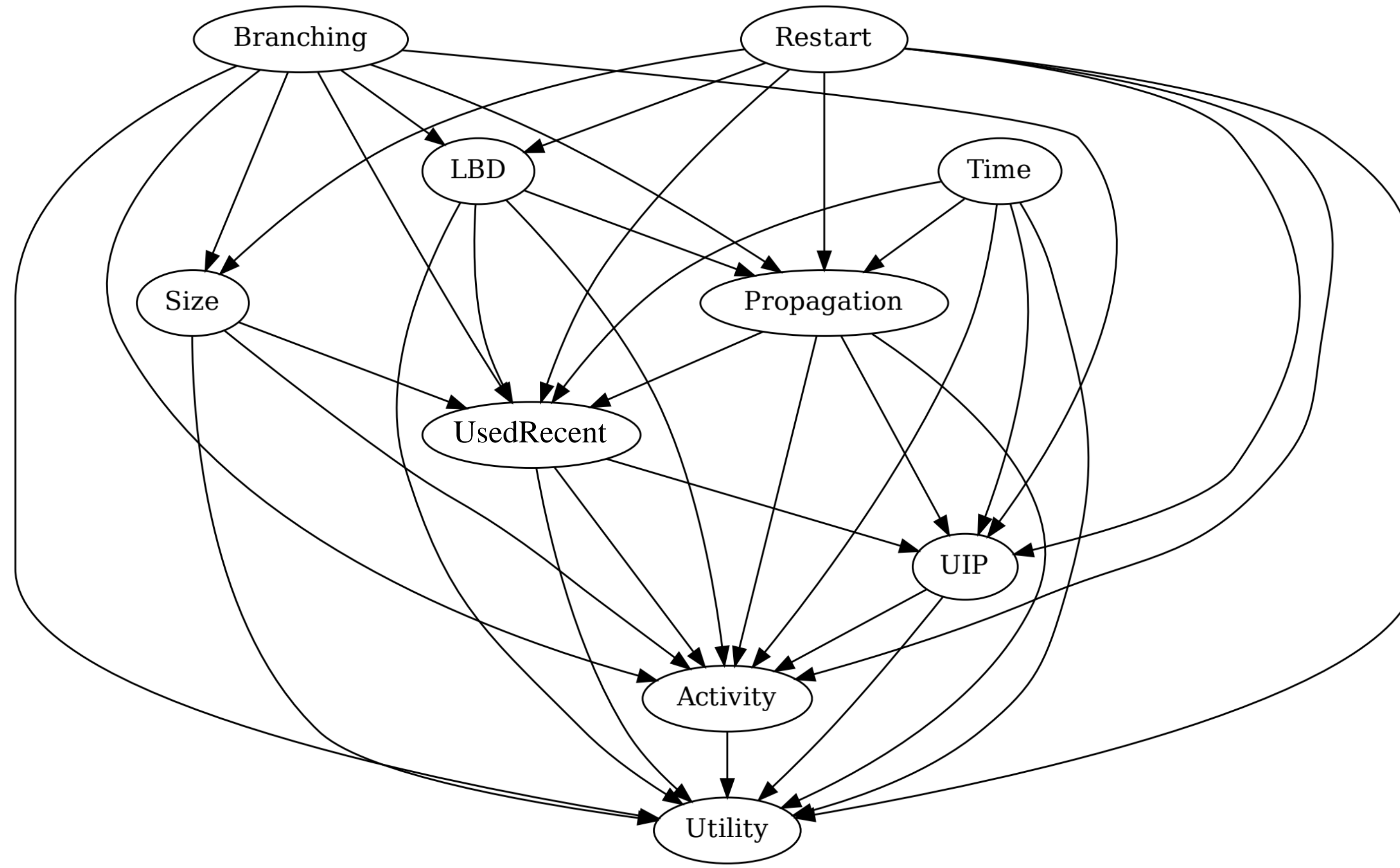
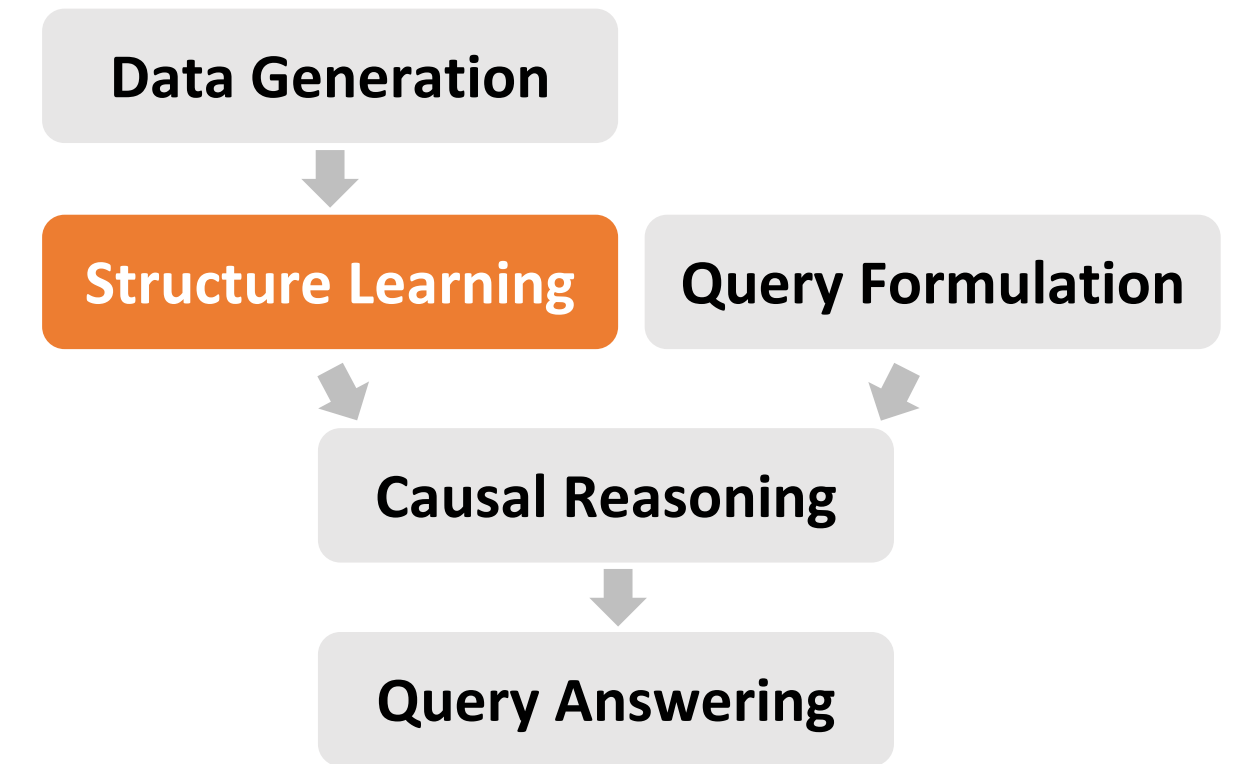
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Clause Utility: the number of times a clause has been used in UNSAT proof during next 10k conflicts.

We generate data using CrystalBall Framework ^[1]

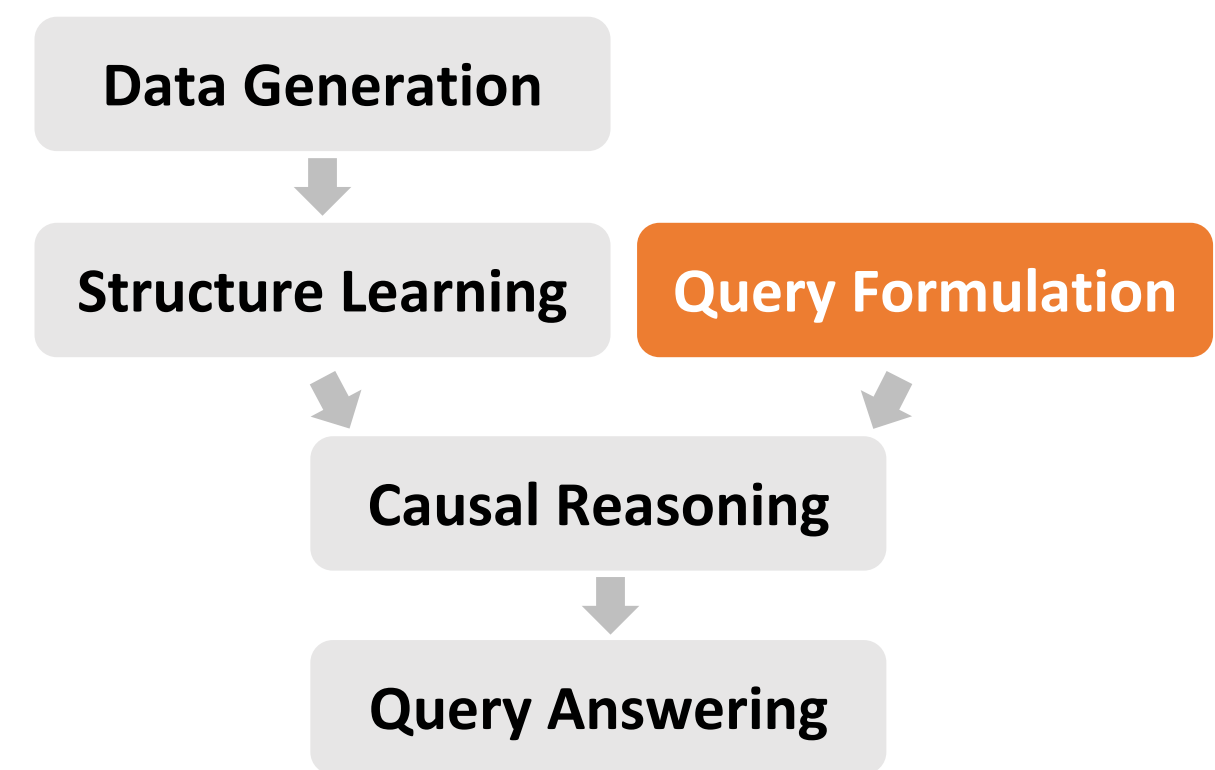
^[1] CrystalBall : Gazing at the Black-box of SAT Solving : Soos, Kulkarni, Meel (SAT '19)

Structure Learning



Causal graph

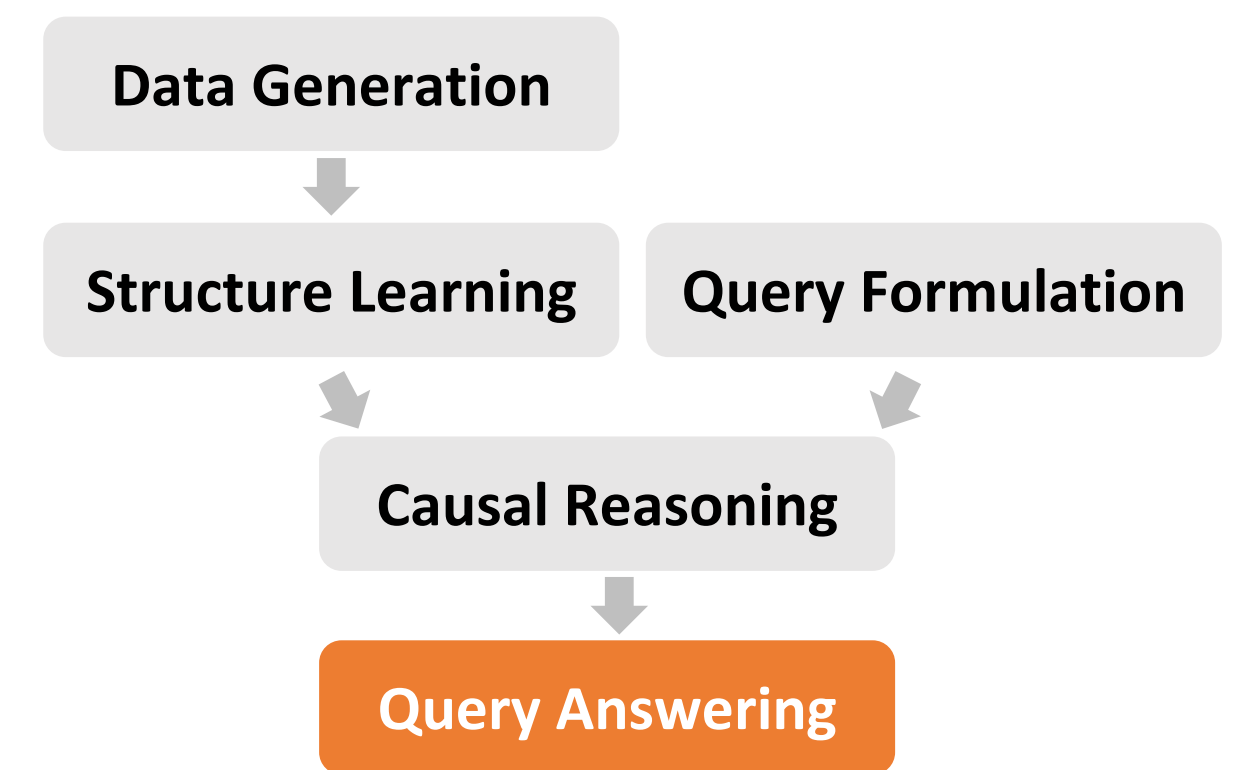
Query Formulation



Question	Query	Explanation
Which clause, with low or high LBD, has greater utility?	$ATE(LBD, Utility, 2, 1) < 0$	$ATE(X, Y, a, b)$: effect on Y if X changes from b to a.
Which clause, with low or high LBD, experiences a rapid drop in utility over time?	$CATE(Time, Utility, LBD \leq 6, 10000, 0) \geq 0$ $CATE(Time, Utility, LBD > 6, 10000, 0) < 0$	$CATE(X, Y, C, a, b)$: ATE given a condition C.
Which type of clause, large or small, has greater utility? What if the LBD is fixed?	$ATE(Size, Utility, 2, 1) < 0$ $ACATE(Size, Utility, LBD, 2, 1) > 0$	$ACATE(X, Y, Z, a, b)$: ATE while Z is fixed

ATE: Average Treatment Effect
CATE: Condition Average Treatment Effect
ACATE: Average CATE

Query Answering



Question	Query	Conclusion
Which clause, with low or high LBD, has greater utility?	$ATE(LBD, Utility, 2, 1) = -0.26 < 0$	Low-LBD clause has greater utility.
Which clause, with low or high LBD, experiences a rapid drop in utility over time?	$CATE(Time, Utility, LBD \leq 6, 10000, 0) = 0.38 > 0$ $CATE(Time, Utility, LBD > 6, 10000, 0) = -0.09 < 0$	High-LBD clause experiences a rapid drop in utility over time.
Which type of clause, large or small, has greater utility? What if the LBD is fixed?	$ATE(Size, Utility, 2, 1) = -0.03 < 0$ $ACATE(Size, Utility, LBD, 2, 1) = -0.02 < 0$	Small clause has greater utility, which also holds when LBD is fixed.

More Conclusions:

1. LBD has a greater impact than clause size.
2. Propagation has the greatest impact on utility besides LBD, size, and Activity.
3. For branching heuristic, Maple leads to greater utility than VSIDS.
4. For restart heuristic, Luby leads to the greatest utility against LBD-based and Geometric.

$ATE(X, Y, a, b)$: effect on Y if X changes from b to a.
 $CATE(X, Y, C, a, b)$: ATE given a condition C.

Future Work

- Causal effect on solving time.
- Study the hardness of benchmarks.
 - Causal effect of attributes on solving time.
 - Attributes of benchmark: #variable, #clause, treewidth, the like.

Q & A