Visualizing Dynamic Programming On Tree Decompositions

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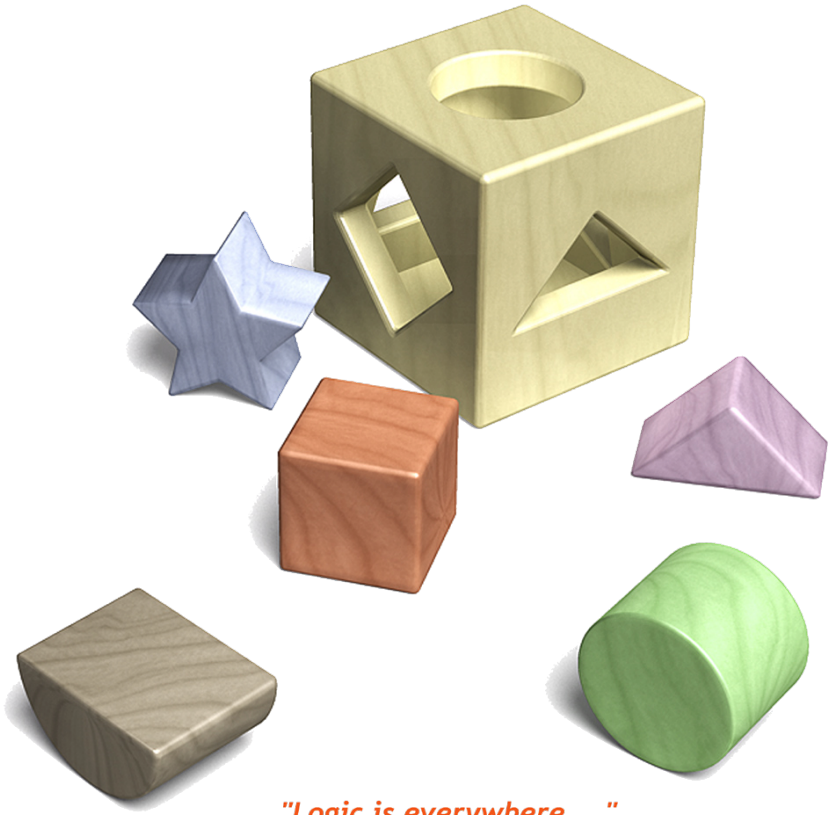
- WHAT **is the motivation**
- WHO **benefits from visualization?**
- CHALLENGES **and solutions**
- WHAT **could be used otherwise?**
- OUTLOOK **and ideas**



"Logic is everywhere ..."

Motivation

- **DP-on-TD-algorithms can solve Model Counting and various combinatorial problems**
- **Implementations of those are competing with modern solvers**
- **But: those are fairly hard to implement efficiently**
- **Practical debug output quickly becomes very large (GB)**
- **Finding the cause of the problem is a time consuming challenge**

The B.T. probably focused too much on the convenience features, and not on the urgent need for better debugging and visualization needs for those algorithms.

Background

The algorithms of interest solve problems of:

- **combinatorics (NP-problems)**
- **model-counting (#P-problems)**

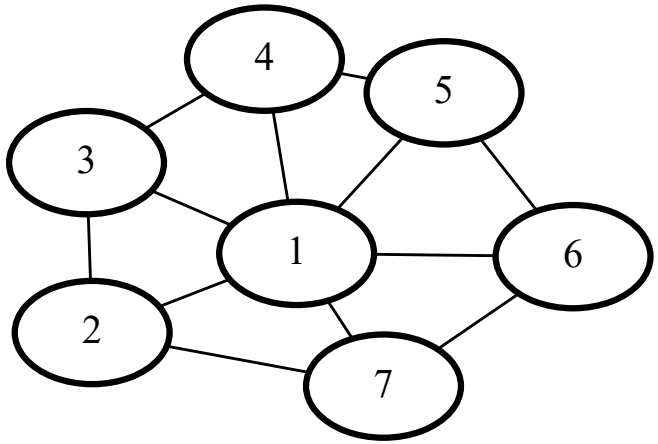
Recent promising results for Projected Model Counting by Markus Hecher[1].
-¿ Show model counting in a tree example

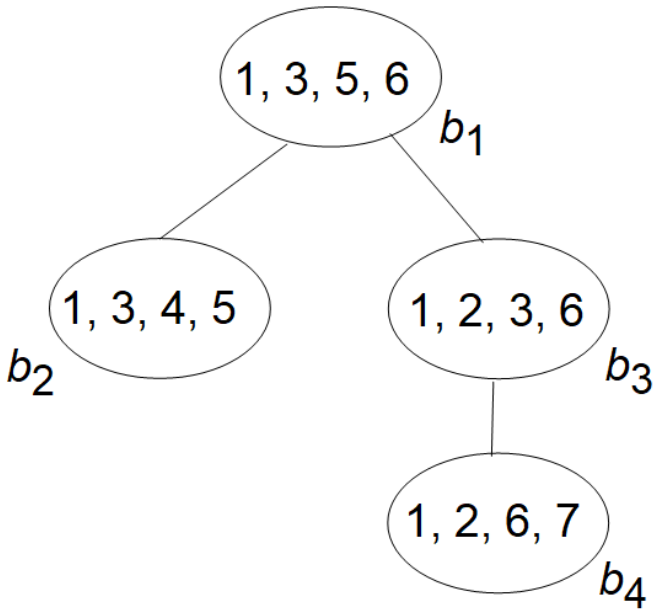
[1] Hecher M., Thier P., Woltran S. (2020) Taming High Treewidth with Abstraction, Nested Dynamic Programming, and Database Technology. In: Pulina L., Seidl M. (eds) Theory and Applications of Satisfiability Testing - SAT 2020. SAT 2020. Lecture Notes in Computer Science, vol 12178. Springer, Cham. https://doi.org/10.1007/978-3-030-51825-7_25

Tree Decomposition

Gives the DP algorithm a partial ordering for sub-problems.

1. **Each vertex must occur in some bag**
2. **For each edge, there is a bag containing both endpoints**
3. **Connected: Subgraph "restricted" to any vertex must be connected**





Width of TD = largest bag -1

Graphs for Boolean Formulas

- **Example set of CNF-clauses:**

$\{c1 = \{v1, v3, \neg v4\}, c2 = \{\neg v1, v6\}, c3 = \{\neg v2, \neg v3, \neg v4\}, c4 = \{\neg v2, v6\}, c5 = \{\neg v3, \neg v4\}, c6 = \{\neg v3, v5\}, c7 = \{\neg v5, \neg v6\}, c8 = \{v5, v7\}\}$

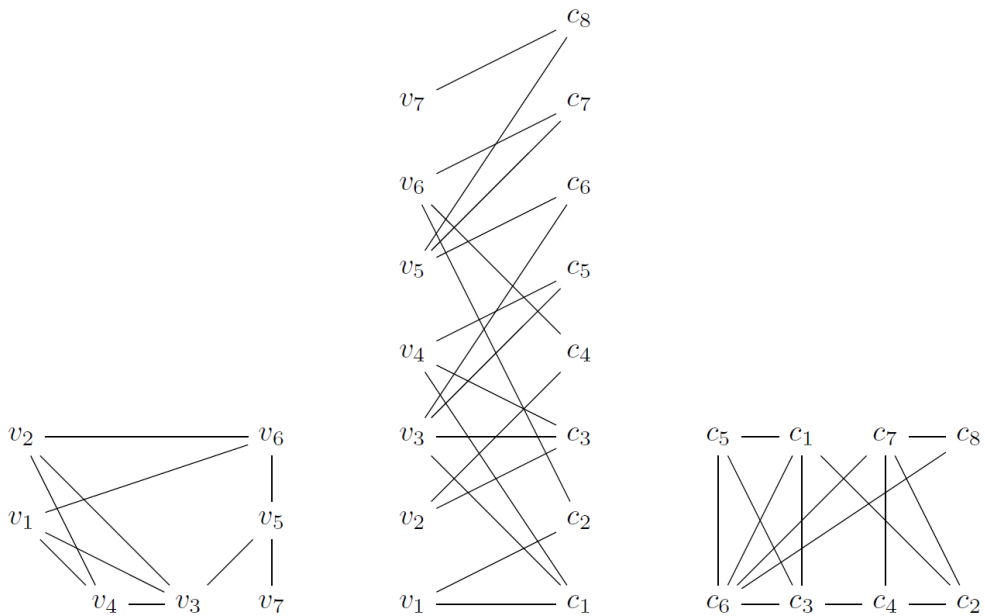
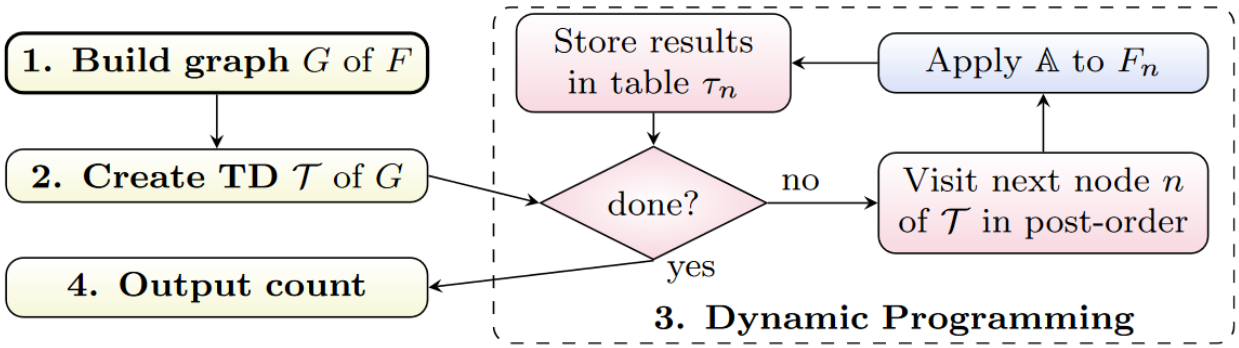
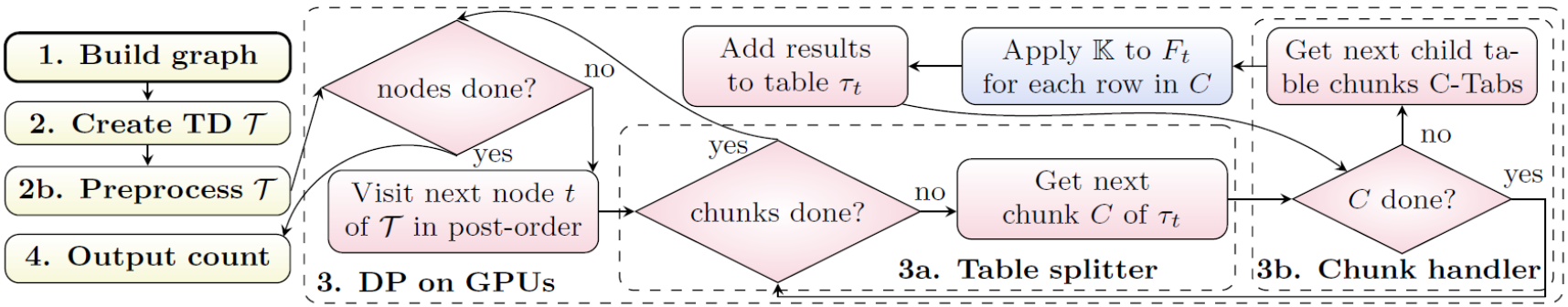


Figure: The primal (left), incidence (middle) and dual (right) graph

gpusat2 - Solving #SAT on GPU



- **Customized tree decompositions**
- **Adapted memory-management**
- **Improved precision handling**



[1] Images: Markus Zisser. *Solving the #SAT problem on the GPU with dynamic programming and OpenCL*. Technische Universität Wien, 2018.

dpdb

Database templates in Python
Generating SQL queries

1. **Create graph representation**
2. **Decompose graph**
3. **Solve sub-problems**
4. **Combine rows**

- #εTab#: `SELECT 1 AS cnt`
- #intrTab#: `SELECT 1 AS val UNION ALL 0`
- #localProbFilter#: $(l_{1,1}$ `OR ... OR` $l_{1,k_1})$ `AND ... AND` $(l_{n,1}$ `OR ... OR` $l_{n,k_n})$
- #aggrExp#: `SUM(cnt) AS cnt`
- #extProj#: τ_1`.cnt * ... *` τ_ℓ`.cnt AS cnt`

(a) Problem #SAT

- #εTab#: `SELECT 0 AS card`
- #intrTab#: `SELECT 1 AS val UNION ALL 0`
- #localProbFilter#: $([\![u_1]\!]$ `OR` $[\![v_1]\!])$ `AND ... AND` $([\![u_n]\!]$ `OR` $[\![v_n]\!])$
- #aggrExp#: `MIN(card) AS card`
- #extProj#: τ_1`.card + ... +` τ_ℓ`.card -` $(\Sigma_{i=1}^{\ell}|\chi(t_i) \cap \{a_1\}|$ `- 1) *` $\tau_1.[\![a_1]\!]$ `- ... -` $(\Sigma_{i=1}^{\ell}|\chi(t_i) \cap \{a_k\}|$ `- 1) *` $\tau_1.[\![a_k]\!]$

(b) Problem MinVC

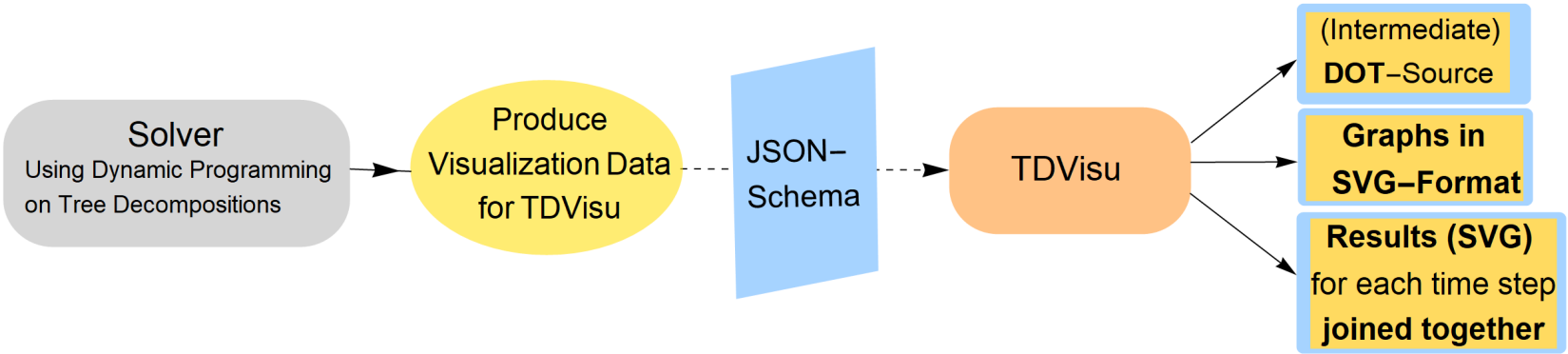
- **SAT and #SAT**
- **#o-Coloring**
- **Vertex cover**

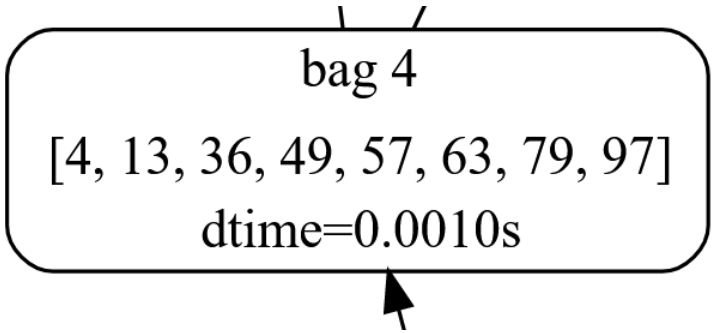
. . .

[1] "Exploiting Database Management Systems and Treewidth for Counting", Johannes Fichte et al. doi: 10.1007/978-3-030-39197-3_10.

Running tdvisu

Figure: TDVisu producing flexible and further processable formats.





sol bag 4						
v4	v13	v49	v57	v63	v97	size
0	1	0	1	1	1	82
1	0	1	1	1	1	83
1	1	0	1	1	1	82
1	1	0	1	0	1	82
1	1	1	0	1	1	82
1	1	1	1	1	1	83
1	0	0	1	1	1	82
1	1	1	1	1	0	83
1	1	1	1	0	1	83
0	1	1	1	1	1	83
1	1	0	0	1	1	81
1	1	0	1	1	0	82
min-size: 81						

Challenge2

- Wie robust ist die Datenverarbeitung in der Visu Restrictions in strings for ids - Was Gedanken bei der Visu waren

Visualization in Action

MinVC example size 90 (expected 82)

Visualization in Action

1. **Inspect visualization**
2. **Verify findings in solver (in this case dpdb)**

public.p3_td_node_59/logicsem/postgres@PostgreSQL 12

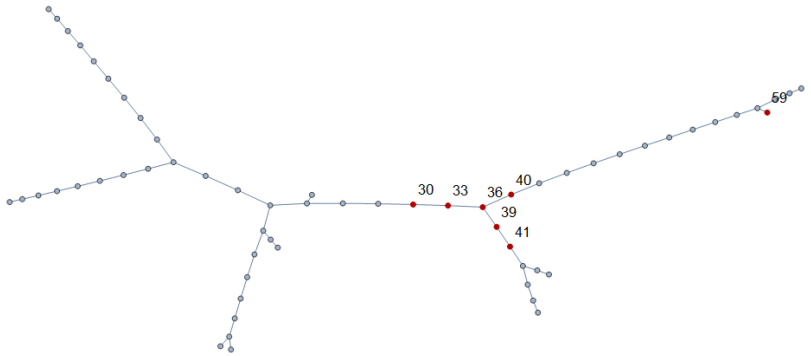
Query Editor | Query History

```
1  SELECT * FROM public.p3_td_node_59
2
```

Data Output | Explain | Messages | Notifications

	v16 boolean	v23 boolean	v40 boolean	v41 boolean	v52 boolean	v55 boolean	v60 boolean	v61 boolean	v66 boolean	v84 boolean	v99 boolean	v100 boolean	size integer
1	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	8

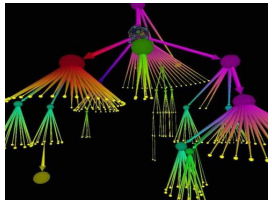
3. **Cross reference with standalone tree-decomposition**



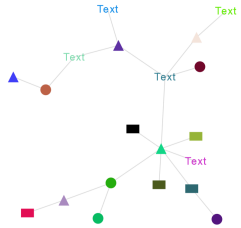
4. **Fix the root cause**

Related Work

- **Fichte, Johannes & Hecher, Markus & Morak, Michael & Woltran, Stefan. (2018). Exploiting Treewidth for Projected Model Counting and Its Limits. 10.1007/978-3-319-94144-8_11.**
- **Hecher, Markus. (2020). Treewidth-aware Reductions of Normal ASP to SAT - Is Normal ASP Harder than SAT after All?. 485-495. 10.24963/kr.2020/49.**
- **Hecher M., Thier P., Woltran S. (2020) Taming High Treewidth with Abstraction, Nested Dynamic Programming, and Database Technology. In: Pulina L., Seidl M. (eds) Theory and Applications of Satisfiability Testing - SAT 2020. SAT 2020. Lecture Notes in Computer Science, vol 12178. Springer, Cham. https://doi.org/10.1007/978-3-030-51825-7_25**



Gephi.org[2] Tulip [3]



[4] Vis.js Sigma.js vasturiano/3d-force-graph [5]

Briefly looked up different formats and graph software. With the diverse / large node labels and special layout the creation of a lightweight and customizable exchange format took precedence over the integration into special layout software.

[2] https://gephi.org/ - Tool for data analysts and scientists keen to explore and understand graphs.
[3] tulip.labri.fr/TulipDrupal/ - Better Visualization Through Research.
[4] https://neo4j.com/developer/tools-graph-visualization/
[5] https://github.com/vasturiano/3d-force-graph

Visualization

Manually for one run

τ_1 :

ID	c_1	c_5	c_6	n Sol
0	0	0	0	48
1	1	0	0	4
2	0	1	0	16
3	1	1	0	0
4	0	0	1	15
5	1	0	1	1
6	0	1	1	10
7	1	1	1	0

τ_4 :

ID	c_1	c_6	n Sol
0	0	0	32
1	1	0	4
2	0	1	10
3	1	1	1

JOIN ⟶

IF ↑

τ_2 :

ID	c_1	c_5	n Sol
0	0	0	12
1	1	0	2
2	0	1	4
3	1	1	0

⟵ JOIN

IF ↑

τ_5 :

ID	c_1	c_2	c_6	n Sol
0	0	0	0	36
1	1	0	0	6
2	0	1	0	4
3	1	1	0	2
4	0	0	1	12
5	1	0	1	2
6	0	1	1	2
7	1	1	1	1

τ_3 :

ID	c_1	c_4	c_5	n Sol
0	0	0	0	16
1	1	0	0	4
2	0	1	0	4
3	1	1	0	2
4	0	0	1	4
5	1	0	1	0
6	0	1	1	0
7	1	1	1	0

IF ↑

τ_6 :

ID	c_1	c_2	n Sol
0	0	0	12
1	1	0	2
2	0	1	2
3	1	1	1

JOIN ⟶

τ_9 :

ID	c_1	c_2	c_3	n Sol
0	0	0	0	16
1	1	0	0	4
2	0	1	0	4
3	1	1	0	2
4	0	0	1	4
5	1	0	1	2
6	0	1	1	2
7	1	1	1	1

IF ↑

τ_7 :

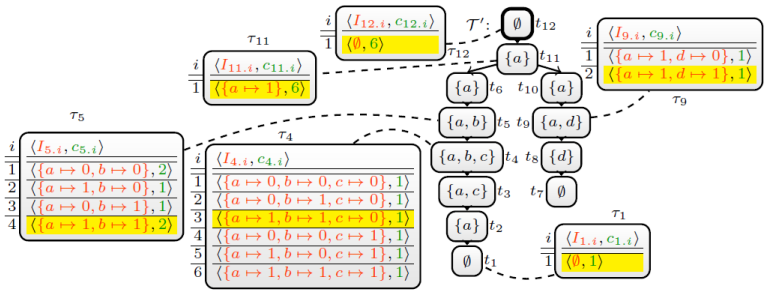
ID	c_2	c_6	n Sol
0	0	0	12
1	1	0	2
2	0	1	4
3	1	1	1

⟵ JOIN

τ_8 :

ID	c_2	c_6	c_7	n Sol
0	0	0	0	16
1	1	0	0	4
2	0	1	0	4
3	1	1	0	1
4	0	0	1	4
5	1	0	1	2
6	0	1	1	0
7	1	1	1	0

IF ↑



[5] "Exploiting Database Management Systems and Treewidth for Counting", Johannes Fichte et al. doi: 10.1007/978-3-030-39197-3_10.

[5] "Solving #SAT on the GPU with Dynamic Programming and OpenCL", Diploma Markus Zisser 2018 Technische Universität Wien, p.33

Outlook

Static $\rightarrow$ Dynamic

Interesting Questions :

- **Utilizing graph databases for visualization and queries for debugging**
- **Enrich the visualization with debugging info for each node**
- **Cross reference the creation of rows in parent nodes**
- **For more advanced debugging tasks you may also need to revise the approach**

Summary

This thesis created tdvisu as a tool that

- **integrates into existing implementations**
- **statically exports data from runs**
- **compiles simple DOT files and SVG graphics**

For further research it provides

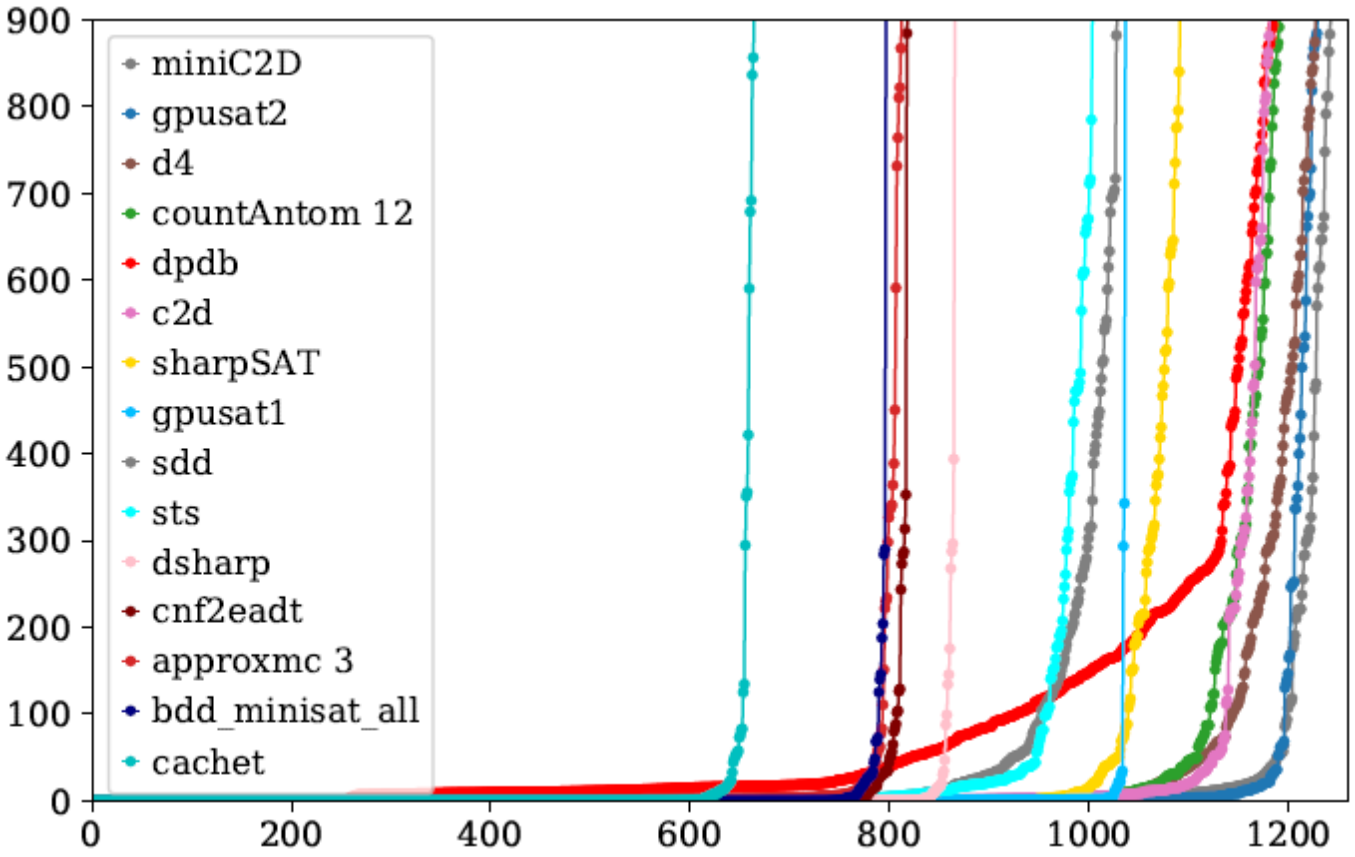
- **starting point for more complex investigations of**
  - **bug spotting**
  - **and fixing by using visualizations**

Bibliography

See the citations in the thesis.

Benchmark

Performance of all three programs on #SAT instances:



Visualization

Manually for dpdb

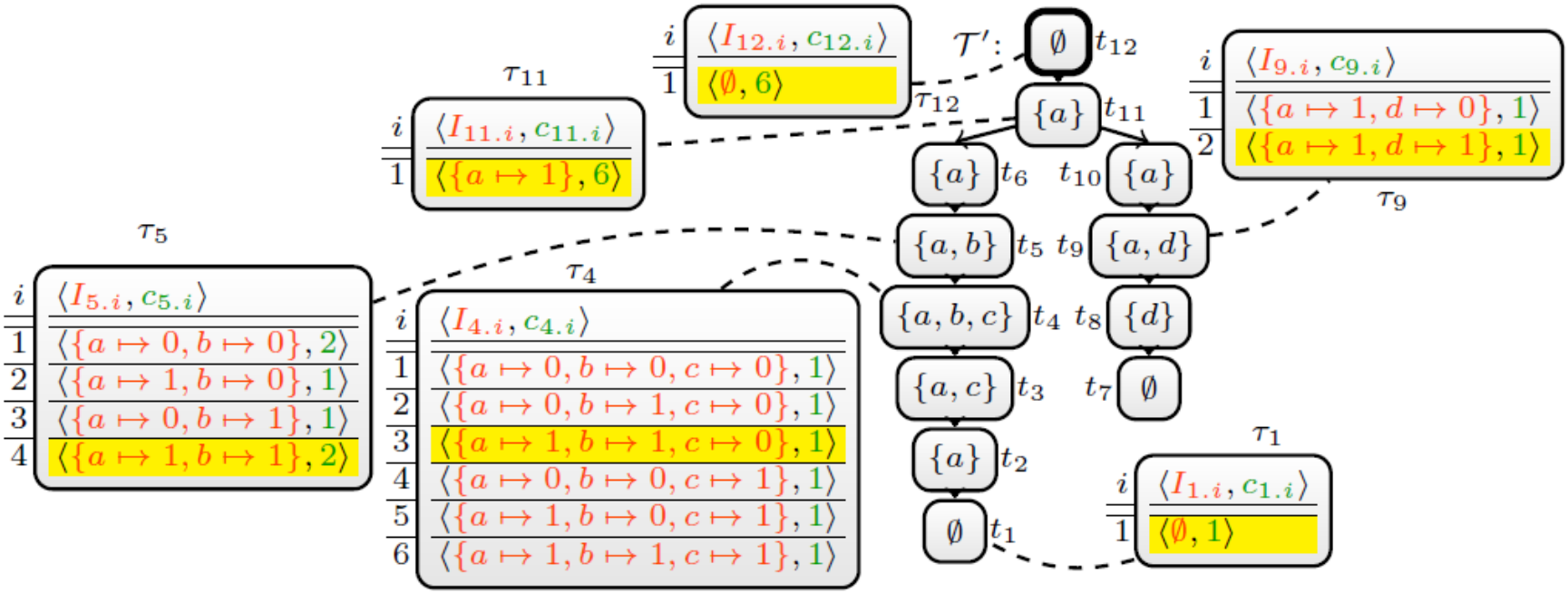


Figure: Handcrafted #SAT example-run from dpdb[6]

[6] "Exploiting Database Management Systems and Treewidth for Counting", Fichte, Hecher, Thier, Woltran