# Visualizing Dynamic Programming On Tree Decompositions

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**Technische Universität Dresden**
**Germany**

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

# Motivation

- DP-on-TD-algorithms can solve various combinatorial problems like model counting
- Efficient (if the treewidth is small)
- Competitive with other modern solvers

- **But tedious and hard to implement if done efficiently**

- Often bugs in the implementation
- DP for model counting is extremely space demanding (much more than SAT)

# Ideas

- **Inspect intermediate data during solving process**
- **Represent the input, tree decomposition and created solutions**
- **Lightweight but customizable output format**

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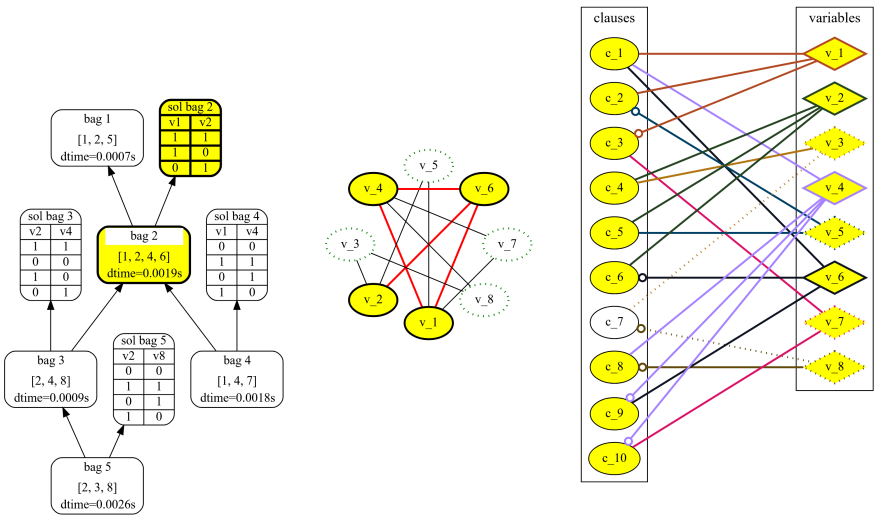

# Contribution

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**

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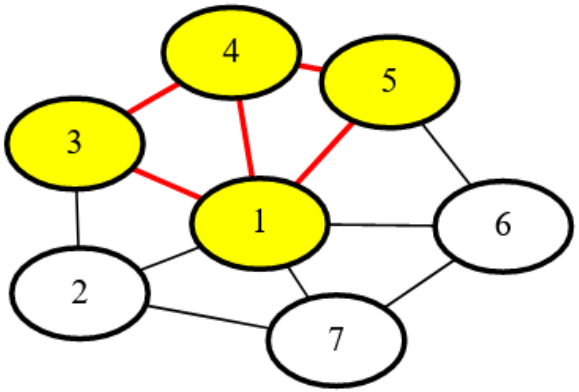

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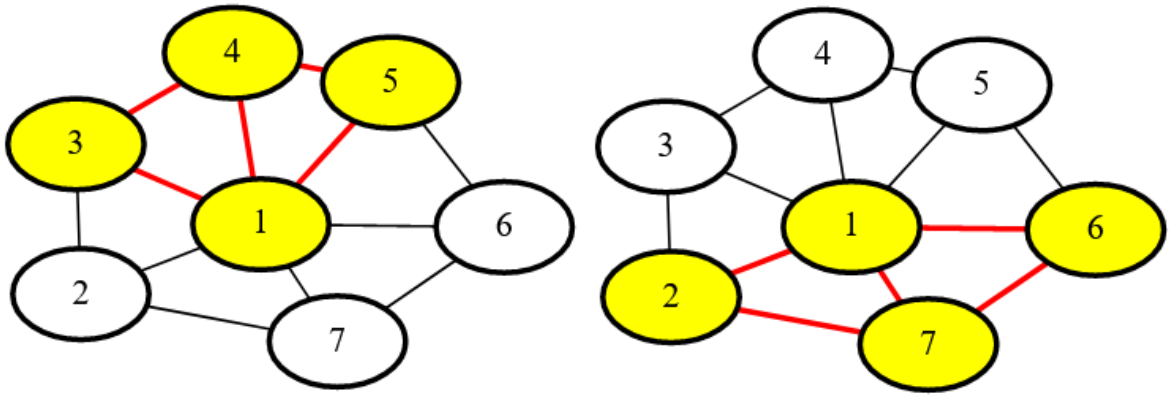
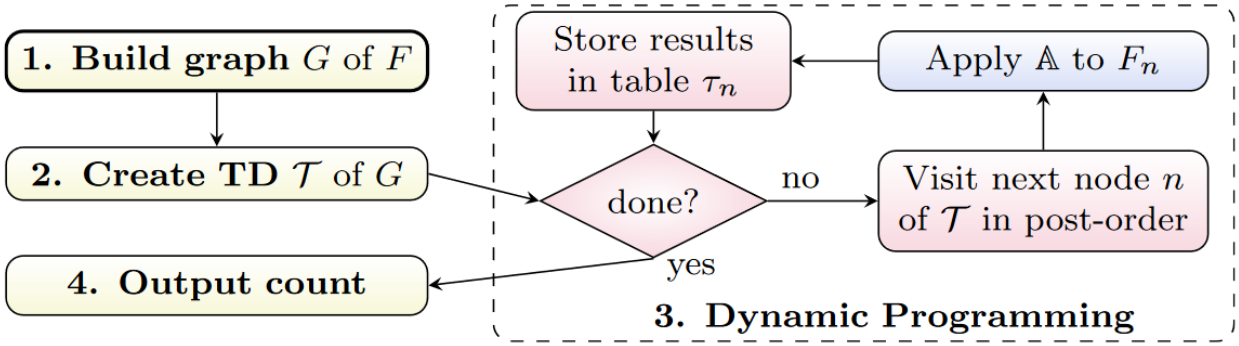


# gpusat2 - Solving #SAT on GPU




- **Customized tree decompositions**

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#: $\tau_1$`.cnt * ... *` $\tau_\ell$`.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#: $\tau_1$`.card + ... +` $\tau_\ell$`.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**

. . .

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

# Tree Decomposition

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

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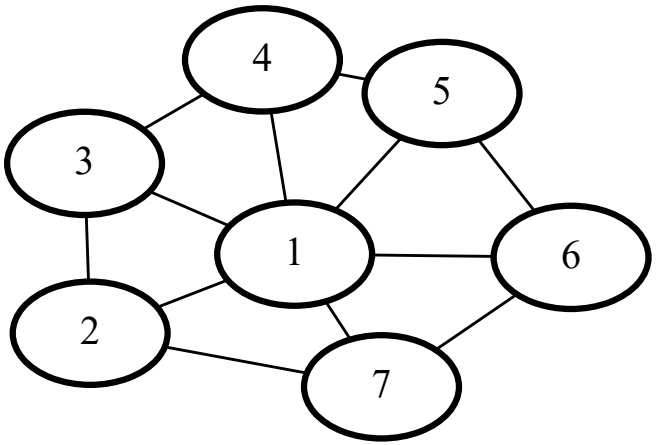


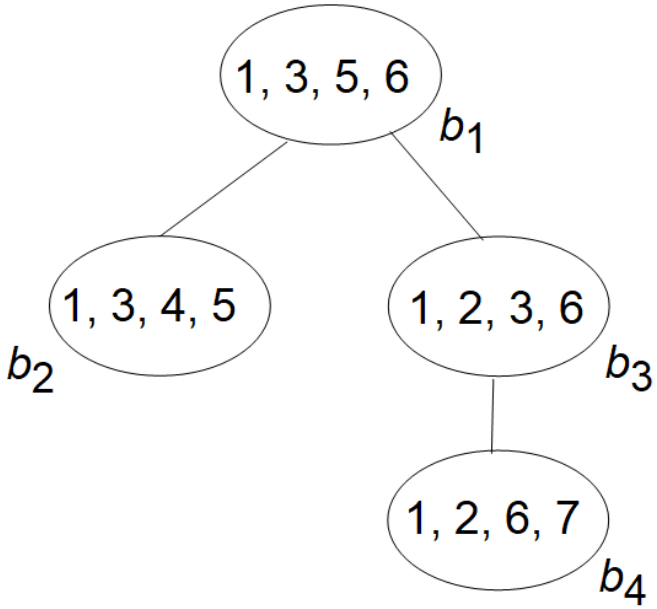


Width of a TD is: size of largest bag -1

***width*** $=$ **3**

# Graphs for Boolean Formulas

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

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

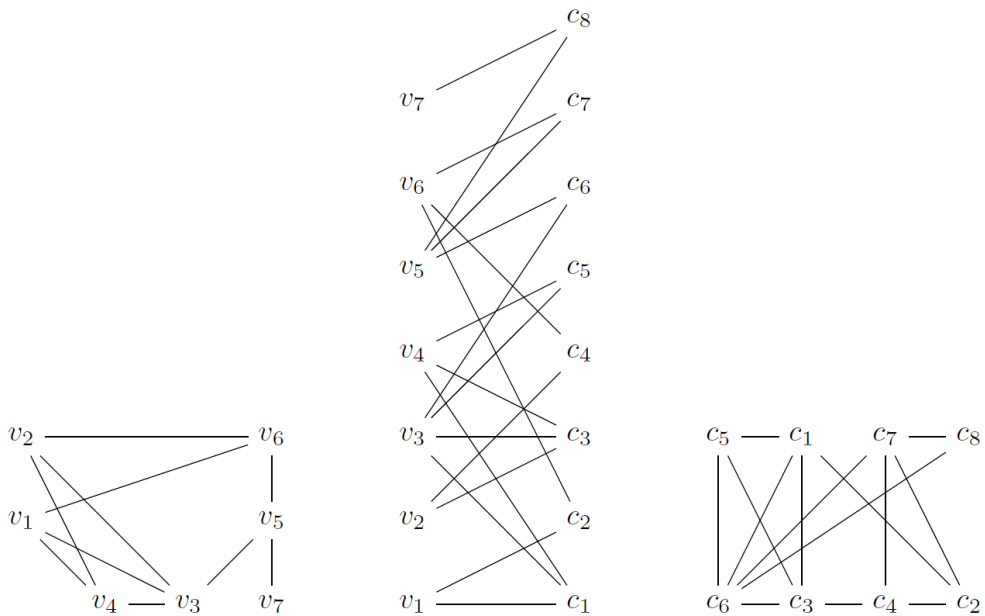


Figure: The primal (left), incidence (middle) and dual (right) graph

# TDVisu

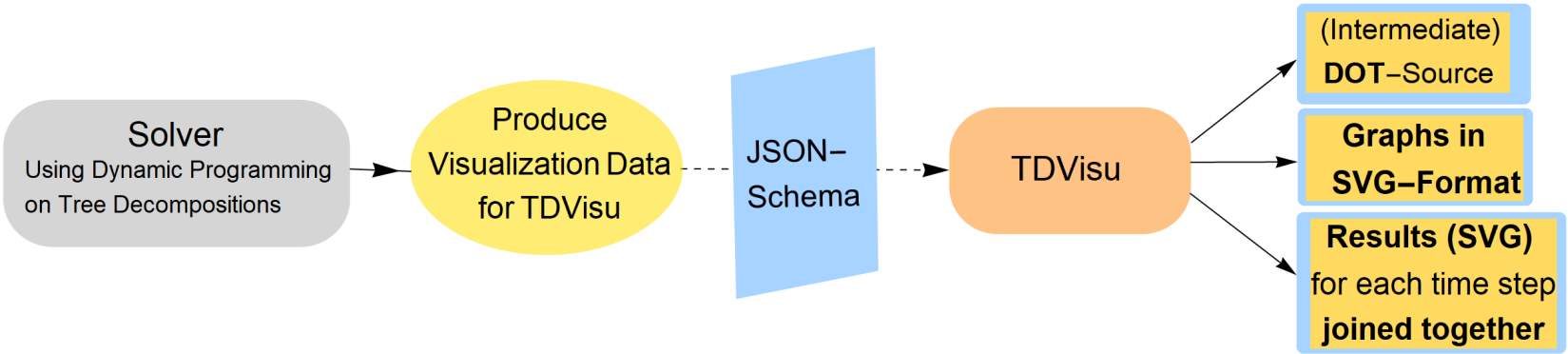


Figure: TDVisu producing flexible and further processable formats

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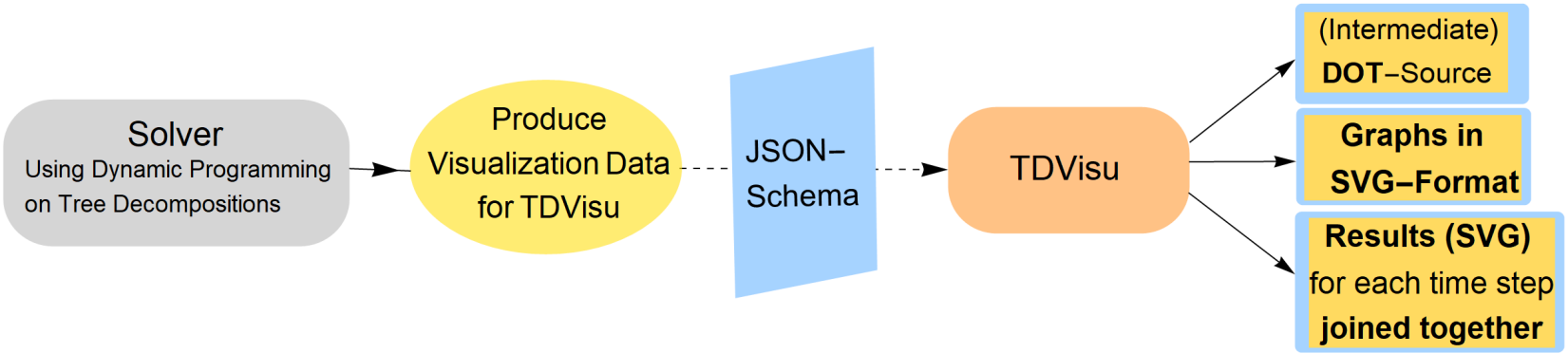


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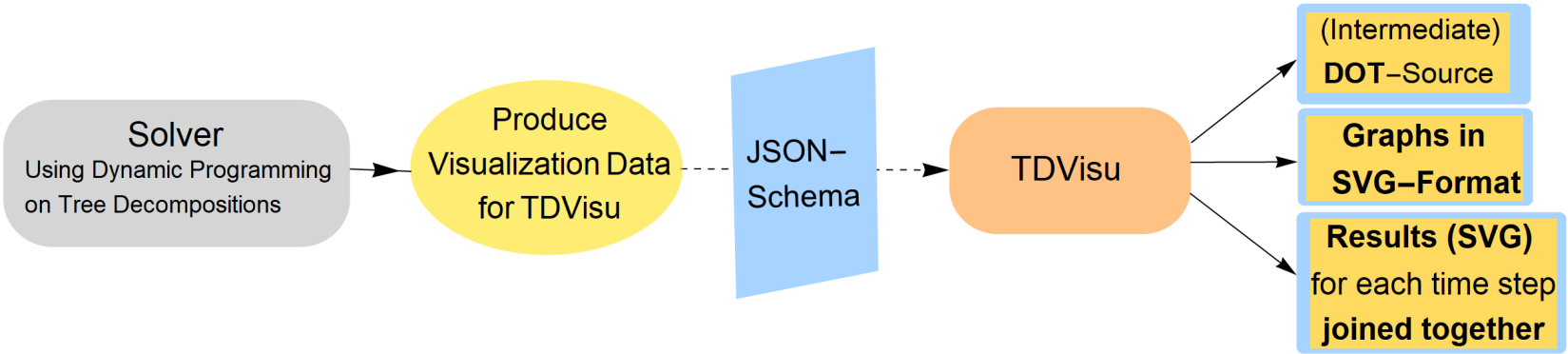



Figure: TDVisu producing flexible and further processable formats

## JSON-Schema specifying:

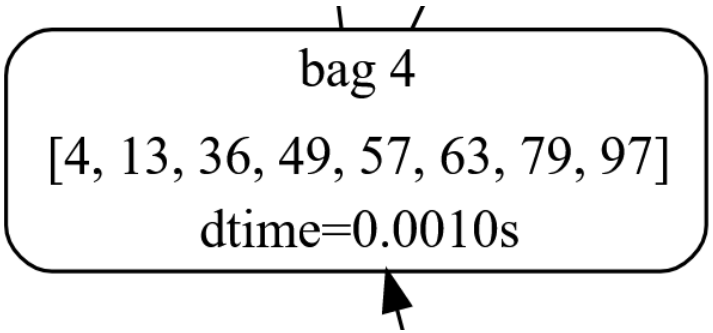
timeline, tree decomposition

incidence graph, general graph

orientation, maximum lines, maximum columns, emphasis, svgjoin info

# Graphics for TD

- **Most cells are interpreted as strings.**
- **Extendable header and footer.**



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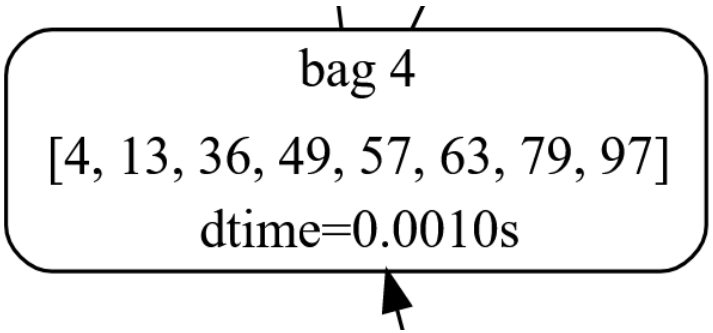


sol bag 4

| 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 |
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| 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

Figure: Bag node and solution node

# Capabilities and Limitations

Integration of solvers via TDVisu.schema.json [1]

**Capabilities:**

- **Extracting basic (extendable) information (TD, solution nodes, order+time of processing...) from gpusat + dpdb**
- **Constructing and enriching the with solver information**
- **Adding multiple graphs for e.g. problems on Boolean formulas**
- **Providing a discrete timeline**
- **Parameters to control the layout and coloring of the data**

**Limitations:**

- **Can not further animate for example the origin of solutions**
- **Maneuvering in very large graphs is not very ergonomic with static content**
- **In the optimal case, a comprehensive test suite should be run prior to this.**

raw.githubusercontent.com/VaeterchenFrost/tdvisu/master/TDVisu.schema.json

# Visualization in Action

MinVC example size 90 (expected 82)

# Debugging with Visualization

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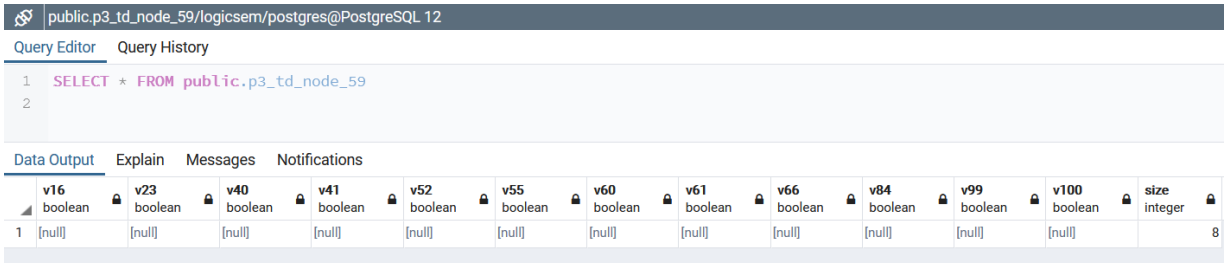


| | v16 boolean | v23 boolean | v40 boolean | v41 boolean | v52 boolean | v55 boolean | v60 boolean | v61 boolean | v66 boolean | v84 boolean | v99 boolean | v100 boolean | size integer |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | [null] | [null] | [null] | [null] | [null] | [null]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

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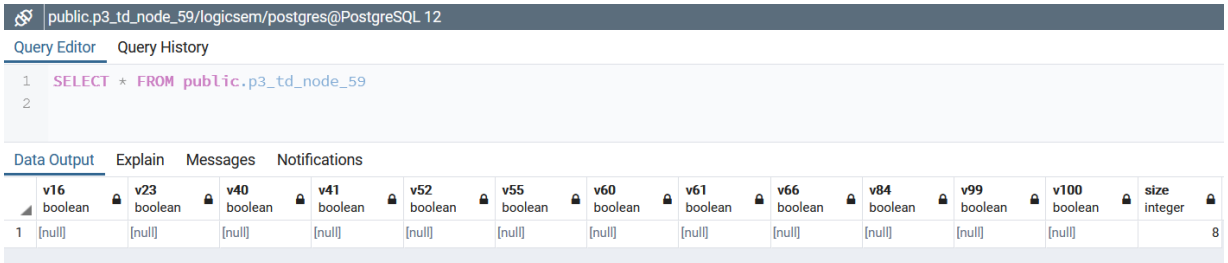


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3. **Cross reference with standalone tree-decomposition**

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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 |
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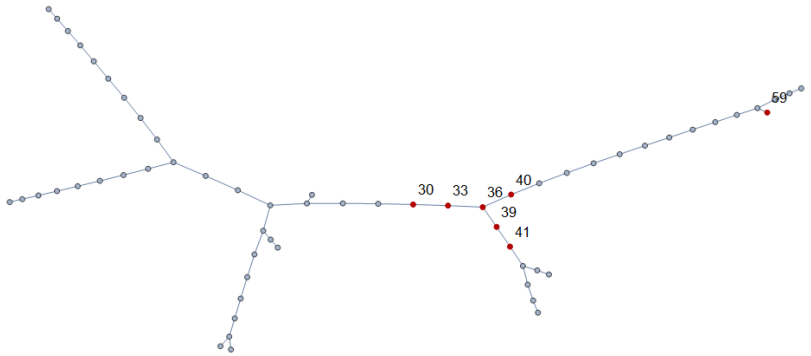

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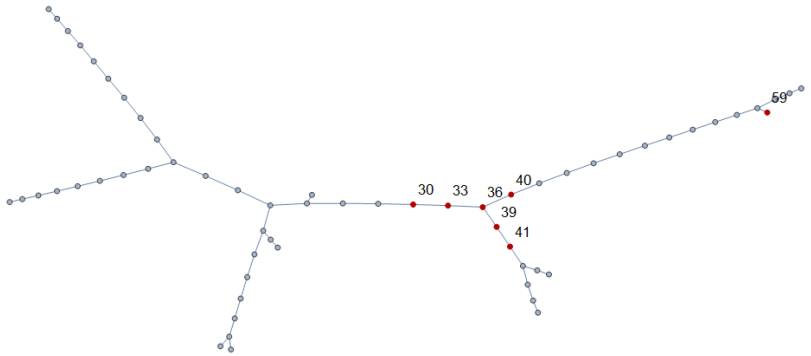



4. **Fix the root cause**

# Related Work on the Algorithms


- 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

# Related Work on Visualizations

- M.-C. Harre, Jelschen, Winter. “ELVIZ: A querybased approach to model visualization”. (Jan. 2014)
- S. Diehl. “Software Visualization. Visualizing the Structure, Behaviour, and Evolution of Software.” Springer, 2007.
- J. Daida et al. “Visualizing Tree Structures in Genetic Programming”. (Mar. 2005)

# Outlook

Static → Dynamic

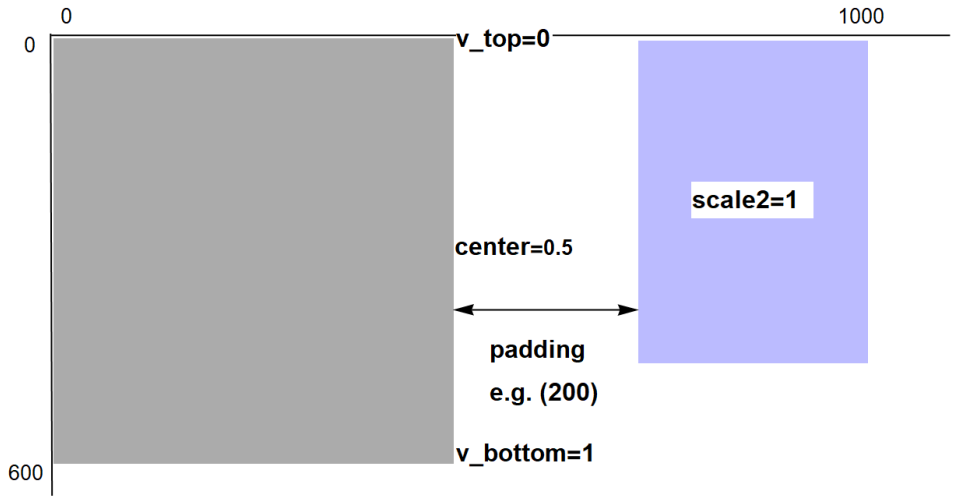
Interesting Questions :

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

# Final slide

# SVG-Join

- **Joining single graphs for each time step**



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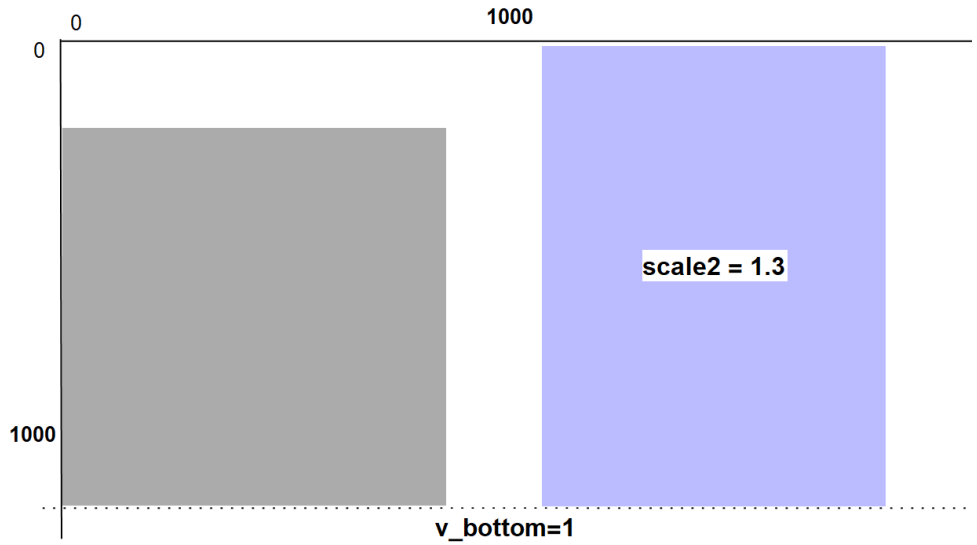
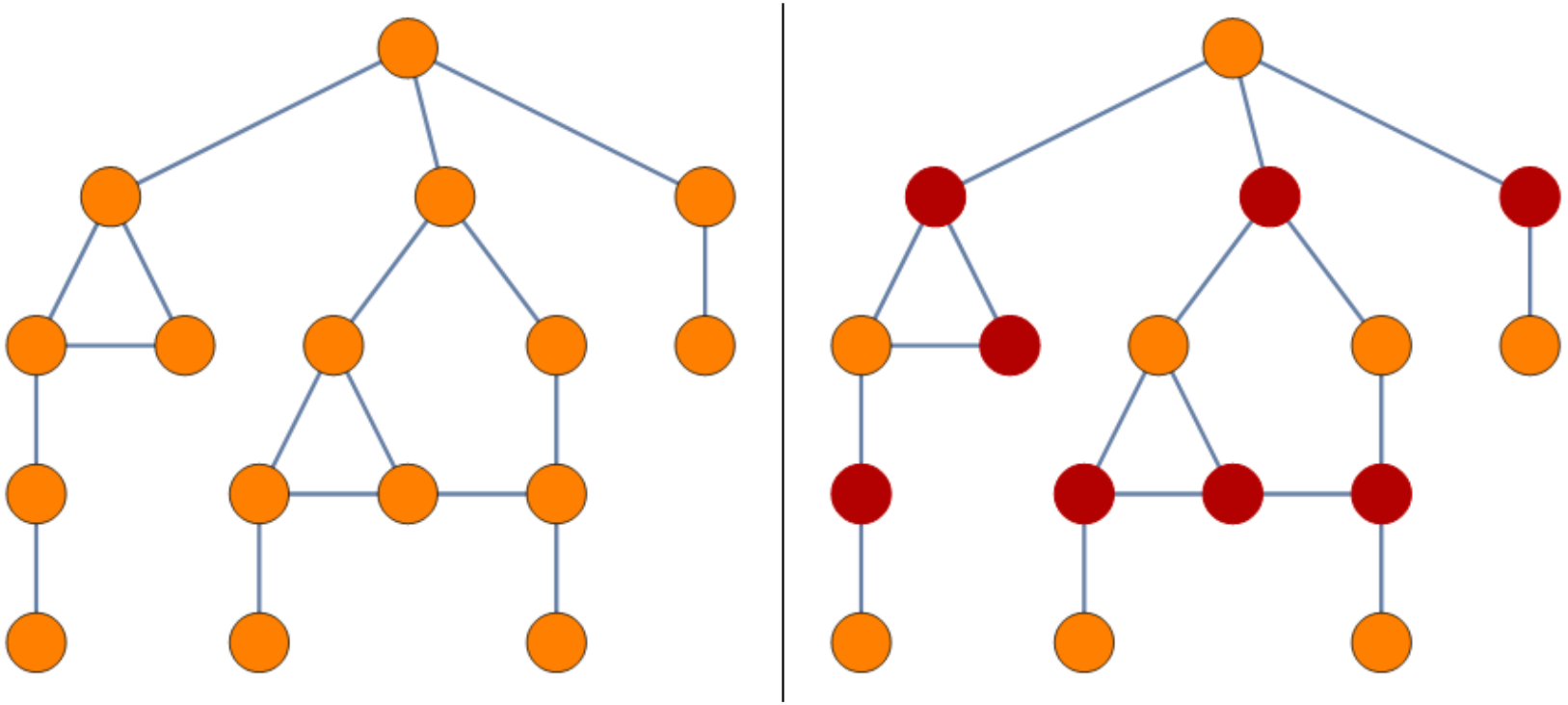
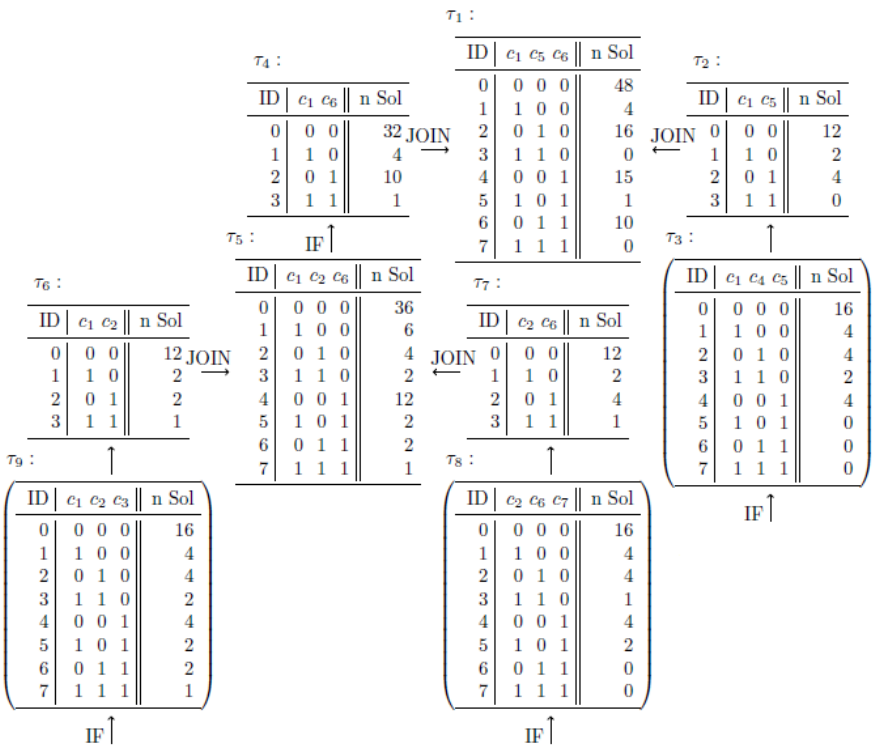


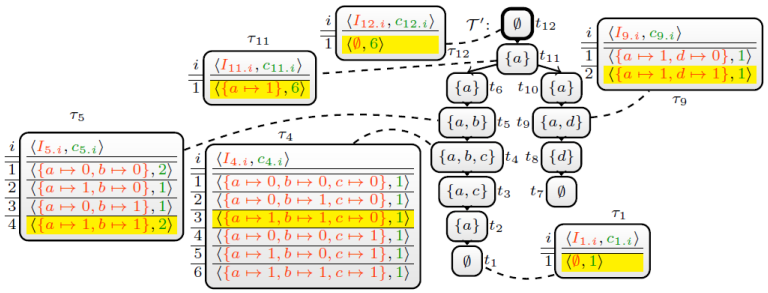
# MinVC for example graph



# Visualization

## Manually for one run

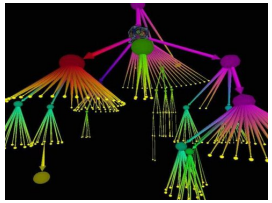


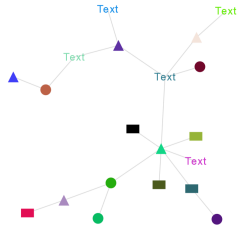

"Exploiting Database Management Systems and Treewidth for Counting", Johannes Fichte et al. doi: 10.1007/978-3-030-39197-3_10.

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





Gephi.org[1] Tulip [2]


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

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.

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

# ELVIZ - Query based approach to software visualization

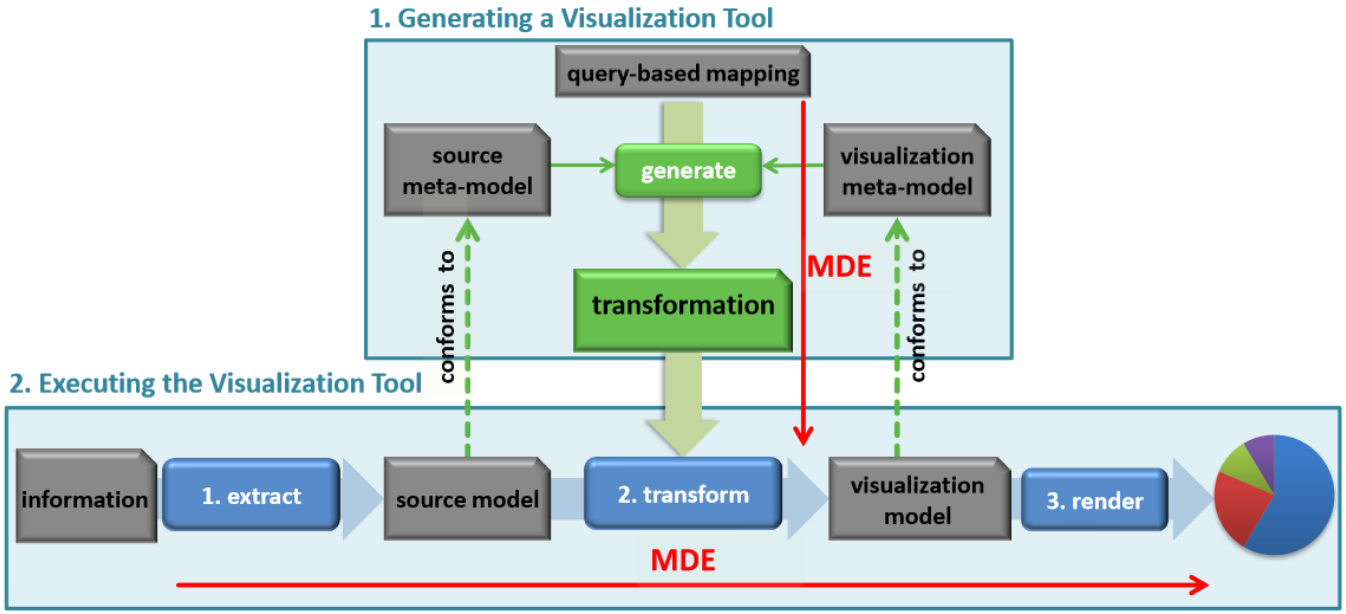


Figure: Overview of the ELVIZ-approach[5]

Fig 1 in: Marie-Christin Harre, J. Jelschen, A. Winter. “ELVIZ: A querybased approach to model visualization”. In: Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft fur Informatik (GI) (Jan. 2014), pp. 105–120.

# Bibliography

See the citations in the thesis.