

Visualizing Dynamic Programming On Tree Decompositions

Martin Röbbke
Fakultät Informatik
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 Model Counting and various combinatorial problems and are provable efficient at it**
- ▶ **Implementations of those are competing with modern solvers**
- ▶ **But: those are fairly tedious to implement efficiently**
- ▶ **Often bugs in the implementation**
- ▶ **Model counting is extremely space intensive (much more than SAT)**

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

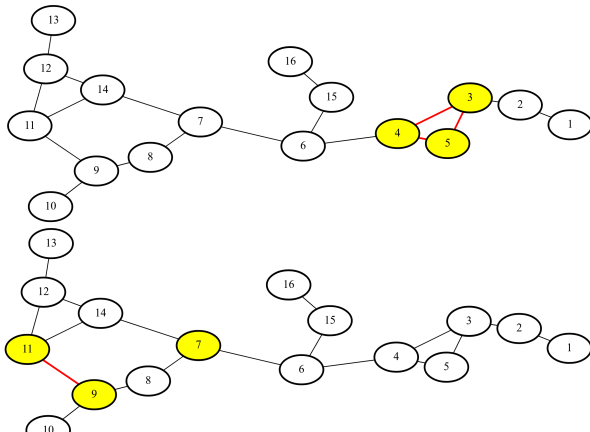
- ▶ **starting point for more complex investigations of**
 - ▷ **bug spotting**
 - ▷ **and fixing by using visualizations**

Background

The algorithms of interest solve problems of:

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

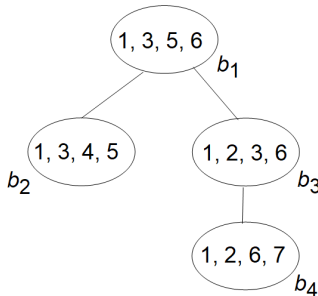
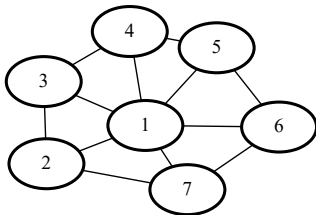
Modelcounting: Instead of **one** solution we want to count **all** solutions.



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. Subgraph “restricted” to any vertex must be connected



Width of a TD is: size of largest bag - 1
width = 3

Graphs for Boolean Formulas

► Example set of CNF-clauses:

$\{c_1 = \{v_1, v_3, \neg v_4\}, c_2 = \{\neg v_1, v_6\}, c_3 = \{\neg v_2, \neg v_3, \neg v_4\}, c_4 = \{\neg v_2, v_6\}, c_5 = \{\neg v_3, \neg v_4\}, c_6 = \{\neg v_3, v_5\}, c_7 = \{\neg v_5, \neg v_6\}, c_8 = \{v_5, v_7\}\}$

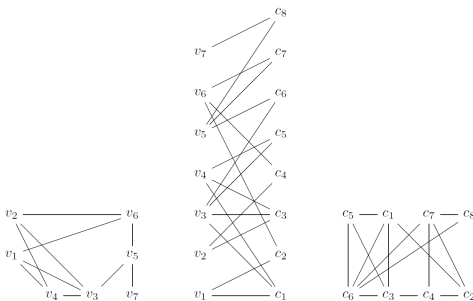
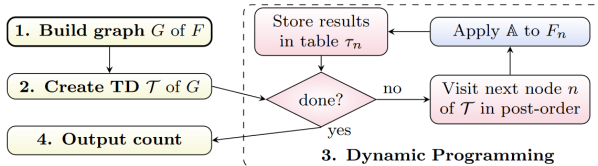


Figure: The primal (left), incidence (middle) and dual (right) graph

gpusat2 - Solving #SAT on GPU



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

⁰Images: Markus Zisser. *Solving the #SAT problem on the GPU with dynamic programming and OpenCL*. Technische Universität Wien, 2018.

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#: (l1,1 OR ... OR l1,k1) AND ... AND (ln,1 OR ... OR ln,kn)
- #aggrExp#:       SUM(cnt) AS cnt
- #extProj#:       τ1.cnt * ... * τℓ.cnt AS cnt

```

(a) Problem #SAT

```

- #εTab#:          SELECT 0 AS card
- #intrTab#:       SELECT 1 AS val UNION ALL 0
- #localProbFilter#: ([u1] OR [v1]) AND ... AND ([un] OR [vn])
- #aggrExp#:       MIN(card) AS card
- #extProj#:       τ1.card + ... + τℓ.card - (Σi=1ℓ |χ(ti) ∩ {a1}| - 1) *
                  τ1. [a1] - ... - (Σi=1ℓ |χ(ti) ∩ {ak}| - 1) * τ1. [ak]

```

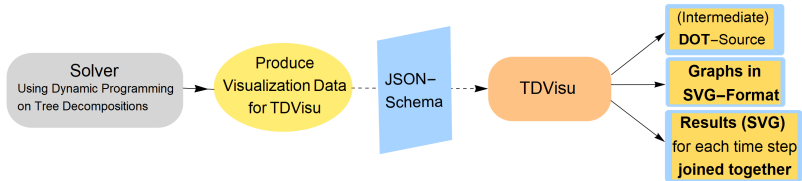
(b) Problem MinVC

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

...

⁰“Exploiting Database Management Systems and Treewidth for Counting”,
Johannes Fichte et al. doi: 10.1007/978-3-030-39197-3_10.

Running tdvisu



TDVisu producing flexible and further processable formats

bag 4
[4, 13, 36, 49, 57, 63, 79, 97]
dtime=0.0010s

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	1	0	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						

Capabilities and Limitations

Capabilities:

- ▶ Extracting basic (extendable) information (TD, solution nodes, order+time of processing...) from gpusat + dpdb
- ▶ Constructing and enriching the tree decomposition with solver information
- ▶ Adding the incidence graph for problems on Boolean formulas, from which primal and dual graphs can be derived
- ▶ Providing a discrete timeline over the solving process
- ▶ Parameters to control the quantity, coloring and, to a limited extent, the layout of the data

Limitations:

- ▶ Extracting basic (extendable) information (TD, solution nodes, order+time of processing...) from gpusat + dpdb
- ▶ Constructing and enriching the tree decomposition with solver information
- ▶ Adding the incidence graph for problems on Boolean formulas, from which primal and dual graphs can be derived
- ▶ providing a discrete timeline over the solving process

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/pgsql/postgres@PostgreSQL 12

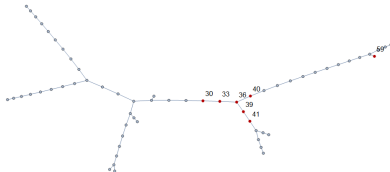
Query Editor Query History

```
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 on the Algorithms

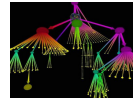
- ▶ Fichte, Johannes & Hecher, Markus & Morak, Michael & Woltran, Stefan. (2018). Exploiting Treewidth for Projected Model Counting and Its Limits. 10.1007/978-3-319-94144-8_11.
- ▶ Hecher, Markus. (2020). Treewidth-aware Reductions of Normal ASP to SAT - Is Normal ASP Harder than SAT after All?. 485-495. 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

- ▶ Marie-Christin Harre, Jan Jelschen, and Andreas Winter. “ELVIZ: A querybased approach to model visualization”. In: Lecture Notes in Informatics (LNI), Proceedings - Series of the Gesellschaft für Informatik (GI) (Jan. 2014), pp. 105–120.
- ▶ Stephan Diehl. Software Visualization. Visualizing the Structure, Behaviour, and Evolution of Software. English. Springer, 2007. 199 pp. isbn: 978-3540465041.
- ▶ Jason Daida et al. “Visualizing Tree Structures in Genetic Programming”. In: Genetic Programming and Evolvable Machines 6 (Mar. 2005). doi: 10.1007/s10710-005-7621-2.



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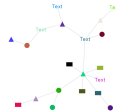
Gephi.org¹ Tulip²



³ Vis.js



Sigma.js



vasturiano/3d-force-graph⁴

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.

¹<https://gephi.org/> - Tool for data analysts and scientists keen to explore and understand graphs.

²tulip.labri.fr/TulipDrupal/ - Better Visualization Through Research.

³<https://neo4j.com/developer/tools-graph-visualization/>

⁴<https://github.com/vasturiano/3d-force-graph>

Outlook

Static \rightarrow Dynamic

Interesting Questions :

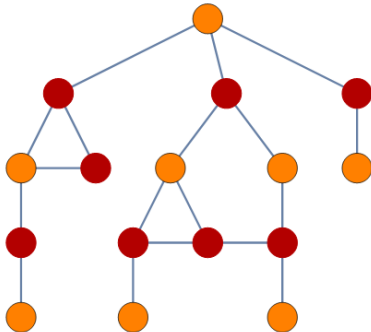
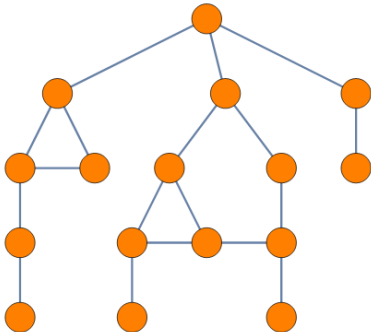
- ▶ **Utilizing graph databases for visualization and queries for debugging**
- ▶ **Enrich the visualization with debugging info for each node**
- ▶ **Cross reference the creation of rows in parent nodes**
- ▶ **For more advanced debugging tasks you may also need to revise the approach**

Final slide

Bibliography

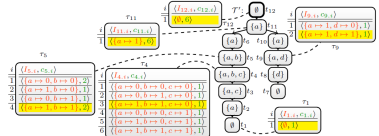
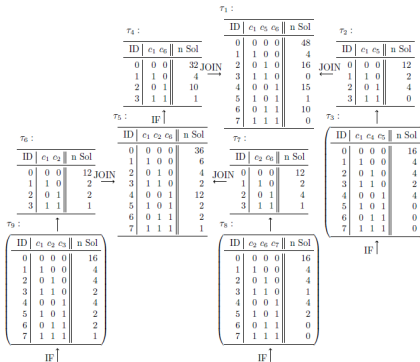
See the citations in the thesis.

MinVC for example graph



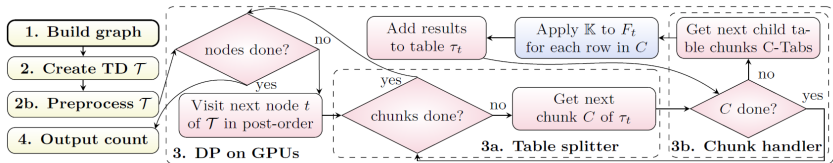
Visualization

Manually for one run



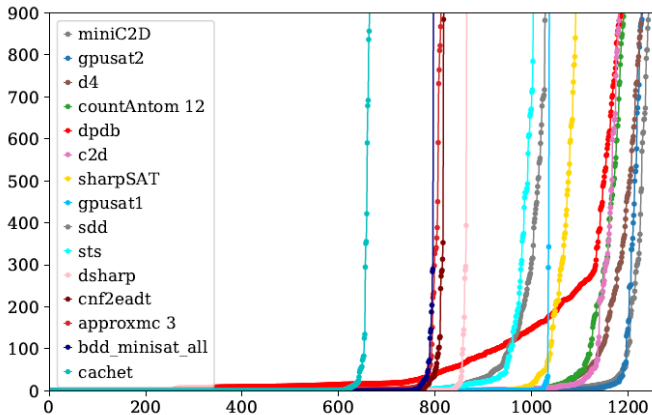
4“Exploiting Database Management Systems and Treewidth for Counting”,
Johannes Fichte et al. doi: 10.1007/978-3-030-39197-3_10.

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



Benchmark

Performance of all three programs on #SAT instances:



ELVIZ - Query based approach to software visualization

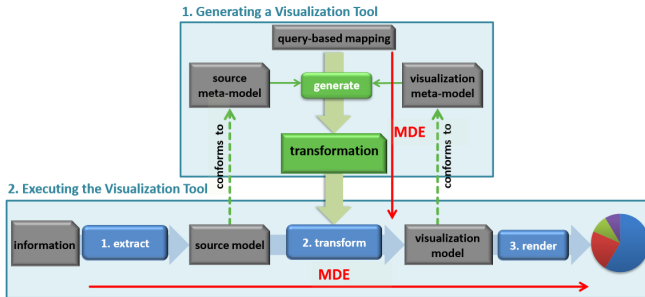


Figure: Overview of the ELVIZ-approach⁵

⁵Fig 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 für Informatik (GI) (Jan. 2014), pp. 105–120.

