



Technische  
Universität  
Braunschweig



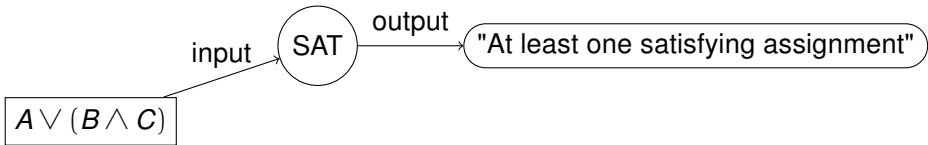
ulm university universität  
**uulm** **ISF**



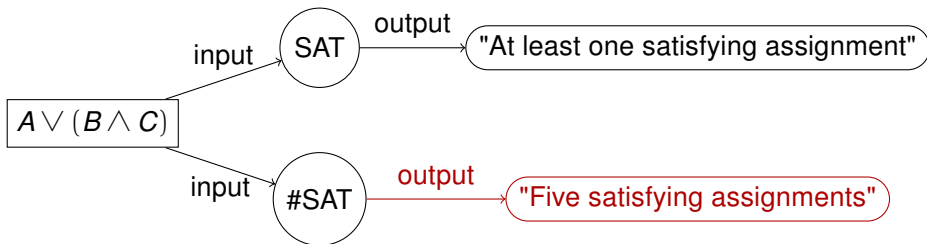
# Evaluating #SAT Solvers on Industrial Feature Models

Chico Sundermann, Thomas Thüm, Ina Schaefer, February 10, 2020

# What is #SAT?



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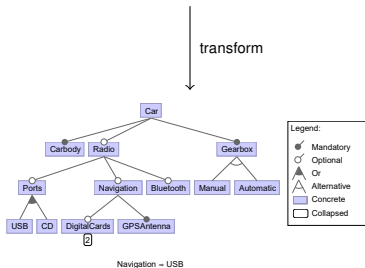


# Procedure

## Configurable System Placeholder

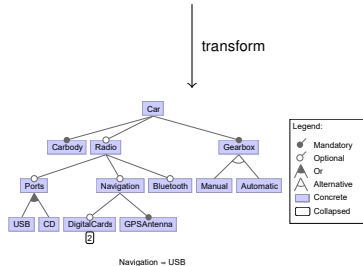
# Procedure

## Configurable System Placeholder



# Procedure

## Configurable System Placeholder

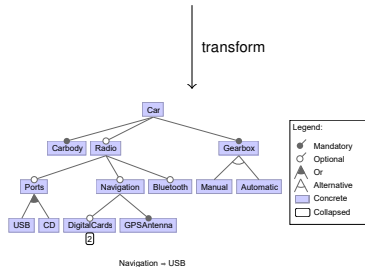


↓ transform

$$[\dots] \wedge (Ports \implies USB \vee CD) \wedge [\dots]$$

# Procedure

## Configurable System Placeholder



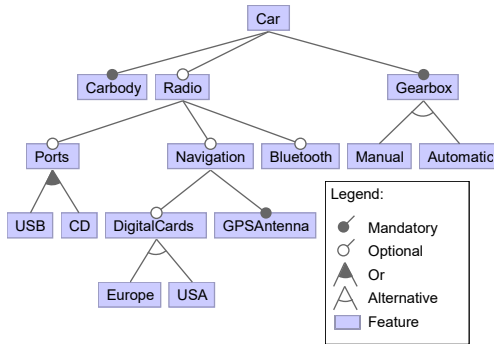
↓ transform

$$[\dots] \wedge (Ports \implies USB \vee CD) \wedge [\dots]$$

↓ input

**#SAT = Number of valid configurations**

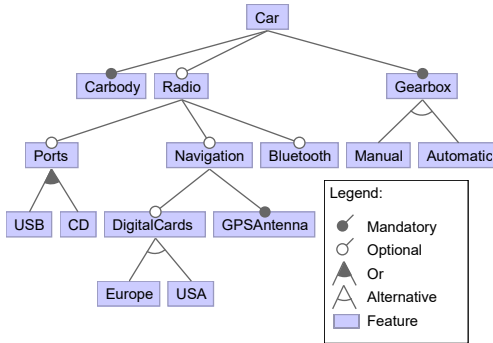
# Motivating Example



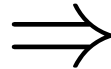
Navigation  $\Rightarrow$  USB



# Motivating Example

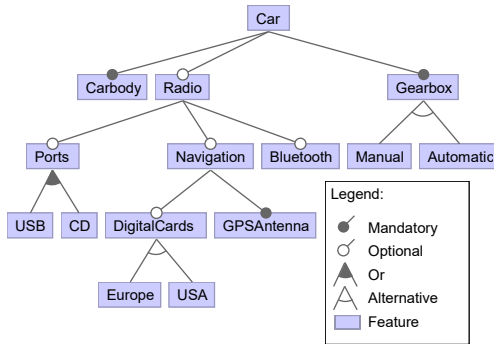


Navigation ⇒ USB



#SAT: 42 valid configurations

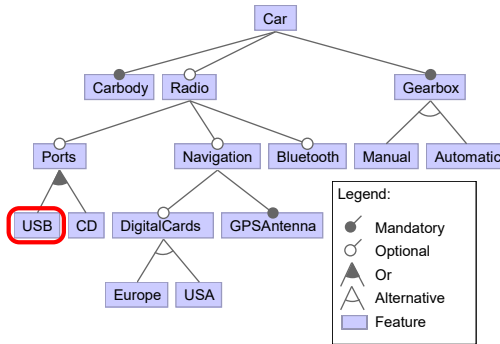
# Why bother? Commonality!



Navigation ⇒ USB

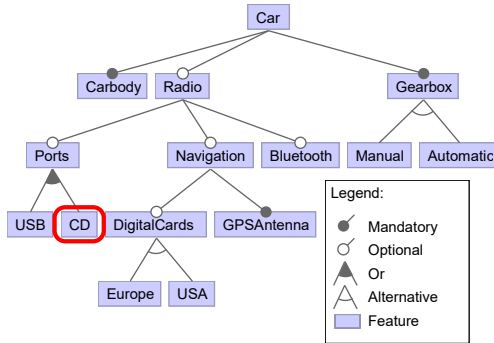
# Why bother? Commonality!

**USB: 32** valid configurations



Navigation = USB

# Why bother? Commonality!

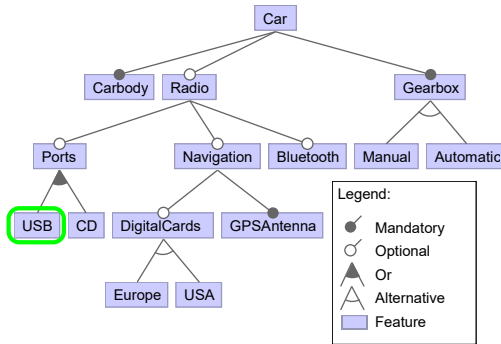


**USB:** 32 valid configurations

**CD:** 20 valid configurations

Navigation ⇒ USB

# Why bother? Commonality!

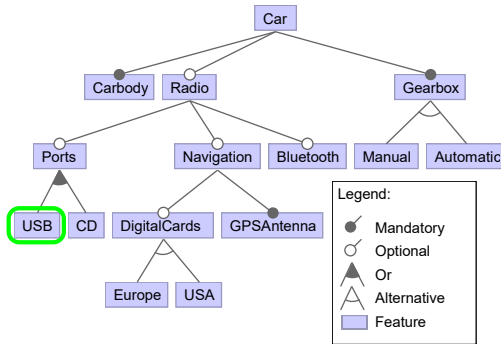


Navigation ⇒ USB

**USB: 32** valid configurations

**CD: 20** valid configurations

# Why bother? Commonality!



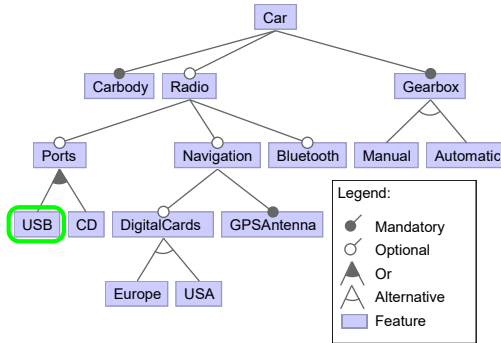
Navigation ⇒ USB

**USB: 32** valid configurations

**CD: 20** valid configurations

***Feature Prioritization!***

# Why bother? Commonality!



Navigation ⇒ USB

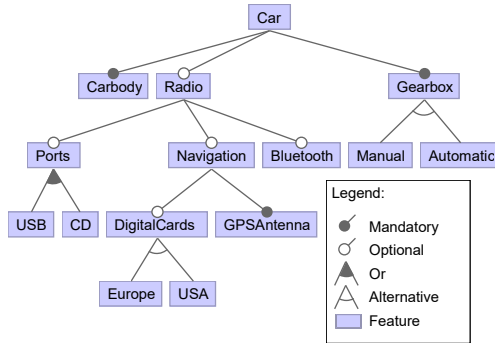
**USB: 32** valid configurations

**CD: 20** valid configurations

***Feature Prioritization!***

***Rating Errors!***

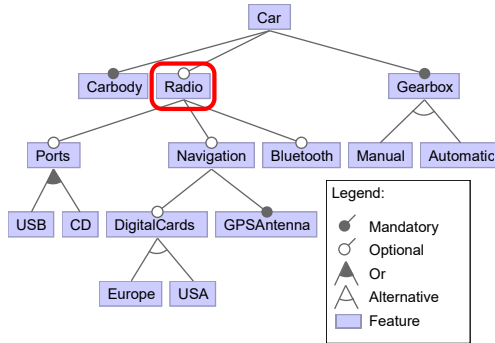
# Why bother? Variability Reduction!



Navigation ⇒ USB



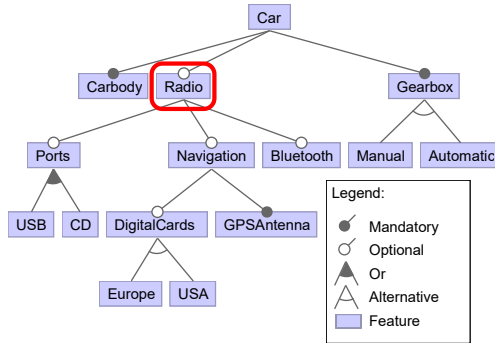
# Why bother? Variability Reduction!



**Radio mandatory?**

Navigation ⇒ USB

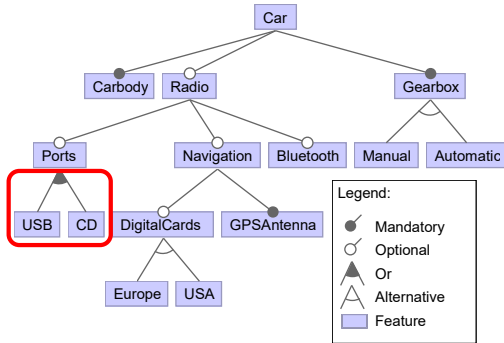
# Why bother? Variability Reduction!



**Radio mandatory? 40 left**

Navigation ⇒ USB

# Why bother? Variability Reduction!

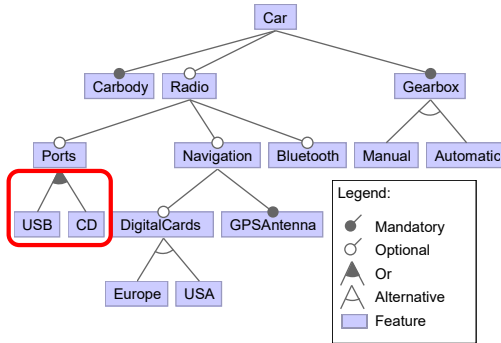


Radio mandatory? 40 left

USB xor CD?

Navigation  $\Rightarrow$  USB

# Why bother? Variability Reduction!

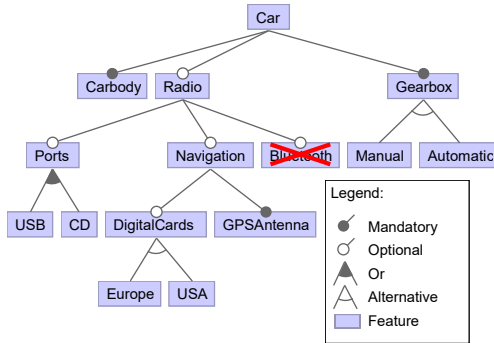


**Radio mandatory?** 40 left

**USB xor CD?** 26 left

Navigation ⇒ USB

# Why bother? Variability Reduction!



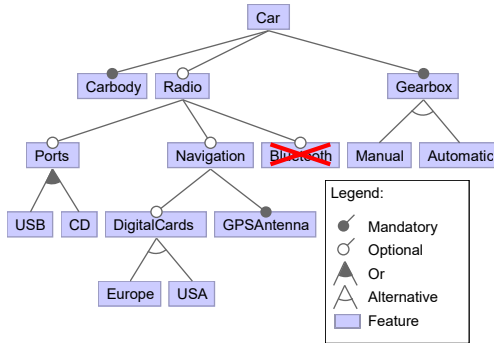
Navigation ⇒ USB

**Radio** mandatory? **40** left

**USB** xor **CD**? **26** left

Remove **Bluetooth**?

# Why bother? Variability Reduction!



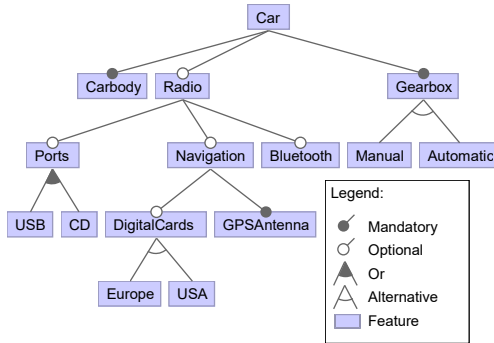
Navigation ⇒ USB

**Radio** mandatory? 40 left

**USB** xor **CD**? 26 left

Remove **Bluetooth**? 22 left

# Why bother? Variability Reduction!



Navigation ⇒ USB

**Radio** mandatory? **40** left

**USB** xor **CD**? **26** left

Remove **Bluetooth**? **22** left



# Use-cases for Configurable Systems

Uniform Random Sampling

Homogeneity

Variability Reduction

Commonality

Rating Errors

Feature Priorization

Product Derivation

...



# Evaluation

- 9 Evaluated Solvers
  - 5 DPLL
  - 3 d-DNNF
  - 1 BDD

## DPLL

countAntom

Cachet

Relsat

sharpSAT

picoSAT

## d-DNNF

d4

c2d

dSharp

## BDD

CNF2OBDD

# Evaluation

- 9 Evaluated Solvers
  - 5 DPLL
  - 3 d-DNNF
  - 1 BDD
- 127 Subject Systems
  - 4 Automotive
  - 116 CDL
  - 7 KConfig

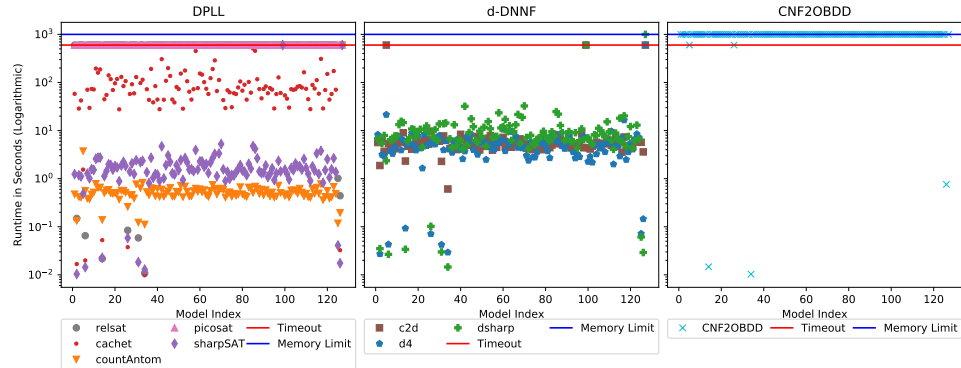
Subject Systems	#Models	#Features	#Constraints
KConfig	7	96- <b>6467</b>	14- <b>3545</b>
CDL	116	1178-1408	816-956
Automotive02	4	14010- <b>18616</b>	666- <b>1369</b>
Automotive03	5	149-588	0-1184
Automotive04	50	127-531	0-623
Automotive05	136	246- <b>1674</b>	0- <b>11632</b>

# Evaluation

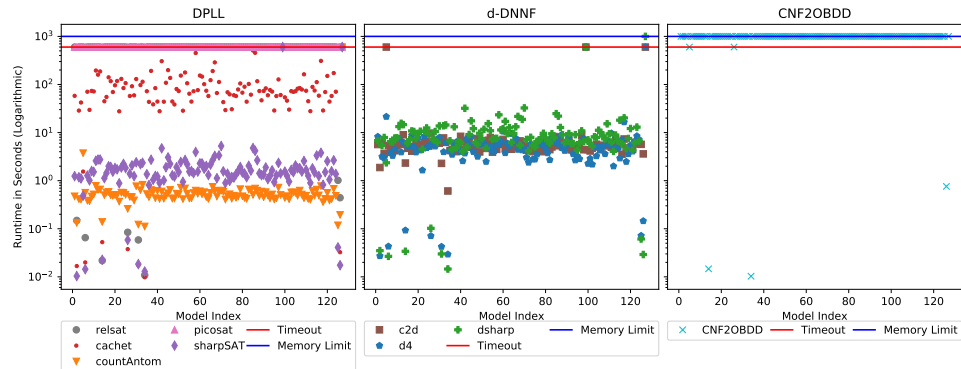
- 9 Evaluated Solvers
  - 5 DPLL
  - 3 d-DNNF
  - 1 BDD
- 127 Subject Systems
  - 4 Automotive
  - 116 CDL
  - 7 KConfig
- 2 stages
  - Timeout 10 minutes
  - Timeout 24 hours

Subject Systems	#Models	#Features	#Constraints
KConfig	7	96- <b>6467</b>	14- <b>3545</b>
CDL	116	1178-1408	816-956
Automotive02	4	14010- <b>18616</b>	666- <b>1369</b>
Automotive03	5	149-588	0-1184
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# Results Runtime

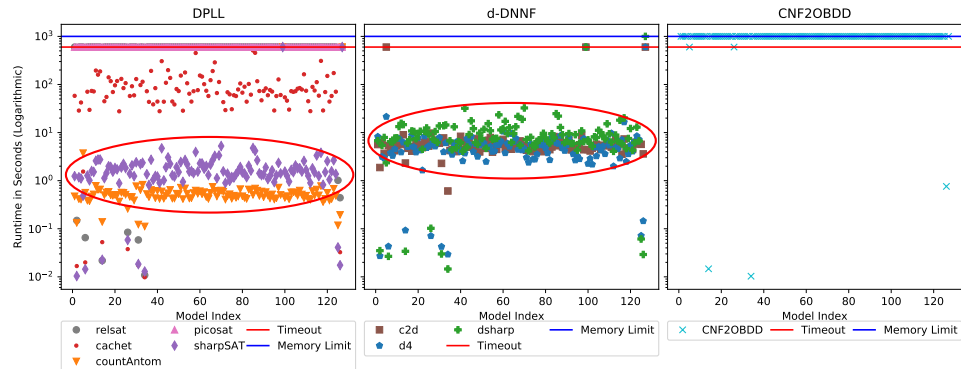


# Results Runtime



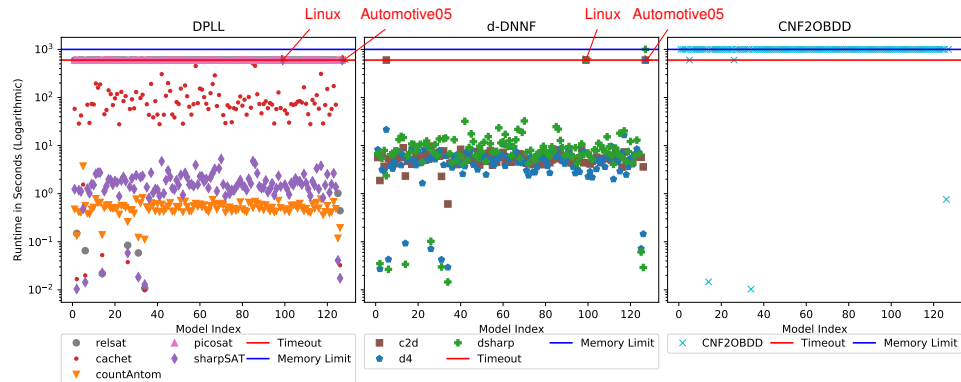
Do #SAT solvers scale to industrial configuration spaces?

# Results Runtime



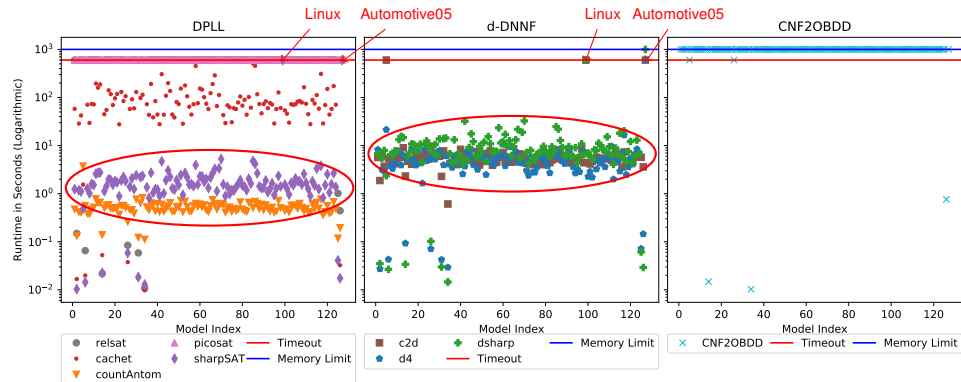
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# Results Runtime



Do #SAT solvers scale to industrial configuration spaces?

# Results Runtime

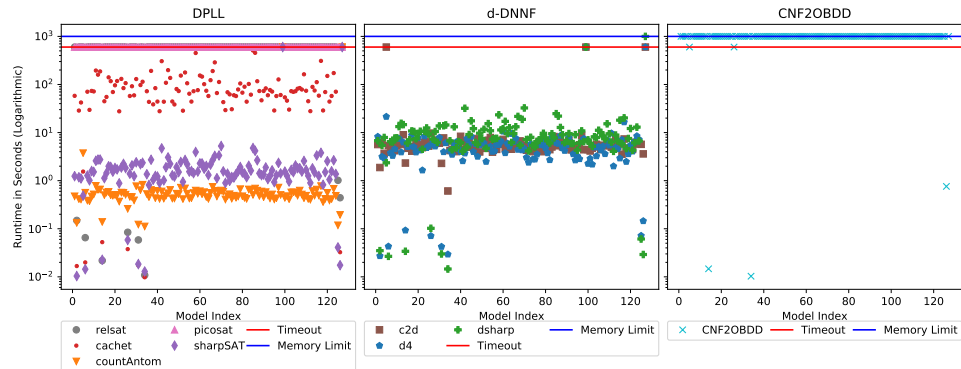


Do #SAT solvers scale to industrial configuration spaces?

To a majority but not all systems.

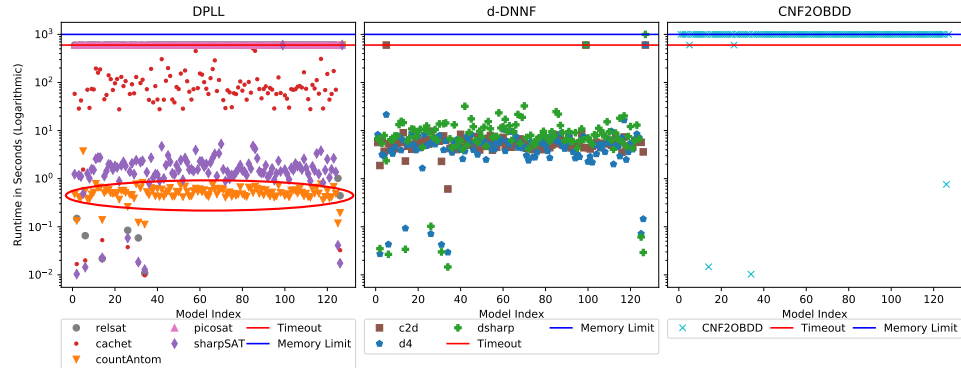


# Results Runtime



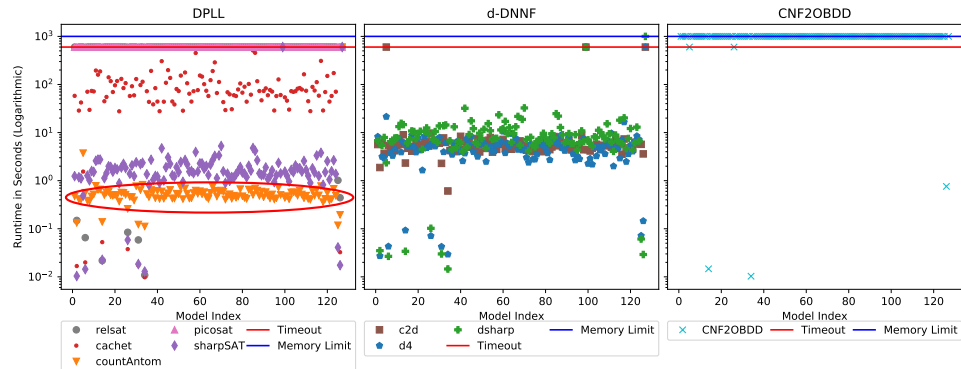
Is one #SAT solver superior to other solvers?

# Results Runtime



Is one #SAT solver superior to other solvers?

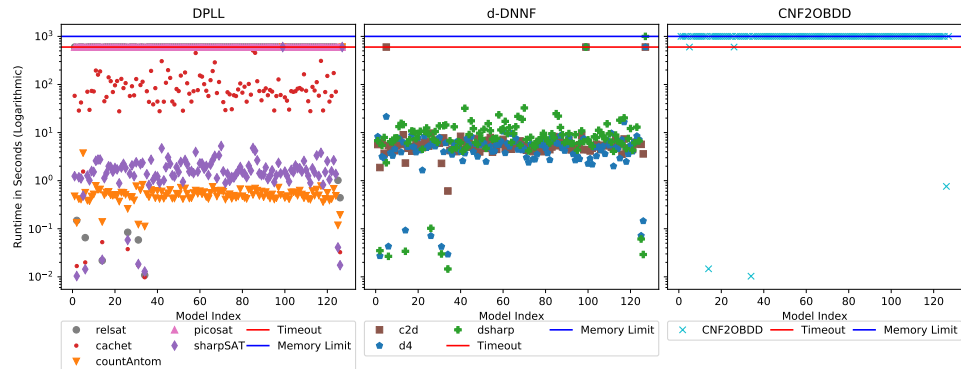
# Results Runtime



Is one #SAT solver superior to other solvers?

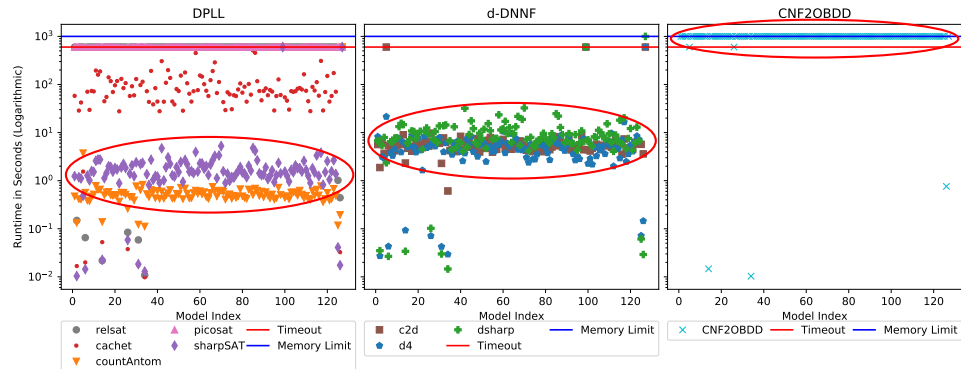
countAntom on a majority of the systems.

# Results Runtime



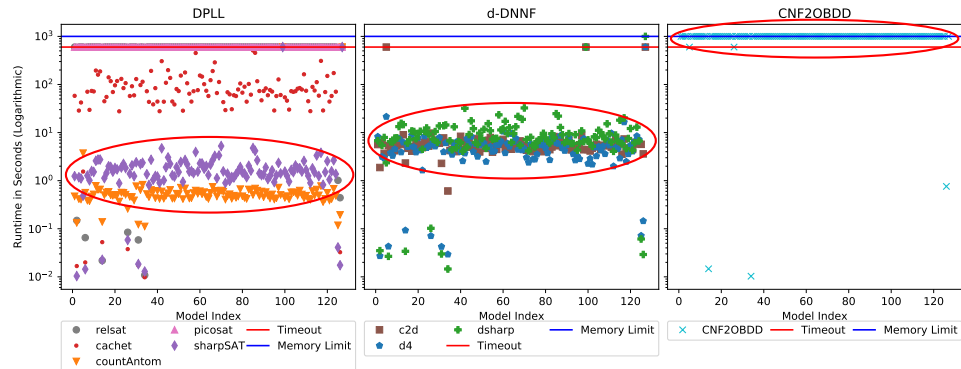
Is one **type** of #SAT solvers superior to other types?

# Results Runtime



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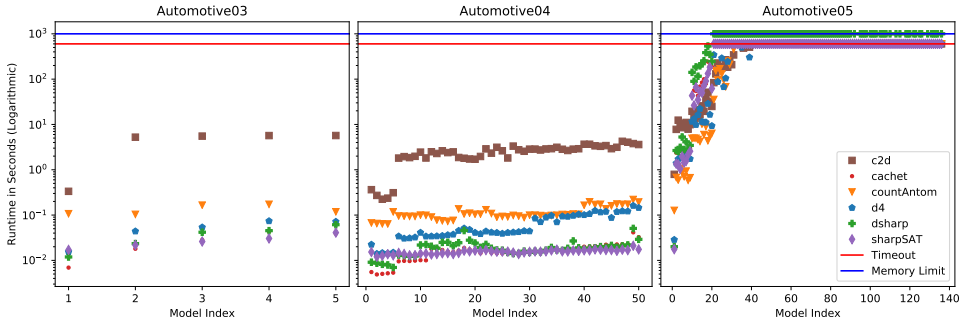
# Results Runtime



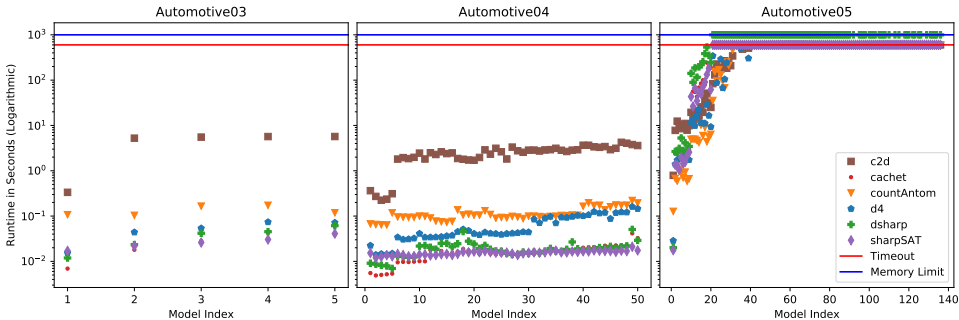
Is one **type** of #SAT solvers superior to other types?

DPLL  $\approx$  d-DNNF  $\overset{?}{>}$  BDD

# Results Runtime



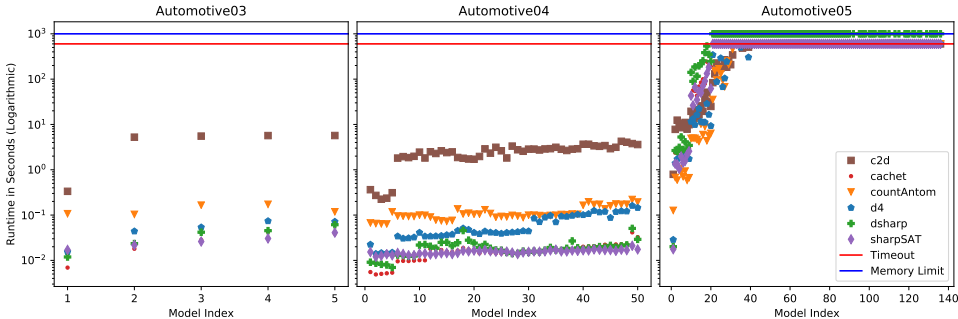
# Results Runtime



How does the runtime change during the evolution of a configurable system?



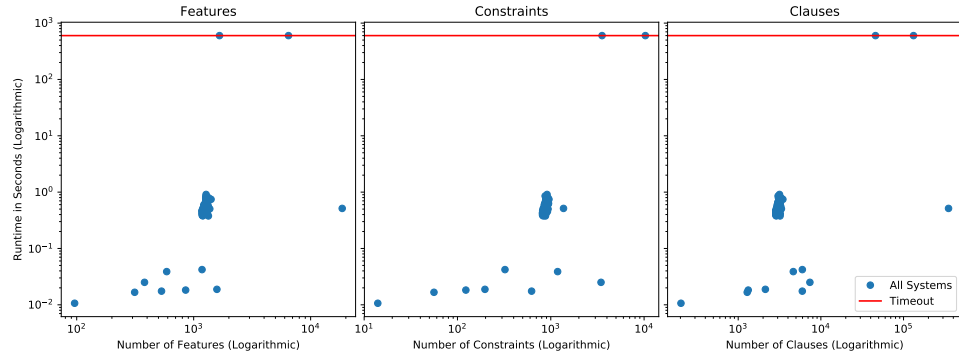
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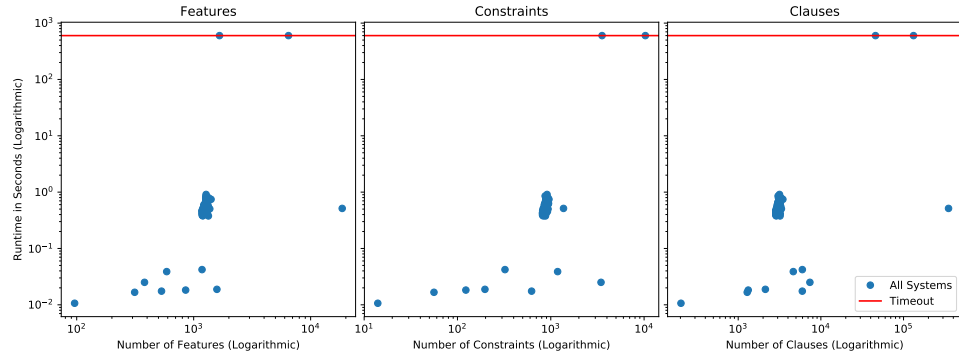
How does the runtime change during the evolution of a configurable system?

Increases over time.

# Results Runtime

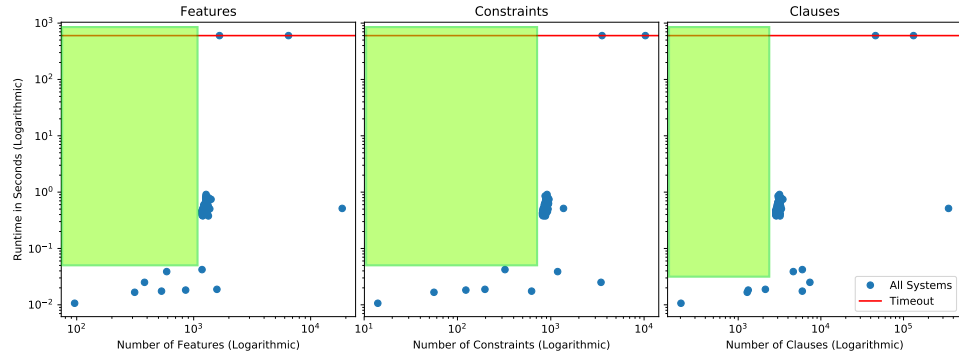


# Results Runtime



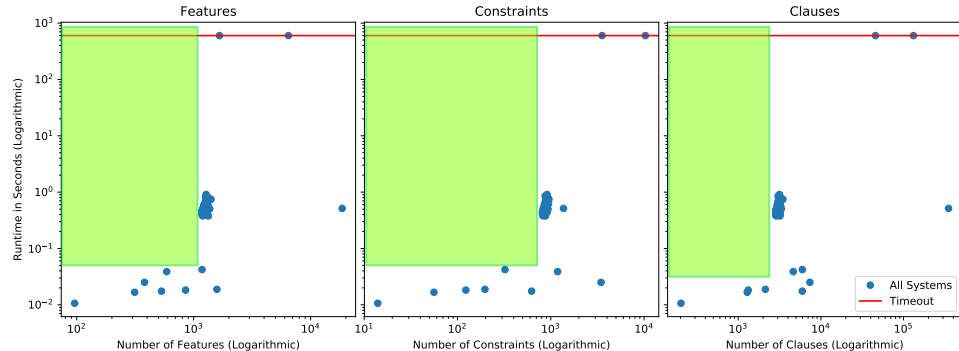
Does the runtime of the solvers correlate to the size or complexity of the configuration space?

# Results Runtime



Does the runtime of the solvers correlate to the size or complexity of the configuration space?

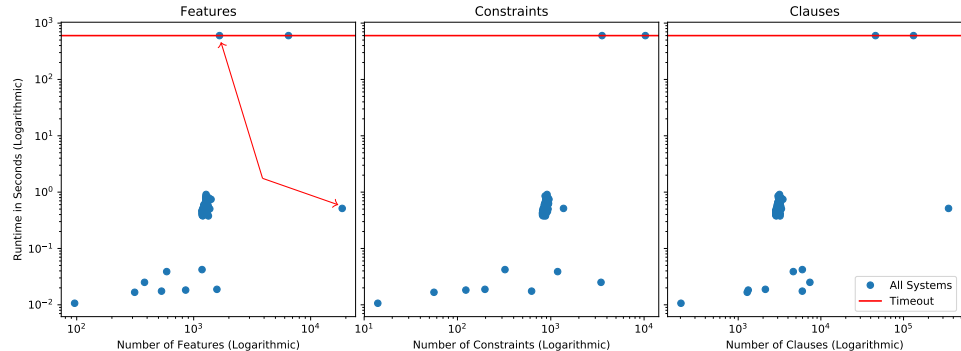
# Results Runtime



Does the runtime of the solvers correlate to the size or complexity of the configuration space?

- Small and incomplex systems are easy to solve ( $< 1000$ )

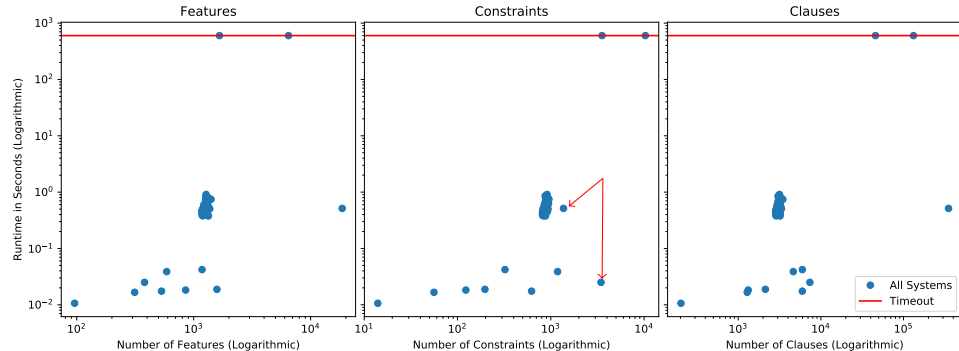
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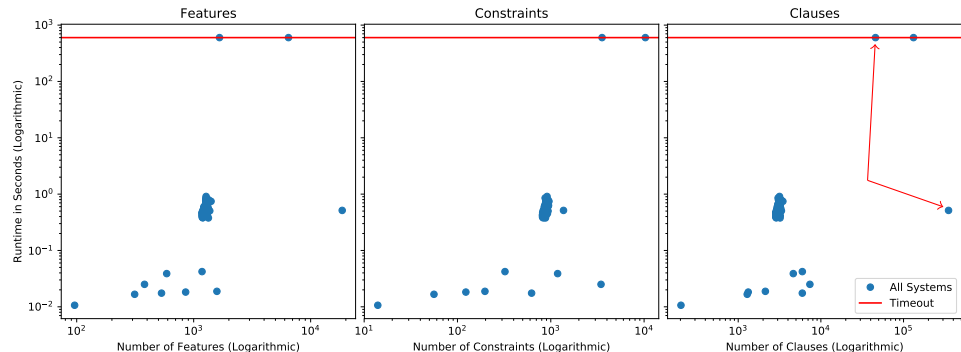
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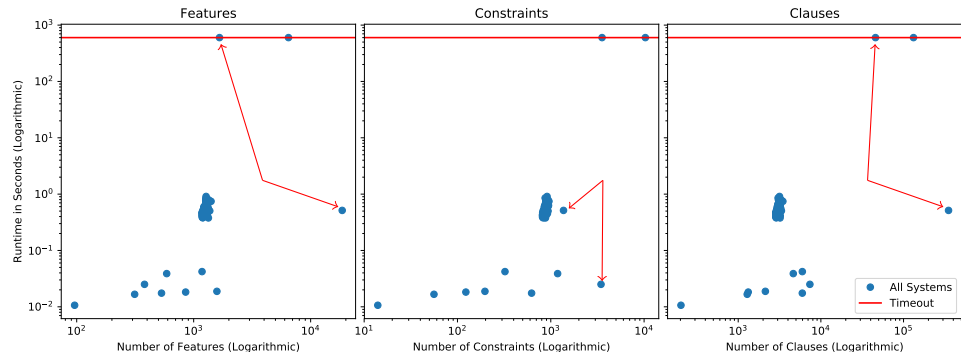


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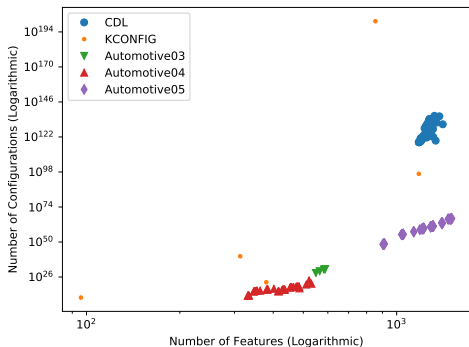
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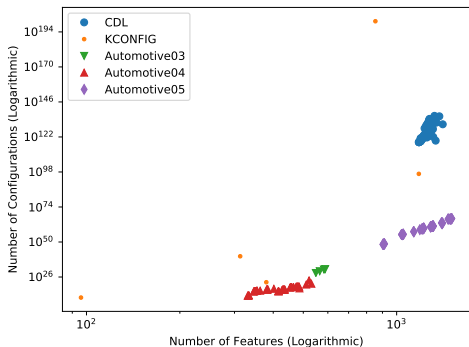
- Small and incomplex systems are easy to solve ( $< 1000$ )
- Unclear for large or complex systems

# Results Variability



Subject System	#Models(Solved)	#Configurations
KConfig	7(6)	$10^{11} - 10^{201}$
CDL	116(116)	$10^{118} - 10^{136}$
Automotive02	4(4)	$10^{1260} - 10^{1534}$
Automotive03	5(5)	$10^{28} - 10^{31}$
Automotive04	50(50)	$10^{13} - 10^{23}$
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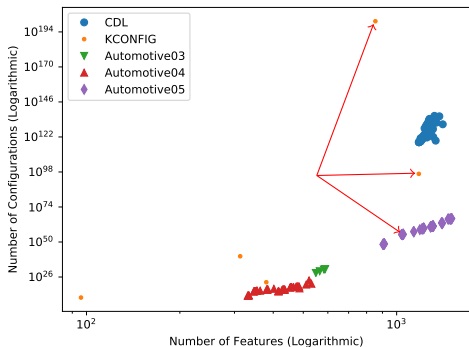
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How does the number of valid configurations relate to the number of all configurations?

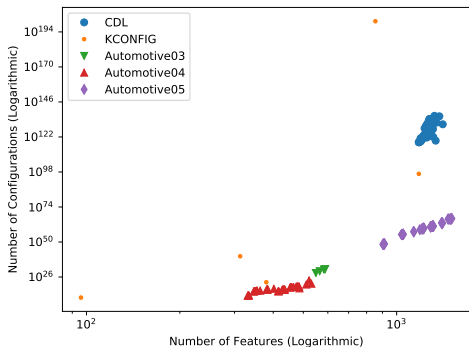
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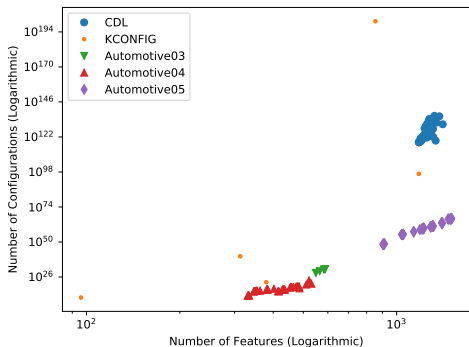


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How does the number of valid configurations relate to the number of all configurations?

Depends on the subject system.

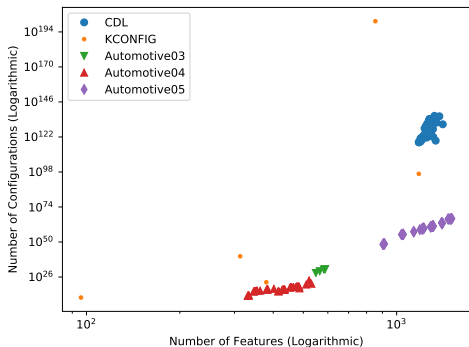
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How does the number of valid configurations change during the evolution of a configurable system?

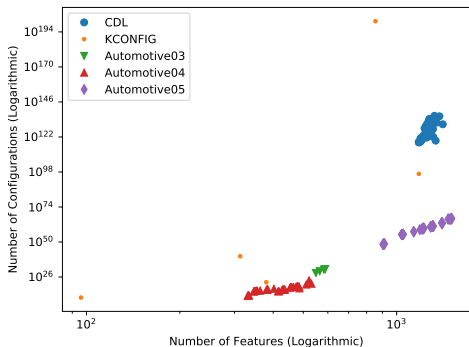
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How does the number of valid configurations change during the evolution of a configurable system?

# Results Variability



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How does the number of valid configurations change during the evolution of a configurable system?

Continuous growth.



# Conclusion

Does #SAT scale?

For which systems?

Solver types?

Evolution of systems?

# Conclusion

Does #SAT scale?

For a majority.

For which systems?

Solver types?

Evolution of systems?

# Conclusion

Does #SAT scale?

For a majority.

For which systems?

Small: ✓ Large: ?

Solver types?

Evolution of systems?

# Conclusion

Does #SAT scale?

For a majority.

For which systems?

Small: ✓ Large: ?

Solver types?

$\text{DPLL} \approx \text{d-DNNF} \stackrel{?}{>} \text{BDD}$

Evolution of systems?

# Conclusion

Does #SAT scale?

For a majority.

For which systems?

Small: ✓ Large: ?

Solver types?

$DPLL \approx d\text{-DNNF} \stackrel{?}{>} BDD$

Evolution of systems?

Configuration spaces are growing.

# Future Work

## ■ Approximate #SAT

### Approximate Model Counting by Partial Knowledge Compilation

Yong Lai<sup>\*</sup>  
College of Computer Science and Technology  
Jilin University  
Changchun 130012, China

### Model Counting: A New Strategy for Obtaining Good Bounds

Carla P. Gomes and Ashish Sabharwal and Bart Selman  
Department of Computer Science  
Cornell University, Ithaca NY 14853-7501, USA  
{gomes,sabhar,selman}@cs.cornell.edu<sup>\*</sup>

### Probabilistic Model Counting with Short XORs

Dimitris Achlioptas<sup>\*</sup> Panos Theodoropoulos<sup>†</sup>  
Department of Computer Science Department of Informatics & Telecommunications  
University of California Santa Cruz University of Athens

### A Scalable Approximate Model Counter<sup>\*</sup> <sup>†</sup>

Supratik Chakraborty<sup>1</sup>, Kuldeep S. Meel<sup>2</sup>, and Moshe Y. Vardi<sup>2</sup>

<sup>1</sup> Indian Institute of Technology Bombay, India

<sup>2</sup> Department of Computer Science, Rice University

# Future Work

- Approximate #SAT
- Memory Usage

	total	used	free
Mem:	16173180	2982184	9513232

VIRT	RES	SHR	S	%CPU	%MEM
4133156	525884	167788	S	8,3	3,3
3261712	267324	120128	S	8,0	1,7
2654184	227896	149544	S	7,0	1,4
1022584	291524	260984	S	4,7	1,8
6735456	21924	17020	S	1,3	0,1

# Future Work

#Features

#Cross tree constraints

#Literals

#Clauses

- Approximate #SAT
- Memory Usage
- Metrics for Meta Solver

Cyclomatic Complexity

#Leaf Features

#Valid Configurations

Ratio Optional Features

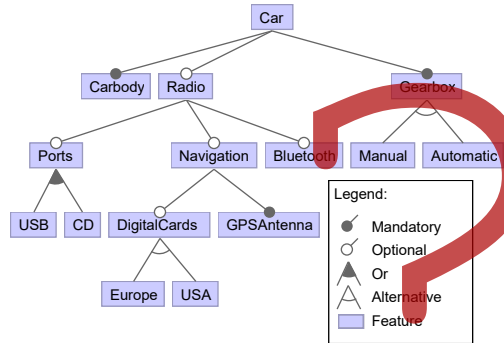
Share of Features appearing in Constraints

...



# Future Work

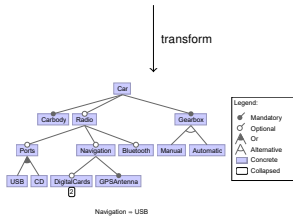
- Approximate #SAT
- Memory Usage
- Metrics for Meta Solver
- More Applications



Navigation = USB

# Summary

## Configurable System



$$[\dots] \wedge (Ports \Rightarrow USB \vee CD) \wedge [\dots]$$

↓ input

#SAT = Number of valid configurations

