[Elbe, Magdeburg]

Tseitin or not Tseitin?

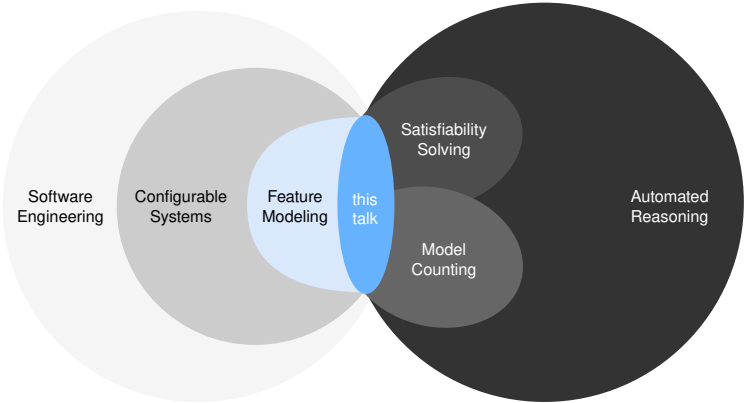
The Impact of CNF Transformations on Feature-Model Analyses

MCW@SAT 2023 (ASE 2022) — July 4 — Alghero, Italy

Elias Kuiter[1], Sebastian Krieter[2], Chico Sundermann[2], Thomas Thüm[2], Gunter Saake[1]

University of Magdeburg[1], Ulm[2], Germany

Software Engineering Meets Automated Reasoning



Implementing Configurable Software Systems

A Configurable Graph

```
class Node {
  #ifdef LABELED
    std::string label;
  #endif
  #ifdef COLORED
    std::string color;
  #endif
};

class Edge {
  #ifdef DIRECTED
    Node from, to;
  #elif UNDIRECTED && HYPER
    std::set<Node> nodes;
  #endif
};
```

Product Line Implementation
(here: C++ with C preprocessor)

Implementing Configurable Software Systems

A Configurable Graph

```
class Node {
  #ifdef LABELED
    std::string label;
  #endif
  #ifdef COLORED
    std::string color;
  #endif
};

class Edge {
  #ifdef DIRECTED
    Node from, to;
  #elif UNDIRECTED && HYPER
    std::set<Node> nodes;
  #endif
};
```

Product Line Implementation
(here: C++ with C preprocessor)

Configuration

A Labeled Directed Graph

```
class Node {
  std::string label;
};

class Edge {
  Node from, to;
};
```

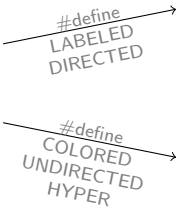
Product Implementation

Implementing Configurable Software Systems

A Configurable Graph

```
class Node {
  #ifdef LABELED
    std::string label;
  #endif
  #ifdef COLORED
    std::string color;
  #endif
};

class Edge {
  #ifdef DIRECTED
    Node from, to;
  #elif UNDIRECTED && HYPER
    std::set<Node> nodes;
  #endif
};
```

Product Line Implementation
(here: C++ with C preprocessor)



Configuration

A Labeled Directed Graph

```
class Node {
  std::string label;
};

class Edge {
  Node from, to;
};
```

A Colored Undirected Hypergraph

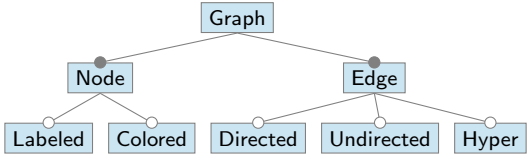
```
class Node {
  std::string color;
};

class Edge {
  std::set<Node> nodes;
};
```

Product Implementation

Modeling Features and their Dependencies

Feature Models

- tree models **features**
- cross-tree **constraints** model dependencies
- solver-based **analyses** can be used to understand the configuration space better



$\neg(\mathit{Directed} \wedge \mathit{Undirected})$ **feature conflict**

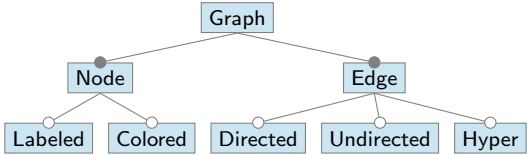
$\mathit{Hyper} \rightarrow \mathit{Undirected}$ **missing implementation**

$\mathit{Directed} \not\leftrightarrow (\mathit{Undirected} \wedge \mathit{Hyper})$ **well-defined #ifdef**

Modeling Features and their Dependencies

Feature Models

- tree models **features**
- cross-tree **constraints** model dependencies
- solver-based **analyses** can be used to understand the configuration space better



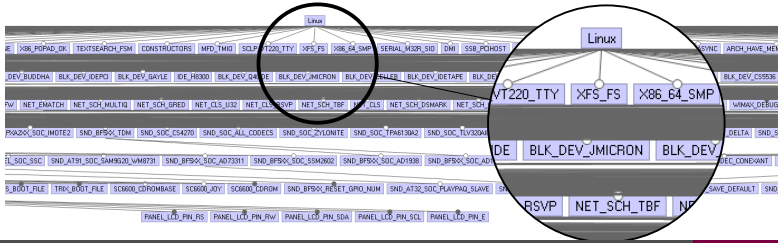
$\neg(\mathit{Directed} \wedge \mathit{Undirected})$ **feature conflict**

$\mathit{Hyper} \rightarrow \mathit{Undirected}$ **missing implementation**

$\mathit{Directed} \nleftrightarrow (\mathit{Undirected} \wedge \mathit{Hyper})$ **well-defined #ifdef**

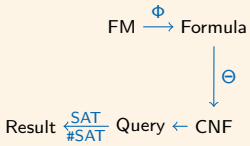
The Linux Kernel

- $>$ 13000 features [2018]
- $> 10^{700}$ products [2007]
- 114 dead features [2013]
- 151 reverse dependency bugs [2019]



Analyzing Feature Models with SAT and #SAT Solvers

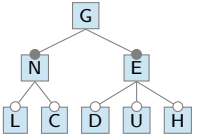
Feature-Model Analysis



Analyzing Feature Models with SAT and #SAT Solvers

Feature-Model Analysis

A Feature Model *FM*



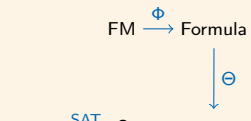
$\neg(D \wedge U)$

$H \rightarrow U$

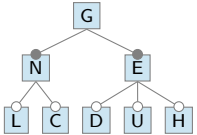
$D \not\leftrightarrow (U \wedge H)$

Analyzing Feature Models with SAT and #SAT Solvers

Feature-Model Analysis



A Feature Model *FM*



$\xrightarrow{\Phi}$

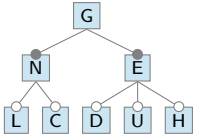
As a Formula $\Phi(FM)$

$$
\begin{aligned}
& G \\
\wedge\ & (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
\wedge\ & ((L \vee C) \rightarrow N) \\
\wedge\ & ((D \vee U \vee H) \rightarrow E) \\
\wedge\ & \neg(D \wedge U) \wedge (H \rightarrow U) \\
\wedge\ & (D \not\Rightarrow (U \wedge H))
\end{aligned}
$$

Analyzing Feature Models with SAT and #SAT Solvers

Feature-Model Analysis

A Feature Model *FM*



$\neg(D \wedge U)$
$H \rightarrow U$
$D \not\leftrightarrow (U \wedge H)$

$\xrightarrow{\Phi}$

As a Formula $\Phi(FM)$

$$
\begin{aligned}
& G \\
\wedge\ & (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
\wedge\ & ((L \vee C) \rightarrow N) \\
\wedge\ & ((D \vee U \vee H) \rightarrow E) \\
\wedge\ & \neg(D \wedge U) \wedge (H \rightarrow U) \\
\wedge\ & (D \not\leftrightarrow (U \wedge H))
\end{aligned}
$$

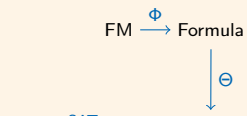
$\downarrow \Theta$

As a CNF $\Theta(\Phi(FM))$

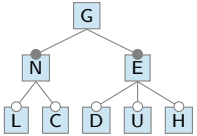
$$
\begin{aligned}
& \{\{G\}, \{\neg N, G\}, \{N, \neg G\}, \\
& \{\neg E, G\}, \{E, \neg G\}, \{\neg L, N\}, \\
& \{\neg C, N\}, \{\neg D, E\}, \{\neg U, E\}, \\
& \{\neg H, E\}, \{\neg D, \neg U\}, \{\neg H, U\}, \\
& \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}\}
\end{aligned}
$$

Analyzing Feature Models with SAT and #SAT Solvers

Feature-Model Analysis



A Feature Model *FM*



Φ →

As a Formula Φ(*FM*)

$$
\begin{aligned}
&G \\
&\wedge\ (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
&\wedge\ ((L \vee C) \rightarrow N) \\
&\wedge\ ((D \vee U \vee H) \rightarrow E) \\
&\wedge\ \neg(D \wedge U) \wedge (H \rightarrow U) \\
&\wedge\ (D \not\Rightarrow (U \wedge H))
\end{aligned}
$$

↓ Θ

As a CNF Θ(Φ(*FM*))

$$
\begin{aligned}
&\{\{G\}, \{\neg N, G\}, \{N, \neg G\}, \\
&\ \{\neg E, G\}, \{E, \neg G\}, \{\neg L, N\}, \\
&\ \{\neg C, N\}, \{\neg D, E\}, \{\neg U, E\}, \\
&\ \{\neg H, E\}, \{\neg D, \neg U\}, \{\neg H, U\}, \\
&\ \{\{D,U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}\}
\end{aligned}
$$

←

Core Feature *F*?

$SAT(\Theta(\Phi(FM)) \wedge \neg F)$

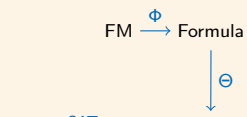
←

Core Features

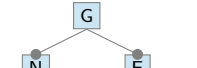
$\{G, N, E\}$

Analyzing Feature Models with SAT and #SAT Solvers

Feature-Model Analysis



A Feature Model *FM*



$\neg(D \wedge U)$
$H \rightarrow U$
$D \not\Leftrightarrow (U \wedge H)$

$\xrightarrow{\Phi}$

As a Formula $\Phi(FM)$

$$
\begin{aligned}
&G \\
&\wedge\ (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
&\wedge\ ((L \vee C) \rightarrow N) \\
&\wedge\ ((D \vee U \vee H) \rightarrow E) \\
&\wedge\ \neg(D \wedge U) \wedge (H \rightarrow U) \\
&\wedge\ (D \not\Leftrightarrow (U \wedge H))
\end{aligned}
$$

$\downarrow \Theta$

As a CNF $\Theta(\Phi(FM))$

$\{\{G\}, \{\neg N, G\}, \{N, \neg G\},$
$\{\neg E, G\}, \{E, \neg G\}, \{\neg L, N\},$
$\{\neg C, N\}, \{\neg D, E\}, \{\neg U, E\},$
$\{\neg H, E\}, \{\neg D, \neg U\}, \{\neg H, U\},$
$\{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}\}$

$\leftarrow$

Core Feature *F*?

$SAT(\Theta(\Phi(FM)) \wedge \neg F)$

$\leftarrow$

Products in *FM*?

$\#SAT(\Theta(\Phi(FM)))$

$\leftarrow$

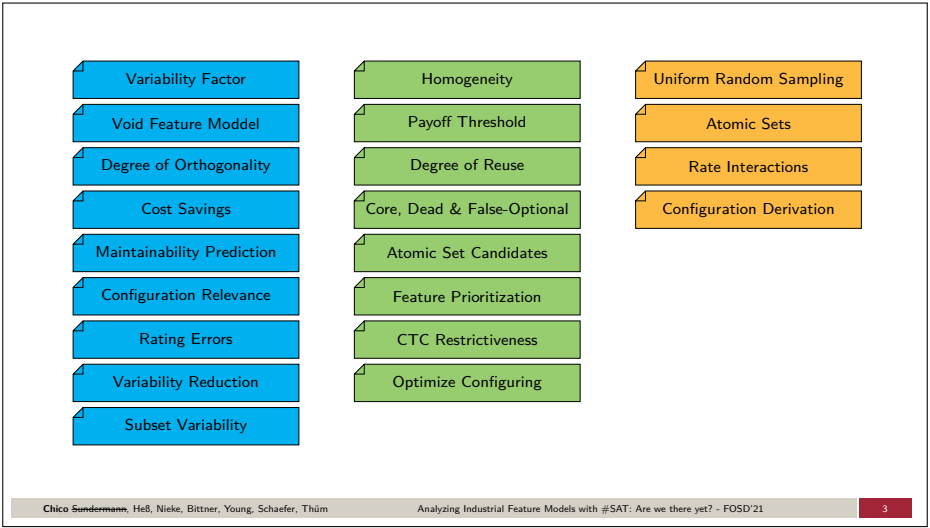
Core Features

$\{G, N, E\}$

Feature Model Cardinality

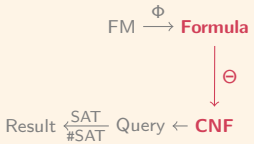
8

Feature Modeling Meets Model Counting



Often Overlooked: Conjunctive Normal Form (CNF)

Feature-Model Analysis



From Formula ...

$$
\begin{aligned}
& G \\
\wedge\ & (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
\wedge\ & ((L \vee C) \rightarrow N) \\
\wedge\ & ((D \vee U \vee H) \rightarrow E) \\
\wedge\ & \neg(D \wedge U) \wedge (H \rightarrow U) \\
\wedge\ & (D \not\leftrightarrow (U \wedge H))
\end{aligned}
$$

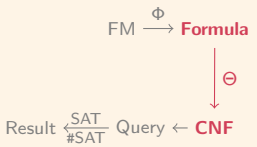
$\downarrow \Theta$

... to CNF

$$
\begin{aligned}
&\{\{G\}, \{\neg N, G\}, \{N, \neg G\}, \\
&\ \{\neg E, G\}, \{E, \neg G\}, \{\neg L, N\}, \\
&\ \{\neg C, N\}, \{\neg D, E\}, \{\neg U, E\}, \\
&\ \{\neg H, E\}, \{\neg D, \neg U\}, \{\neg H, U\}, \\
&\ \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}\}
\end{aligned}
$$

Often Overlooked: Conjunctive Normal Form (CNF)

Feature-Model Analysis



Conjunctive Normal Form

- **conjunction** $\wedge$ of **disjunctions** $\vee$ of **literals** X, $\neg X$
- here: a set of **clauses**, which are sets of literals
- used by almost all solvers

From Formula ...

$$
\begin{aligned}
& G \\
\wedge\ & (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
\wedge\ & ((L \vee C) \rightarrow N) \\
\wedge\ & ((D \vee U \vee H) \rightarrow E) \\
\wedge\ & \neg(D \wedge U) \wedge (H \rightarrow U) \\
\wedge\ & (D \not\leftrightarrow (U \wedge H))
\end{aligned}
$$

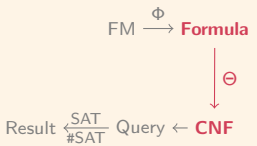
$\downarrow \Theta$

... to CNF

$$
\begin{aligned}
& \{\{G\}, \{\neg N, G\}, \{N, \neg G\}, \\
& \{\neg E, G\}, \{E, \neg G\}, \{\neg L, N\}, \\
& \{\neg C, N\}, \{\neg D, E\}, \{\neg U, E\}, \\
& \{\neg H, E\}, \{\neg D, \neg U\}, \{\neg H, U\}, \\
& \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}\}
\end{aligned}
$$

Often Overlooked: Conjunctive Normal Form (CNF)

Feature-Model Analysis



Conjunctive Normal Form

- **conjunction** $\wedge$ of **disjunctions** $\vee$ of **literals** X, $\neg X$
- here: a set of **clauses**, which are sets of literals
- used by almost all solvers

From Formula ...

$$
\begin{aligned}
& G \\
\wedge\ & (N \leftrightarrow G) \wedge (E \leftrightarrow G) \\
\wedge\ & ((L \vee C) \rightarrow N) \\
\wedge\ & ((D \vee U \vee H) \rightarrow E) \\
\wedge\ & \neg(D \wedge U) \wedge (H \rightarrow U) \\
\wedge\ & (D \not\leftrightarrow (U \wedge H))
\end{aligned}
$$

$\downarrow \ominus$

... to CNF

$$
\begin{aligned}
& \{\{G\}, \{\neg N, G\}, \{N, \neg G\}, \\
& \{\neg E, G\}, \{E, \neg G\}, \{\neg L, N\}, \\
& \{\neg C, N\}, \{\neg D, E\}, \{\neg U, E\}, \\
& \{\neg H, E\}, \{\neg D, \neg U\}, \{\neg H, U\}, \\
& \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}\}
\end{aligned}
$$

Our Goal: Raise Awareness for CNF Transformations [ASE'22]

- how to **transform** feature-model formulas **into CNF**?
  $\Rightarrow$ describe and classify CNF transformations
- does this **impact** the work of **practitioners and researchers**?
  $\Rightarrow$ evaluate efficiency and correctness on feature models

CNF Transformations

Distributive $\Theta = D$

apply laws of logic (**De Morgan's laws** and **distributivity**)

$$D \not\leftrightarrow (U \wedge H)$$
$$\xrightarrow{D} (D \vee (U \wedge H)) \wedge (\neg D \vee \neg (U \wedge H))$$
$$\xrightarrow{D} \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}$$

✓ **equivalence**
SAT ✓, $\#SAT = 4$

✓ easy to implement

✗ **exponential** complexity

CNF Transformations

Distributive $\Theta = D$

apply laws of logic (**De Morgan's laws** and **distributivity**)

$$D \not\Leftrightarrow (U \wedge H)$$
$$\xrightarrow{D} (D \vee (U \wedge H)) \wedge (\neg D \vee \neg (U \wedge H))$$
$$\xrightarrow{D} \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}$$

✓ **equivalence**
SAT ✓, $\#SAT = 4$
✓ easy to implement
✗ **exponential** complexity

Tseitin $\Theta = T$ ['83]

abbreviate a subformula ϕ with an auxiliary variable $x_\phi \leftrightarrow \phi$

$$D \not\Leftrightarrow (U \wedge H)$$
$$\xrightarrow{T} (D \not\Leftrightarrow x) \wedge x \leftrightarrow (U \wedge H)$$
$$\xrightarrow{D} \{\{D, x\}, \{\neg D, \neg x\}, \{\neg x, U\}, \{\neg x, H\}, \{\neg U, \neg H, x\}\}$$

✓ **quasi-equivalence**
SAT ✓, $\#SAT = 4$
✓ **linear** complexity
✗ take care of new variables

CNF Transformations

Distributive $\Theta = D$

apply laws of logic (**De Morgan's laws** and **distributivity**)

$$D \not\Leftrightarrow (U \wedge H)$$
$$\xrightarrow{D} (D \vee (U \wedge H)) \wedge (\neg D \vee \neg (U \wedge H))$$
$$\xrightarrow{D} \{\{D, U\}, \{D, H\}, \{\neg D, \neg U, \neg H\}\}$$

✓ **equivalence**
SAT ✓, $\#SAT = 4$
✓ easy to implement
✗ **exponential** complexity

Tseitin $\Theta = T$ ['83]

abbreviate a subformula ϕ with an auxiliary variable $x_\phi \leftrightarrow \phi$

$$D \not\Leftrightarrow (U \wedge H)$$
$$\xrightarrow{T} (D \not\Leftrightarrow x) \wedge x \leftrightarrow (U \wedge H)$$
$$\xrightarrow{D} \{\{D, x\}, \{\neg D, \neg x\}, \{\neg x, U\}, \{\neg x, H\}, \{\neg U, \neg H, x\}\}$$

✓ **quasi-equivalence**
SAT ✓, $\#SAT = 4$
✓ **linear** complexity
✗ take care of new variables

Plaisted-Greenbaum $\Theta = PG$ ['86]

abbreviate a subformula ϕ with an auxiliary variable $x_\phi \rightarrow \phi$

$$D \not\Leftrightarrow (U \wedge H)$$
$$\xrightarrow{PG} (D \not\Leftrightarrow x) \wedge x \rightarrow (U \wedge H)$$
$$\xrightarrow{D} \{\{D, x\}, \{\neg D, \neg x\}, \{\neg x, U\}, \{\neg x, H\}\}$$

✓ **equi-assignability** SAT ✓
✓ **linear** complexity $< T$
✗ **equi-countability** $\#SAT = 5$

Evaluation

Research Questions

RQ 1 **efficiency** of CNF transformations?

RQ 2 CNF transformation → **efficiency** of analyses?

RQ 3 CNF transformation → **correctness** of analyses?

Evaluation

Research Questions

RQ 1 **efficiency** of CNF transformations?

RQ 2 CNF transformation → **efficiency** of analyses?

RQ 3 CNF transformation → **correctness** of analyses?

Experimental Setup

- 22 configurable software systems
- 3 CNF transformation tools
- 23 SAT and #SAT solvers

Evaluation

Research Questions

RQ 1 **efficiency** of CNF transformations?

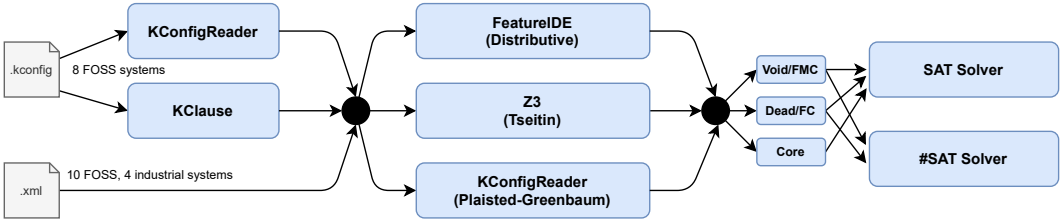
RQ 2 CNF transformation → **efficiency** of analyses?

RQ 3 CNF transformation → **correctness** of analyses?

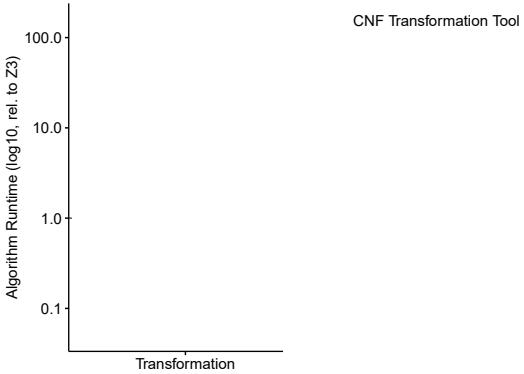
Experimental Setup

- 22 configurable software systems
- 3 CNF transformation tools
- 23 SAT and #SAT solvers

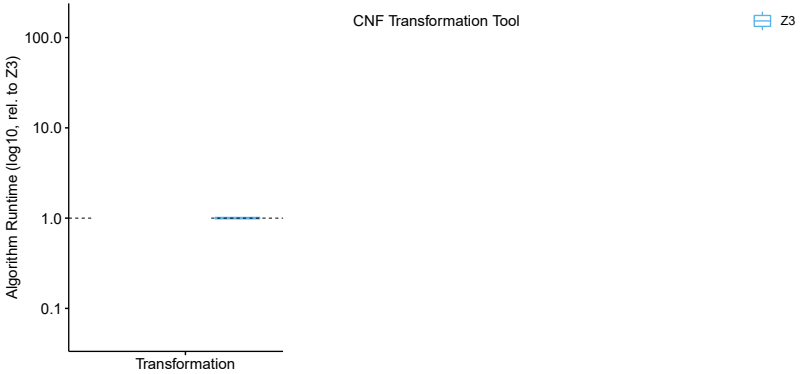
Stage 1: Formula Extraction | **Stage 2: CNF Transformation** | **Stage 3: Automated Analysis**



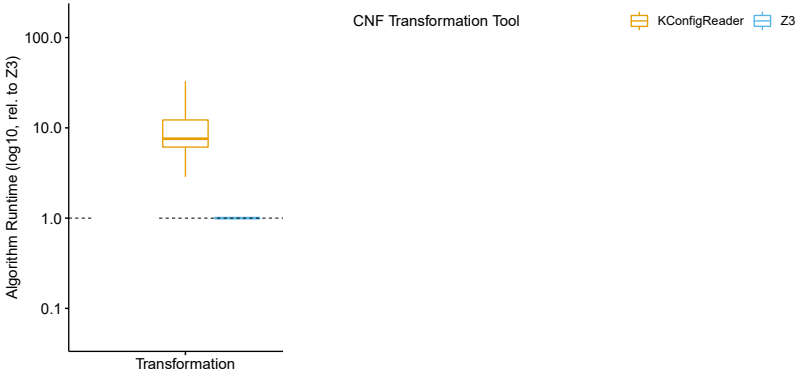
Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)



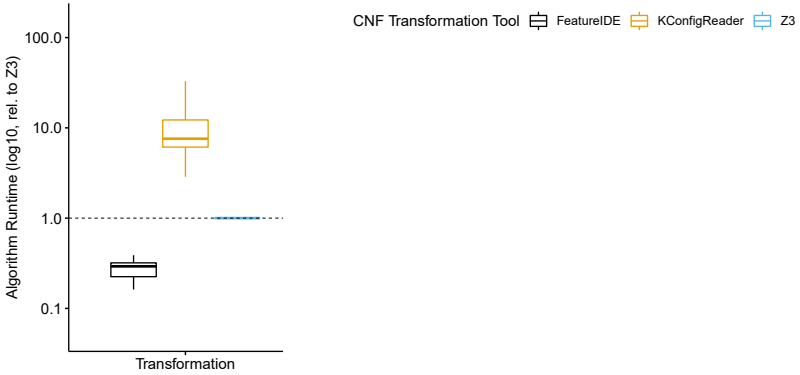
Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)



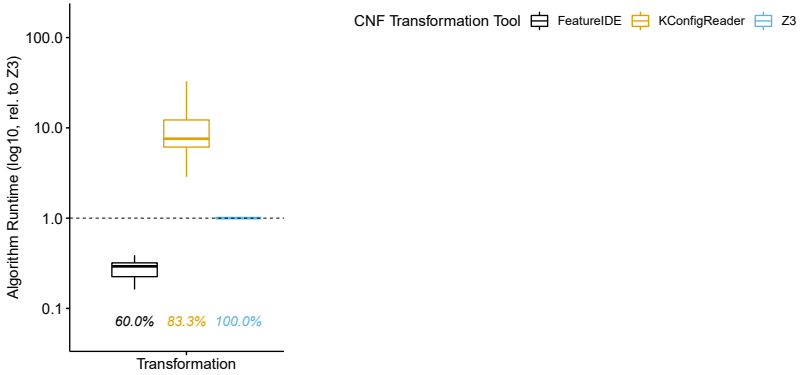
Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)



Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)

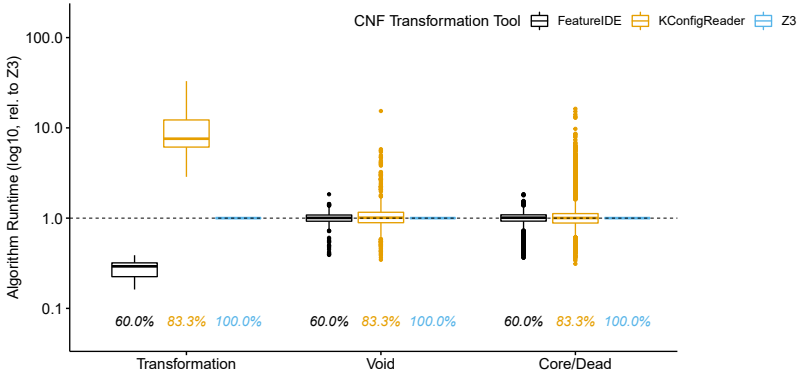


Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)



RQ 1: *D* **often fails**, tools **differ significantly**

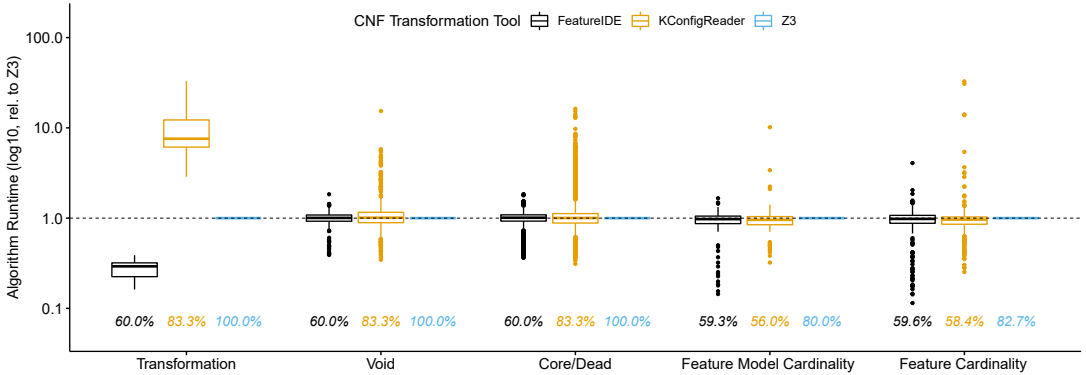
Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)



RQ 1: *D* **often fails**, tools **differ significantly**

RQ 2 (SAT): almost all calls succeed, **solve time varies** by factor 0.31–16.27

Efficiency of CNF Transformations (RQ 1) and Analyses (RQ 2)



RQ 1: *D* **often fails**, tools **differ significantly**

RQ 2 (SAT): almost all calls succeed, **solve time varies** by factor 0.31–16.27

RQ 2 (#SAT): 81.6% of calls succeed, **solve time varies** by factor 0.11–32.7

Correctness of #SAT-Based Analyses (RQ 3)

How Many Valid Configurations in BusyBox 1.35.0?

FeatureIDE (Distributive) says:

4784204604487300838413517649496919484532 17980737275928522342 35800557238486733859 78971326945465595845 72908124465341304467 84732350200161989505 38440744692509401678 99136000000000000000 000000000

Tseitin (Z3) says:

4784204604487300838413517649496919484532 17980737275928522342 35800557238486733859 78971326945465595845 72908124465341304467 84732350200161989505 38440744692509401678 99136000000000000000 000000000

KConfigReader (Plaisted-Greenbaum) says:

15751357446718468213 90135655996554596226 77965648288591932216 37368937605749145888 80850342078354075798 38471914912986177301 71318442740266744344 68038795993960163378 18607616000000000000 000000000 **0 ⇒ off by factor 3.292**

Correctness of #SAT-Based Analyses (RQ 3)

How Many Valid Configurations in BusyBox 1.35.0?

FeatureIDE (Distributive) says:

4784204604873008384 13517649496919484532 17980737275928522342 35800557238486733859
78971326945465595845 72908124465341304467 84732350200161989505 38440744692509401678
99136000000000000000 000000000

Tseitin (Z3) says:

4784204604873008384 13517649496919484532 17980737275928522342 35800557238486733859
78971326945465595845 72908124465341304467 84732350200161989505 38440744692509401678
99136000000000000000 000000000

KConfigReader (Plaisted-Greenbaum) says:

15751357446718468213 90135655996554596226 77965648288591932216 37368937605749145888
80850342078354075798 38471914912986177301 71318442740266744344 68038795993960163378
18607616000000000000 000000000 **0 $\Rightarrow$ off by factor 3.292**

RQ 3

- with PG, $\approx$ 70% of #SAT calls return **incorrect results**
- incorrect by factor $\approx$ 3 (median)
- incorrect by factor $\approx 10^{77}$ (worst)

Correctness of #SAT-Based Analyses (RQ 3)

How Many Valid Configurations in BusyBox 1.35.0?

FeatureIDE (Distributive) says:

4784204604487300838 4 135176494969194845 32 179807372759285223 42 358005572384867338 59
789713269454655958 45 729081244653413044 67 847323502001619895 05 384407446925094016 78
991360000000000000 000000000

Tseitin (Z3) says:

4784204604487300838 4 135176494969194845 32 179807372759285223 42 358005572384867338 59
789713269454655958 45 729081244653413044 67 847323502001619895 05 384407446925094016 78
991360000000000000 000000000

KConfigReader (Plaisted-Greenbaum) says:

157513574467184682 13 901356559965545962 26 779655482885919322 16 373689376057491458 88
808503420783540757 98 384719149129861773 01 713184427402667443 44 680387959939601633 78
186076160000000000 000000000 **0 ⇒ off by factor 3.292**

RQ 3

- with PG, $\approx$ 70% of #SAT calls return **incorrect results**
- incorrect by factor $\approx$ 3 (median)
- incorrect by factor $\approx 10^{77}$ (worst)

Our Recommendations

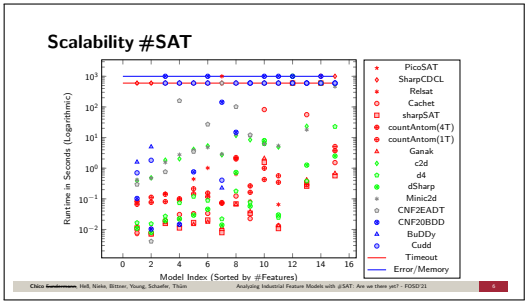
RQ 1 D for small, T for large models

RQ 2 largely depends on the model
$\Rightarrow$ future work

RQ 3 do not use PG for #SAT

Perspective: Model Counting Meets Feature Modeling?

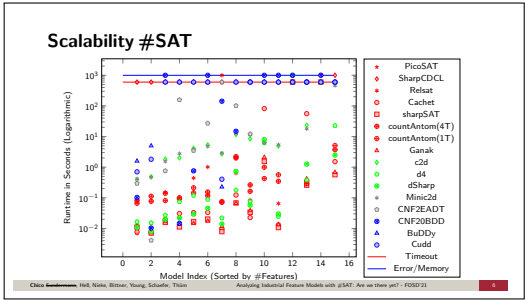
Perspective: Model Counting Meets Feature Modeling?

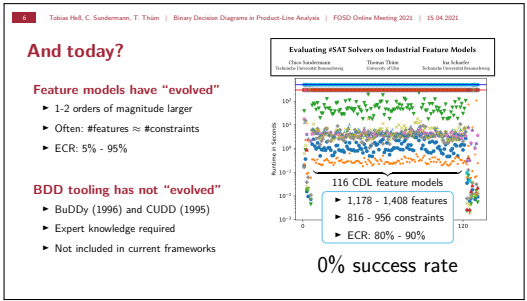


Compiling to d-DNNFs [Chico Sundermann]

works on most models (but not Linux/Automotive)
15 software systems, 130 models (some industrial)

Perspective: Model Counting Meets Feature Modeling?





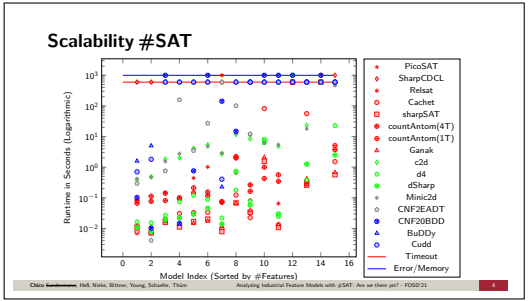
Compiling to d-DNNFs [Chico Sundermann]

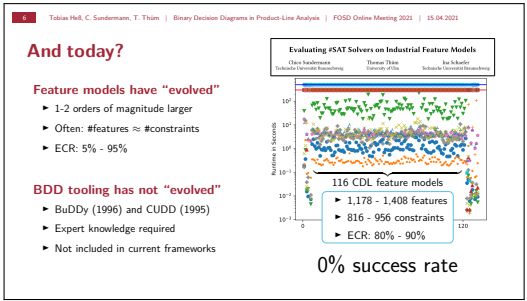
works on most models (but not Linux/Automotive)
15 software systems, 130 models (some industrial)

Compiling to BDDs [Tobias Heß]

works on most small models (but not Linux/CDL)
largely depends on variable ordering

Perspective: Model Counting Meets Feature Modeling?





Compiling to d-DNNFs [Chico Sundermann]

works on most models (but not Linux/Automotive)
15 software systems, 130 models (some industrial)

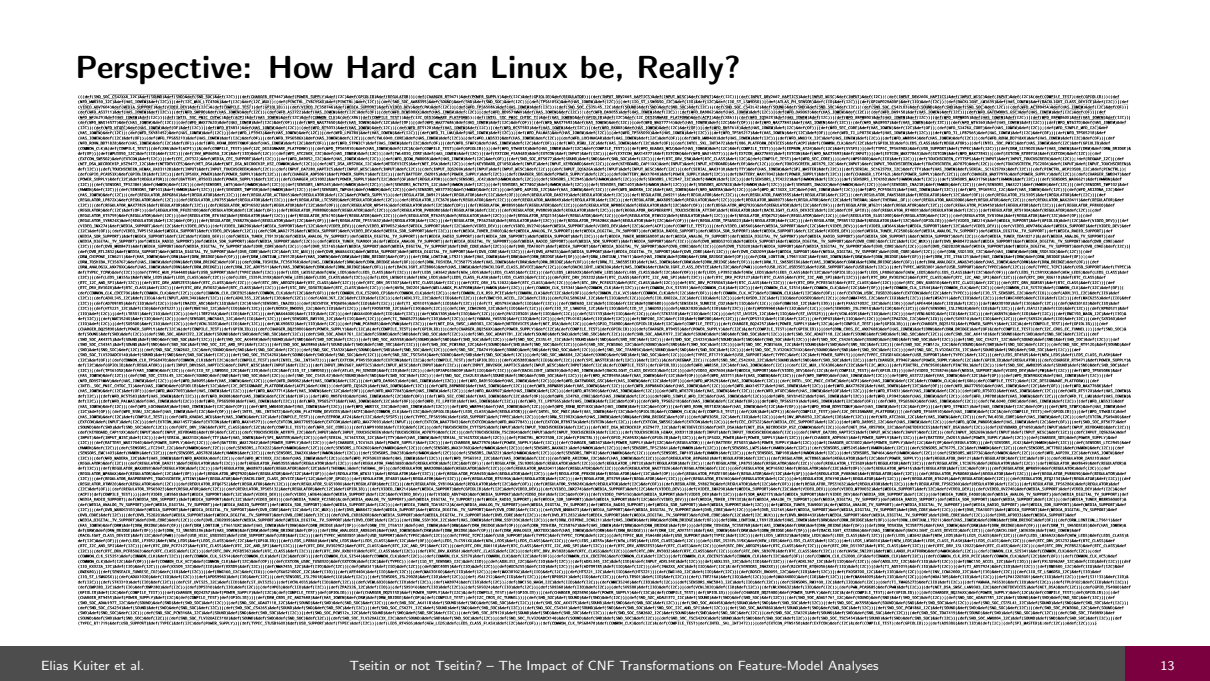
Compiling to BDDs [Tobias Heß]

works on most small models (but not Linux/CDL)
largely depends on variable ordering

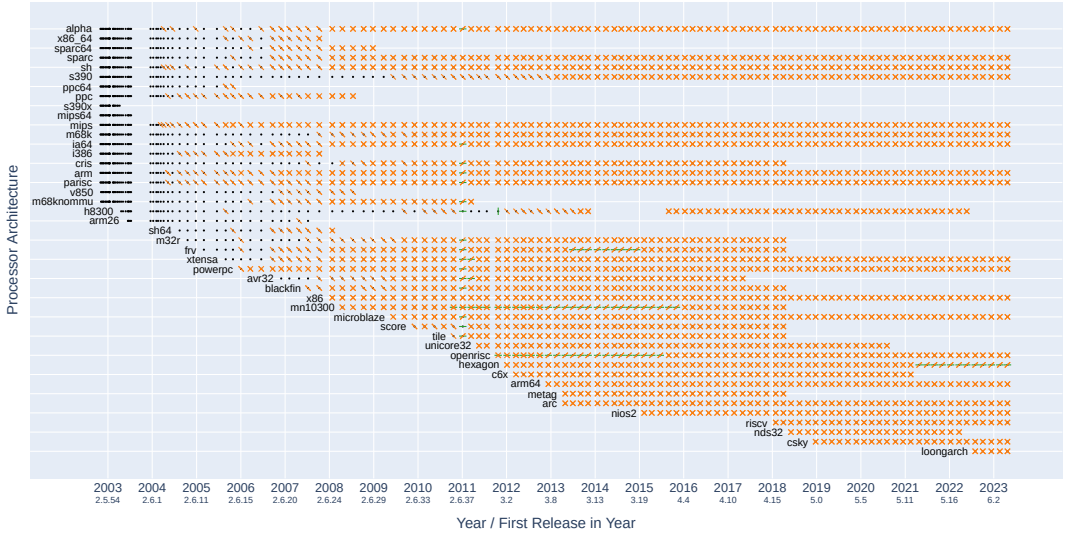
our opinion: feature models are interesting, diverse, and potentially hard problem instances for benchmarking (#)SAT and knowledge compilation. maybe they could contribute to the SAT and MC competition as well?

Perspective: How Hard can Linux be, Really?

Perspective: How Hard can Linux be, Really?



Perspective: How Hard can Linux be, Really? [SharpSAT-td+Arjun, d4]



Conclusion

The Impact of CNF Transformations on Feature-Model Analyses

Distributive	Tseitin	Plaisted-Greenbaum
apply laws of logic	abbreviate ϕ with $x_\phi \leftrightarrow \phi$	abbreviate ϕ with $x_\phi \rightarrow \phi$
✓ **equivalence** ✓ easy to implement ✗ **exponential** complexity	✓ **quasi-equivalence** ✓ **linear** complexity ✗ take care of new variables	✓ **equi-assignability** ✓ **linear** complexity ✗ **equi-countability**
FeatureIDE	**Z3**	**KConfigReader**
often fails on large models	succeeds correctly on all models	often incorrect for #SAT calls

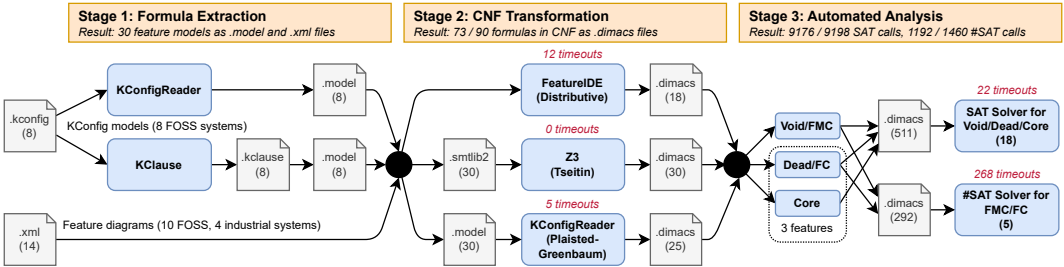
Compiling to **d-DNNFs**

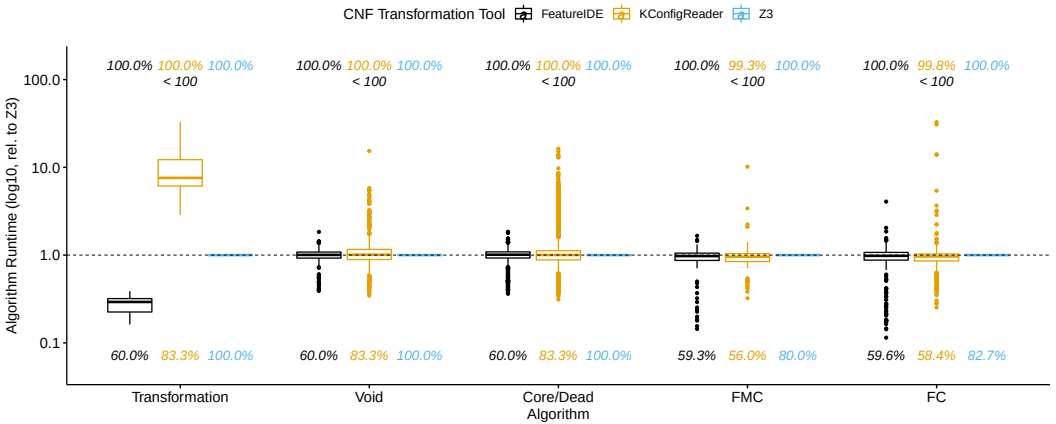
Compiling to **BDDs**

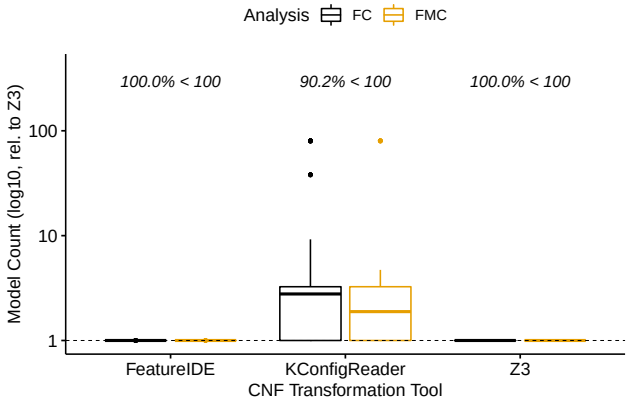
Counting **Linux** is hard

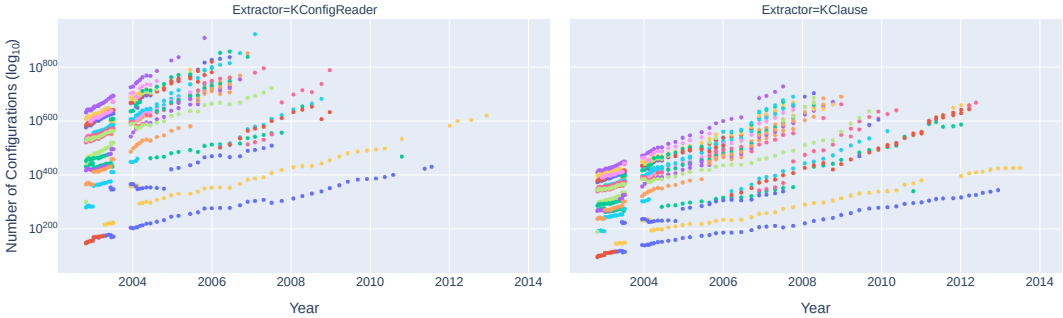
find out more:

github.com/ekuiter/tseitin-or-not-tseitin


Stage 1: Formula Extraction
Result: 30 feature models as .model and .xml files
Stage 2: CNF Transformation
Result: 73 / 90 formulas in CNF as .dimacs files
Stage 3: Automated Analysis
Result: 9176 / 9198 SAT calls, 1192 / 1460 #SAT calls
.kconfig (8)
KConfigReader
KClause
KConfig models (8 FOSS systems)
.model (8)
.kclause (8)
.model (8)
.xml (14)
Feature diagrams (10 FOSS, 4 industrial systems)
12 timeouts
FeatureIDE (Distributive)
.dimacs (18)
0 timeouts
.smtlib2 (30)
Z3 (Tseitin)
.dimacs (30)
5 timeouts
.model (30)
KConfigReader (Plaisted-Greenbaum)
.dimacs (25)
Void/FMC
Dead/FC
Core
3 features
.dimacs (511)
22 timeouts
SAT Solver for Void/Dead/Core (18)
.dimacs (292)
268 timeouts
#SAT Solver for FMC/FC (5)


CNF Transformation Tool
FeatureIDE
KConfigReader
Z3
Algorithm Runtime (log10, rel. to Z3)
100.0
10.0
1.0
0.1
100.0% 100.0% 100.0%
< 100
100.0% 100.0% 100.0%
< 100
100.0% 100.0% 100.0%
< 100
100.0% 99.3% 100.0%
< 100
100.0% 99.8% 100.0%
< 100
60.0% 83.3% 100.0%
60.0% 83.3% 100.0%
60.0% 83.3% 100.0%
59.3% 56.0% 80.0%
59.6% 58.4% 82.7%
Transformation
Void
Core/Dead
Algorithm
FMC
FC


Analysis
FC
FMC
100.0% < 100
90.2% < 100
100.0% < 100
Model Count (log10, rel. to Z3)
100
10
1
FeatureIDE
KConfigReader
Z3
CNF Transformation Tool


Extractor=KConfigReader
Extractor=KClause
Number of Configurations ($\log_{10}$)
10^{800}
10^{600}
10^{400}
10^{200}
2004
2006
2008
2010
2012
2014
Year