

# **ReMax – A MaxSAT aided Product (Re-)Configurator**

Rouven Walter

Wolfgang Kuechlin

Symbolic Computation Group  
WSI Informatics  
University of Tuebingen, Germany

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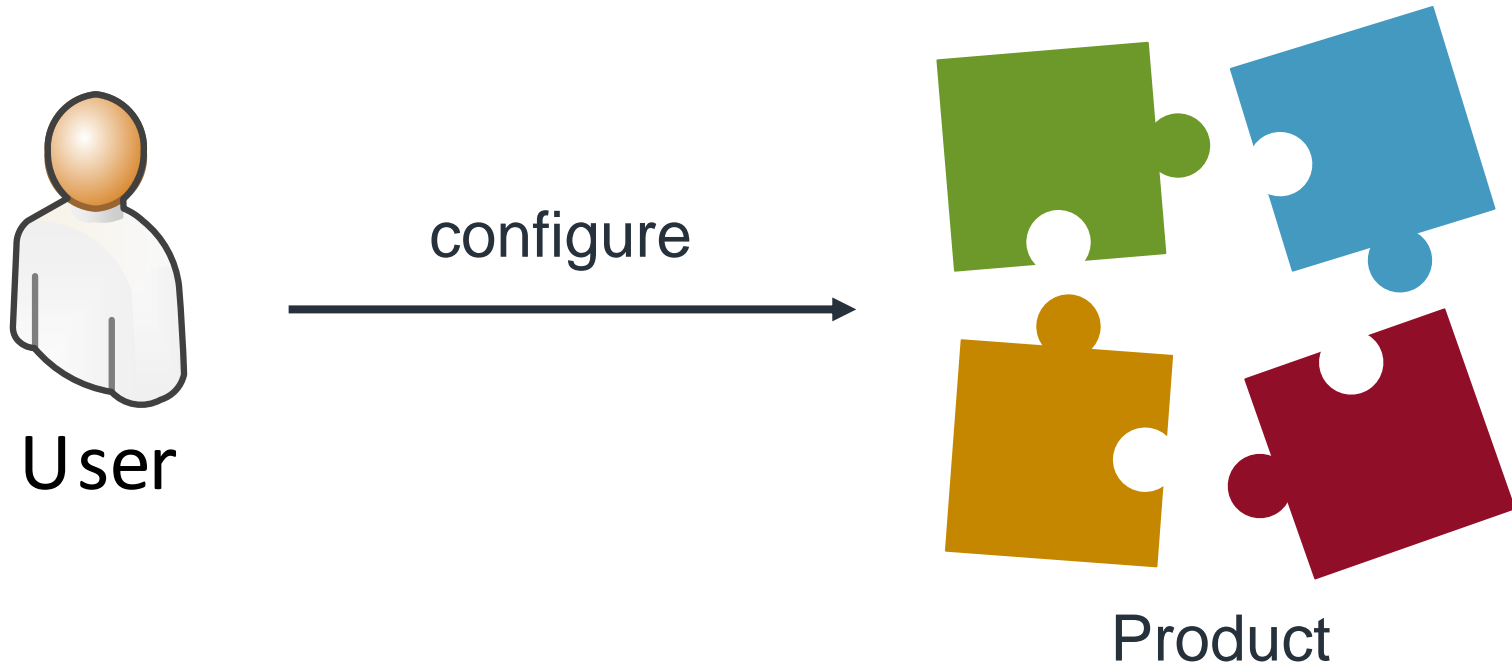
# Overview

- Motivation
- MaxSAT aided Product (Re-)Configuration
- Experimental Results

# Overview

- **Motivation**
- MaxSAT aided Product (Re-)Configuration
- Experimental Results

# Product Configuration



- Families:  $\mathcal{F}$  (Mainboard, CPU, ...)
- Rules:  $\mathcal{R}$  (M1 conflicts with CPU2, ...)
- User selections:  $\mathcal{S}$  (M1, CPU1, ...)

# Example: PC Configuration

Family	Type	Members
Mainboard	regular	M1, M2
CPU	regular	C1, C2
Power Supply	regular	P1, P2, P3
CD-Drive	optional	CD1, CD2
Card-Reader	optional	CR1, CR2

Rules		
M1	→	$C2 \wedge (P1 \vee P2)$
M2	→	$P1 \vee P3$
P1	→	$C2$
P3	→	$\neg CD2$
CD1	→	$C2 \wedge (P1 \vee P2)$
CD2	→	$C1$
CR1	→	$\neg CD1$
CR2	→	$\neg M2 \vee \neg (C2 \wedge P1 \wedge CD1)$

Family Type	Restriction
regular	$= 1$
optional	$\leq 1$
at-least-one	$\geq 1$
no-restriction	

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	Yes	
	M2	Yes	
CPU	C1	Yes	
	C2	Yes	
Power Supply	P1	Yes	
	P2	Yes	
	P3	Yes	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	Yes	

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	Yes	
	C2	Yes	
Power Supply	P1	Yes	
	P2	No	
	P3	Yes	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	Yes	

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	
	P2	No	
	P3	Yes	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	No	



# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	No	

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	X
	CD2	No	
Card-Reader	CR1	No	
	CR2	No	

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	X
	CD2	No	
Card-Reader	CR1	No	
	CR2	No	

 User wants to select CR2

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	X
	CD2	No	
Card-Reader	CR1	No	
	CR2	No	

← Manually Deselection

← User wants to select CR2

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	No	

← Manually Deselection

← User wants to select CR2

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	No	

← Manually Deselection

← Manually Deselection

← User wants to select CR2

# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	
	P2	No	
	P3	Yes	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	No	

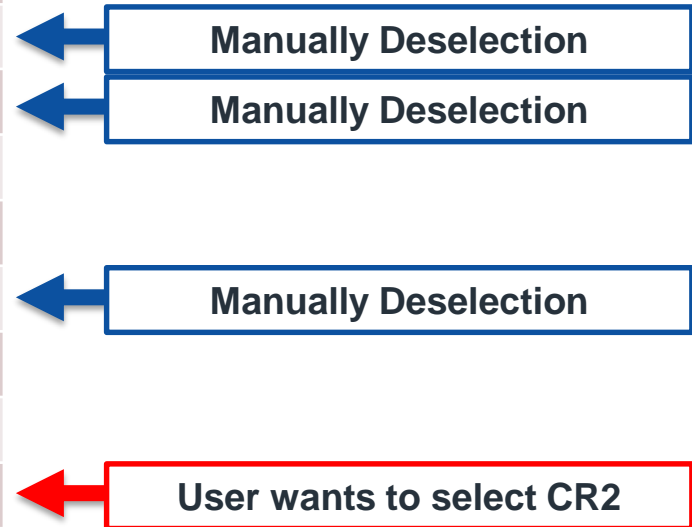
← Manually Deselection

← Manually Deselection

← User wants to select CR2

# SAT aided Product Configuration

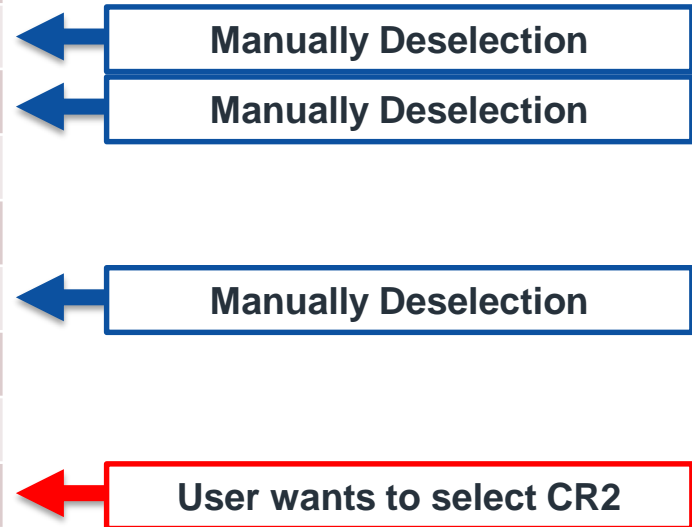
Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	
	P2	No	
	P3	Yes	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	No	





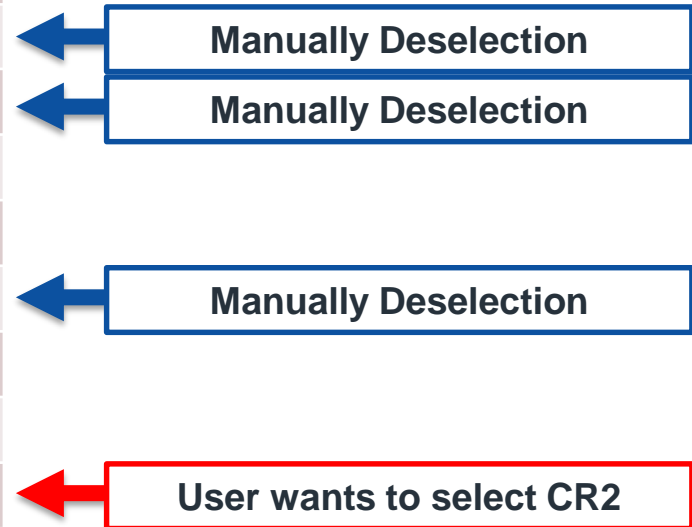
# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	Yes	
	C2	Yes	
Power Supply	P1	Yes	
	P2	No	
	P3	Yes	
CD-Drive	CD1	Yes	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	Yes	



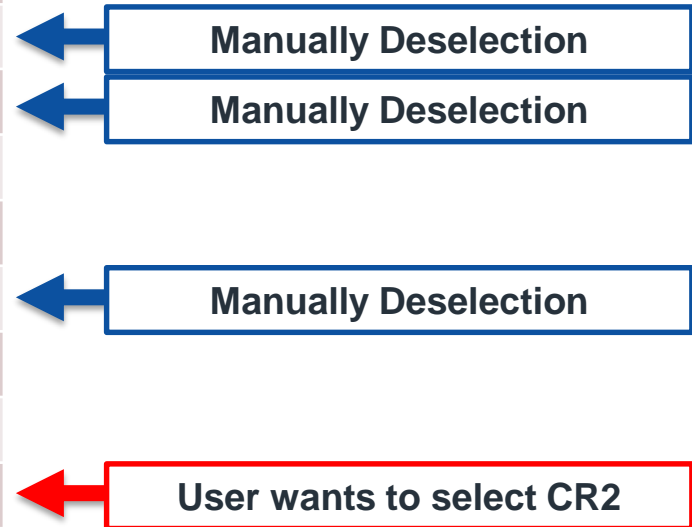
# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	Yes	X
	C2	No	
Power Supply	P1	No	
	P2	No	
	P3	Yes	
CD-Drive	CD1	No	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	Yes	



# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	Yes	X
	C2	No	
Power Supply	P1	No	
	P2	No	
	P3	Yes	X
CD-Drive	CD1	No	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	Yes	



# SAT aided Product Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	Yes	X
	C2	No	
Power Supply	P1	No	
	P2	No	
	P3	Yes	X
CD-Drive	CD1	No	
	CD2	No	
Card-Reader	CR1	Yes	
	CR2	Yes	X

← Manually Deselection

← Manually Deselection

← Manually Deselection

← User wants to select CR2

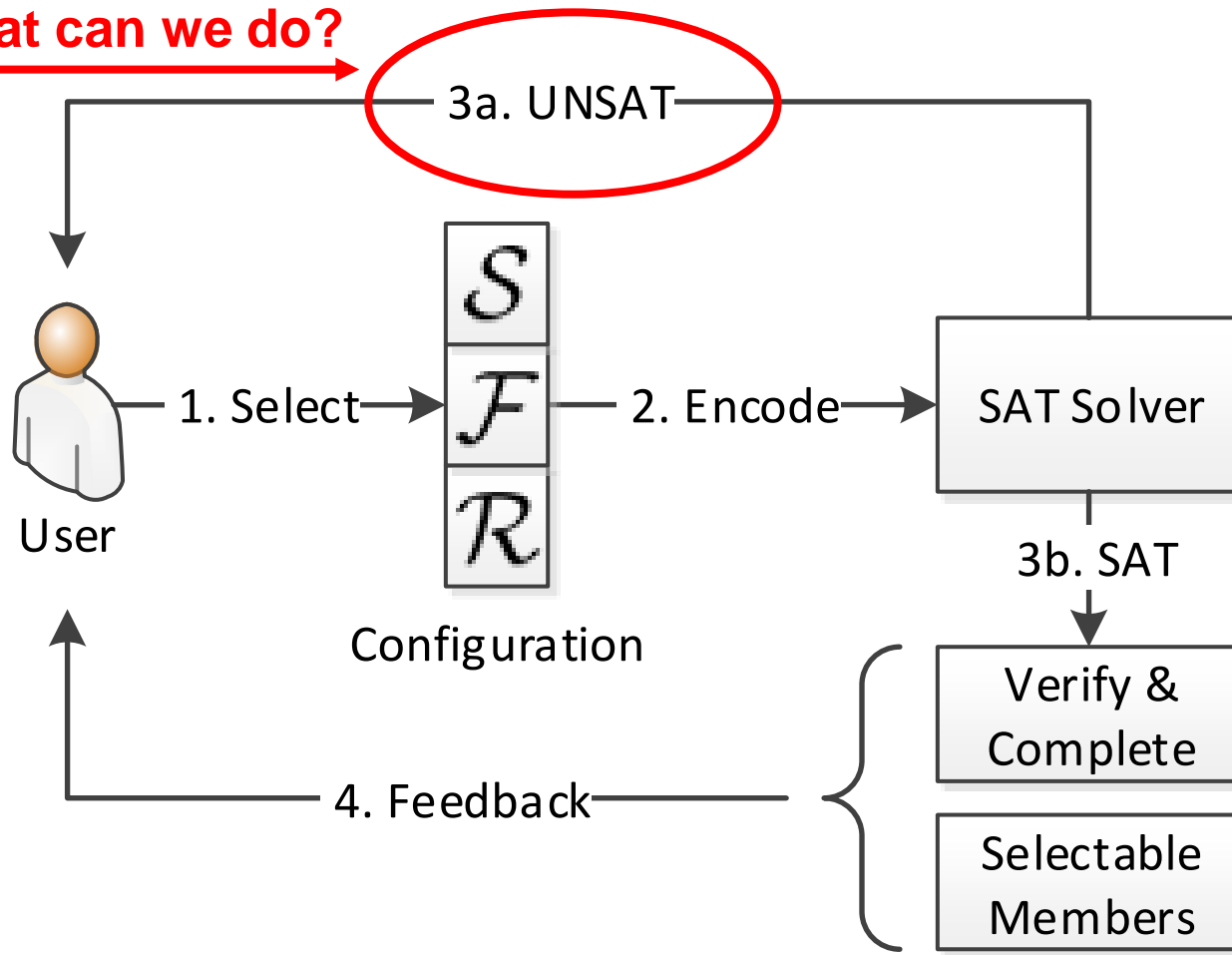
Result: 3 Changes to get CR2

Question: Are less changes possible?

Question: How many changes are *minimally* necessary?

# SAT aided configuration process

What can we do?



# Overview

- Motivation
- **MaxSAT aided Product (Re-)Configuration**
- Experimental Results

# Algorithm: Re-Configuration

**Input:**  $(\mathcal{R}, \mathcal{F}, \mathcal{S})$

**Output:** (optimum, model), where optimum is the minimal number of changes to regain a valid configuration and model is a model for the optimum

Hard  $\leftarrow \emptyset$

Soft  $\leftarrow \emptyset$

**foreach**  $R \in \mathcal{R}$  **do**

  | Hard  $\leftarrow$  Hard  $\cup$  CNF(R)

**foreach**  $F \in \mathcal{F}$  **do**

  | Hard  $\leftarrow$  Hard  $\cup$  CC(F)

**foreach**  $(s, p) \in \mathcal{S} \wedge p \neq 0$  **do**

  | **if**  $p = \infty$  **then**

    | Hard  $\leftarrow$  Hard  $\cup$   $\{s\}$

  | **else**

    | Soft  $\leftarrow$  Soft  $\cup$   $\{s\}$

(optimum, model)  $\leftarrow$  PartialMinUNSAT(Hard, Soft)

**return** (optimum, model)

# MaxSAT aided Product Re-Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	X
	CD2	No	
Card-Reader	CR1	No	
	CR2	No	

← User wants to select CR2



# MaxSAT aided Product Re-Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	X
	CD2	No	
Card-Reader	CR1	No	
	CR2	No	X



Invalid configuration



User wants to select CR2

# MaxSAT aided Product Re-Configuration

Family	Member	Selectable?	Choice	Result
Mainboard	M1	No		X
	M2	Yes	X	
CPU	C1	No		
	C2	Yes	X	X
Power Supply	P1	Yes	X	X
	P2	No		
	P3	No		
CD-Drive	CD1	Yes	X	X
	CD2	No		
Card-Reader	CR1	No		
	CR2	No	X	X

Minimal changes necessary: 1

# ReMax - Screenshot

AutoConfig - Prototyp (STZ OIT Tübingen) - Version 2014-09-21

File Selection Operations Automatic Operations Settings About

Input Order (5): M2(1) C2(1) P1(1) CD1(1) CR2(1)

Output Order (5): C2 CD1 CR2 M1 P1

Next

Rules Custom Rules Families

**Mainboard** (Mainboard of the computer)  
**CPU** (CPU of the computer)  
**Power Supply** (Power supply of the computer)  
**CD-Rom** (CD-Rom device of the computer)  
**Card Reader** (Card reader of the computer)

Selection	Priority	Name	Description
<input type="checkbox"/>	0	M1	Mainboard 1
<input checked="" type="checkbox"/>	1	M2	Mainboard 2

# Algorithm: Re-Configuration with Priorities

**Input:**  $(\mathcal{R}, \mathcal{F}, \mathcal{S})$

**Output:** (optimum, model), where optimum is the minimal number of priority points to change to regain a valid configuration and model is a model for the optimum

Hard  $\leftarrow \emptyset$

Soft  $\leftarrow \emptyset$

**foreach**  $R \in \mathcal{R}$  **do**

└ Hard  $\leftarrow$  Hard  $\cup$  CNF( $R$ )

**foreach**  $F \in \mathcal{F}$  **do**

└ Hard  $\leftarrow$  Hard  $\cup$  CC( $F$ )

**foreach**  $(s, p) \in \mathcal{S} \wedge p \neq 0$  **do**

┌ **if**  $p = \infty$  **then**

└ Hard  $\leftarrow$  Hard  $\cup \{s\}$

**else**

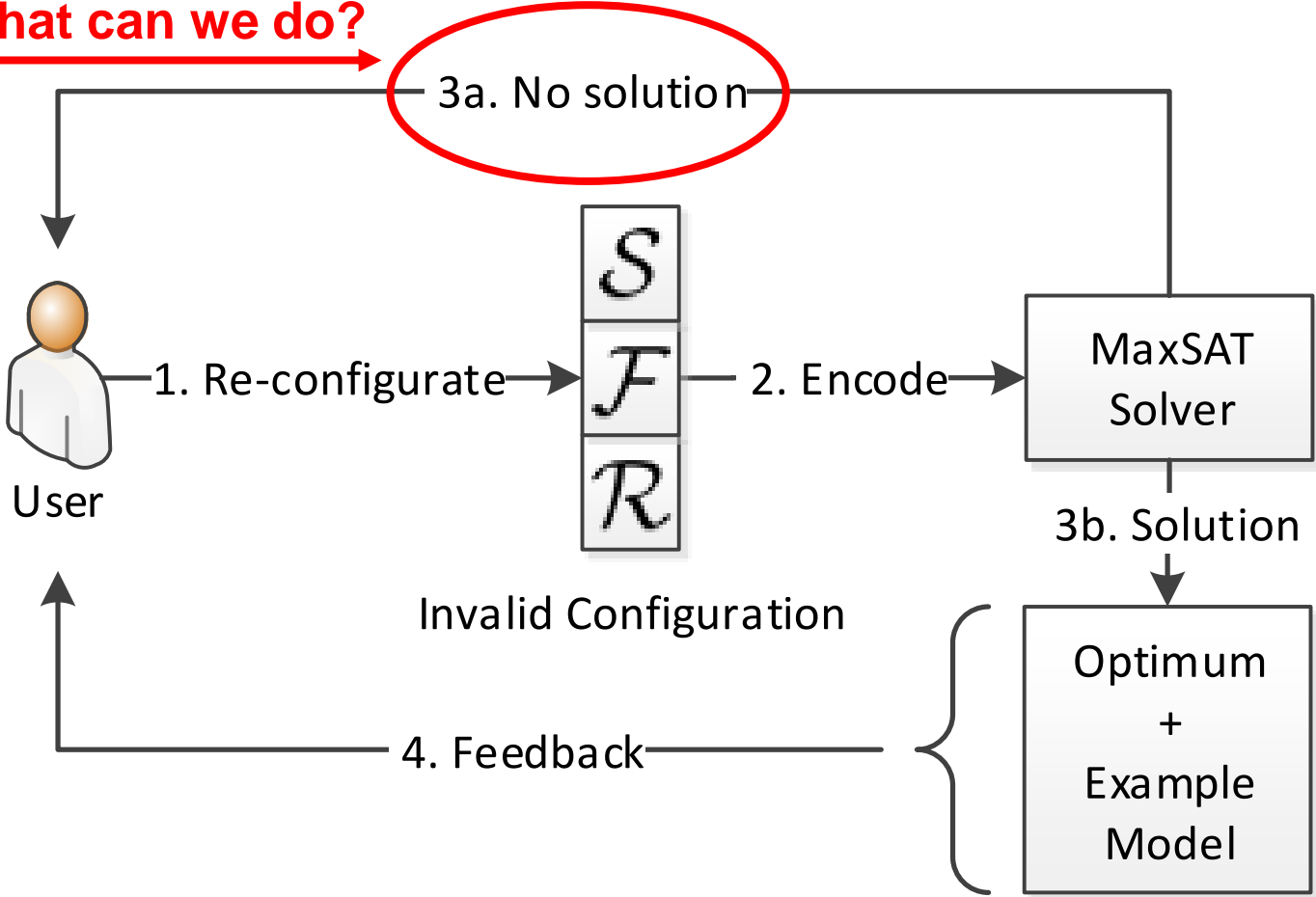
└ Soft  $\leftarrow$  Soft  $\cup \{(s, p)\}$

(optimum, model)  $\leftarrow$  PartialWeightedMinUNSAT(Hard, Soft)

**return** (optimum, model)

# MaxSAT aided configuration process

What can we do?



# Algorithm: Re-Configuration of Rules

**Input:**  $(\mathcal{R}, \mathcal{F}, \mathcal{S})$

**Output:** (optimum, model), where optimum is the minimal number of changes to regain a valid configuration and model is a model for the optimum

Hard  $\leftarrow \mathcal{S}$

Soft  $\leftarrow \mathcal{S}$

**foreach**  $F \in \mathcal{F}$  **do**

└ Hard  $\leftarrow$  Hard  $\cup$  CC(F)

**foreach**  $R \in \mathcal{R} \wedge \mathcal{S}_{\mathcal{R}}(R) \neq 0$  **do**

└ **if**  $p = \infty$  **then**

└└ Hard  $\leftarrow$  Hard  $\cup$  CNF(R)

└ **else**

└└ Hard  $\leftarrow$  Hard  $\cup$  CNF( $b_R \rightarrow R$ )

└└ Soft  $\leftarrow$  Soft  $\cup \{b_R\}$

**foreach**  $(s, p) \in \mathcal{S} \wedge p \neq 0$  **do**

└ **if**  $p = \infty$  **then**

└└ Hard  $\leftarrow$  Hard  $\cup \{s\}$

└ **else**

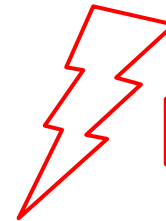
└└ Soft  $\leftarrow$  Soft  $\cup \{s\}$

(optimum, model)  $\leftarrow$  PartialMinUNSAT(Hard, Soft)

**return** (optimum, model)

# MaxSAT aided Product Re-Configuration

Family	Member	Selectable?	Choice
Mainboard	M1	No	
	M2	Yes	X
CPU	C1	No	
	C2	Yes	X
Power Supply	P1	Yes	X
	P2	No	
	P3	No	
CD-Drive	CD1	Yes	X
	CD2	No	
Card-Reader	CR1	No	
	CR2	No	X



Invalid configuration

# MaxSAT aided Product Re-Configuration

Invalid Order: M2, C2, P1, CD1, CR2

Rules			Result
M1	→	$C2 \wedge (P1 \vee P2)$	X
M2	→	$P1 \vee P3$	X
P1	→	C2	X
P3	→	$\neg CD2$	X
CD1	→	$C2 \wedge (P1 \vee P2)$	X
CD2	→	C1	X
CR1	→	$\neg CD1$	X
CR2	→	$\neg M2 \vee \neg (C2 \wedge P1 \wedge CD1)$	

Minimal changes necessary: 1

Remove/Change



# Use Case #1

## - Different optimization goals -

- Maximal/Minimal number of components
- Maximal/Minimal costs
  
- Maximal/Minimal weight (automotive configuration)
- Maximal/Minimal CO2 output (automotive configuration)
  
- **Optimization of your favorite component attribute**

# Use Case #2

## - Sales Division -

- **Re-Configuration within the Sales Division**
  - Label replaceable rules
  - Fix not replacable rules
- **Computation:**  
Minimale changes of the rules to make order valid

# Use Case #3

## - Engineering Division-

- **Goal: Generate a valid order (automotive engineering)**
  - Fix engine, cubic capacity, country, etc
  - Selection of further componenty by hand
  - If order is invalid, re-configure to keep maximal selections
  
- **Goal: Make order valid**
  - Given an invalid order
  - Computation:  
Minimal removal/change of rules to make order valid

# Overview

- Motivation
- MaxSAT aided Product (Re-)Configuration
- **Experimental Results**

# Experimental Results

	Rules		Families		
	Quantity	#Variables	Quantity	Avg. size	
Car Manufacturer 1	M01_01	2074	1772	34	34,294
	M01_02	2430	<b>2087</b>	41	<b>39,293</b>
	M01_03	1137	880	30	18,233
Car Manufacturer 2	M02_01	<b>11627</b>	996	<b>188</b>	6,282
	M02_02	4465	612	174	5,321

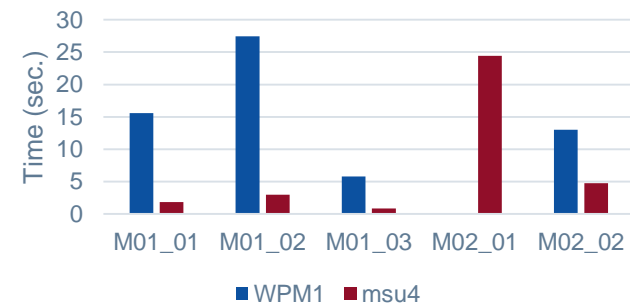
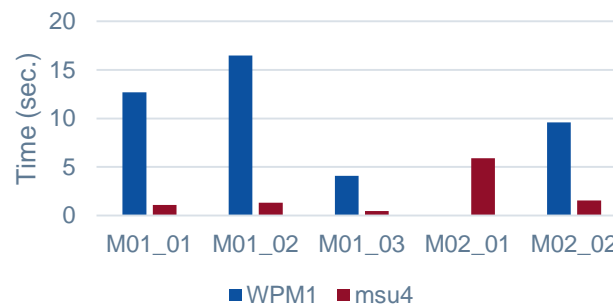
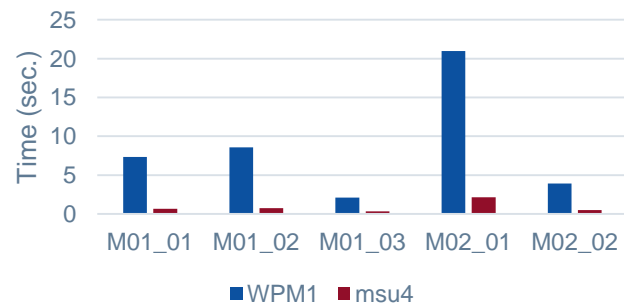
# Use Case: Re-Configuration of weighted selections

	30%		50%		70%	
	WPM1	msu4	WPM1	msu4	WPM1	msu4
M01_01	7,34	<b>0,66</b>	12,70	<b>1,08</b>	15,59	<b>1,84</b>
M01_02	8,59	<b>0,74</b>	16,48	<b>1,32</b>	27,44	<b>2,96</b>
M01_03	2,10	<b>0,33</b>	4,10	<b>0,45</b>	5,80	<b>0,85</b>
M02_01	20,99	<b>2,16</b>	exc.	<b>5,91</b>	exc.	<b>24,45</b>
M02_02	3,90	<b>0,48</b>	9,60	<b>1,56</b>	13,01	<b>4,77</b>

30%

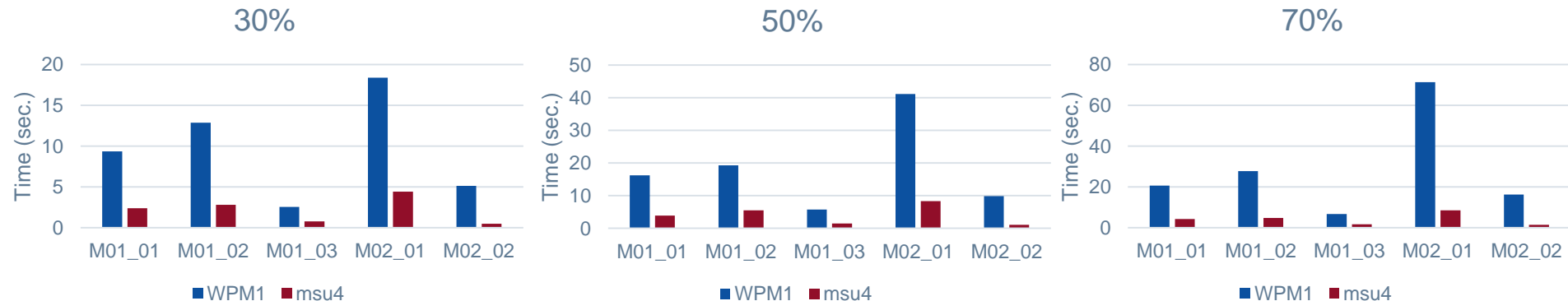
50%

70%



# Use Case: Re-Configuration of rules

	30%		50%		70%	
	WPM1	msu4	WPM1	msu4	WPM1	msu4
M01_01	9,35	<b>2,39</b>	16,19	<b>3,93</b>	20,63	<b>4,35</b>
M01_02	12,86	<b>2,80</b>	19,32	<b>5,47</b>	27,82	<b>4,82</b>
M01_03	2,54	<b>0,78</b>	5,71	<b>1,45</b>	6,76	<b>1,74</b>
M02_01	18,40	<b>4,43</b>	41,16	<b>8,33</b>	71,29	<b>8,55</b>
M02_02	5,13	<b>0,49</b>	9,88	<b>1,04</b>	16,32	<b>1,48</b>



# Summary

- Motivation
  - SAT: Validate configuration
  - SAT: Selectable members
- MaxSAT aided Product (Re-)Configuration
  - “Repair” invalid configuration optimally
  - Re-Configure rules
- Experimental Results
  - Benchmarks based on real automotive configuration
  - Reasonable average time  
(except two runs for own solver)

**Thank you for your attention**