Applications of MaxSAT in Automotive Configuration

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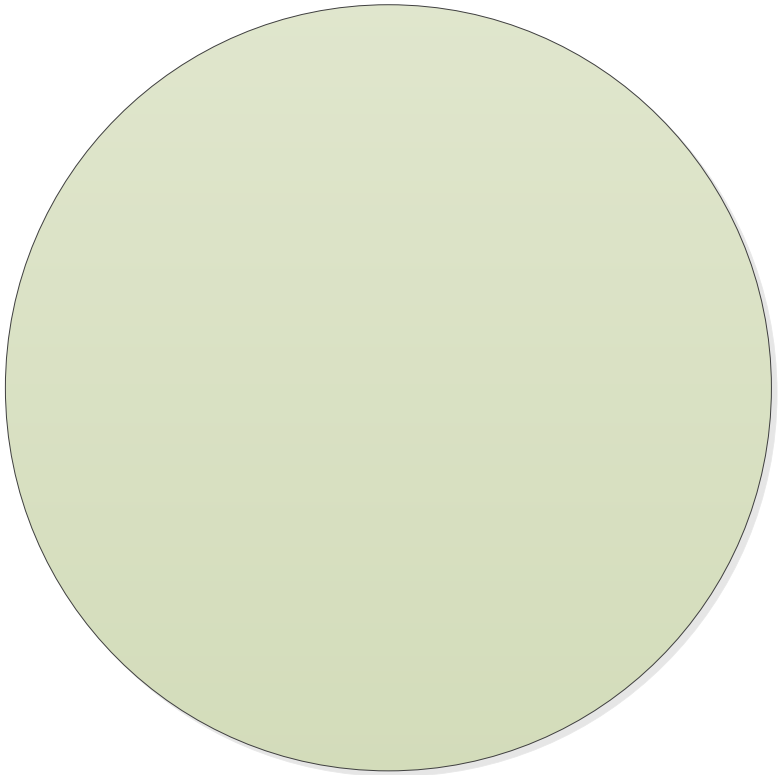
Overview

1. Motivation
2. Applications in Automotive Configuration
3. Experimental Results

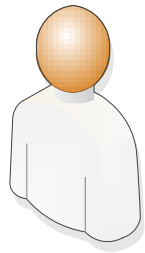
Overview

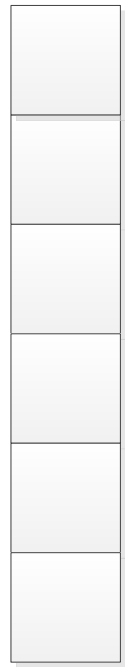
Motivation

product overview formula

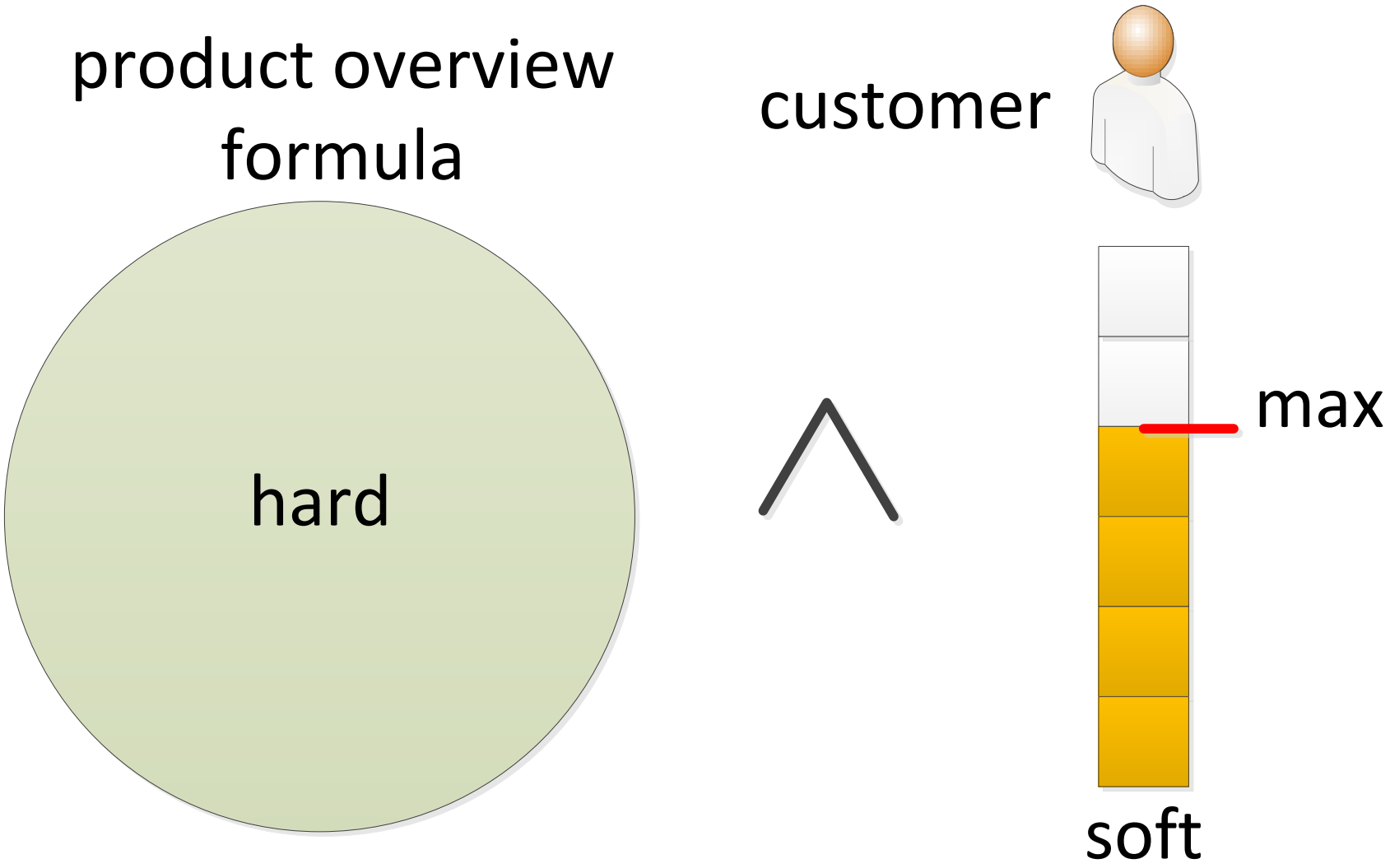


customer

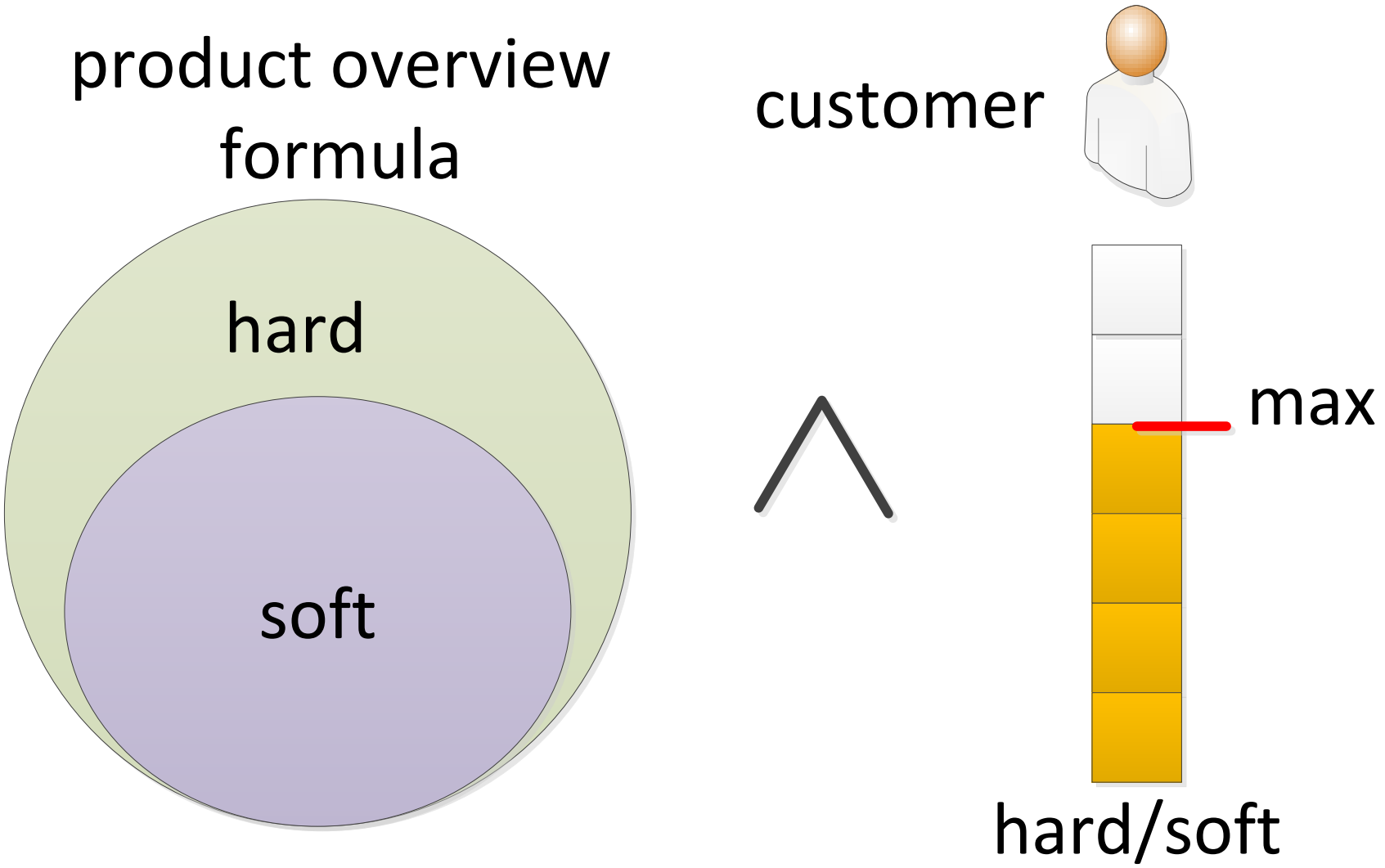




Motivation (cont'd)



Motivation (cont'd)



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Applications in Automotive Configuration

Definition (SAT-Problem)

Let $\varphi = \bigwedge_{i=1}^{m} \psi_i$ a formula in CNF.

- Question: Does an assignment v exist with $\|\varphi\|_v = 1$?

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- Question (MaxSAT): How many clauses can be maximally satisfied?

Applications in Automotive Configuration (cont'd)

Automotive Configuration with SAT

Product overview formula (POF):

- Each component c is represented by a variable x_c
- Families of components: φ_{cc}
- Dependencies between components: φ_{dep}
- Resulting formula:

$$\varphi_{car} := \varphi_{cc} \wedge \varphi_{dep}$$

Applications in Automotive Configuration (cont'd)

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Possible Verifications:

- Validation of a partial configuration
- Test for forced components
- Test for redundant components

Applications in Automotive Configuration (cont'd)

Drawbacks with the SAT-based approach

In case of an invalid configuration. . .

Applications in Automotive Configuration (cont'd)

Drawbacks with the SAT-based approach

In case of an invalid configuration. . .

- Which components cause the conflict?

Applications in Automotive Configuration (cont'd)

Drawbacks with the SAT-based approach

In case of an invalid configuration...

- Which components cause the conflict?
- Which components to omit to get a valid configuration with a maximal number of chosen components?

Applications in Automotive Configuration (cont'd)

Automotive Configuration with MaxSAT – idea

- Reconsider resulting formula from SAT-based configuration:

$$\varphi_{car} := \varphi_{cc} \wedge \varphi_{dep}$$

Applications in Automotive Configuration (cont'd)

Automotive Configuration with MaxSAT – idea

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- Set φ_{cc} clauses as hard clauses

Applications in Automotive Configuration (cont'd)

Automotive Configuration with MaxSAT – idea

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Applications in Automotive Configuration (cont'd)

Automotive Configuration with MaxSAT – idea

- Reconsider resulting formula from SAT-based configuration:

$$\varphi_{car} := \varphi_{cc} \wedge \varphi_{dep}$$

- Set φ_{cc} clauses as hard clauses
- Set φ_{dep} clauses as hard clauses
- Set certain clauses from the sales division as soft clauses (with weights)

Applications in Automotive Configuration (cont'd)

Possible scenarios

1) Maximization of chosen components: Customer options $x_{c_1}, \ldots, x_{c_n}$.

$$\underbrace{\varphi_{car}}_{\text{hard clauses}} \quad \wedge \quad \underbrace{x_{c_1} \wedge \ldots \wedge x_{c_n}}_{\text{soft clauses}}$$

Applications in Automotive Configuration (cont'd)

Possible scenarios

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$$\underbrace{\varphi_{car}}_{\text{hard clauses}} \quad \wedge \quad \underbrace{x_{c_1} \wedge \ldots \wedge x_{c_n}}_{\text{soft clauses}}$$

2) Maximization of priorities:
Customer options $x_{c_1}, \ldots, x_{c_n}$ with priorities $p_1, \ldots, p_n$.

$$\underbrace{\varphi_{car}}_{\text{hard clauses}} \quad \wedge \quad \underbrace{(x_{c_1}, p_1) \wedge \ldots \wedge (x_{c_n}, p_n)}_{\text{soft clauses}}$$

Applications in Automotive Configuration (cont'd)

Possible scenarios

3) Minimization of costs: Options $c_1, \ldots, c_n$ with prices $p_1, \ldots, p_n$.

$$\underbrace{\varphi_{car}}_{\text{hard clauses}} \quad \wedge \quad \underbrace{(\neg x_{c_1}, p_1) \wedge \ldots \wedge (\neg x_{c_n}, p_n)}_{\text{soft clauses}}$$

Use Partial Weighted MinUNSAT Solver!

Example

Table : Component families with limitations

family	alternatives	limit
engine	E_1, E_2, E_3	$= 1$
gearbox	G_1, G_2, G_3	$= 1$
control unit	C_1, C_2, C_3, C_4, C_5	$= 1$
dashboard	D_1, D_2, D_3, D_4	$= 1$
navigation system	N_1, N_2, N_3	≤ 1
air conditioner	AC_1, AC_2, AC_3	≤ 1
alarm system	AS_1, AS_2	≤ 1
radio	R_1, R_2, R_3, R_4, R_5	≤ 1

Table : Component dependencies

premise	conclusion
G_1	$E_1 \vee E_2$
$N_1 \vee N_2$	D_1
N_3	$D_2 \vee D_3$
$AC_1 \vee AC_3$	$D_1 \vee D_2$
AS_1	$D_2 \vee D_3$
$R_1 \vee R_2 \vee R_5$	$D_1 \vee D_4$

Example (cont'd)

Table : Customer choices and Partial MaxSAT results

family	choice	result
engine	E_1	E_1
gearbox	G_2	G_2
control unit	C_2	C_2
dashboard	$\boldsymbol{D_3}$	$\boldsymbol{D_1}$
navigation system	N_2	N_2
air conditioner	AC_1	AC_1
alarm system	$\boldsymbol{AS_1}$	–
radio	R_2	R_2

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Experimental Results

Algorithmic techniques

- Branch-and-Bound
- Basic SAT-based

Algorithm 1: Basic SAT-based approach

Input: $\varphi = \{\psi_1, \ldots, \psi_m\}$
Output: Minimal number of unsatisfied clauses
$\varphi \leftarrow \{\psi_1 \vee b_1, \ldots, \psi_m \vee b_m\}$
$cost \leftarrow m$
while $\mathrm{SAT}(\varphi \cup \mathrm{CNF}(\sum_{i=1}^{m} b_i < cost))$ **do**
  $cost \leftarrow cost - 1$
return *cost*

- Core-guided SAT-based

Experimental Results (cont'd)

Table : Benchmark details

	Benchmark categories		
	Order	Packages	Packages & more
#instances	777	777	777
Avg. #variables	896	896	896
Avg. #hard clauses	4474	3928	3592
Avg. #soft clauses	15	561	897
#no optimum	0	688	0
#with optimum	777	89	777
Avg. optimum	2.127	1.348	4.067

Experimental Results (cont'd)

Table : Benchmark results with a time limit of 3,600 sec. per instance

Avg. time (sec)	akmaxsat	Fu & Malik	PM2
Order	**0.165**	4.367	4.180
Packages	**0.025**	1.664	exceeded limit
Packages & more	**0.535**	5.387	exceeded limit

Experimental Results (cont'd)

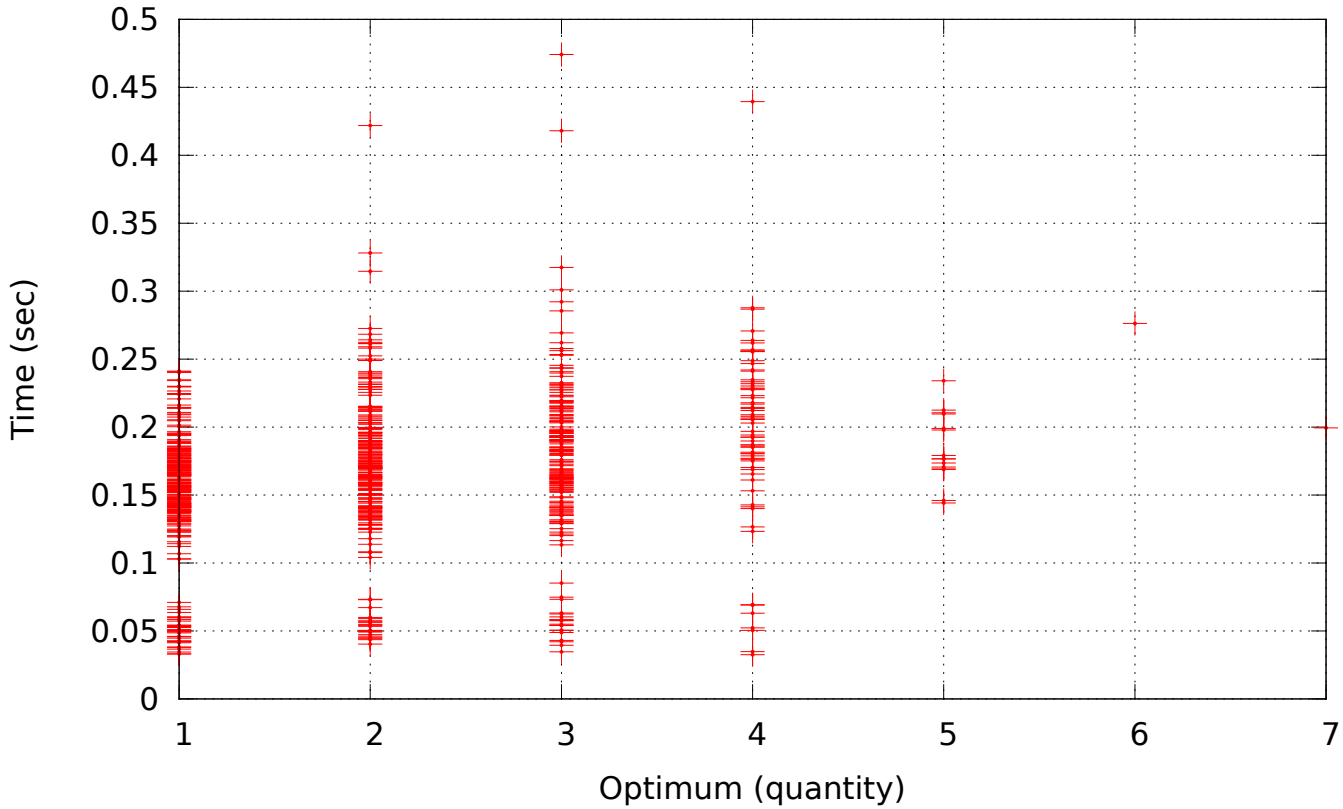

Figure : Benchmark 'Order' with akmaxsat

Experimental Results (cont'd)

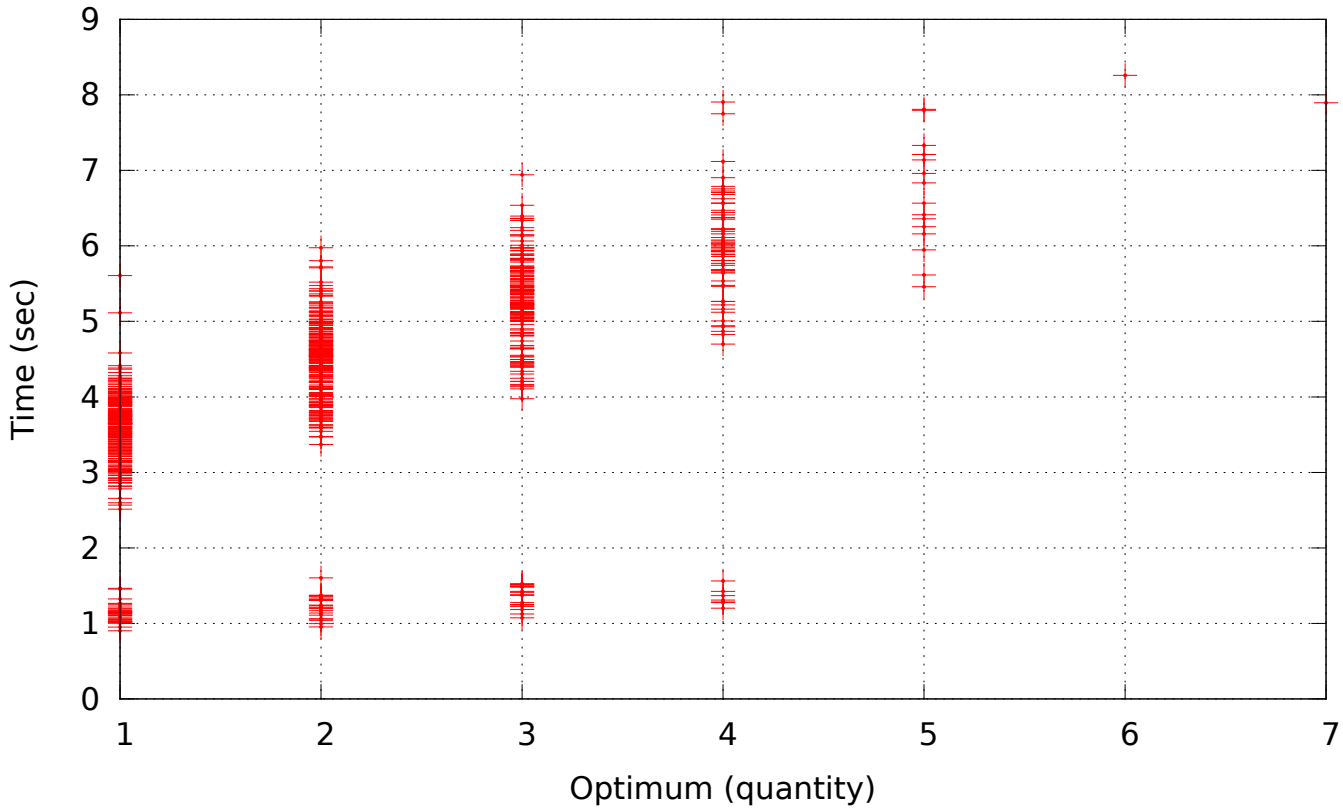

Figure : Benchmark 'Order' with Fu & Malik

Experimental Results (cont'd)

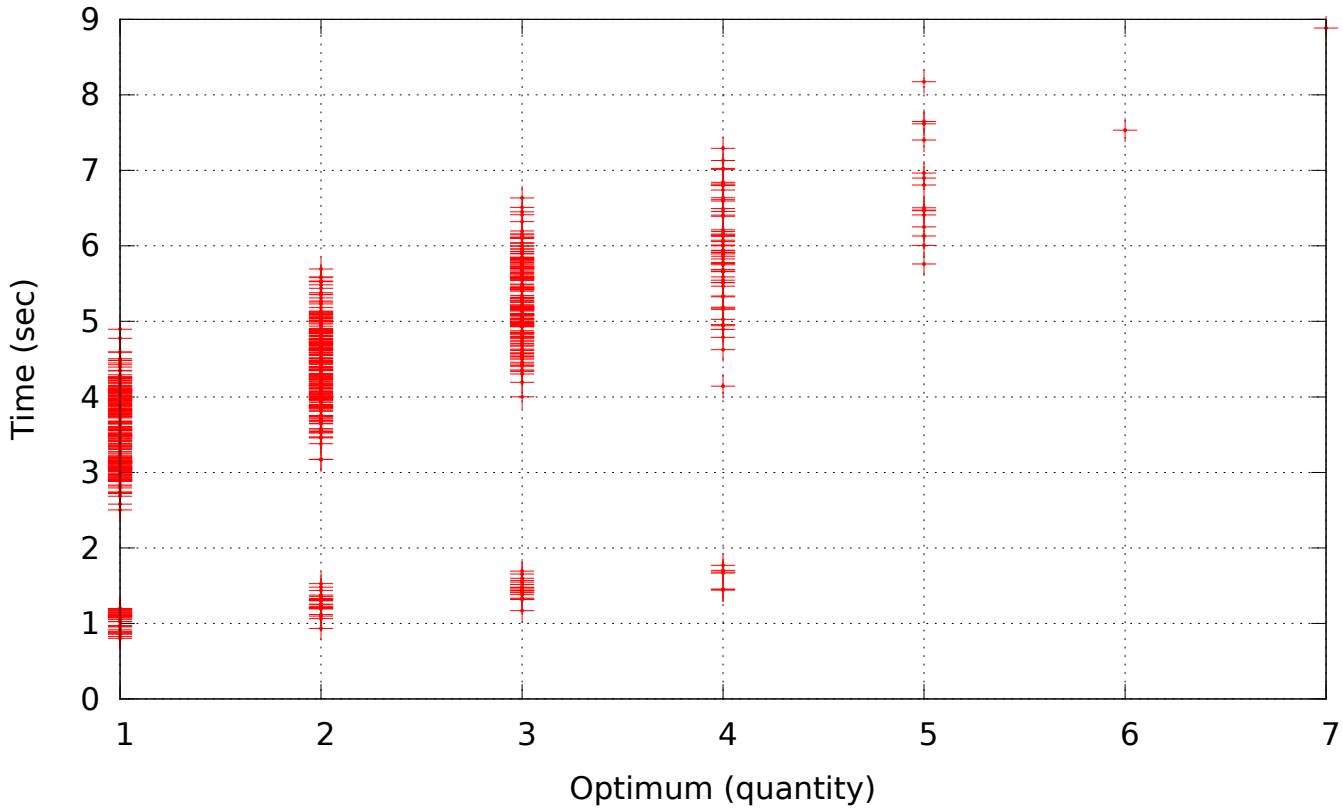

Figure : Benchmark 'Order' with PM2

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   - Application example
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   - Benchmark details
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Thank you for your attention