

Task scheduling for dual-arm industrial robots through constraint programming

MiniZinc modeling and solver comparison

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Outline

1 Introduction

- YuMi®
- Project goal
- Job Shop Problem
- MiniZinc
- Solvers

2 Case Study

3 Model

- Filter

4 Evaluation

- Results



Introduction - YuMi®

- Dual-armed robot
 - Flexible
 - Fine motor skills



Photo: ABE

Task scheduling for dual-arm industrial robots through constraint programming



■ Dual-armed robot
■ Flexible
■ Fine motor skills

Photo: ABB

- 1. Montera endast mellan maskiner utan tray

Introduction - Project goal



Introduction - Job Shop Problem



Introduction - MiniZinc



Criteria

- FlatZinc parser
- Free



Solvers Tested

- G12/FD
- JaCoP
- Gecode
- or-tools
- Opturion CPX
- Choco3



G12/FD

- G12 Team, NICTA
- Mercury
- Default solver for MiniZinc



JaCoP

- Java Constraint Programming solver
- Open Source
- Developed since 2001 - Krzysztof Kuchcinski & Radoslaw Szymanek
- Silver medal



Gecode

- C++
- Open Source
- Christian Schulte
- Parallel searches - utilising multiple cores
- All gold medals 2008-2012



Task scheduling for dual-arm industrial robots through constraint programming

└ Introduction

└ Solvers

└ Gecode

Gecode

- C++
- Open Source
- Christian Schulte
- Parallel searches - utilising multiple cores
- All gold medals 2008-2012

1. Christian Schulte: lett utvecklingen, många andra som bidragit
2. All gold medals 2008-2012: i alla kategorier

or-tools

- C++
- Google - Operational Research
- Open Source
- Utilising multiple cores
- Gold medals 2013-2014



Task scheduling for dual-arm industrial robots through constraint programming

└ Introduction

└ Solvers

└ or-tools

- C++
- Google - Operational Research
- Open Source
- Utilising multiple cores
- Gold medals 2013-2014

1. Utilising multiple cores: Inte säker om parallel sökning, nämns i dokumentationen som "parallel solving", explicit utesluten ur dokumentationen

Opturion CPX

- Opturion Pty Ltd
- Commercial
- SAT combo
- Gold medals 2013, all silver medals 2014



Task scheduling for dual-arm industrial robots through constraint programming

└ Introduction

└ Solvers

└ Opturion CPX

- Opturion Pty Ltd
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- Gold medals 2013, all silver medals 2014

1. Opturion Pty Ltd: Härstammar från G12
2. Commercial: kostar, akademisk licens
3. SAT combo: FD + SAT, SAT = satslogik, väldigt effektiv på att lösa stora problem, sägs att satslogik -*å* sökning inte slöas ner av stora domäner

Choco3

- Java
- Open Source
- Developed since early 2000 - Jean-Guillaume Fages & Charles Prud'homme
- Not same as predecessor Choco2



Case Study

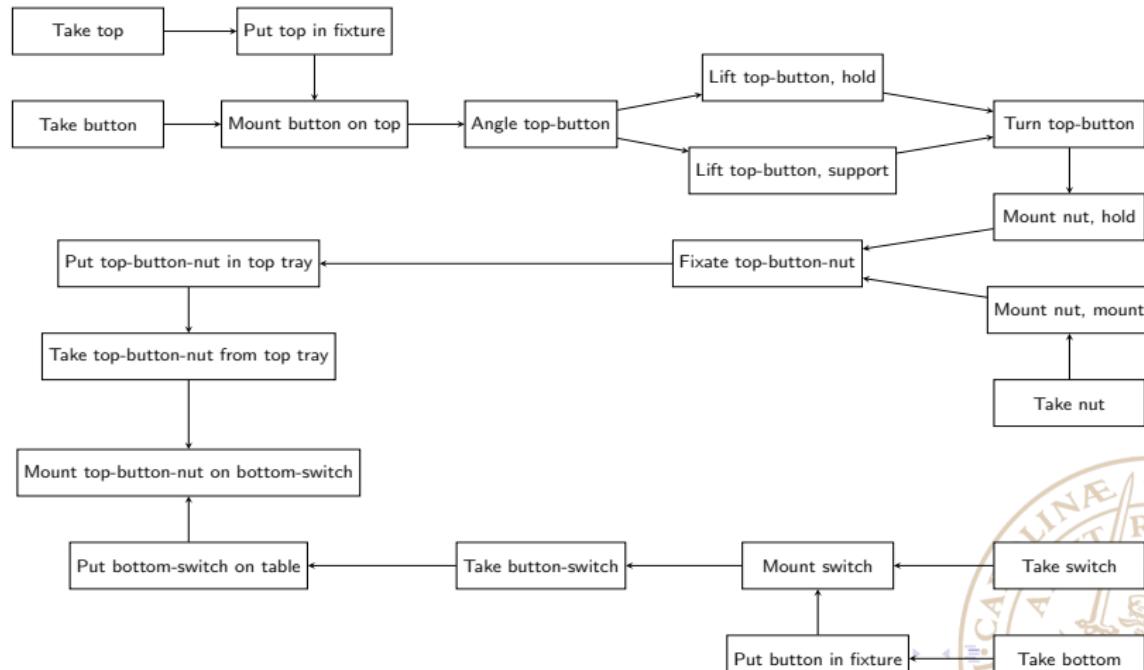


Entities

- Machines
- Tools
- Tray
- Fixture
- Output



Assembly



Model



Filter



Evaluation



Results

	Pred & Temp		Pred		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186
or-tools	271	!	380	!	302	!	457	!
Opturion CPX	-	!	-	!	-	!	-	!
Choco3	-	-	-	-	-	-	-	-

Results

	Pred & Temp		Pred		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186
or-tools	271	!	380	!	302	!	457	!
Opturion CPX	-	!	-	!	-	!	-	!
Choco3	-	-	-	-	-	-	-	-

Task scheduling for dual-arm industrial robots through constraint programming

Evaluation

Results

Results

Results

	Prod & Temp		Prod		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
In2ITU	-	-	-	-	-	-	-	-
InCoP	898	80	1011136	-	-	-	-	-
Gecode	-	1	-	71761	-	99	-	71186
ar-tools	271	1	380	1	302	1	457	1
Optimus CPK	-	-	-	-	-	-	-	-
Choco2	-	-	-	-	-	-	-	-

Hittar lösning, inte optimal

Results

	Pred & Temp		Pred		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186
or-tools	271	!	380	!	302	!	457	!
Opturion CPX	-	!	-	!	-	!	-	!
Choco3	-	-	-	-	-	-	-	-

Task scheduling for dual-arm industrial robots through constraint programming

Evaluation

Results

Results

Results

	Prod & Temp		Prod		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
In2ITU	1.6	-	-	-	-	-	-	-
InCoP ⁺	898	-	3511156	-	-	-	-	-
Gecode	-	40	-	71761	-	99	-	71186
ar-tools	271	1	380	1	302	1	457	1
Optimus CPK	-	1	-	1	-	-	-	-
Choco2	-	-	-	-	-	-	-	-

Hittar hittar alla lösningar, inklusive optimala

Results

	Pred & Temp		Pred		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186
or-tools	271	!	380	!	302	!	457	!
Opturion CPX	-	!	-	!	-	!	-	!
Choco3	-	-	-	-	-	-	-	-

Task scheduling for dual-arm industrial robots through constraint programming

└ Evaluation

└ Results

└ Results

Results

	Prod & Temp		Prod		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
In2ITU	-	-	-	-	-	-	-	-
InCoP	898	-	3011156	-	-	-	-	-
Gecode	-	80	-	71161	-	99	-	71186
ar-tools	271	1	380	1	302	1	457	1
Optimus CPK	-	-	-	-	-	-	-	-
Choco2	-	-	-	-	-	-	-	-

Hittar 3 lösningar, inklusive optimala

Results

	Pred & Temp		Pred		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186
or-tools	271	!	380	!	302	!	457	!
Opturion CPX	-	!	-	!	-	!	-	!
Choco3	-	-	-	-	-	-	-	-

Task scheduling for dual-arm industrial robots through constraint programming

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Results

Results

	Prod & Temp		Prod		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
IntCoP	-	-	-	-	-	-	-	-
IntCoP [*]	898	-	3011156	-	-	-	-	-
Gecode	-	80	-	71165	-	99	-	-
ar-tools	271	1	380	1	302	1	437	1
Optimus CPK	-	-	-	-	-	-	-	-
Choco2	-	-	-	-	-	-	-	-

Hittar 1 lösning, den optimala, på ungefär samma tid som den tidigare

Results

	Pred & Temp		Pred		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186
or-tools	271	!	380	!	302	!	457	!
Opturion CPX	-	!	-	!	-	!	-	!
Choco3	-	-	-	-	-	-	-	-

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Evaluation

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Results

Results

	Prod & Temp		Prod		Temp		None	
	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1	1.6	2.0.1
InCoP	-	-	-	-	-	-	-	-
InCoP [*]	898	-	3011156	-	-	-	-	-
Gecode	-	80	-	71761	-	99	-	-
ar-tools	271	1	380	1	302	1	457	1
Optimus CPK	-	-	-	-	-	-	-	-
Choco2	-	-	-	-	-	-	-	-

Hittar 2 lösningar direkt