

2015-02-19

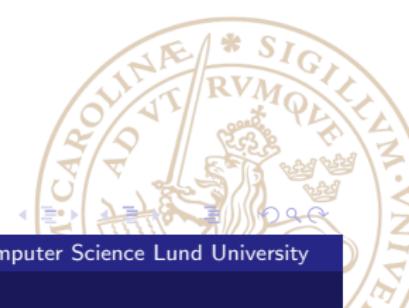
Task scheduling for dual-arm industrial robots through constraint programming

MinZinc modeling and solver comparison

Tommy Kvant

Institute of Computer Science
Lund University

February 19, 2015



Outline

1 Introduction

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

2 Case Study

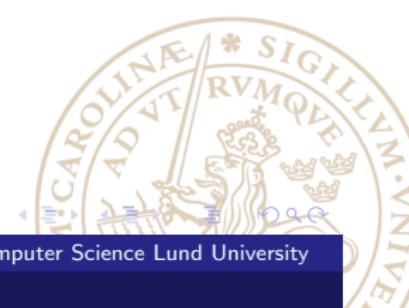
3 Model

- Components
- Storage Mediums
- Tools
- Labeling
- Grouping
- Filter

4 Evaluation

└ Outline

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- Dual-armed robot
 - Flexible
 - Fine motor skills

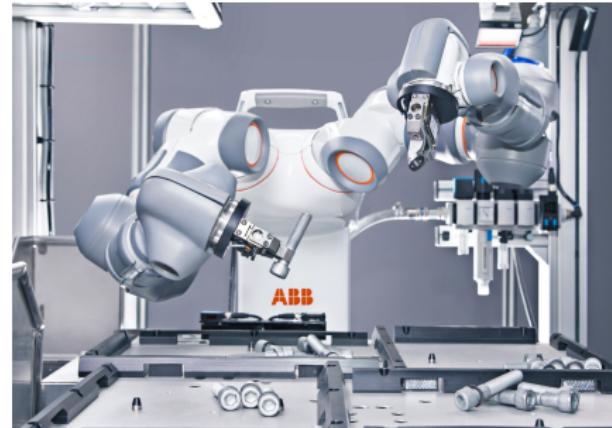


Photo: ABB



Introduction - Project goal

2015 02 10



Introduction - Job Shop Problem

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—Introduction

└ Job Shop Problem

└ Introduction - Job Shop Problem

67-30-612



Introduction - MiniZinc

2015 02 10



Criteria

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- FlatZinc parser
 - Free



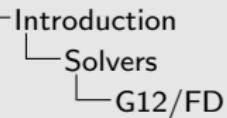
Solvers Tested

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



Task scheduling for dual-arm industrial robots through constraint programming



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

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

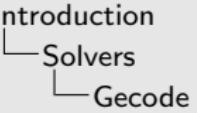
- Java Constraint Programming solver
- Open Source
- Developed since 2001 - Krzysztof Kuchcinski & Radoslaw Szymanek
- Silver medal



Gecode

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

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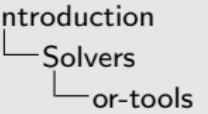


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- C++
- Open Source
- Christian Schulte
- Parallel searches - utilising multiple cores
- All gold medals 2008-2012

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





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

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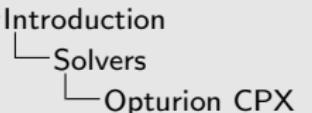
1. Utilising multiple cores: Inte säker om parallel sökning, nämns i dokumentationen som "parallel solving", explicit utesluten ur dokumentationen



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



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- Opturion Pty Ltd
- Commercial
- SAT combo
- 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

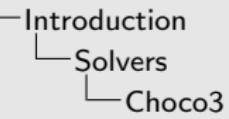


Choco3

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

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Task scheduling for dual-arm industrial robots through constraint programming



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



Case Study

Task scheduling for dual-arm industrial robots through constraint programming

└ Case Study

└ Case Study

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Case Study



Entities

Task scheduling for dual-arm industrial robots through constraint programming

- └ Case Study
- └ Entities

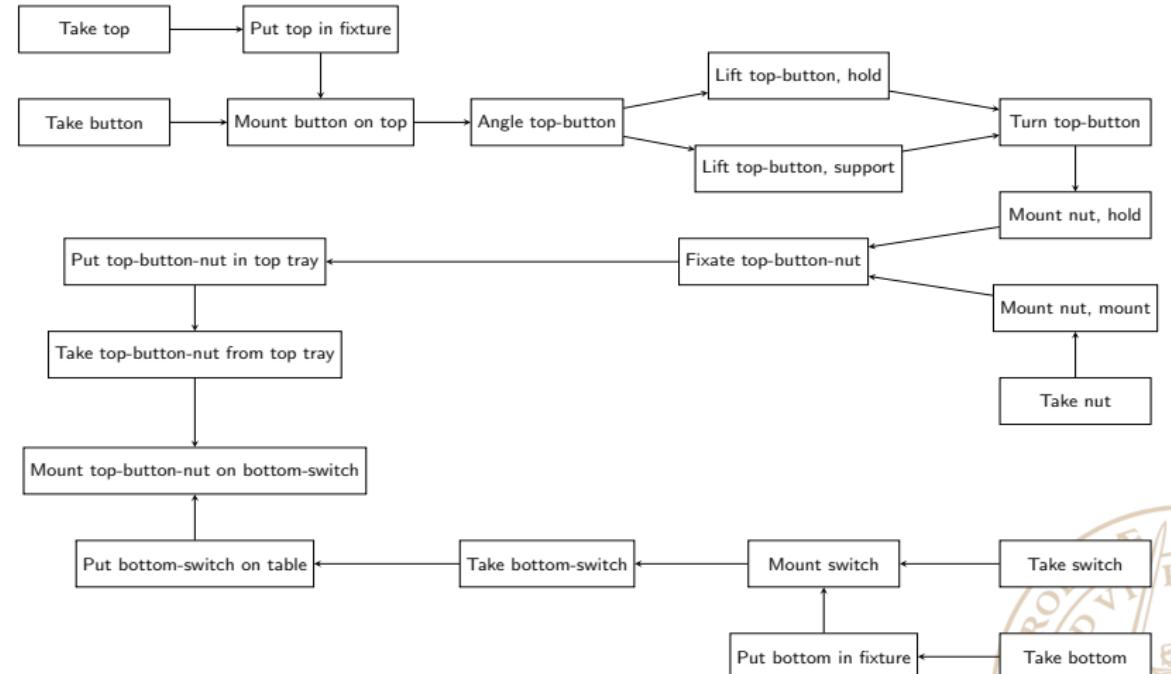
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- Machines
- Tools
- Tray
- Fixture
- Output

- Machines
- Tools
- Tray
- Fixture
- Output



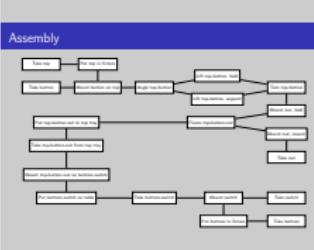
Assembly



Task scheduling for dual-arm industrial robots through constraint programming

Case Study

└ Assembly



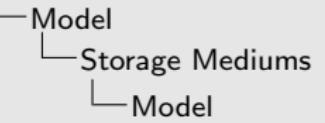
Model

Storage mediums

- Tray - Top tray, Button tray, etc.
- Fixture
- Output

Task scheduling for dual-arm industrial robots through constraint programming

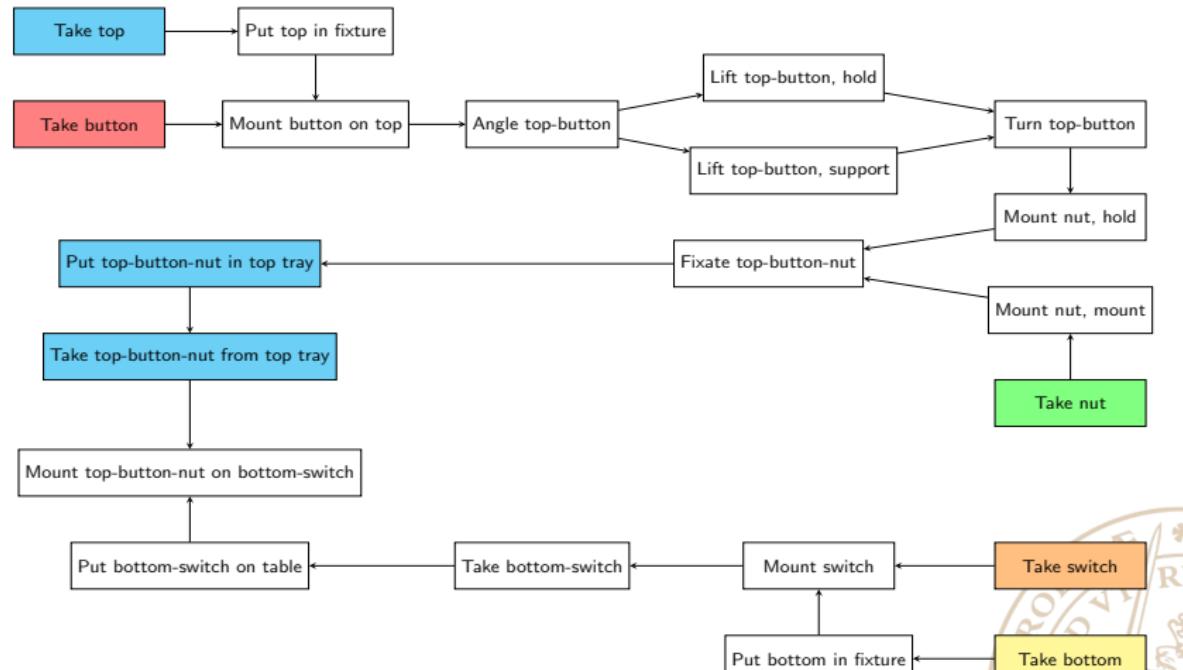
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Model

Storage mediums
■ Tray - Top tray, Button tray, etc.
■ Fixture
■ Output

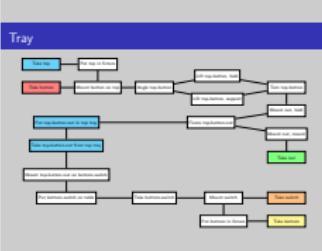
Tray



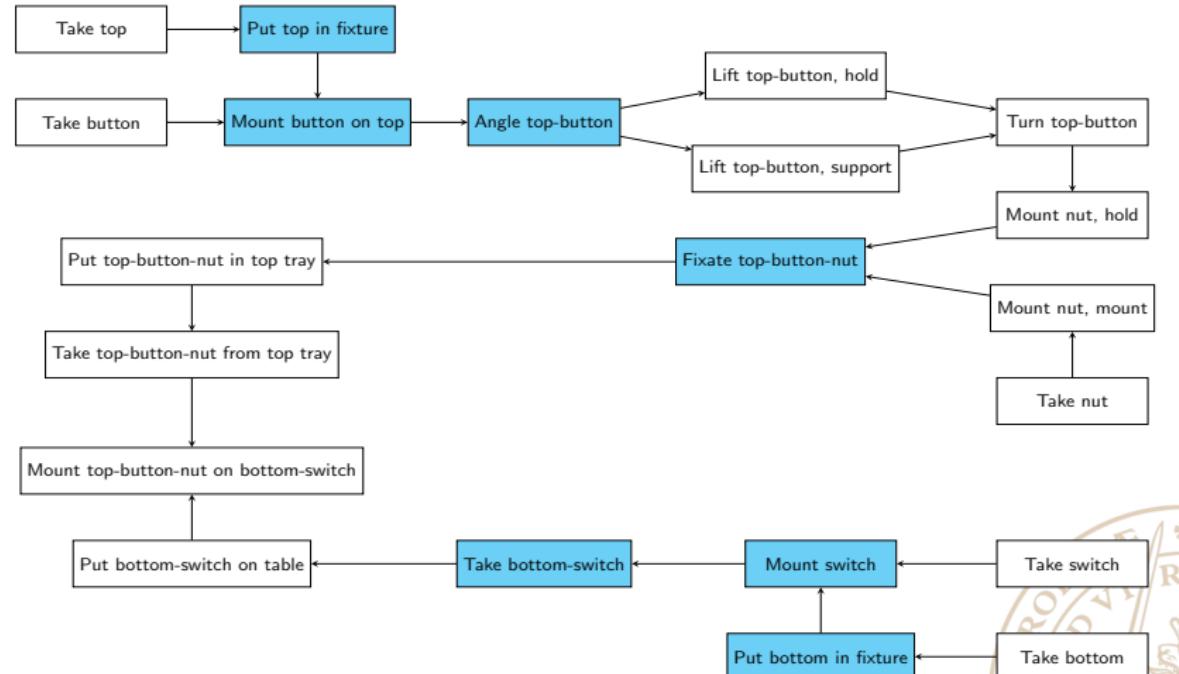
Task scheduling for dual-arm industrial robots through constraint programming

Model
└ Storage Mediums
 └ Tray

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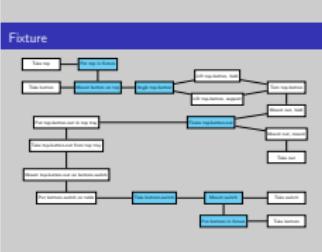
Fixture



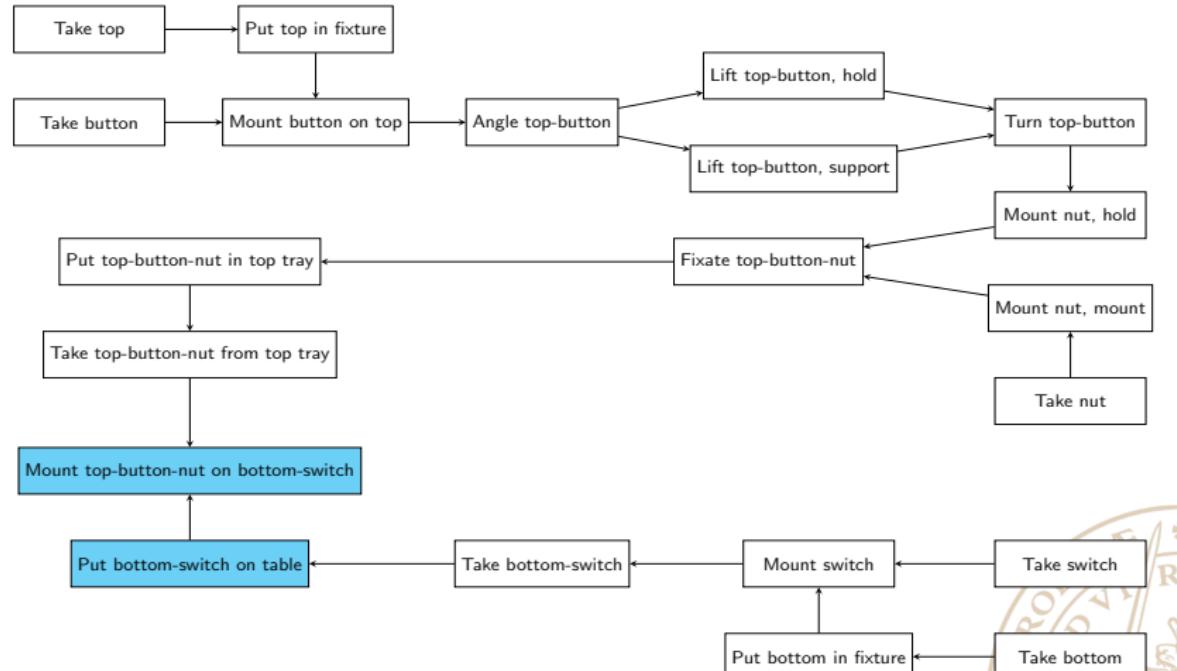
Task scheduling for dual-arm industrial robots through constraint programming

Model
└ Storage Mediums
 └ Fixture

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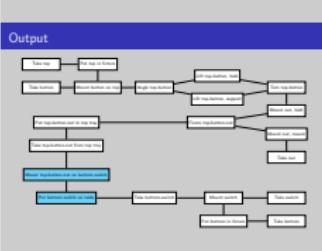
Output



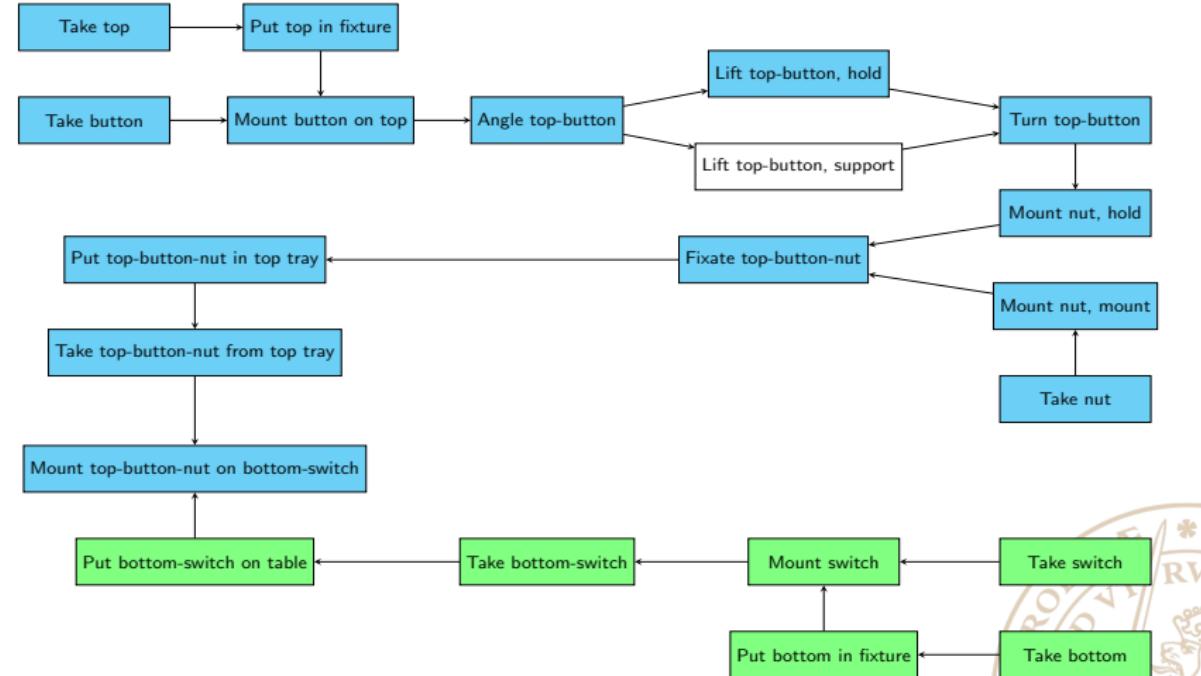
Task scheduling for dual-arm industrial robots through constraint programming

Model
└ Storage Mediums
└ Output

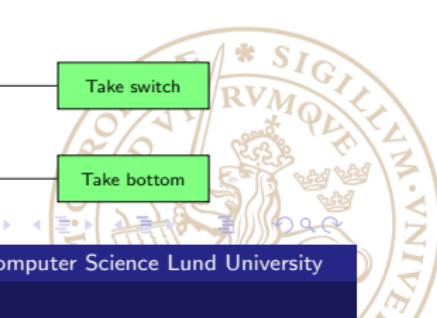
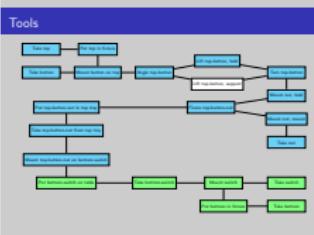
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Tools



Notera att "Lift top-button" inte har tool specificerad



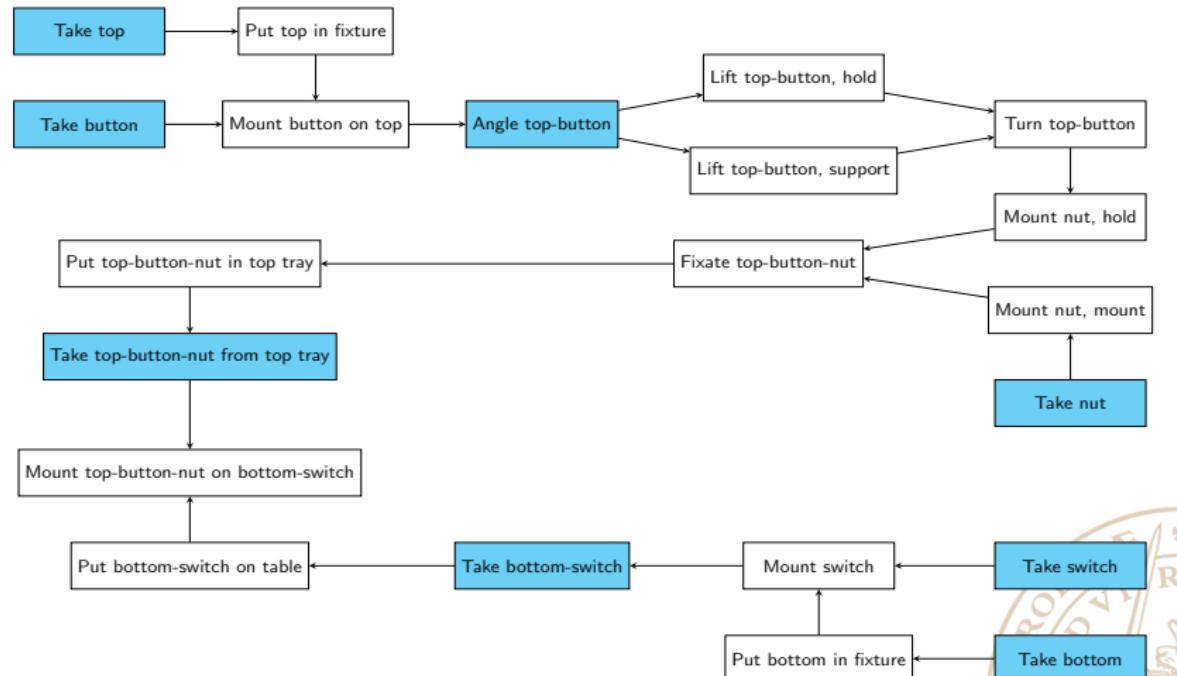
Model

Label tasks

- Taking
- Mounting
- Putting
- Moving



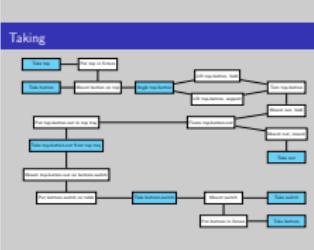
Taking



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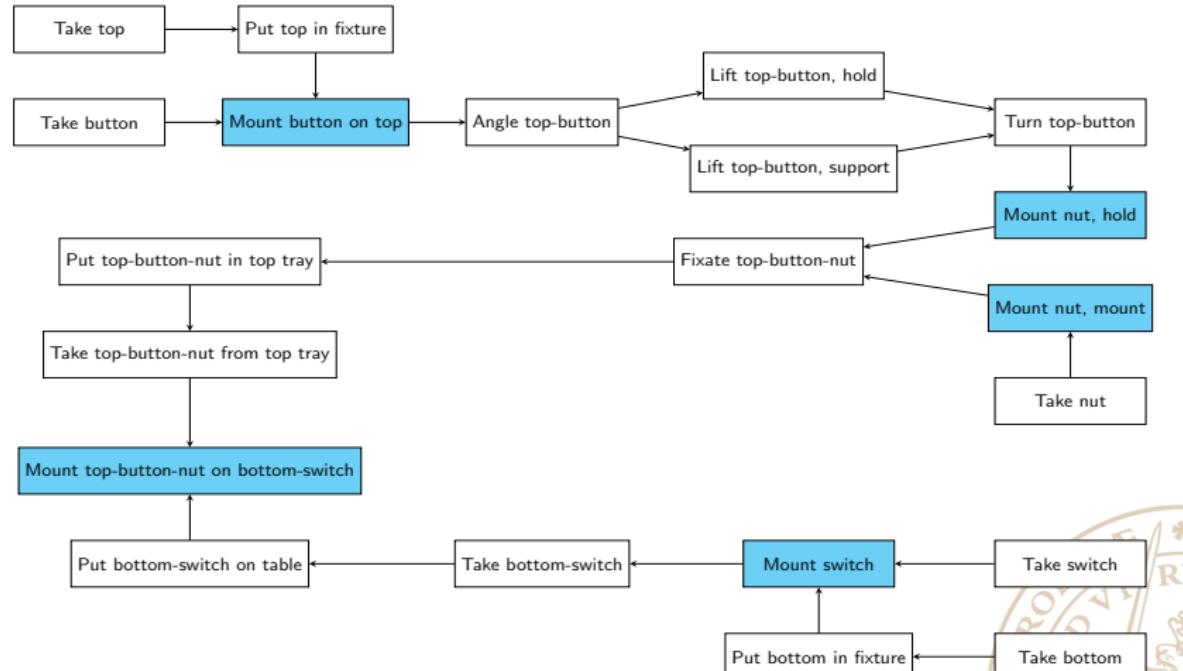
Task scheduling for dual-arm industrial robots through constraint programming

- └ Model
- └ Labeling
- └ Taking



Angle skulle kunna delas in i två tasks, en taking och en moving

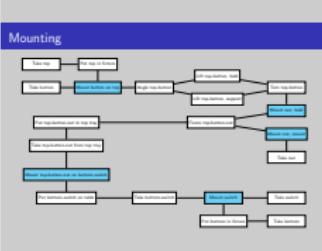
Mounting



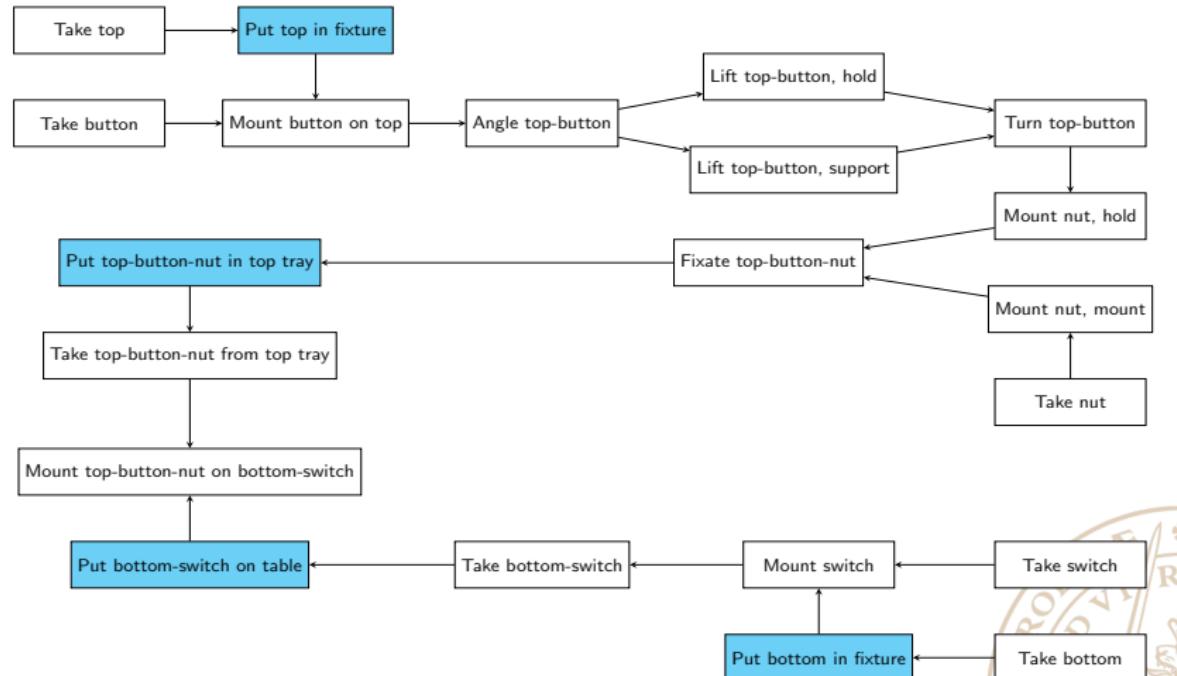
Task scheduling for dual-arm industrial robots through constraint programming

Model
└─ Labeling
└─ Mounting

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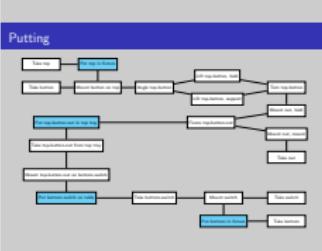
Putting



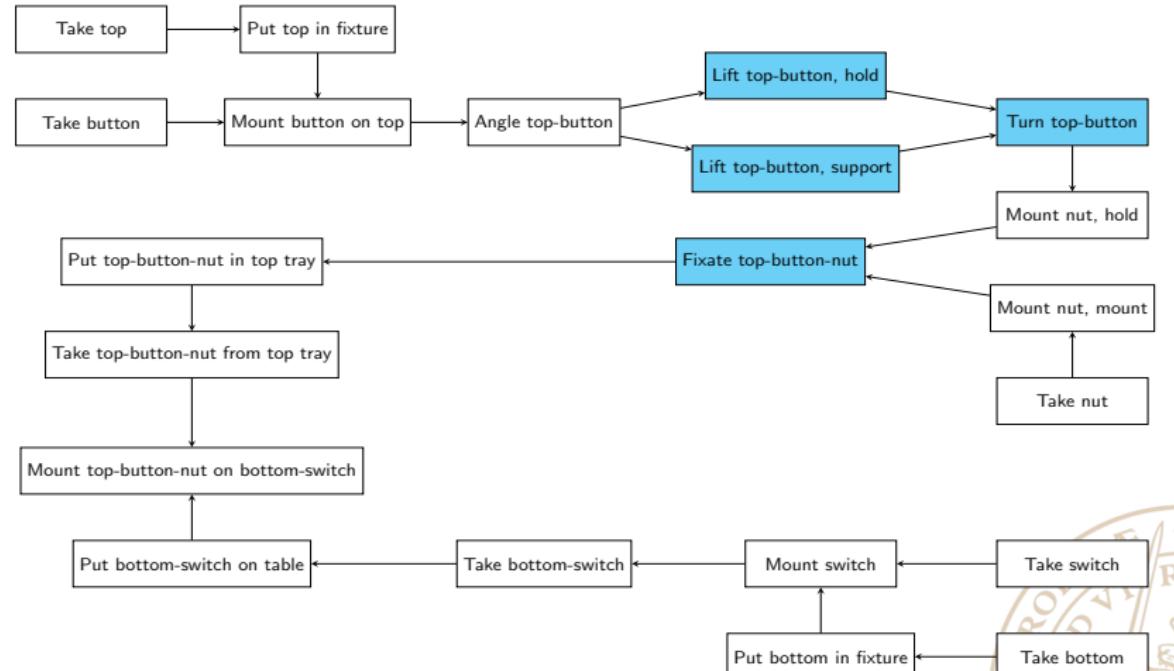
Task scheduling for dual-arm industrial robots through constraint programming

Model
└ Labeling
 └ Putting

2015-02-19



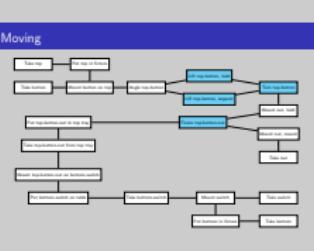
Moving



Task scheduling for dual-arm industrial robots through constraint programming

Model
└─ Labeling
└─ Moving

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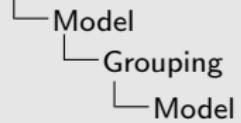


Model

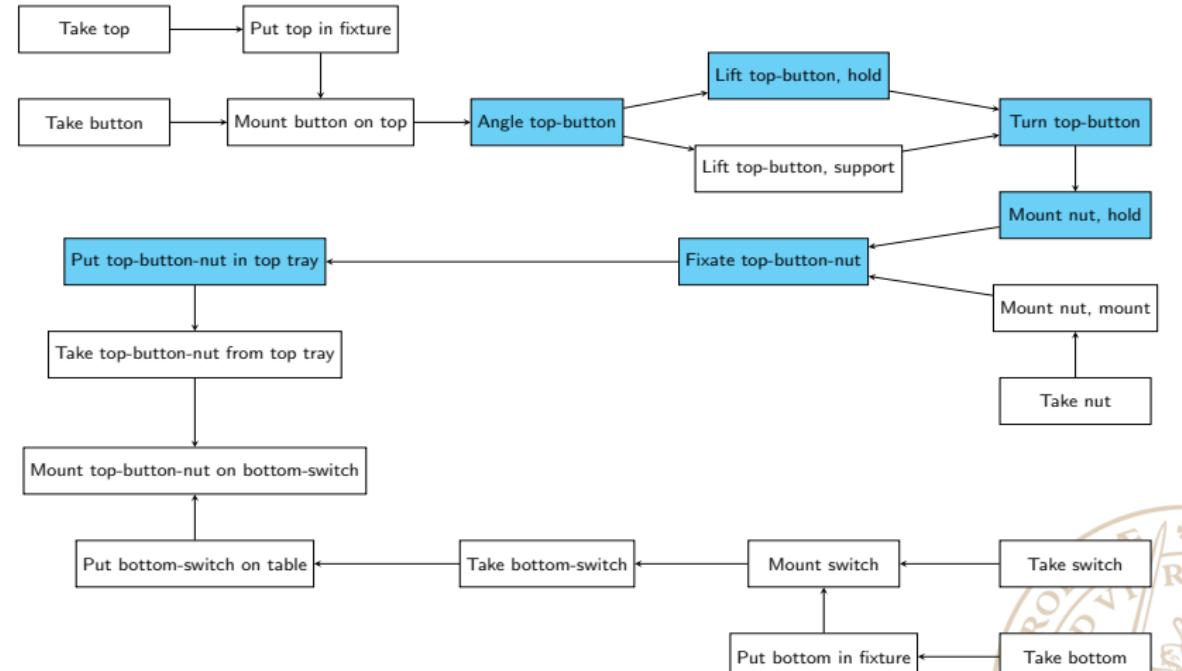
Group tasks

- Ordered group
- Concurrent group

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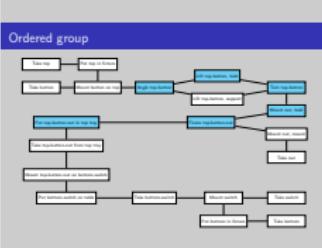
Ordered group



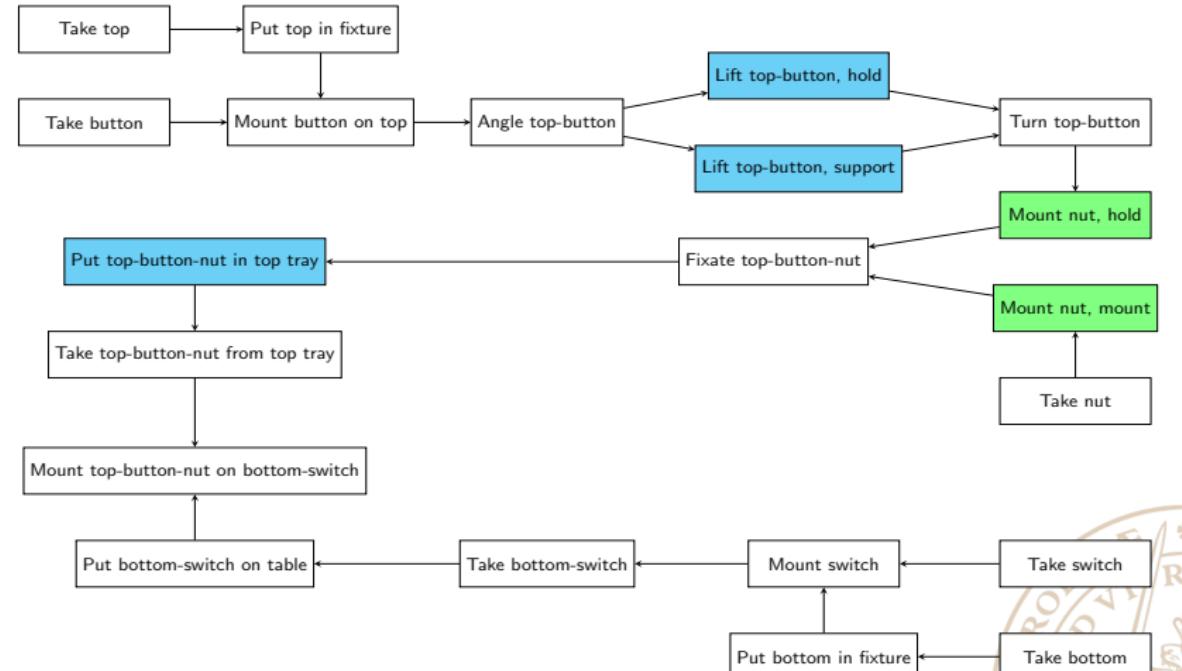
Task scheduling for dual-arm industrial robots through constraint programming

- └ Model
- └ Grouping
- └ Ordered group

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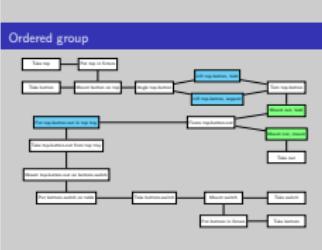
Ordered group



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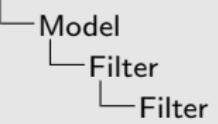
Task scheduling for dual-arm industrial robots through constraint programming

- Model
- Grouping
- Ordered group



- Temporal filter
- Predecessor filter

Task scheduling for dual-arm industrial robots through constraint programming



■ Temporal filter
■ Predecessor filter

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Temporal Filter

Task scheduling for dual-arm industrial robots through constraint programming

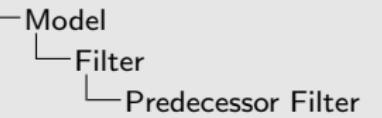


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Predecessor Filter

Task scheduling for dual-arm industrial robots through constraint programming



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Evaluation

◎ 11

Evaluation



Assembly Times

Task scheduling for dual-arm industrial robots through constraint programming

└ Evaluation
 └ Results
 └ Assembly Times

Assembly Times

Manual Time
516 t.u.

Manual Time
516 t.u.



Assembly Times

Manual Time
516 t.u.

Solver Time
512 t.u.

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Task scheduling for dual-arm industrial robots through
constraint programming

- └ Evaluation
- └ Results
- └ Assembly Times

Manual Time
516 t.u.
Solver Time
512 t.u.



Solver Time

Task scheduling for dual-arm industrial robots through constraint programming

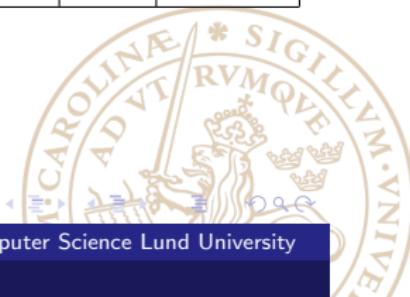
- └ Evaluation
- └ Results
- └ Solver Time

Solver Time

	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	-	-	-	-	-	-	-	-

2015-02-19

	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	-	-	-	-	-	-	-	-



Solver Time

Task scheduling for dual-arm industrial robots through constraint programming

- └ Evaluation
- └ Results
- └ Solver Time

2015-02-19

Solver Time

	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	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186	-	-
or-tools	271	!	380	!	302	!	457	!	-	-
Opturion CPX	-	!	-	!	-	!	-	!	-	-
Choco3	-	-	-	-	-	-	-	-	-	-

Hittar lösning, inte optimal

	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	-	-	-	-	-	-	-	-



Solver Time

Task scheduling for dual-arm industrial robots through constraint programming

- └ Evaluation
- └ Results
- └ Solver Time

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Solver Time

	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	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186	-	-
or-tools	271	!	380	!	302	!	457	!	-	-
Opturion CPX	-	!	-	!	-	!	-	!	-	-
Choco3	-	-	-	-	-	-	-	-	-	-

Hittar hittar alla lösningar, inklusive optimala

	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	-	-	-	-	-	-	-	-



Solver Time

Task scheduling for dual-arm industrial robots through constraint programming

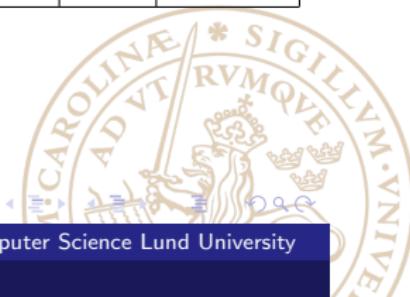
- └ Evaluation
- └ Results
- └ Solver Time

Solver Time

	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	1.6	2.0.1
G12/FD	-	-	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	-	-	-	-	-	-	-
Gecode	-	60	-	71761	-	99	-	71186	-	-
or-tools	271	!	380	!	302	!	457	!	-	-
Opturion CPX	-	!	-	!	-	!	-	!	-	-
Choco3	-	-	-	-	-	-	-	-	-	-

Hittar 3 lösningar, inklusive optimala

	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	-	-	-	-	-	-	-	-



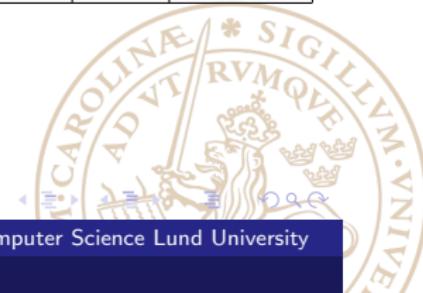
Solver Time

Task scheduling for dual-arm industrial robots through constraint programming

- └ Evaluation
 - └ Results
 - └ Solver Time

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

2015-02-19



Solver Time

Task scheduling for dual-arm industrial robots through constraint programming

- └ Evaluation
- └ Results
- └ Solver Time

2015-02-19

Solver Time

	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	-	-	-	-	-	-	-	-

Hittar 2 lösningar direkt

	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	-	-	-	-	-	-	-	-

