

## Task scheduling for dual-arm industrial robots through constraint programming

2015-02-20

# Task scheduling for dual-arm industrial robots through constraint programming

## MiniZinc modeling and solver comparison

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February 20, 2015

# Outline

## 1 Introduction

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

## 2 Case Study

## 3 Model

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

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## └ Outline

Outline
1 Introduction
2 Case Study
2.1 Tasks
2.2 Components
2.3 Storage Mediums
2.4 Tools
2.5 Labeling
2.6 Grouping
2.7 Filter
3 Evaluation
3.1 Results



- Dual-armed robot
  - Flexible
  - Fine motor skills

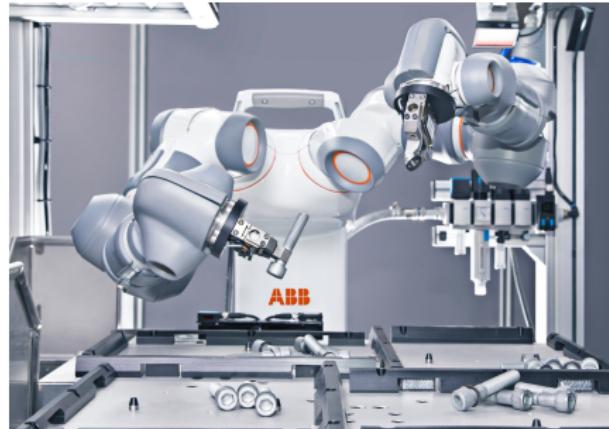
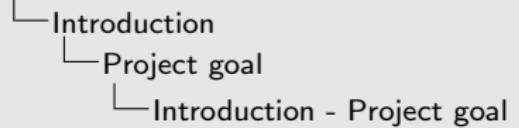


Photo: ABB

## Introduction - Project goal

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## Introduction - Job Shop Problem

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Introduction - MiniZinc

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## Criteria

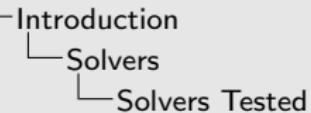
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- FlatZinc parser
  - Free

# Solvers Tested

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

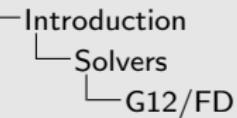
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- G12/FD
- JaCoP
- Gecode
- or-tools
- Opturion CPX
- Choco3

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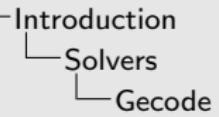
- G12 Team, NICTA
- Mercury
- Default solver for MiniZinc



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

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



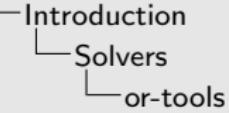
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Gecode

- 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

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



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

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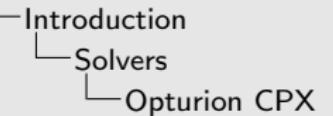
1. Utilising multiple cores: Inte säker om parallel sökning, nämns i dokumentationen som "parallel solving", explicit utesluten ur dokumentationen

# Opturion CPX

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

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## Task scheduling for dual-arm industrial robots through constraint programming



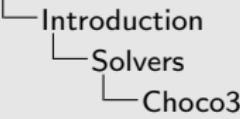
1. Opturion Pty Ltd: Härstammar från G12
2. Commercial: kostar, akademisk licens
3. SAT combo: FD + SAT, SAT = satslogik, väldigt effektiv på att lösa stora problem, sägs att satslogik -*&* sökning inte slöas ner av stora domäner

# 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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# Physical Entities

- Machines
- Tools
- Components
- Tray
- Fixture
- Output

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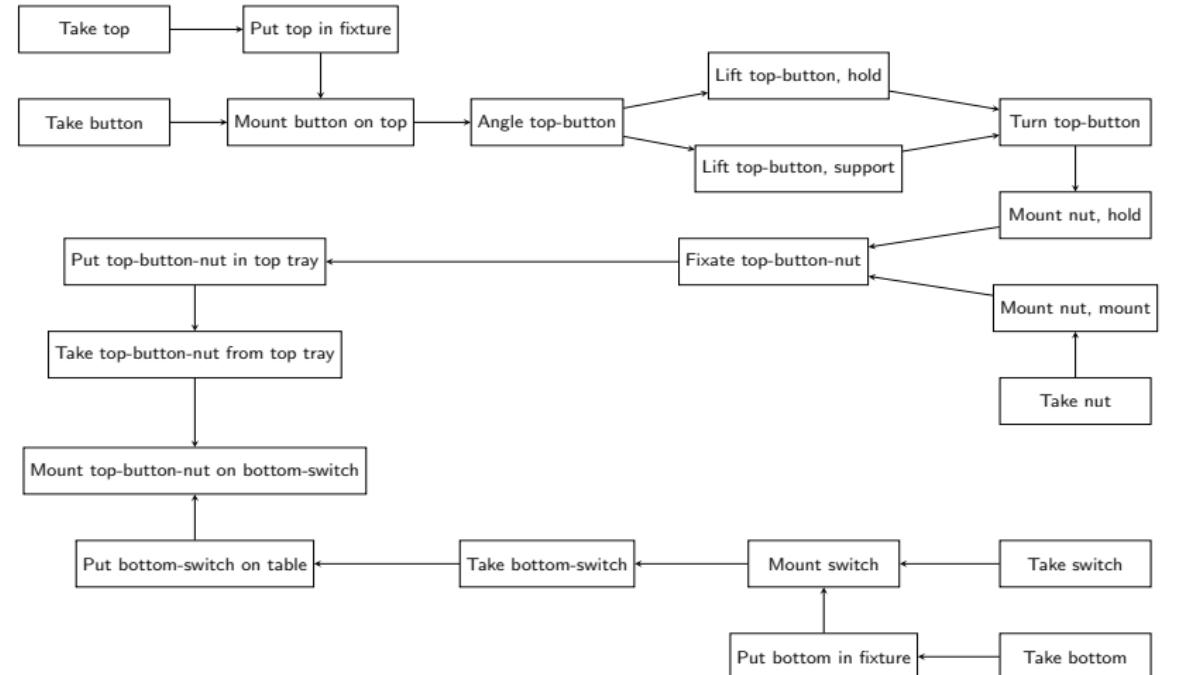
Task scheduling for dual-arm industrial robots through constraint programming

- └ Case Study
- └ Physical Entities

Physical Entities

- Machines
- Tools
- Components
- Tray
- Fixture
- Output

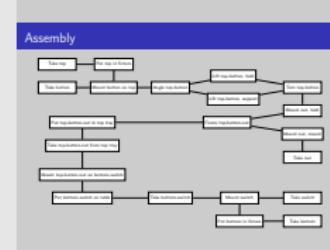
# Assembly



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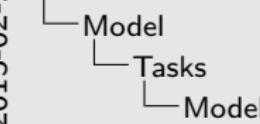
## Task scheduling for dual-arm industrial robots through constraint programming

- Case Study
- Assembly



# Model

Task scheduling for dual-arm industrial robots through constraint programming



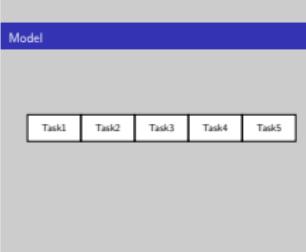
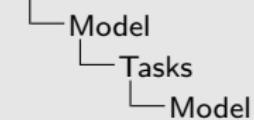
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# Model



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## Task scheduling for dual-arm industrial robots through constraint programming



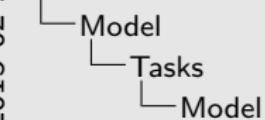
Model

Task1 Task2 Task3 Task4 Task5

- Vi vill schemalägga tasks
- En task kommer efter den andra
- Men tasks:en sker på olika ställen i rummet → det tar tid att flytta sig mellan dem → måste räkna med det

## Model

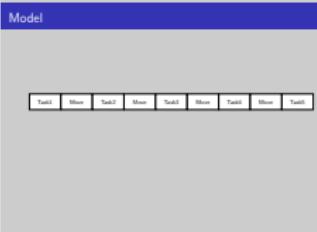
## Task scheduling for dual-arm industrial robots through constraint programming



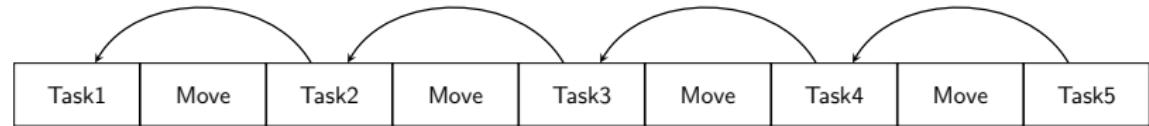
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- Hur lång tid det tar beror på vilken task som kommer innan → vi måste veta vilken task som kommer innan, *predecessor*

Task1	Move	Task2	Move	Task3	Move	Task4	Move	Task5
-------	------	-------	------	-------	------	-------	------	-------



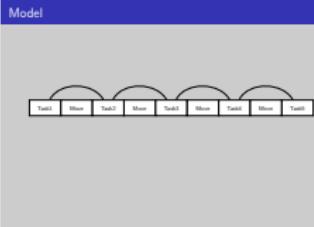
# Model



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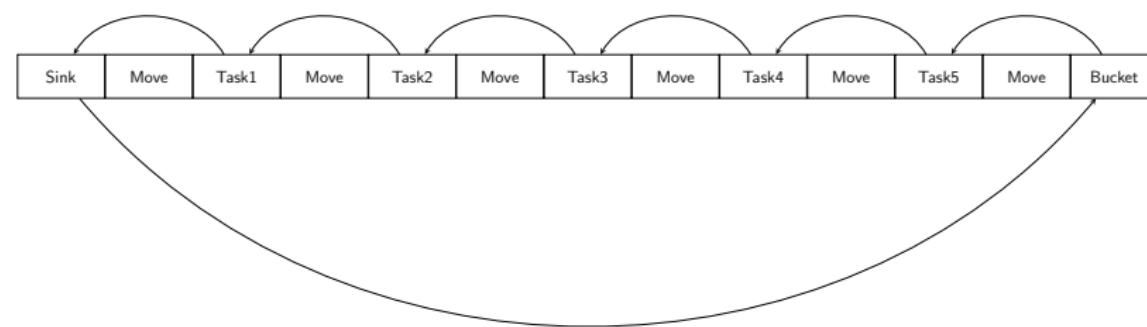
## Task scheduling for dual-arm industrial robots through constraint programming

- └ Model
  - └ Tasks
    - └ Model



- För att se till att detta uppfylls kan constraintet circuit användas
- Skapar en Hamiltonian circuit
- Uppnår det genom att koppla ihop första och sista noden.
- Constraint som säger att task måste komma efter sin predecessor → Första och sista task:en kan inte kopplas ihop

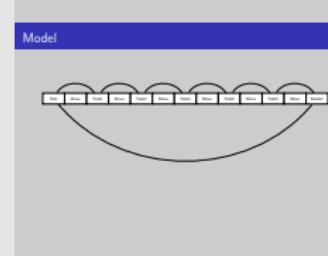
# Model



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## Task scheduling for dual-arm industrial robots through constraint programming

- └ Model
  - └ Tasks
    - └ Model

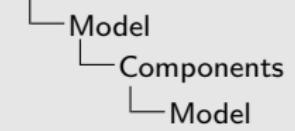


- Introducerar sink node/startTask & bucket node/goalTask
- Hintintills 4 saker att schemalägga: tasks, moves, predecessors & sink/bucket
- Men detta måste göras för varje mackin, tasks måste fördelas

# Model

## Components

- Primitive components
- Sub-assemblies



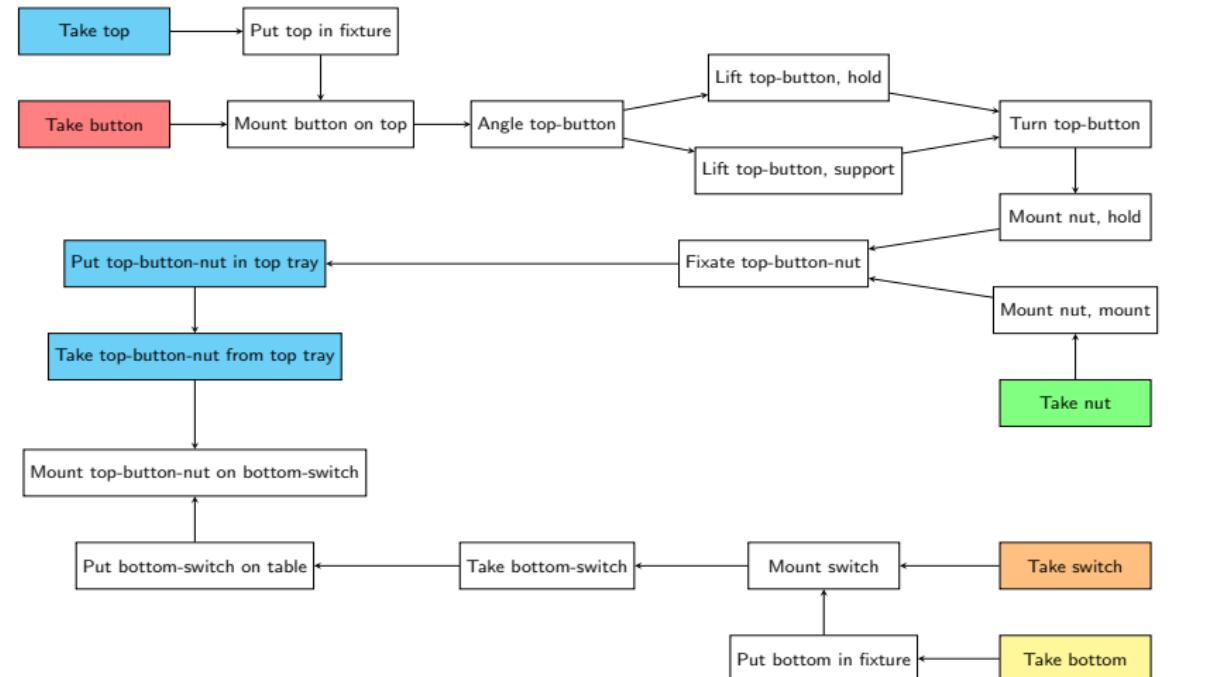
Model

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## Storage mediums

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

## Tray

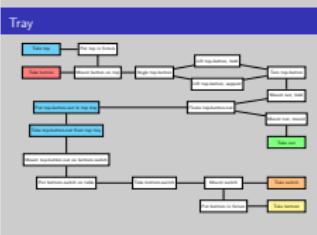


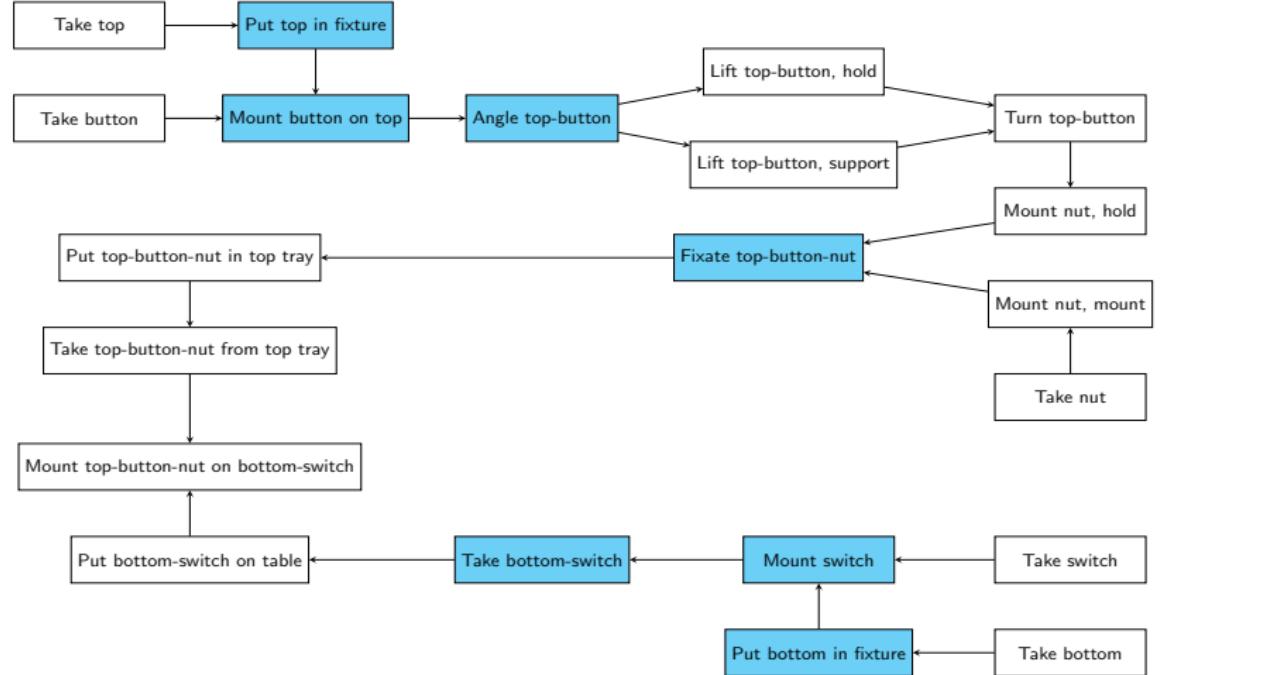
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## Task scheduling for dual-arm industrial robots through constraint programming

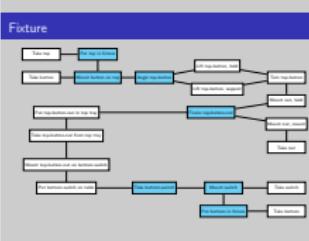
## Model

- Storage Mediums
- Tray

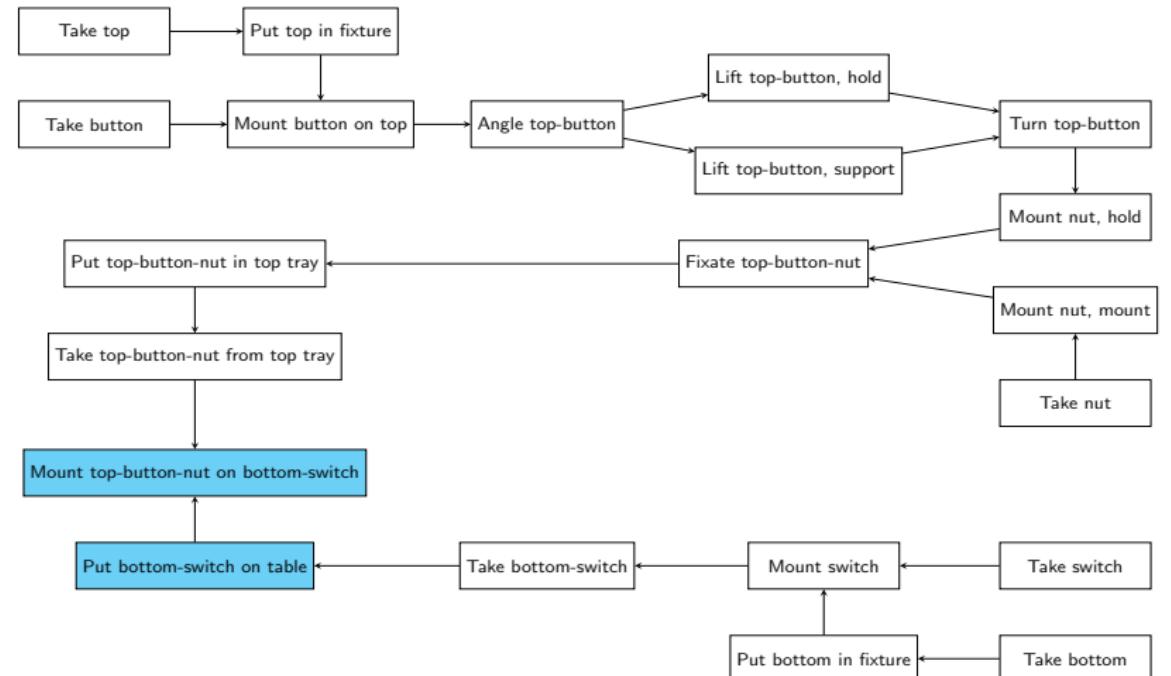




- Individuella tasks får inte överlappa på fixtures
  - Tiden då fixtures är upptagna får inte överlappa, identifiera put och take för en komponent och komponent som har put komponenten som en del i dess sub-assembly



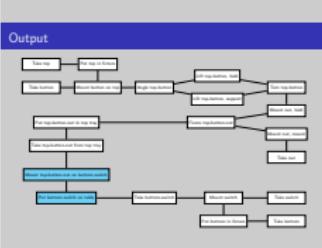
# Output



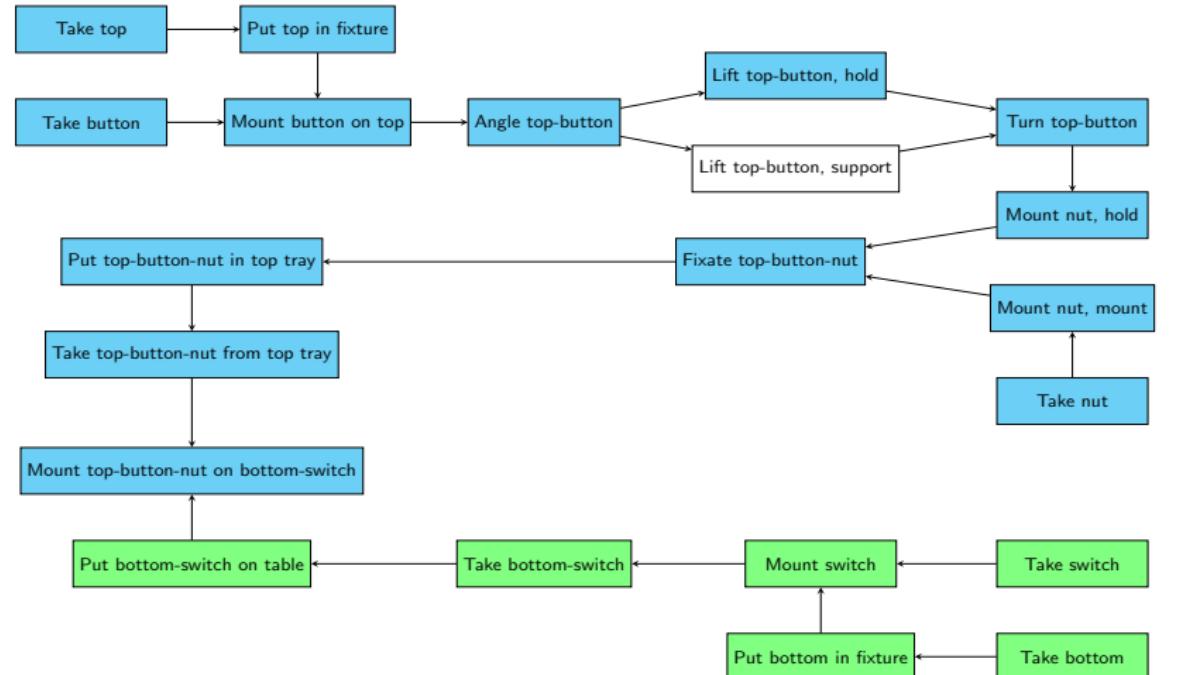
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Model  
└ Storage Mediums  
└ Output

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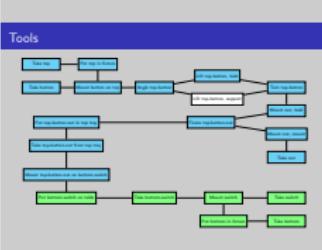
## Tools



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## Task scheduling for dual-arm industrial robots through constraint programming

- └ Model
- └ Tools
- └ Tools



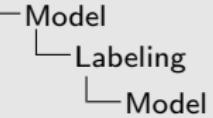
Notera att "Lift top-button" inte har tool specificerad

# Model

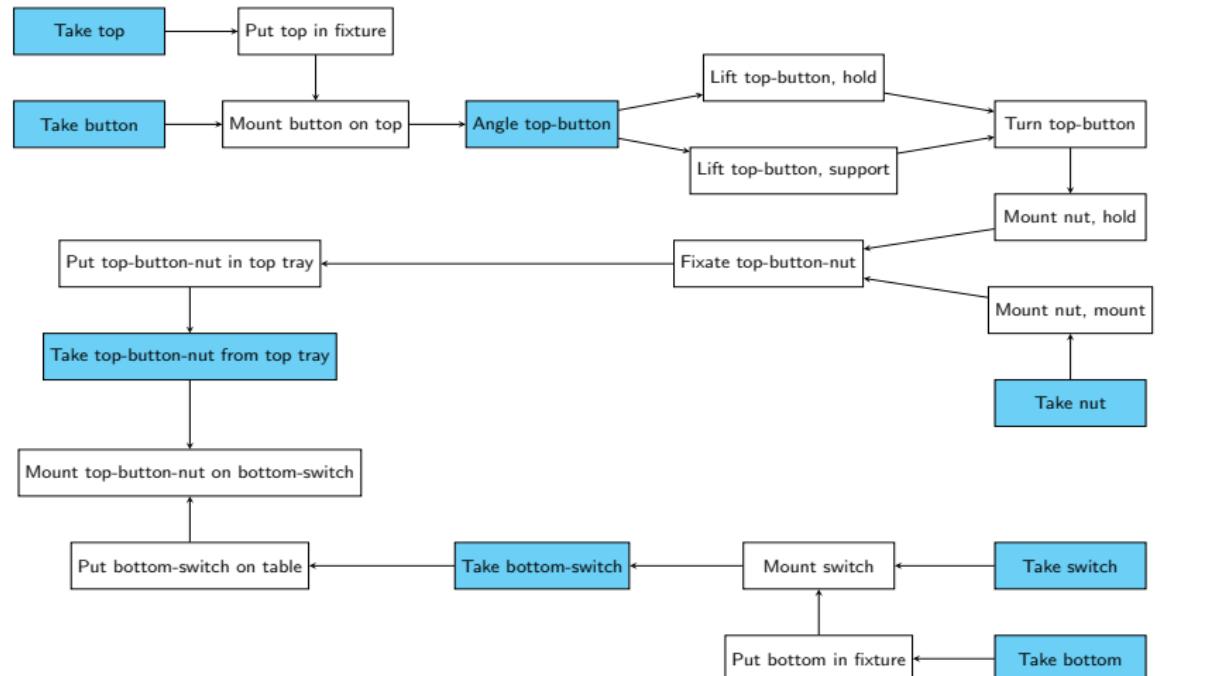
## Label tasks

- Taking
- Mounting
- Putting
- Moving

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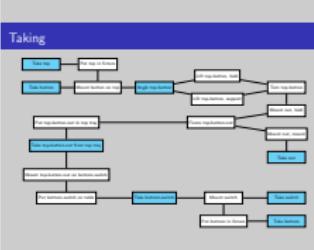
# Taking



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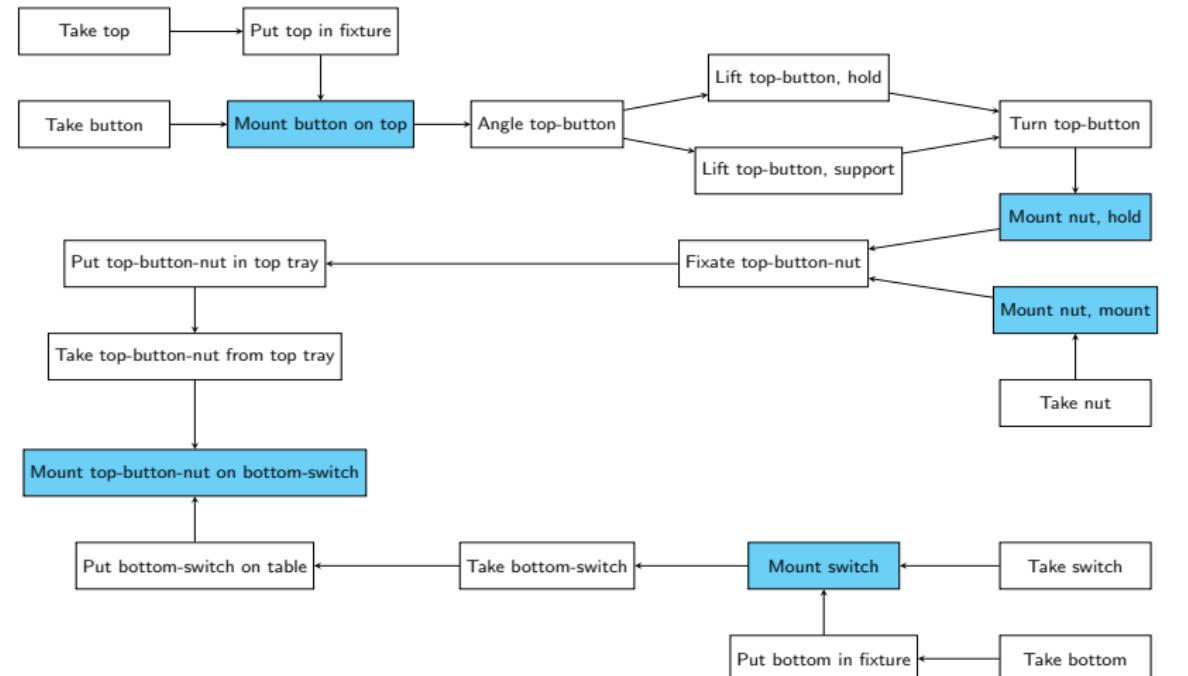
## Task scheduling for dual-arm industrial robots through constraint programming

- Model
- Labeling
- Taking



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

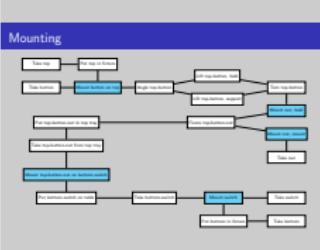
# Mounting



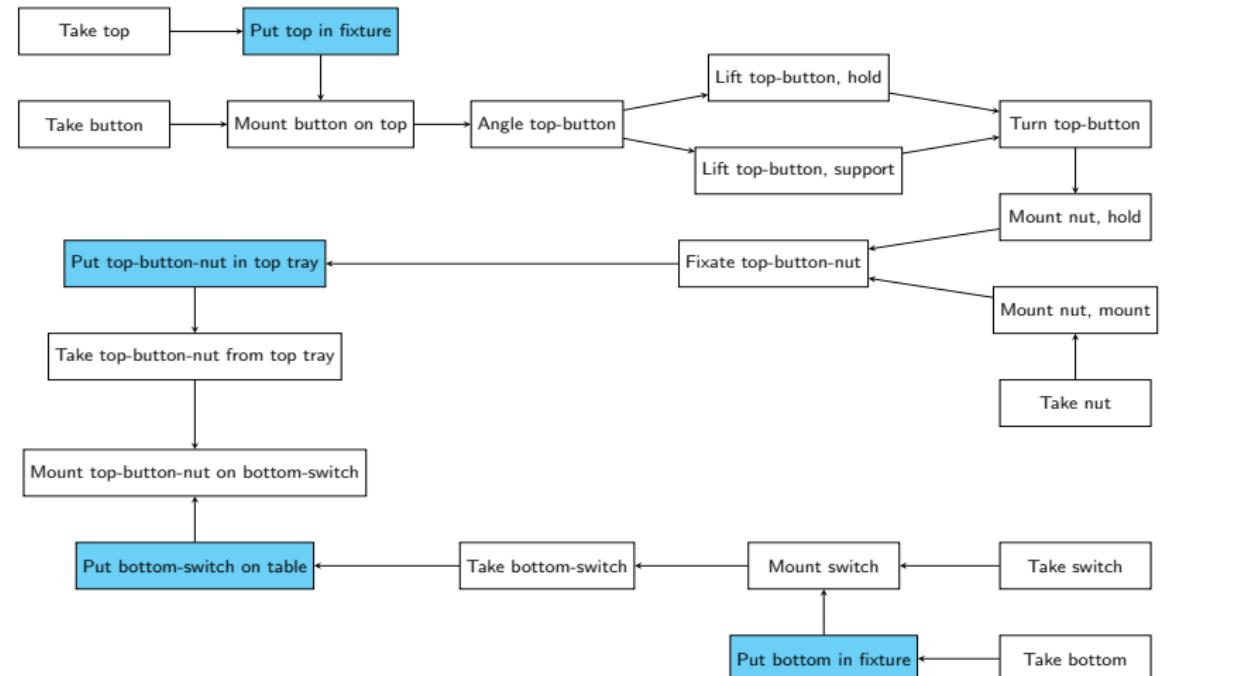
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## Task scheduling for dual-arm industrial robots through constraint programming

- Model
- Labeling
- Mounting



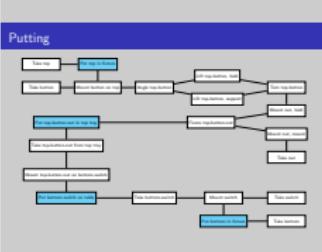
# Putting



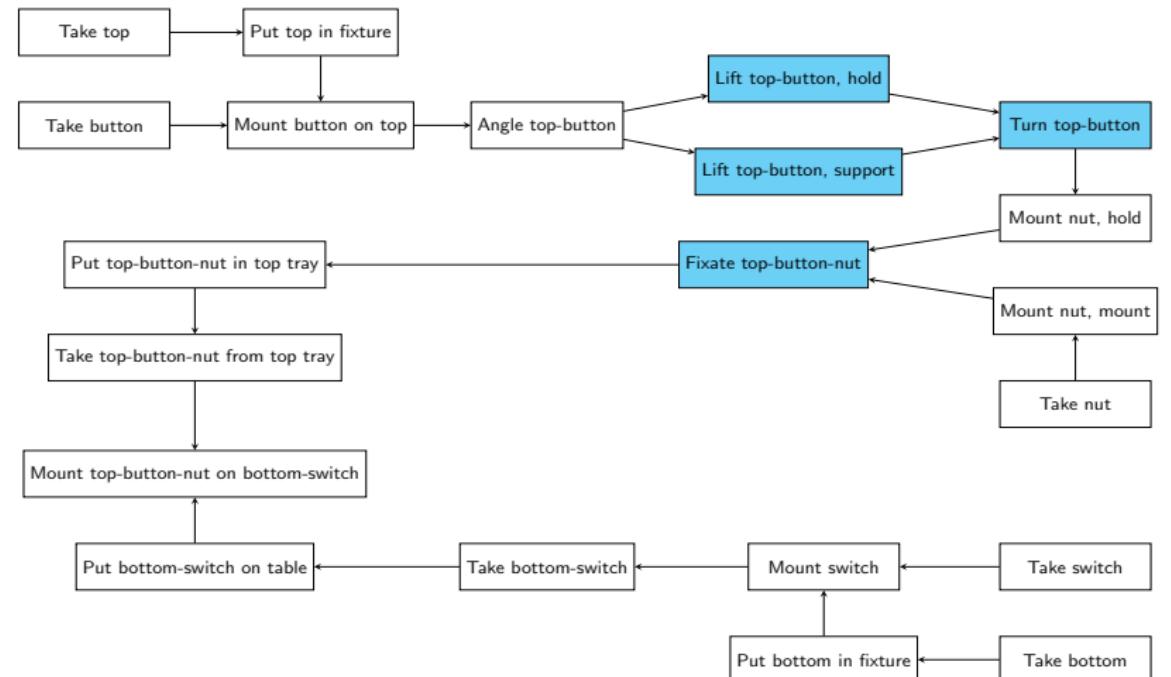
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## Task scheduling for dual-arm industrial robots through constraint programming

- Model
- Labeling
- Putting



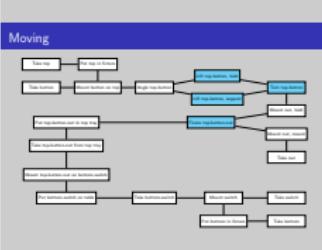
# Moving



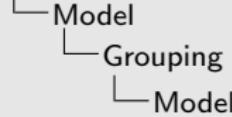
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## Task scheduling for dual-arm industrial robots through constraint programming

- Model
- Labeling
- Moving



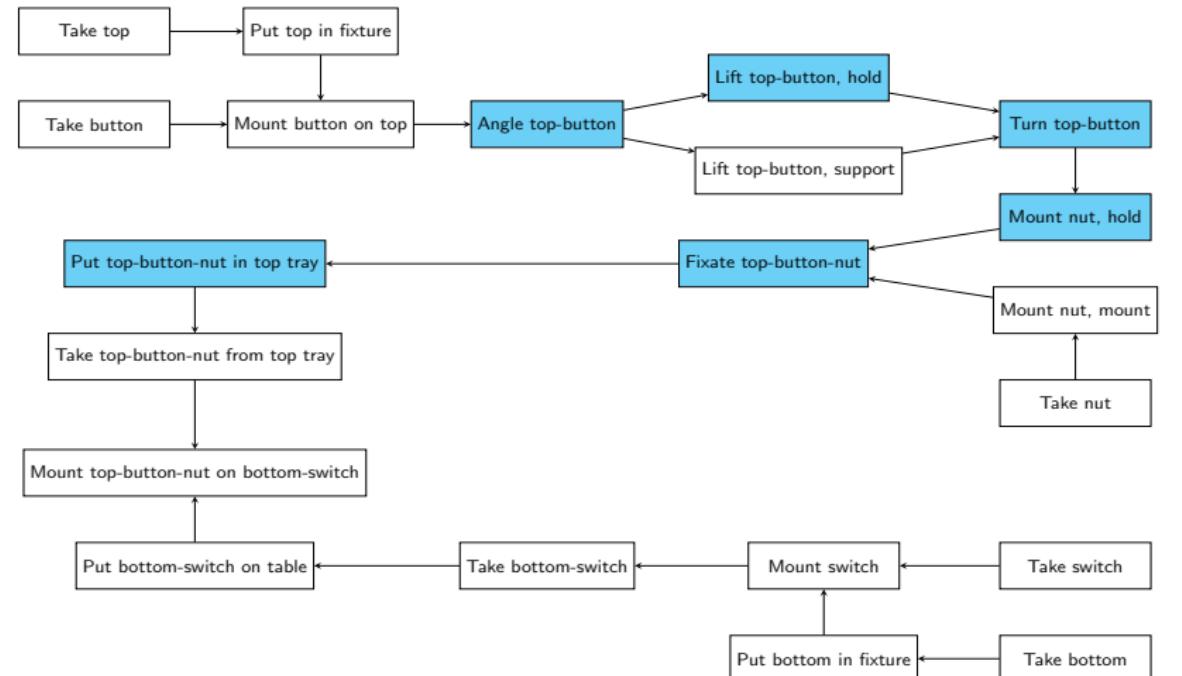
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## Group tasks

- Ordered group
- Concurrent group

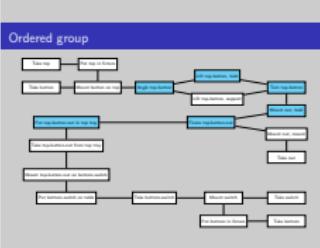
# Ordered group



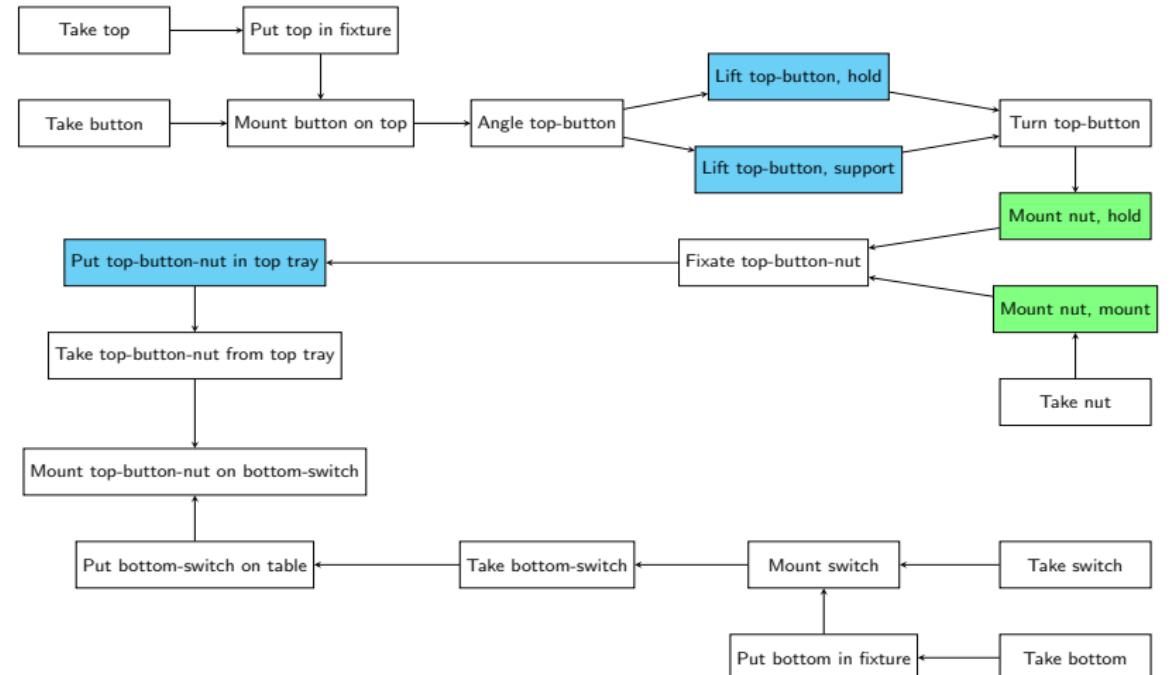
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Task scheduling for dual-arm industrial robots through constraint programming

- Model
- Grouping
- Ordered group



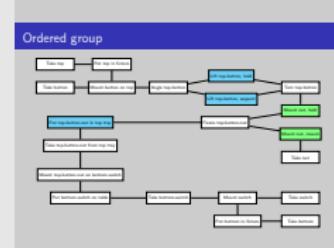
# Ordered group

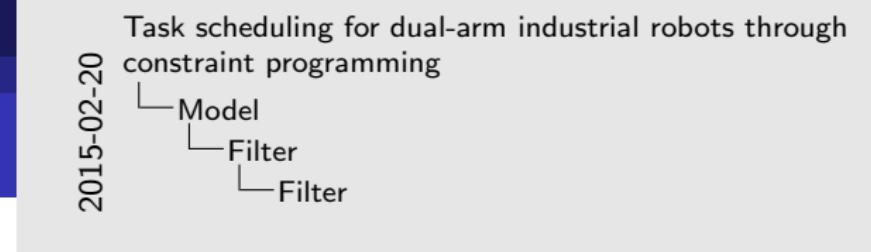


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## Task scheduling for dual-arm industrial robots through constraint programming

- └ Model
- └ Grouping
- └ Ordered group





Temporal filter  
Predecessor filter

- Temporal filter
- Predecessor filter

# Temporal Filter

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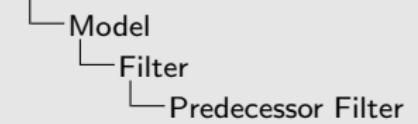
## Task scheduling for dual-arm industrial robots through constraint programming



# Predecessor Filter

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## Task scheduling for dual-arm industrial robots through constraint programming



# Evaluation

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Evaluation

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

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

## Solver Time

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

- └ Evaluation
- └ Results
- └ Solver Time

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Hittar lösning, inte optimal

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

## Solver Time

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

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- └ Evaluation
- └ Results
- └ Solver Time

	Solver Time								
	Pred	1.6							
G12/FD	658	898	-	1011156	-	71761	-	302	-
JaCoP	-	60	-	380	-	99	-	457	-
Gecode	-	271	-	71761	-	302	-	99	-
or-tools	-	-	-	-	-	-	-	-	-
Opturion CPX	-	-	-	-	-	-	-	-	-
Choco3	-	-	-	-	-	-	-	-	-

Hittar hittar alla lösningar, inklusive optimala

## Solver Time

## Task scheduling for dual-arm industrial robots through constraint programming

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- └ Evaluation
- └ Results
- └ Solver Time

	Solver Time		
	Pred & Temp	Pr	PS
	1.6	2.0.1	1.6
G12/FD	-	-	-
JaCoP	658	-	1011156
Gecode	-	60	-
or-tools	271	!	380
Opturion CPX	-	!	-
Choco3	-	-	-

Hittar 3 lösningar, inklusive optimala

	Pred & Temp	Pr	PS
	1.6	2.0.1	1.6
G12/FD	-	-	-
JaCoP	658	-	1011156
Gecode	-	60	-
or-tools	271	!	380
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	IP	PS
G12/FD	1.6	2.0.1	1.6
JaCoP	658	-	1011156
Gecode	-	60	-
or-tools	271	!	380
Opturion CPX	-	!	-
Choco3	-	-	-

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

	Pred & Temp	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr	Pr
G12/FD	1.6	2.0.1	1.6	-	-	-	-	-	-	-	-
JaCoP	658	-	1011156	71761	-	99	-	71186	71761	-	302
Gecode	-	60	-	!	302	!	457	!	!	380	99
or-tools	271	!	380	!	-	!	-	-	!	457	1
Opturion CPX	-	!	-	-	-	-	-	-	-	-	-
Choco3	-	-	-	-	-	-	-	-	-	-	-

G12/FD  
JaCoP  
Gecode  
or-tools  
Opturion CPX  
Choco3

-	-	-	-	-	-	-	-	-
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└ Evaluation  
└ Results  
└ Solver Time

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Hittar 2 lösningar direkt

