



Universiteit  
Leiden  
The Netherlands

## **Constraint-based analysis of business process models**

Changizi, B.

### **Citation**

Changizi, B. (2020, February 21). *Constraint-based analysis of business process models*. *IPA Dissertation Series*. Retrieved from <https://hdl.handle.net/1887/85677>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/85677>

**Note:** To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/85677> holds various files of this Leiden University dissertation.

**Author:** Changizi, B.

**Title:** Constraint-based analysis of business process models

**Issue Date:** 2020-02-25

# Constraint-Based Analysis of Business Process Models

**Proefschrift**

te verkrijging van  
de graad van Doctor aan Universiteit Leiden,  
op gezag van Rector Magnificus Prof. Mr. C.J.J.M. Stolker,  
volgens besluit van het College voor Promoties  
te verdedigen 25 February 2020  
klokke 13:45

door

Behnaz Changizi

Geboren te Hamedan, Iran, in 1979

**Promotor:** Prof. Dr. F. Arbab

**Copromotor:** Dr. N. Kokash (Peoples' Friendship University of Russia)

**Promotiecommissie:**

Prof. Dr. F.S. de Boer

Prof. Dr. A. Plaat

Prof. Dr. M. Sirjani (Malardalen University)

Prof. Dr. A. Lazovik (University of Groningen)

Dr. M.M. Bonsangue



The work in this thesis has been carried out at Centrum Wiskunde & Informatica and Leiden University, and under the auspices of the research school IPA: Institute for Programming research and Algorithmics. The research was partially funded by the EU project EU FP7 IST project COMPAS: Compliance-driven Models, Languages, and Architectures for Services.

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Contributions . . . . .	4
1.2	Outline . . . . .	5
1.3	Publications . . . . .	7
<b>2</b>	<b>Business Process Model and Notation</b>	<b>9</b>
2.1	Introduction . . . . .	9
2.2	BPMN 2 elements . . . . .	10
2.2.1	Connecting objects . . . . .	10
2.2.2	Events . . . . .	11
2.2.3	Activities . . . . .	14
2.2.4	Gateways . . . . .	16
2.2.5	Swimlanes and artifacts . . . . .	16
<b>3</b>	<b>Reo Coordination Language</b>	<b>19</b>
3.1	Introduction . . . . .	19
3.2	Reo . . . . .	20
3.3	Examples . . . . .	22
3.4	Extensible Coordination Tools (ECT) . . . . .	23
<b>4</b>	<b>Formal Semantics for Reo</b>	<b>27</b>
4.1	Introduction . . . . .	27
4.2	Constraint automata . . . . .	29
4.3	Constraint automata with state memory . . . . .	32
4.4	Constraint automata with priority . . . . .	36
4.5	Connector coloring . . . . .	41
4.6	Reo automata . . . . .	44
4.7	Complexity . . . . .	45

<b>5</b>	<b>Mapping BPMN to Reo</b>	<b>49</b>
5.1	Transaction refinement . . . . .	51
5.2	Atlas Transformation Language . . . . .	56
5.3	Mapping BPMN 2 to Reo . . . . .	58
5.3.1	Definition . . . . .	59
5.3.2	Process . . . . .	60
5.3.3	Task and subprocess . . . . .	61
5.3.4	Throw and catch events . . . . .	62
5.3.5	Gateway . . . . .	64
5.3.6	Transaction . . . . .	68
5.3.7	Other elements . . . . .	70
5.4	Example . . . . .	77
5.5	Related Work . . . . .	77
<b>6</b>	<b>A Constraint-Based Semantics Framework for Reo</b>	<b>81</b>
6.1	Introduction . . . . .	81
6.2	Reo constraint satisfaction problem (RCSP) . . . . .	82
6.2.1	Encoding Reo elements in RCSPs . . . . .	85
6.2.2	Solving RCSPs . . . . .	87
6.2.3	Constructing CASM . . . . .	90
6.3	Hiding . . . . .	92
6.4	Correctness and compositionality . . . . .	95
6.4.1	Performance evaluation . . . . .	100
6.5	Conclusions . . . . .	101
<b>7</b>	<b>Priority</b>	<b>105</b>
7.1	Introduction . . . . .	105
7.2	Priority flow . . . . .	106
7.3	Numeric priority . . . . .	113
7.4	Case study . . . . .	114
7.5	Related work . . . . .	117
7.6	Conclusions and future work . . . . .	119
<b>8</b>	<b>Conclusion</b>	<b>121</b>

# Listings

4.1	Calculating $\mathcal{R}$ . . . . .	40
4.2	Calculating seepage relation $\mathcal{S}$ . . . . .	40
5.1	Refinement of transactions . . . . .	54
5.2	Refinement of transactions (dealing with task completion) . . . . .	56
5.3	Refinement of transactions (dealing with compensations) . . . . .	57
5.4	Definition mapping rule . . . . .	58
5.5	Process mapping rule . . . . .	59
5.6	Mapping tasks and collapsed subprocesses . . . . .	61
5.7	Mapping an expanded subprocess . . . . .	62
5.8	Mapping tasks and collapsed subprocesses . . . . .	63
5.9	Mapping non-conditional catch event . . . . .	64
5.10	Mapping published throw message event . . . . .	65
5.11	Mapping propagated throw events . . . . .	66
5.12	Mapping conditional event . . . . .	67
5.13	Mapping parallel gateway . . . . .	67
5.14	Mapping inclusive gateway . . . . .	68
5.15	Mapping exclusive gateway . . . . .	69
5.16	Mapping the generated compensation order complex gateway . . . . .	71
5.17	Finding the connecting node to a complex gateway . . . . .	72
5.18	Mapping incoming flows of the compensation order gateway . . . . .	73
5.19	Mapping the post compensation complex gateway . . . . .	74
5.20	Mapping the cancel flow to the post compensation gateway . . . . .	74
5.21	Mapping the compensation completion . . . . .	75
5.22	Mapping the task completion . . . . .	76





# List of Figures

1.1.1 The BPMN to Reo converter menu in ECT . . . . .	5
1.1.2 The mapping of Figure 1.1.1 . . . . .	5
2.2.1 An example of messaging in BPMN . . . . .	18
3.3.1 An example of a context-dependent Reo network . . . . .	22
3.3.2 An example of a data-aware Reo network . . . . .	22
3.3.3 A Reo network for a FIFO <sub>2</sub> buffer . . . . .	23
4.2.1 A context-dependent Reo connector . . . . .	31
4.2.2 CA of Figure 4.2.1 . . . . .	32
4.2.3 A data-aware Reo connector . . . . .	32
4.2.4 CA of Figure 4.2.3 . . . . .	32
4.3.1 FIFO <sub>2</sub> . . . . .	36
4.3.2 CA of Figure 4.3.1 . . . . .	36
4.5.1 A context-dependent Reo connector . . . . .	42
4.5.2 A data-aware Reo connector . . . . .	43
5.1.1 Figure 5.1.1a after refinement . . . . .	55
5.3.1 The meta-model of FlowNode . . . . .	60
5.3.2 Mapping of the compensation order complex gateway . . . . .	70
5.3.3 Mapping of the post compensation complex gateway . . . . .	72
5.3.4 Mapping the refined BPMN 2 example of Figure 5.1.1b to Reo . . . . .	77
6.2.1 A data-aware Reo connector . . . . .	87
6.2.2 A context-dependent Reo connector . . . . .	89
6.2.3 CASMs generated for Figures 6.2.1 and 6.2.2 . . . . .	91
6.2.4 CASM for Figure 6.2.2 . . . . .	92
6.2.5 CC for Figure 6.2.2 . . . . .	92

6.3.1 Two $FIFO_1$ s forming $FIFO_2$ . . . . .	94
6.3.2 Hiding the empty transition . . . . .	94
6.4.1 A sample Reo network . . . . .	95
6.4.2 CASM corresponding to Figure 6.4.1 . . . . .	95
6.4.3 A coloring annotated state of the CC corresponding to Figure 6.4.1 . . . . .	96
6.4.4 7-Sequencer . . . . .	100
6.4.5 Performance evaluation based on N-Sequencer network . . . . .	102
7.4.1 An example of a sales process modeled in BPMN . . . . .	114
7.4.2 The process of a sample on-line shop modeled in Reo . . . . .	115
7.4.3 Ignoring priorities in Figure 7.4.2 . . . . .	117

# List of Tables

4.2.1 Constraint automata for basic Reo primitives . . . . .	30
4.4.1 Priority constraint automata of commonly used Reo primitives . . . . .	37
4.5.1 Connector coloring semantics of the Reo network of Figure 4.5.1 . . . . .	43
4.5.2 Connector coloring semantics of commonly used Reo primitives . . . . .	43
4.5.3 Connector coloring semantics of the Reo network of Figure 4.5.2 . . . . .	44
4.6.1 Reo automata for basic Reo primitives . . . . .	45
6.2.1 Context-independent encoding of Reo primitives . . . . .	86
6.2.2 Context-dependent encoding of Reo primitives . . . . .	86
7.2.1 Constraint encoding of Reo with priority . . . . .	109
7.4.1 Priority data of Figure 7.4.3 . . . . .	118

