



Petri Net Synthesis

Eric Badouel, Luca Bernardinello, Philippe Darondeau

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This book is dedicated to the memory of our friend Philippe Darondeau.

Foreword

A Petri net synthesis problem can be seen as a model transformation from a behavioural to a structural description of a concurrent system. In its original version formulated by Andrzej Ehrenfeucht and myself, the behavioural description was given by transition systems and the structural description was given by elementary net systems. The solution we provided was based on the theory of regions of transition systems which also yielded an automatic synthesis of an elementary net system whose behaviour was captured by a given transition system.

Since then (1989) Petri net synthesis has become a very vivid and successful research area. The original approach was extended at both ends: the behavioural and the structural descriptions. The acceptable behavioural specifications were extended to, for example, formal languages and execution traces. The structural descriptions were extended first to Place/Transition nets and then to, for example, Petri Nets augmented with priorities or inhibitor arcs. Also, the types of operational semantics were extended to, for example, step sequence semantics (where several actions can be executed simultaneously) which can be constrained by various firing policies (such as maximal parallelism). The notion of a region (suitably adapted) proved to be robust in all these extensions—as a matter of fact it became a basic/central notion of the framework of Petri nets and beyond. All these research efforts were accompanied by the development of suitable algorithms for net synthesis.

Application areas of net synthesis currently cover, among others, the construction of distributed systems, supervisory control, process discovery, and the design of asynchronous circuits. One can already identify the influence of net synthesis research on the design of asynchronous circuits operating under relative timing, and process mining technologies aimed at understanding causal relationships in the behaviour of complex business systems.

Altogether Petri net synthesis has become a full-fledged, relevant, and exciting research area. This book provides an impressive in-depth account of a wide range of the existing results and techniques. It extensively covers the theory and the algorithms and it also provides a good insight into applications. The book is an impressive achievement that will be very valuable for both novices entering this research field and for researchers in this area as a rich and reliable reference as well as a source of relevant research problems.

The very high technical and presentation quality of the book is certainly due to the fact that all three authors made fundamental contributions to this research area. Unfortunately, Philippe Darondeau passed away much too early, so that he could not see the final product of this project. The book is a tribute to this outstanding and inspiring researcher.

Grzegorz Rozenberg
Leiden, The Netherlands 2015

Preface

The synthesis problem for Petri nets consists in building a Petri net satisfying a given behavioural specification. In its applications, quite often the initial specification is inherently sequential, and part of the problem consists in eliciting potential concurrence.

This book aims at giving a comprehensive and systematic survey of the synthesis problem and of region theory, which underlies its solution.

Region theory arose from the work by Ehrenfeucht and Rozenberg on 2-structures, starting from the late 1980s. A 2-structure is a special case of a labelled transition system, where labels denote actions producing state changes. A region in a 2-structure (or in a transition system) is a subset of states whose “frontier” is uniformly crossed, or not crossed, by all occurrences of the same label.

In the marking graph of an elementary Petri net, the extension of a place (or condition) is a region. Ehrenfeucht and Rozenberg showed that the set of all regions of a transition system serve as the places of a net whose marking graph is isomorphic to the given transition system, provided the latter satisfies a set of axioms, which can be checked by computing the set of regions.

Since then, the synthesis problem and the theory of regions have attracted several researchers. The original notions have been extended, generalized, and adapted to different classes of Petri nets, and to different initial specifications, other than transition systems.

The algebraic properties of several variants of the original notion of regions have been extensively studied, and some software tools have been developed which solve the synthesis problem.

Eric Badouel was first introduced to the theory of regions by a tutorial given by P.S. Thiagarajan at a Summer School in Gargnano, Italy, which was co-organized by Luca Bernardinello. In his talk P.S. Thiagarajan presented a joint work with Mogens Nielsen and Grzegorz Rozenberg on the use of regions to relate some models of concurrency. This was a source of inspiration for introducing a variant of regions for the characterization of trace automata defined by structural operational specifications. This work, done jointly with Philippe Darondeau, was the starting point for a long and fruitful collaboration.

Around the same period Jörg Desel and Wolfgang Reisig wrote a survey on the synthesis problem of Petri nets, Luca Bernardinello showed the central rôle played by minimal regions and Giorgio De Michelis applied net synthesis techniques in the context of workflow management systems.

In retrospect, the origins of this book can be traced back to a meeting held in 1992 in Leiden, The Netherlands, during a *REX Concurrency Day*, where the above-mentioned persons were invited by Grzegorz Rozenberg to exchange

ideas on region theory. This meeting marked the start of the collaboration on this subject among the three authors. Later, this collaboration was strengthened when Luca moved to Rennes to join Eric and Philippe for a year and a half.

A first comprehensive survey of the field was written by Eric Badouel and Philippe Darondeau in 1998, but the flow of publications on the subject remained steady, showing a combination of theoretical and application-oriented interest.

The vitality of the field, more than twenty years since its birth, is witnessed by the series of ART (Applications of Region Theory) workshops, held in 2010, 2011, and 2013. The topic has been nurtured by the contributions of many researchers including among others Eike Best, Benoît Caillaud, Josep Carmona, Jordi Cortadella, Raymond Devillers, Michael Kishinevsky, Jetty Kleijn, Alex Kondratyev, Maciej Koutny, Luciano Lavagno, Robert Lorenz, Marta Pietkiewicz-Koutny, and Alex Yakovlev.

Writing this book has followed a long process. It was started at the end of 2010 by Eric and Philippe. A first draft of the book was almost completed by the end of 2012, when Philippe had knowledge that he was suffering from a cancer that would leave him little time to live. At this point, Luca joined the team. Philippe passed away on Monday March 18th, 2013. He fought a courageous battle, and remained active until the very end. His pain was strong during his last days, but he wanted to complete his contribution to this book.

With the loss of a dear friend and colleague and the completion of this book we are aware that we are closing a period of our lives rich in experiences and emotions. We hope that this book will be an opportunity for others to open new pages.

As authors, we gratefully acknowledge the support by Springer, and particularly by Ronan Nugent, who has backed the book project throughout its drafting. A warm thank goes to the anonymous referees and to the copy editor, whose contribution has significantly improved the quality of the book.

Finally, a special thank goes to Grzegorz Rozenberg, who kindly agreed to write a foreword, and who has always been a source of inspiration and of encouragement.

Eric Badouel, Rennes, France
Luca Bernardinello, Milano, Italy
2015

Contents

Introduction	1
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Part I Elementary Net Synthesis

1 Introduction to Elementary Net Synthesis	15
1.1 An Informal Introduction to Elementary Nets	15
1.2 Elementary Net Systems and Their Firing Rule	17
1.3 Regions and Elementary Transition Systems	24
1.4 Admissible Sets of Regions and the Separation Axioms	35
1.5 Minimal Regions Are Sufficient for Synthesis	42
1.6 Minimal Admissible Sets of Regions	45
1.7 Regions and State Machine Decompositions	48
1.8 Regions of Labelled Partial 2-Structures \dagger	51
Problems	56
Further Reading	58
2 Other Forms of the Synthesis Problem	59
2.1 Canonical Net Versions Yield Optimal Realizations	59
2.2 Relaxing the State Separation Property	66
2.3 Net Synthesis from Languages	72
2.4 Minimal Regions and Approximate Synthesis	78
2.5 Minimal Regions and Synthesis up to Language Equivalence ..	80
Problems	81
3 Algorithms of Elementary Net Synthesis	83
3.1 <i>NP</i> -Completeness of Synthesis \dagger	83
3.1.1 The Separation Problems Are <i>NP</i> -Complete	84
3.1.2 The Elementary Net Synthesis Problem Is <i>NP</i> -Complete	87
3.2 Algorithms of Elementary Net Synthesis	90
3.2.1 Rough Sets	91

3.2.2	Signatures of Rough Sets	95
3.2.3	Rough Regions	98
3.2.4	Extracting Regions from a Rough Region	101
3.2.5	Net Synthesis Algorithms	103
3.2.6	The Heuristic Approach of PETRIFY	107
	Problems	109

Part II Types of Nets

4	Variations of Elementary Net Synthesis	121
4.1	The Synthesis of Event/Condition Nets	121
4.2	Types of Nets	129
4.3	Regions as Morphisms and Synthesized Nets	136
4.4	Boolean Nets \dagger	139
	Problems	147
5	A Unified Theory of Net Synthesis	153
5.1	Duality Between Nets and Transition Systems	155
5.2	Representation Results	160
5.3	Taking Concurrency into Account \dagger	164
5.3.1	Transition Systems with a Concurrency Relation	165
5.3.2	Step Transition Systems	169
	Problems	177
	Further Reading	181

Part III P/T-Net Synthesis

6	The Linear Algebraic Structure of Regions	187
6.1	Flip-Flop Net Synthesis	187
6.2	Introduction to P/T-Nets and P/T-Regions	194
6.3	Algebraic Structure of P/T-Regions	198
	Problems	210
7	Synthesis of P/T-Nets from Finite Initialized Transition Systems	213
7.1	Exact Synthesis of Pure P/T-Nets	213
7.2	Approximate Synthesis of Pure P/T-Nets	218
7.3	Synthesis of Impure P/T-Nets	220
7.4	Synthesis of Bounded Nets from Regular Languages	221
7.5	Synthesis of Pure and Bounded Nets from Finite Languages ..	222
7.6	Open Issues \dagger	223
	Problems	225

8	Synthesis of Unbounded P/T-Nets	227
8.1	Rational Sets and Semilinear Sets	227
8.2	Unbounded P/T-Regions of Languages	230
8.3	Synthesis of Unbounded P/T-Nets from Languages	234
8.4	Unbounded P/T-Regions of Transition Systems \dagger	238
8.5	Synthesis of Nets from Infinite Transition Systems \dagger	246
9	P/T-Nets with the Step Firing Rule \dagger	253
9.1	Regions of Step Transition Systems	254
9.2	P/T-Net Realization of Finite Step Transition Systems	255
9.3	P/T-Net Realization of Step Languages	259
9.4	Partial Languages and Token Flows	260
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Part IV Applications of Net Synthesis		
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10	Extracting Concurrency from Transition Systems \dagger	269
10.1	Distributed Realization of Transition Systems	269
10.1.1	Distributed Transition Systems	270
10.1.2	Distributable P/T-Nets	271
10.1.3	Splitting a Distributable Net into Pieces	273
10.1.4	Distributed Implementation of a Transition System ...	273
10.1.5	Synthesizing Distributable P/T-Nets	276
10.2	Compacting Automata and Products of Automata	279
11	Process Discovery \dagger	283
11.1	Discovering Workflow Nets from Event Logs	283
11.2	Logs and Their Regions	287
11.3	P/T Net Identification	295
	Problems	297
12	Supervisory Control \dagger	301
12.1	Ramadge and Wonham's Theory of Supervisory Control	301
12.2	Petri Net Supervisory Control	304
12.3	Region-Based Supervisory Control of Petri Nets	305
12.4	Region-Based Supervisory Control of Discrete Event Systems	312
12.5	Distributed Control of Discrete Event Systems	315
13	Design of Speed Independent Circuits \dagger	319
References		327
Index		337