Linear Time, Branching Time and Partial Order in Logics and Models for Concurrency

School/Workshop, Noordwijkerhout, The Netherlands
May 30 – June 3, 1988
Editorial Board
D. Barstow  W. Brauer  P. Brinch Hansen  D. Gries  D. Luckham
C. Moler  A. Pnueli  G. Seegmüller  J. Stoer  N. Wirth

Editors
J.W. de Bakker
Centre for Mathematics and Computer Science
Kruislaan 413, 1098 SJ Amsterdam, The Netherlands

W.-P. de Roever
Department of Computing Science
Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven, The Netherlands

G. Rozenberg
Institute of Applied Mathematics and Computer Science
University of Leiden
P.O. Box 9512, 2300 RA Leiden, The Netherlands

CR Subject Classification (1987): B.1, C.1–2, D.4, F.1, F.3–4

This work is subject to copyright. All rights are reserved, whether the whole or part of the material
is concerned, specifically the rights of translation, reprinting, re-use of illustrations, recitation,
broadcasting, reproduction on microfilms or in other ways, and storage in data banks. Duplication
of this publication or parts thereof is only permitted under the provisions of the German Copyright
Law of September 9, 1965, in its version of June 24, 1985, and a copyright fee must always be
paid. Violations fall under the prosecution act of the German Copyright Law.
© Springer-Verlag Berlin Heidelberg 1989
Printed in Germany
Printing and binding: Druckhaus Beltz, Hemsbach/Bergstr.
2145/3140-543210 – Printed on acid-free paper
PREFACE

Modelling the behaviour of concurrent and distributed systems has grown into one of the most challenging and vigorous research areas within theoretical computer science. The last decade has seen the emergence of three independent approaches to this problem, some of them capturing differences between systems that others ignore. The first one models a system by describing its execution runs, the second one by analysing the execution trees, and the third one models a system by describing the (in)dependencies and choices between the various events that may occur. Paradigmatic for these approaches are semantic domains with linear or branching elements, linear time and branching time temporal logic, and net theory. Although it seems that the more features a system captures the better, if one wants some measure of abstractness and parsimony, some of such features may be too detailed for a given level of description.

This volume reviews these intrinsically different approaches and evaluates their relative advantages. It is based on the "School/Workshop On Linear Time, Branching Time and Partial Order in Logics and Models for Concurrency" organized by the editors and held in the period May 30 - June 3, 1988 at Noordwijkerhout, The Netherlands. The School/Workshop was an activity of the project REX - Research and Education in Concurrent Systems sponsored by the Netherlands NFI (Nationale Faciliteit Informatica) Programme. The meeting was organized under auspices of the EATCS and was furthermore supported by the Centre for Mathematics and Computer Science, the University of Leiden, and the Eindhoven University of Technology.

The material presented in this volume has been prepared by the lecturers (and their coauthors) after the meeting took place - in this way the papers reflect also the vivid discussions that took place during the meeting. We are proud that we had such an excellent group of lecturers and such an eager and enthusiastic group of participants. We are very grateful to both groups for making the meeting both scientifically interesting and socially very pleasant, and to the Program Committee consisting of M. Hennessy, E.-R. Olderog, A. Pnueli, J. Sifakis, and P.S. Thiagarajan for their help in preparing the scientific program of the meeting.

We gratefully acknowledge the financial support from the Netherlands National Facility for Informatics (NFI).

The Centre for Mathematics and Computer Science was responsible for the technical organization of the meeting. The University of Leiden and the Eindhoven University of Technology have cooperated in the organization on a number of vital points. As directors of the School/Workshop we want to extend our special thanks to Ms. Loes Vasmel-Kaarsemaker, Ms. Marja Hegt, and Mr. Frans Snijders for organizational assistance beyond the call of duty.
IV

We hope that in the future development of the theory of concurrent systems this volume may help in bringing at least partial order into the branching structure that this development undoubtedly will have.

January, 1989

The Editors,

J.W. de Bakker
W.P. de Roever
G. Rozenberg
THE REX PROJECT

The REX - Research and Education in Concurrent Systems-project investigates syntactic, semantic and proof-theoretic aspects of concurrency. In addition, its objectives are the education of young researchers and, in general, the dissemination of scientific results relating to these themes.

REX is a collaborative effort of the Leiden University (G. Rozenberg), the Centre for Mathematics and Computer Science in Amsterdam (J.W. de Bakker), and the Eindhoven University of Technology (W.P. de Roever), representing the areas syntax, semantics and proof theory, respectively. The project is supported by the Netherlands National Facility for Informatics (NFI); its expected duration is four years starting in 1988. In the years 1984-1988, the same groups worked together in the Netherlands National Concurrency Project (LPC), supported by the Netherlands Foundation for the Advancement of Pure Research (ZWO).

The research activities of the REX project will include, more specifically,

(i) Three subprojects devoted to the themes:
- syntax of concurrent systems: a graph oriented framework for structures and processes
- process theory and the semantics of parallel logic programming languages
- high-level specification and refinement of real-time distributed systems.

(ii) Collaboration with visiting professors and post-doctoral researchers, in particular focused on the research themes mentioned above. In 1988/1989 these visitors include dr. E.-R. Olderog (Kiel), prof. P.S. Thiagarajan (Madras), dr. S. Ramesh (Indian Institute of Technology).

(iii) Workshops and Schools. The School/Workshop on Linear Time, Branching Time and Partial Order in Logics and Models for Concurrency was the first in a series of such events. For 1989, we plan a workshop on "Stepwise Refinement of Distributed Systems: Models, Formalisms, Correctness". In 1990, we shall organize a meeting on "Actor systems, object-oriented languages and massive parallelism" (tentative title).

The educational activities of REX include regular "concurrency days". A concurrency day may consist of tutorial introductions to selected topics, and of presentations of research results to a non-specialist audience. Often, experts from abroad are invited to contribute to these days. In addition, visiting professors are asked to present lecture series concerning recent developments in their fields of specialization. Clearly, the School/Workshops
have as well an important educational function, providing their participants with an intensive introduction to new areas.

Finally, we mention another aspect of the REX project. We shall continue the regular contacts with other European projects in the area of concurrency built up during the LPC years. In particular, this applies to the French C³-Cooperation, Communication, Concurrency- program, to the British Computer Society - Formal Aspects of Computer Science group, and to groups within the Gesellschaft für Mathematik und Datenverarbeitung (GMD) in Bonn.

As mentioned already, REX continues the LPC cooperation. Some highlights of the LPC years are:

(i) the organization of the ESPRIT/LPC Advanced School on Current Trends in Concurrency (1985, proceedings appeared as Lecture Notes in Computer Science, Vol. 224, Springer, 1986);

(ii) Ph.D. research on the topics vector synchronized systems, dataflow semantics, and real-time temporal logic;

(iii) fruitful interaction with ESPRIT projects 415 (Parallel Architectures and Languages for AIP: a VLSI-directed approach) and 937 (Descartes, Debugging and Specification of ADA Real-Time Embedded Systems). LPC contributed to the local organization of ESPRIT 415 conference PARLE - Parallel Architectures and Languages Europe (1987, Proceedings appeared as Lecture Notes in Computer Science Vol. 258, 259, Springer);

(iv) the setting-up of the international exchanges referred to above.

We would like to conclude this brief presentation of the future (past) of the REX (LPC) project by inviting everyone who is interested in more information concerning REX (possibility of visits, plans for workshops, other forms of exchanges, etc.) to write to one of the project leaders.

J.W. de Bakker
W.P. de Roever
G. Rozenberg
CONTENTS

PREFACE ........................................ V

THE REX PROJECT .............................. VII

TUTORIALS

J. van Benthem
Time, logic and computation ........................ 1

J.A. Bergstra, J.W. Klop
Process theory based on bisimulation semantics .... 50

E.A. Emerson, J. Srinivasan
Branching time temporal logic ....................... 123

M. Hennessy
Observing processes ............................ 173

Z. Manna, A. Pnueli
The anchored version of the temporal framework .... 201

A. Mazurkiewicz
Basic notions of trace theory ........................ 285

G. Winskel
An introduction to event structures .................. 364

TECHNICAL CONTRIBUTIONS

A. Bouajjani, S. Graf, J. Sifakis
A logic for the description of behaviours and properties of concurrent systems .......... 398

G. Boudol, I. Castellani
Permutation of transitions: An event structure semantics for CCS and SCCS .......... 411

E.M. Clarke, I.A. Draghicescu
Expressibility results for linear-time and branching-time logics ....... 428
P. Degano, R. De Nicola, U. Montanari
Partial orderings descriptions and observations of nondeterministic concurrent processes ........................................ 438

H. Gaifman
Modeling concurrency by partial orders and nonlinear transition systems .............................................................. 467

S. Katz, D. Peled
An efficient verification method for parallel and distributed programs ................................................................. 489

K. Lodaya, R. Ramanujam, P.S. Thiagarajan
A logic for distributed transition systems ........................................ 508

M. Nielsen, U. Engberg, K.S. Larsen
Fully abstract models for a process language with refinement ...... 523

E.-R. Olderog
Strong bisimilarity on nets: a new concept for comparing net semantics ................................................................. 549

A. Rabinovich, B.A. Trakhtenbrot
Nets of processes and data flow .............................................. 574

W. Reisig
Towards a temporal logic of causality and choice in distributed systems ............................................................... 603

J.J.M.M. Rutten
Correctness and full abstraction of metric semantics for concurrency ................................................................. 628

C. Stirling
Temporal logics for CCS .......................................................... 660

M.W. Shields
Behavioural Presentations .......................................................... 673

W. Thomas
Computation tree logic and regular \( \omega \)-languages .......................................................... 690