

# Lecture Notes in Computer Science

Edited by G. Goos and J. Hartmanis

489

---

J.W. de Bakker W.P. de Roever  
G. Rozenberg (Eds.)

## Foundations of Object-Oriented Languages

REX School/Workshop  
Noordwijkerhout, The Netherlands, May 28–June 1, 1990  
Proceedings

---



Springer-Verlag

Berlin Heidelberg New York London Paris  
Tokyo Hong Kong Barcelona Budapest

**Editorial Board**

D. Barstow W. Brauer P. Brinch Hansen D. Gries D. Luckham  
C. Moier A. Pnueli G. Seegmüller J. Stoer N. Wirth

**Volume Editors**

J. W. de Bakker  
Centre for Mathematics and Computer Science  
P.O. Box 4079, 1009 AB Amsterdam, The Netherlands

W. P. de Roever  
Institut für Informatik und Praktische Mathematik II  
Christian-Albrechts-Universität Kiel  
Preußerstraße 1–9, W-2300 Kiel 1, FRG

G. Rozenberg  
Department of Computer Science, Leiden University  
P.O. Box 9512, 2300 RA Leiden, The Netherlands

CR Subject Classification (1991): D.1.5, F.3.2–3

ISBN 3-540-53931-X Springer-Verlag Berlin Heidelberg New York  
ISBN 0-387-53931-X Springer-Verlag New York Berlin Heidelberg

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 current version, and a copyright fee must always be paid. Violations fall under the prosecution act of the German Copyright Law.

© Springer-Verlag Berlin Heidelberg 1991  
Printed in Germany

Printing and binding: Druckhaus Beltz, Hemsbach/Bergstr.  
2145/3140-543210 – Printed on acid-free paper

## PREFACE

Over the last years, object-oriented programming has been recognized as the best way currently available for structuring software systems. It emphasizes grouping together data and the operations performed on them, encapsulating the whole behind a clean interface, and organizing the resulting entities in a hierarchy based on specialization in functionality. In this way it provides excellent support for the construction of large systems, which can be built cheaply out of reusable components, and which can be adapted easily to changing requirements.

Up to now, object-oriented programming has largely been a field of practitioners, who were driven by an intuitive understanding of the important concepts, arising out of the experience of building actual systems. There has been relatively little effort to develop formal theories about these concepts. However, in order for the field to mature, a more formal understanding of the basic concepts of object-oriented programming is necessary, forming a solid foundation for refinement and further development.

The aim of the School/Workshop on Foundations of Object-Oriented Languages (FOOL) was to bring together researchers involved in the mathematical foundations of object-oriented programming. This volume is based on this meeting (organized by the editors and held in the period May 28 - June 1, 1990 in Noordwijkerhout, The Netherlands). The School/Workshop was an activity of the project REX - **R**esearch and **E**ducation in **C**oncurrent **S**ystems sponsored by the Netherlands NFI (Nationale Faciliteit Informatica) Programme. The meeting was organized under the auspices of the EATCS and supported by the Centre for Mathematics and Computer Science, Leiden University and the Eindhoven University of Technology.

The material presented in this volume was prepared by the lecturers (and their co-authors) after the meeting took place - in this way the papers also reflect discussions that took place during the meeting. We were fortunate in having such an excellent group of lecturers and such an active group of participants. We are grateful to both groups for contributing to the success of the meeting. Special thanks go to P.H.M. America for his invaluable help in preparing the scientific program of the meeting.

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

The Centre for Mathematics and Computer Science was responsible for the technical organization of the meeting. Leiden University and the Eindhoven University of Technology 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, Mr. Frans Snijders and Dr. J. Coremans for organizational assistance beyond the call of duty.

February 1991

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 of 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 include, more specifically:

(i) Three subprojects devoted to the following 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. The visitors so far include Prof. L. Cherkasova (Novosibirsk), Dr. F. Cristian (Almaden), Prof. P. Degano (Pisa), Prof. A. Emerson (Austin, Texas), Prof. M. Joseph (Warwick), Prof. A. Mazurkiewicz (Warsaw), Prof. E.-R. Olderog (Kiel), Dr. W. Penczek (Warsaw), Dr. S. Ramesh (Indian Institute of Technology) and Prof. P.S. Thiagarajan (Madras).

(iii) Workshops and Schools. In 1988 we organized a School/Workshop on "Linear Time, Branching Time and Partial Order in Logics and Models for Concurrency"; its proceedings appeared as Lecture Notes in Computer Science, Vol. 354, Springer, 1989. In 1989 we organized a Workshop on "Stepwise Refinement of Distributed Systems"; its proceedings appeared as Lecture Notes in Computer Science, Vol. 430, Springer, 1990. The School/Workshop on Foundations of Object-Oriented Languages (FOOL) in 1990 was the third in a series of such events. For 1991, we plan a workshop "Real-time: Theory in Practice".

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 function, providing their participants with an intensive introduction to new areas.

Finally, we mention another aspect of the REX project. We 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 C<sup>3</sup> - Cooperation, Communication, Concurrency - program, to the British Computer Society - the 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 Vols. 258 and 259, Springer).

(iv) Setting up the international exchanges referred to above.

We would like to conclude this brief presentation of the REX (formerly 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 .....	III
The Rex Project .....	V

## Technical Contributions

G. Agha The structure and semantics of actor languages .....	1
P. America Designing an object-oriented programming language with behavioural subtyping .....	60
P. America, J. Rutten A layered semantics for a parallel object-oriented language .....	91
F.S. de Boer A proof system for the language POOL .....	124
W.R. Cook Object-oriented programming versus abstract data types .....	151
E. Cusack, M. Lai Object-oriented specification in LOTOS and Z or, my cat really is object-oriented! .....	179
H.-D. Ehrich, J.A. Goguen, A. Sernadas A categorical theory of objects as observed processes .....	203
J. Engelfriet, G. Leih, G. Rozenberg Net-based description of parallel object-based systems or POTs and POPs .....	229

J. Fiadeiro, T. Maibaum	
Describing, structuring and implementing objects . . . . .	274
G. Ghelli	
Modelling features of object-oriented languages in second order functional languages with subtypes . . . . .	311
D. Janssens, G. Rozenberg	
Graph grammar-based description of object-based systems . . . . .	341
T. Watanabe, A. Yonezawa	
An actor-based metalevel architecture for group-wide reflection . . . . .	405
P.M. Yelland	
Producing abstract models for object-oriented languages . . . . .	426