The π-calculus: a Theory of Mobile Processes

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Quelli che s'innamoran di pratica sanza scientia
son come 'l nocchiere ch'entra in navilio sanza timone o bussola,
che mai ha certezza dove si vada.

– Leonardo da Vinci

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Foreword

Computer science aims to explain the way computational systems behave for us. The notion of calculational process, or algorithm, is a lot older than computing technology; so, oddly enough, a lot of computer science existed before modern computers. But the invention of real stored-program computers presented enormous challenges; these tools can do a lot for us if we describe properly what we want done. So computer science has made immense strides in ways of *presenting* data and algorithms, in ways of manipulating these presentations themselves as data, in matching algorithm description to task description, and so on. Technology has been the catalyst in the growth of modern computer science.

The first large phase of this growth was in free-standing computer systems. Such a system might have been a single computer program, or a multi-computer serving a community by executing several single programs successively or simultaneously. Computing theorists have built many mathematical models of these systems, in relation to their purposes. One very basic such model – the λ-calculus – is remarkably useful in this role, even if it was designed by Alonzo Church around 1940.

The second phase of the growth of computer science is in response to the advent of computer networks. No longer are systems freestanding; they interact, collaborate and interrupt each other. This has an enormous effect on the way we think about our systems. We can no longer get away with considering each system as sequential, goal-directed, deterministic or hierarchical; networks are none of these. So if we confine ourselves to such concepts then we remain dumb if asked to predict whether a network will behave in a proper – or an improper – way; for example, whether someone logging in to his bank may (as happened recently) find himself scanning someone else's account instead of his own.

The present book is a rigorous account of a basic calculus which aims to underpin our theories of interactive systems, in the same way that the λ-calculus did for freestanding computation. The authors are two of the original researchers on the π-calculus, which is now over ten years old and has served as a focus for much theoretical and practical experiment. It cannot claim to be definitive; in fact, since it was designed it has become common to express ideas about interaction and mobility in variants of the calculus. So it has become a kind of workshop of ideas.

That's the spirit in which the book is written. Half the book analyses the constructions of the calculus, searching out its meaning and exploring its expressivity by looking at weaker variants, or by looking at various type disciplines. Enthusiasts about types in programming will be struck to find that π-calculus types don't just classify *values*; they classify *patterns of behaviour*. This reflects the fact that what matters most in mobile interactive systems is not values, but connectivity and mobility of processes. With or without types, the unifying feature is *behaviour*, and what it means to say that two different processes behave the same.

The later part of the book deals with two generic applications. One of these is classical; how the π-calculus can actually do the old job which the λ-calculus does in underpinning conventional programming. The other is modern; how the calculus informs one of the most important models of interaction, the *object-oriented* model. These applications bring together much of the theory developed earlier; together, they show that a small set of constructs, provided that they emphasize *interaction* rather than calculation, can still bring some conceptual unity to the greatly extended scope of modern computing.

This book has been a labour of love for the authors over several years. Their scholarship is immense, and their organisation of ideas meticulous. As one privileged to have worked closely with them both, it's a great pleasure to be able to recommend the result as a storehouse of ideas and techniques which is unlikely to be equalled in the next decade or two.

Robin Milner
Cambridge
February 2001

Preface

Mobile systems, whose components communicate and change their structure, now pervade the informational w orldand the wider world of which it is a part. But the science of mobile systems is yet immature. This science must be developed if w eare properly to understand mobile systems, and if w eare to design systems so that they do what they are intended to do. This book presents the π-calculus, a theory of mobile systems, and shows how to use it to express systems precisely and reason about their behaviour rigorously.

The book is in tended to serve both as a reference for the theory and as an extended demonstration of ho wto use the π-calculus to express systems and analyse their properties. The book therefore presents the theory in detail, with emphasis on proof techniques. How to use the techniques is shown both in proofs of results that form part of the theory and in example applications of it.

The book is in seven P arts. Part I in troduces the π-calculus and develops its basic theory. Part II presents v ariations of the basic theory and important subcalculi of the π-calculus. A distinctive feature of the calculus is its rich theory of types for mobile systems. Part III introduces this theory, and Part IV shows ho w it is useful for understanding and reasoning about systems. Part V examines the relationship betw een theπ-calculus and higher-order process calculi. P art VI analyses the relationship between the π-calculus and the λ-calculus. Part VII shows ho wideas from π-calculus can be useful in object-oriented design and programming.

The book is written at the graduate level and is in tended for computer scientists in terestedin mobile systems. It assumes no prior acquaintance with the π-calculus: both the theory and the viewpoint that underlies it are explained from the beginning.

Although the book cov ers quite a lot of ground, several topics, notably logics for mobility, and denotational and non-interleaving semantics, are not treated at all. The book contains detailed accounts of a selection of topics, chosen for their interest and because they allow us to explore concepts and techniques that can also be used elsewhere. Each Part ends with some references to sources and additional notes on related topics. We have not attempted the arduous task of referring to all relevant published work. The references given provide starting points for a reader who wishes to go more deeply into particular topics. Sometimes, an element of arbitrariness in the choice of references was inevitable.

Many exercises are suggested to help appreciation of the material; the more difficult of them are marked with an asterisk. We intend to maintain a Web page for general information and auxiliary material about the book. At the time of writing, this page is located at

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http://www-sop.inria.fr/mimosa/personnel/Davide.Sangiorgi/
        Book_pi.html
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