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Rudolf Avenhaus and Morton John Canty
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Foreword

Trust but verify! is the advice that Lenin is supposed to have imparted to his followers (see the motto of Chapter 1); *Trust and Verify* is the title of the very useful Bulletin issued by the Verification Technology Information Centre to keep us informed on current developments in arms control, disarmament and associated verification requirements; *Verify and enjoy doing it well!* might well be the subtitle of this book, which is quite remarkable for its engaging style. It covers a considerable amount of material, including quite technical stuff (with theorems proved and calculations worked out in detail), yet its two authors have managed to write it with such lively prose, and to include such a wealth of witty examples, as to make it a most enjoyable read, as even the casual browser will immediately discover.

But this book should appeal not only to the casual browser: it deserves to be read by all those who have an interest in verification — even if they are unable to appreciate all its mathematical niceties. And it will certainly be studied by those who have a professional involvement in this essential aspect of international relations. They will thereby discover many non-trivial, interesting and amusing twists to the games they play: indeed, some of them will perhaps be surprised, as was Molière's gentleman who did not know he was talking prose, to find out that verification has many gaming aspects, not only through its obvious relation with the mathematical theory of games, but also because it can evidently be approached in a gaming mood.

Yet verification is a most serious business, since it lies at the very core of much of the recent progress in arms control and disarmament, and, in our imperfect world, it is still badly needed as an essential confidence- and security-building measure. Of course, the transition from antagonistic to co-operative verification regimes is a desirable development; but most

of the analyses in this book are no less relevant to the latter than to the former. Indeed, in reading through this book it comes to mind that many a verification problem is used to check — perhaps, as it were, subliminally — one's own behavior, even in one's day-to-day activity. For instance, “creative” mathematical research in fact always uses some sort of verification technique, i.e., spot checks guided by plausibility evaluations, in assessing how much care should be devoted, while solving some novel problem, to making sure every step of the relevant calculations is indeed correct; one must always find the proper balance between ending up on the wrong path by adopting an excessively cavalier pace, or instead stifling the emergence of new ideas by trying to dot all the i's and cross all the t's in the early stages of developing some new ideas. Then of course one must eventually go through a second cycle of verification, to transform conjectures into theorems, half-baked ideas into coherent theories, and so on.

So, verification is in fact an ever present element in our life. But undoubtedly its most crucial application belongs to the arms control context, which indeed constitutes the main applicative focus of this book. In this context, the difficulty of guaranteeing adequate verification is still considered by many — to be sure, sometimes surreptitiously — as the key impediment to certain developments, such as the transition to a Nuclear-Weapon-Free World, which are universally recognized as essential *sooner or later* to the continuation of the human experiment on Earth. Here, of course, it will be of utmost importance to watch over the next few years the viability of the transition to a Chemical-Weapon-Free World, as instituted by the Chemical Weapons Convention which will hopefully soon be coming into force. This should be viewed as a development of comparable importance to the creation of the United Nations Organization after World War II, precisely because its verification provisions — much analyzed in this book — will create an organization to supervise the world-wide chemical industry, a gigantic undertaking which might well constitute the seed of a more effective world governance than we have today, just as the European Coal and Steel Community was the germ of the European Union.

In conclusion, we hope and expect this book will enjoy the wide readership it deserves, as a quite unique introduction to verification, remarkable for its solid scholarship as well as its most engaging presentation.

Rome
March, 1995

Francesco Calogero

Preface

Die im Gegensatz zur aristotelischen Philosophie in der Neuzeit sich durchsetzende Ansicht, daß ein Erkenntniszusammenhang in der wirklichen Welt nur gefunden werden kann, soweit qualitative Bestimmungen auf quantitative zurückgeführt werden, ist von fundamentaler Wichtigkeit geworden.

— Hermann Weyl

Ut oculus ad colores, auris ad sonos, ita mens hominis non ad quaevis sed ad quanta intelligenda condita est.

— Johannes Kepler

The original incentive for this book was the interest aroused by an article published by the authors in the Bulletin of the European Safeguards Research and Development Association, entitled *Inspection Randomization for Pedestrians*. In it we demonstrated, with a tongue-in-cheek example, how a simple game-theoretical treatment could justify, and even quantify, a proposal which had often been made for purely pragmatic reasons. The proposal was to concentrate IAEA inspection resources in the most sensitive areas of the nuclear fuel cycle whilst reducing safeguards effort at power reactors. Our article not only supported this idea, but showed that the concentration would not incur any real loss in detection capability.

That short paper now forms the basis for the introductory example in the present book, a work which might well have been given the title *Verification Theory for Pedestrians*. Wishing to avoid condescension, and notwithstanding such erudite precedents as H. J. Lipkin's classic *Lie Groups for Pedestrians*, we chose a slightly more pedestrian title. We have however tried to maintain the relaxed and informal style of our original article without, we fervently hope, overdoing it.

There was of course another, more compelling reason for writing a book on verification theory. More than 20 years of development and analysis of safeguards systems have produced a wealth of knowledge which, we feel, has not been adequately digested or implemented by practitioners. Indeed, it is our impression that certain well-established results and methods are less common knowledge now than they were several years ago, when considerably more active work in this area was under way. A concise and accessible overview of the subject seemed to be called for. We were convinced that the body of knowledge which has been accumulated so far could be reduced to not too many — in fact only a few — standard problems and their solutions and that such a reduction would be of value to a general readership. The presentation, we felt, should emphasize insight and understanding of the mechanisms of verification procedures based on observation, measurement and random sampling, and this at the expense of mathematical rigor at one extreme and ‘cookbook’ type recipes at the other.

Therefore, in producing a new book on this subject, we have not attempted to create an additional monograph on statistics and game theory to replace manuals and textbooks which are now available. Instead our objective has been to explain why verification methodologies differ from more conventional ones which are applied, for example, in process or quality control, and why game theory — or more generally decision theory — should, and indeed must, be used to provide answers of practical relevance. The material is introduced in terms of problem area and verification objectives, not according to methodology, as would have been the case in a more traditional textbook approach. In trying to convey an understanding of the unique and challenging nature of inspection problems we hope to inspire a greater appreciation of verification theory and to encourage its practical implementation.

Many professionals who take up this book may be unaccustomed to thinking about inspection problems in the formal, analytical way promulgated here. Indeed they may even have an aversion to any mathematical treatment of the subject whatsoever. Yet it is our conviction that progress in the design and assessment of verification regimes is in direct proportion to the degree to which qualitative perceptions of real-world relationships can be expressed within a formal framework. This is, as the opening quotations of Weyl and Kepler testify, a conviction not new to science. We hope that all our readers may come to share it.

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Without the myriad of practical verification problems presented to us by colleagues in industry, government and inspection agencies over many years of involvement in safeguards research and development, much of the material presented here would never have evolved at all. For their patience, support and interest in our admittedly at times rather abstract solutions we are extremely grateful.

The last and most fundamental chapter of this book was written in close collaboration with Bernhard von Stengel, to whom we owe special thanks. He opened our eyes not only to the subtleties of equilibrium selection theory, but also to its extraordinary power and relevance to inspection problems and to the concept of deterrence.

Verification is a subject which lends itself to seemingly endless discussion and negotiation. Not surprisingly, for it is a complex field, with often very serious technological, commercial and political ramifications. Unfortunately, the basic principles can become confused in the course of argumentation sometimes motivated more by self-interest than by logic. It is therefore our earnest wish that this book will help to isolate and clarify the objective, quantifiable and unemotional part of a difficult aspect of human relations.

Munich and Jülich
June, 1995

Rudolf Avenhaus
Morton Canty