

**South African
Computer
Journal
Number 19
February 1997**

**Suid-Afrikaanse
Rekenaar-
tydskrif
Nommer 19
Februarie 1997**

**Computer Science
and
Information Systems**

Proceedings of WOFACS'96

**Rekenaarwetenskap
en
Inligtingstelsels**

**The South African
Computer Journal**
*An official publication of the Computer Society
of South Africa and the South African Institute of
Computer Scientists*

**Die Suid-Afrikaanse
Rekenaartydskrif**
*'n Amptelike publikasie van die Rekenaarvereniging
van Suid-Afrika en die Suid-Afrikaanse Instituut
vir Rekenaarwetenskaplikes*

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	Annual	Single copy
Southern Africa:	R50,00	R25,00
Elsewhere:	\$30,00	\$15,00

An additional \$15 per year is charged for airmail outside Southern Africa

to be sent to:

*Computer Society of South Africa
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Introduction

WOFACS '96: Workshop on Formal and Applied Computer Science

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"What I tell you three times is true", said the Bellman in Lewis Carroll's *The Hunting of the Snark*. By somewhat the same principle, it is often held that three events of the same kind serve to make a series. And so, after WOFACS '92, '94 and now '96, we may claim to have a well-established biennial Southern African series of Workshops in the area of Formal Aspects of Computer Science.

This issue of the SACJ is devoted to the *Proceedings* of WOFACS '96. In other words, it contains survey articles written especially for this volume by the invited speakers (and their collaborators), on the topics they lectured on during the Workshop. These were:

- **Dr Maarten de Rijke** (University of Warwick): *Reasoning with Incomplete and Changing Information*.
- **Dr Holger Schlingloff** (Technische Universität München): *Verification of Finite-state Systems with Temporal Model Checking*.
- **Prof Jan Peleska** (Universität Bremen): *Test Automation for Safety-Critical Reactive Systems*.
- **Dr Jeff Sanders** (Oxford University): *Application-oriented Program Semantics*.

The format of WOFACS '96 followed the same pattern as before. Each speaker gave a course of 10 lectures, at a rate of one lecture per day. Material was pitched at about Honours level, and students had the opportunity of offering WOFACS courses for credit in their degree programmes at their respective home universities. Those who took up this option did some exercises and assignments and were evaluated by the speaker(s) concerned, thus gaining valuable

insight into material, methods and expectations at an international level. WOFACS '96 was organised by FACCS-Lab (the Laboratory for Formal Aspects and Complexity in Computer Science), and was co-hosted by the Department of Mathematics and Applied Mathematics and the Department of Computer Science at the University of Cape Town. Accommodation was available in a University residence, and we were able to make available some financial support for travel and accommodation to participants (especially students) who could not obtain funding from their home institutions. Attendance stood at about 50 participants. Cape Town is a pleasant place to visit, even in winter, and we took care to have suitable outings and social events for our visitors. I am pleased to be able to mention that the WOFACS series has now attracted international attention, and that WOFACS 98 is being planned under the auspices of IFIP (the International Federation of Information Processing), specifically Working Group 2.3 on Programming Methodology.

No event of this nature can succeed without the hard work of a number of people. I would like to express my grateful thanks to:

- the invited speakers, for the care they took and the quality of their presentations;
- the Foundation for Research Development and the UCT Research Committee, for sponsorship;
- Diana Dixon, Jeanne Weir, Peter Jipsen and other FACCS-Lab staff members, for their hard work, and
- all participants, for attending.

SACJ is produced with kind support from
Mosaic Software (Pty) Ltd.

Reasoning about Changing Information

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Abstract

The purpose of these notes is two-fold: (i) to give a reasonably self-contained introduction to a particular approach to theory change, known as the Alchourrón-Gärdenfors-Makinson (AGM) approach, and to discuss some of the alternatives, and extensions that have been proposed to it over the past few years; (ii) to relate the AGM approach to other 'information-oriented' branches of logic, including intuitionistic logic, non-monotonic reasoning, verisimilitude, and modal and dynamic logic.

Keywords: Theory change, knowledge representation, modal logic, dynamic logic.

Computing Review Categories: F.4.0, F.4.1, I.2.3, I.2.4.

1 Introduction

In these notes we study a number of approaches to *theory change* alias *belief revision* alias *belief change* alias *theory revision*. This enterprise is about coping with changing information, either because new facts have become known, or because the world has changed. If the newly obtained information is consistent with our old theory, there's no problem: we can simply extend our theory with the new piece of information. However, complex decisions need to be made when the new information conflicts with our old theory. For example, it may be that the new information casts a doubt on parts of our old theory — in that case we will probably want to get rid of the doubtful parts. But it may also be that the newly obtained information is in outright contradiction with our old theory. Assuming that we want to keep our theory consistent, this will force us to make adjustments. But how? Here's an example; assume that the following are part of our theory:

- Bert is a post-doc in logic. (1)
- Bert lives in Amsterdam. (2)
- Amsterdam is located in the Netherlands. (3)
- All Dutch post-docs in logic are unemployed. (4)

From our theory we can derive the following:

- Bert is unemployed. (5)

Assume next that *as a matter of fact* Bert happens to have a job, say at CWI. This means that we want to extend our theory with the fact $\neg(5)$. But then inconsistency strikes. So if we want to keep our theory consistent, we have to per-

form some kind of change, and give up some of the beliefs in our original theory. As we went through considerable effort to arrive at our theory in the first place, we don't want to give up the whole of it. But then, which of the *reasons* for the inconsistency do we have to give up? Also, which of the *consequences* of the old theory do we want to keep? For example, the following is a direct consequence of (4):

All Dutch post-docs in logic who aren't
Bert are unemployed.

Should we keep this (slightly weaker) generalization or not? This is not easy to decide. The complicating factor is that our theory is more than just a collection of atomic facts: there are complex logical dependencies between the elements of our theory, and logical considerations alone are not going to tell us which beliefs to give up.

Actual operations of theory change tend to be rather non-trivial functions whose definition may involve various orderings and relations on theories and sentences; usually, the additional structure reflects the importance of certain information. A number of general laws have been proposed to describe the behaviour of such operations; some of these are discussed below.

Semantically, one may view acts of belief revision as moves in an information space. The states of this space are some sort of information carriers, and a sentence ϕ can be part of a theory associated with an information state; in this case ϕ represents a static piece of information — it simply describes a belief engaged in that state. However, if ϕ does not belong to the theory associated with a given state, we may view it as an instruction telling us to move to a state whose theory does include ϕ ; see Figure 1. Various formal languages for reasoning about such structures will

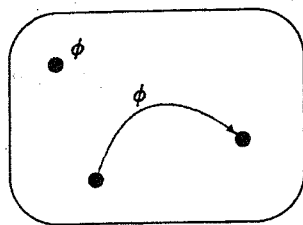


Figure 1. Information space

be presented below.

Similar ideas of viewing the meaning of sentences as instructions, actions or transitions have emerged in many current theories of natural language semantics, logic and artificial intelligence. Such approaches are usually called *dynamic* approaches; it turns out that there are fundamental links between various information-based approaches in logic, including theory change.

A Brief Overview

Part I

The Alchourrón-Gärdenfors-Makinson (or AGM) tradition proposes a set of postulates that are meant to govern the ways in which intelligent agents (human or mechanical) cope with theory change. In Part I of the notes we will discuss this theory, as well as some refinements, extensions and alternative proposals.

In addition to the AGM postulates we discuss various proposals for giving explicit definitions of operations of theory change that satisfy these laws.

Part II

In Part II of the notes we change tack. We consider various information-oriented formalisms in logic, and try to link these to AGM theory. The formalisms considered are non-monotonic logic, verisimilitude, and descriptive approaches based on modal and dynamic logic.

Part I

The AGM Theory

2 Preliminaries

Before we introduce the Alchourrón-Gärdenfors-Makinson theory of belief change, we review a number of underlying basic assumptions, both concerning the methodology and concerning the conceptual and logical apparatus.

Kinds of Theory Change

We will assume the beliefs are represented by sentences of some formal language, and that beliefs ϕ can only be

- accepted, or
- rejected (accept $\neg\phi$), or
- neither accepted nor rejected.

At first sight there only seem to be two basic kinds of theory change, namely

- to insert (or accept) information, and
- to delete information (that is, to switch from acceptance to rejection, or to 'neither acceptance nor rejection').

What we are interested in is how, and under which circumstances, these basic actions are performed. The proposals for handling theory change found in the literature can be divided into two kinds: a *direct* mode, and an *indirect* mode.

In the direct mode one simply inserts or deletes information without bothering about the consistency requirement. Such simple operations are accompanied by a complex, usually para-consistent or defeasible inference engine to determine which conclusions can actually be drawn from the theory. Thus, in the direct mode the complexity of theory change is hidden in the inference engine. Truth maintenance systems form an important example of the direct mode (see [6]).

In the indirect mode one tries to perform theory changes subject to (some or all of) the following methodological assumptions:

Consistency. The beliefs in a theory should be kept consistent whenever possible. This assumption may well be the dominating motive for the whole enterprise of 'theory change.' It is certainly what distinguishes theory change from such fields as para-consistent logic, where one is also interested in handling conflicting information without, however, necessarily deleting reasons for conflict, by changing the inference engine.

Closure. If the theory implies a belief ϕ , then ϕ should be in the theory. This is an obvious idealization, but for the time being we will adhere to it.

The Consistency and Closure assumptions concern the static aspects of theory change: the things that are actually being changed. The following two assumptions concern the way in which theory change takes place.

Minimality. The amount of information lost in a belief change should be kept minimal. The idea is that information doesn't come for free and unnecessary losses are therefore to be avoided.

First Things Last. If there is a measure according to which some beliefs are considered to be more important than others, one should give up the least important ones first.

Functionality. For every theory K and every sentence ϕ , there is a *unique* theory representing the removal or addition of ϕ from or to K . In other words: theory change is a *function* from theories and formulas to theories.

If one tries to play the game following the above constraints, the theory change operations themselves become highly non-trivial, but in return one can use standard logics as the underlying inference engine.