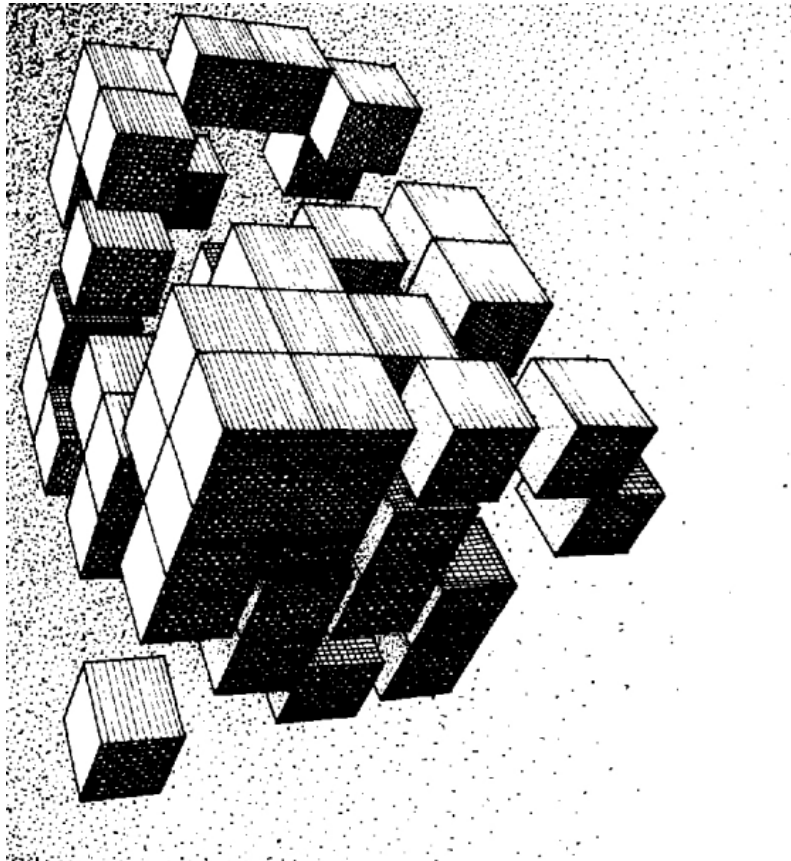


Pieter. M. Kroonenberg

The three-way world knows no boundaries



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The Three-Way World Knows No Boundaries

Farewell address by

Pieter M. Kroonenberg

upon his retirement from the
Special Chair of Multivariate analysis, in particular of three-way data
at Leiden University
on Friday, 14 November 2014

The three-way world knows no boundaries

*Lecture on the occasion of Pieter M. Kroonenberg's farewell
Professor by special appointment of
Multivariate analysis, in particular of three-way data*

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*Madam Dean of the Faculty of Social and Behavioural Sciences,
Madam Director of the Institute of Education and Child Studies
Members of the board of the Foundation for the Advancement of Data Theory as a Science*

*,
Members of the Board of Governors for this special Chair,
Valued members of the audience,
including those of you who are unfortunately not able to understand Dutch, and who will have to
content themselves with enjoying this special occasion by looking at the pictures in the hand-out,
and by inspecting these august surroundings and their present occupants.*

The past: how did we get here?

It is nearly ten years ago that I last addressed you. My inaugural lecture was about how beautiful a subject three-way analysis is, and I explained to you what it entails. Initially my thought was that this second lecture could build on the first, and that you would have revised the text of that first lecture before coming here today, to arrive properly prepared. But it was not long before I realised that many of you have only been attending this university for eight years or less, so I can hardly demand of you to have done your homework. I will therefore provide a brief recapitulation of the material covered previously.

This lecture will consist of four parts: Past, present and future. The first part deals with something in my past that has been weighing heavily on my conscience, which had its origin in my personal history as a young academic.

Personal history

Master's thesis

In order for me to explain what this is about, we must travel forty years or so back in time. As a master's student in Applied Mathematics, I had had to *memorise* a lot of maths during my studies, complete with proofs. To complete my degree work, I really wanted to *do* something mathematical. Writing a master's thesis for a Mathematics degree was not usual at the time, and the lecturer I approached for a subject told me in so many words that I couldn't seriously expect him to pull a subject out of the bag for every single student; this was in 1975. Thankfully, I was a research assistant at Data Theory, which was a department of the Faculty of Social and Behavioural Sciences at the time. I asked my boss, Jan de Leeuw, whether he had something for me to write my thesis on. Barely a day later I was given six sheets of orange graph paper, with six formulae written on each sheet with a thick marker. "Read Tucker's article on three-way analysis, program the algorithm described on these pieces of paper, add an application and there's your thesis." I set to work and 3000 punched cards later the computer program was ready. I wrote the thesis on an electric typewriter with four "golf balls" that you could swap over to get different fonts. Mistakes were covered up with correction tape.

Job

In December 1975, this thesis also turned out to open the door to a job at the Department of Education and Child Studies, because, well, it is easier to teach a mathematician about education

than the other way round, seemed to have been the thought behind appointing me rather than anyone else.

Back to my feelings of unease. It was in the time that newspapers criticised academics for not working hard enough. Compared to the situation now, that was a fair assessment. I only had to teach one sixteen-week course and the rest of the time I was meant to be doing research, but my managers were not specific as to what that should be. It was not until the early eighties that members of staff were expected to write a PhD thesis.

First article

In 1978 I reworked my master's thesis into a Dutch three-way article for a small journal that has long since gone to the wall. One day, Jan de Leeuw wanted to know whether a 'real' article for an English-language journal was forthcoming. He had even heard that there was some competition. And had he mentioned that I should really expand the three-way model from my thesis with a second, more well-known variant? Otherwise it would not do. So I did some more programming, this time on a real Teletype typewriter linked to an IBM mainframe, so no need for punched cards.

In 1979 I wrote the article that went with it, typed it up in IBM's DisplayWrite3 on a word processor the size of a bookcase, photocopied it six times, and sent it by post to a journal of note.

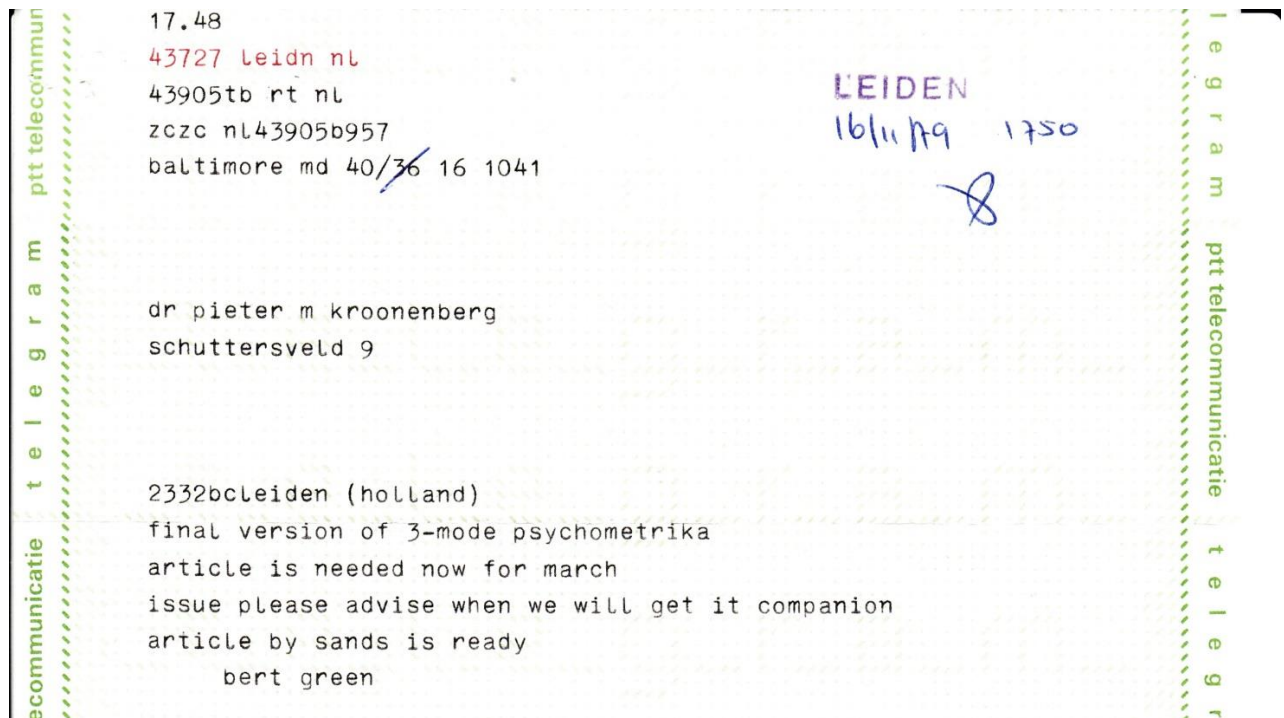


Figure 1. Telegram from *Psychometrika*: Where is your article?

A few months later I received to my surprise a letter from the journal (email did not yet exist at the time) with two other articles enclosed about multivariate analysis, three-way data in particular, that had been submitted to them. They wanted me to say what I thought of those articles in relation to my own. I went to see Jan de Leeuw, somewhat shell-shocked: "What am I supposed to do with this?" "Well, answer the questions of course," he said, "and tell them what

you think”. This is what they call “reviewing an article”, but it was the first I’d heard of it. No matter, I rolled up my sleeves and got the job done.

A little after that I received a message to say my article had been accepted, conditional on certain additions and revisions. I set to work once more, but took my time. Until one day, 35 years ago now, an actual telegram arrived from the journal (Figure 1): “Where is your final version? We want to include your article in our March issue alongside one of the others that you reviewed”. I finished it quickly and sent it off. My very first real international publication. I have been proud of this during my entire academic career, and I still am.

My doctoral thesis

Meanwhile, I was working on a subject that could lead to a doctoral thesis, together with my dear friend Albert Verbeek, who sadly died much too young. It was a thrilling topic: ‘Exact tests in contingency tables’. By now I was writing many computer programs on an actual PC, instead of a mainframe. I’m afraid they are all tucked away in a corner at the moment, gathering dust, awaiting my retirement. When I announced my intention to write my thesis on those exact tests to what was then the Department of Educational Studies, it was met with some resistance. Not because of the limited amount of content related to Education Studies, but because they felt I should first bring my research into three-way analysis to a proper conclusion. I did not have a lot of choice and I solemnly promised that I would do that, and start on the thesis about exact tests in contingency tables afterwards.

And now we have arrived at the matter that has been weighing on my conscience. I never managed it. I did not keep my promise. I still have not finished my three-way research. I still have unfinished articles about three-way analysis on my hard disk.

I hope, you don’t mind me taking this opportunity to humbly ask the Institute for Education and Child Studies to forgive me for this breach of their trust in me. The thesis on exact tests in contingency tables also remains unwritten and now it is too late. I hope my thesis on three-way analysis and my other articles, lectures and speeches on this topic will be enough to earn your forgiveness.

What is three-way analysis?

We have now arrived at the main topic of this lecture: What is happening at the moment in the world where three-way analysis is an important matter? For those of you who are struggling to recall every detail of my first lecture, I will start with a little revision.

A simple definition of three-way analysis is ‘the analysis of three-way data’. To illustrate this, you will find in your booklet the same example (see Figure 2) as I used in my first lecture in this series. On the left you can see a single record of four ‘variables’, particularly scores on IQ, English, Arithmetic and PE for a number of primary school children (these are *two-way data*), and on the right you see six records of the same data (and these are *three-way data*).

To make sure you understand what it is all about I will give you another more detailed example. Those of you who attended my previous lecture will doubtless have a feeling of *déjà entendu*.

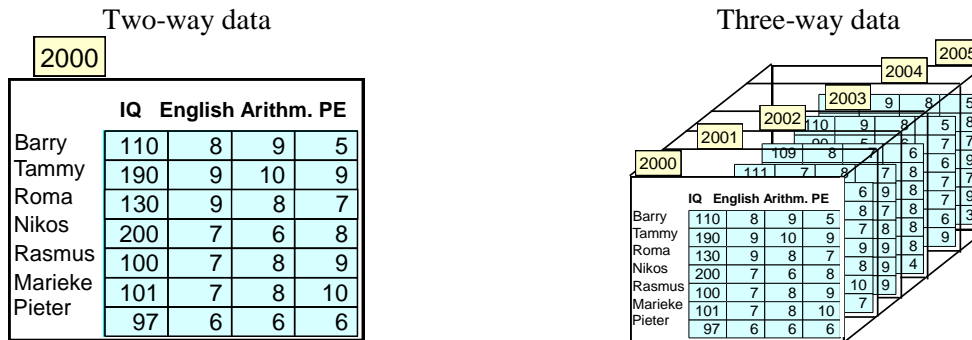


Figure 2. Example of three-way data. To the left: scores collected in a single year (*two-way data*); to the right: scores collected over six consecutive years (*three-way data*).

A musical example: reprise

At the Institute for Psychoacoustics and Electronic Music at Ghent University, researchers take a keen interest in the physical experience and perception of music, and whether this is influenced by musical education. Pieter-Jan Maes researched how adjectives can be used to describe music. Students were played three lyrical and three heroic sections from Brahms' *First Piano concerto*. Each of these six fragments had to be evaluated using 24 pairs of opposite adjectives (see Table 1), such as *nervous* versus *calm*, *dominant* versus *humble*, and *heavy* versus *light*. The 38 students were played a heroic and a lyrical fragment alternately. Thus, the students' answers provided three-way data: there were 6 fragments of music (*first way*), 24 pairs of adjectives (*second way*) and 38 evaluators (*third way*) (Figure 3).

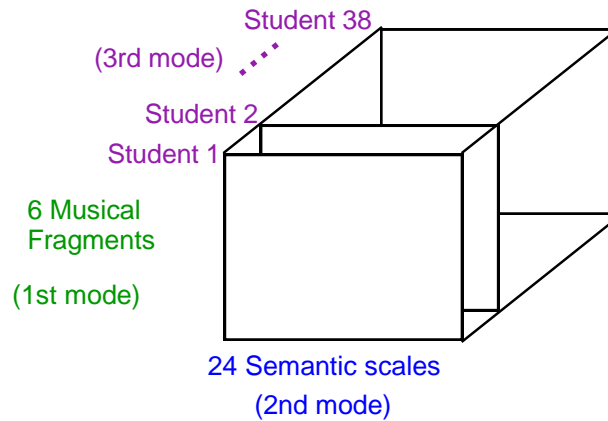


Figure 3. Musical data cube: Music fragments \times semantic scales \times students

Table 1. Semantic differentials (Scores from 1 to 7)

Contrasting adjective pairs		Heroic	Lyric
Heavy (= 1)	Light (= 7)		
Vigorous	Frail		
Nervous	Tranquil		
Rough	Delicate		
Hard	Soft		
Energetic	Soothing		
Dominant	Humble		
Big	Small		
Rigid	Fluent		
Anxious	Secure		
Fast	Slow		
Worried	Carefree		
Exalting	Serene		
Serious	Playful		
Compact	Airy		
Dense	Diffuse		
Regular	Chaotic		
Balanced	Unbalanced		
Broad	Narrow		
Thick	Thin		
Vertical	Horizontal		
Bright	Muted		
High (= 1)	Low (= 7)		

Just as he did nine years ago, university organist Casper de Jonge will play two fragments for you, to illustrate what I am talking about. If you wish, you can score along in Table 1 in your booklet but you won't have much time. That is why I have made a pre-selection of the most important contrasting pairs for you.

< **Casper de Jonge** plays a heroic and a lyrical fragment from Brahms' *First Piano concerto* on the University organ >

The aim of this particular study was to find out how different evaluators judged specific types of music fragments using specific pairs of adjectives. The analysis of the interplay between music fragments, adjectives and evaluators is precisely the domain of three-way analysis. How did the students characterise the heroic and lyrical fragments in descriptive terms? And was there a difference between musically trained and untrained students? As for the first question: there was a great deal of consensus among the students about which adjectives matched which fragments. You will see this depicted in Figure 4.

discussions. Also, the new discoveries did not filter through into day to day substantive research, or a method of analysis was used in only a very limited academic field. The aim of the establishment of this chair is to change this.”

In other words, the chair was intended to initiate discipline- and boundary-crossing work.

I will show that three-way analysis truly knows no boundaries, and that there are examples of applications in many different fields of study. In an earlier version of the Leiden professors’ website I said “My wish is someday to become a data-analytical *homo universalis* by applying three-way analysis in as many different fields as possible in order to gain an insight into these disciplines.” I never managed this, of course, but I am pleased to be able to report that I did get quite some way towards this goal. Of course there are many fields that escaped my notice – I only held this post for ten years – and I need to leave something to fill my post-retirement days.

I am of course not the only one performing three-way analyses. This emerged crystal clear from the symposium earlier today, during which several of my colleagues revealed the impact that three-way analysis has had, and still has, on their subject areas. This shows that the boundaries between disciplines are fading – today we have heard about contributions to psychology, chemistry, agriculture, signal detection, systems biology, linear algebra, and the Japanese activities in the field. Geographically, three-way analysis also knows no boundaries. A large number of today’s speakers came from across the border: Australia, Belgium, Denmark, Japan and the United States. No wonder that there was once a proposal to name the three(!)-yearly conferences about three-way analysis the MAD Meetings: Multi-way analysis in All Disciplines, but it was decided that this was a slightly unfortunate abbreviation.

The present day: the state of three-way affairs

A brief revision

In the next section of my lecture, I would like to go into the question of what state the three-way world is in at the moment, by briefly sketching the development over the past ten years and giving an overview of applications in various different sciences, as presented at today’s symposium.

Three-way analysis over the past ten years

You will probably remember my previous treatise about the first researchers to study three-way data analysis, such as, for example, Ledyard Tucker and Richard Harshman. Back then, I showed you the tumultuous development that three-way analysis went through before 2004. What happened in the years after that, you can see in Figure 5.

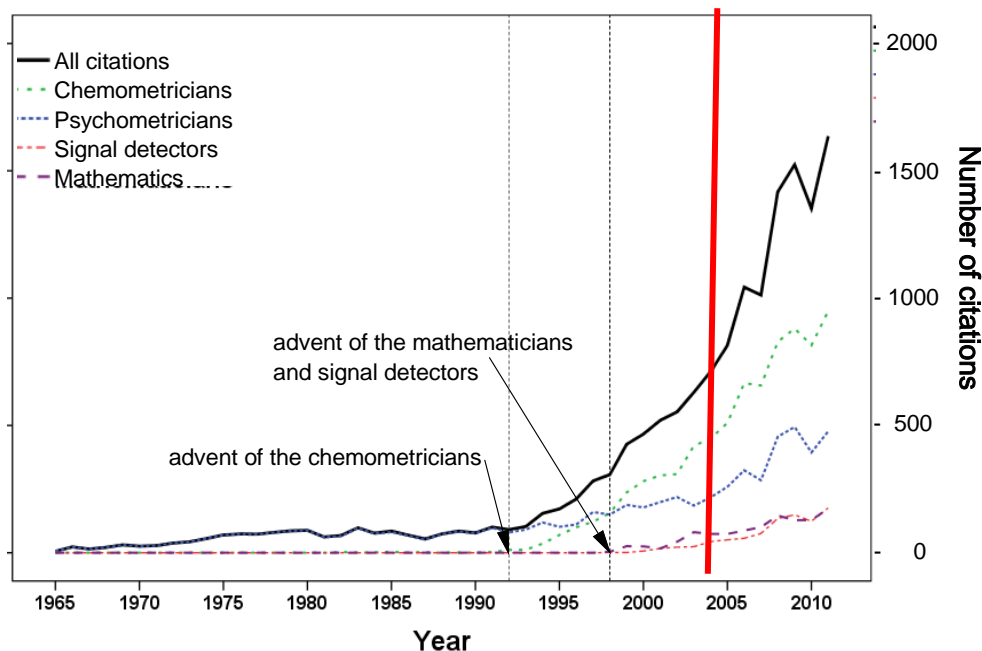


Figure 5. Quotations of articles about three-way analysis by authors from various disciplines (1965 – 2011). The red line marks the year I was appointed.

The curves in this figure represent the number of citations to articles written by authors from the fields of psychology, chemistry, signal detection (something your mobile phone is constantly doing, should you still have it switched on) and mathematics, respectively. You can see that the acceleration that I mentioned nine years ago in my lecture has continued in full force, and that for the time being, there seems no end in sight. We have clearly not yet reached a saturation point.

We can see that particularly in the field of chemistry the unbridled enthusiasm has continued unabated, but that researchers from other disciplines have also started to employ three-way analysis. As for mathematics, it is interesting to note that theoretical mathematicians came up with three-way models in 1927, but that they seem to have forgotten about them for a long time. It was not until 1998 that these sorts of models attracted their attention once more. At an earlier occasion, Lieven De Lathauwer indicated that tensors, the mathematical elements that form the basis for many multi-way models, are the golden tools for “signal processing, array processing, data mining, machine learning, system modelling, scientific computing, statistics, wireless communication, audio and image processing, biomedical applications, bio-informatics and so forth”². In short, a veritable cornucopia of applications.

Incidentally, the increase in citations to psychometric three-way articles seems to reflect the upsurge in their use in the social and behavioural sciences. Unfortunately, Figure 6 shows a very different picture. This figure is based on references to the work of two of the foundational researchers into three-way analysis, split according to whether the citing author works in natural sciences or social and behavioural sciences. From this figure it can be seen that the increase in citations of the work of the psychometricians Tucker and Harshman is purely due to researchers from the natural sciences, rather than to researchers from their own discipline.

² Lieven De Lathauwer (2014). Tensor decompositions: Golden tools for data mining. Lecture presented at the 25th Anniversary VOC Meeting 2014. Rolduc, 7 November 2014.

Three-way analysis in social and behavioural sciences

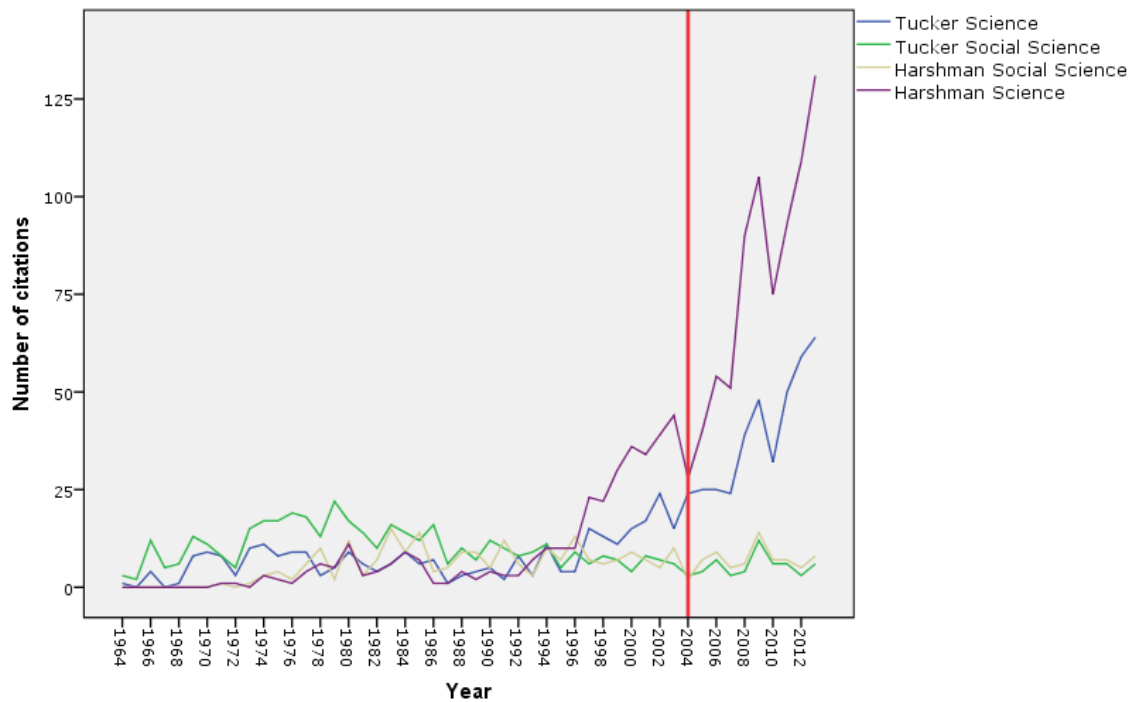


Figure 6. Number of references to articles by Ledyard Tucker and Richard Harshman, split into Natural and bio-sciences on the one hand and Social and behavioural sciences on the other (1964 – 2013). The red line indicates the year I was appointed as professor. Data source: Web of Science.

Why is this? It could be that describing patterns in data does not especially appeal to social and behavioural scientists, but that they prefer testing new and well-founded theories about human behaviour. This testing is done through *inferential* rather than *descriptive* statistics. In addition, many social scientists focus on finding the cause of a phenomenon and predicting future behaviour. This is something three-way methods have not yet been designed for, but the first steps in this direction have been made. Another factor that could play a part is a justifiable desire to keep analyses as simple as possible in order to prevent conflicts with journal editors and their reviewers. They are not always well versed in advanced statistical methods, after all. A further important aspect is that multivariate descriptive techniques, and three-way techniques in particular, are mainly intended to find individual differences and are less focused on testing group characteristics such as averages, standard deviations, correlations, etc.

In my opinion, social and behavioural scientists are missing something that in natural sciences such as chemistry is the motor for a lot of three-way work: substantive theories that take the form of the models used in three-way analysis. Because of this, three-way techniques directly provide the estimates for the parameters of the formal mathematical models, and there is no need to wonder afterwards how these parameters should be interpreted -- which happens not infrequently in our discipline.

It is interesting to note that only a week ago Denny Borsboom, professor at the University of Amsterdam, remarked that psychological theories are primarily developed without support from formalised models. This means that theories in psychology and child and family studies are characteristically developed along more verbal lines. Borsboom urged psychometricians to devote

themselves to developing formalised theories³. As you can imagine we three-way specialists are standing at the side-lines with bated breath, waiting for these revolutionary theories that will materialise in the form of our models, so that we can be a match for the researchers working in chemistry and other natural sciences.

Applications of three-way analysis

I already mentioned that earlier today a number of three-way specialists, some of them from abroad, expanded on what three-way analysis has meant for their fields of research, and I will now give a brief overview of the topics that they touched upon. This will simultaneously serve as a representative sample of the breadth of three-way techniques, and a demonstration of the fact that the three-way world has no borders.

Chemistry

Besides physical models, chemistry also employs ‘linked’ measuring instruments that work together to produce three-way data. As a result of this, the chemometricians have developed methods to employ three-way models for online process control in industry – a perfect example of what now in Dutch university parlance is called *valorisation*. If you want to know more about this, I can refer you to my colleagues Barry Wise from the United States and Rasmus Bro from Denmark.

Agriculture

In the field of agriculture, plant breeders want specific varieties of crops, for instance peanuts that have particular attributes to suit specific purposes. They also want to know which crops can best be grown in which locations. Analysis of individual variation is of prime importance here: the industry wants peanuts that can easily be turned into peanut butter, while consumers want king-size peanuts that feel right in the mouth. To find out more, you can speak to my colleague Kaye Basford from Australia, who is here today.

Signal detection

In my earlier lecture I already mentioned the importance of three-way analysis for signal detection, particularly for keeping signals from different devices separate. Is there anyone nowadays who does not have a device on them that constantly detects signals, whether it is a mobile phone, tablet or sat nav? Lieven De Lathauwer from Leuven, who is also here today, can provide you with more information.

Systems biology

A very special area of application is systems biology – a discipline that aims to study organisms as a whole, with specialisms such as *metabolomics* (the systematic study of the unique chemical characteristics of specific cell processes) and *proteomics* (the large scale study of proteins, particularly their structure and function). If you want to know all the details, I can refer you to my three-way colleague Age Smilde from Amsterdam who knows all about it.

³ Denny Borsboom (2014) All quiet on the psychometric front? Goals and challenges for 21st century psychometrics. Lecture presented at the 25th Anniversary VOC Meeting 2014. Rolduc, 7 November 2014.

Psychology

Although just now I was registering my dissatisfaction with the low level of penetration of three-way analysis in the social and behavioural sciences, there has been progress in various areas. Iven Van Mechelen and Eva Ceulemans from Leuven, and Henk Kiers, Marieke Timmerman and Jos ten Berge from Groningen have given us an overview at the symposium today, in a much more compelling way than I can do for you here.

Japan

My Japanese colleagues Takashi Murakami and Hisao Miyano took us through the Japanese three-way landscape and described its geography.

Three-way and two-way

Finally, my colleague and the president of the foundation that established my chair, Willem Heiser, together with Jacqueline Meulman, has characteristically devoted himself to showing us how three-way techniques can form a new inspiration for long established techniques used for two-way data.

The Netherlands

As you can tell, various Dutch researchers have played a prominent role in the three-way world and I am hopeful that this will remain the case in the future, especially with giants such as Heiser, Kiers, Meulman, Smilde, Ten Berge, and Timmerman who continue, undeterred, to spread the word, while various young Dutch scientists are bringing the subject to life with their boundless enthusiasm. I, too, hope to carry on with my three-way activities beyond the borders of retirement.

The Future: three-way analysis in the social and behavioural sciences

The value of three-way analysis for the social and behavioural sciences

In the third part of this lecture I would like to explore the use of three-way analysis in social and behavioural scientific research in more depth, because just like it did nine years ago, the question remains: “Is descriptive analysis, but three-way analysis in particular, actually necessary in the social and behavioural sciences?” Despite the relatively modest growth in three-way applications, I maintain that it is definitely necessary, but to my mind this applies to all descriptive analytical techniques.

Three-way data in the social and behavioural sciences

To answer the question of usefulness, we must first establish if the data collected actually call for three-way techniques. In order to eliminate any doubt on this point, I have made a non-exhaustive overview of major types of three-way data encountered in the social and behavioural sciences. You will find this overview in the appendix. A quick glance will show that even without Borsboom’s functional models, there are plenty of data in the social and behavioural sciences that simply cry out for a three-way analysis.

Use of three-way data in the social and behavioural sciences

Part of the blame for the limited use of three-way methods lies with the psychometricians themselves. And I myself also plead guilty here. As lecturers, I think we have not stopped to consider that the use of statistical methods is dictated in part by what we teach and how these methods are presented to colleagues and students. In the future we will have to take into account that academics are interested in their own fields, not in our methods. So if we want to show them that we have something to offer, the burden is on us to demonstrate this. In concrete terms, this means that we must publish plenty of applications in which we show that three-way methods have an added value compared to the standard toolset, and that they can deliver results that cannot be obtained any other way. We will also need to be aware of the limited time social and behavioural scientists have to learn complex statistical techniques, and of the desirability of straightforward analysis methods. The success of SPSS as a statistical program is due to its simplicity.

Statistical packages: calculator and advisor in one!

Generally, statistical programs for three-way analysis are not half as simple to use as SPSS. Quite apart from this, I would like to encourage you to follow Wilkinson's example in his statistical suite SkyTree Advisor. After performing an analysis, this program will immediately print off a paragraph in which the results are described and the technical implications of the results are explained. In this way, the program functions as an 'analyser' and personal advisor in one. Various textbooks about multivariate statistics give examples of how the results of a certain analysis can be interpreted, but they always deal with the authors' data, not the researcher's. In other words, programs for statistical analysis should explain the meaning of the results provided in their output. Until now, user-friendliness of computer programs has focused almost exclusively on input rather than output. Realising this wish for three-way analysis programs seems like a perfect, boundary-pushing project for a retired professor.

Assignment for three-way researchers in the social and behavioural sciences

To summarise: Starting from the premise that three-way analysis can make a contribution to research in the social and behavioural sciences, I would like to set methodologists (including myself) the following tasks: (1) show the added value of the techniques – in applied articles in non-methodological journals; (2) present relevant analyses in collaboration with researchers working in the field, at their own conferences; (3) train young academics specialising in these subjects in the use of three-way techniques by organising/running courses that offer plenty of opportunity to practise with people's own data; (4) produce guides for performing analyses, not just in writing but also through intelligent and self-explanatory computer programs with easily accessible input and output.

Hearing all this, you may be getting the impression that I am once again giving an inaugural address in which I set out all my plans for the future, but sadly this is not the case. I will have to content myself with the thought that wisdom comes with age, and that the incubation period for insights into what must be done can be long. Here, too, there seems to be room for boundary-transcending, or in this case age-transcending, behaviour.

Conclusion

Message: three-way analysis knows no boundaries

The most important message of this lecture is that the three-way world knows no boundaries. And as you know, all good things come in threes. Three-way analysis transcends the boundaries of discipline, the boundaries between countries and transcends boundaries of age with ease. But multiway analysis is also on the rise, and it would seem that good things can also come in four or more because the number of citations relating to multiway analysis is also starting to transcend boundaries.

A word of thanks

Finally, I have arrived at the fourth part of my triptych. You see, there is one more thing that knows no boundaries, and that is my gratitude to all who have made it a joy for me to work at this university. Leiden University, the Institute of Education and Child Studies and the Department of Child and Family studies in their many guises and through many changes of name have housed me for 40 years, and given me the opportunity to practise my academic hobby. In addition to this they have allowed me to preach the blessings of statistics and research methods to a total of roughly eight thousand students. I have been given the opportunity to try to persuade them of all that statistics has to offer them in their future life, academic or not. Nothing could be more wonderful, surely.

I am also immensely grateful to the Foundation for the Advancement of Data Theory as a Science, founded by John van de Geer. In 2004, the Foundation established the special chair for Multivariate Analysis, in particular of three-way data, and appointed me to this chair. Jan de Leeuw set me on the three-way road, and his pages of graph paper with formulae formed the basis for my master's thesis and the starting point for my doctoral thesis. (Those pieces of paper may yet become famous: Jan emailed me recently to ask if I could send him a scan.) Willem Heiser and Jacqueline Meulman were my closest colleagues for a long time and I have always observed their work and their dedication to their work with great admiration. The years that we taught a course on applied multivariate analysis together have also made an impact on me.

In my immediate working environment there have been many people who have contributed, each in their own way, to what I see as success in my career. As director of the Department of Child and Family studies, Rien van IJzendoorn gave me the space to develop my skills as a teacher, statistical advisor, independent three-way researcher, and even as resident photographer. He was the one to point me in the direction of NIAS, where I was able to write the bulk of what he has described as my magnum opus. The other professors and my colleagues in the department have also contributed in different ways to my development as an academic and, perhaps unwittingly, as a statistician who could present statistics with examples from Education and Child studies, despite my frequent insistence that I knew nothing of either education or child studies.

My work over the years would not have been possible without the support of excellent people such as Doreen Arnoldus, Gea Kortman, Reineke Mom and Esther Peelen and all those managing the Institute. They have all been important contributors to my wellbeing in the department, the institute and the university. Many thanks to you all for everything you have done for me. And without the wonderful work of, in no particular order, Joost van Ginkel, Ralph Rippe and Gea

Kortman this day would not have been possible and none of you would have been sitting here now.

But... of course I also want to express my boundless gratitude to my wife, Ineke Smit, our children, Judith and Adriaan, and our grandchildren. My life would have been so very different without them. They know the particulars, as I have often expressed them privately, and so I will spare you those.

Thank you.

Final words of thanks

Dear Colleagues, Friends and Family,

Even though I am speechless, I have to address a few words in answer to the previous speakers, who have delivered what sounded like a series of *laudationes* after a PhD ceremony.

Much of what I have done was driven by a need to contribute to the statistical education of our students, to the statistical quality of the Institute's research, and to the development of three-way analysis in the world at large, across the boundaries of disciplines and countries.

I really appreciate the way people have looked back on my career at this university, but I hope in the future to be useful to the academic community in various ways.

To close this ceremony I would like to answer the burning question that seems to be on everybody's lips: provide statistical assistance if asked to do so, make excursions around Leiden on my racing bike, finish all those incomplete papers that clutter my directories, learn a new human language, write a book about multivariate statistics in the humanities, learn a new computer language, go out and make photographs, give courses in three-way methods (have a course, will travel!), restore Dinky Toys, travel around the world with Ineke, play with my grandchildren – in other words, continue with my wonderful life.

Thank you.

Appendix

Types of three-way data collected in the social and behavioural sciences

- **Three-way profile data** – individuals have scores on a number of variables measured under several conditions or on several occasions.
Example: It is recorded whether children seek proximity to strangers, observe them with distrust, etc., when child, father and stranger are in the same room; when the child is alone with the stranger; and when the stranger enters after the child has been left alone in the room.
- **Repeated measures data** – participants are measured several times on the same variables.
Example: Each year the reading ability of the same primary school children is assessed on several different measures.
- **Three-way rating data** – subjects judge their emotions in different situations; stimulus-response data.
Example: Children with asthma indicate on several scales how they would react in different situations, for example playing alone in the street, walking alone in the woods, playing with their friends in the school grounds, going on a cycling trip with friends. For each of the situations the children are asked to imagine how afraid they would be to get an asthmatic attack, how lonely they would feel, or how exhilarated they would be.
- **Sets of correlation matrices**
Example: the correlations between subtests of an intelligence test for children of different ages are studied.
- **Sets of similarity matrices**
Example: children are asked to indicate in how far they prefer peanut butter sandwiches over jam, cheese, kippers, truffles, etc.
- **Results of fMRI studies**
Example: the results of brain scans measured in various locations in the brain, under different conditions, in different individuals.
- **Three-way interactions** from analysis of variance and loglinear analyses of contingency tables.
- **Large categorical and binary three-way data sets.**

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- 1967-1968 Bachelor student, University of Kansas
1968-1971 Bachelor of Science in Astronomy, Leiden University
1971-1972 Bachelor of Science in Mathematics, Leiden University
1972-1975 Master of Science in Applied mathematics, Leiden University
1983 PhD, Faculty of Social and Behavioural Sciences, Leiden University;
Thesis: *Three-mode principal component analysis: Theory and applications.*
- 1974 Student trainee, Shell Computer Centre, London
1974-1975 Student assistant, Department of Data Theory, Leiden University
1975-1985 Lecturer in statistics, Department of Education, Leiden University
1986-2014 Senior lecturer, Institute of Education and Child Studies, Leiden University
1987-1988 Senior lecturer, Department of Psychology, University of Queensland, Australia
2004-2014 Chair by special appointment in *Multivariate analysis, in particular of three-way data* at the Faculty of Social and Behavioural Science, Leiden University. Chair instituted by the Foundation for the Promotion of Data Theory as a Science.
2015- Director of The Three-Mode Company, an independent statistical consulting agency especially for three-way and multiway data analysis

The increasing complexity of data collection procedures and the continuing growth of data sets require more and more sophisticated methods for their analysis. A great deal of research in many disciplines is directed at uncovering the patterns and structures in such large data sets, and at discovering differences between 'individuals', whether these are persons, molecules or chemical compounds. Specifically, the question is how these individual differences can be described in terms of the structures defined by the variables in the study.

My fascination with data analysis has always been how to investigate these large data sets and present their structure in a graphical and understandable way. Throughout my academic life I have been occupied with three-way data, which are characterised by the relationships between three different aspects, such as scores of *individuals* on a number of *variables* during a number of *years* or under a number of *conditions*. Three-way data turn up in virtually every discipline, and for me one of the joys of statistics and data analysis is that statistical methods including three-way methods are useful everywhere.

My wish was and is to become a data-analytic *homo universalis* by carrying out three-way analyses in as many disciplines as possible – not only because I want to show the world their power, but also because I am interested in the 'content' of these disciplines. The beauty of it is that in this way I have come into contact with many fascinating people from all corners of the academic world.