

# Categorical Data Analysis and Visualisation

## Part I: An Introduction

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## Outline

### *Part I – An Introduction*

- A Quick Historical Overview of the Visualisation of Categorical Data

### *Part II – Two Categorical Variables*

- The Contingency Table and the Chi-Squared Statistic
- Measures of Symmetric Association for I x J Contingency Tables
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- Correspondence Analysis
  - Symmetric association & Simple Correspondence Analysis – SCA)
  - Asymmetric association & Non-symmetrical correspondence analysis – NSCA)
  - Some other issues (ordinal variables, over-dispersion)
- Distance-RC(M) Association Model

### *Part III – Multiple Categorical Variables*

- Multiple Correspondence Analysis (MCA)
- Multi-way Correspondence Analysis (MWCA)

## Outline

Tutorial

### *Part I – An Introduction*

- **A Quick Historical Overview of the Visualisation of Categorical Data**

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- **Multi-way Correspondence Analysis (MWCA)**

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## What is Categorical Data?

Tutorial

- *Categorical data arises whenever counts are made instead of measurements*

Plackett (1974, p. vii)

- *... [Categorical data] can only take on a finite or countable number of values*

Andersen (1991, p. 1)

- *A categorical variable has a measurement scale consisting of a set of categories*

Agresti (2013, p. 1)

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## What is Categorical Data?

Tutorial

- *Categorical data consists of variables whose values comprise a set of discrete categories. Such data requires different statistical and graphical methods from those commonly used for quantitative [numerical] data*

Friendly (2000, p. 1)

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## Why Visualise Data?

Tutorial

*If statistical graphics, although born just yesterday, extends its reach every day, it is because it replaces long tables of numbers and it allows one not only to embrace at glance the series of phenomena, but also to signal the correspondence or anomalies, to find the causes, to identify the laws.*

(Cheysson, circa 1877)

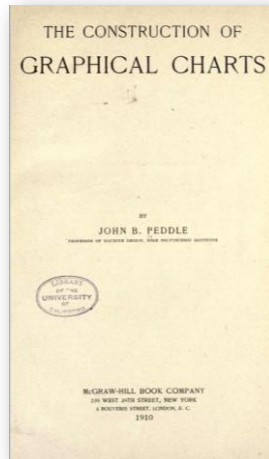


Émile Cheysson  
(1836 – 1919)

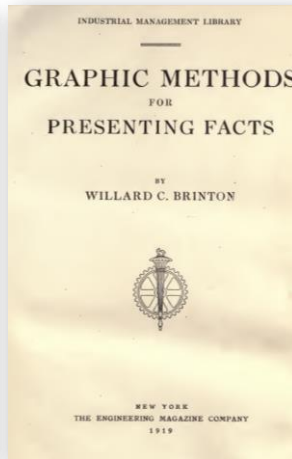
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## Some Key Visualisation Texts

Tutorial



1910  
(109 pages & 8 chapters)



1914  
(371 pages & 17 chapters,  
reprinted 1919)

Freely available from  
[www.archive.org](http://www.archive.org).

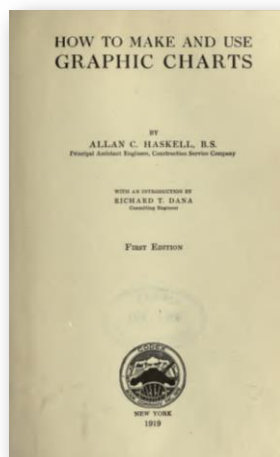
Peddle's book (1910) is rather technical with lots of mathematics and diagrams about how to construct a graphical display.

Brinton (1914) presents portraits, maps, sketches, etc. It deserves to be made available for future generations.

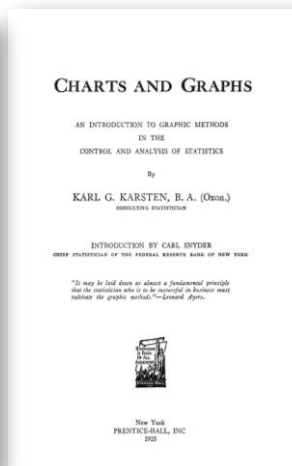
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## Some Key Visualisation Texts

Tutorial



1919  
(539 pages & 18 Chapters)



1925  
(712 pages & 58 Chapters with  
6 Appendices)

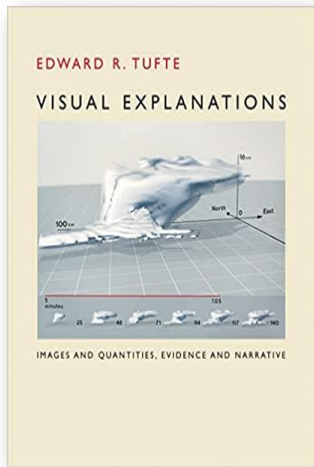
The 18 chapters of Haskell (who was an engineer) deal with graphical analysis in different engineering practical problems (nomographic and alignment charts).

Karsten's book discusses physical visualisations used in engineering. Many of these were previously discussed in Peddle's 1910 book

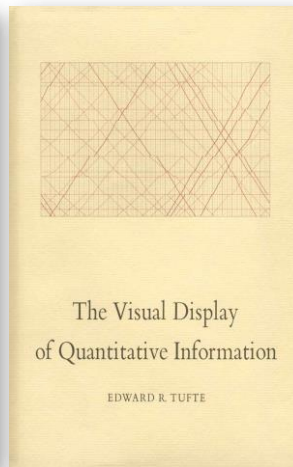
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## Some Key Visualisation Texts

Tutorial



1997



2001

The 1997 book is a masterpiece. It includes statistical graphics, charts for making important decisions in engineering and medicine.

The 2001 book provides excellent color reproductions of the many graphics of William Playfair, and presents 250 illustrations of the best (and a few of the worst) statistical graphics

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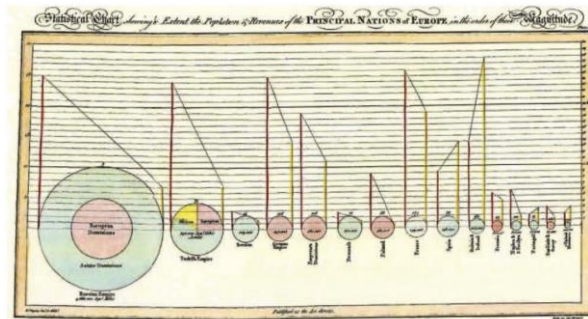
## The Pie Chart

Data Visualisation

- The story of the *pie chart begins with William Playfair*.
- After proposing the *line graph* and *barchart* in 1786, he (in 1801) constructed the *pie chart* as a visual aid to compare the geographical size of each of European regions, and the areas around the world they occupied.



William Playfair  
(1759 – 1823)



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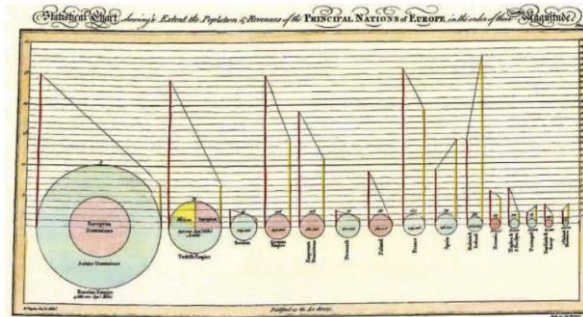
## The Pie Chart

The circles area allows for a comparison of the land area (in square miles) each region occupied, given the geopolitical situation in Europe in 1801.

- Green coloured regions = countries that were adjudged a maritime power,
- Red colour regions = countries with no maritime power.
- Vertical lines compare the population of each region (by the red line)
- Green line reflect the tax revenues



William Playfair  
(1759 – 1823)



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Funkhouser (1937, p. 273) says that Playfair may be regarded as the “father of the graphic method in statistics”.

## The Pie Chart

An early variation of the pie chart was called the *coxplot* – see the diagram on the next page. It was proposed by Famous English nurse Florence Nightingale who was also a highly accomplished statistician.

Nightingale became enraged at the deplorable sanitary conditions of army hospitals during the Crimean War\* (1853 – 1856) and fought for reforms to improve their conditions. Her literary and mathematical skills were instrumental in these reforms, and many of her arguments were highly statistical.



Florence Nightingale  
(1820 – 1910)

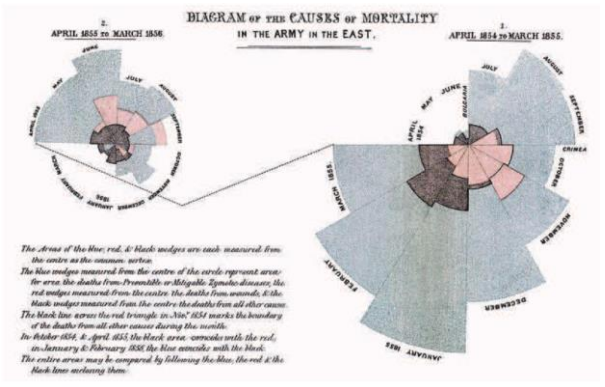
\* The Crimean War was fought along the Crimean peninsula that is located on the northern coast of the Black Sea (now part of modern day Ukraine). It was between the Russian Empire and the alliance formed between the French, British, Ottoman Empires and Sardinia.

*Fun Fact:* In 1859 Nightingale was elected the first female member of the Royal Statistical Society and she later became an honorary member of the American Statistical Association

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## The Pie Chart

Data Visualisation



Florence Nightingale (1820 – 1910)

This *coxplot* first appears in Nightingale (1858, between pp. 310 – 311) . . .

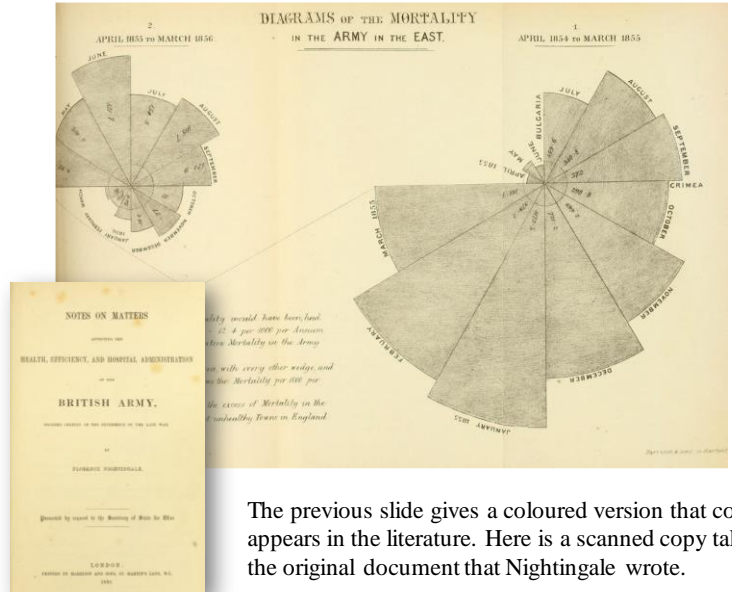
*Notes on matters affecting the Health, Efficiency and Hospital Administration of the British Army*

It highlights from April 1855 to March 1856 those **death rates** as a result of battle wounds, **preventable diseases** and deaths due to **other causes**. The death rates are reflected by the area of each bar of the *coxplot* not its length.

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## The Pie Chart

Data Visualisation



The previous slide gives a coloured version that commonly appears in the literature. Here is a scanned copy taken from the original document that Nightingale wrote.

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## Two Categorical Variables

Data Visualisation

- ❖ Two Categorical Variables
  - Fourfold Display
  - Mosaic Displays
  - Correspondence Plot
  - Biplot
- ❖ One Categorical & One Numerical Variable
  - Side-by-side boxplot
- ❖ Other
  - Chernoff Faces (multiple variables)
  - Andrew's curves
  - Dendrograms

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## Two Categorical Variables

Data Visualisation

- ❖ Two Categorical Variables
  - **Fourfold Display**
  - **Mosaic Display**
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## Data Visualisation

Friendly . . . Data Visualisation



Michael Friendly at CARME2015  
(Naples, Italy) © Pieter Kroonenberg

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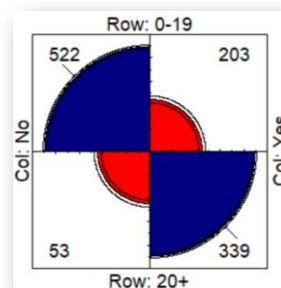
## The Fourfold Display

Two Categorical Variables

- When analysing 2x2 tables . . .

Occupational exposure (years)	Asbestosis		Total
	No	Yes	
0-19	522	203	725
20+	53	339	392
Total	575	542	1117

$$OR = \frac{522 \times 339}{53 \times 203} = 16.45$$



Fienberg, S.E. (1975)

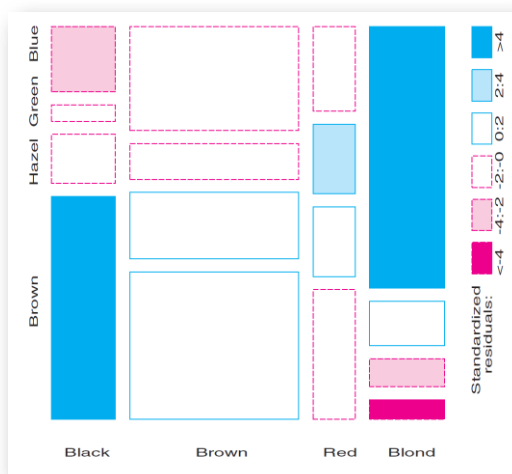
- The area of each quarter circle is proportional to the joint relative frequencies, but scaled in a way that depicts the sample odds ratio
- An association (odds-ratio) is indicated by the tendency of diagonally opposite cells in one direction differing in size from those in the other direction
- The use of circular wedges which vary in radii to depict parts of a whole has a history which goes back to the “coxcomb” (or rose chart) used by Florence Nightingale
- Constructed using the `fourfold()` function in the `vcd` R package

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## The Mosaic Plot

- Width of each bar reflects the magnitude of the marginal totals
- Height of each bar reflects the conditional distribution of the cells
- “Complete independence” leads to equal area mosaics
- Shadings reflect deviations from independence

(red = negative, blue = positive)



Source:

Friendly, M. (2000), *Visualizing Categorical Data*, SAS Institute Inc., p. 6)

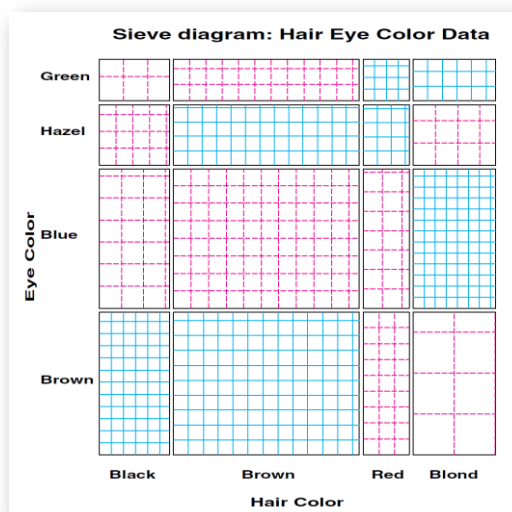
## The Mosaic Plot

### Sieve Diagrams

(or Parquet diagram)

- *Density of Shading:*  
Difference between the observed and expected cell frequencies  
(where observed > expected, more denser than average)
- *Colour:*  
Deviations from independence

(red = negative, blue = positive)



Source:

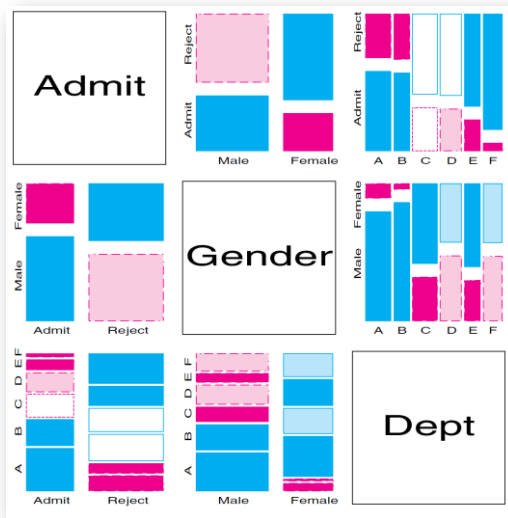
Friendly, M. (2000), *Visualizing Categorical Data*, SAS Institute Inc., p. 86)

## The Mosaic Plot

Three Categorical Variables

### *Mosaic Matrix*

- Good for multiple categorical variables
- Only represents bivariate associations
- Does not represent trivariate or “higher”-variate association structures



Source:  
Friendly, M. (2000), *Visualizing Categorical Data*, SAS Institute Inc., p. 132)

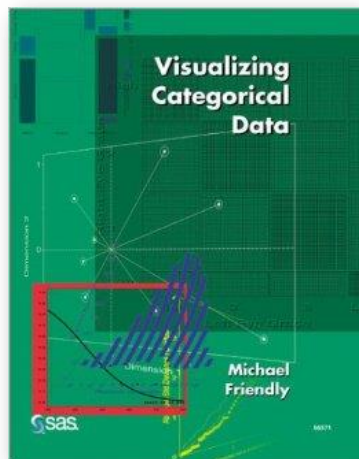
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## The Mosaic Plot

Two Categorical Variables



Made popular by Michael Friendly (York University, Ontario) in a series of papers spanning two decades and this 2000 book



Can be constructed using



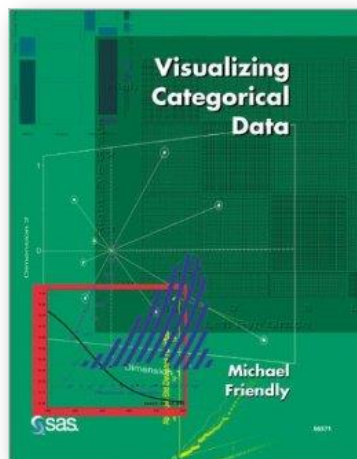
22

## The Mosaic Plot

Two Categorical Variables



**Made popular** by Michael Friendly (York University, Ontario) in a series of papers spanning two decades



Friendly published the paper . . .

Friendly, M. (1994), Mosaic displays for multi-way contingency tables, *Journal of the American Statistical Association*, 89, 190 – 200.

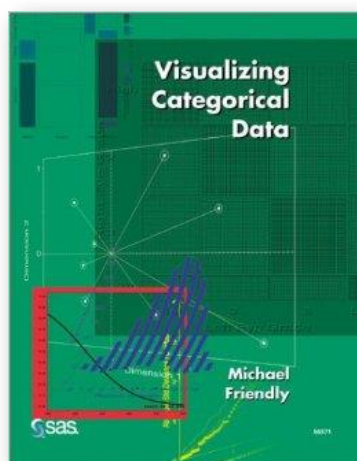
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## The Mosaic Plot

Two Categorical Variables



**Made popular** by Michael Friendly (York University, Ontario) in a series of papers spanning two decades



Although often accredited to . . .

Hartigan, J.A. and Kleiner, B. (1981), Mosaics for contingency tables, In *Computer Science and Statistics: Proceedings of the 13<sup>th</sup> Symposium on the Interface* (ed. W.F. Eddy), Springer, pp. 268 – 273 (a follow-up paper appeared in JASA in 1984)

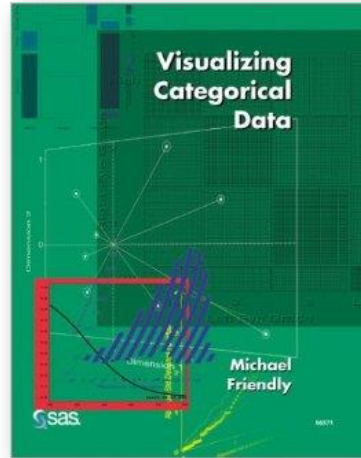
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## The Mosaic Plot

Two Categorical Variables



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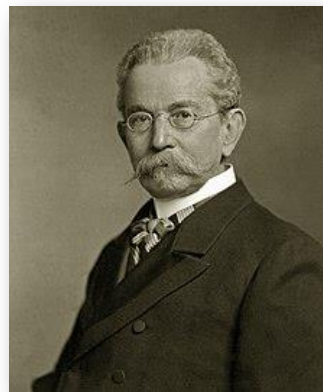
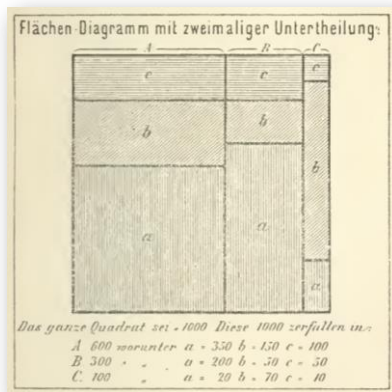


... *but* ...

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## The Mosaic Plot

Two Categorical Variables



Georg von Mayr  
(1841 – 1925)

In English, he referred to them as a

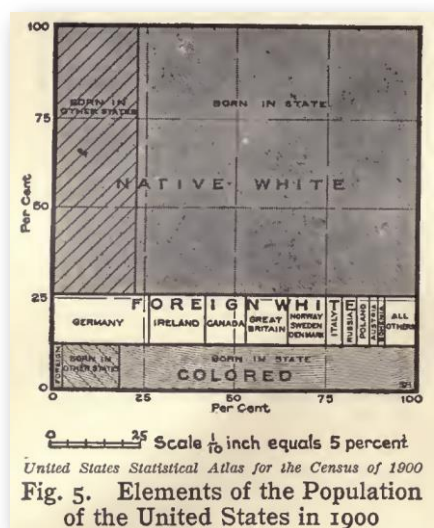
“*Proportional Square*”

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Von Mayr, G. (1877), *Die Gesetzmässigkeit im Gesellschaftsleben*, Munich, Germany. (p. 79)

## The Mosaic Plot

Two Categorical Variables



In Fig. 5 the whole population of the United States is divided first into native white, foreign white, and colored, then each of these groups is subdivided according to place of birth. This is an excellent type of chart to use if subdivisions in the component parts of any unit have to be shown. If the scale to which the chart is drawn is specified, it is possible for the reader to measure, with an ordinary ruler or with an engineer's scale, the exact percentage size of each of the different components.

Brinton (1914, p. 7)

United States Statistical Atlas for the Census of 1900  
**Fig. 5. Elements of the Population of the United States in 1900**

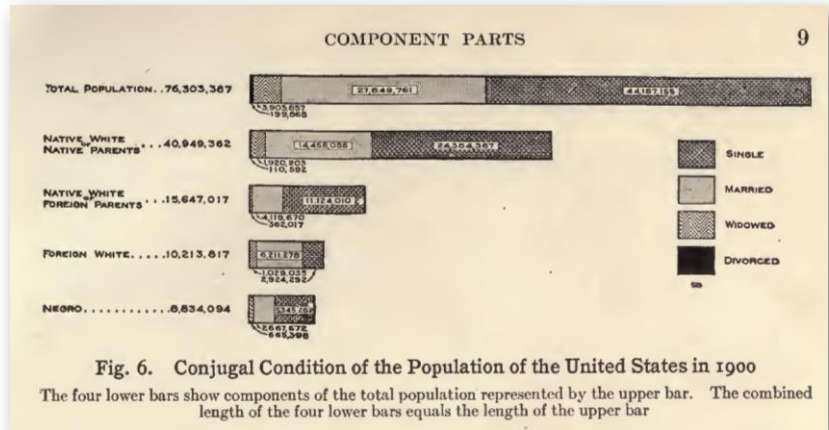
Brinton (1914, p. 8)

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## The Mosaic Plot

Two Categorical Variables

Brinton (1914, p. 9) suggested the following *bar chart* be used as an alternative to his “mosaic plot”

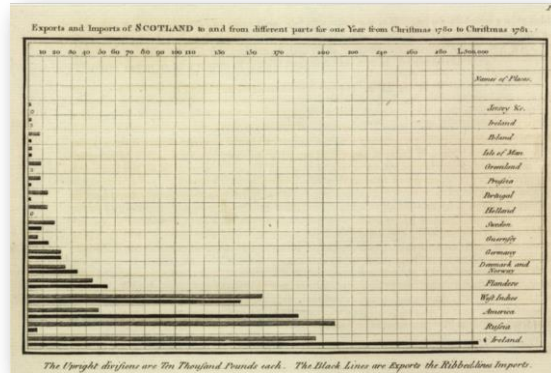


**Fig. 6. Conjugal Condition of the Population of the United States in 1900**  
 The four lower bars show components of the total population represented by the upper bar. The combined length of the four lower bars equals the length of the upper bar

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## The Bar Chart

The bar chart was first constructed by William Playfair (also an early proponent of the pie chart). Here is the first known bar chart that Playfair published in his 1786 book *Commercial and Political Atlas*.



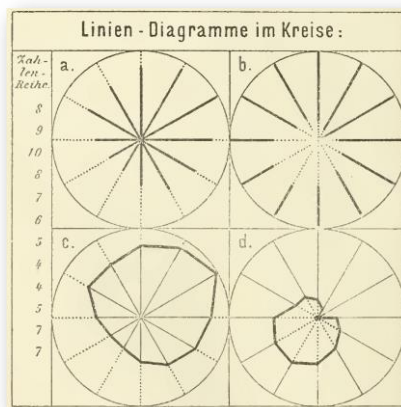
This bar chart summarises Scotland's imports and exports in comparison with those 17 countries in 1781

Count Data

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## The Radar Plot

Sometimes called a *radar chart*, *spider chart*, *polar charts* (among other names), depicts counts as a proportion of sample size, or ratings (for example, 1 – 5)



George von Mayr  
Also the “developer” of mosaic plots

Count Data

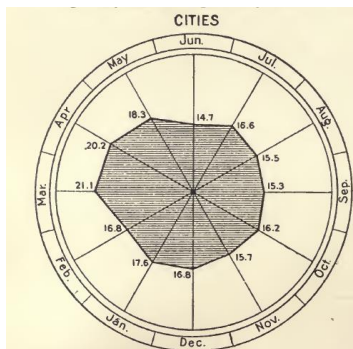
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Von Mayr, G. (1877), *Die Gesetzmässigkeit im Gesellschaftsleben*, Munich, Germany. (p. 78)

## The Radar Plot

Count Data

Brinton (1914, pg 80) presented this radar plot . . .



Charts like that shown in Fig. 78 are quite frequently used in public health reports. It is difficult to see how such an unsatisfactory type of chart ever came into general use, unless it was because there are twelve months in a year and twelve hours on the face of a clock. If the death rates for the different months of the year were plotted in a curve, using rectangular coordinates, the data would be just as easy to read and to understand as when shown by the radial scheme (polar co-

United States Statistical Atlas of the 1900 Census  
Fig. 78. Death Rate from Consumption per 1000 Inhabitants for Each Month of the

**This type of chart should be banished to the scrap heap. Charts on rectangular ruling are easier to draw and easier to understand**

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## The Chernoff Face

Other Plots

Six measurements recorded of 87 “nummulite” fossil specimens (ID) from northwest Jamaica for the following six variables:

- $Z_1$  = inner diameter of embryonic chamber (each little segment that makes up a whirl)
- $Z_2$  = total number of whorls
- $Z_3$  = number of changes in the first whorl
- $Z_4$  = number of changes in last whorl
- $Z_5$  = maximum height of chambers in first whorl (microns)
- $Z_6$  = maximum height of chambers in last whorl (microns)



Hermann Chernoff (1923 - ) applied mathematician, statistician



TABLE 1. 6 MEASUREMENTS ON 87 NUMMULITED SPECIMENS FROM THE EOCENE YELLOW LIMESTONE FORMATION, JAMAICA

ID	$Z_1$	$Z_2$	$Z_3$	$Z_4$	$Z_5$	$Z_6$	ID	$Z_1$	$Z_2$	$Z_3$	$Z_4$	$Z_5$	$Z_6$
1	160	51	10	28	70	450	48	190	34	9	26	96	1070
2	155	52	8	27	85	400	49	285	30	11	19	100	990
3	141	49	11	25	72	380	50	300	30	9	20	102	1120
4	150	50	10	26	75	560	51	225	30	10	22	105	985
5	161	50	10	27	70	665	52	260	34	8	22	97	1090
6	155	50	12	27	88	570	53	280	30	8	20	112	1200

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Chernoff, H. (1973). The use of faces to represent points in K-dimensional space graphically, *Journal of the American Statistical Association*, 68, 361 - 268



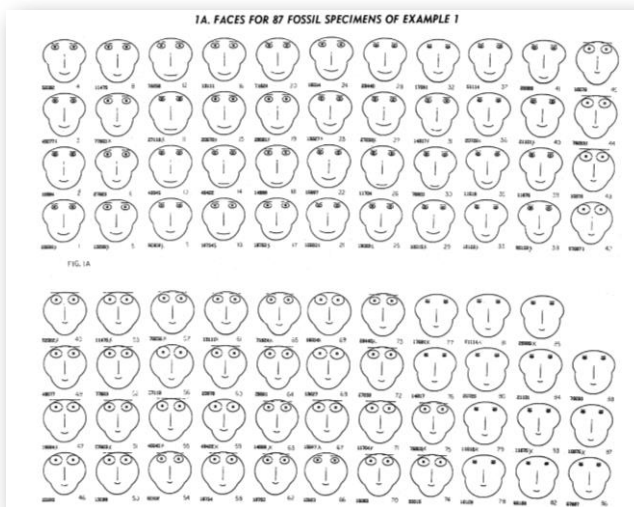
## The Chernoff Face

From Chernoff's 1973 paper where he proposed his faces . . .



Hermann Chernoff (1923 - )

Other Plots



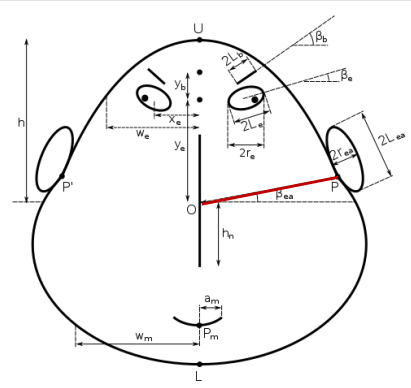
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## The Chernoff Face



Hermann Chernoff (1923 - )

Other Plots



- $Z_1$  = inner diameter of embryonic chamber (microns) . . . . . (distance from O to P of face)
- $Z_2$  = total number of whorls . . . . . (angle of OP to horizontal line)
- $Z_3$  = number of changes in the first whorl . . . . . (eccentricity of upper face)
- $Z_4$  = number of changes in last whorl . . . . . (vertical position of the mouth)
- $Z_5$  = maximum height of chambers in first whorl (microns) (curvature of the mouth)
- $Z_6$  = maximum height of chambers in last whorl (microns) . (size of the eyes)

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## The Chernoff Face



Hermann Chernoff  
(1923 - )

Chernoff says . . .

“I was frustrated by how to visualize points in  $n$ -dimensional space and it suddenly occurred to me that the idea of drawing a face would in some way resolve the problem. David Hinkley was visiting that year. His wife, Betty, was an ace programmer and I talked her into writing the program to draw this simple face. It took her a couple of days to do it....”

Bather (1996, p. 345)

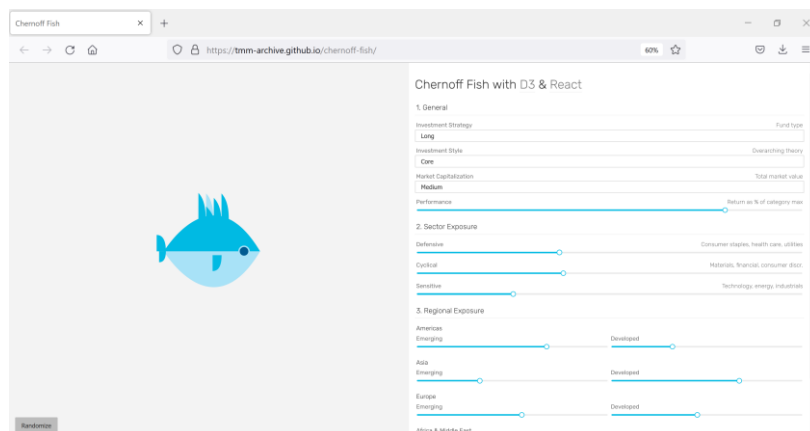
Other Plots

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## The Chernoff Face

### Variations

#### *Chernoff Fish*



Other Plots

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<https://tmm-archive.github.io/chernoff-fish/>

## The Chernoff Face

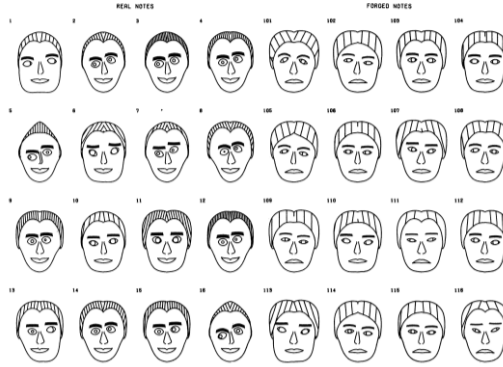
Other Plots

### Variations

#### Asymmetrical Faces

- The left and right side of Chernoff's (1973) face give the same information.
- Flury & Riedwyl (1981) proposed the *asymmetrical face* allows for the features on the left and right side to differ allowing for twice as much information to be represented

Figure 6. 16 Real and 16 Forged Swiss Bank Notes



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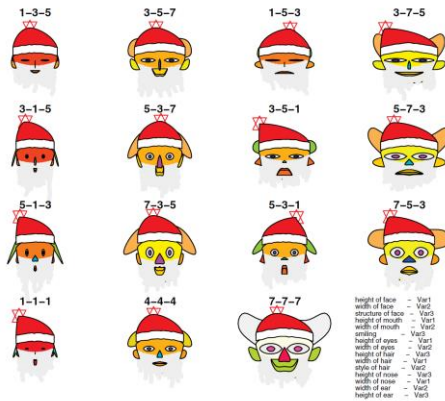
## The Chernoff Face

Other Plots

### Variations

#### Santa Clause Faces

Obtained by executing `faces(faces.type = 2)` in the R package `aplpack`



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## The Andrews Curve

Suppose we consider the following point in a multi-dimensional space . . .

$$(x_1, x_2, x_3, x_4, x_5, \dots)$$

One may visualise this space in **two dimensions** using the *Andrews curves*.

To visualize them, the Andrews plot defines a finite Fourier series ( $t \in [-\pi, \pi]$ ) and may be defined so that

$$f_i(t) = \frac{1}{\sqrt{2}}x_1 + x_2 \sin(t) + x_3 \cos(t) + x_4 \sin(2t) + x_5 \cos(2t) + \dots$$

Points positioned close to each other in multi-dimensional space will have very similar looking *Andrews curves*

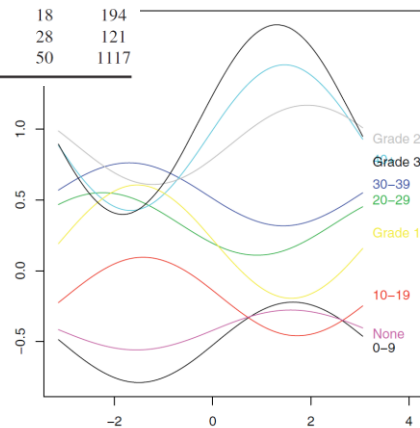
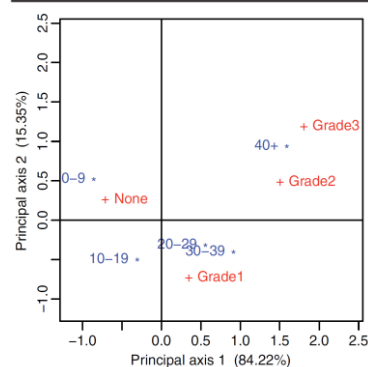
- Been used in the context of correspondence analysis (Rovan, 1994; Khattree & Naik, 2002; Beh & Lombardo, 2014, pp. 23 – 24)
- Tests of significance can be performed (Goodchild & Vijayan, 1974)
- Three dimensional versions proposed (Wegman & Shen, 1993)
- Other variations discussed (Embrechts & Herzberg, 1991)
- `andrewsplot()` function in the R package `pracma`

Other Plots

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## The Andrews Curve

Occupational Exposure (yrs)	Asbestos grade			Diagnosed Grade 3	Total
	None	Grade 1	Grade 2		
0-9	310	36	0	0	346
10-19	212	158	9	0	379
20-29	21	35	17	4	77
30-39	25	102	49	18	194
40+	7	35	51	28	121
Total	575	366	126	50	1117



Beh &amp; Lombardo (2014, Chapter 1)

Other Plots

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## Key Texts on Categorical Data Analysis

Texts

There are so many more contributors to the topic

For example, one may consider papers by (but not feel confined to)

- Leo Goodman
- Shelby Haberman
- Alan Agresti
- Michael Greenacre

In this tutorial we will consider a broad spectrum of popular, and not-so-popular, issues raised in the visualisation and analysis of categorical data.

The tools by themselves are not enough to give a flavour of their development, so we will also be considering the description of techniques with a historical twist.

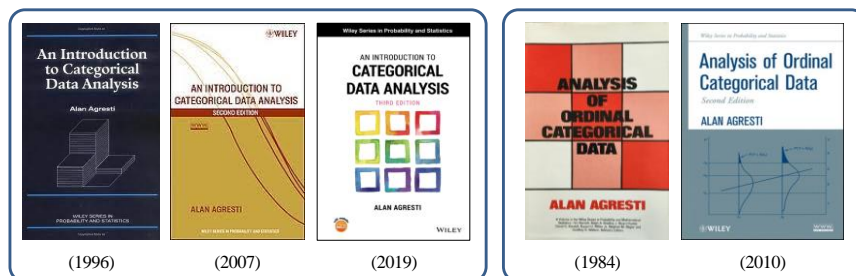
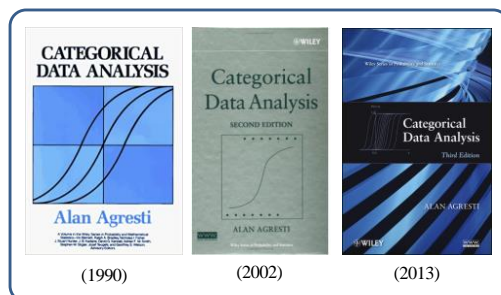
We will look at the graphical display of categorical data but focus much of our attention on the contingency table (two-way and multi-way)

... but first ... an account of the key books on the subject ...

41

## Books on Categorical Data Analysis

Alan Agresti



42

## Books on Categorical Data Analysis

Early Pioneers



(1969)



(1974)



(1981)



(1978)



(1978)



(1979)



(1978)



(1979)



(1984)

43

## Books on Categorical Data Analysis

Early Pioneers



(1977)



(1992)



(1975, MIT Press)



(2007, Springer)



(1997)



(1990)



(1991)



(1994)



(1980, MIT Press)

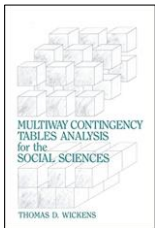


(2007, Springer)

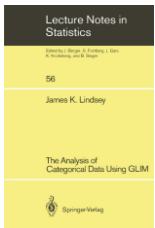
44

## Books on Categorical Data Analysis

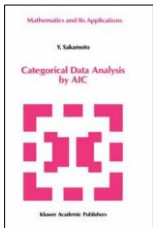
Some More Key Texts



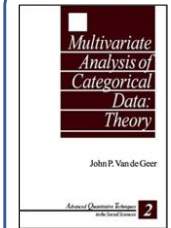
(1989)



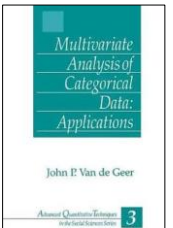
(1989)



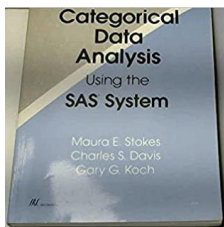
(1992)



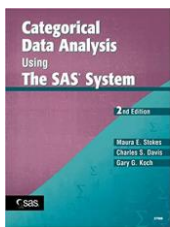
(1993)



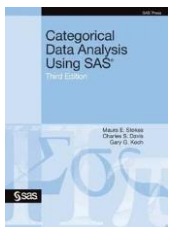
(1993)



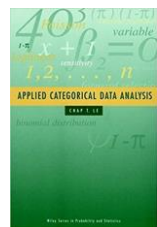
(1995)



(2001)



(2012)

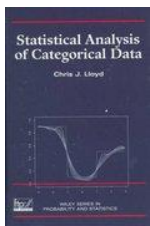


(1998)

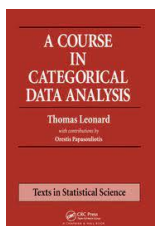
45

## Books on Categorical Data Analysis

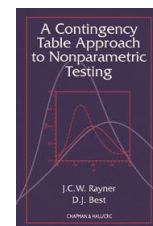
Some More Key Texts



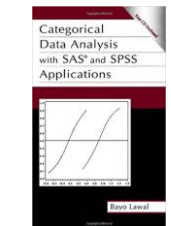
(1999)



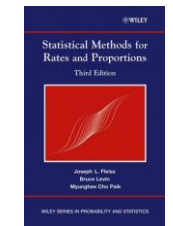
(2000)



(2001)



(2003)



(2003)



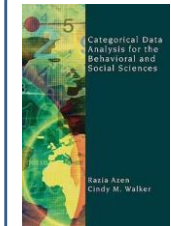
(2003)



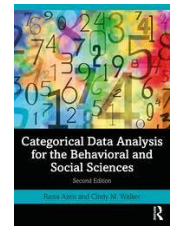
(2005)



(2008)



(2010)

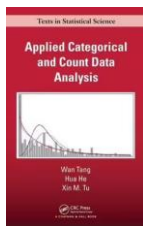


(2021)

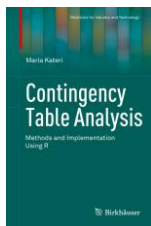
46

## Books on Categorical Data Analysis

Some More Key Texts



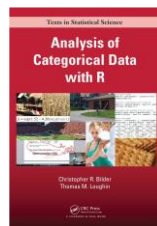
(2012)



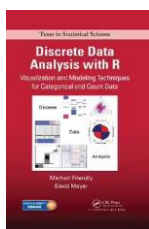
(2014)



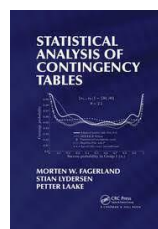
(2014)



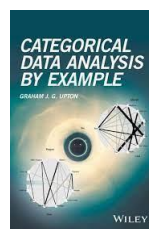
(2015)



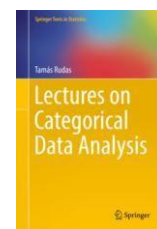
(2016)



(2017)



(2017)

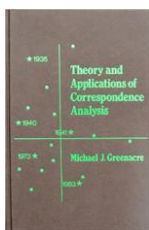


(2018)

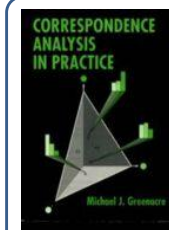
47

## Books on Correspondence Analysis

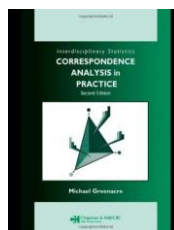
Michael Greenacre



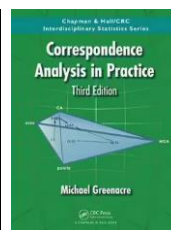
(1984)



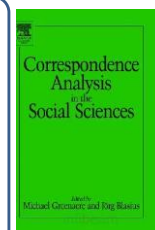
(1993)



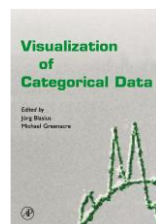
(2007)



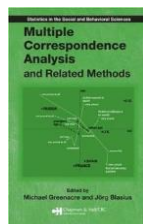
(2017)



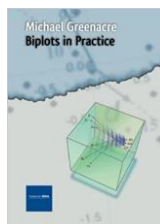
(1994)



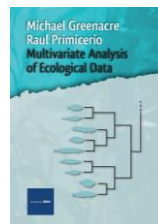
(1998)



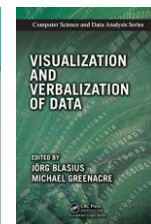
(2006)



(2010)



(2013)



(2014)

48



## Books on Correspondence Analysis

Some More Key Texts



(1973)



(1973)



(1984)



(1988)



(1990)



(1990)



(1991)



(1992)



(1998)



(2004)

49

## Books on Correspondence Analysis

Some More Key Texts



(2005)



(2008)



(2010)



(2013)



(2015)



(2019)



(2011)



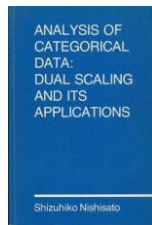
(2017)

50

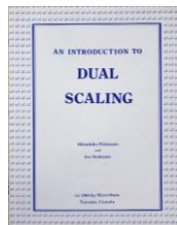
25

## Books on Correspondence Analysis

Shizuhiko Nishisato



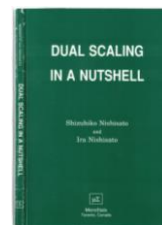
(1980)



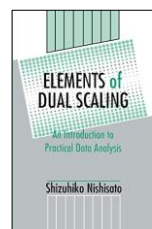
(1984)



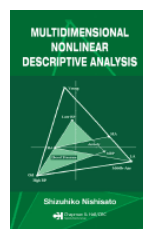
(1986)



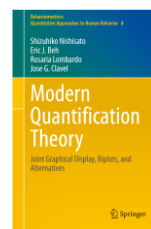
(1994)



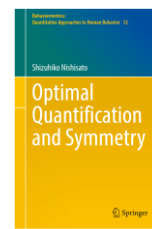
(1994)



(2007)



(2021)

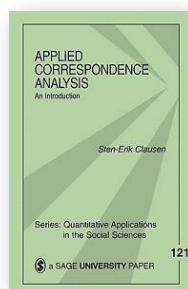


(2022)

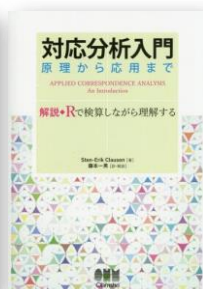
51

## Books on Correspondence Analysis

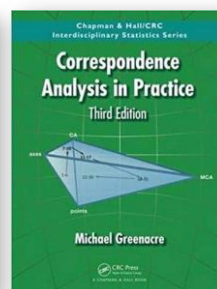
Japanese Translations



(1998)



(2015)



(2016)



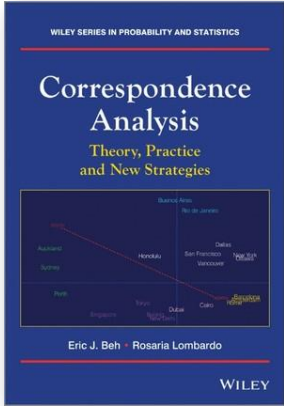
(2020)

Translation by Kazuo Fujimoto of Sakushin Gakuin University, Utsunomiya, Japan

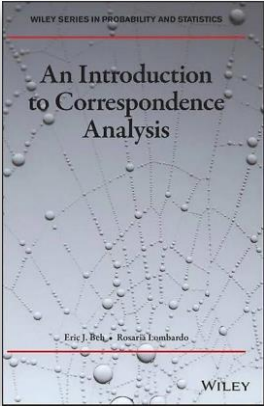
52

## Books on Correspondence Analysis

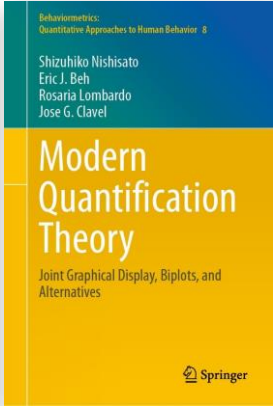
A Little Bit of Self Promotion ©



(2014)



(2021)



(2021)

53

## Some Books on Data Visualisation

Some More Key Texts



(1978)



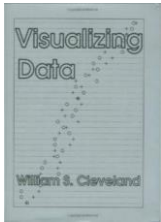
(1983, AT&T)



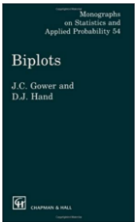
(2018, CRC Press)



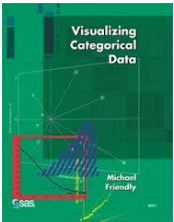
(1985)



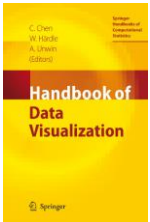
(1993)



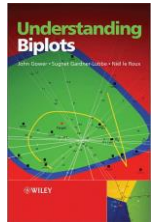
(1996)



(2000)



(2008)



(2011)

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