`classify` command: Over 260 measures of association and forecast evaluation for categorical data

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To express anything important in mere figures is so plainly impossible that there must be endless scope for well-paid advice on how to do it.

— K. A. C. Manderville, The Undoing of Lamia Gurdleneck

Measuring association & similarity

Contingency table

	Male	Female	Total
Blonde	8	16	24
Brunette	14	18	32
Total	22	34	56

Measuring associations and similarities

Contingency table

	Male	Female	Total
Blonde	$n_{11} = 8$	$n_{12} = 16$	$n_{1+} = 24$
Brunette	$n_{21} = 14$	$n_{22} = 18$	$n_{2+} = 32$
Total	$n_{+1} = 22$	$n_{+2} = 34$	$n = 56$

- Dice coefficient: $\frac{2n_{11}}{n_{1+}+n_{+1}} = 0.44$
- Yule association coefficient Q: $\frac{n_{11}n_{22}-n_{12}n_{21}}{n_{11}n_{22}+n_{12}n_{21}} = 0.26$
- Heidke skill score: $\frac{2(n_{11}n_{22}-n_{12}n_{21})}{n_{+1}n_{2+}+n_{1+}n_{+2}} = 0.12$

Evaluating categorical forecasts

Confusion matrix

Predicted values	Actual values: Positive	Actual values: Negative
Positive	True positive (TP)	False positive (FP)
Negative	False negative (FN)	True negative (TN)

- Accuracy: $\frac{TP+TN}{n} = 0.57$
- Peirce skill score: $\frac{TP \times TN - FP \times FN}{(TP+FN)(FP+TN)} = 0.11$
- F_1-score: $\frac{2TP}{2TP+FP+FN} = 0.44$
- Yule correlation r_φ: $\frac{TP \times TN - FP \times FN}{\sqrt{(TP+FP)(TP+FN)(FP+TN)(FN+TN)}} = 0.12$

Evaluating probabilistic forecasts of categorical data

Diagnostic probability scores

- Brier score:

$$\frac{1}{2n}\sum_{i=1}^{n}\sum_{k=1}^{K}\left(\Pr\left(y_i=k\right)-\delta_{ik}\right)^2$$

- Logarithmic score:

$$-\frac{1}{n}\sum_{i=1}^{n}\sum_{k=1}^{K}\delta_{ik}\ln(\Pr(y_i=k))+(1-\delta_{ik})\ln(1-\Pr(y_i=k))$$

- Ranked probability score:

$$\frac{1}{n(K-1)}\sum_{i=1}^{n}\sum_{k=1}^{K-1}\left(\sum_{j=1}^{k}\Pr\left(y_i=j\right)-\sum_{j=1}^{k}\delta_{ij}\right)^2$$

Literature on measures of association

is poorly integrated across different fields

- a wide variety of scalar statistics have been developed and used in different fields
- a similarly wide variety of nomenclature has appeared in relation to these statistics
- some of these measures have been reinvented, duplicated and misattributed on multiple occasions in other fields
- confusing terminology is confounded further by different notation

Reinvention and duplication

- Cohen kappa coefficient in psychometrics and inter-rater reliability (1960): $\frac{n\sum_{k=1}^{K} n_{kk} - \sum_{k=1}^{K} n_{k+}n_{+k}}{n^2 - \sum_{k=1}^{K} n_{k+}n_{+k}}$

Reinvention and duplication

- Cohen kappa coefficient in psychometrics and inter-rater reliability (1960): $\frac{n\sum_{k=1}^{K} n_{kk} - \sum_{k=1}^{K} n_{k+}n_{+k}}{n^2 - \sum_{k=1}^{K} n_{k+}n_{+k}}$

- Heidke skill score in meteorological forecast verification (1926): $\frac{2(n_{11}n_{22} - n_{12}n_{21})}{n_{+1}n_{2+} + n_{1+}n_{+2}}$

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- Heidke skill score in meteorological forecast verification (1926): $\frac{2(n_{11}n_{22} - n_{12}n_{21})}{n_{+1}n_{2+} + n_{1+}n_{+2}}$
- Doolittle association ratio in early weather-forecast verification (1887)

Reinvention and duplication

Year	Name / attribution	Field
1909	**Czekanowski**	Anthropology, taxonomy, numerical classification
1920	**Gleason**	Plant ecology, quadrat comparison
1945	**Dice**	Ecology, species association
1948	**Sørensen**	Plant sociology, ecological similarity
1948	**Burt**	Psychometrics / classification catalogues
1956	**Bray–Curtis**	Ecology, ordination, community ecology
1966	**Lance–Williams**	Numerical taxonomy, cluster analysis
1974	**F_1-score**	Information retrieval; machine learning.
1977	**Upholt *F***	Molecular genetics, restriction-fragment comparison
1979	**Nei–Li coefficient**	Molecular evolution, genetic similarity
1980s	**Pirlot/White**	Binary-similarity catalogues, classification literature
1994	**Zijdenbos**	Medical image segmentation, neuroimaging
2000s	**Fleiss–Levin–Paik**	Inter-rater reliability, agreement analysis

Alternative terminology

- Accuracy
- (Crude) agreement
- Causal support
- Classification rate
- Count R^2
- Hit score
- Holsti $C.R.$ coefficient
- Kendall coefficient
- Osgood coefficient
- Proportion correct
- Rand coefficient
- Ratio test discriminant
- Simple matching coefficient
- Sokal-Michener coefficient

A new Stata command classify

Output

- A contingency table (confusion matrix)
- 256 measures of association and 11 diagnostic scores for probabilistic forecasts
- The global ranges for each measure
- The class-specific measures for each class as well as their simple and weighted averages
- An Excel file with all computed measures

Output of command classify

Input: contingency table (confusion matrix)

```
. matrix Confusion = (11,2,1 \ 4,16,1 \ 3,8,7)

. classify, mat(Confusion)
```

Contingency Table

Actual	1	2	3
Predicted			
1	11	2	1
2	4	16	1
3	3	8	7

Selected association & similarity measures

Measure	Range	Value
1. Accuracy	[0 → 1]	**0.64**
11. Balanced accuracy	[0 → 0.5 → 1]	**0.67**
42. Clayton skill score	[-1 → 0 → 1]	**0.46**
54. Cramer concordance	[0 → 1]	**0.24**
129. Goodman-Kruskal lambda weighted	[0 → 1]	**0.43**
131. Gorodkin Rk	[-1 → 0 → 1]	**0.47**
136. Hamann	[-1 → 1]	**0.28**
139. Heidke skill score	[-1 → 0 → 1]	**0.46**
190. Peirce skill score	[-1 → 0 → 1]	**0.49**
211. Scott pi	[-1 → 1]	**0.45**
216. Sokal-Sneath 1	[0 → 1]	**0.78**
232. Theil	[0 → 1]	**0.21**
235. Tschuprow T bias corrected	[0 → 1]	**0.46**

Output of command classify

Input: values of two variables

```
. classify x2 y2
```

Contingency Table

x2=	1	0
y2=		
1	58	127
0	40	54

Selected association & similarity measures

Measure	Range	Value	Class 1	Class 0	Macro avg	Weighted avg
1. Accuracy	[0 → 1]	0.40				
11. Balanced accuracy	[0 → 0.5 → 1]	0.45				
42. Clayton skill score	[-1 → 0 → 1]	-0.11				
56. Czekanowski	[0 → 1]	0.41	0.41	0.39	0.40	0.40
84. G-mean	[0 → 1]	0.42	0.42	0.42	0.42	0.42
130. Goodman-Kruskal tau	[0 → 1]	0.01				
136. Hamann	[-1 → 1]	-0.20				
139. Heidke skill score	[-1 → 0 → 1]	-0.09				
140. Hit rate	[0 → 1]	0.59	0.59	0.30	0.45	0.40
190. Peirce skill score	[-1 → 0 → 1]	-0.11				
197. Precision	[0 → 1]	0.31	0.31	0.57	0.44	0.48
211. Scott pi	[-1 → 1]	-0.20				
253. Yule phi	[-1 → 0 → 1]	-0.11	-0.11	-0.11	-0.11	-0.11
254. Yule Q	[-1 → 0 → 1]	-0.24	-0.24	-0.24	-0.24	-0.24
255. Yule Y	[-1 → 0 → 1]	-0.12	-0.12	-0.12	-0.12	-0.12

Output of command classify

Input: observed values & predicted probabilities

```
. quietly oprobit y bias house gdp spread

. predict p1 p2 p3
(option pr assumed; predicted probabilities)

. classify y, probs(p1 p2 p3) metrics(p1 p7 p11 1 3 56 139 140 190 211 )
```

Confusion Matrix

Actual	-1	0	1
Predicted			
-1	30	9	0
0	25	163	26
1	0	9	17

Selected probabilistic scores

Score	Range	Value
Brier score	[0 ← 1]	**0.1679**
Ranked probability score (ORD)	[0 ← 1]	**0.0847**
Zero-one score	[0 ← 1]	**0.2473**

ORD: suited for ordinal data only.

Selected association & similarity measures

Measure	Range	Value	Class -1	Class 0	Class 1	Macro avg	Weighted avg
1. Accuracy	[0 → 1]	**0.75**					
3. Adjusted noise-to-signal ratio	[0 ← 1 ← 278]		**0.07**	**0.58**	**0.10**	**0.25**	**0.40**
56. Czekanowski	[0 → 1]		**0.64**	**0.83**	**0.49**	**0.65**	**0.74**
139. Heidke skill score	[-1 → 0 → 1]	**0.46**					
140. Hit rate	[0 → 1]		**0.55**	**0.90**	**0.40**	**0.61**	**0.75**
190. Peirce skill score	[-1 → 0 → 1]	**0.41**					
211. Scott pi	[-1 → 1]	**0.46**					

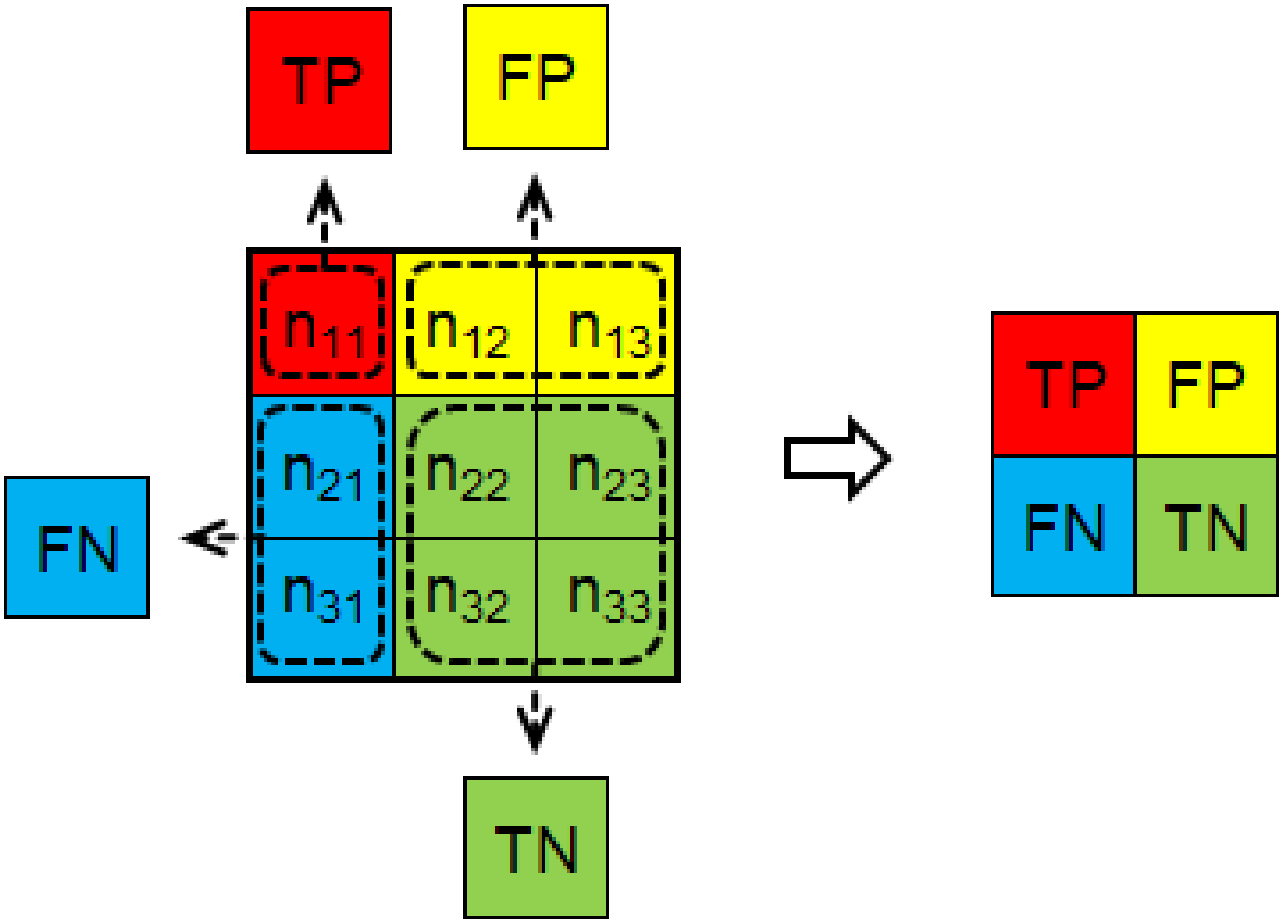
Multy-class confusion matrix

	$x=1$	...	$x=K$
$y=1$	n_{11}	...	n_{1K}
...	...	...	...
$y=K$	n_{K1}	...	n_{KK}

- Accuracy: $\frac{1}{n}\sum_{k=1}^{K} n_{kk}$
- Gorodkin R_K: $\frac{n\sum_{k=1}^{K} n_{kk} - \sum_{k=1}^{K} n_{k+}n_{+k}}{\sqrt{\left(n^2 - \sum_{i=1}^{K} n_{i+}^2\right)\left(n^2 - \sum_{j=1}^{K} n_{+j}^2\right)}}$
- Tschuprow T bias-corrected: $\sqrt{\frac{1}{K-(K-1)^2/(n-1)-1}\max\left(0, \sum_{i=1}^{K}\sum_{j=1}^{K}\frac{(n_{ij}-n_{i+}n_{+j}/n)^2}{n_{i+}n_{+j}} - \frac{(K-1)^2}{n-1}\right)}$

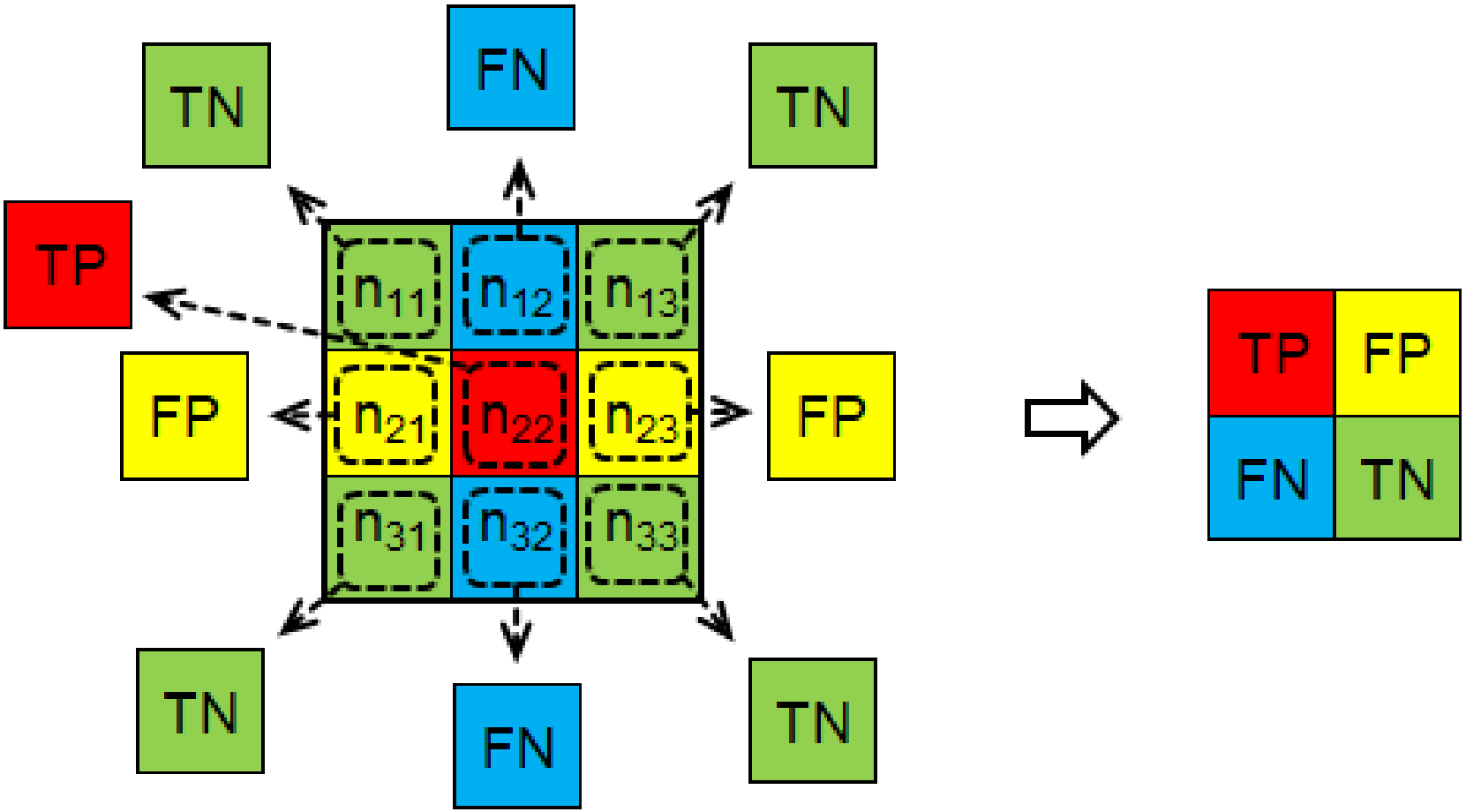
Class-specific measures

Class 1



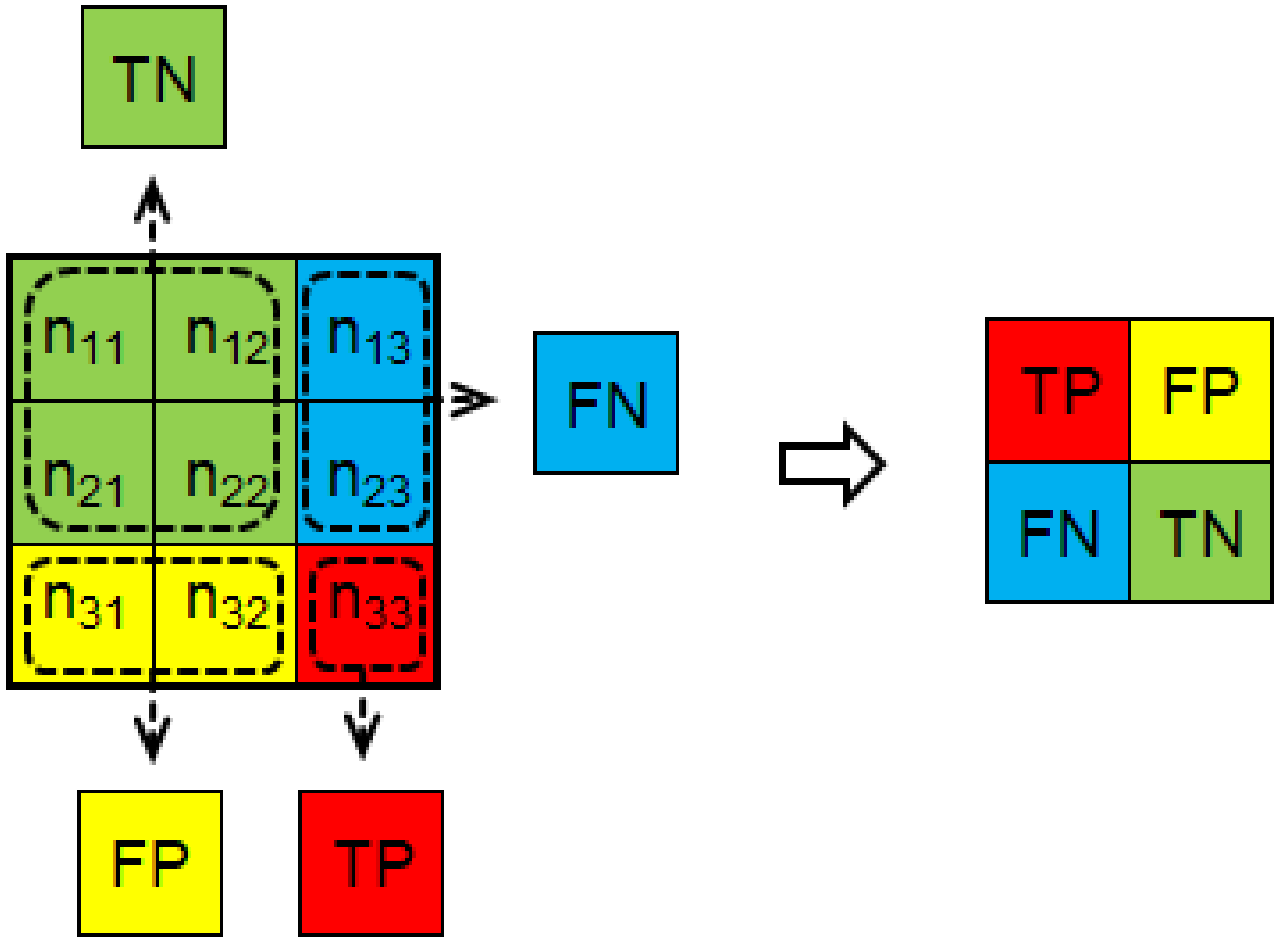
Class-specific measures

Class 2



Class-specific measures

Class 3



Class-specific measures

Arithmetic and weighted averages

- The `classify` command also computes the simple arithmetic and weighted arithmetic averages of all class-specific measures as:

$$Measure_{macro} = \frac{1}{K}\sum_{k=1}^{K} Measure_k$$

$$Measure_{weighted} = \sum_{k=1}^{K} Measure_k \frac{n_{+k}}{n}$$

- The macro-averaged measure calculates unweighted mean of class-specific coefficients.
- The weighted-averaged measure makes a weighted mean.

Classify but use common sense

" . . . there is no absolutely general measure of the degree of dependence. Every attempt to measure a conception like this by a single number must necessarily contain a certain amount of arbitrariness and suffer from certain inconveniences."

— Cramér (1924)