# Watching our figures

How mathematical psychology visualises cognitive modelling, and how it could improve



Erin Walsh



چ)Watching Our Figures

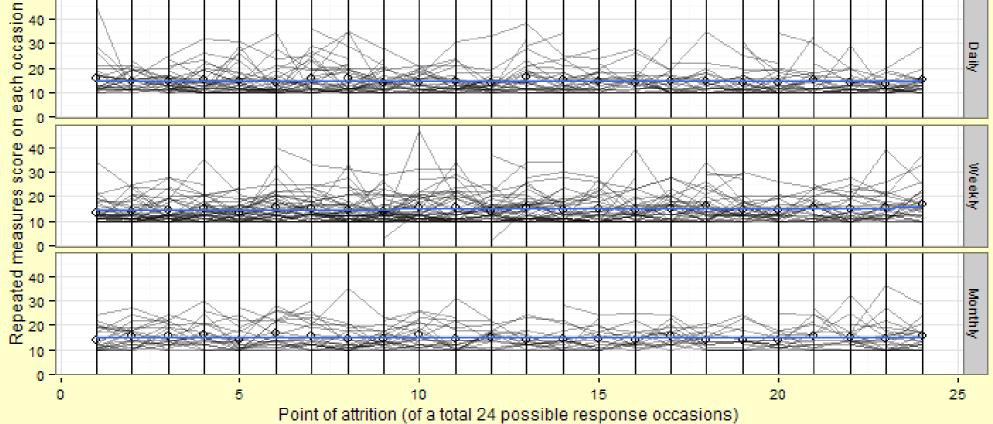
### Importance of visualisations

- Visualisations simplify and clarify (Wood, 1994)
- Scientific visualisation should communicate information in the most efficient, unambiguous manner possible (Tufte & Graves-Morris, 1983)







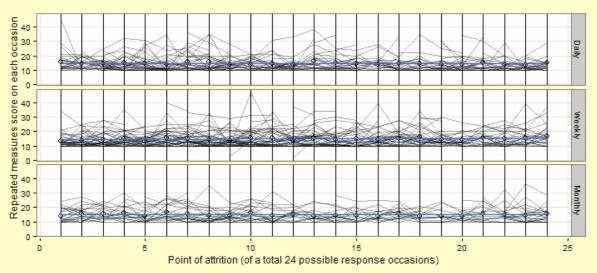


2 ü





Repeated responses and attrition points by time, across all modes





#### Even ggplot can't save this one

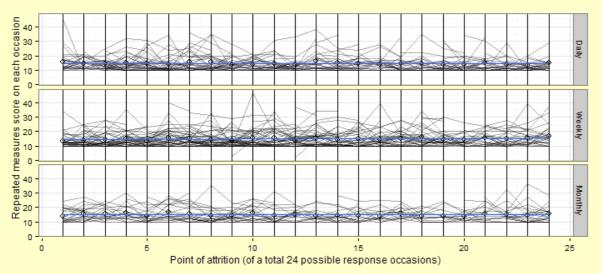




# چ)Watching Our Figures

### This is a hot mess.

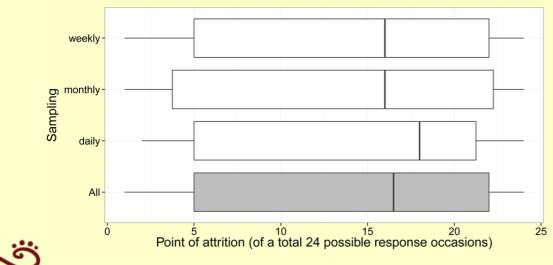
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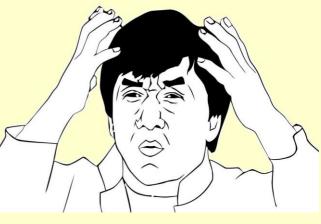




Even ggplot can't save this one

### Same information, better visualisation.



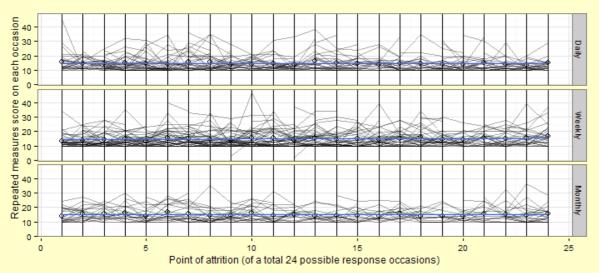




# ی Watching Our Figures

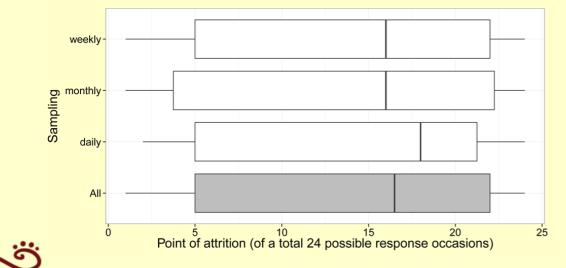
### This is a hot mess.

Repeated responses and attrition points by time, across all modes



Description is important to clarify what works and what doesn't.

### Same information, better visualisation.

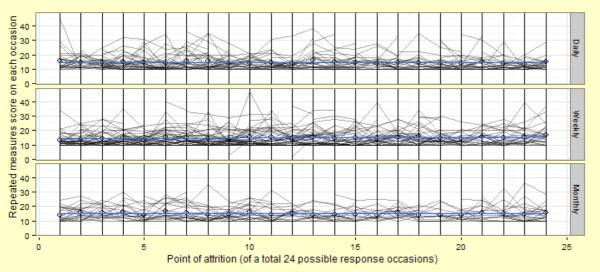




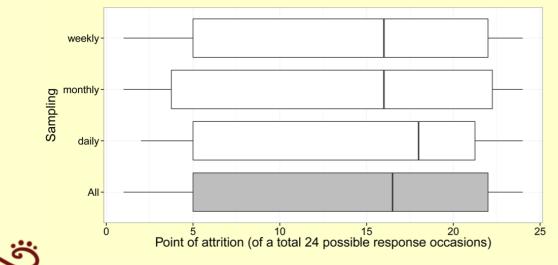
# ی Watching Our Figures

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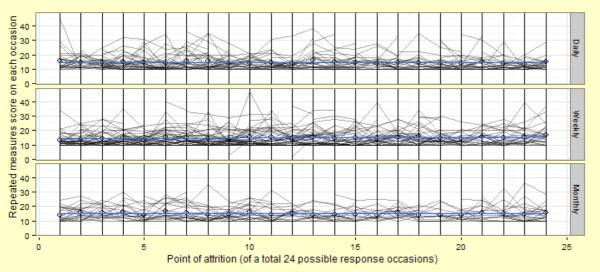
How should we describe these visualisations?

- Value judgement
  - Unsystematic, informal
- Surface features
  - Inconsistent, ungeneralisable

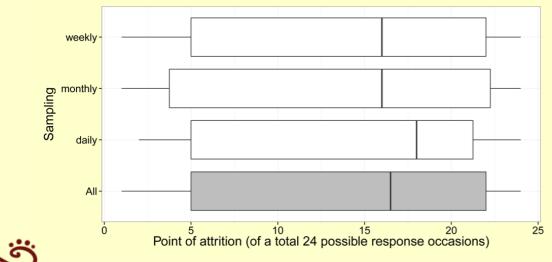
# چ) Watching Our Figures

### This is a hot mess.

Repeated responses and attrition points by time, across all modes



### Same information, better visualisation.



Description is important to clarify what works and what doesn't.

 Just like scientific language, scientific visualisations have a form of syntax and grammar

(Dimopoulos et al., 2003; Kelleher & Wagener, 2011; Mathai & Ramadas, 2009; Tversky, 2011).

 Visualisations are complex, so description schemes are also complex



• The science visualisation literature is fractured.





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- The science visualisation literature is fractured.
  - Theoretical foundations, i.e.
    - Dual-code model (Levie, 1987)
    - Mental model construction (Glenberg & Langston, 1992; Hegarty & Just, 1993; Subramaniam & Padalkar, 2009)
    - Based on image appearance or function (Clark & Lyons, 2010)





# چ)Watching Our Figures

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  - Theoretical foundations, i.e.
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    - Based on image appearance or function (Clark & Lyons, 2010)
  - Many aren't clearly operationalised (Clark & Lyons, 2010; Goldsmith, 1987).
  - Focus more on how to construct a visualisation, but not how to describe it





# چ Watching Our Figures Typologies

- The current state of typologies
  - Typologies based on a grab-bag of descriptors, i.e. Descriptive lists by Clark & Lyons, 2010
  - Lack theoretical basis
  - Tend to be artificially reductionist





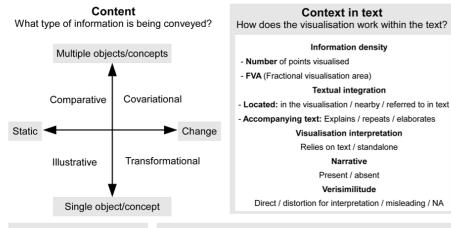
# ي Watching Our Figures Typologies

- The current state of typologies
  - Typologies based on a grab-bag of descriptors, i.e. Descriptive lists by Clark & Lyons, 2010
  - Lack theoretical basis
  - Tend to be artificially reductionist
- Theories don't talk to each other
- Descriptors are artificially specific
- Synthesis of multiple viewpoints needed (Gahegan, 1999)





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#### Intended audience

Letters / symbols

Frame weight

Who will view the visualisat	ion? How does the	How does the visualisation symbolically relate to the information being conveyed?			
- Age			Instructional		
- Textual literacy - Visual literacy - Informational literacy		Analogical	Arbitrary	Representational	
Rhetorical intentio What is the point?	n	A bird's wingspan is the same as a football's	The bird has a wing- span of 28cm.	The bird has a wingspan	
- Engagement - Exploratory - Communicative: rote/elabora - Efficiency	tive Surface featu What does it lool	Unreal	Realis	of 28cm.	
Colour and shading	Proximity and group	Арреа	Appealing		
- Number of colours used If not monochromatic:	Spacing on page		Animation y / n	Interactive y / n	
- Decorative / informative	Linear / scattered / shape	/ single Explana	atory agent y / n	2D or 3D	
- Arbitrary / realistic	Relative to the reade		Conventional Type		
- Plain / bright - Attractive / unpleasant - Distracting	Close / distant / ambig Location on page Centered / asymmetr	- Bar c ical - Histo	- Bar chart - Photograph - Histogram - Polar chart		
Shapes and symbols - Lines	Relative to other eleme Clumped / diffuse / ambig			3D schematic	
- Arrows uni / bidirectional	Frames		- Box plot		
- Circles - Boxes	No frames / frames - Frame shape		- Polar chart - Detailed line drawing		

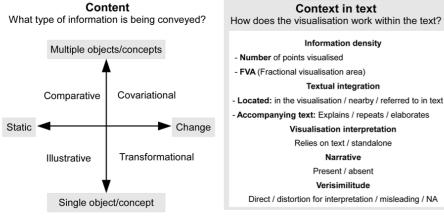
Abstraction

Schematic line drawing

### The CCAIRS typology



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#### Intended audience





- Textual literacy

Visual literacy

Informational literacy

#### **Rhetorical intention** What is the point?

Engagement

Exploratory

- Boxes

- Letters / symbols

- Communicative: rote/elaborativ Efficiency
- Colour and shading Number of colours used If not monochromatic: - Decorative / informative - Arbitrary / realistic Plain / bright - Attractive / unpleasant Distracting Shapes and symbols Lines Arrows uni / bidirectional Circles

				Verisimilitu	
oncept	t	Dire	ect / distortio	on for interpretat	
n?	How does the v	isualisa	Abstra ation symb being cor	olically relate	
				Instructiona	
	Decorative	Ana	logical	Arbitrary	
	The bird has a wingspan of 28cm.	A bird's wingspan is the same as a football's length, 28cm.		H The bird has a wing span of 28cm.	
What does it look like?					
Pro	ximity and group	Appeal	ing 🗲		
	Spacing on page	Ū	1	Animation y /	
Linear / scattered / shape / single Explanatory agent y					
Relative to the reader Conven					
Clo	ose / distant / ambigu				

Location on page

Relative to other elements

Clumped / diffuse / ambiguous

Frames

No frames / frames

- Frame shape

Frame weight

Centered / asymmetrical

### How does the visualisation work within the text?

Accompanying text: Explains / repeats / elaborates

e to the information al

### Representational

#### The bird has a wingspa of 28cm lism Photo real Uqly

#### n Interactive y / n 2D or 3D onal Type - Bar chart - Photograph - Histogram - Polar chart - Line graph - 3D schematic Scatter plot - Box plot

- Polar chart
- Detailed line drawing
- Schematic line drawing

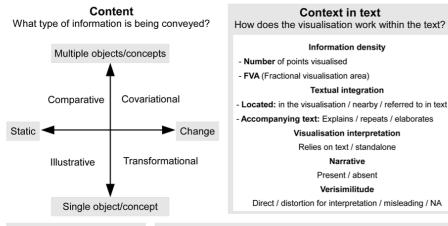
### The CCAIRS typology

- Qualitative coding scheme for visualisations
  - Content
  - Context in text
  - Abstraction
  - Intended Audience
  - **Rhetorical Intention**
  - Surface features



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Representational



#### Intended audience Abstraction Who will view the visualisation? How does the visualisation symbolically relate to the information being conveyed? - Cultural heuristics - Age Instructional - Textual literacy Decorative Analogical Arbitrary Visual literacy Informational literacy The bird has a wind span of 28cm Rhetorical intention What is the point? A bird's wingspan is th Engagement Exploratory Communicative: rote/elabora Efficiency Colour and shading Number of colours used If not monochromatic: Decorative / informative - Arbitrary / realistic - Plain / bright

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- Attractive / unpleasant Distracting

Shapes and symbols

- Arrows uni / bidirectional

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		ame as a football's length, 28cm.	The bird has a wingspan of 28cm.			
at	ive Surface features What does it look like	? Unrealistic	Photo real			
	Proximity and grouping	Appealing				
	Spacing on page Linear / scattered / shape / single Relative to the reader Close / distant / ambiguous Location on page Centered / asymmetrical Relative to other elements Clumped / diffuse / ambiguous	Animation y	//n Interactive y/n			
		Explanatory agent	y/n 2D or 3D			
		Conven	Conventional Type			
		- Bar chart - Histogram - Line graph - Scatter plot	- Photograph - Polar chart - 3D schematic			
	Frames No frames / frames - Frame shape	- Box plot - Polar chart - Detailed line draw	ing			

Schematic line drawing

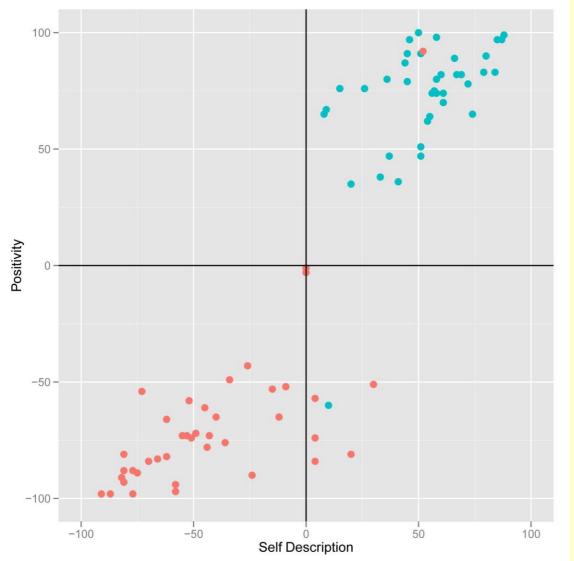
### The CCAIRS typology

- Draws from psychology (from perception through persuasion theory), science communication, advertising, and art theory
- Combines a number of descriptor-based typologies
- Explicitly built to be practically applied as a descriptive tool
- **BROADLY** applicable

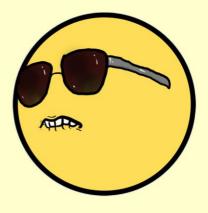


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### The CCAIRS typology



### Still some subjectivity



'Dat graph!



# چ Watching Our Figures Method

- Select some likely journals
  - Psychometrika
  - The Journal of Mathematical Psychology





### Method

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- Select some likely journals
  - Psychometrika
  - The Journal of Mathematical Psychology
- Discard any paper without a visualisation
- Discard any paper on an irrelevant topic
- Say farewell to friends and loved ones (the next bit will take a while)
- Isolate pages with visualisations





# Method

چ) Watching Our Figures

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# Method

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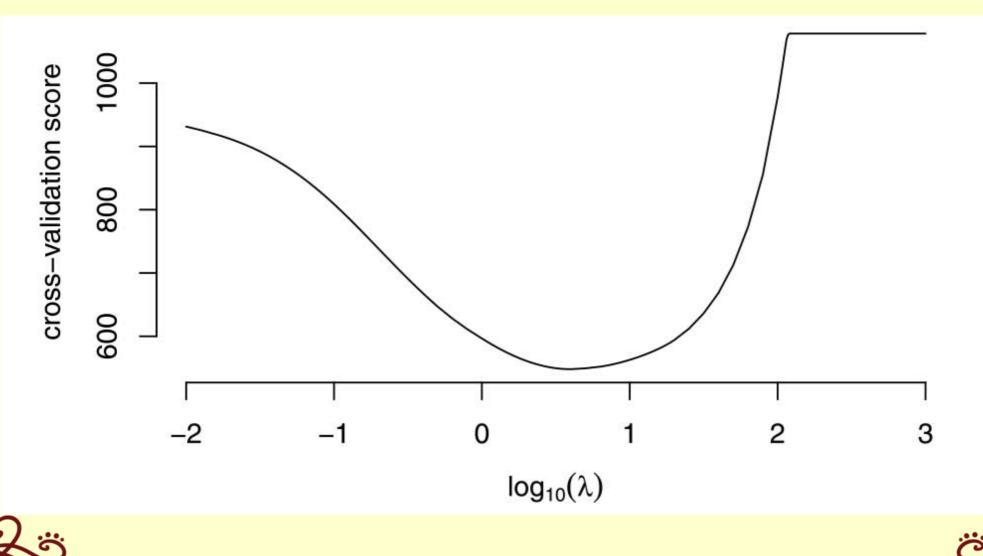
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- Say farewell to friends and loved ones (the next bit will take a while)
- Isolate pages with visualisations
- Systematically apply the CCAIRS to the visualisations
- Random (ish) sample of 150 images from 2000-2014





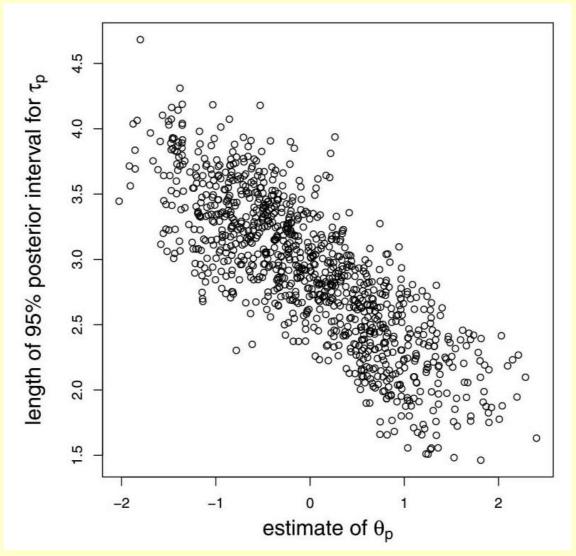
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Line (73%)



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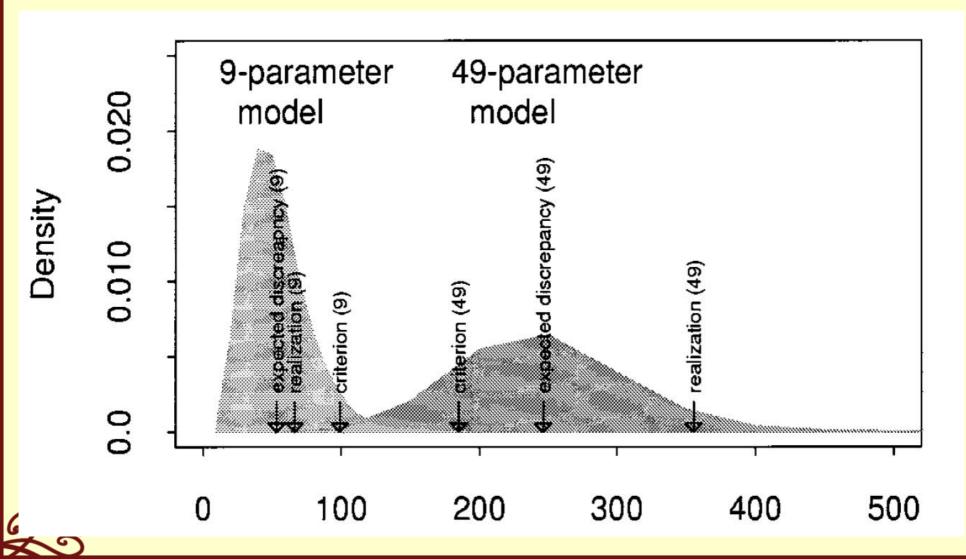
Scatter (22%)

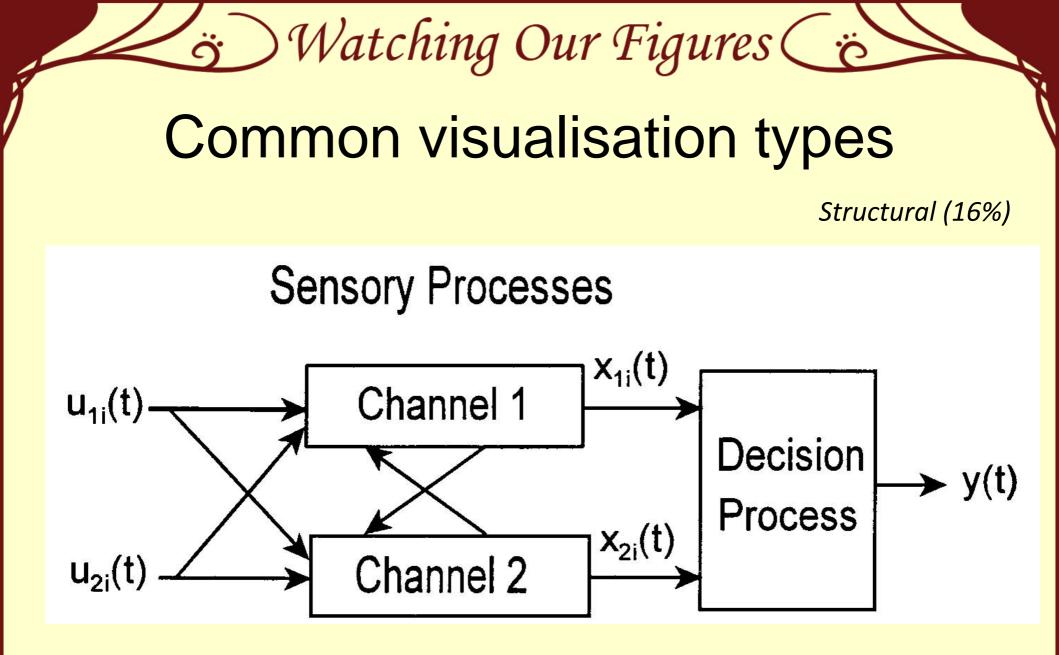




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Density (17%)









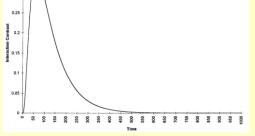
چ)Watching Our Figures ت

#### Line (73%)

#### Scatter (22%)

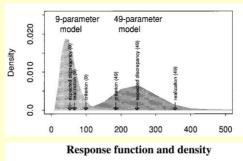
#### Density (17%)

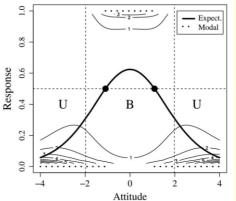
#### 1000 cross-validation score length of 95% posterior interval for $\tau_p$ 800 -2 0 3.0 $\log_{10}(\lambda)$ 2.5 $x_2$ 2.0 s(t) $\mathbf{x}(0)$ -1 0.3 0.25



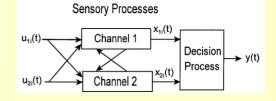
estimate of  $\theta_r$ 

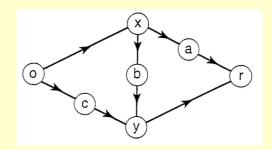
(f) All Sites (Controlled for Site Effect)

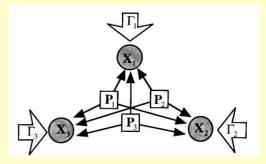




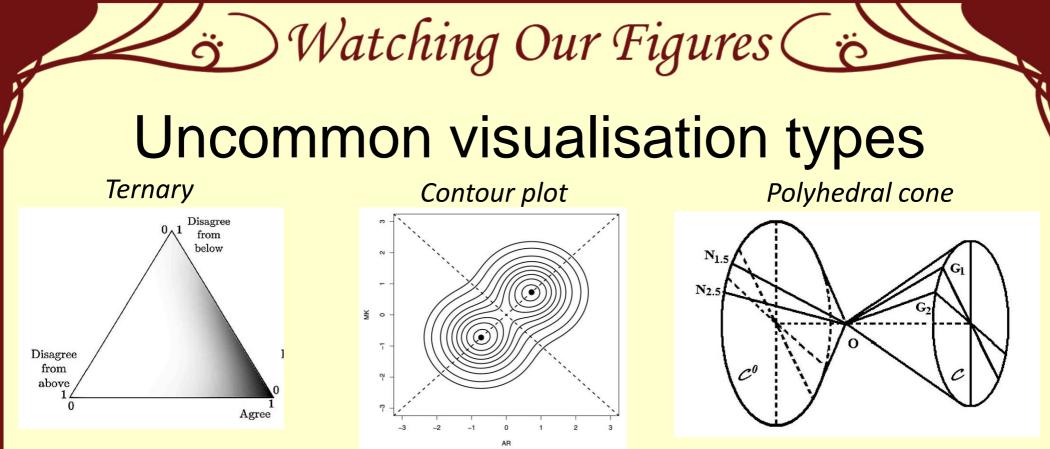
#### Structural (16%)







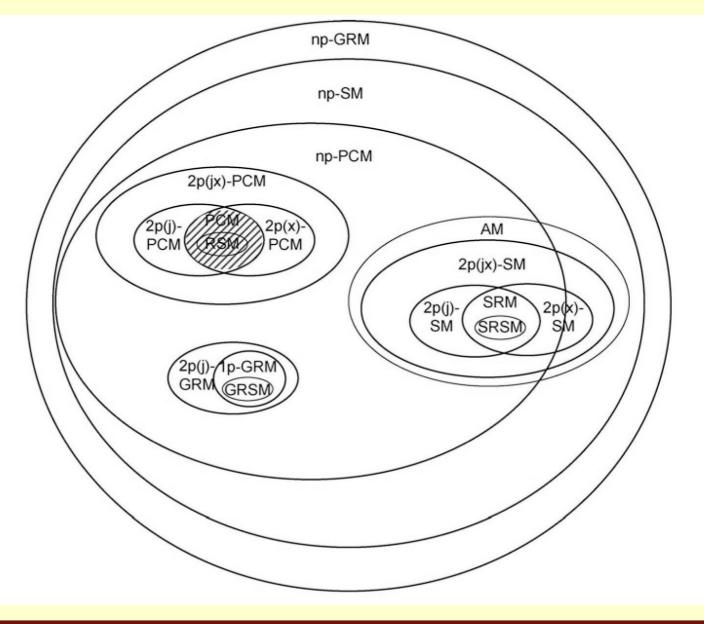




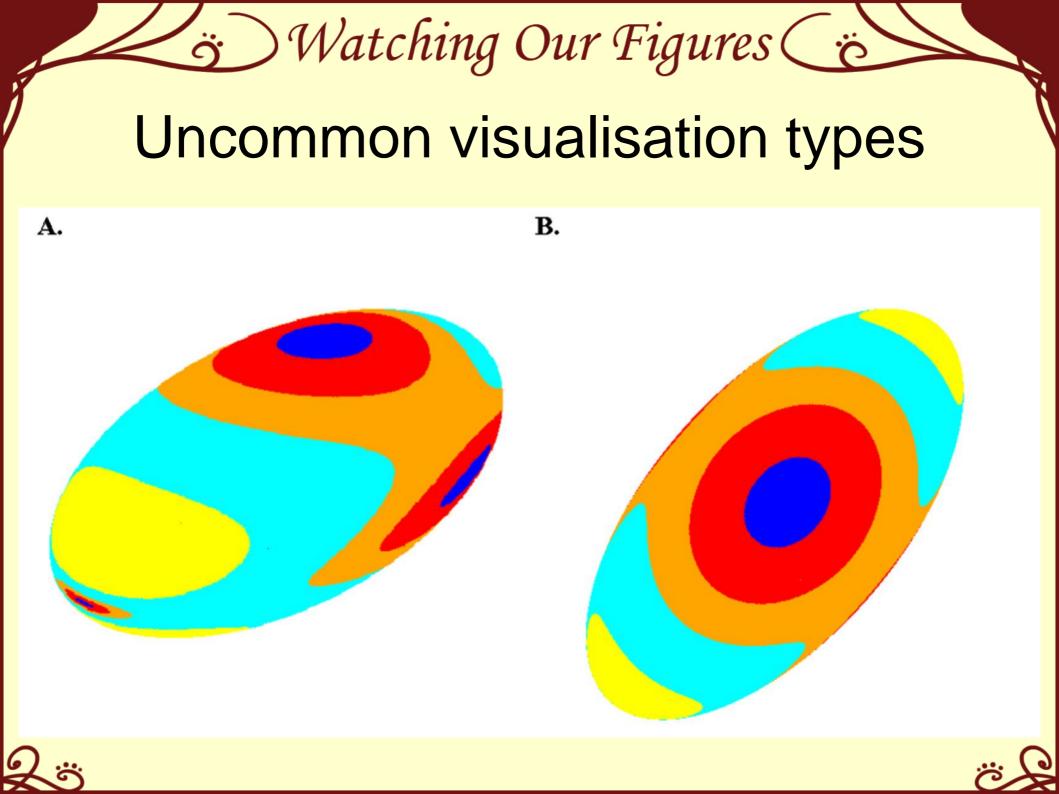


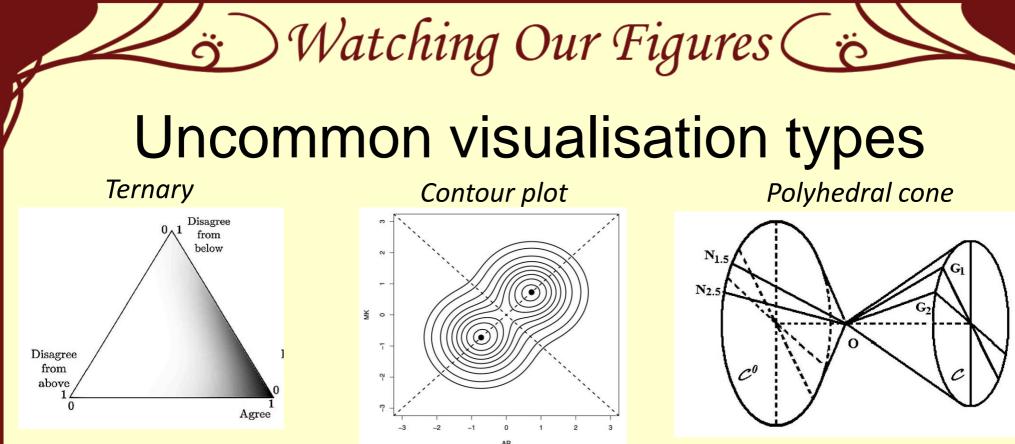


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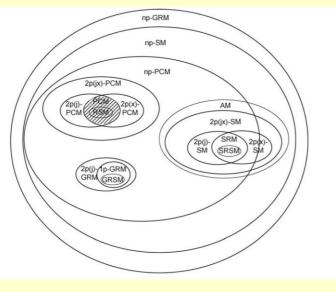


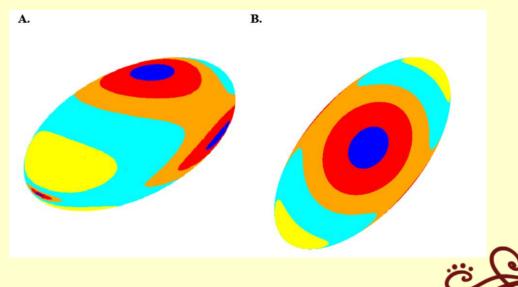




#### Contour and structural plot had a baby

#### Correlation weight... heat maps







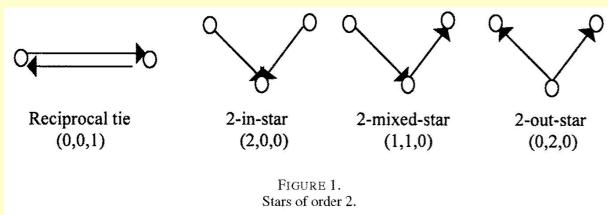
Supportive of visual literacy





# چ Watching Our Figures The good

- Supportive of visual literacy
  - 62% would need high visual literacy (familiarity with the figure) to obtain meaning





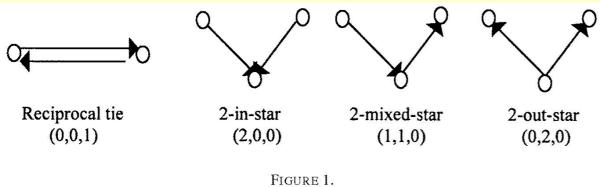


چ) Watching Our Figures

### The good

### Supportive of visual literacy

- 62% would need high visual literacy (familiarity with the figure) to obtain meaning
- Uncommon figures generally explained well



Stars of order 2.

 $\begin{bmatrix} P(X_i = 1 | \mathbf{X}^{\text{ff}} \dots = \mathbf{x}^{\text{ff}} \dots \mathbf{V} = \mathbf{x}) \end{bmatrix}$ 

$$\log \left[\frac{I(\mathbf{x}_{i}) - I_{i}(\mathbf{x}_{i}) - I_{i}(\mathbf{x}_{i}) - \mathbf{x}_{j-(i)}^{T} \cdot \mathbf{x}_{j-(i)}^{T} \cdot \mathbf{x}_{j}}{P(\mathbf{X}_{i} = 0|\mathbf{X}_{j-(i)}^{T} - \mathbf{x}_{j-(i)}^{T} - \mathbf{x}_{j-(i)}^{T}, \mathbf{Y} = \mathbf{y})}\right]$$

$$\sum_{e_{i}(i)} \sum_{R \subseteq I - |i|} \sum_{Q \subseteq I \in \mathcal{M}(R)} \gamma_{R \cup Q \cup |i|} \prod_{k \in R} \mathbf{X}_{k} (i, t) \in Q} \mathbf{y}_{it}.$$
(7)

In the case of binary attributes, suppose that  $X_i = 1$  signifies that i "possesses" the attribute and that  $X_i = 0$  signifies the opposite. Then, the parameter  $\gamma_{R \cup Q \cup \{i\}}$  is associated with the statistic

PSYCHOMETRIKA

 $\prod x_k \prod y_{st}$ 

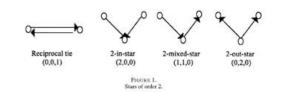
If the parameter is positive, the odds of i possessing the attribute is enhanced as long as the actors in R also have the attribute and as long as the network ties are in place on the couples in Q. Social influence arises because i's attribute is affected by the attributes of the actors in R, who may have social relations with i through the network ties in Q. In sections 4 and 5, we give examples of models based on specific dependency structures that define certain classes of R and Q.

Our strategy for model development is to hypothesize a dependence structure represented by a chain dependence graph. This can then be expressed in terms of the expansion of (5), or of (7) for binary attributes. We then derive simpler models by restricting the number of vertices we consider in  $R \cup Q$ . This last step is akin to concentrating on main effects and lower order interaction terms, by setting higher-order interaction terms to zero.

#### 3.3. Sufficient Statistics and Homogeneity Constraints

Frank and Strauss (1986) assumed a Markov condition for conditional dependence among network variables. In a Markov directed graph, possible ties are assumed to be conditionally dependent whenever they have an actor in common: that is, the variables Yij and Yit are conditionally dependent if and only if  $\{i, j\} \cap \{s, t\} \neq \emptyset$ . By assuming that these are the only dependencies, Frank and Strauss (1986) showed that sufficient statistics for the model are confined to indicators of certain network configurations: ties, reciprocal ties, in-stars, out-stars, mixed-stars, and all possible triadic configurations.

A reciprocal tie occurs between i and j when  $y_{ij} = y_{ji} = 1$ . A star has a number of ties lirected towards and away from a particular node. We refer to an (s, t, r)-star when s + r ties are directed to a node, t + r ties directed away from a node, and r of these incoming and outgoing ties are reciprocated (in other words, the actor represented by the node has s incoming ties, outgoing ties and r reciprocated ties). The order of an (s, t, r) star is said to the s + t + 2r. A reciprocal tie can then be considered as a (0, 0, 1) star of order 2. A k-in-star is a (k, 0, 0) star, whereas a k-out-star is a (0, k, 0) star. A k-mixed-star is of the form (s, t, 0) where  $s, t \neq 0$  and + t = k. Figure 1 depicts these configurations for stars of order 2.



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- Generally efficient
  - Efficiency is using the minimum number of visual elements to convey meaning



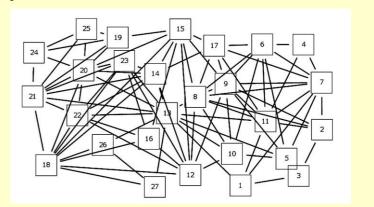


### The good

چ) Watching Our Figures

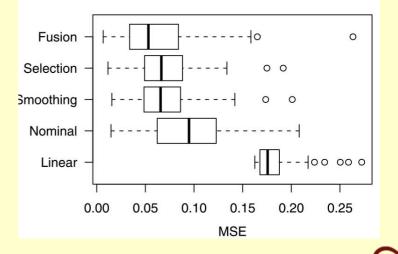
### Generally efficient

- Efficiency is using the minimum number of visual elements to convey meaning
  - 0 = completely inefficient
  - 100 = completely efficient



Poor efficiency (only one connection discussed in text)

Great efficiency (meaning clear, all discussed in text)





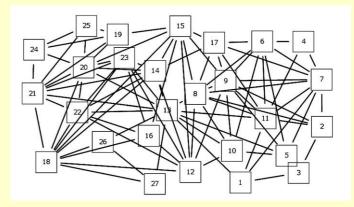
### The good

چ) Watching Our Figures

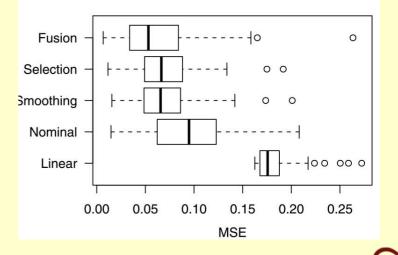
### Generally efficient

- Efficiency is using the minimum number of visual elements to convey meaning
  - 0 = completely inefficient
  - 100 = completely efficient
- Average efficiency of 76%

#### Poor efficiency (only one connection discussed in text)



Great efficiency (meaning clear, all discussed in text)



# ی Watching Our Figures The bad

#### • CLUTTER!

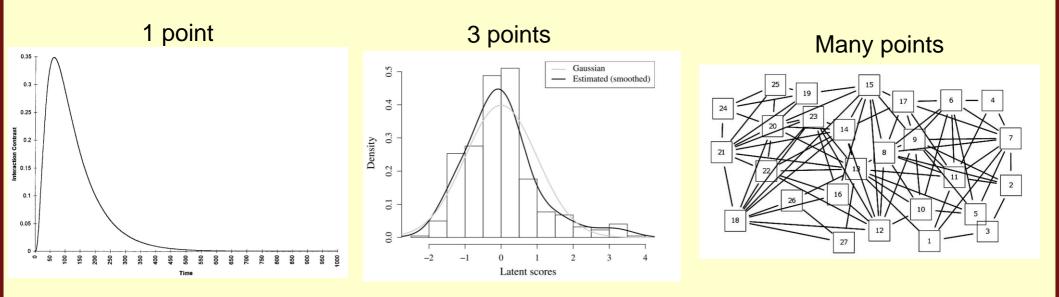
Cramming a lot of information into a figure





### ی Watching Our Figures The bad • CLUTTER! • Cramming a lot of information into a figure

(20% had 5 or more points, 10% 10 or more!)



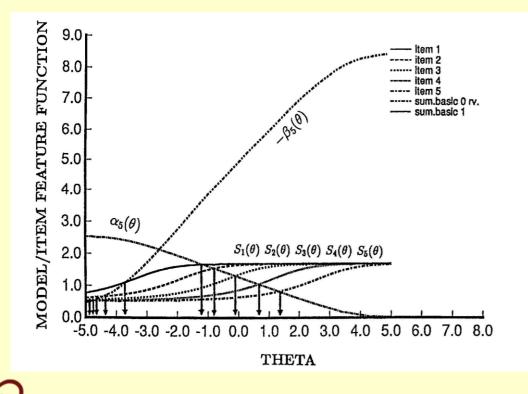


# The bad

چ) Watching Our Figures خ

#### • CLUTTER!

Cramming a lot of information into a figure
 (20% had 5 or more points, 10% 10 or more!)
 Heavy annotation



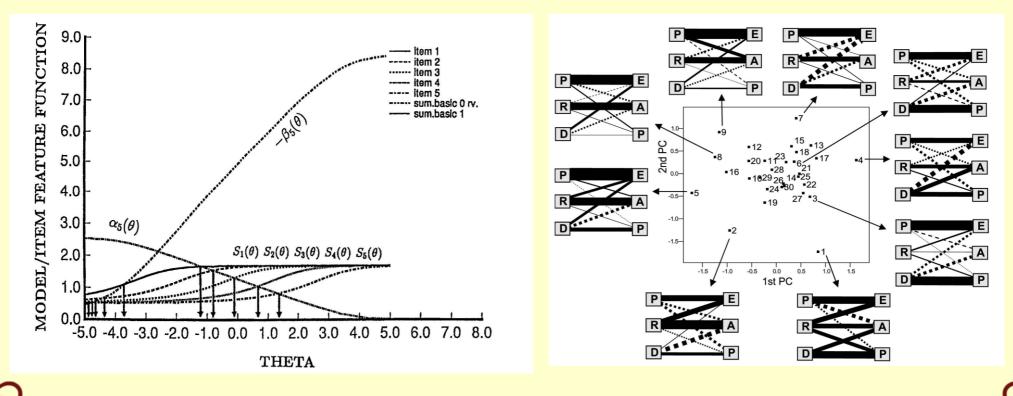


# The bad

چ) Watching Our Figures خ

#### • CLUTTER!

Cramming a lot of information into a figure
 (20% had 5 or more points, 10% 10 or more!)
 Heavy annotation
 Hybrid oddity



# ي Watching Our Figures The bad

#### • CLUTTER!

 Cramming too many complex panels into a page

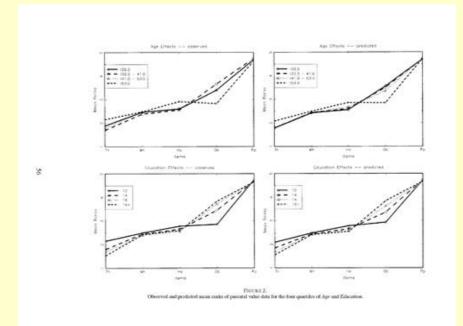




# ج Watching Our Figures The bad

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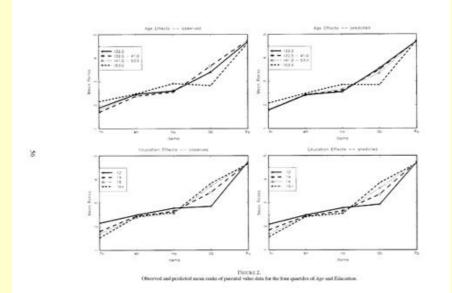




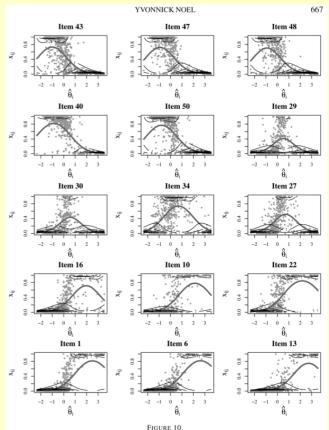
# چ Watching Our Figures The bad

#### • CLUTTER!

 Cramming too many complex panels into a page



### Fetch the magnifying glass!



Observed data, response density contours, and expectation function for the abortion data. The thick plain lines display the expected rating curve, the thin lines the response density contours as functions of attitude. Figures in the contour lines are the density values at that particular level.

### The bad

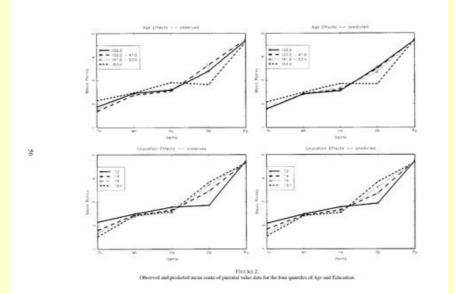
چ) Watching Our Figures خ

#### • CLUTTER!

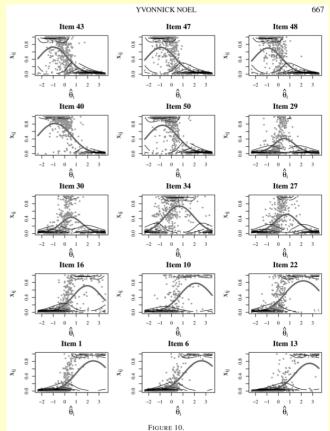
Cramming too many complex panels

into a page

- Mostly 2,4, or 9 panels per figure
- Ranges from 1 to 15 panels per page



# Fetch the magnifying glass!

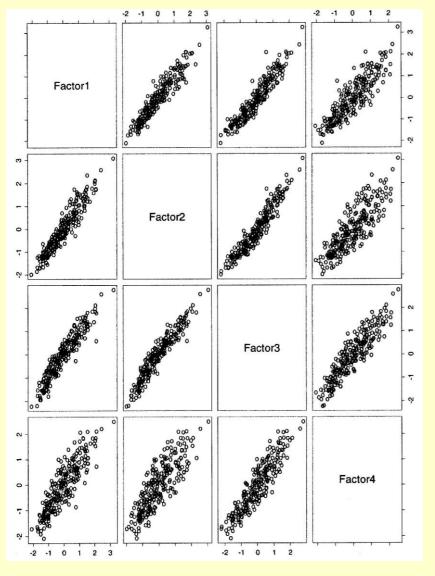


Observed data, response density contours, and expectation function for the abortion data. The *thick plain lines* display the expected rating curve, the *thin lines* the response density contours as functions of attitude. Figures in the contour lines are the density values at that particular level.

### چ)Watching Our Figures

### Totally just Figure 1

Theoretically valid

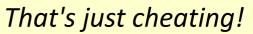


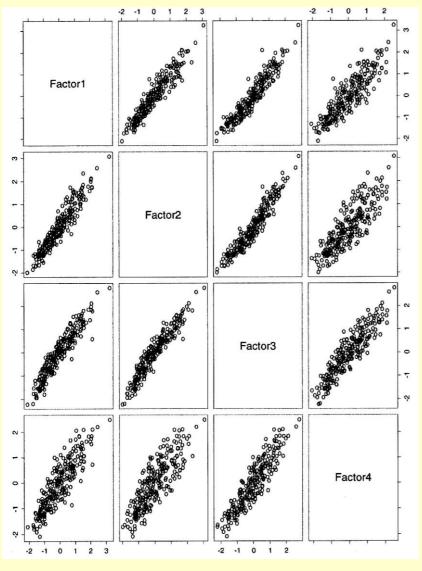


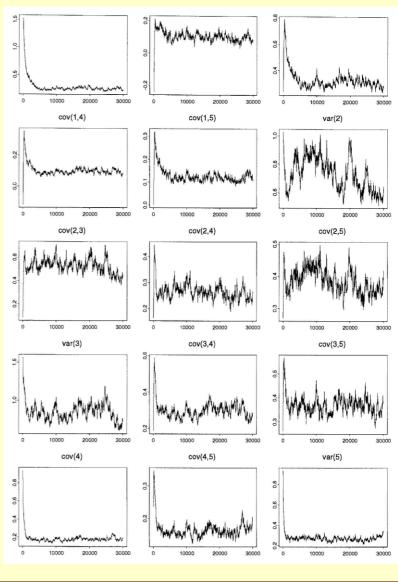
### چ) Watching Our Figures 😴

### Totally just Figure 1

Theoretically valid









#### The bad

• Cut the clutter





# ی Watching Our Figures

### The bad

- Cut the clutter
  - Crammed panels
    - If you don't go through it in detail in text, you don't need it



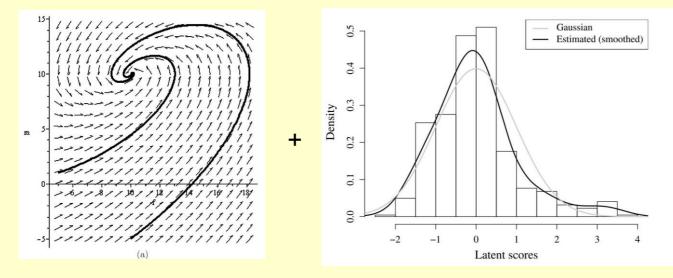


# چ) Watching Our Figures

### The bad

#### Cut the clutter

- Crammed panels
  - If you don't go through it in detail in text, you don't need it
  - Use shading and colour to differentiate important visual elements



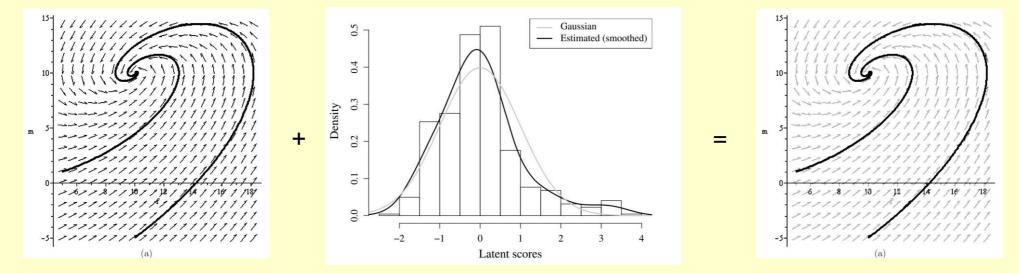


# چ) Watching Our Figures

### The bad

#### Cut the clutter

- Crammed panels
  - If you don't go through it in detail in text, you don't need it
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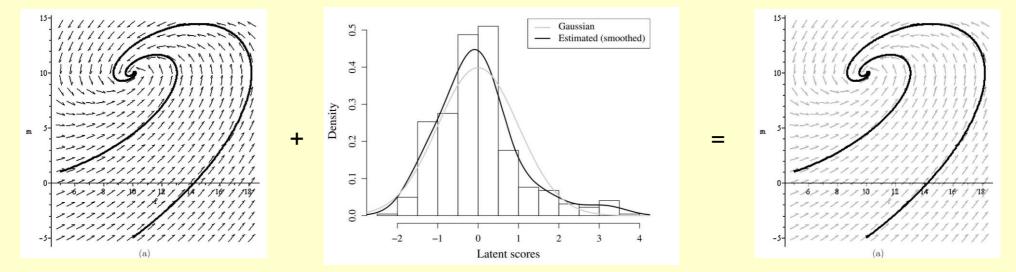


# چ)Watching Our Figures

### The bad

#### Cut the clutter

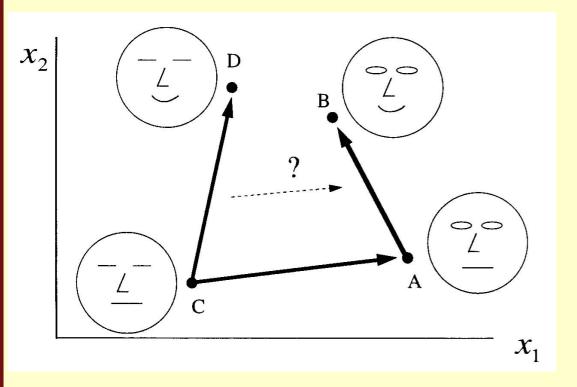
- Crammed panels
  - If you don't go through it in detail in text, you don't need it
  - Use shading and colour to differentiate important visual elements



- Crammed pages
  - Do you really need all those panels?



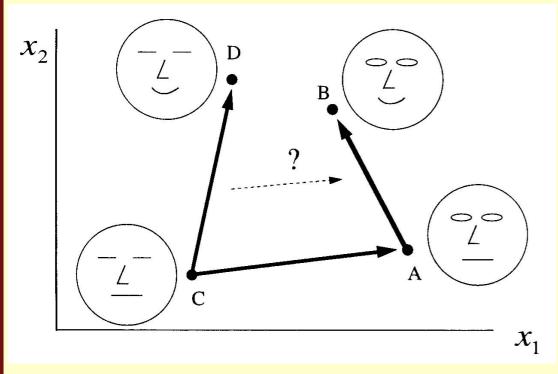
















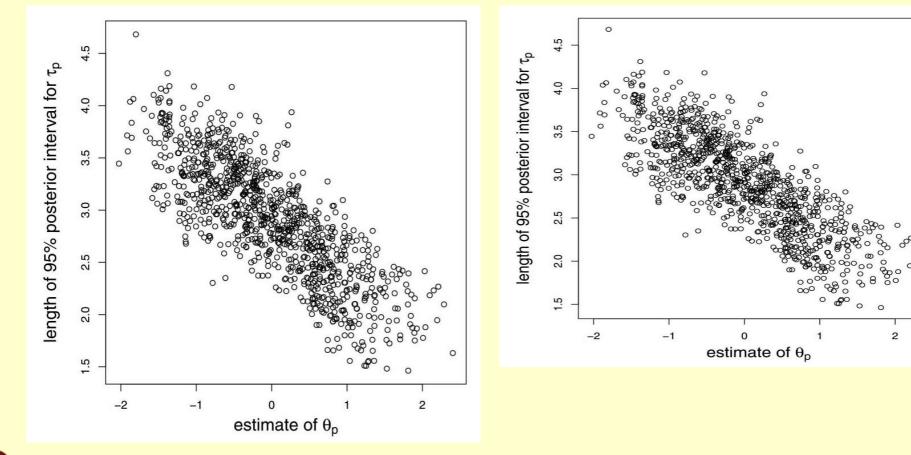




The ugly

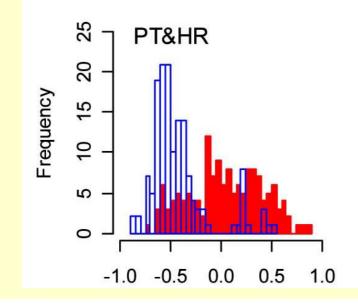
Aspect ratio errors

- Makes words difficult to read
- Can distort interpretation



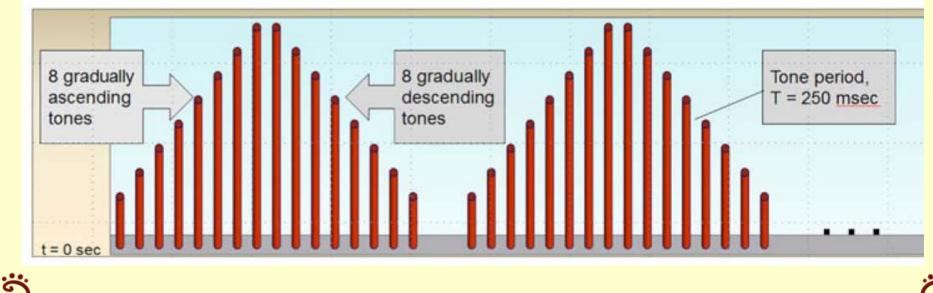
# چ)Watching Our Figures

#### The ugly

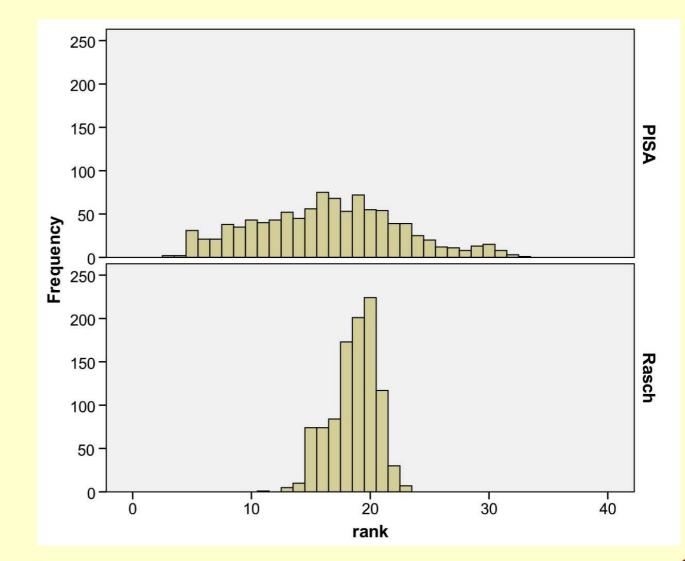


#### Colours without meaning

- Distracting
- Make those who can't afford colour budget jealous



# چ Watching Our Figures The ugly



Straight from SPSS • No.

# چ Watching Our Figures ج

#### Straight from your analysis • No.

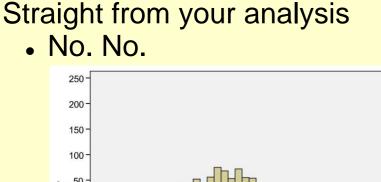
250 200-150 -PISA 100 50 Frequency 0 250 200 Rasch 150 100-50 0-20 30 Ó 10 40 rank

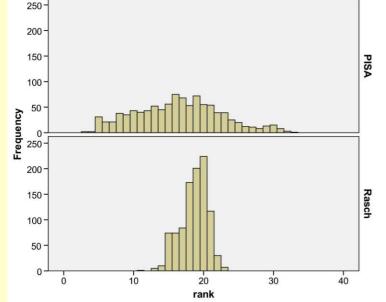




# چ) Watching Our Figures The ugly

#### CCAIRS = R for rhetorical intention



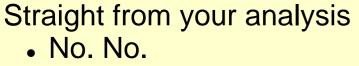


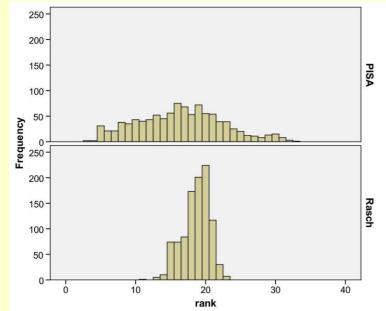
- Engage an audience?
- Facilitate an ongoing process?
- Encourage rote learning?
- Encourage elaborative learning?
- Make a passing point (no need for recall)



# چ Watching Our Figures The ugly

#### CCAIRS = R for rhetorical intention



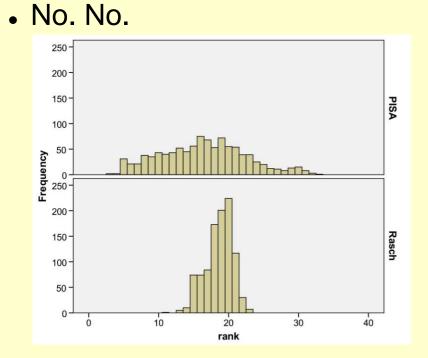


- Engage an audience?
- Facilitate an ongoing process?
- Encourage rote learning?
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# ي Watching Our Figures The ugly

#### CCAIRS = R for rhetorical intention



Straight from your analysis

- Engage an audience?
  - Facilitate an ongoing process?
  - Encourage rote learning?
  - Encourage elaborative learning?
  - Make a passing point (no need for recall)



# چ)Watching Our Figures

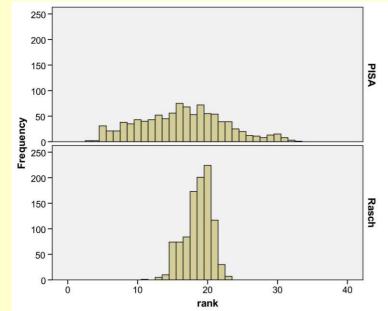
#### The ugly

#### Aspect ratio errors

- Makes words difficult to read
- Can distort interpretation

#### Straight from your analysis

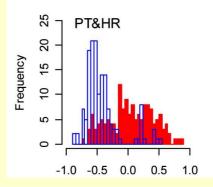
• No. No. No.



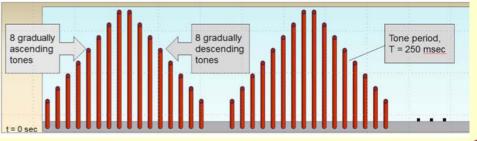
#### **Colours without meaning**

- Distracting
- Make those who can't afford colour budget jealous

#### These colours clarify interpretation



#### These colours help nobody



چ Watching Our Figures ت Conclusions

#### Keep doing these things:

- Explain how to interpret unusual figures
- Convey meaning efficiently





### Conclusions

#### Keep doing these things:

- Explain how to interpret unusual figures
- Convey meaning efficiently

#### Don't do these things:

- Cram your figures with panels
- Cram your panels with visual clutter
- Use colour where it doesn't convey meaning

ی Watching Our Figures ت

Use visualisations straight from your analysis





### Conclusions

#### Keep doing these things:

- Explain how to interpret unusual figures
- Convey meaning efficiently

#### Don't do these things:

- Cram your figures with panels
- Cram your panels with visual clutter
- Use colour where it doesn't convey meaning
- Use visualisations straight from your analysis

#### **Consider doing these things:**

 Use fewer elements and panels, and discuss them in more depth

چ)Watching Our Figures

- Use greys and colours to avoid clutter
- Treat your visualisations like you do your text: craft and draft.





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#### Keep doing these things:

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**Clark, R., & Lyons, C.** (2010). Graphics for learning: Proven guidelines for planning, designing, and evaluating visuals in training materials (pp. 23–66).

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Chimp http://blogs.houstonzoo.org/2013/06/protecting-the-zoos-chimpanzee-counterparts-in-the-wild/ Ecosystem http://eschooltoday.com/ecosystems/images/ecosystemillustration.jpg

http://celebrating200years.noaa.gov/breakthroughs/ecosystems/gulf\_of\_alaska\_Ime\_650

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