The Many Dimensions of SHAPE

I spy an anchor, a musical note,
A crayon and a snake and a small billy goat;
A pair of sunglasses, a tiny bird cage–
I also spy something from every other page.

The image above is from www.scholastic.com/ispy. The "I Spy" books by Walter Wick and Jean Marzollo are filled with visual images and riddles requiring visual search, typically using shape, in order to solve. "I Spy" books are available from Amazon, Barnes and Noble, etc.

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The Many Dimensions of Shape

Outline

- Motivation
- Shape?
- Background
- 6 Experiments using shapes on different datasets
- A model?

* All conjecture – nothing proven!

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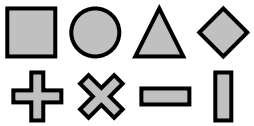
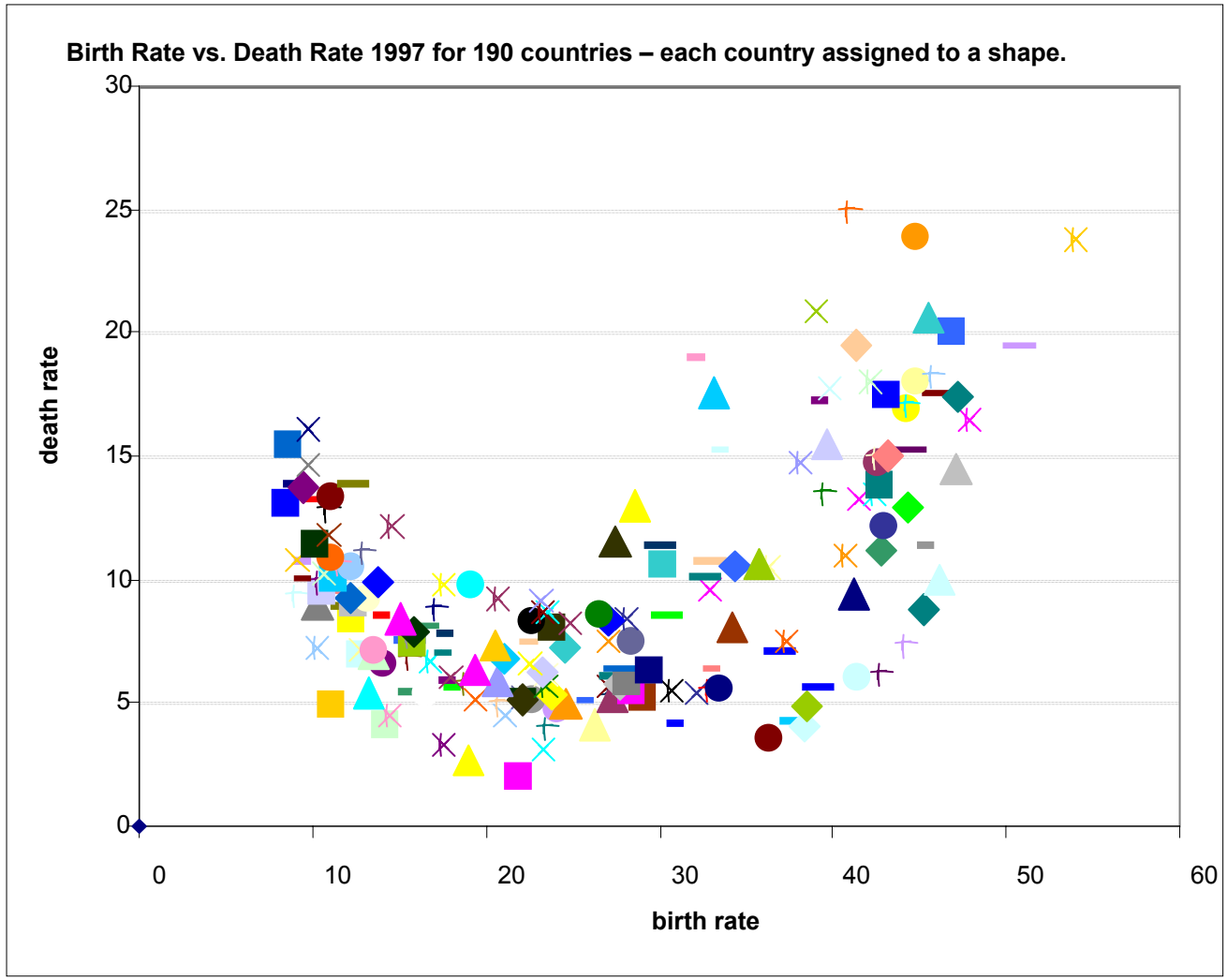
Shapes

There are 4-10 basic shapes in most charts, paint packages, etc.



Why limited to 10?

What if you need more than 10?



Excel chart.
10 shapes, then repeats (with different color)!

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Pictographs

- There are limitless number of pictographs.
- But…
  - Design required
  - Abstract nouns, adjectives difficult to encode/decode
  - Ambiguity
  - Perceptually effectiveness?

www.aiga.org/content.cfm/symbol-signs

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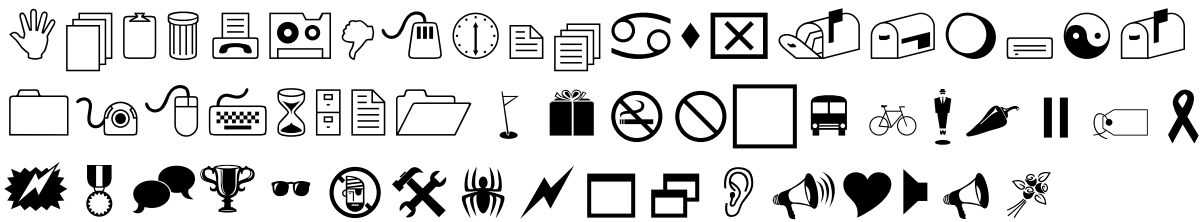
What is Shape?

A. Simple geometry:

- What's in-between these two?
- Can shapes convey more than one (or two or 5) attribute(s)?
- Are some shapes more perceptually effective?

B. Pictographs:



Limitless visual representation, typically of nouns.

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Intermediate Shapes…

Alphanumerics

- A B C D E
- a b c d e
- 1 2 3 4 5
- i ii iii iv v vi

Symbols

- & ! ( ) ; : @ ?
- € £ ¥ ₣
- + - / x
- √ ∞ ≠ ≤ ≥ ≈

More Symbols

♈♉♊♋♌♍♐♑

But:

- Are these shapes perceptually efficient?
- Can they convey quantitative values (i.e. magnitudes), not just separate categories?
- Can they convey more than one attribute?

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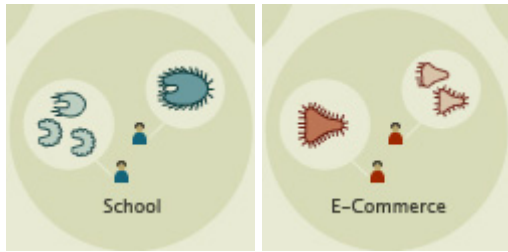
Compound Shapes…

Pictograph on Basic Geometry

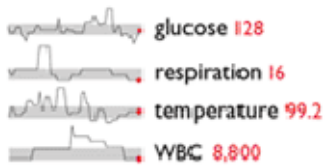
Icons from AIGA
www.aiga.org/content.cfm/symbol-signs

Hair on a Base Shape



Anymails: Visualization of Email Inbox
Design & Concept: Carolin Horn
Code: Florian Jenett

1,2,3…n bars, charts & small multiples.



Edward Tufte: Beautiful Evidence

- Are there ways to convey multiple attributes other than just welding component shapes together?

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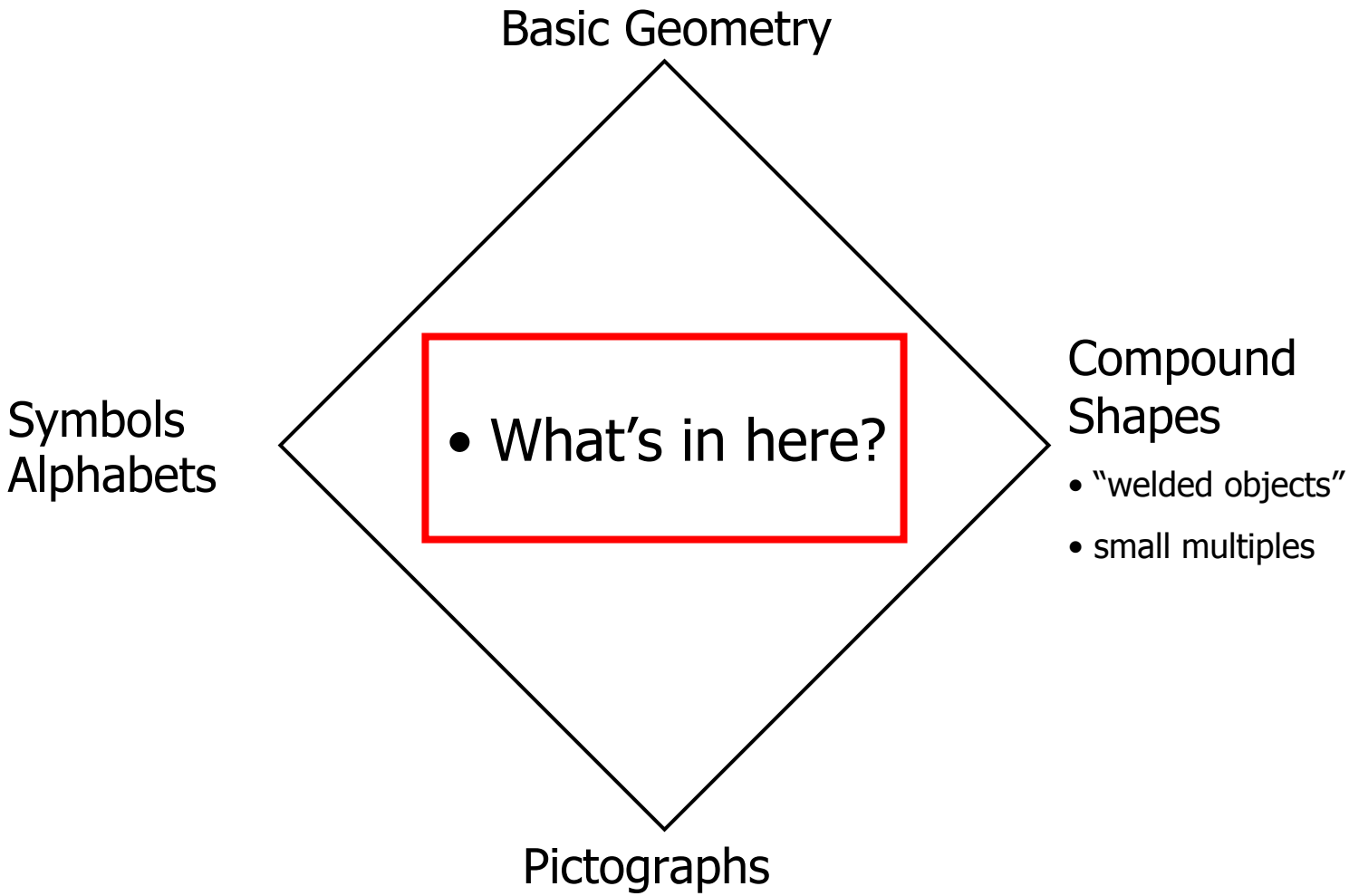
What are the potentials of Shape?
Where are the limits?
What are the dimensions?



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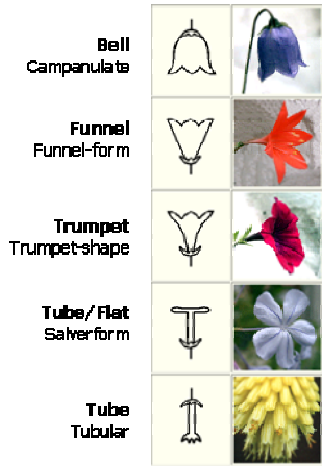
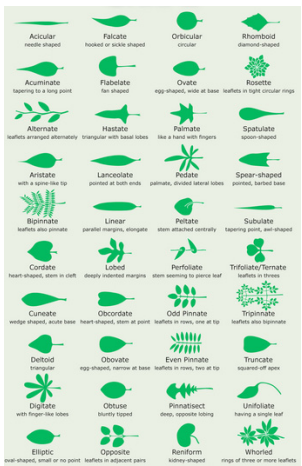
Many domains utilize shape for differentiation, aesthetics, search, identification, functions, etc.

I Spy books: Walter Wick and Jean Marzollo. Scholastic Publishing. www.scholastic.com

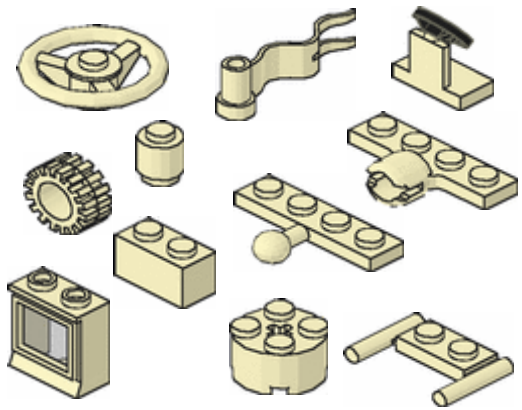


Sample flower shapes. From theseedsite.co.uk/flowershapes.html

Aircraft silhouette identification –LIFE Magazine 1944, Andreas Feininger. Via Google LIFE image search.

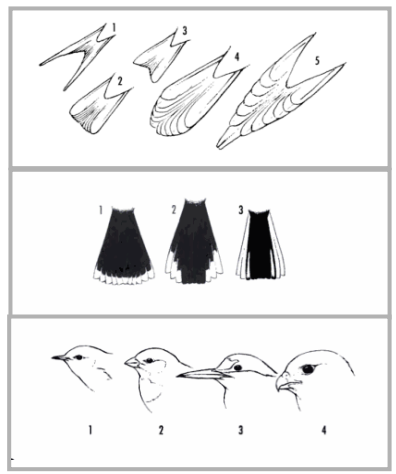


Leaf Morphology from wikimedia.org



A few of examples of more than 14,000 unique LEGO parts catalogued by fans on: peeron.com

Wassily Kandinsky - Composition VIII - 1923 wassilykandinsky.net



Example shape attributes used in bird identification, from *A Field Guide to the Birds* by Roger Tory Peterson

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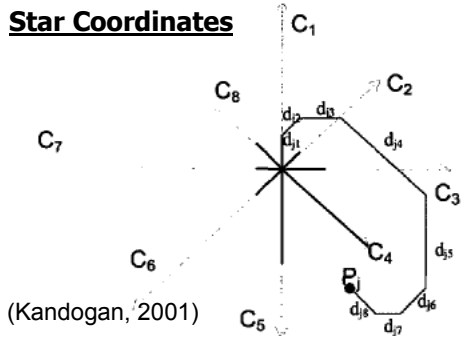
Many Shape Techniques in InfoVis and SciVis

but is there a formal list of shape attributes?

Star Coordinates



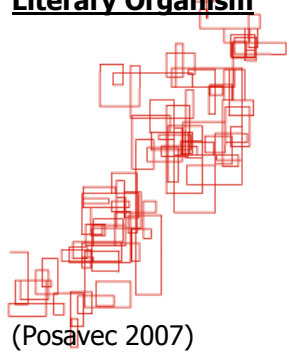
(Kandogan, 2001)

Sparklines

Financial	11/04 – 10/05	CV
$ Revenues in mil		17.58
$ Expenses in mil		12.33
$ Profits in mil		5.25
Market Share in %		43.0

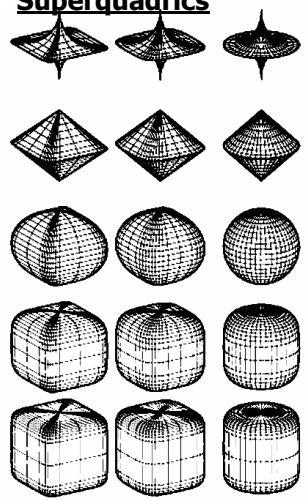
www.bonavistasystems.com/OnlineDemoReports.html

Literary Organism



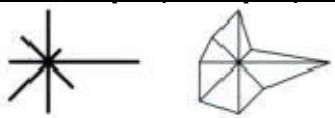
(Posavec 2007)

Superquadrics



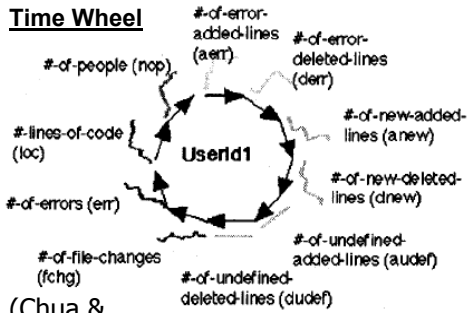
(Barr 1981)

Whisker plot, Star plot, Exvis Stick



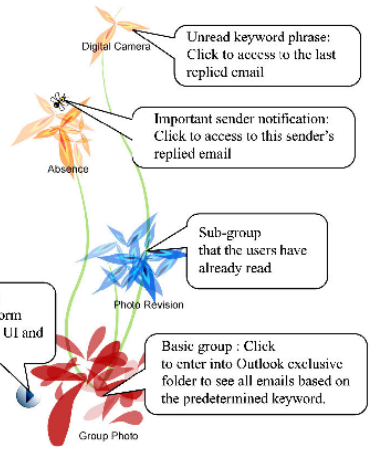
From Colin Ware's book.

Time Wheel

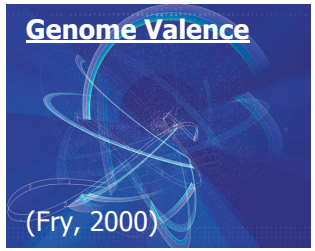


(Chua & Eick, 1997)

Info-Lotus (Zhang et al, 2005)



Genome Valence

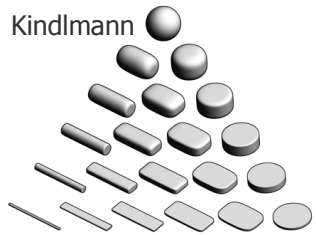


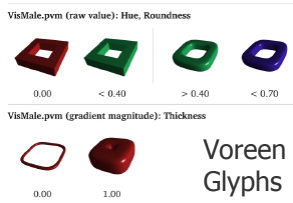
(Fry, 2000)

Malwarez

Dragulescu

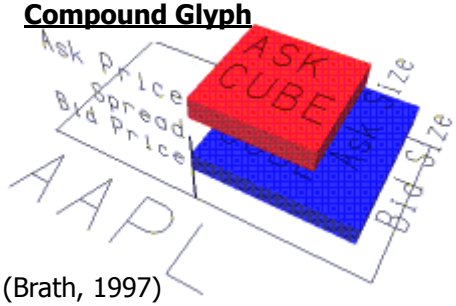
Kindlmann





Voreen Glyphs

Compound Glyph

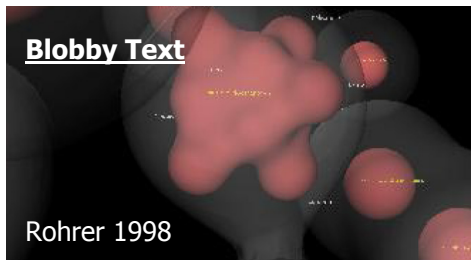


(Brath, 1997)

Bodies and (Chernov) Faces

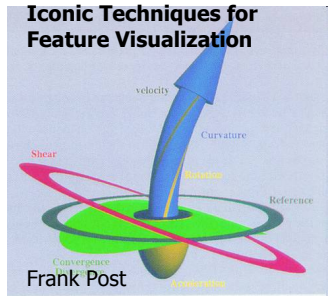
(Stephen Rose, ???)

Blobby Text

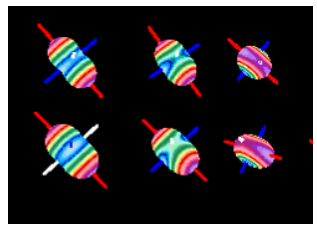


Rohrer 1998

Iconic Techniques for Feature Visualization



Frank Post



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Visual Attributes

as defined by visualization researchers and perceptual psychologists

Table of Visual Attributes and suitability for encoding data according to various researchers.	**Bertin (67)**		**Cleveland (85)**	**MacKinlay (86)**		**MacEachren (9x)**		**Wilkinson (9x)**		**Mazza (0x)**		**Peceptual Psychology**
Attribute	C	Q	na	C	Q	C	Q	C	Q	C	Q	P
Color												
Hue	Y	x	Y	Y	Y	Y	~	Y		Y	x	Y
Brightness	Y	Y		Y	Y	~	Y	Y		x	Y	Y
Saturation				Y	Y	~	Y	Y				
Transformation												
Length/Width			Y	Y	Y					x	Y	Y
Size (Area)	Y	Y	Y	Y	Y	Y	Y	Y		x	~	Y
Volume			Y	Y	Y							
Orientation	Y	x		Y	Y	Y	~	Y		x	Y	Y
Slope			Y	Y	Y							
Form												
Shape	x	x		Y		x	Y	Y		Y	x	
Added Marks										Y	x	
Curvature										x	~	Y
Concavity/Convexity										x	~	
Closure												Y
Intersection												Y
Terminators												Y
Holes												Y
Spatial												
2D position	Y	Y	Y	Y	Y	Y	Y			~	Y	Y
Grouping/Containment				Y		~	x			x	x	Y
3D Depth										x	x	Y
Connection				Y								
Numerosity										x	Y	Y
Shadow Direction												Y
Movement/Optics												
Flicker										~	x	Y
Motion										x	~	Y
Transparency						~	~	Y				
Blur/Crispness						x	~	Y				
Shininess												Y
Texture	Y	x		Y	X	Y	Y	Y*				

C = Categoricial/Nominal scale (Bertin's Selection)

Q = Quantitative/Ordinal scale.

P = Perceptually preattentive, i.e. can preattentively distinguish between two categories.

Sources:

Bertin 67: Semiology of Graphics

Cleveland 85: The Elements of Graphing Data

MacKinlay 86: Automating the Design of Graphical Presentations

MacEachren 95: How Maps Work

Wilkinson 99: The Grammar of Graphics

Mazza 09: Introduction to Information Visualization

Perceptual Psychology: scholarpedia.org/article/Visual_search

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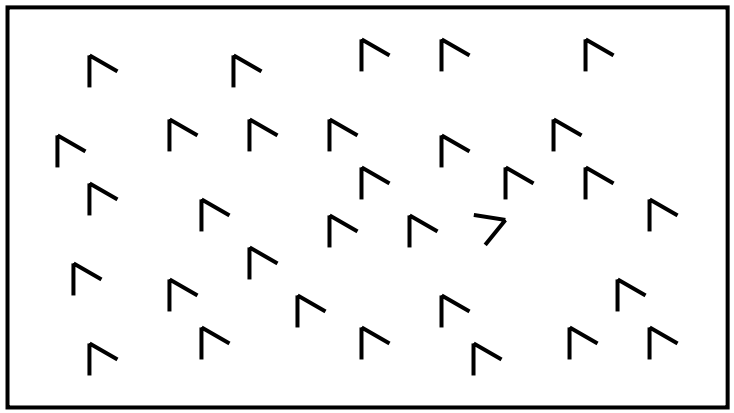
Note: Researchers are not consistent, even in terminology

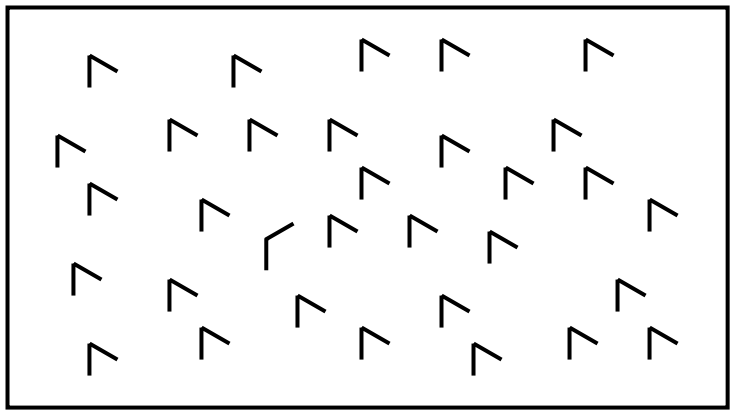
Rotation/Angle/Orientation/Slope:

- Wilkinson: Rotation
- Cleveland: Angle
- Bertin: Orientation
- MacKinlay: Slope/Angle
- MacEachren: Orientation
- Mazza: Orientation

My opinion – Angle and orientation are two separate dimensions of visual attributes



Vary in orientation only.



Vary in angle only.

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Gaps in our knowledge about shape:

Attribute	Binary	Category	Order/Qty
Size*	Y	Y	Y Y
Orientation	Y	Y	N -
Shape Δ◇O+?		Y	N N
Added Marks		?	? N
Curvature	Y	N	- -
Angle		Y	N
Closure	Y		
Intersection	Y		
Terminators	Y		
Holes	Y		

1

2

3

Consensus.
But these are uniform transformations on shape, not about shape itself.

Incomplete
No consensus

…
Therefore: do a series of small experiments to explore these attributes more..

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Experiment #1: Categories of Curves

GOAL:

- Use curves to represent different categories.

HOW:

- Gas station survey. 1000 people surveyed:
  - Which gas station
  - Age
  - Fuel grade purchased (regular, mid-grade, premium)
  - Payment method
  - Gender
  - Etc.

Attribute	Binary	Category	Order/Qty
• Size*	**Y**	**Y**	**Y**
• Orientation	**Y**	**Y**	-
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	Y	N	-
• Angle			
• Closure	Y		
• Intersection	Y		
• Terminators	Y		
• Holes	Y		

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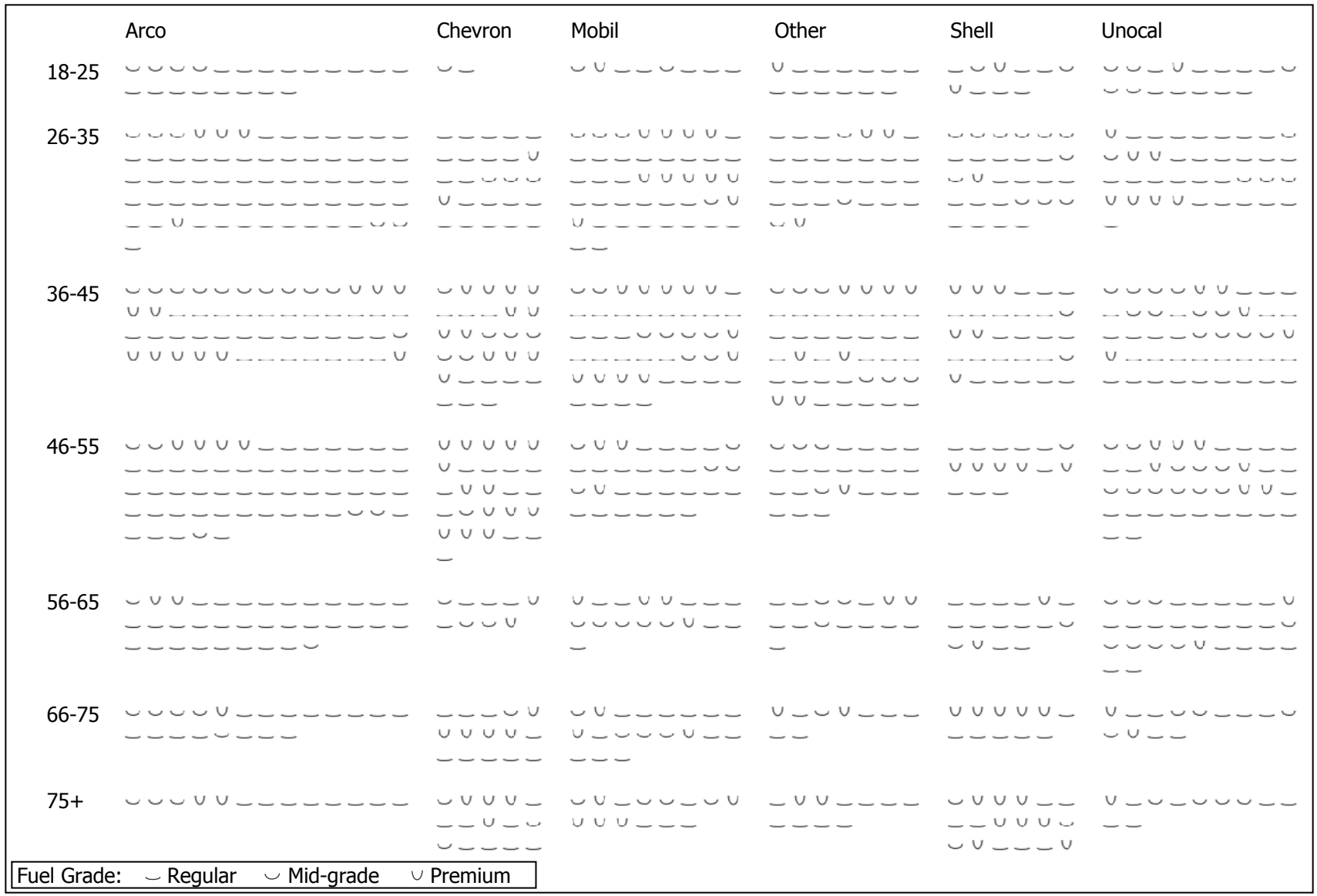
Gas Survey: Fuel Grade → Curve

Who sells the most premium (U) gasoline? Do the U's stand out? I think so!



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Experiment #1

- Seems like curves can effectively show 3 different categories.

Experiment #2: More categories of curves

- How about more curves?

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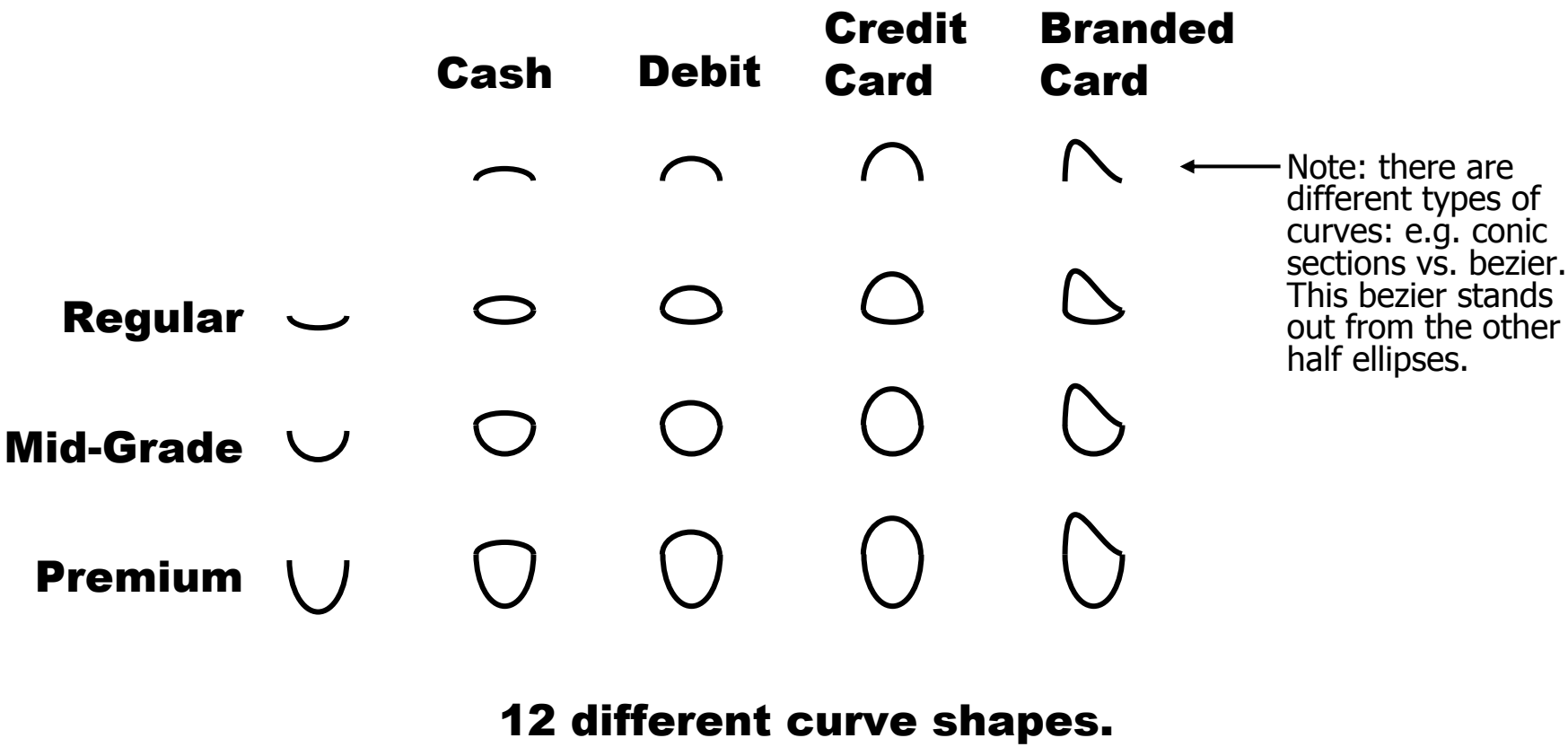
More Curves

using a morphological approach

Gas station survey data set:

- See both "fuel grade" and "payment method" using only curves:



12 different curve shapes.

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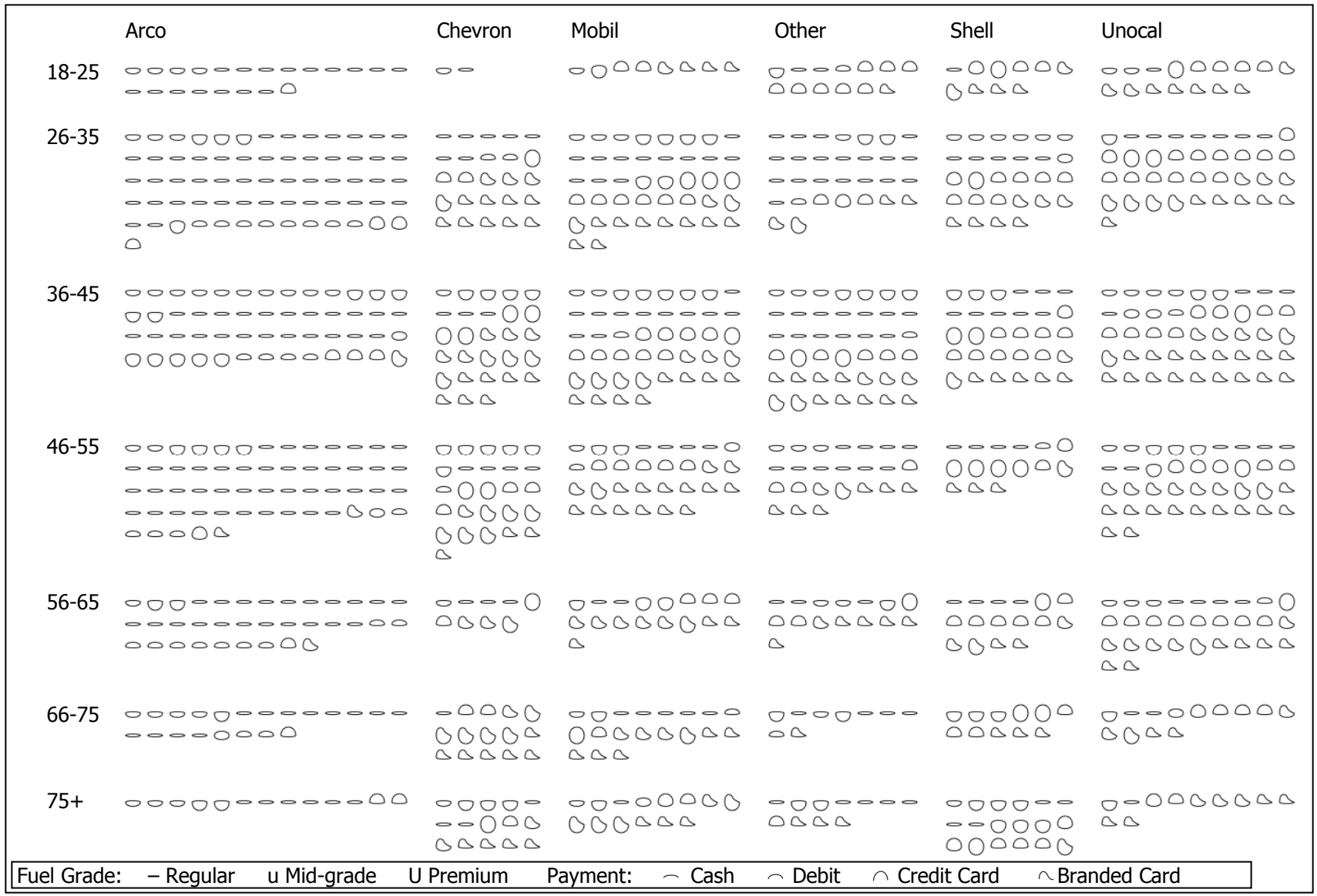
Gas Survey: Payment Method → 2nd Curve

How are they paying for that gasoline – cash or charge?



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Experiment #2 Findings

1. Curves could work for more than 3 categories
2. Multiple attributes of curves can be utilized to create different perceptually distinguishable curve shapes:
   - amplitude
   - skew
   - bulginess
3. And, we should repeat this experiment for angle, hole, terminators, etc

Attribute	Binary	Category	Order/Qty
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	**Y**	y	-
• Angle			
• Closure	**Y**		
• Intersection	**Y**		
• Terminators	**Y**		
• Holes	**Y**		

Attribute	Binary	Category	Order/Qty
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	**Y**	y	-
• Angle			
• Closure	**Y**		
• Intersection	**Y**		
• Terminators	**Y**		
• Holes	**Y**		

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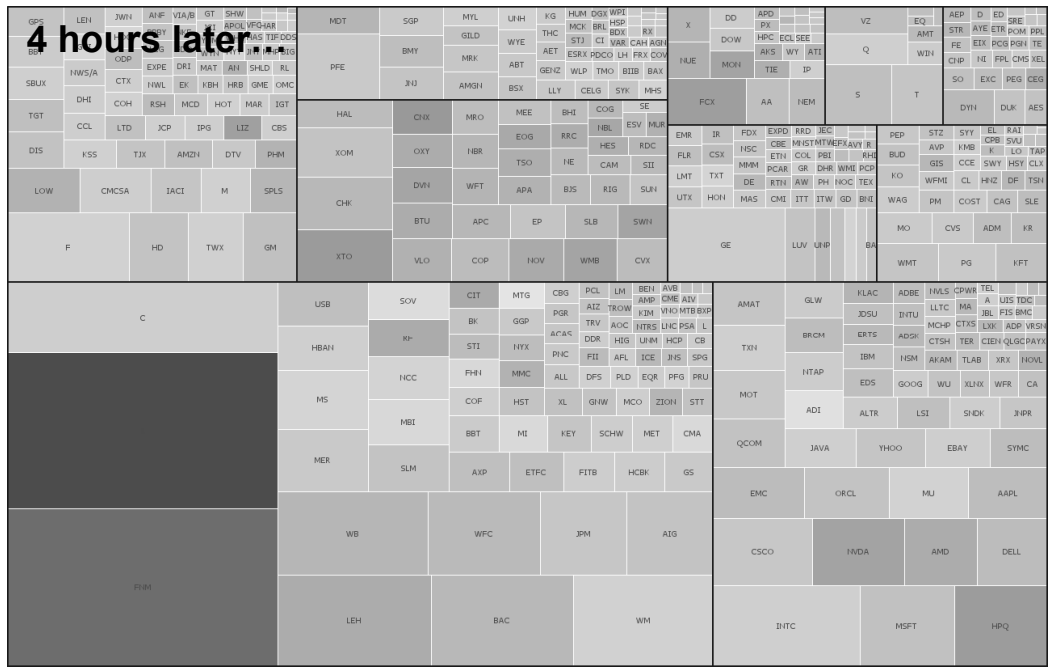
Experiment #3:

GOAL:

Replace a Treemap using quantitative shapes

Attribute	Binary	Category	Order/Qty
Shape		**Y**	N
Added Marks		**Y**	N
Curvature	**Y**	y	-
Angle			
Closure	**Y**		
Intersection	**Y**		
Terminators	**Y**		
Holes	**Y**		



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Inspiration: the use of angles in the Chappe Telegraph

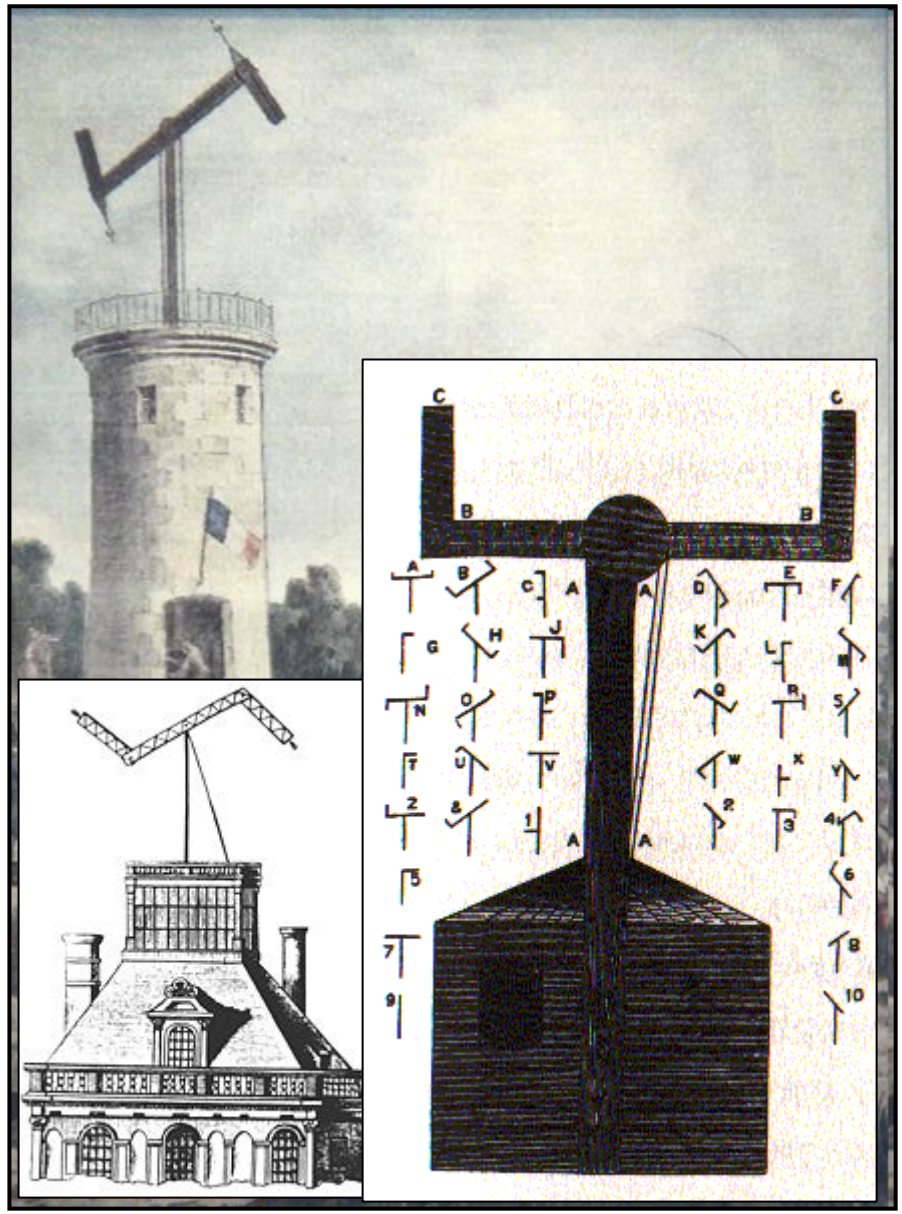

Image src: wikipedia.org www.ucalgary.ca/~bakardji/ElectricComm/Diag%201.gif

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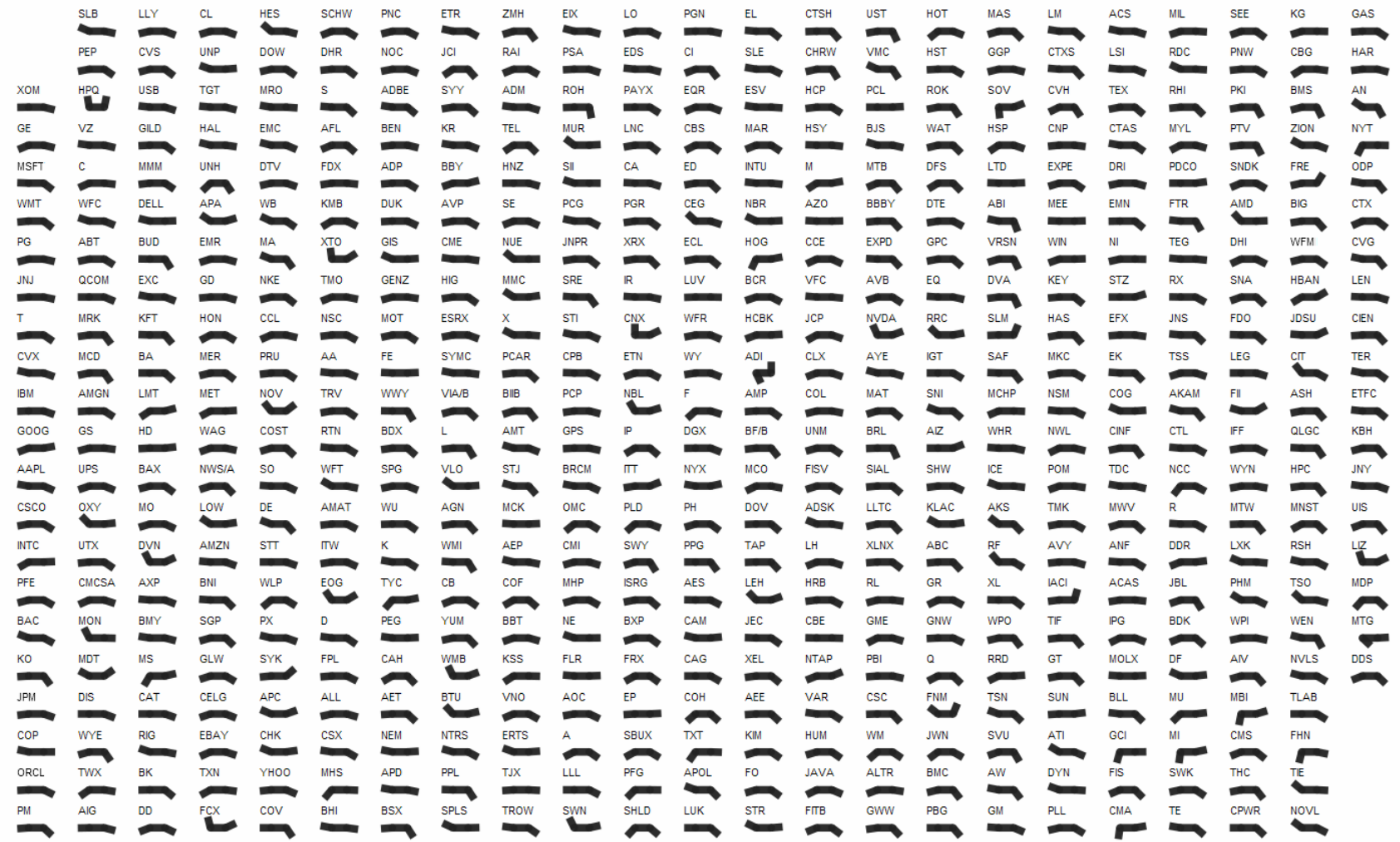
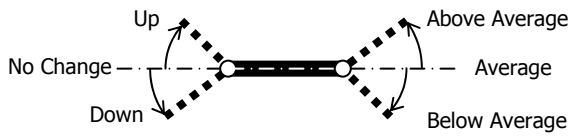
Chappe Telegraph as applied to S&P 500 data

left arm = percent change; right arm = volume relative to 30 day avg; horizontal = 0.



Stock Price
Percent change in stock price today



Volume
Today's volume compared to 30 day average volume

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Experiment #3: Chappe Telegraph Findings

Looks like angles work.

Attribute	Binary	Category	Order/Qty
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	**Y**	y	-
• Angle		y	y
• Closure	**Y**		
• Intersection	**Y**		
• Terminators	**Y**		
• Holes	**Y**		

Experiment #4: What about more?

Which other shape attributes can be efficient at representing quantitative data?

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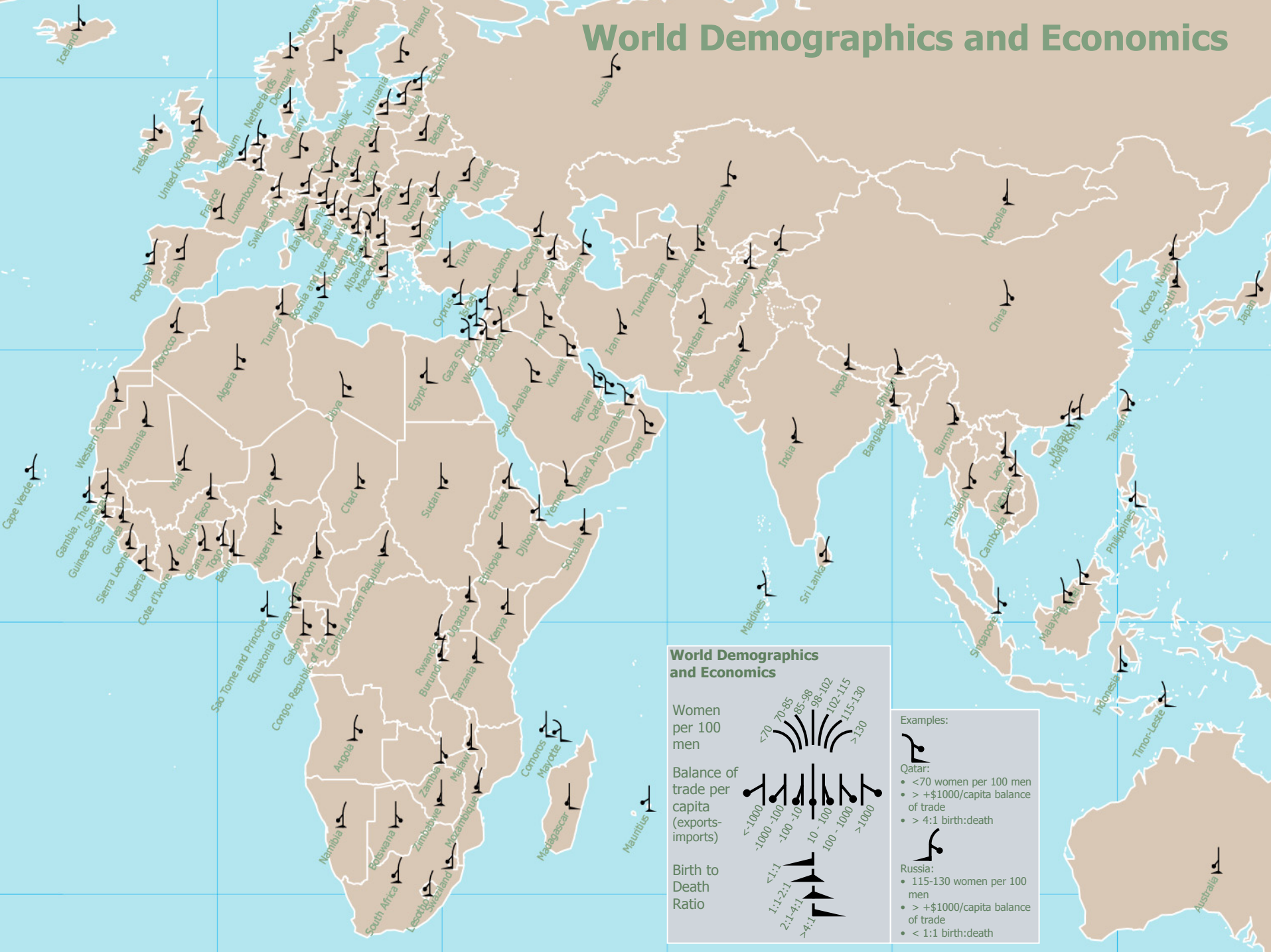
World Demographics and Economics



Experiment #4 Conclusions

- Curve, Angle and Terminator all potentially effectively
- Likely effective for categories too.
- And should try the other shape attributes too.

Attribute	Binary	Category	Order/Qty
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	**Y**	y	y
• Angle		y	y
• Closure	**Y**		
• Intersection	**Y**		
• Terminators	**Y**	y	y
• Holes	**Y**		

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Experiment #5:
What other shape attributes are there?

Attribute	Binary	Category	Order/Qty
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	**Y**	y	y
• Angle		y	y
• Closure	**Y**		
• Intersection	**Y**		
• Terminators	**Y**	y	y
• Holes	**Y**		

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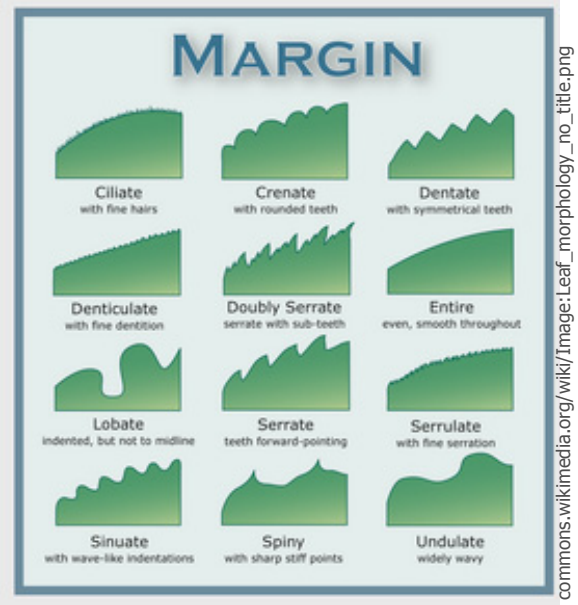
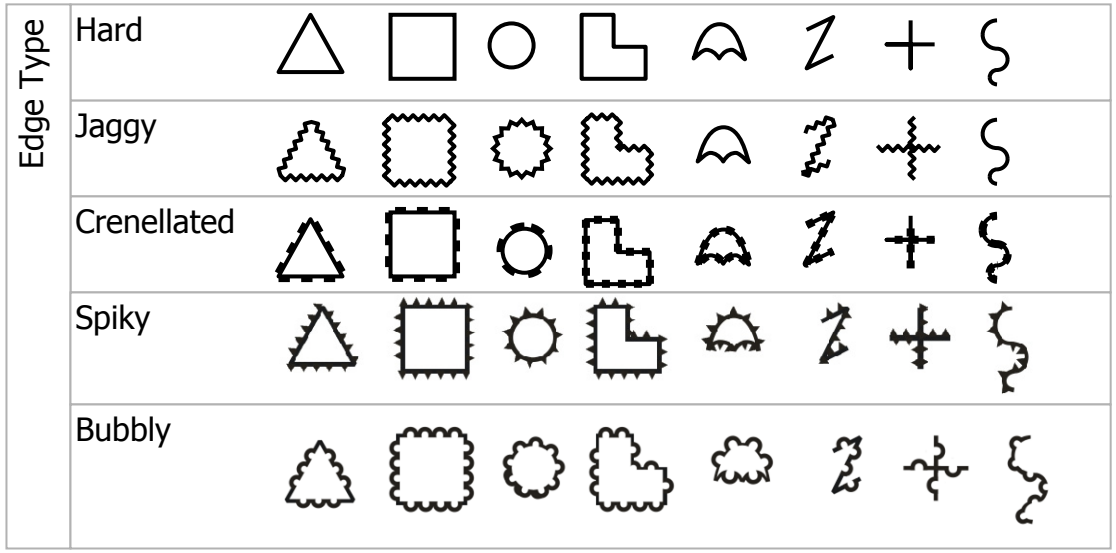
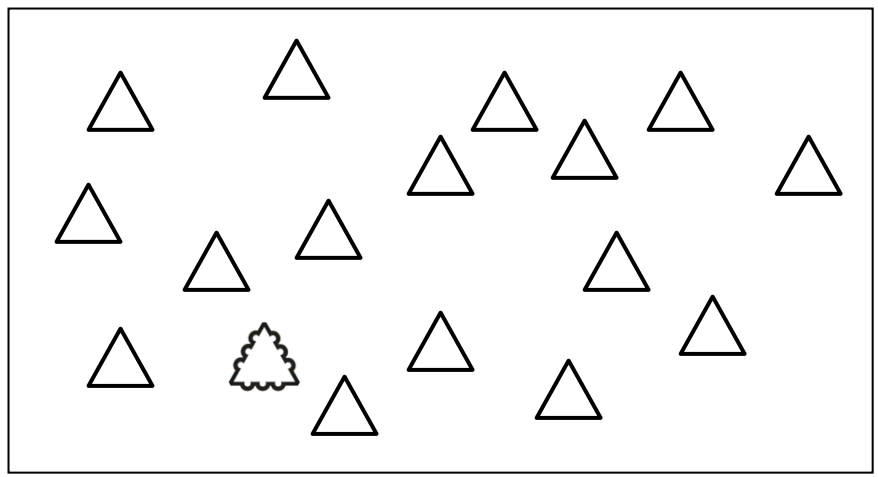
Edge type as Shape Attribute?



commons.wikimedia.org/wiki/Image:Leaf_morphology_no_title.png



Attribute	Binary	Category	Order/Qty
• Shape		**Y**	N
• Added Marks		**Y**	N
• Curvature	**Y**	y	y
• Angle		y	y
• Closure	**Y**		
• Intersection	**Y**		
• Terminators	**Y**	y	y
• Holes	**Y**		
• *Edge Type*	y		



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More attributes

And even more shape attributes:

- **Corners**: hard, rounded, beveled, corner hatch, bulleted, serifed, etc.
- **Warp**: shear, bend, wobble, twist, etc.
- **External Whiskers**: None, 1 (on longest side), 2 (on same side), 2 (on longest 2 sides), 1 (off of corner) (also internal whiskers, crossing whiskers).
- **Notch/Bump**: None, 1, 2, etc,
- **Internal Splits?**: None, 1 (vertical split into equal area), 1 (angular split 75/25), 2 splits, etc.

Attribute	Binary	Category	Order/Qty
Shape		**Y**	N
Added Marks		**Y**	N
Curvature	**Y**	y	y
Angle		y	y
Closure	**Y**		
Intersection	**Y**		
Terminators	**Y**	y	y
Holes	**Y**		
Edge Type	y		
Corner Type			
Warp			
Notch Bump			

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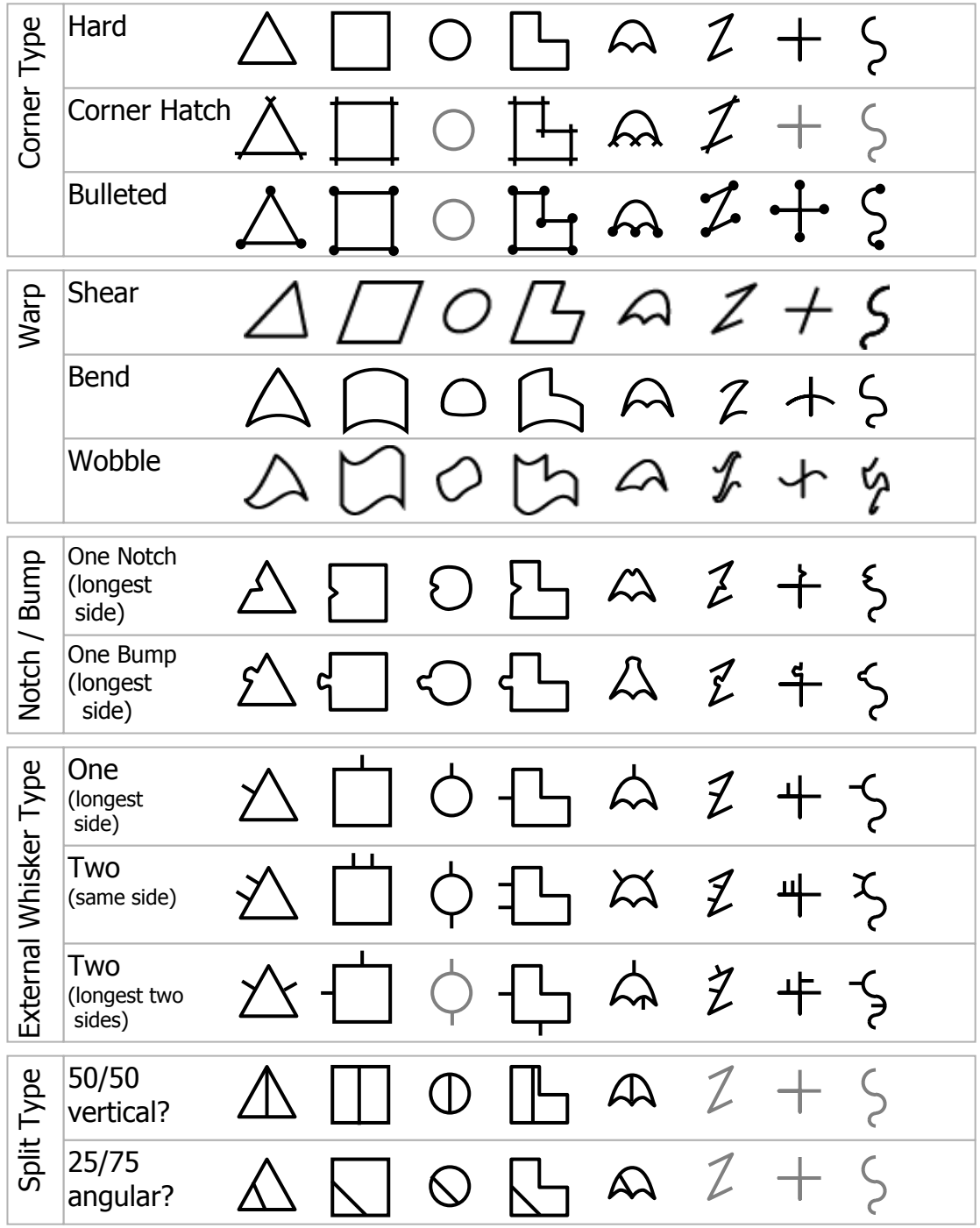
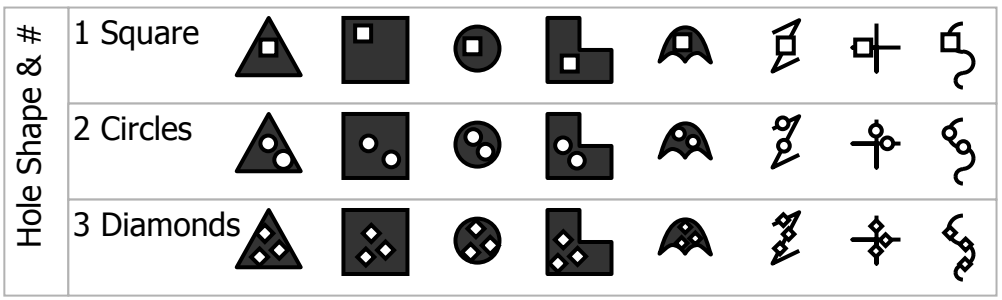
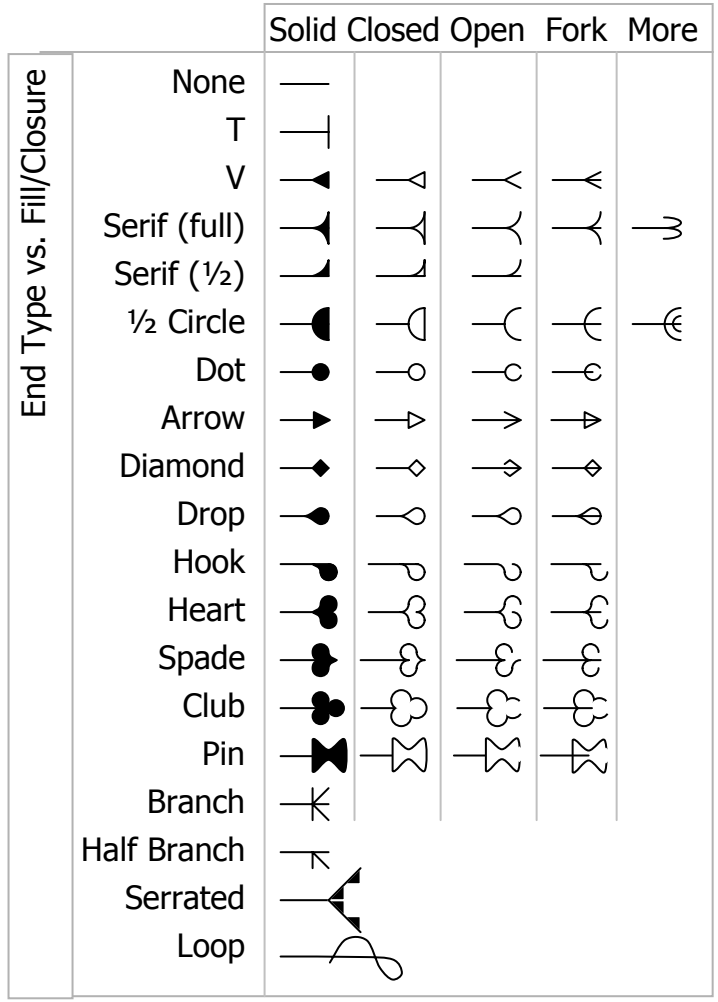


And even more attributes

Each of these attributes may have multiple sub-dimensions of richness. Consider:

- **Terminator Type**:
  - V, serif, dot, arrow, drop…
  - solid, closed, open, fork…
- **Holes**
  - 1, 2, 3…
  - square, circle, diamond…





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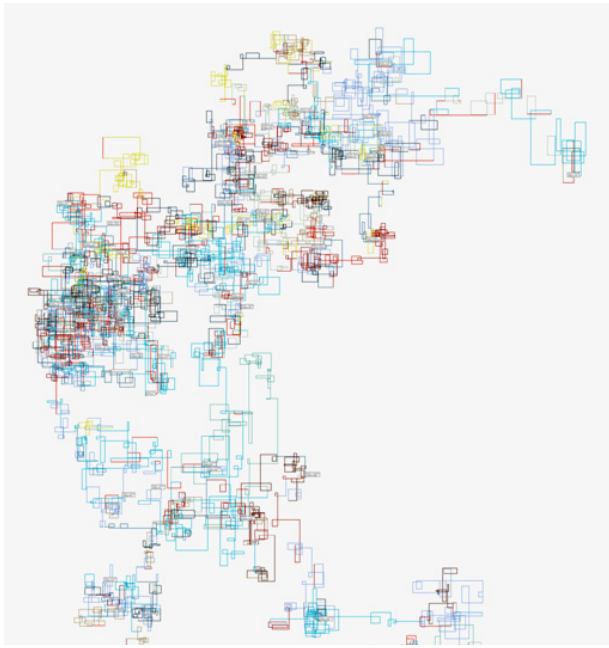
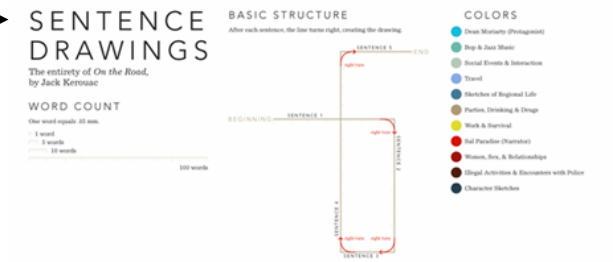
Consider Aesop's Fables

- ~80 very brief stories (5-15 sentences)
  - Multiple authors, editors, revisions over time
- What similarities exist between stories?
  - In vocabulary
  - In sentence structure
  - In dialogue
- Inspiration: Stephanie Posavec's Sentence Drawing visualizations; but with more shape attributes





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Aesop's Fables with curves, line type, terminators, angles.

Example:

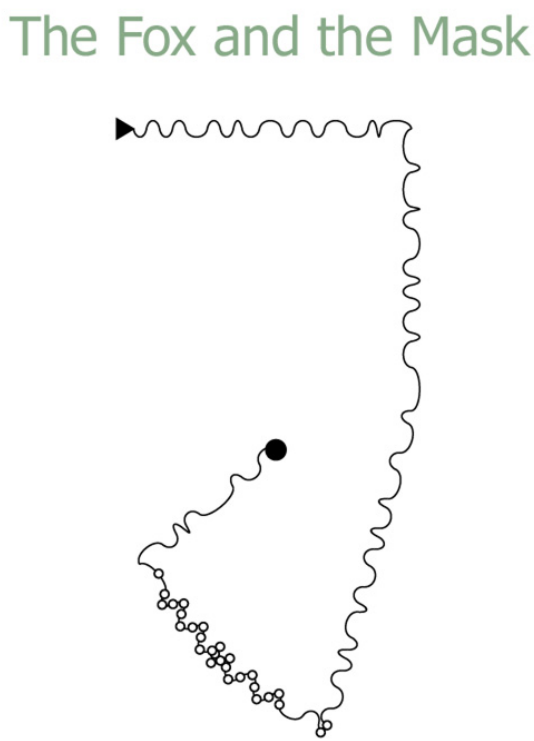
The Fox and the Mask

A Fox had by some means got into the store-room of a theatre.

Suddenly he observed a face glaring down on him and began to be very frightened; but looking more closely he found it was only a Mask such as actors use to put over their face.

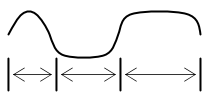
"Ah," said the Fox, "you look very fine; it is a pity you have not got any brains."

Outside show is a poor substitute for inner worth.

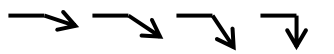


A story is a line between a *start* and *end:*

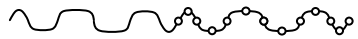
Each word is an alternating *curve:*



Punctuation *angles* the line:



Dialog differs in *line style:*



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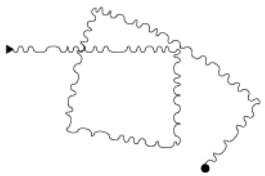
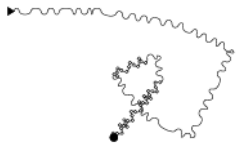
Aesop's Fables with curves, line type, terminators, angles

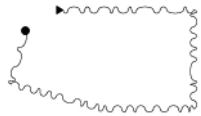
The Dog and the Shadow



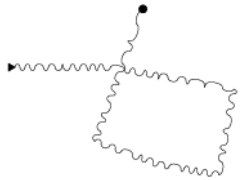
The Fisher



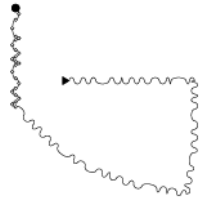
The Serpent and the File



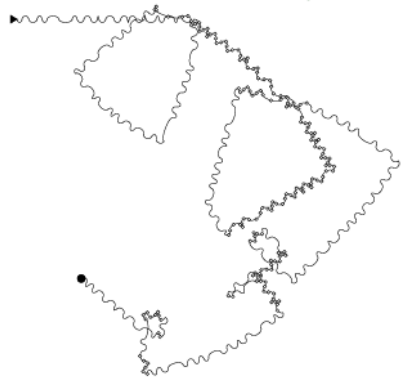
The Man and the Wood



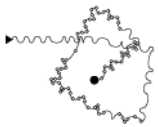
The Bald Man and the Fly



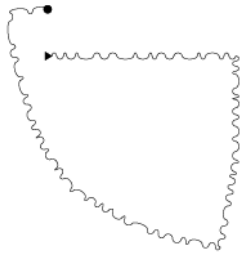
The Town Mouse and the Country Mouse



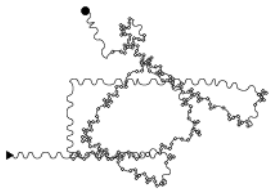
The Wolf and the Kid



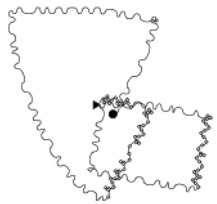
The Wolf in Sheep's Clothing



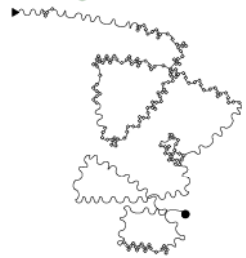
The Dog and the Wolf



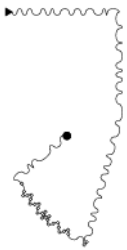
The Nurse and the Wolf



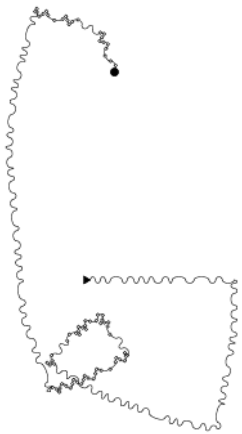
The Frog and the Ox



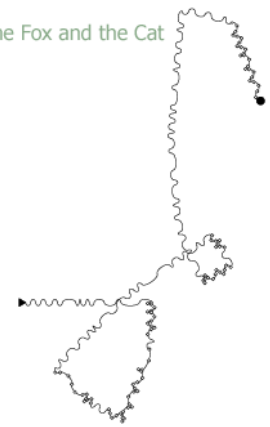
The Fox and the Mask



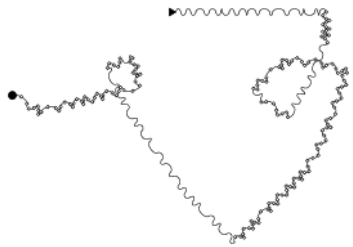
The Fox and the Stork



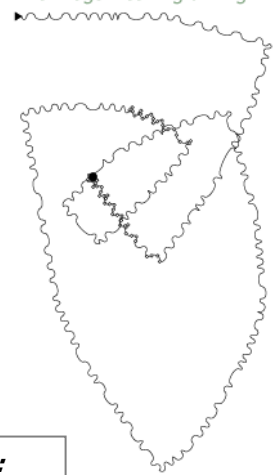
The Fox and the Cat



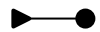
The Fox and the Crow



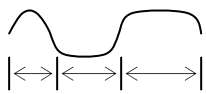
The Frogs Desiring a King



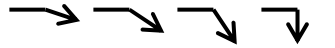
A story is a line between a *start* and *end:*



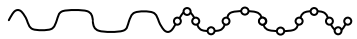
Each word is an alternating *curve:*



Punctuation *angles* the line:



Dialog differs in *line style:*



Experiment #5: Further Work

- Yet more attributes to consider

Attribute	Binary	Category	Order/Qty
Shape		**Y**	N
Added Marks		**Y**	N
Curvature	**Y**	y	y
Angle		y	y
Closure	**Y**		
Intersection	**Y**		
Terminators	**Y**	y	y
Holes	**Y**		
Edge Type	y		
Corner Type			
Warp			
Notch/Bump			

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Experiment #6: Sub-Attributes

Sub-attributes?

- Curve:
  - 2 control points, each with direction and amplitude
- Terminator:
  - Shape and filled/closed/open/forked
- Holes
  - Shape and number

Could sub-attributes make a star/radar glyph more effective?

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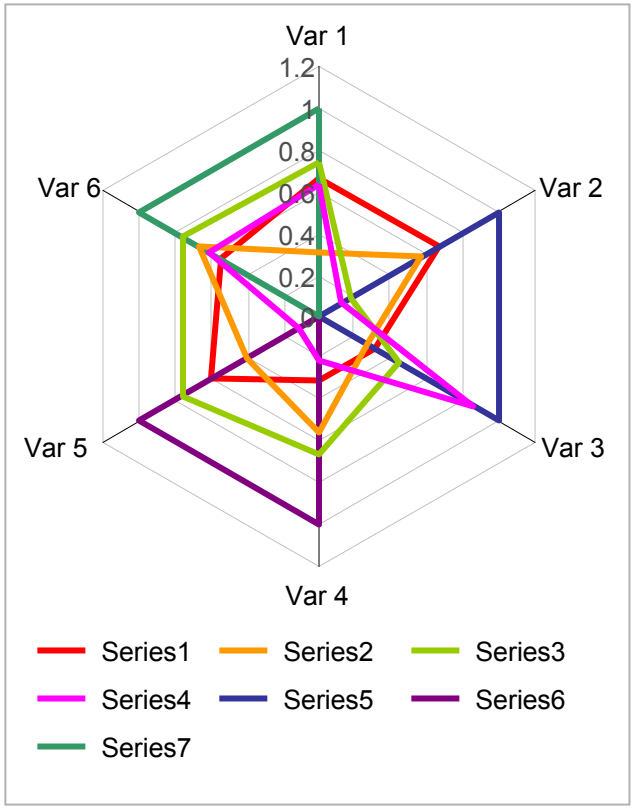
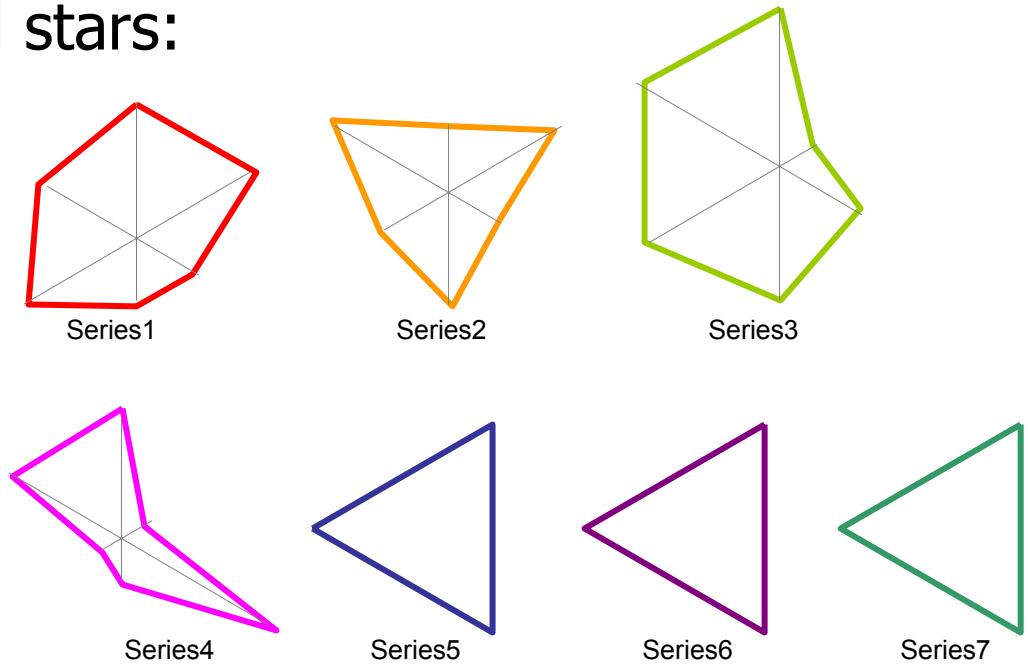
Shape with High Dimensions

Problems with radars and stars:





1. Many overlapping lines: Spaghetti difficult to visually separate and decipher.
2. Can be solved by separation. But shape without a reference difficult to decode.
3. Can add a reference (star) but some shapes are still ambiguous.
4. Can add reference and axes.
5. Not just about shape anymore.

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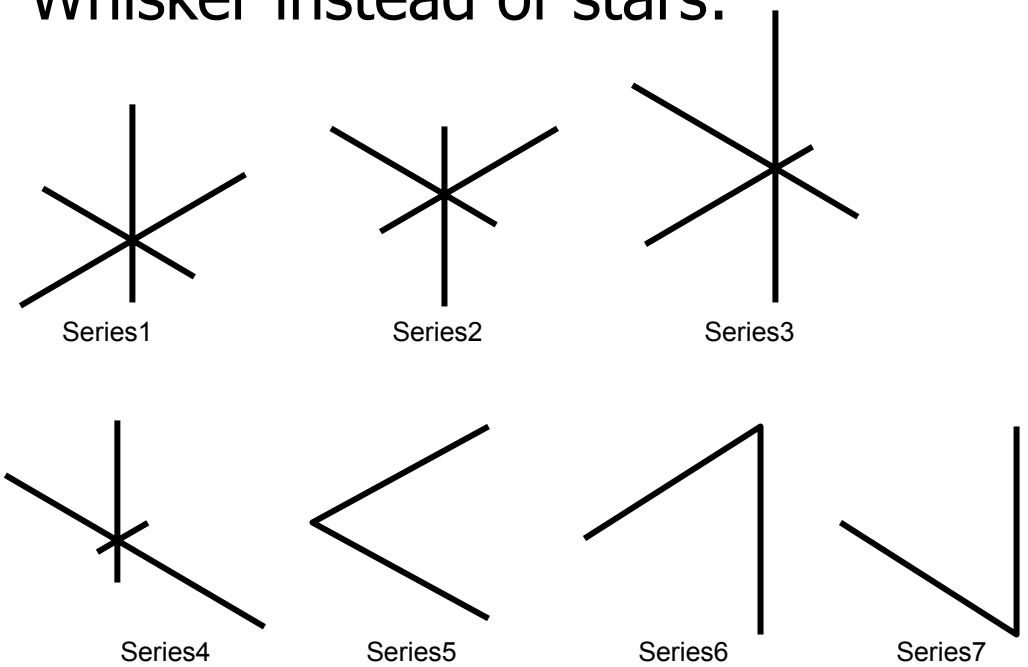
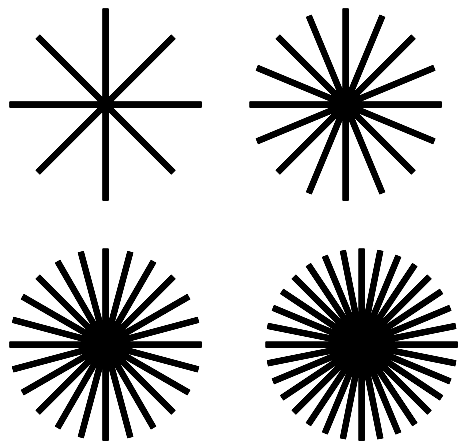
Shape with High Dimensions

Whisker instead of stars:



+ Ambiguity from radar resolved.
- Can the technique scale up to 8, 16, 24, 32, 100 attributes?
- How can one refer to which axis?
- Doesn't it just become noise with real data each axis of a different length?
- Possibly solvable with interactive filtering. But interaction limits potential in collaboration and hardcopy.



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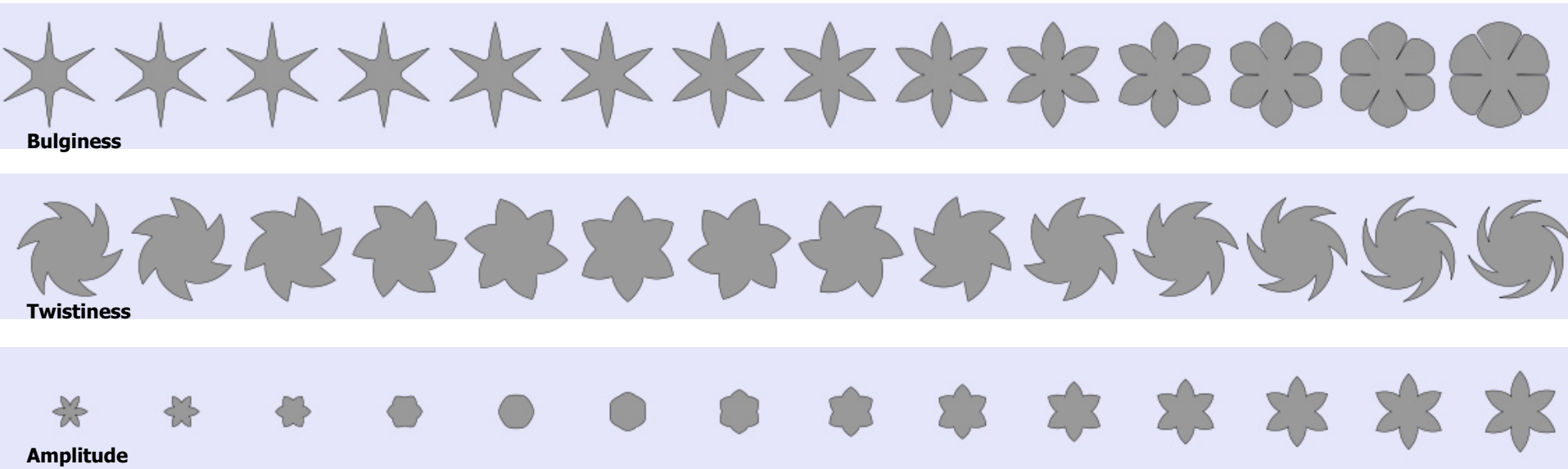
Consider star glyphs, but with additional shape warping attributes…



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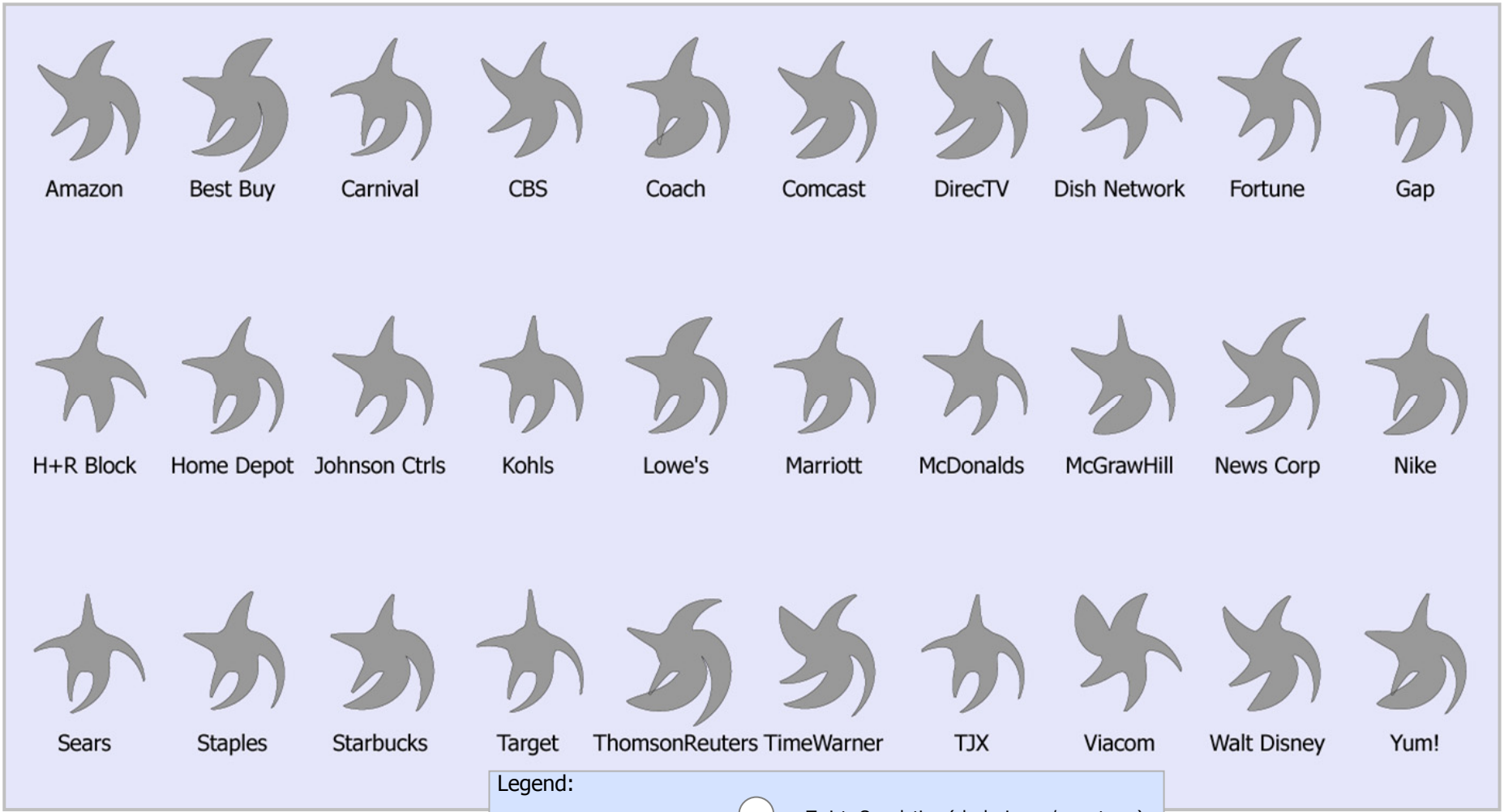
Correlations via Twist, Bulge and Amplitude



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Experiment #6: Sub-Attributes

- Yet more attributes to consider

Attribute	Binary	Category	Order/Qty	*Sub-Attributes*
Shape		**Y**	N	*square/circle/triangle/dash/star/kite/etc*
Added Marks		**Y**	N	*whiskers/etc, amplitude, density*
Curvature	**Y**	y	y	*amplitude, bulge*
Angle		y	y	*angle*
Closure	**Y**			*degree of closure?*
Intersection	**Y**			*number of branches, tree attributes*
Terminators	**Y**	y	y	*width, depth, none/serif/circle/square*
Holes	**Y**			*shape, size, number*
Edge Type	y	y		*shape, amplitude, frequency*
Corner Type				*shape, amplitude, frequency*
Warp				*bulge/pinch, amplitude, twist, shear*
Notch/Bump				*semi-circle/v/square, amplitude, width, number*

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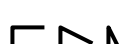
The Many Dimensions of Shape

Shape has many attributes and sub-attributes, worth much more exploration, experimentation and evaluation. Here's a possible framework for shape attributes and sub-attributes:

Shape Attribute		Categoric	Quantitative
1. Closure		closed/open	degree of closure?
2. Curvature		curved a bit/alot/not	amplitude, skew, bulge
3. Corner Angle		obtuse/right/acute	degree of angle
4. Edge Type		straight/spiky/etc	amplitude, frequency
5. Corner Type		sharp/round/serif/etc	size
6. End Type		none/serif/dot/etc	width, depth
7. Notch/Bump		v/half-round/etc	width, depth
8. Whiskers (?)		on/not/slope/etc	density, length
9. Holes		shape	size, number
10. Intersection		three/four/five	number of spokes
11. Local Warp		shear, twist, bulge	factor

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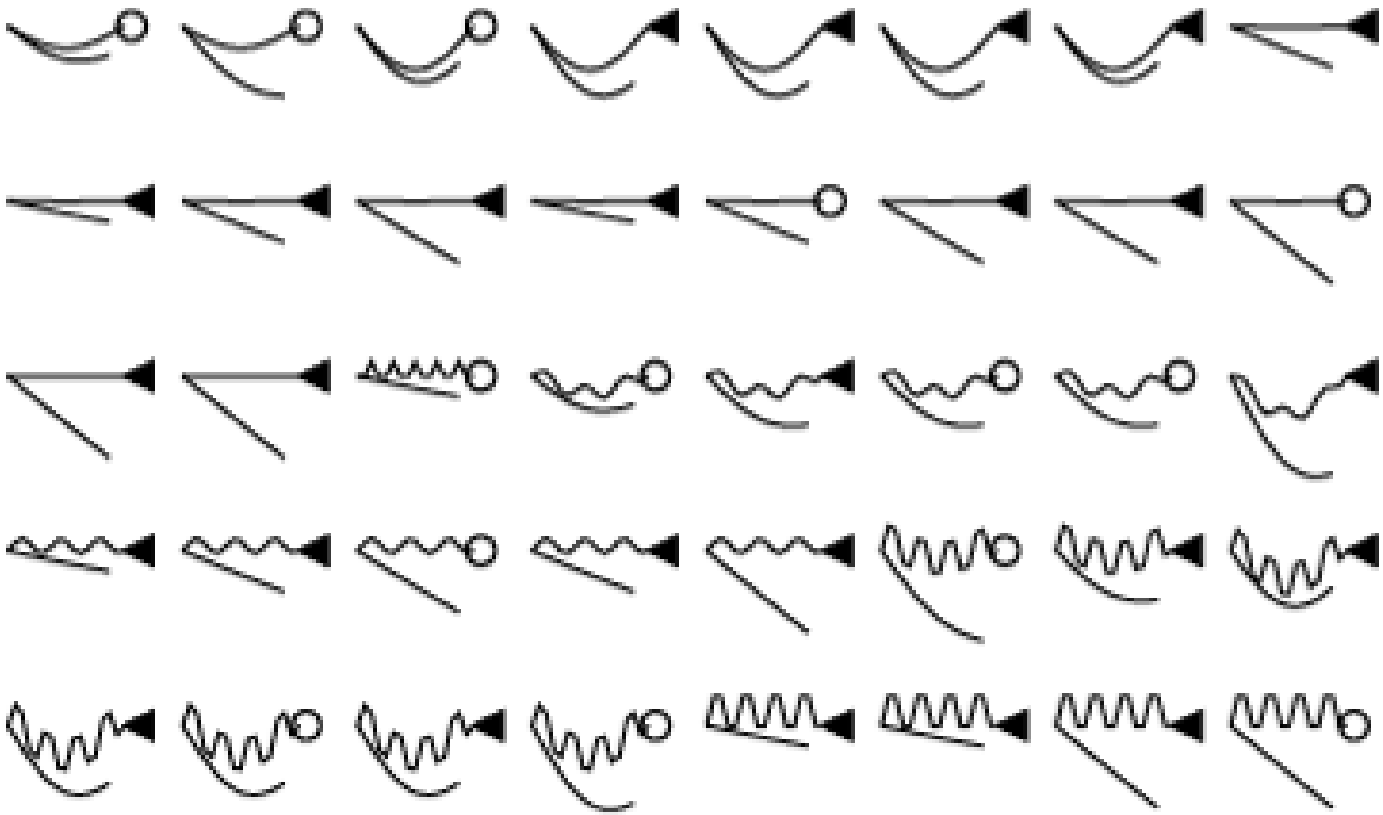
Thank You!



Fuel Purchases at Mobil by people ages 36-45:

Fuel Grade
- Regular
- Mid-grade
- Premium

Payment
- Cash
- Debit
- CreditCard
- BrandCard

Gender
- Male
- Female

Income
- Low
- Lower-Middle
- Middle-High
- High

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