

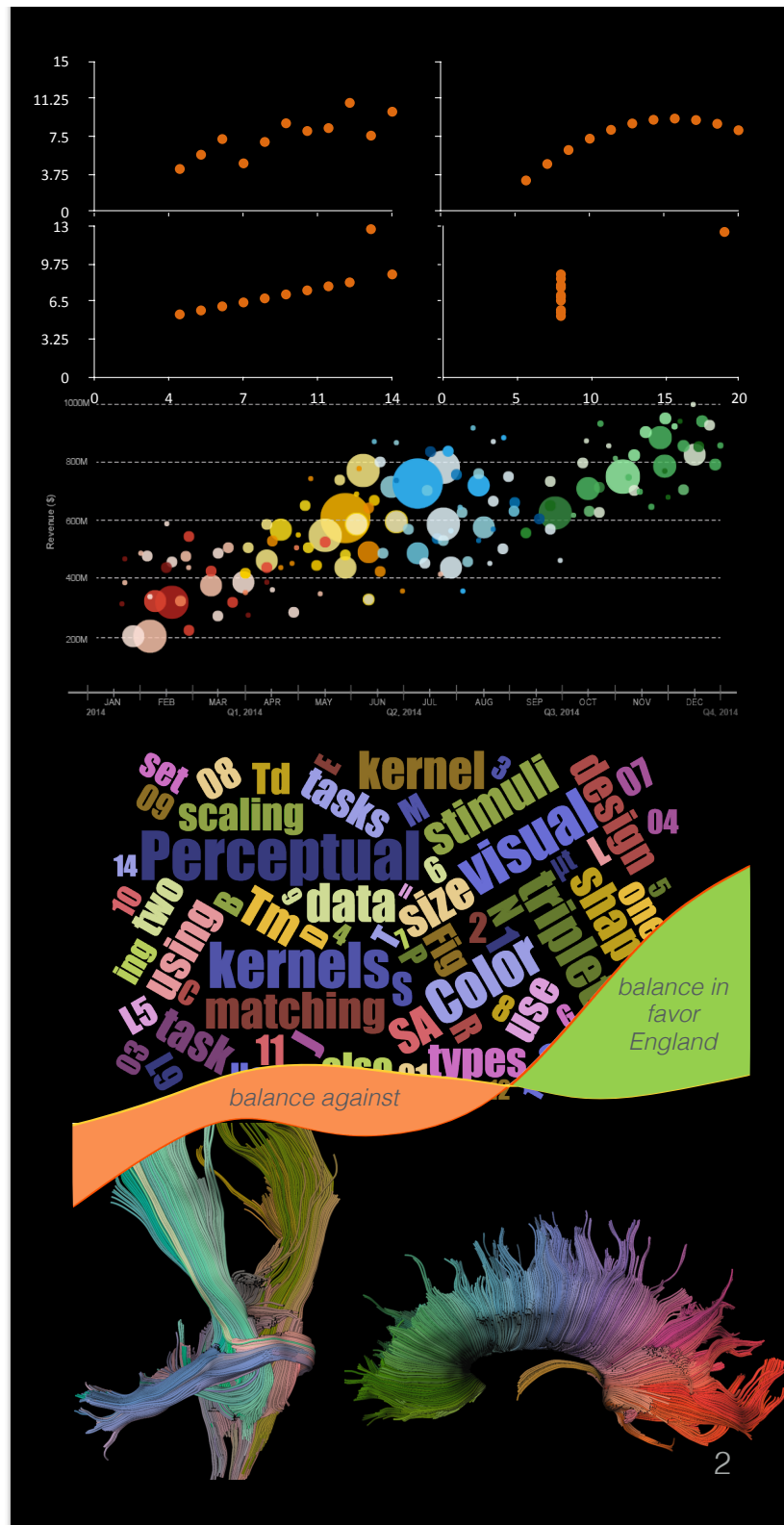
Learning Perceptual Kernels for Visualization Design

Çağatay Demiralp
Stanford University

Michael Bernstein
Stanford University

Jeffrey Heer
University of Washington

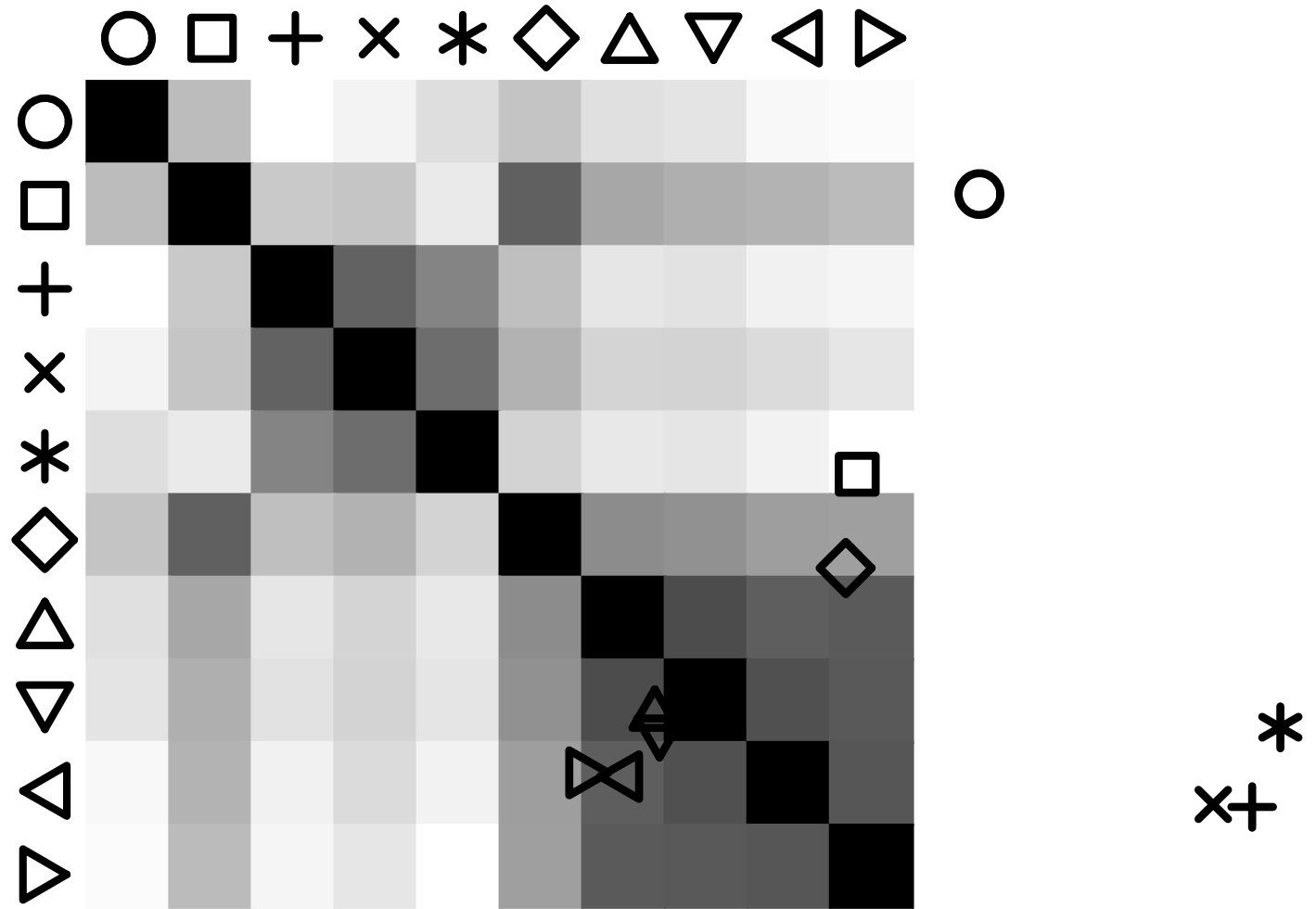
Visualizations Leverage Perception



Engineering
Perception
Into
Visualization
Design?



A Measure of Perceptual Reality



Perceptual Kernel

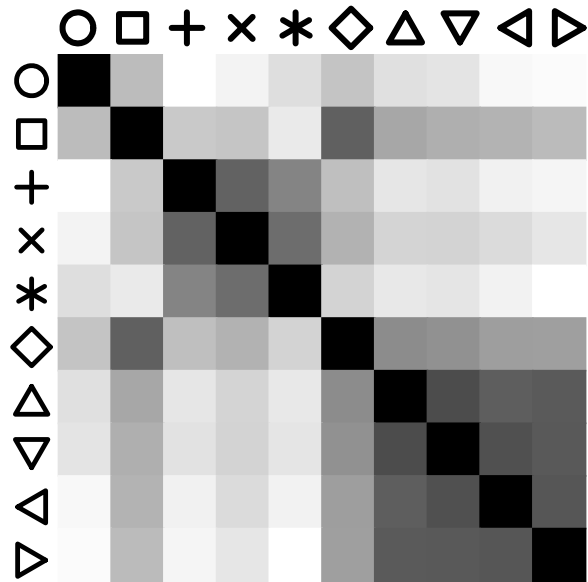
2D Projection

What are
Perceptual
Kernels
Useful For?

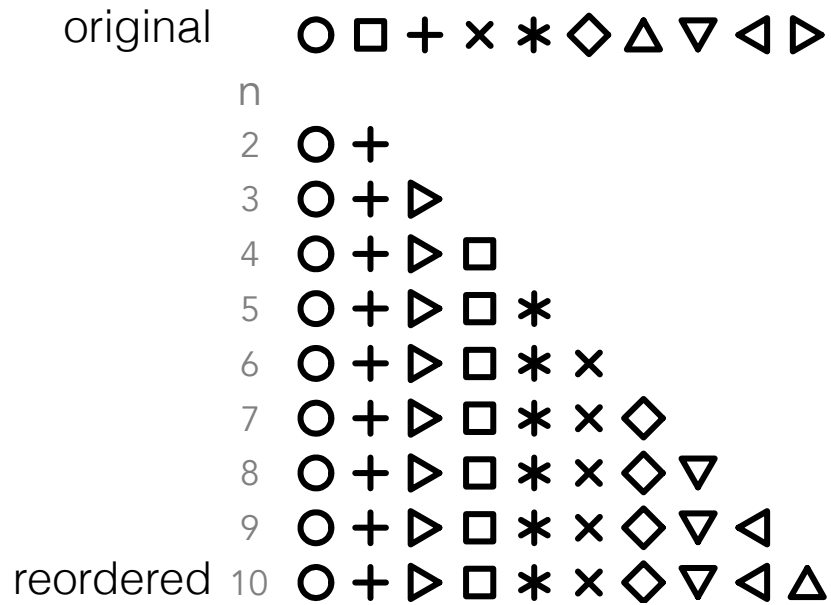
Automating Visualizations



Palette Design

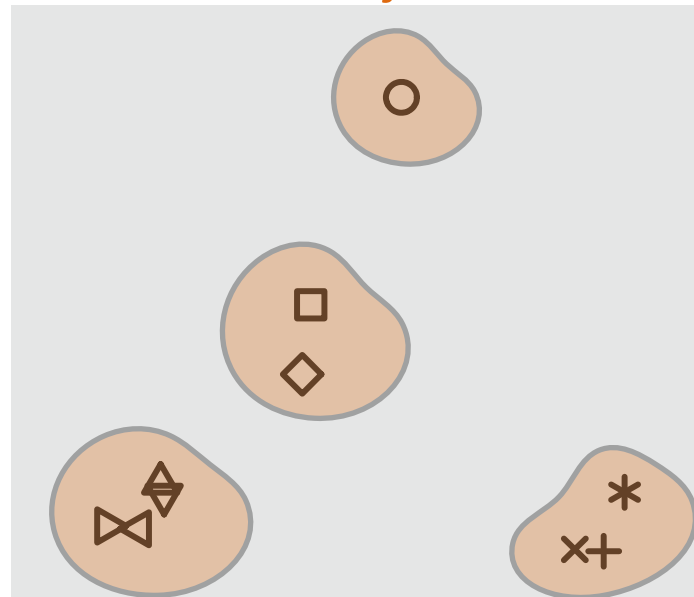


Palette Design



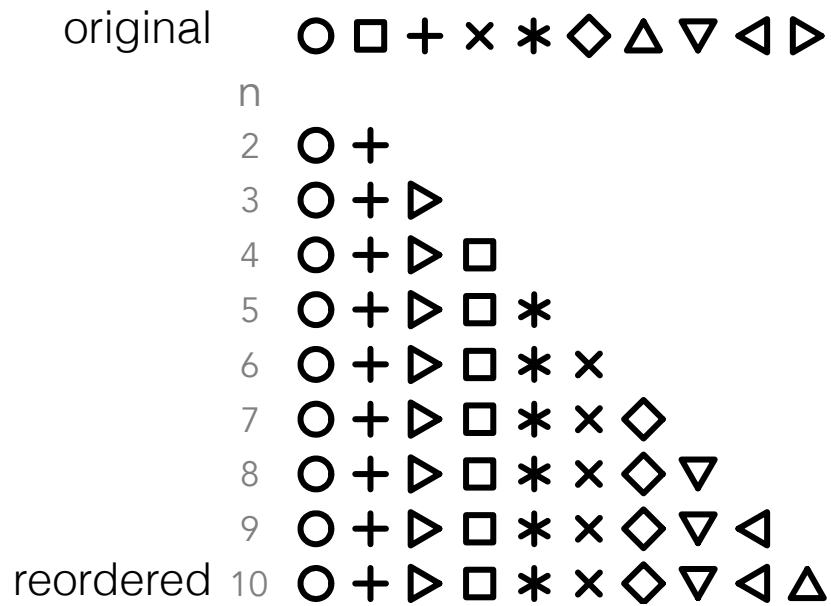
Palette Design

2D Projection

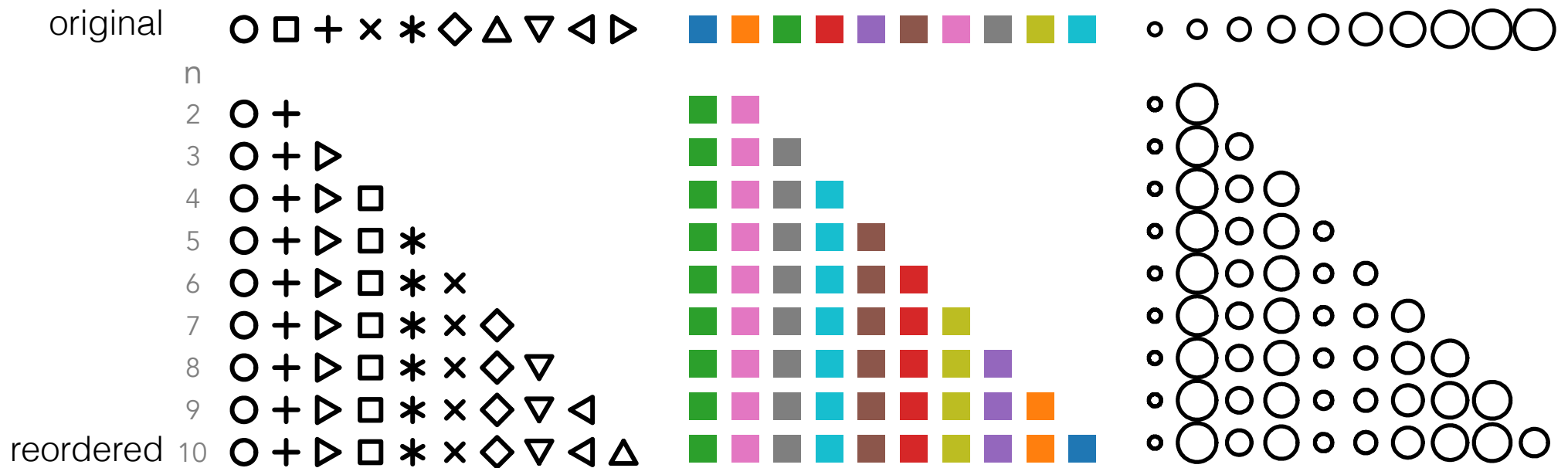


reordered ○ + ▷ ◻ * × ◊ ▽ ◀ ▶

Palette Design



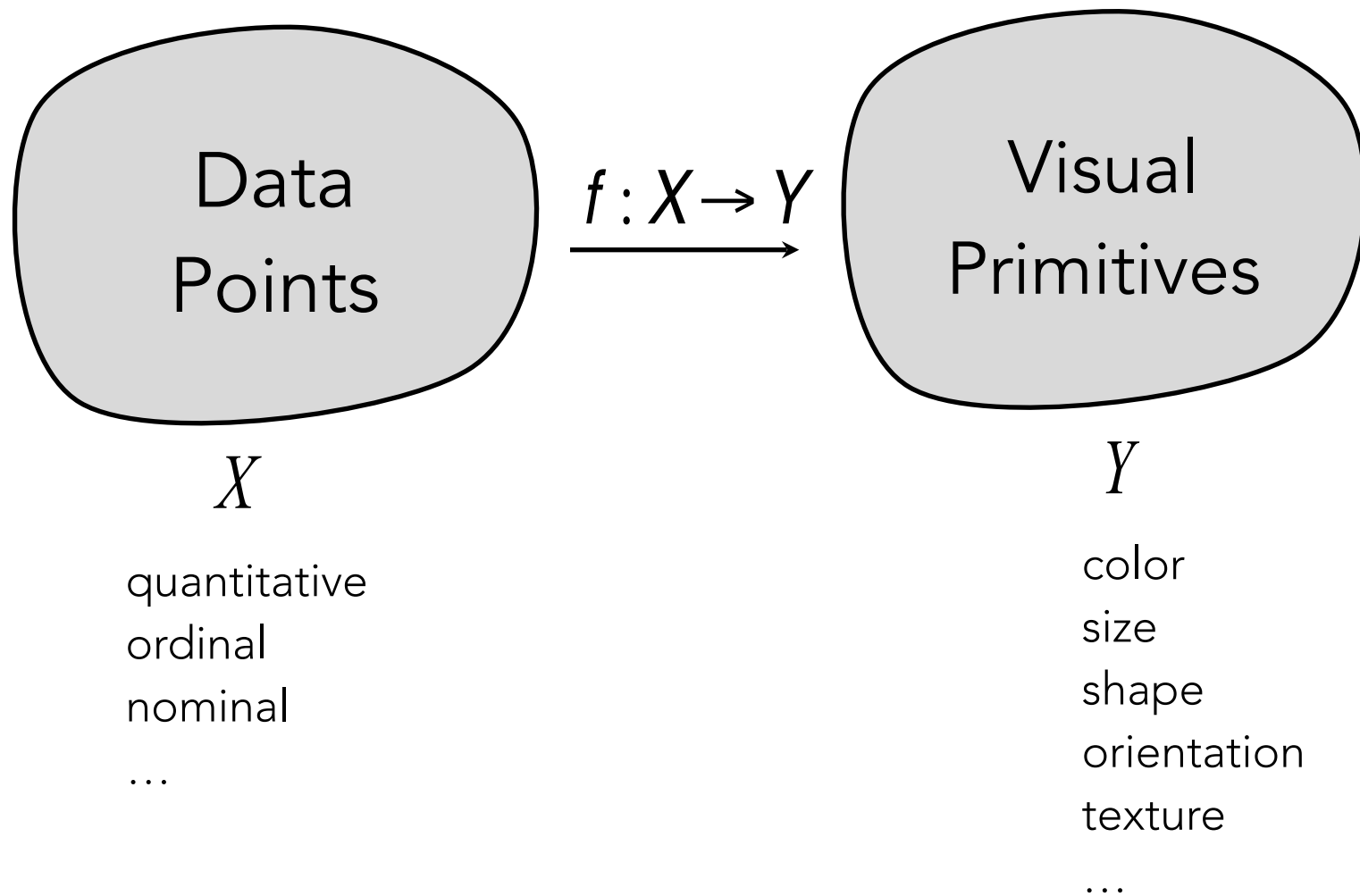
Palette Design



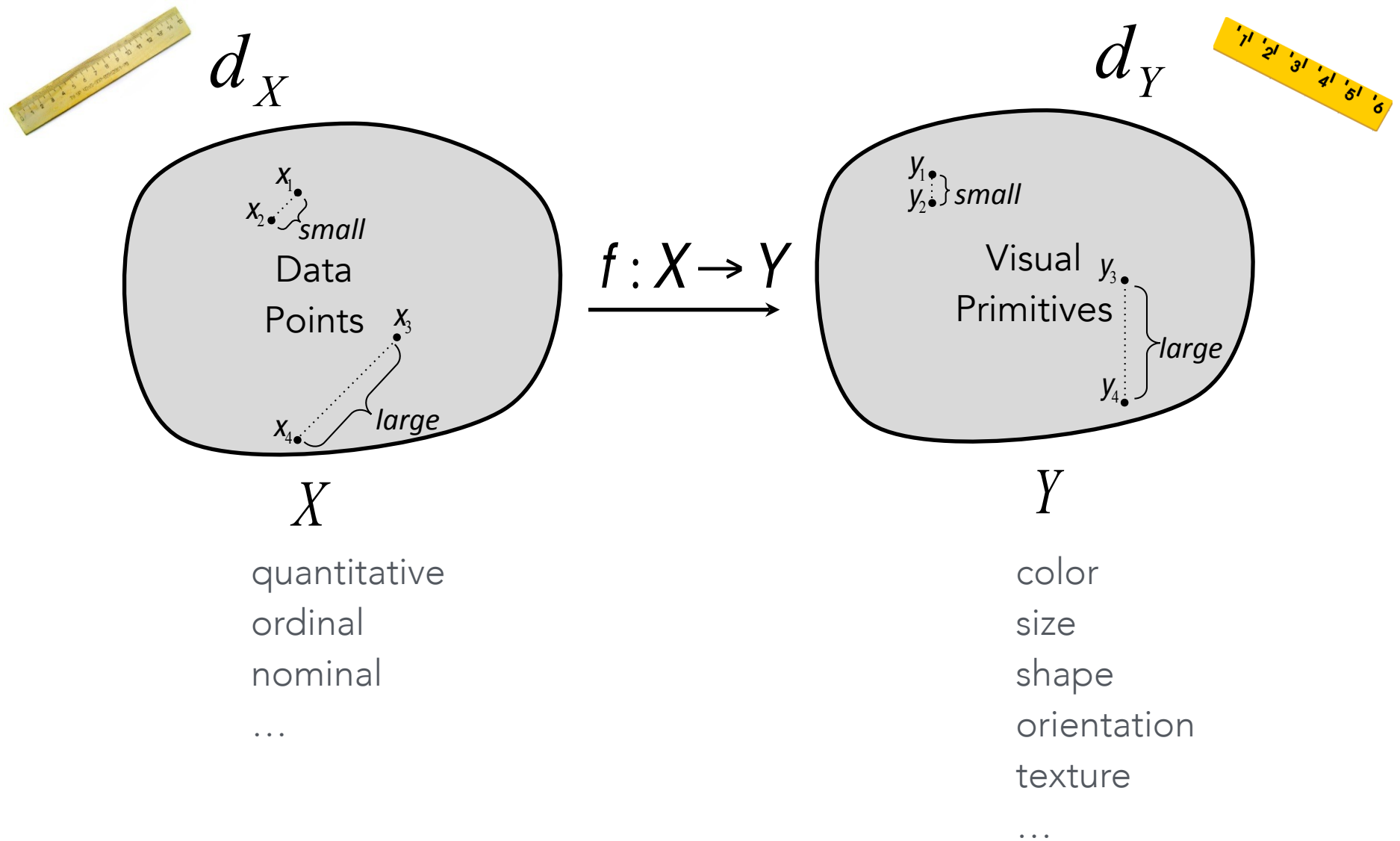
Palettes re-ordered to maximize perceptual discriminability

Visual Embedding: A Model for Visualization

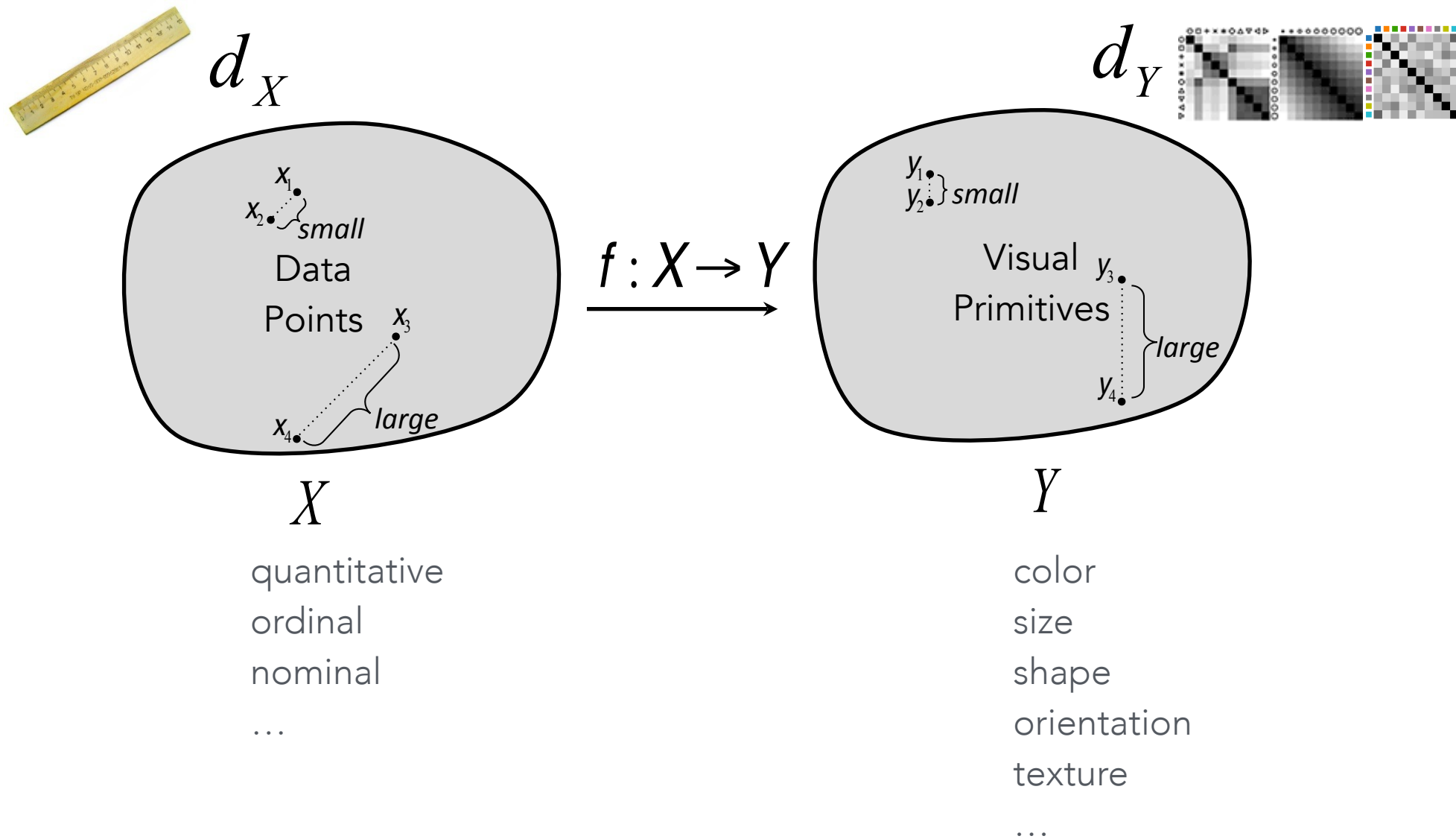
Visualizations as Functions



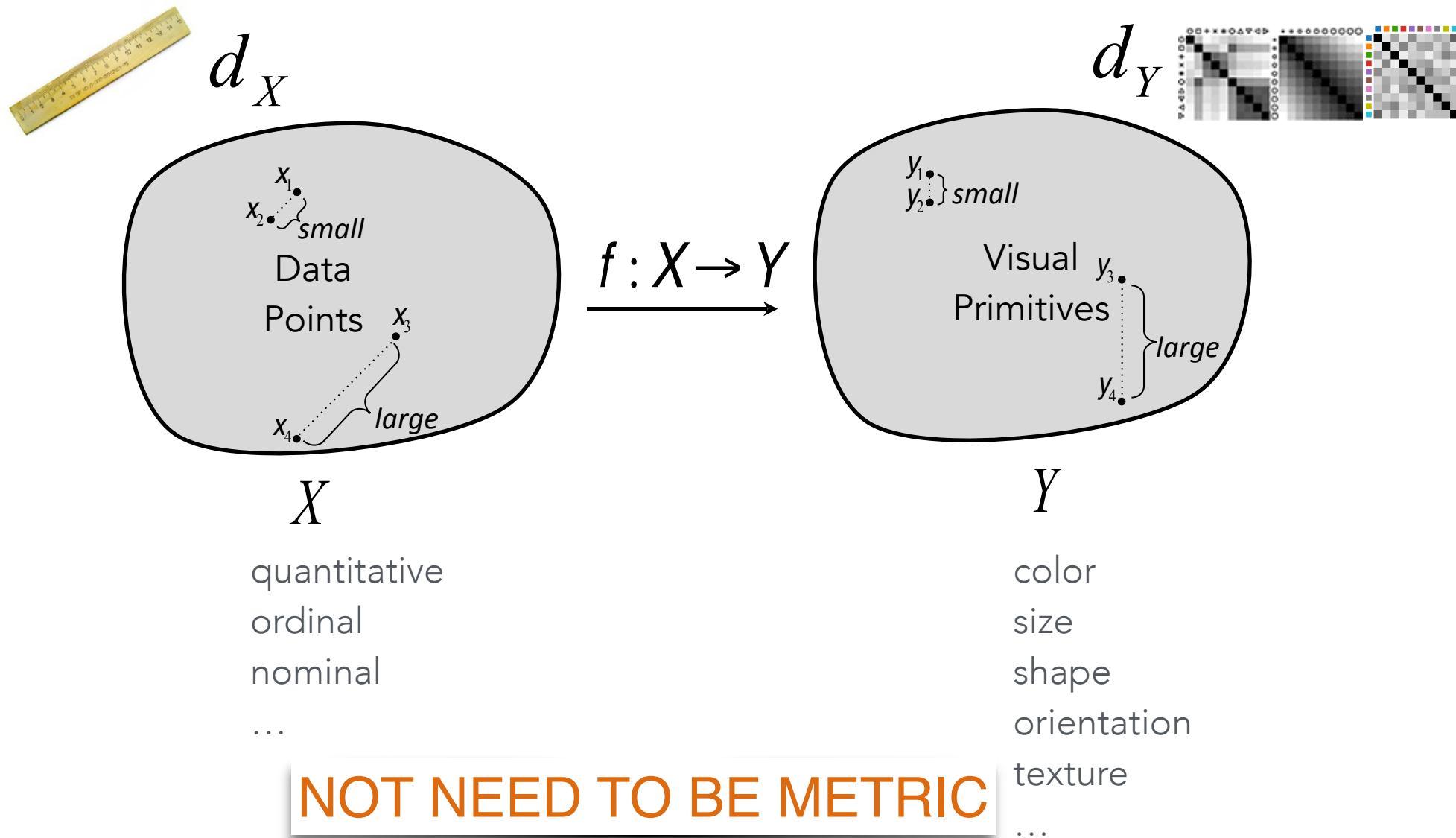
Visual Embedding



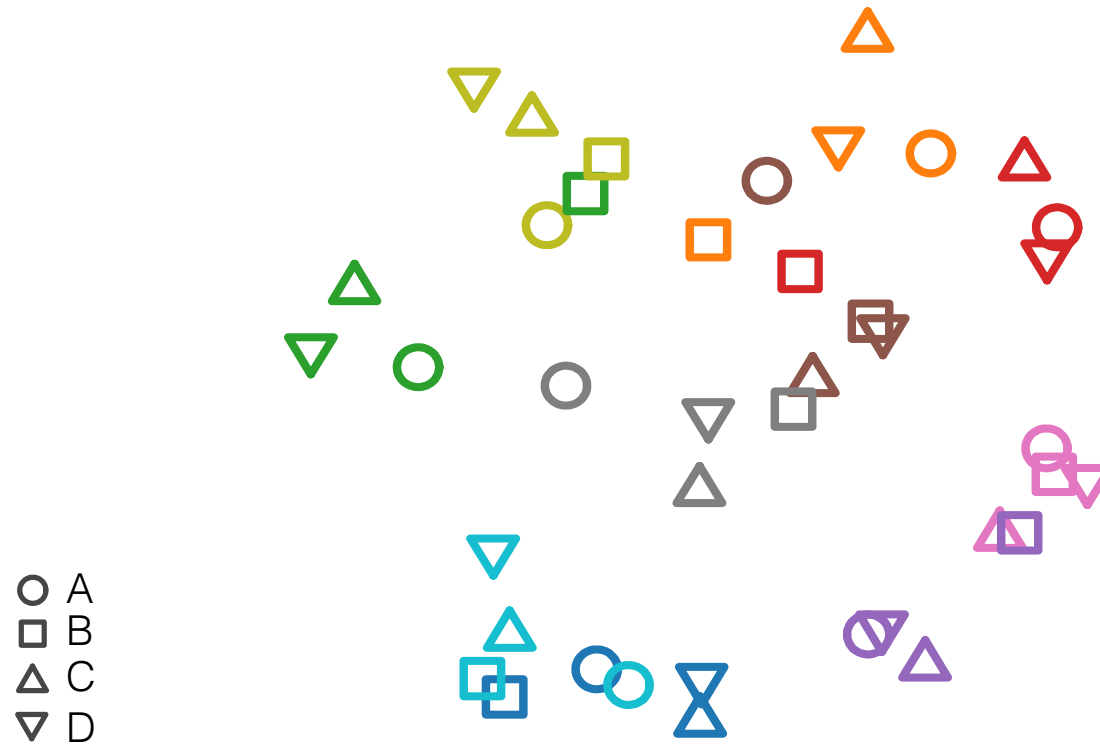
Visual Embedding



Visual Embedding



Rank Correlations



	A	B	C	D
A	1.00	0.75	0.67	0.59
B		1.00	0.81	0.77
C			1.00	0.87
D				1.00

Rank Correlations

○	A
□	B
△	C
▽	D

	A	B	C	D
A	1.00	0.75	0.67	0.59
B		1.00	0.81	0.77
C			1.00	0.87
D				1.00

Rank Correlations

○	A
□	B
△	C
▽	D

	A	B	C	D
A	1.00	0.75	0.67	0.59
B		1.00	0.81	0.77
C			1.00	0.87
D				1.00

Rank Correlations

○	A
□	B
△	C
▽	D

	A	B	C	D
A	1.00	0.75	0.67	0.59
B		1.00	0.81	0.77
C			1.00	0.87
D				1.00

Rank Correlations

○	A
□	B
△	C
▽	D

	A	B	C	D
A	1.00	0.75	0.67	0.59
B		1.00	0.81	0.77
C			1.00	0.87
D				1.00

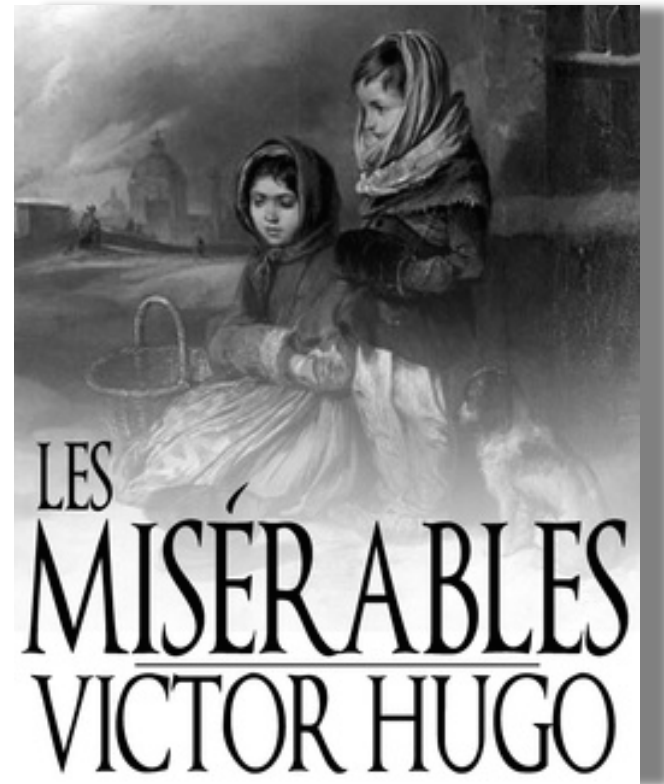
Rank Correlations

○	A
□	B
△	C
▽	D

	A	B	C	D
A	1.00	0.75	0.67	0.59
B		1.00	0.81	0.77
C			1.00	0.87
D				1.00

Cluster Connectivity

Encode community clusters in a character co-occurrence graph.





CONTRIBUTIONS

CONTRIBUTIONS

1) Estimate perceptual kernels

shape ○ □ + × * ◇ △ ▽ ◁ ▷
size ○ ○ ○ ○ ○ ○ ○ ○ ○ ○
color ■ ■ ■ ■ ■ ■ ■ ■ ■ ■

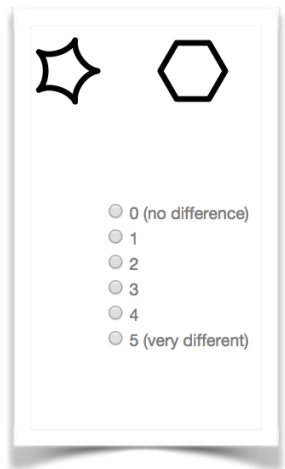
shape-size □ + × ◇ □ + × ◇ □ + × ◇ □ + × ◇ □ + × ◇

shape-color □ + × ◇ □ + × ◇ □ + × ◇ □ + × ◇ □ + × ◇ □ + × ◇

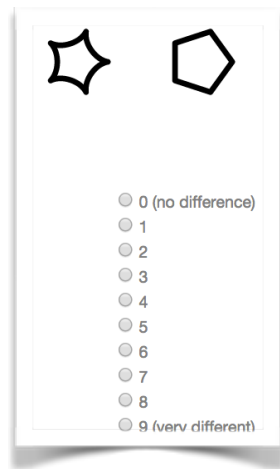
size-color ○

CONTRIBUTIONS

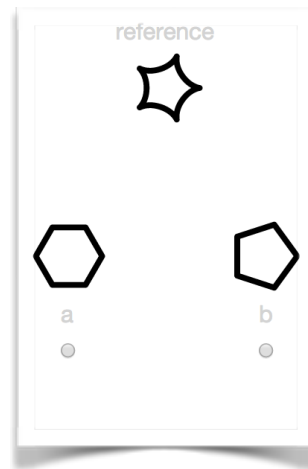
2) Compare alternative judgment types



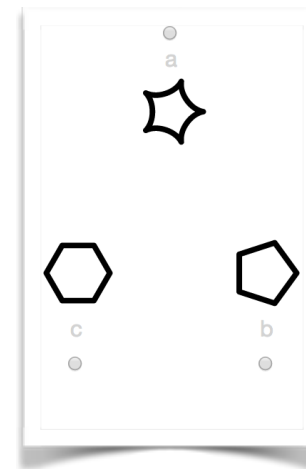
pairwise-5



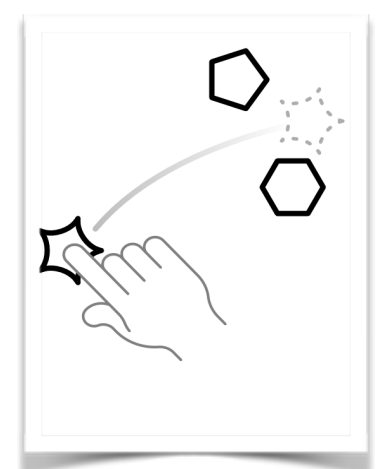
pairwise-9



triplet
matching



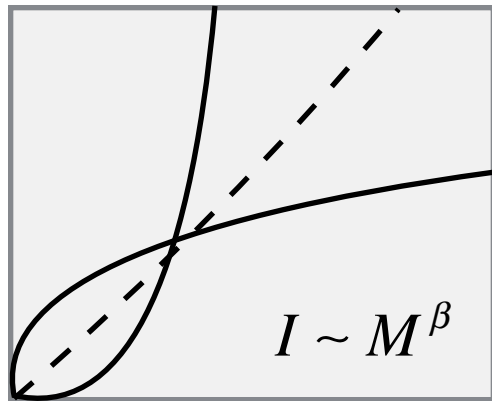
triplet
discrimination



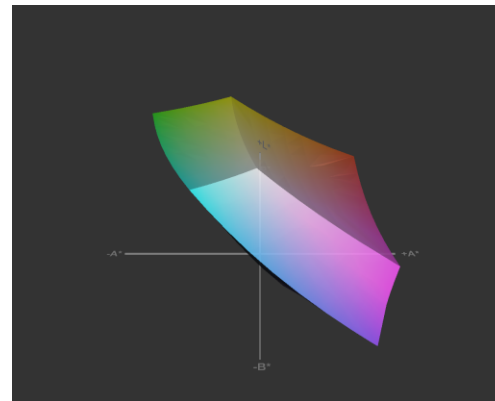
manual

CONTRIBUTIONS

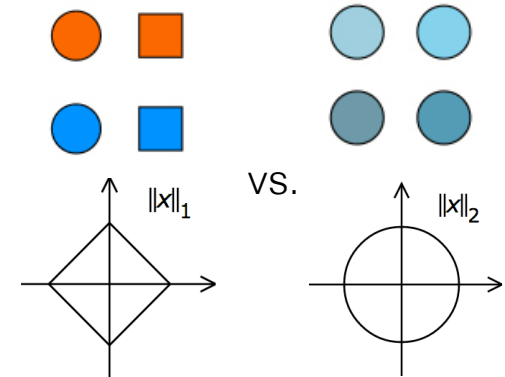
3) Assess using existing models



Stevens' Power Law



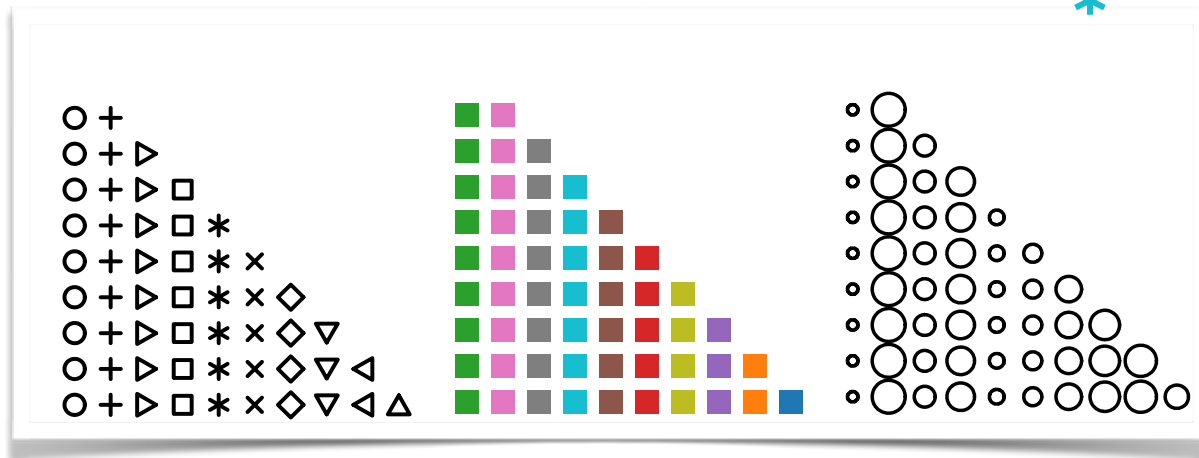
CIELAB
CIEDE2000
Color Names



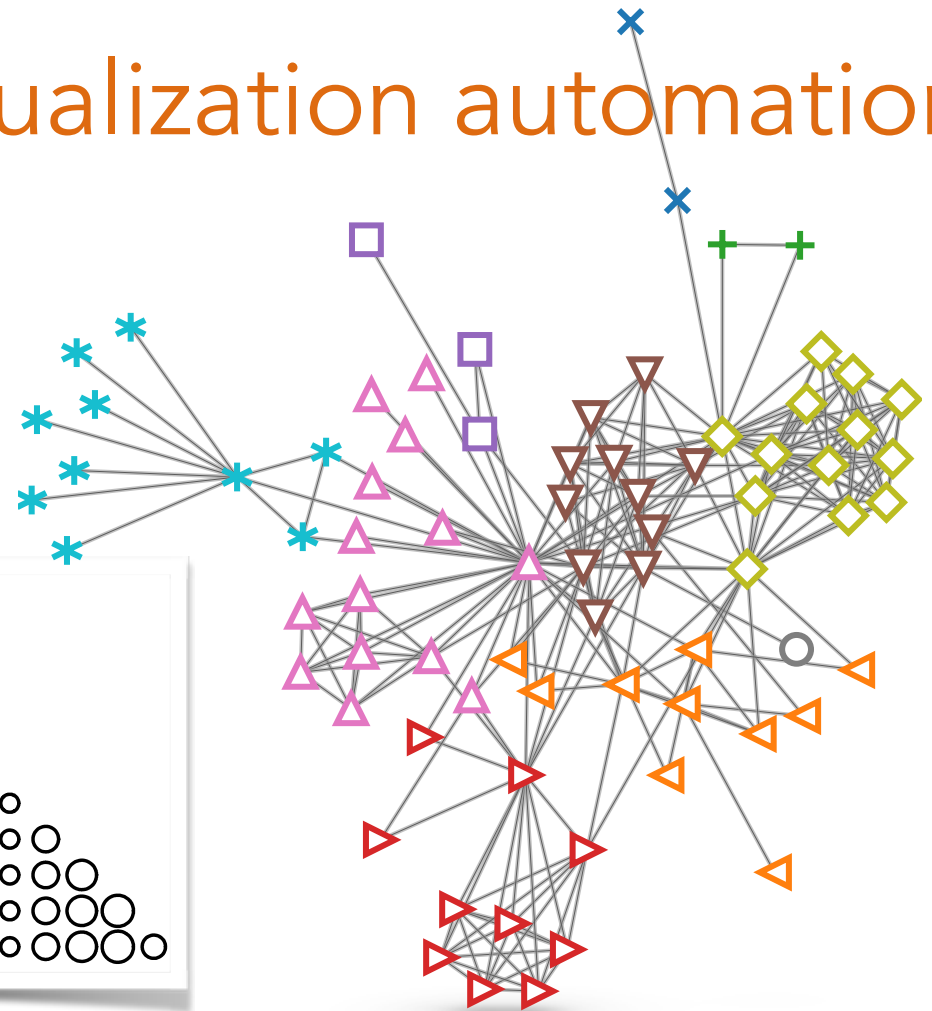
Garner's Integrality

CONTRIBUTIONS

4) Demonstrate in visualization automation



designing palettes



visual embedding

Crowd-sourcing Perceptual Kernels

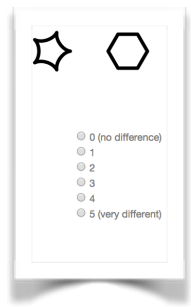


Study Overview

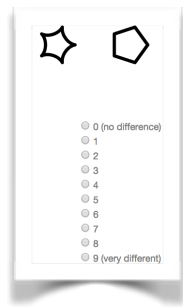
Variables

shape ○ □ + × * ◇ △ ▽ ◁ ▷ Tableau
size ○ ○ ○ ○ ○ ○ ○ ○ ○ ○
color ■ ■ ■ ■ ■ ■ ■ ■ ■ Tableau
shape-size □ + × ◇ □ + × ◇ □ + × ◇
shape-color □ + × ◇ □ + × ◇ □ + × ◇
size-color ○ ○ ○ ○ ○ ○ ○ ○ ○ ○

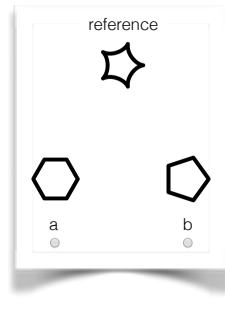
Tasks



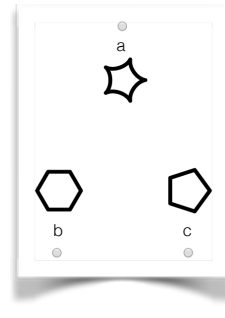
pairwise-5
L5



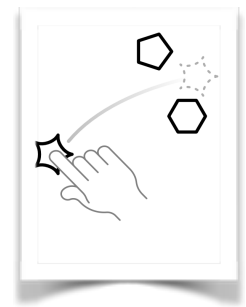
pairwise-9
L9



triplet matching
Tm



triplet discrimination
Td



manual spatial arrangement
SA

Subjects

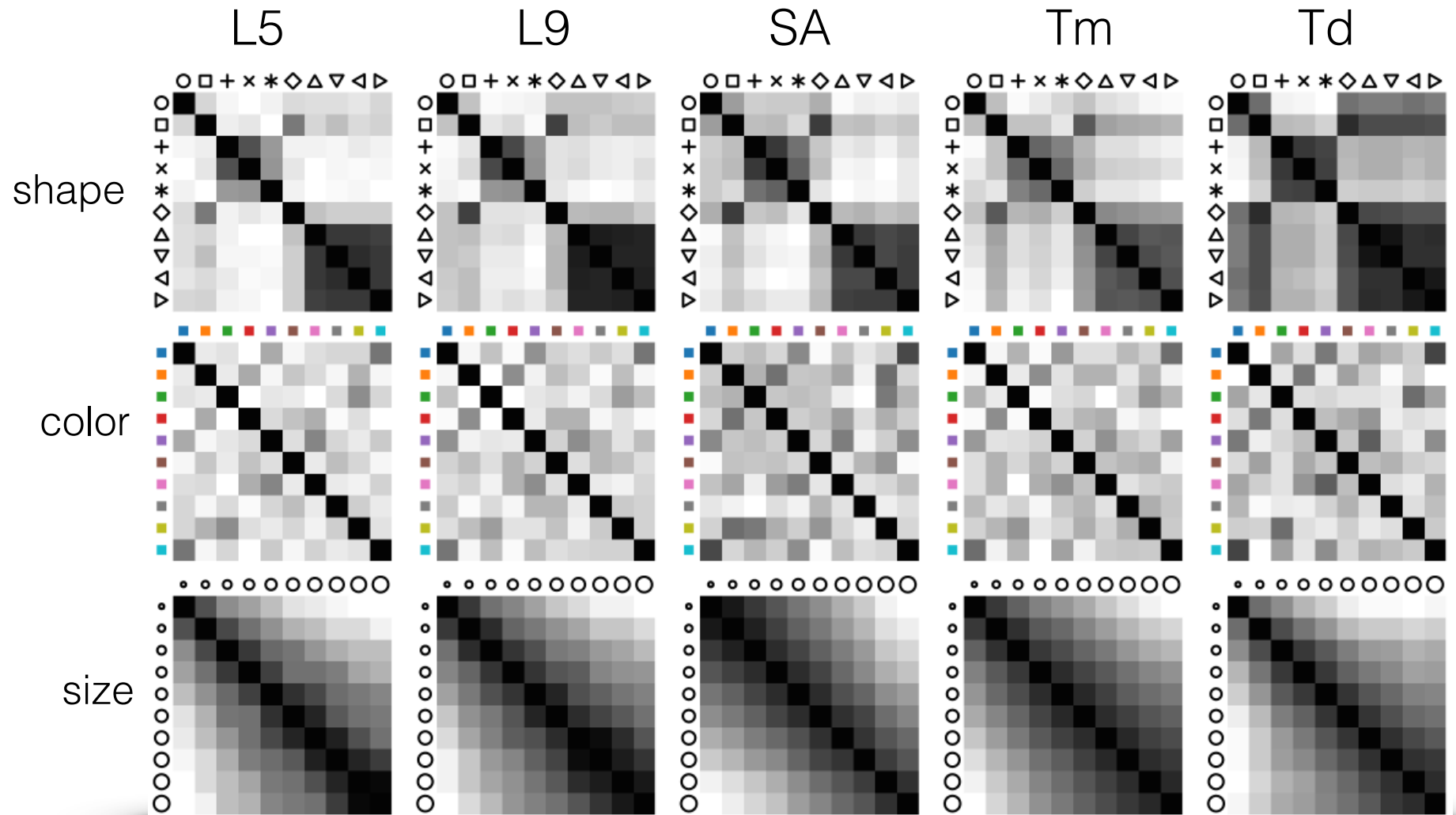


600 Turkers based in the US
95% approval rate
minimum 100 approved HITs

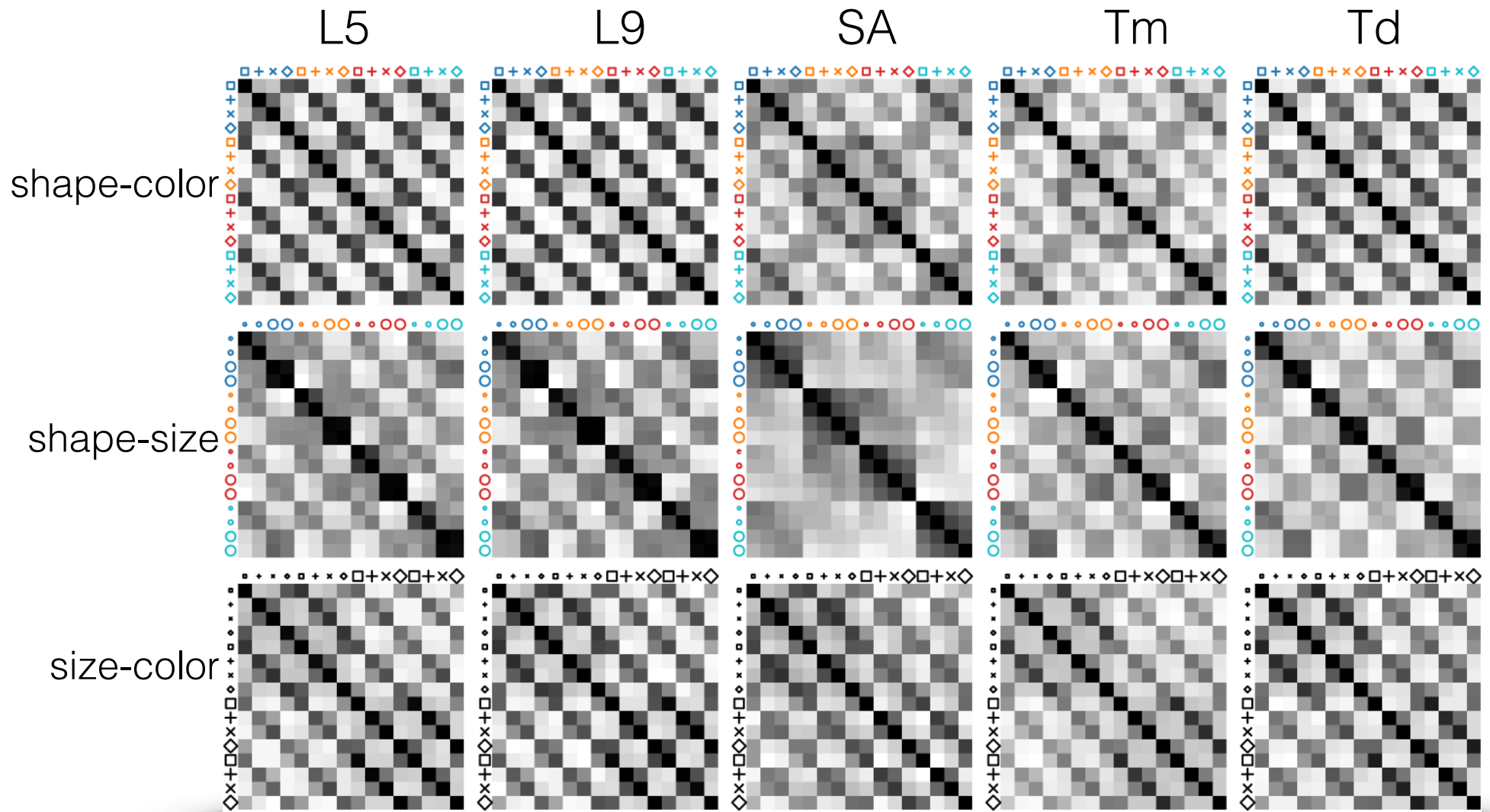
Platform



Univariate Perceptual Kernels



Bivariate Perceptual Kernels



Judgment Tasks

1. Pairwise rating on 5-point scale (L5)
2. Pairwise rating on 9-point scale (L9)
3. Triplet ranking with matching (Tm)
4. Triplet ranking with discrimination (Td)
5. Spatial arrangement (SA)

Judgment Tasks

1. Pairwise rating on 5-point scale (L5)

symbol pair to be rated

advances to next symbol pair

matrix is filled as ratings are entered

a rating can be selected by clicking on it or by typing the number directly on the keyboard

0

0 (identical)

1

2

3

4

5 (no resemblance)

next

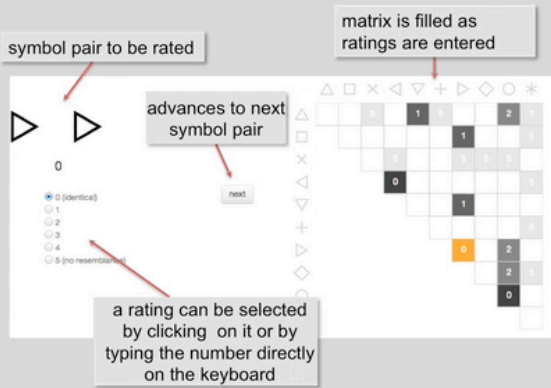
△	□	×	◁	▽	+	▷	◇	○	*
		5		1	5			2	5
						1			5
			5			5	5	5	
				0					5
						1			
									5
							0		
								2	
								2	5
									0

Judgment Tasks

1. Pairwise rating on 5-point scale (L5)

How different does a given symbol pair look?

We are going to show you 55 pairs of symbols and your task is to rate how visually different they look to you!
You will enter your rating as a number between 0 and 5 (valid entries: 0, 1, 2, 3, 4, 5). The following picture shows a snapshot of the task interface.



The screenshot shows the task interface with several callouts:

- symbol pair to be rated**: Points to two identical right-pointing triangles.
- advances to next symbol pair**: Points to a 'next' button.
- matrix is filled as ratings are entered**: Points to a triangular matrix of cells, some containing numbers (0, 1, 2).
- a rating can be selected by clicking on it or by typing the number directly on the keyboard**: Points to a rating scale with radio buttons for 0, 1, 2, 3, 4, and 5.

A rating of **0** means that there is **NO DIFFERENCE** between the two symbols (they are the **SAME**).
1 means that the two symbols look **VERY SIMILAR**.
5 means that the two symbols look **VERY DIFFERENT** (for example, 5 times as different as a very similar symbol pair).
Any rating between 1 and 5 should reflect the degree of visual difference between the symbols.
Complete each task as accurately and quickly as possible.

[start training](#)

Judgment Tasks

2. Pairwise rating on 9-point scale (L9)

symbol pair to be rated

advances to next symbol pair

matrix is filled as ratings are entered

a rating can be selected by clicking on it or by typing the number directly on the keyboard

next

0

0 (identical)

1

2

3

4

5

6

7

8

9 (no res)

◇	▽	+	*	□	×	○	▷	◁	△
◇	0				8				
▽		9				3			
+			8	2	9				
*							8		
□								9	
×						0			
○								0	
▷									
◁									
△									

Judgment Tasks

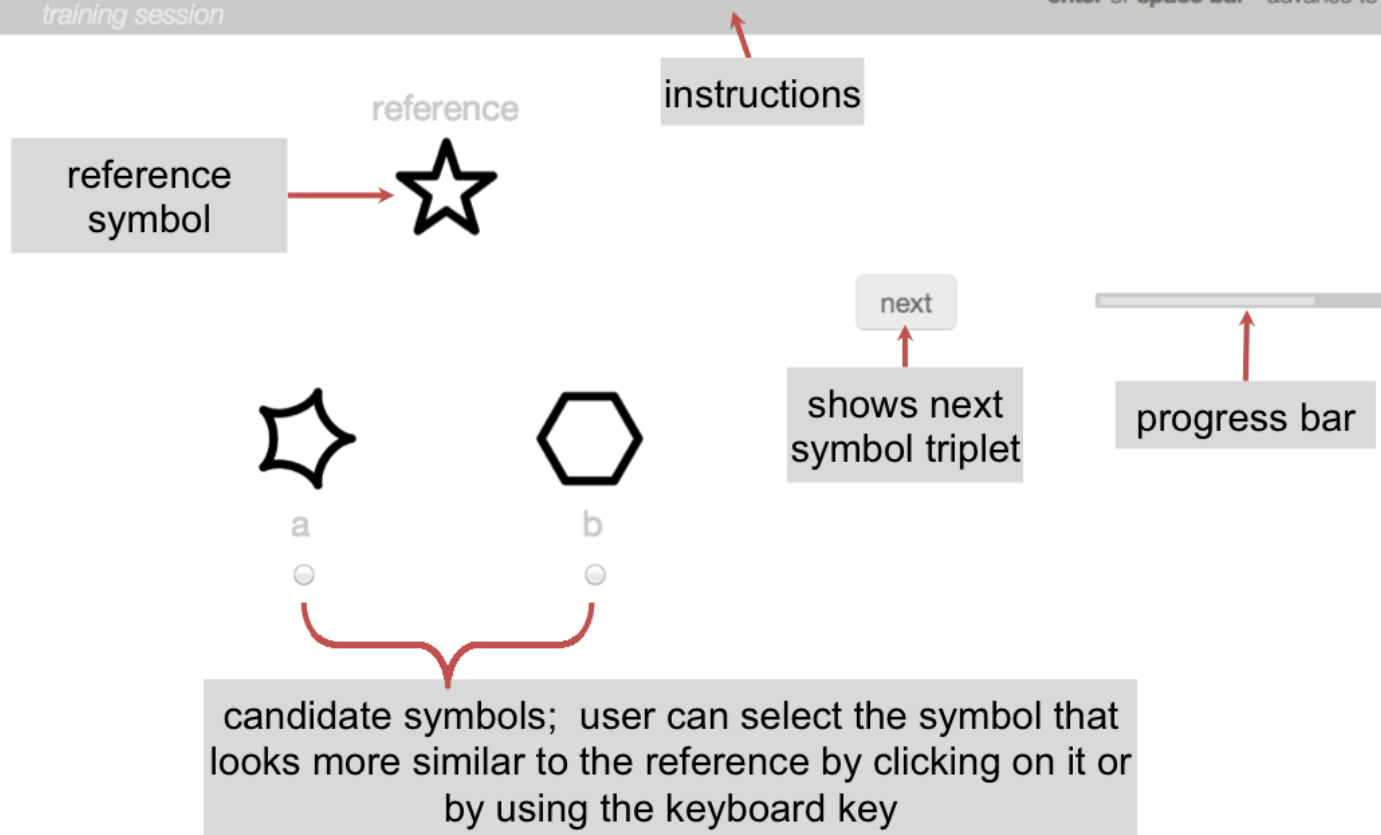
3. Triplet ranking with matching (Tm)

Which is more similar to reference, **a** or **b**?

Your task is to select the symbol that looks more similar to the reference. You can make your selection by clicking on the symbol or by using the keyboard key. Complete each task as accurately and quickly as possible.

training session

Shortcut Keys:
a - select the symbol a
b - select the symbol b
enter or **space bar** - advance to next task

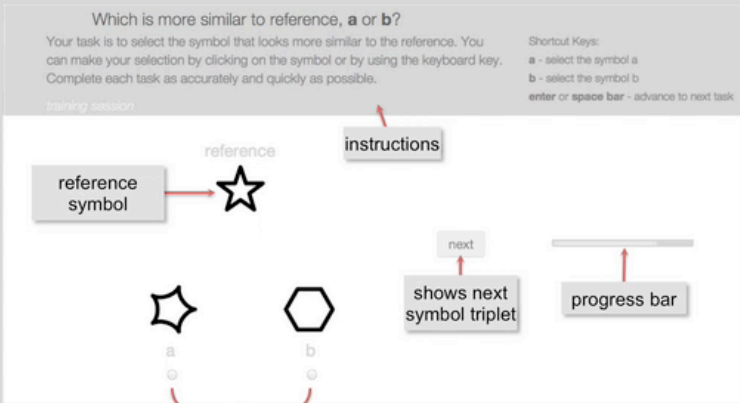


Judgment Tasks

3. Triplet ranking with matching (Tm)

Which symbol looks more similar to the reference?

In a series of tasks, we are going to show you a reference symbol and two other symbols. Your job is to decide which one of the two symbols looks more similar to the reference (see the task interface below).



Which is more similar to reference, **a** or **b**?

Your task is to select the symbol that looks more similar to the reference. You can make your selection by clicking on the symbol or by using the keyboard key. Complete each task as accurately and quickly as possible.

training session

reference symbol → reference (star)

instructions

next

shows next symbol triplet

progress bar

a (star) b (hexagon)

candidate symbols; user can select the symbol that looks more similar to the reference by clicking on it or by using the keyboard key

Shortcut Keys:
a - select the symbol a
b - select the symbol b
enter or space bar - advance to next task

Complete each task as accurately and quickly as possible.

We will start with a short training session to get you familiarized with the task interface. Click the button below to continue with the training session.

start training

Judgment Tasks

4. Triplet ranking with discrimination (Td)

Which one looks the most different, **a** or **b** or **c**?

Your task is to select the symbol that looks the most different from the other two. You can make your selection by clicking on the symbol or by using the keyboard key. Complete each task as accurately and quickly as possible.

Shortcut Keys:
a - select symbol a
b - select symbol b
c - select symbol c
enter or **space bar** - advance to next task

training session

instructions

symbol triplet

a

c

b

next

shows next symbol triplet

progress bar

user can select the symbol that is visually the most different from the rest by clicking on the symbol or by using the keyboard key

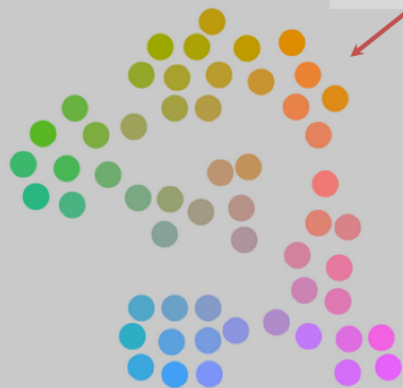
Judgment Tasks

5. Spatial arrangement (SA)

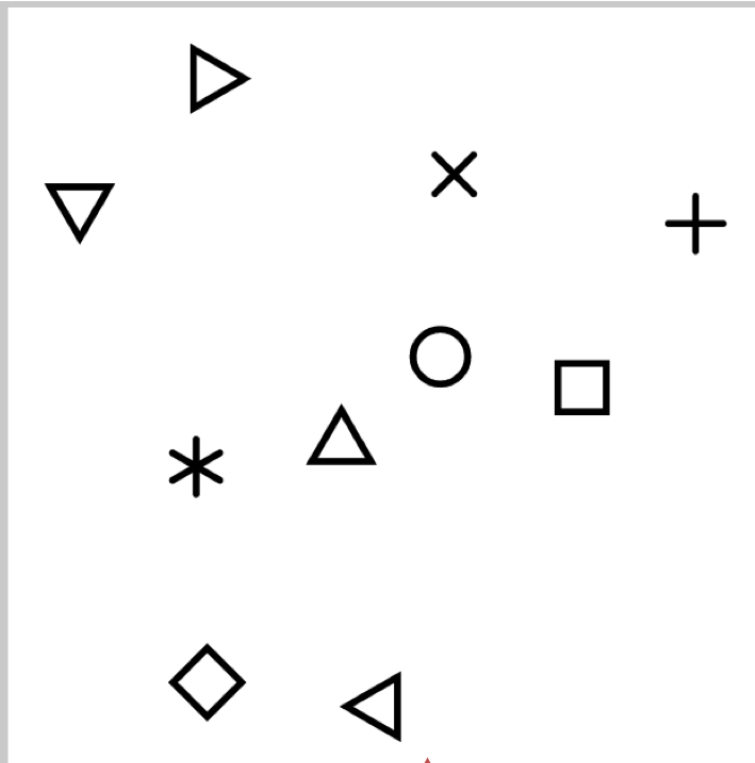
instructions

- Arrange the shapes on the right so that similar symbols are nearer each other and dissimilar symbols are farther away from each other.
- The final layout should accurately reflect your sense of the visual similarities and differences among the shapes.
- Drag and drop the shapes to change their position.
- Please perform the task as accurately and quickly as possible. When you are done, click the next button.
- Consider the example below. Here, we have placed each color such that similar colors are near each other and dissimilar colors are farther apart. Your task is to construct a similar layout for shapes.

example:



example



layout area, where shapes can be arranged with drag and drop

advances to next stage

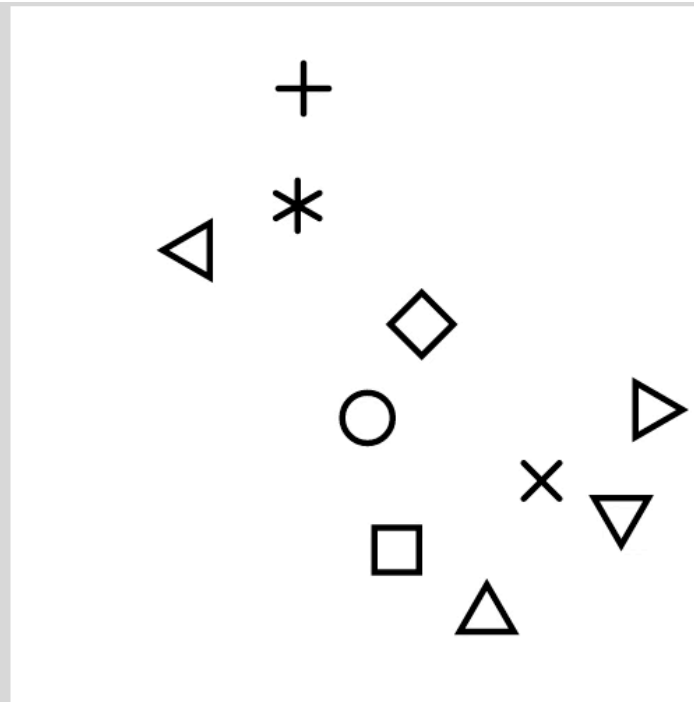
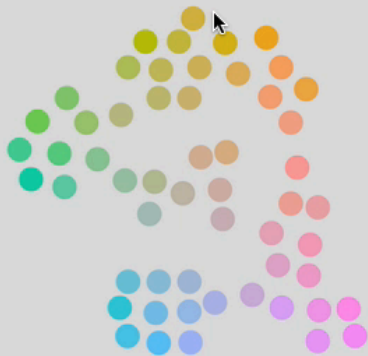
next

Judgment Tasks

5. Spatial arrangement (SA)

- Arrange the shapes on the right so that similar symbols are nearer each other and dissimilar symbols are farther away from each other.
- The final layout should accurately reflect your sense of the visual similarities and differences among the shapes.
- Drag and drop the shapes to change their position.
- Please perform the task as accurately and quickly as possible. When you are done, click the next button.
- Consider the example below. Here, we have placed each color such that similar colors are near each other and dissimilar colors are farther apart. Your task is to construct a similar layout for shapes.

example:

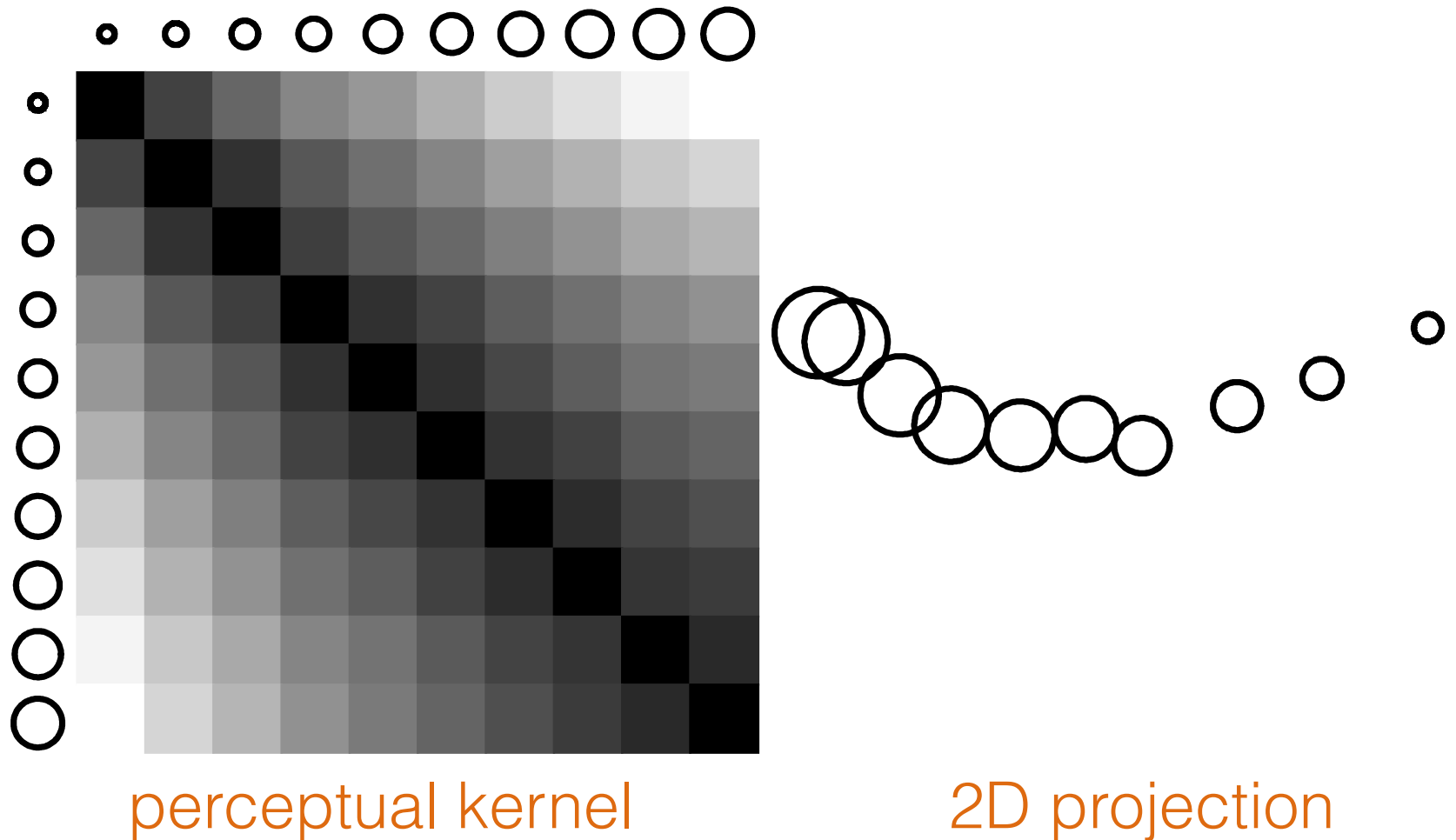


next

Perceptual Kernels & Models of Perception

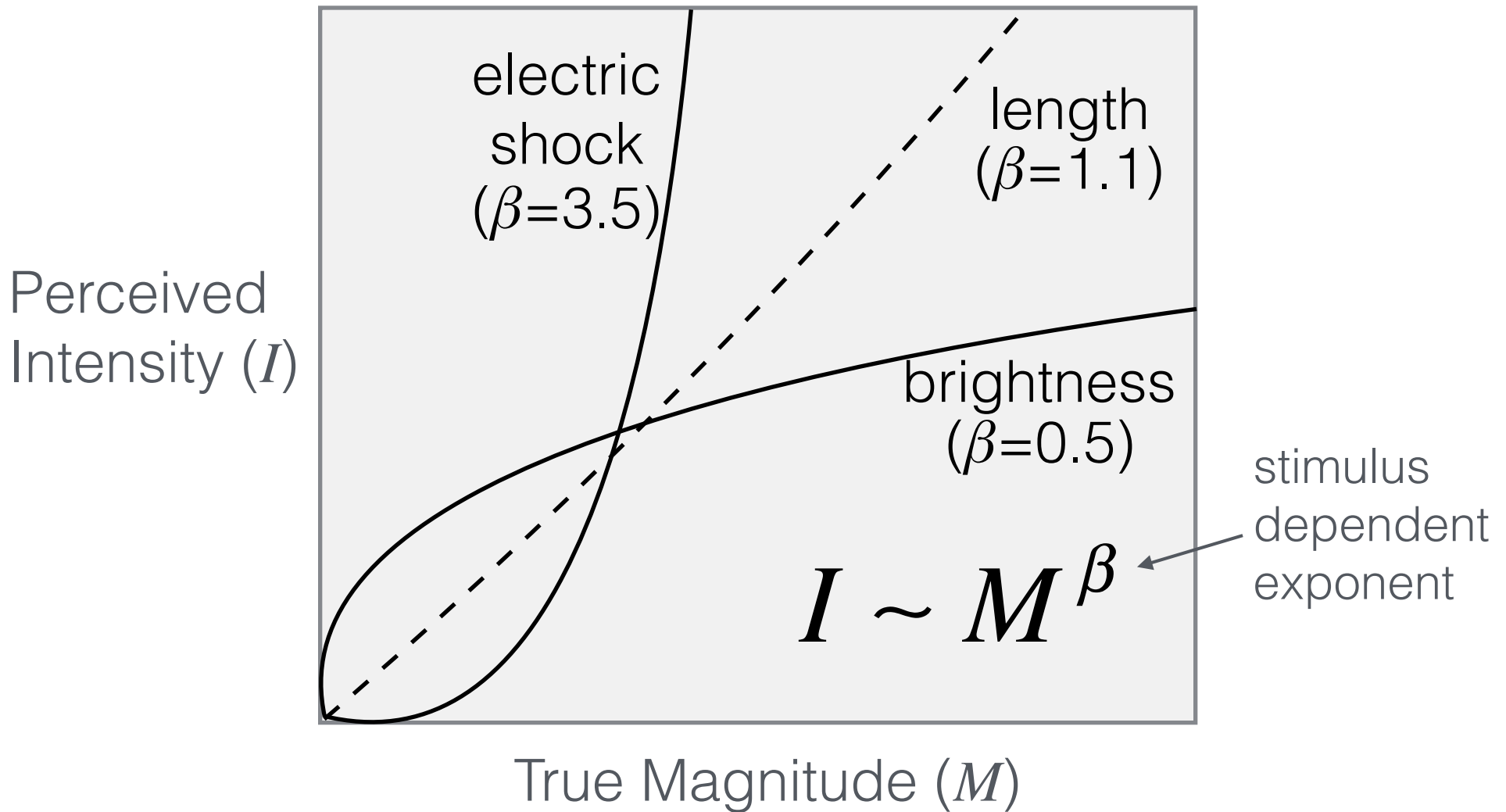


Size (T_m)

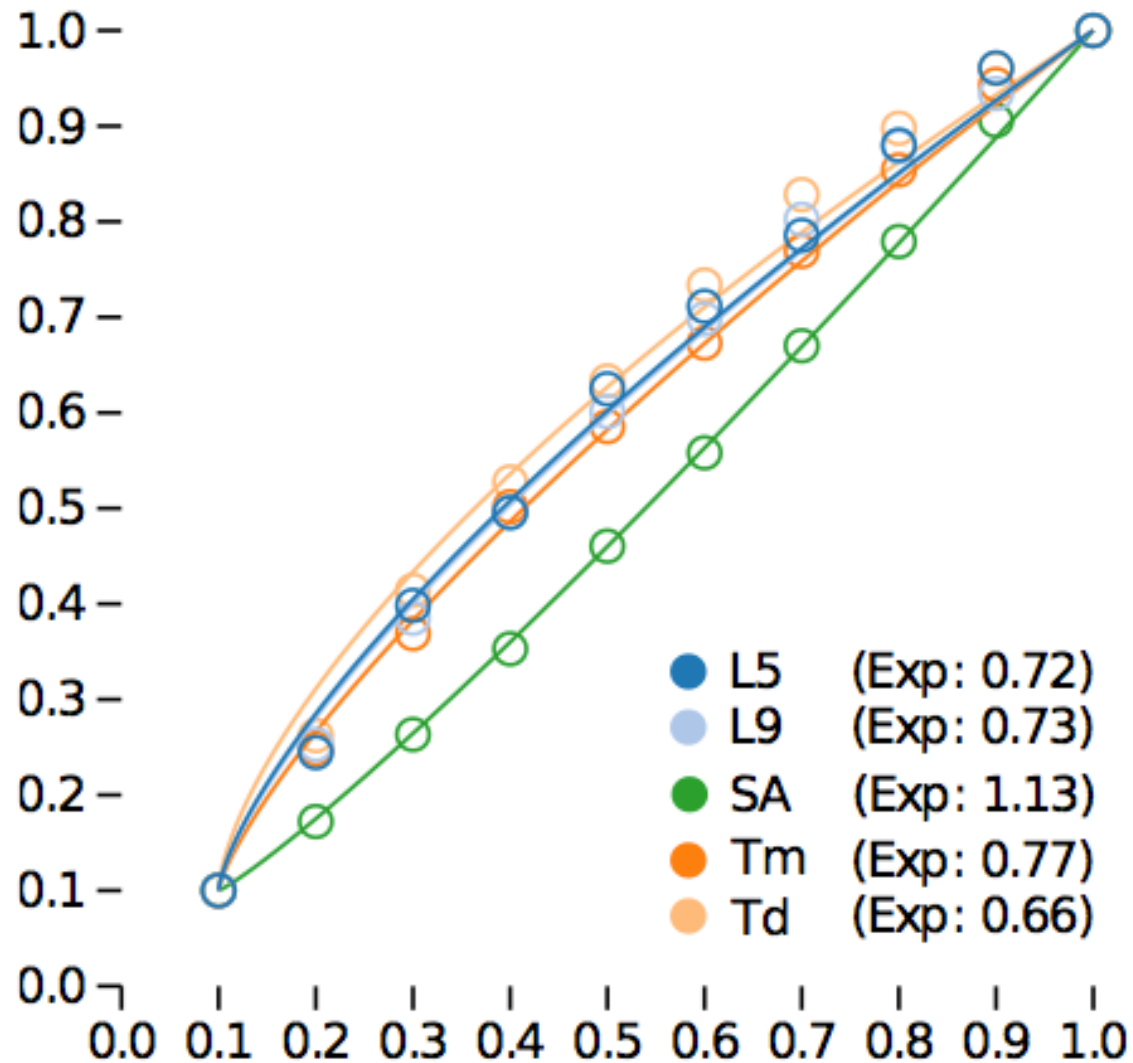


Consistent with Stevens' Power Law!

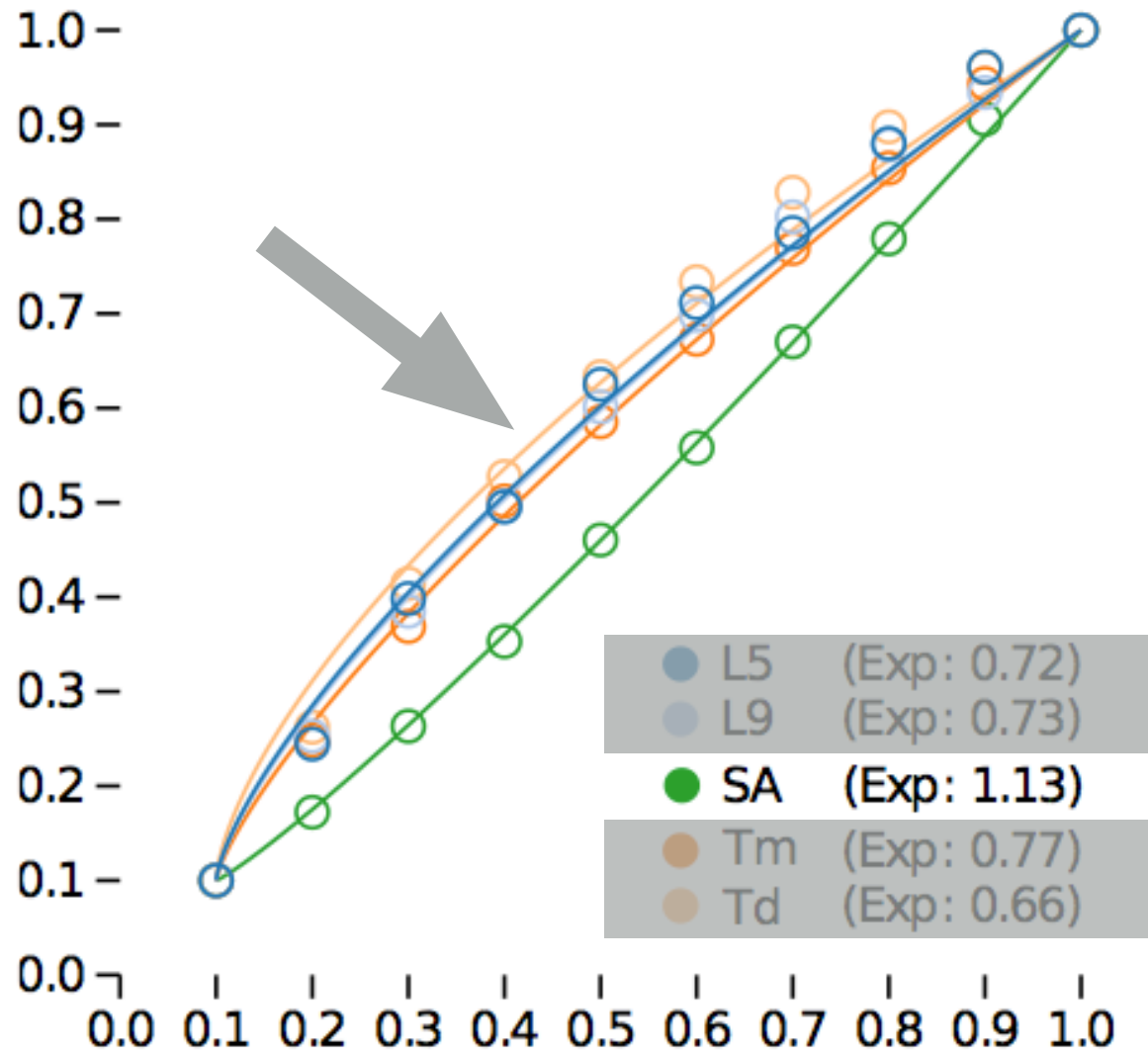
Stevens' Power Law



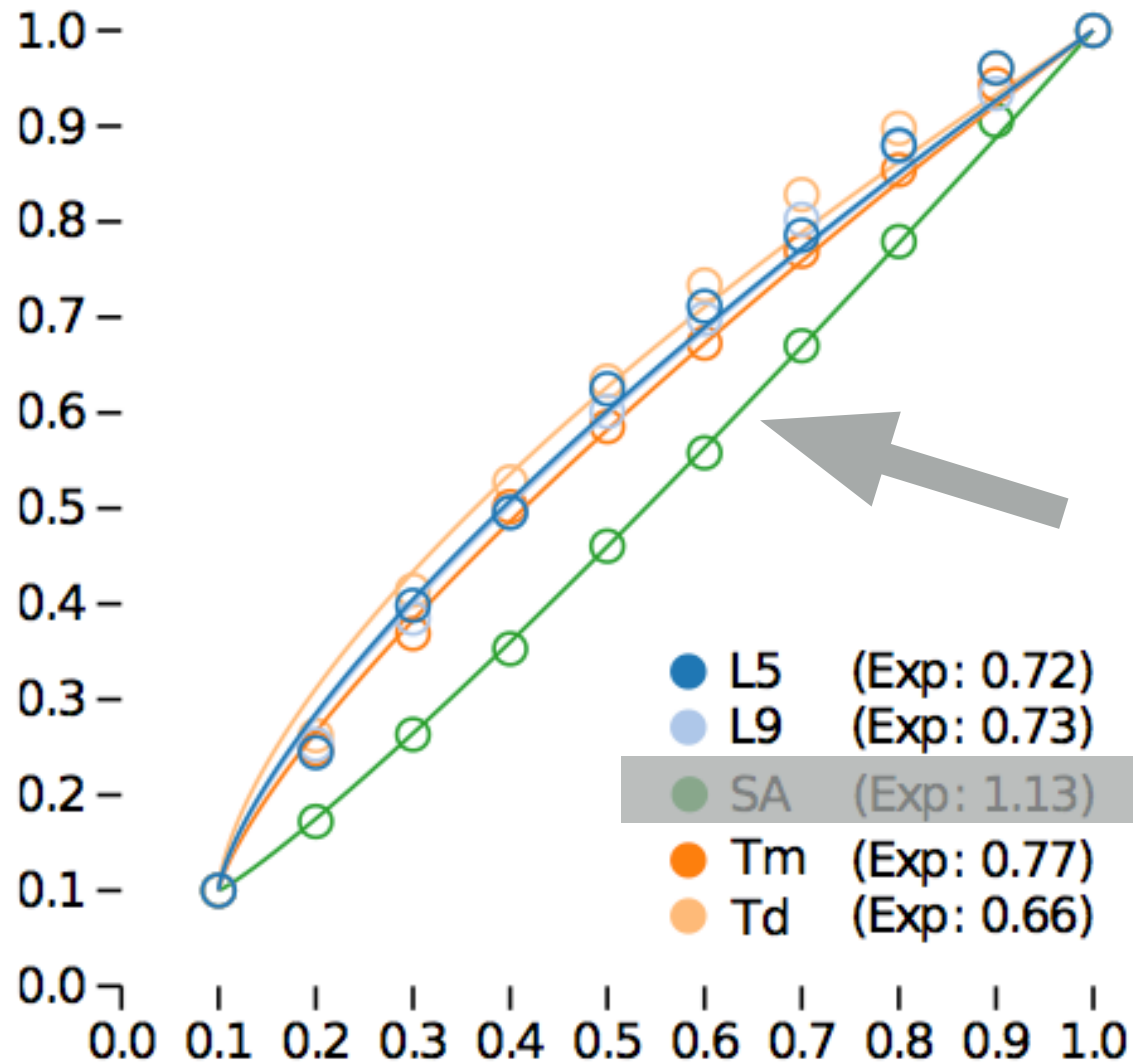
Stevens' Power Law Fit



Stevens' Power Law Fit

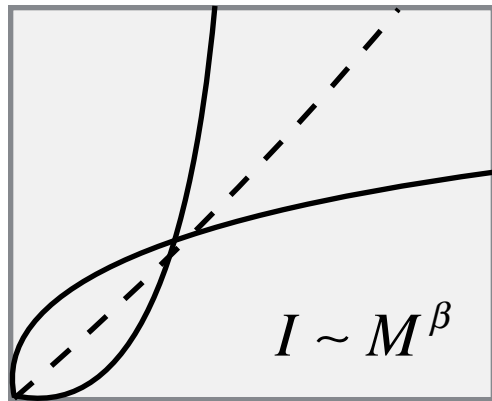


Stevens' Power Law Fit

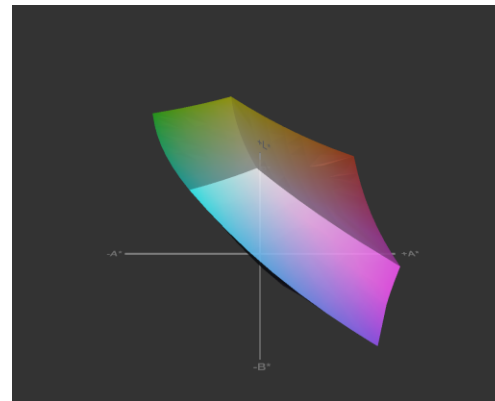


CONTRIBUTIONS

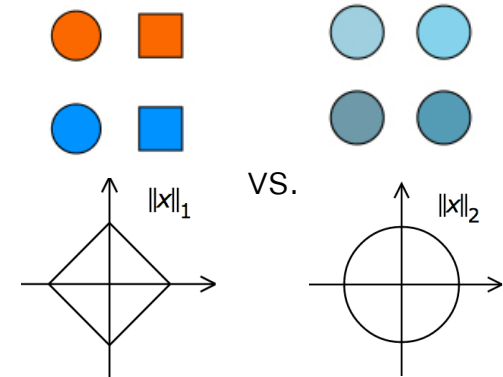
3) Assess using existing models



Stevens' Power Law



CIELAB
CIEDE2000
Color Names



Garner's Integrality

details are in the paper

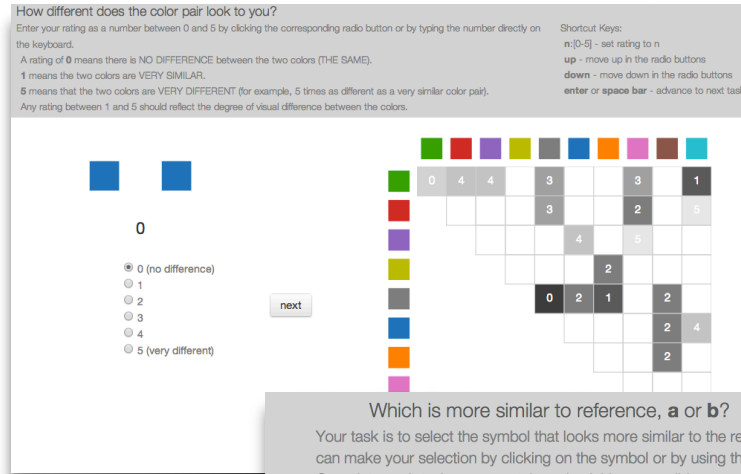
Which Judgment Task to Use?

How different does the color pair look to you?

Enter your rating as a number between 0 and 5 by clicking the corresponding radio button or by typing the number directly on the keyboard.

A rating of 0 means there is NO DIFFERENCE between the two colors (THE SAME).
1 means the two colors are VERY SIMILAR.
5 means that the two colors are VERY DIFFERENT (for example, 5 times as different as a very similar color pair).
Any rating between 1 and 5 should reflect the degree of visual difference between the colors.

Shortcut Keys:
n:[0-5] - set rating to n
up - move up in the radio buttons
down - move down in the radio buttons
enter or space bar - advance to next task

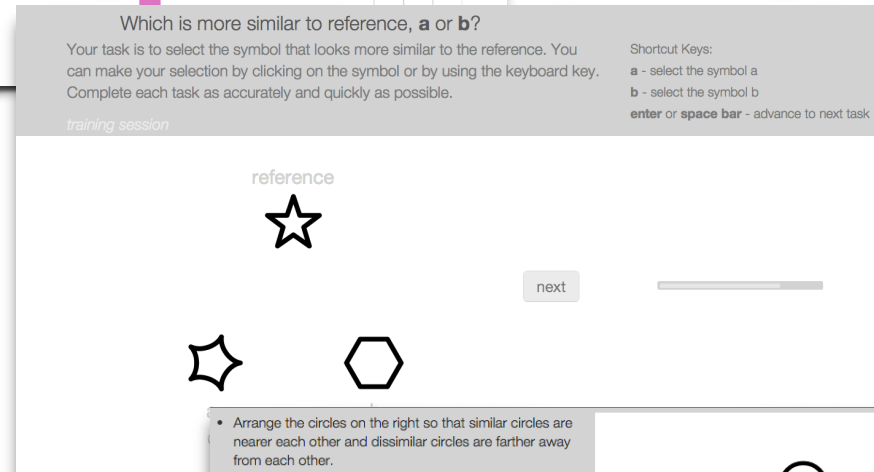


Which is more similar to reference, a or b?

Your task is to select the symbol that looks more similar to the reference. You can make your selection by clicking on the symbol or by using the keyboard key. Complete each task as accurately and quickly as possible.

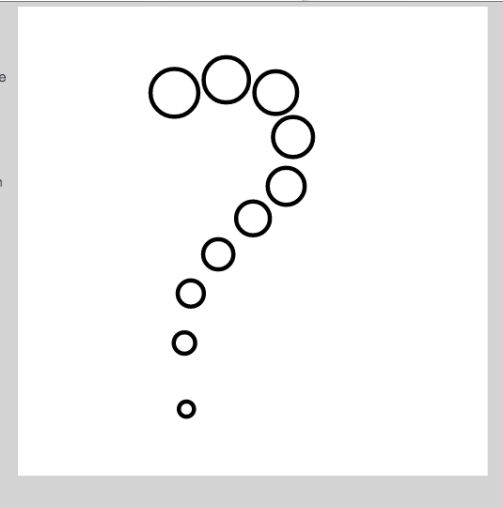
training session

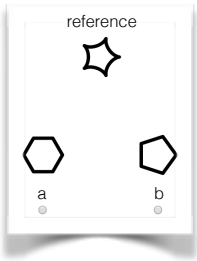
Shortcut Keys:
a - select the symbol a
b - select the symbol b
enter or space bar - advance to next task



- Arrange the circles on the right so that similar circles are nearer each other and dissimilar circles are farther away from each other.
- The final layout should accurately reflect your sense of the visual similarities and differences among the circles.
- Drag and drop the circles to change their position.
- Please perform the task as accurately and quickly as possible. When you are done, click the next button.
- Consider the example below. Here, we have placed each color such that similar colors are near each other and dissimilar colors are farther apart.

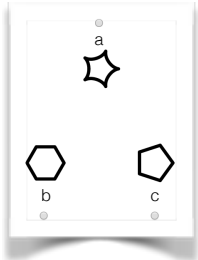
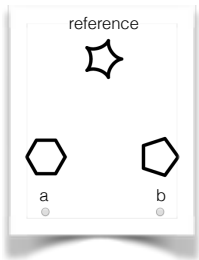
example:





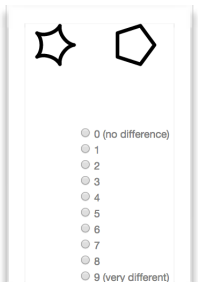
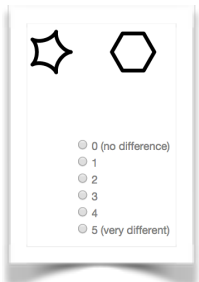
Triplet matching (Tm)

lowest variance, most robust, shortest unit



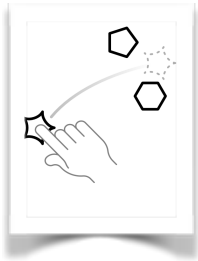
Triplet comparisons (Tm & Td)

longest experiment time, highest cost



Pairwise Likert ratings (L5 & L9)

faster & cheaper than triplet comparisons

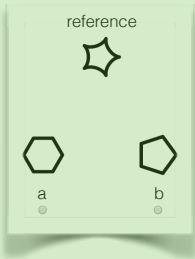


Manual spatial arrangement (SA)

fastest, cheapest

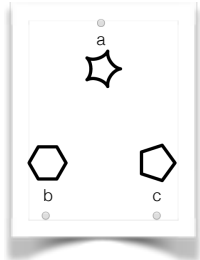
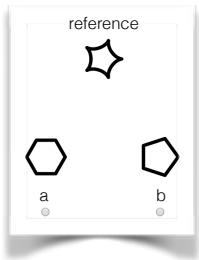
high variance, high sensitivity

best



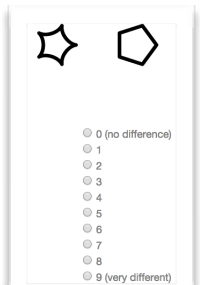
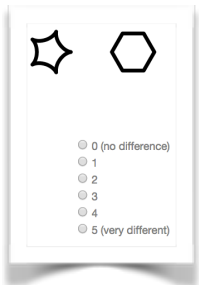
Triplet matching (Tm)

lowest variance, most robust, shortest unit



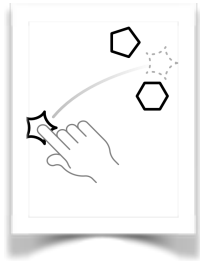
Triplet comparisons (Tm & Td)

longest experiment time, highest cost



Pairwise Likert ratings (L5 & L9)

faster & cheaper than triplet comparisons

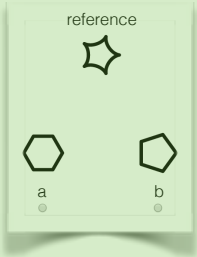


Manual spatial arrangement (SA)

fastest, cheapest

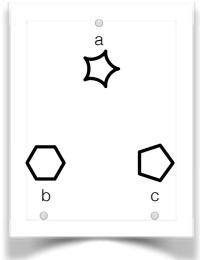
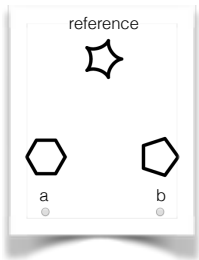
high variance, high sensitivity

best



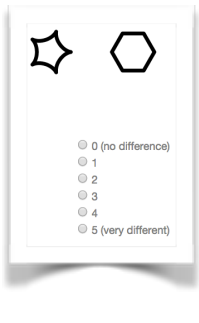
Triplet matching (Tm)

lowest variance, most robust, shortest unit



Triplet comparisons (Tm & Td)

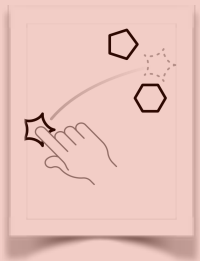
longest experiment time, highest cost



Pairwise Likert ratings (L5 & L9)

faster & cheaper than triplet comparisons

worst



Manual spatial arrangement (SA)

fastest, cheapest

high variance, high sensitivity

Perceptual Kernels

operational model

Use ordinal triplet matching

CONCLUSIONS
unless prohibited by time & cost

Avoid manual spatial arrangement

Read the paper



Acknowledgments



IDL Group Members



ISTC
BIG DATA



data & source code

<https://github.com/uwdata/perceptual-kernels>

<https://github.com/uwdata/visual-embedding>

Data Processing

Pairwise judgments

- Produce a distance matrix directly

- Identical pairs to detect spammers

Triplet judgments

- Generalized non-metric multidimensional scaling

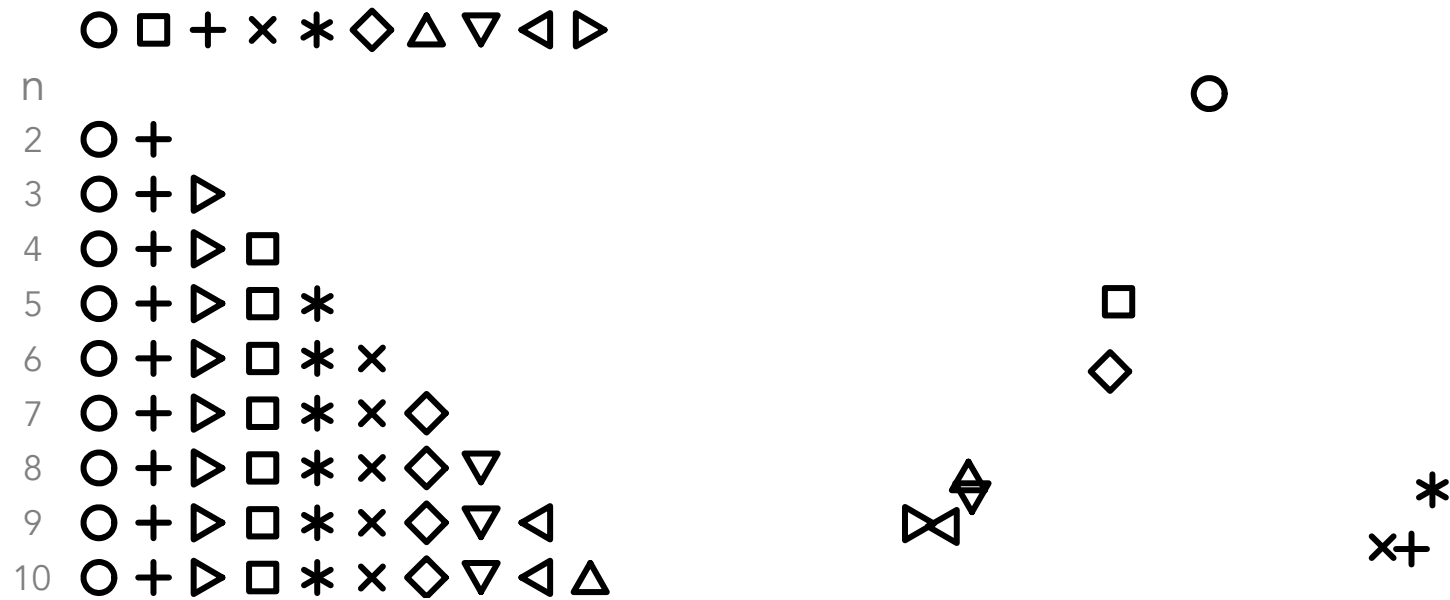
- Use triplets with two identical elements to detect spammers

Spatial arrangements

- Align to a reference and filter-out the outliers

- Planar Euclidean distances produce a distance matrix

Palette Design



What About Context?

What About Context?

What about it?

What About Context?

Which is more similar to reference, **a** or **b**?

Your task is to select the symbol that looks more similar to the reference. You can make your selection by clicking on the symbol or by using the keyboard key. Complete each task as accurately and quickly as possible.

training session

instructions

reference shape

reference

candidate shapes; user can select the shape that looks more similar to the reference by clicking on it or by directly typing its label (a or b) on the keyboard

Shortcut Keys:
a - select symbol a
b - select symbol b
enter or space bar - advance to next task

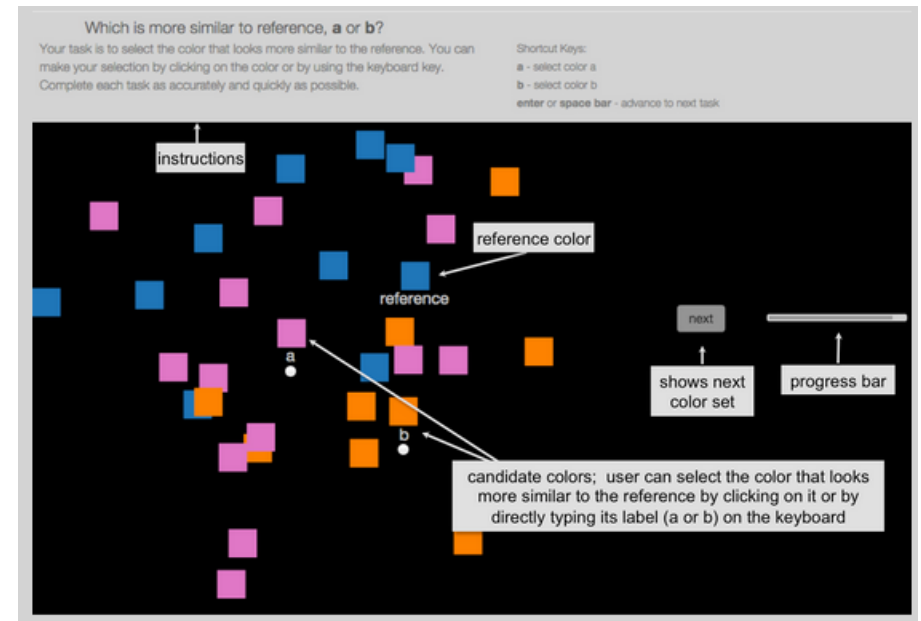
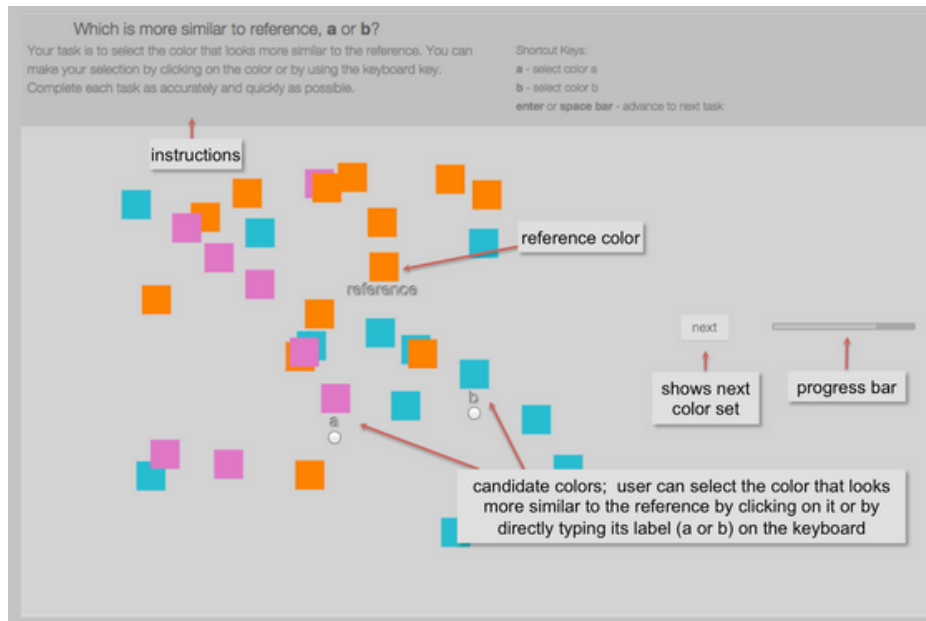
next

shows next shape set

progress bar

The image shows a user interface for a shape similarity task. At the top, there is a title "Which is more similar to reference, a or b?" and a paragraph of instructions: "Your task is to select the symbol that looks more similar to the reference. You can make your selection by clicking on the symbol or by using the keyboard key. Complete each task as accurately and quickly as possible." Below the instructions, there is a "training session" label. The main area contains a "reference shape" (a pentagon) and a "reference" label. Below the reference, there are two candidate shapes labeled "a" and "b". The "a" candidate is a star, and the "b" candidate is a hexagon. There are many other shapes scattered around, including stars and hexagons. A "next" button is located to the right of the candidate shapes, and a "progress bar" is located below it. A text box at the bottom right explains that the user can select a shape by clicking on it or by typing its label (a or b) on the keyboard. A text box at the top left explains the shortcut keys: 'a' for symbol a, 'b' for symbol b, and 'enter' or 'space bar' to advance to the next task.

What About Context?



early results suggest no significant effect

Why Tableau?

Why Tableau?

I have Tableau stocks

Why Tableau?

I have Tableau stocks?

Why Tableau?

~~I have Tableau stocks?~~

Why Tableau?

Manually designed with perceptual considerations in mind

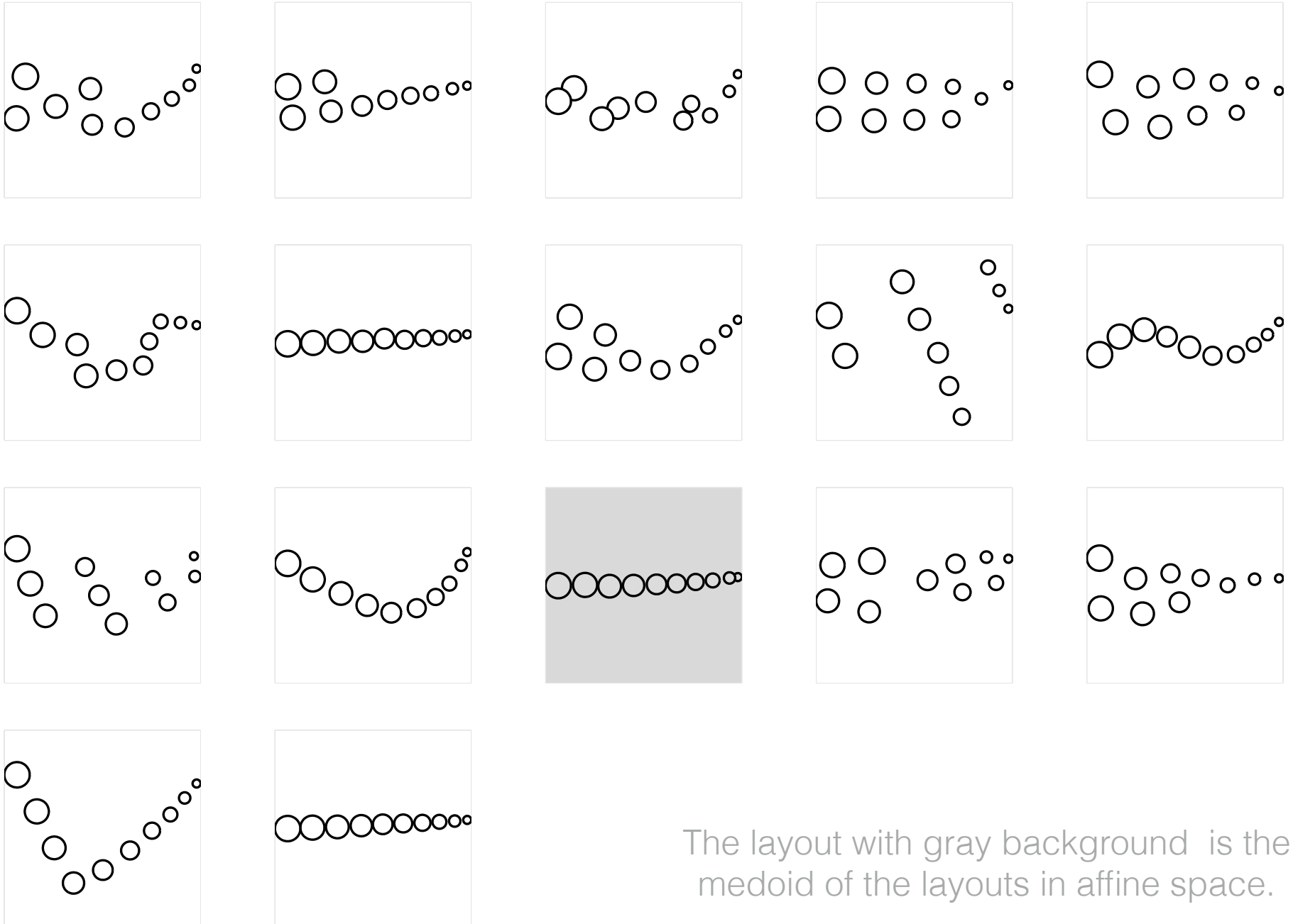
discriminability, saliency and naming of colors, robustness to spatial overlap of shapes

Provides

ecological validity and good baseline

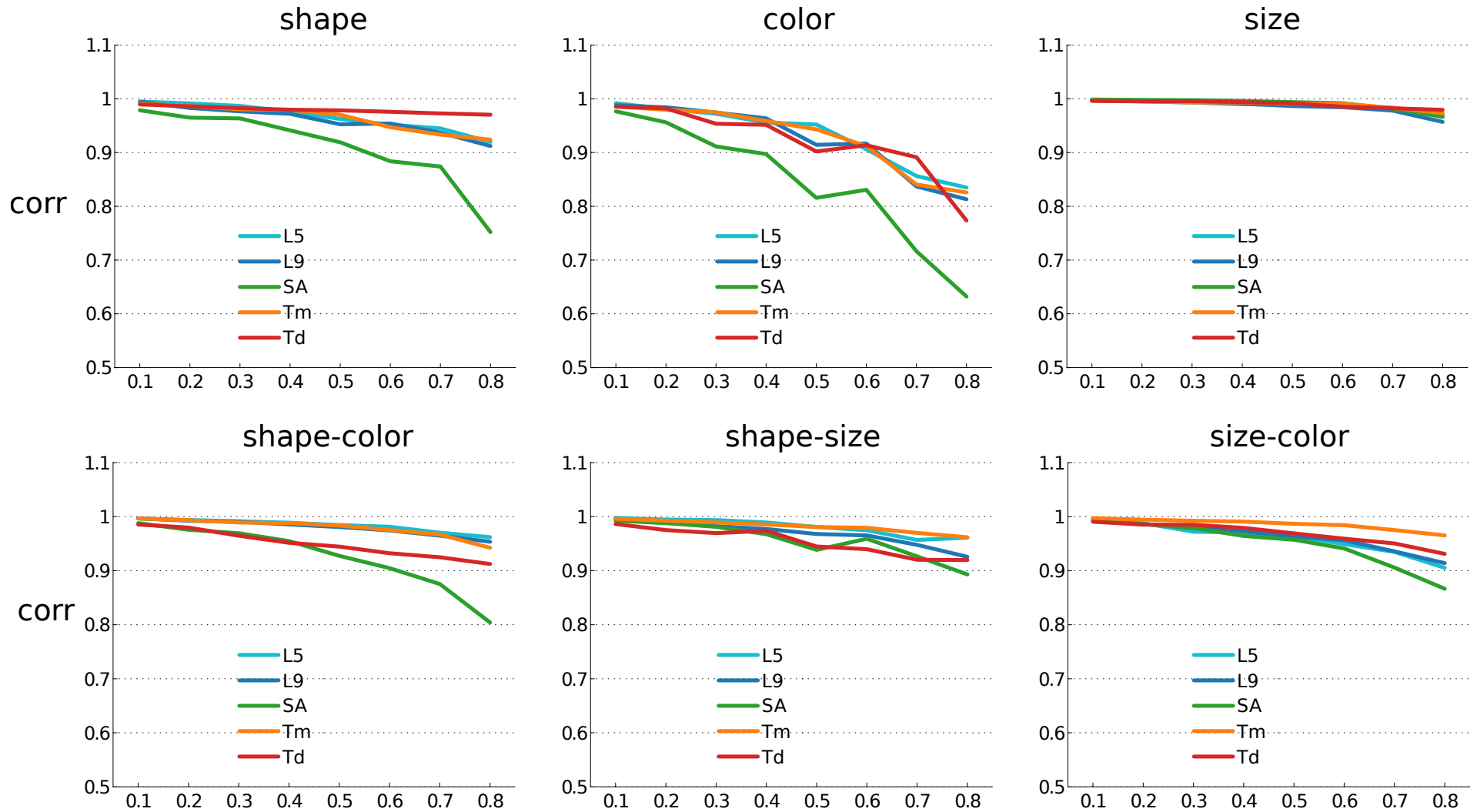
What About Individual Differences?

Per-subject SAs: size



The layout with gray background is the medoid of the layouts in affine space.

Sensitivity



Why SA Performs Poorly?

Why SA Performs Poorly?

Unstructured nature, leading to higher variance across subjects

Expressivity limited to two dimensions
expression of perceptual structures.

Why Tm Outperforms Td?

Why Tm Outperforms Td?

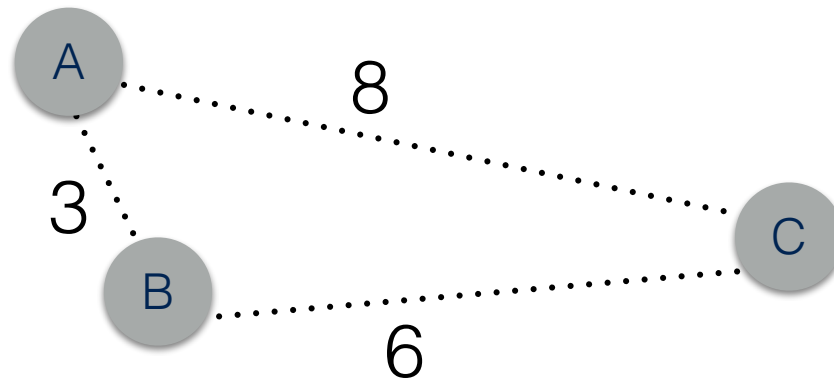
It involves a binary decision (vs. trinary)

Detects more fine-grained similarities

Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

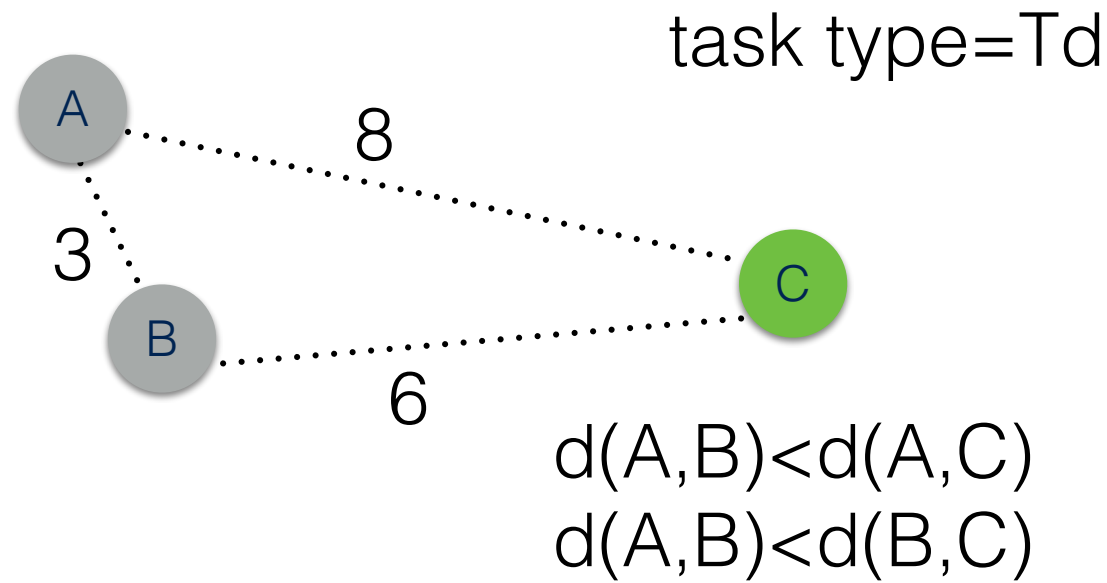
Detects more fine-grained similarities



Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

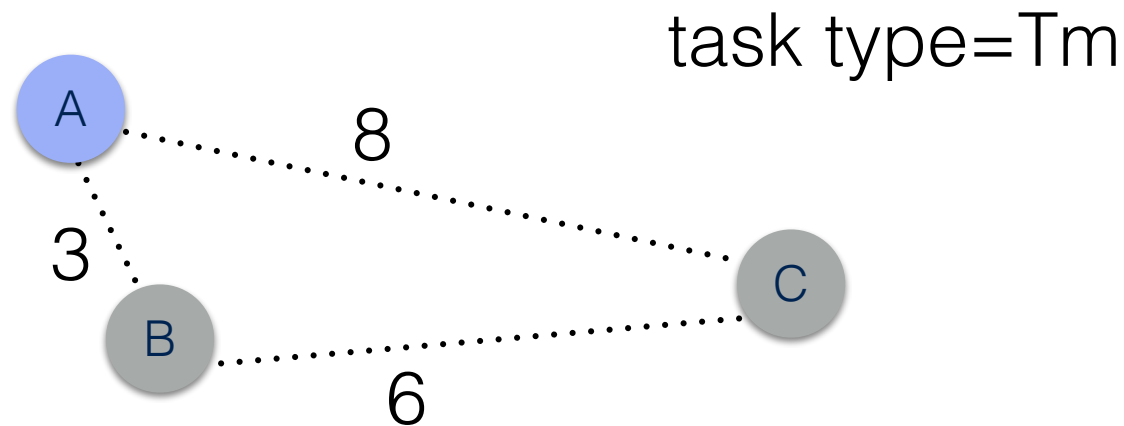
Detects more fine-grained similarities



Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

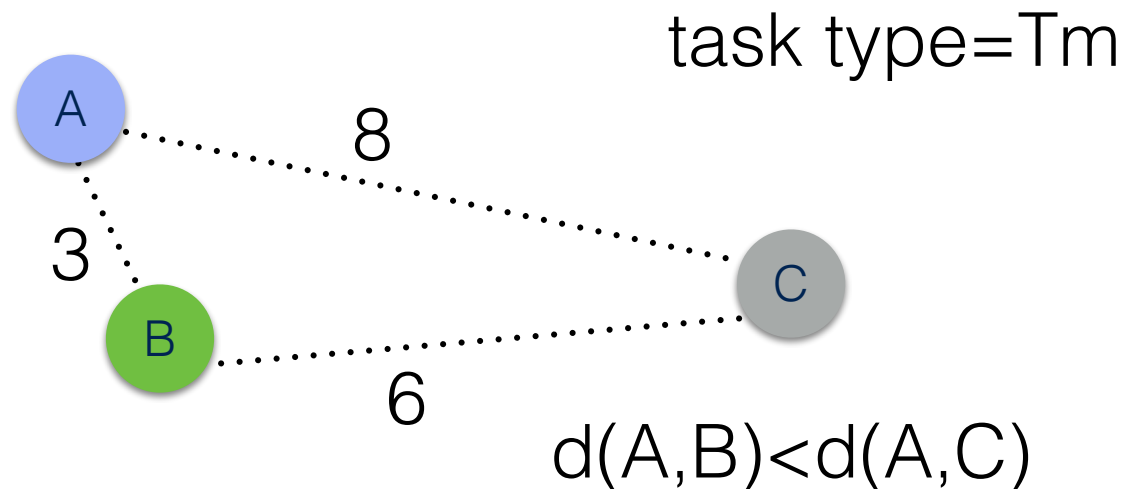
Detects more fine-grained similarities



Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

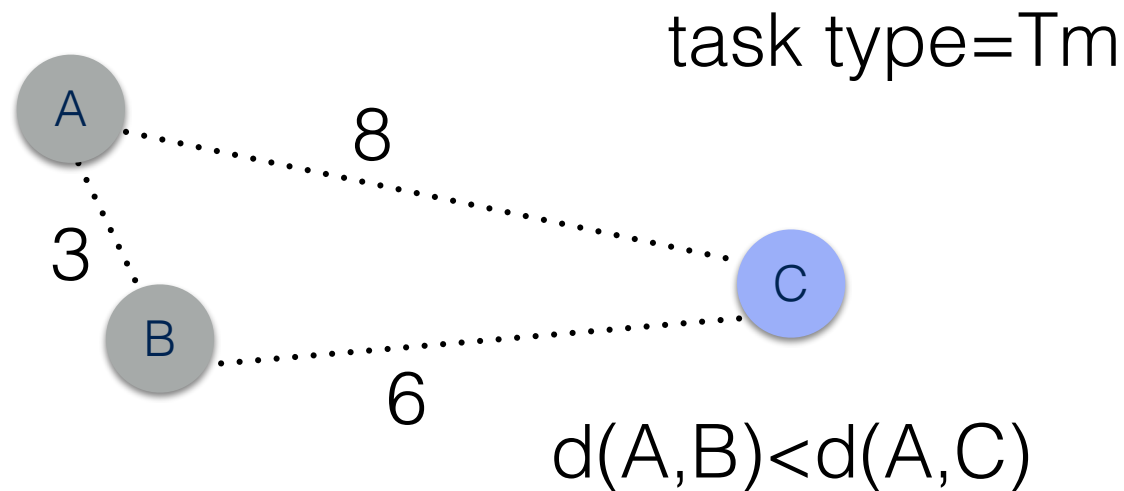
Detects more fine-grained similarities



Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

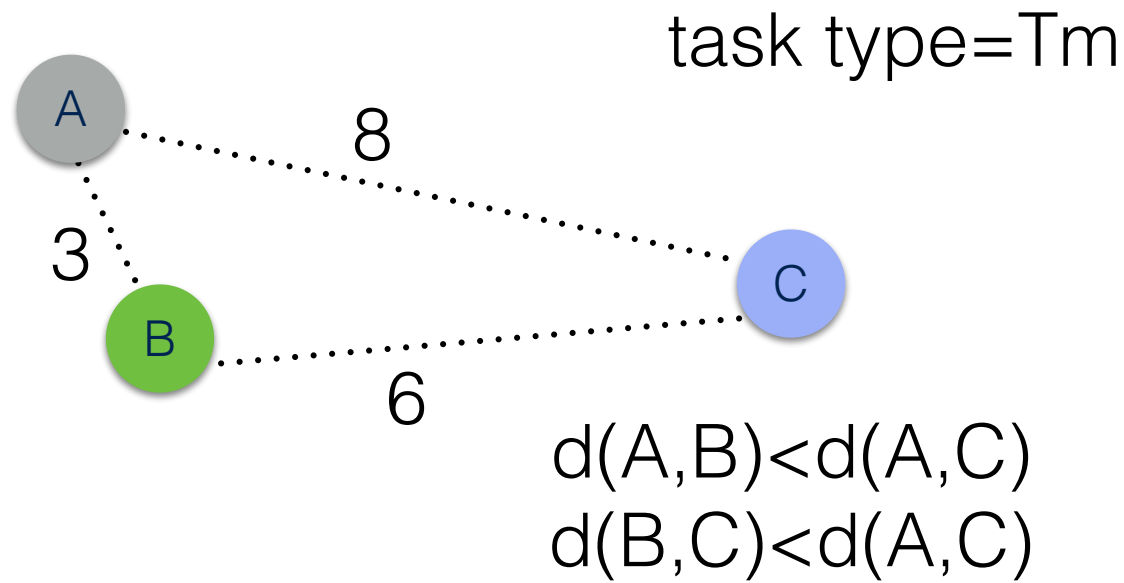
Detects more fine-grained similarities



Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

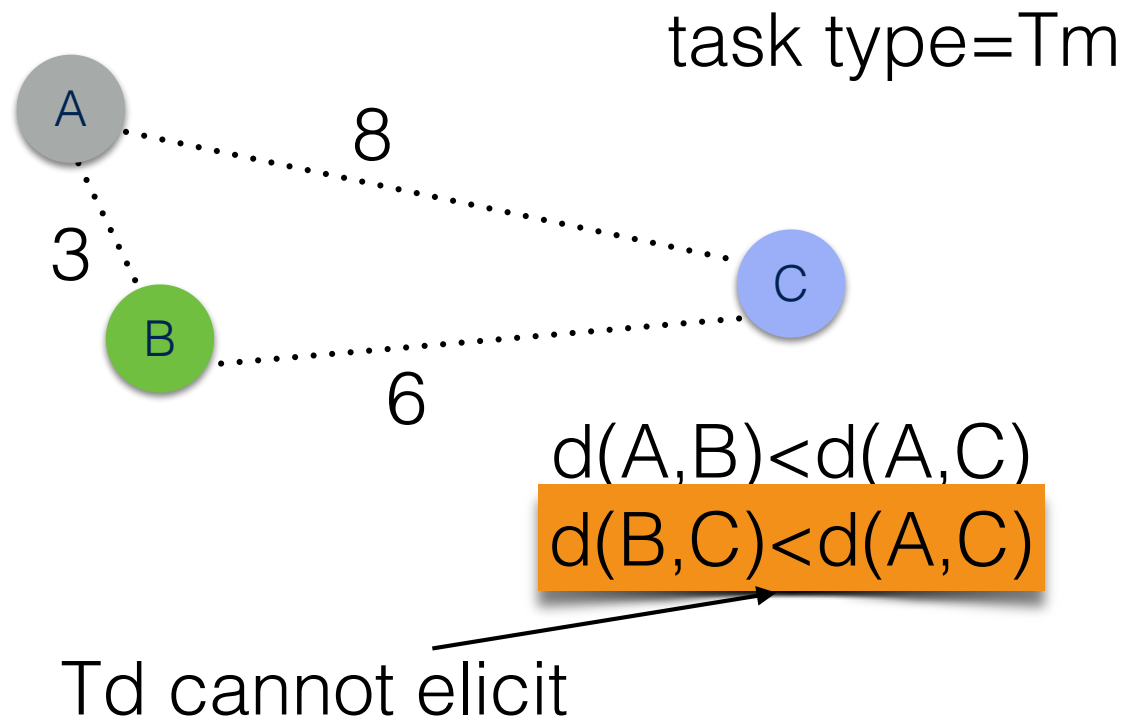
Detects more fine-grained similarities



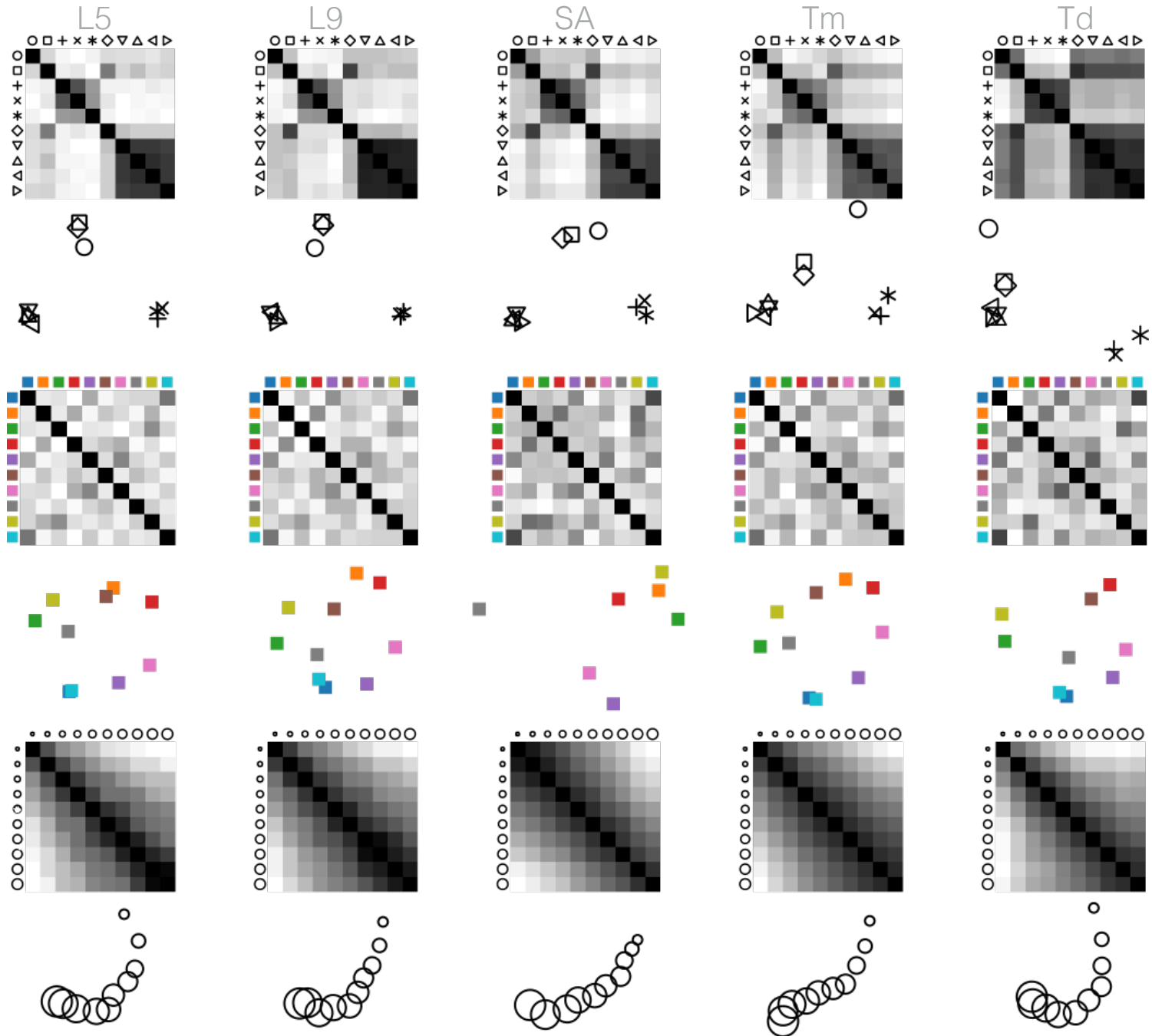
Why Tm Outperforms Td?

It involves a binary decision (vs. trinary)

Detects more fine-grained similarities

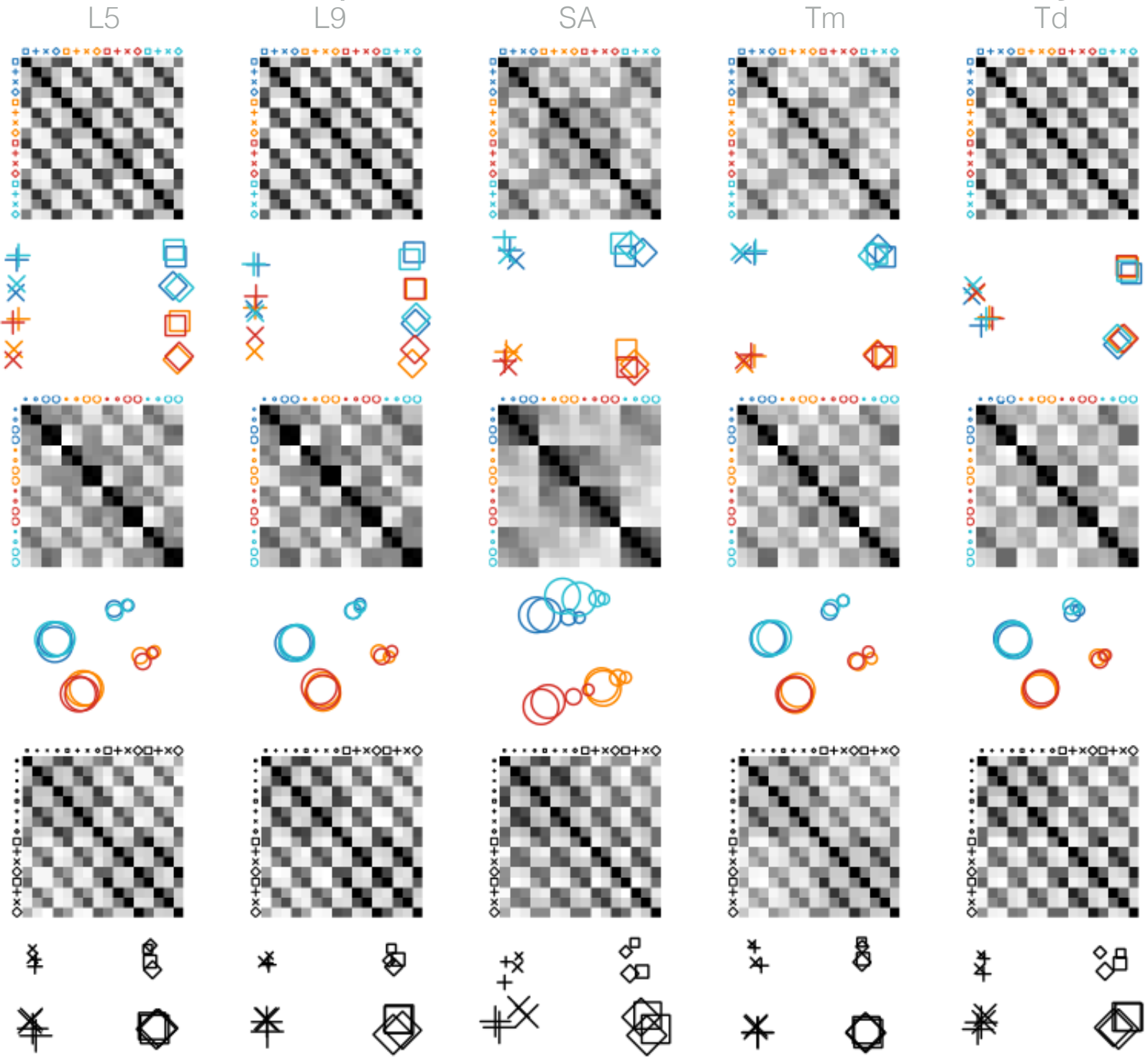


Univariate Perceptual Kernels with MDS Projections*

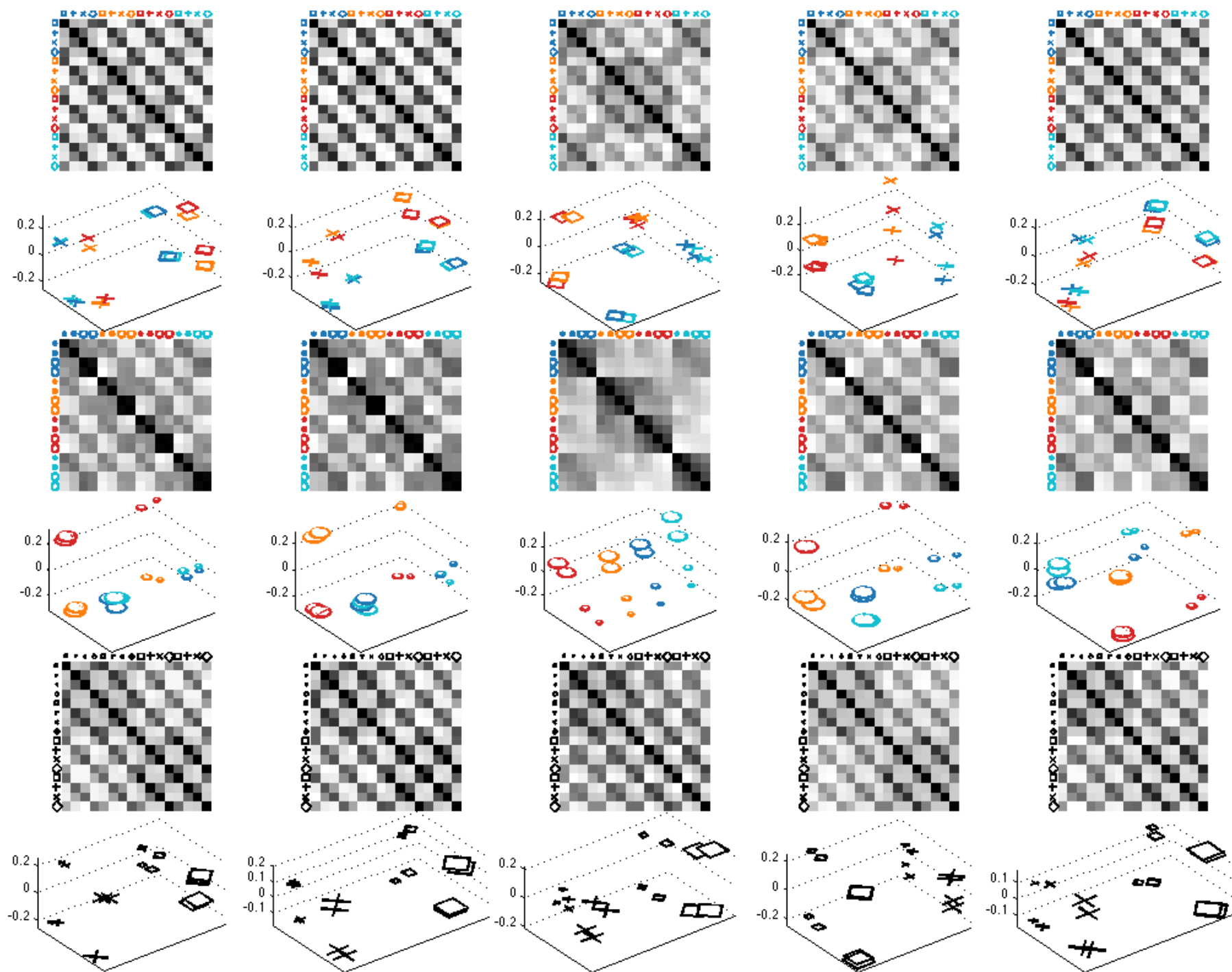


*For each visual variable, projections are aligned to the projection of the L5 kernel

Bivariate Perceptual Kernels with MDS Projections



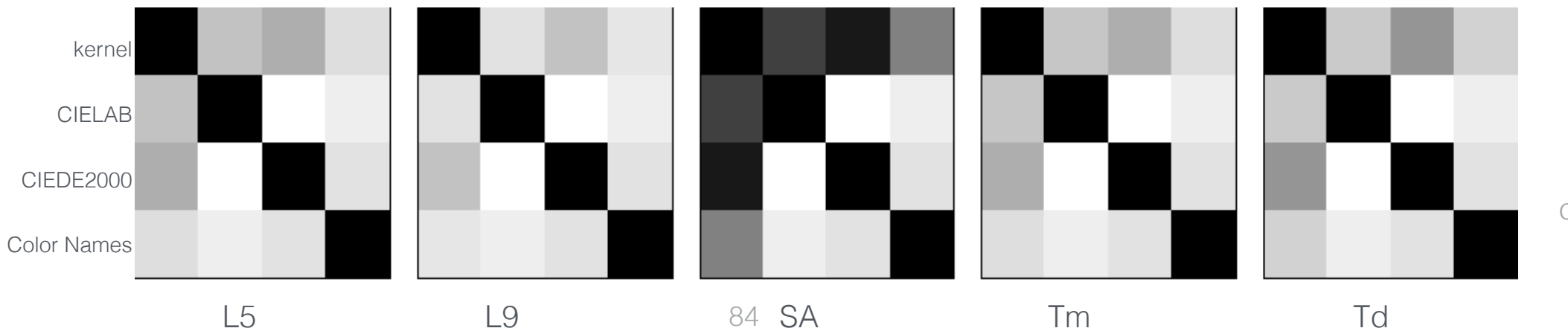
Bivariate Perceptual Kernels with 3D MDS Projections



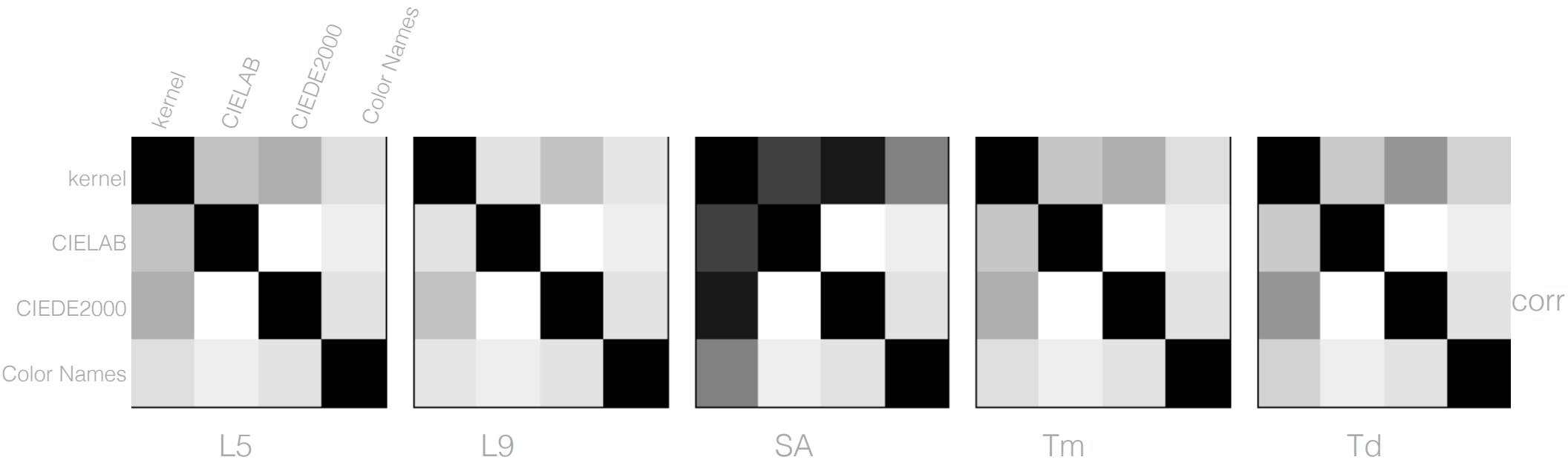
Comparison of Perceptual Kernels with Color Models: Rank Correlation Matrices

	kernel (L5)	CIELAB	CIEDE2000	Color Names	kernel (L9)	CIELAB	CIEDE2000	Color Names	kernel (SA)	CIELAB	CIEDE2000	Color Names		
kernel (L5)	1.00	0.67	0.59	0.76	kernel (L9)	1.00	0.77	0.66	0.79	kernel (SA)	1.00	0.23	0.09	0.45
CIELAB	0.67	1.00	0.88	0.82	CIELAB	0.77	1.00	0.88	0.82	CIELAB	0.23	1.00	0.88	0.82
CIEDE2000	0.59	0.88	1.00	0.77	CIEDE2000	0.66	0.88	1.00	0.77	CIEDE2000	0.09	0.88	1.00	0.77
Color Names	0.76	0.82	0.77	1.00	Color Names	0.79	0.82	0.77	1.00	Color Names	0.45	0.82	0.77	1.00

	kernel (Tm)	CIELAB	CIEDE2000	Color Names	kernel (Td)	CIELAB	CIEDE2000	Color Names	
kernel (Tm)	1.00	0.68	0.60	0.76	kernel (Td)	1.00	0.69	0.51	0.72
CIELAB	0.68	1.00	0.88	0.82	CIELAB	0.69	1.00	0.88	0.82
CIEDE2000	0.60	0.88	1.00	0.77	CIEDE2000	0.51	0.88	1.00	0.77
Color Names	0.76	0.82	0.77	1.00	Color Names	0.72	0.82	0.77	1.00

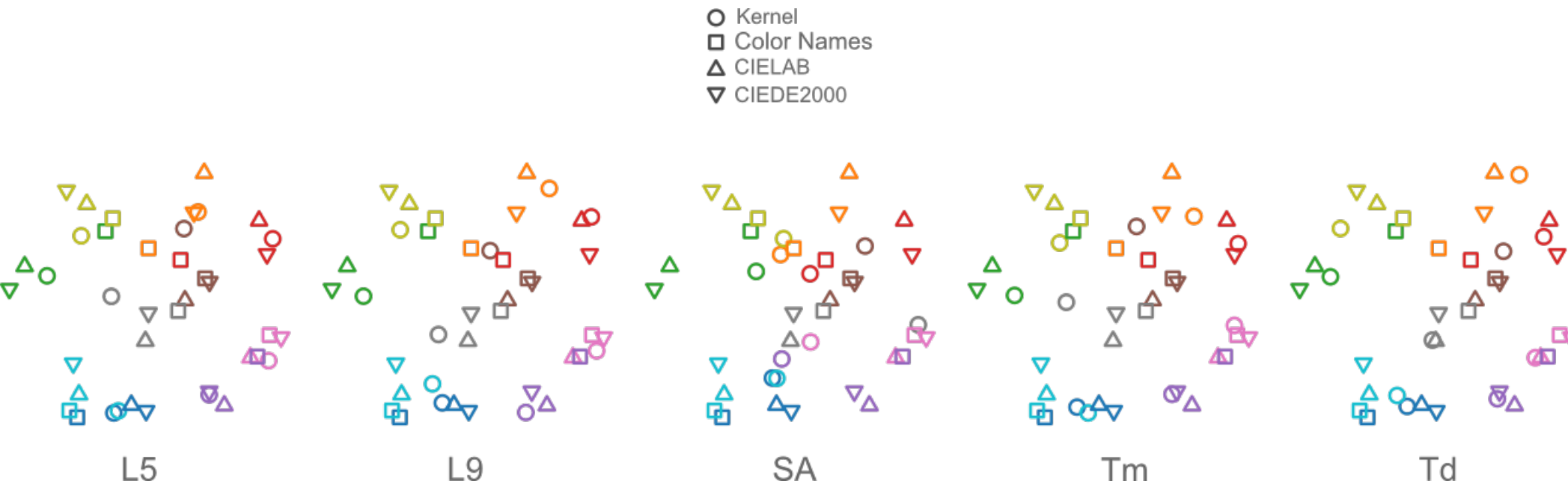


Comparison of Perceptual Kernels with Color Models



Rank correlation matrices displayed as gray-scale images (brighter entries indicate higher correlations)

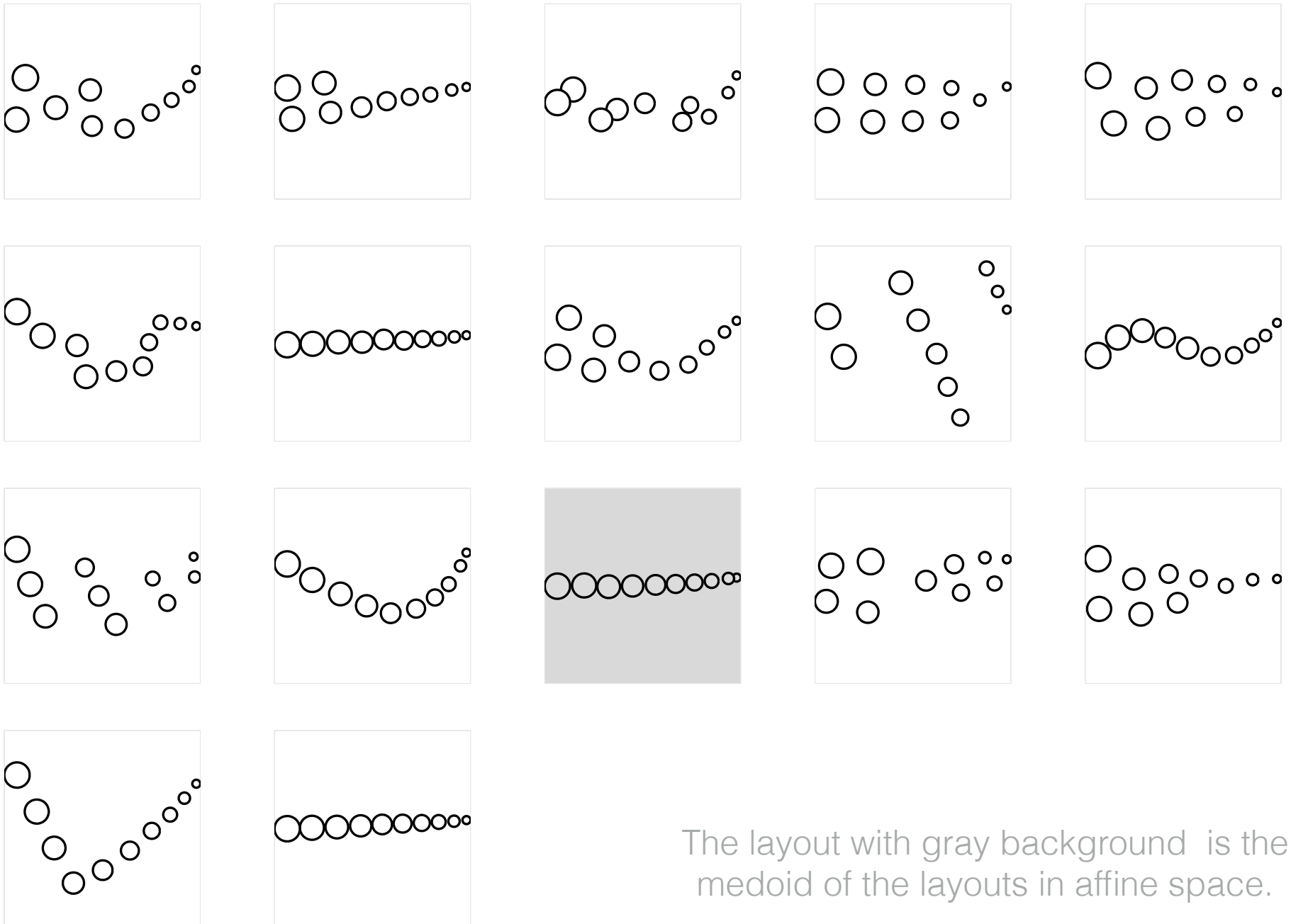
Comparison of Perceptual Color Kernels with Color Models



The palette shapes representing the models are chosen automatically with visual embedding (using the triplet matching kernel). They reflect the correlations between the variables. For example the correlation between the CIELAB and CIEDE2000 is higher than the correlation between the perceptual kernels and color names and the assigned shapes reflect this relationship perceptually.

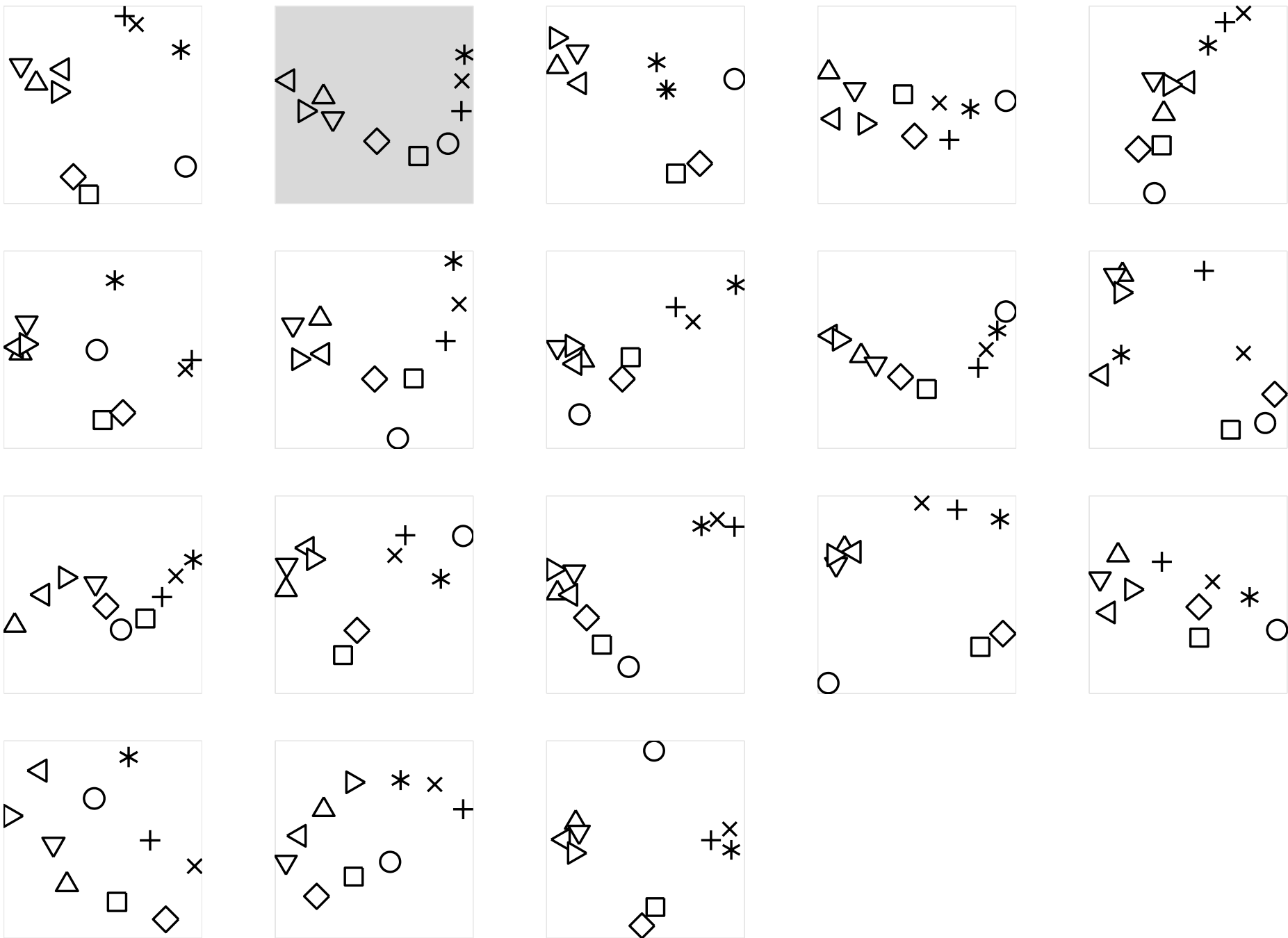
All projections are aligned to the CIELAB projection in the plane using similarity transformations

Per-subject SAs: size

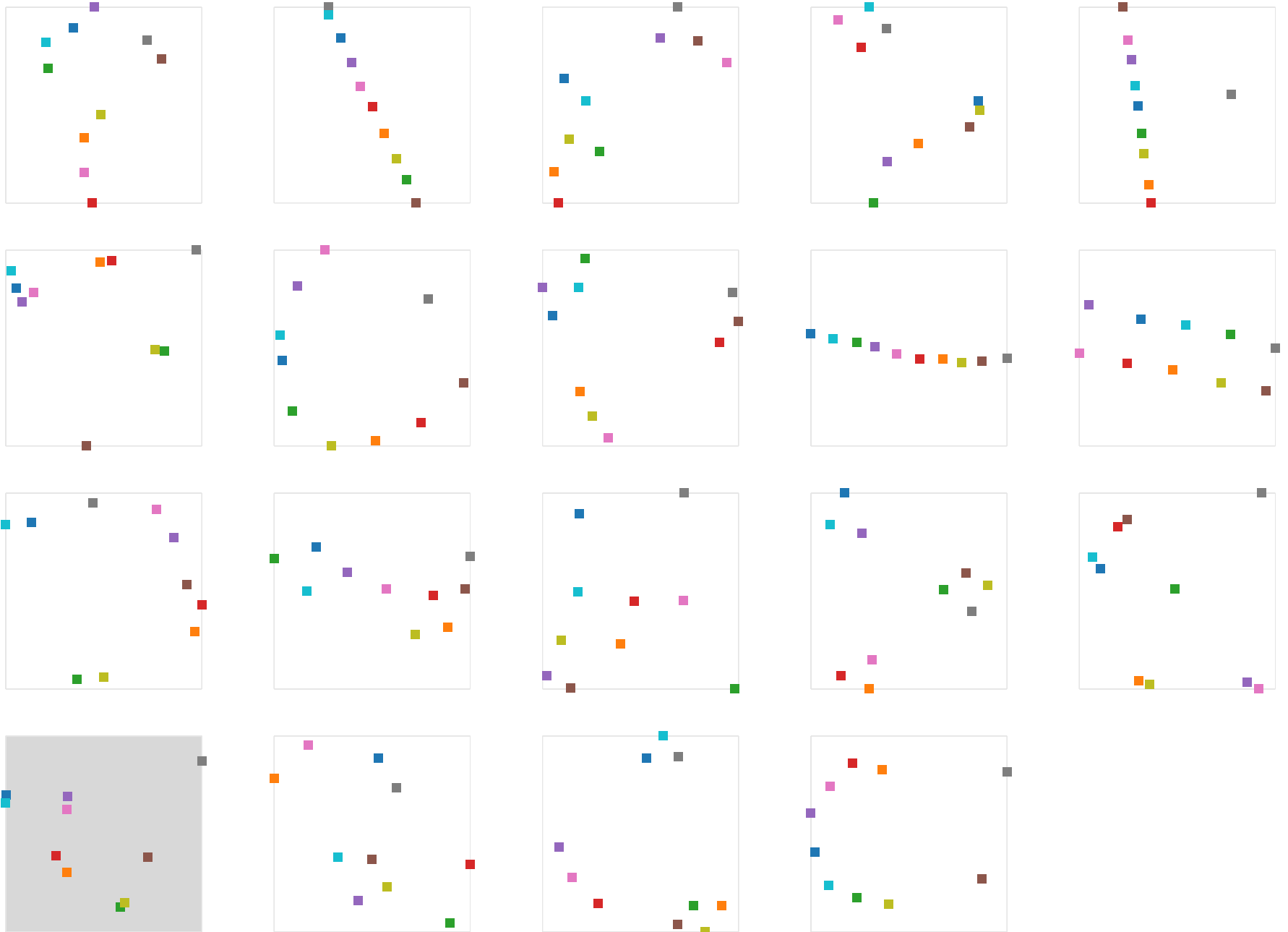


The layout with gray background is the medoid of the layouts in affine space.

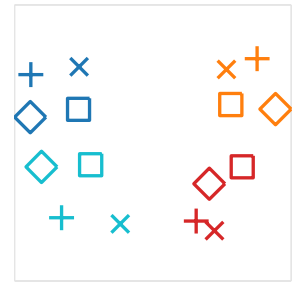
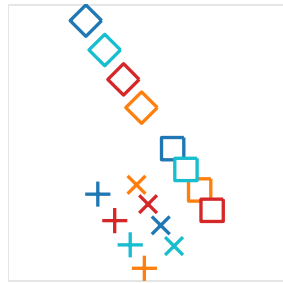
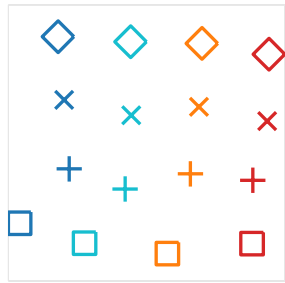
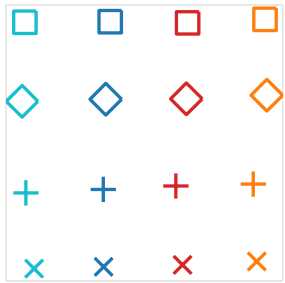
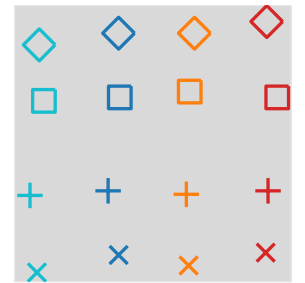
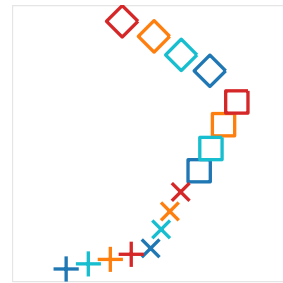
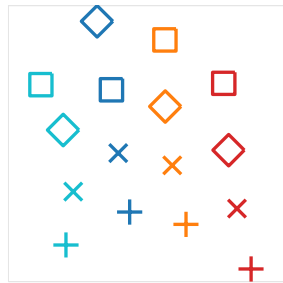
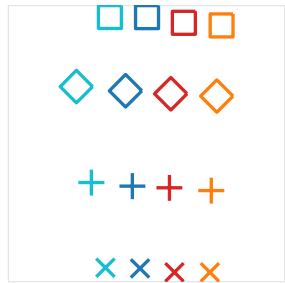
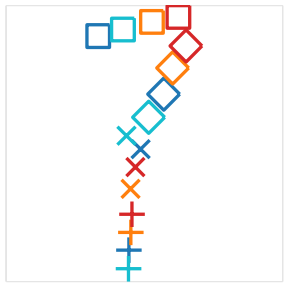
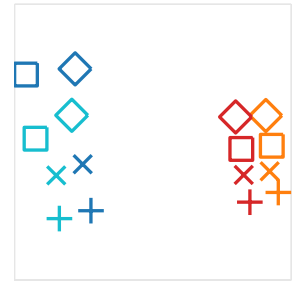
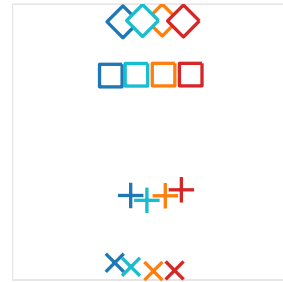
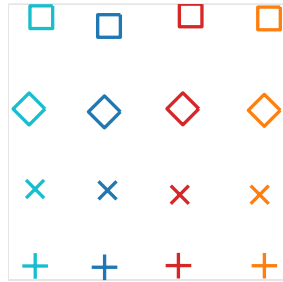
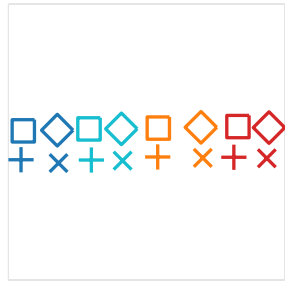
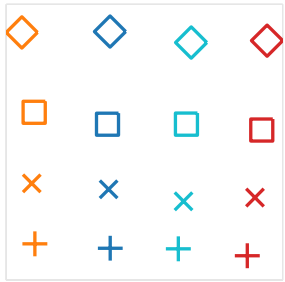
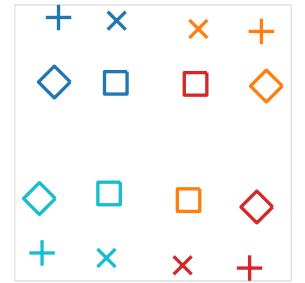
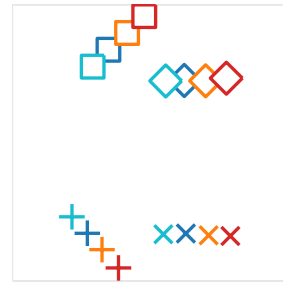
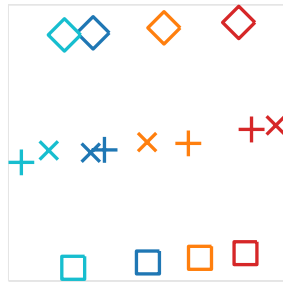
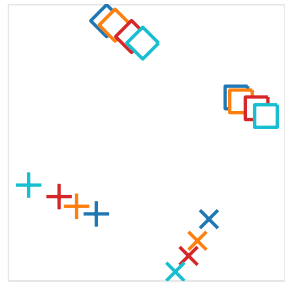
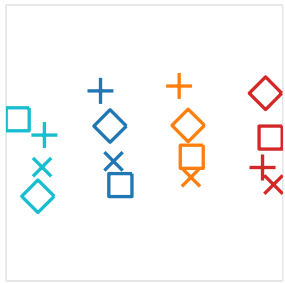
Per-subject SAs: shape



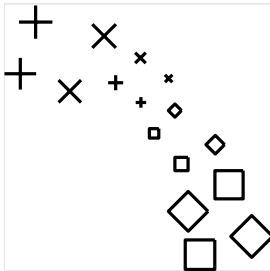
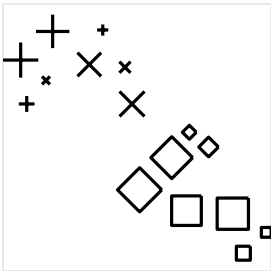
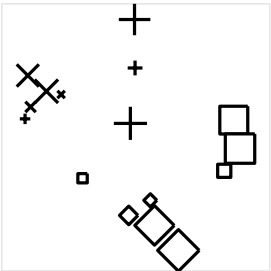
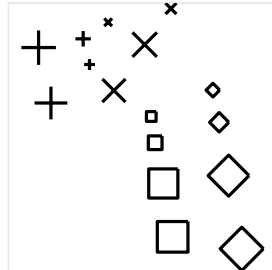
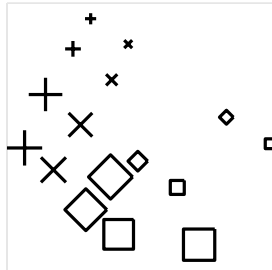
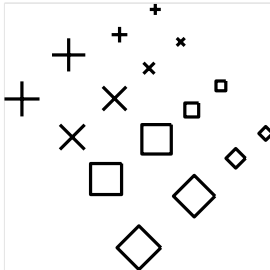
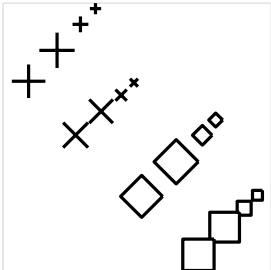
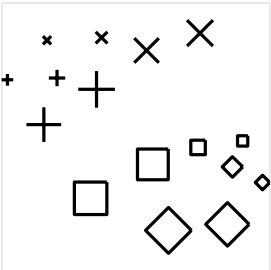
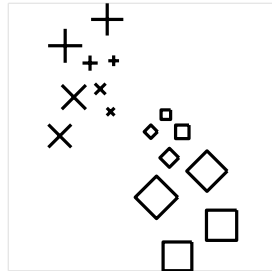
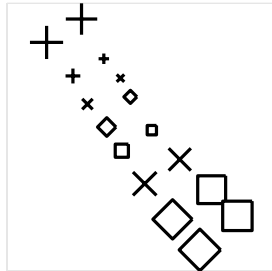
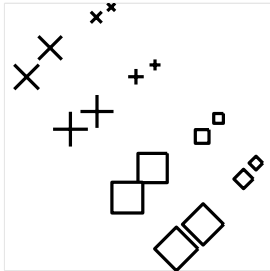
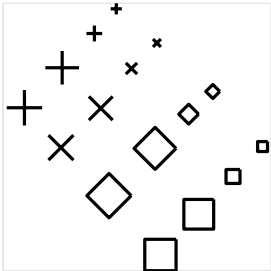
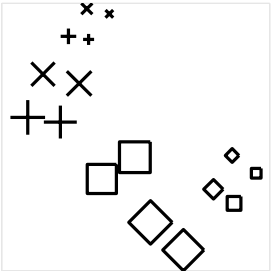
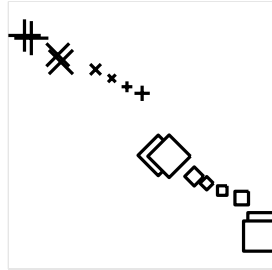
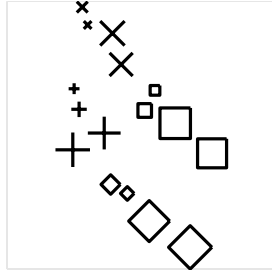
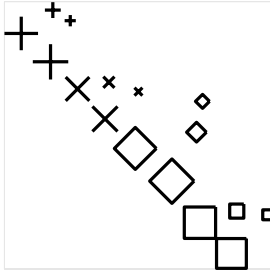
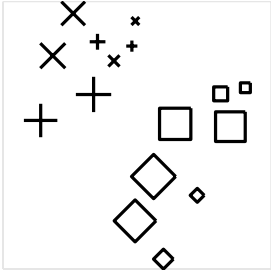
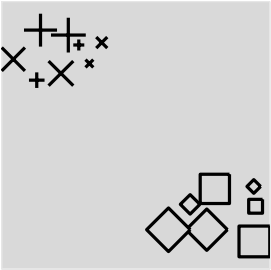
Per-subject SAs: color



Per-subject SAs: shape-color



Per-subject SAs: shape-size



Per-subject SAs: size-color

