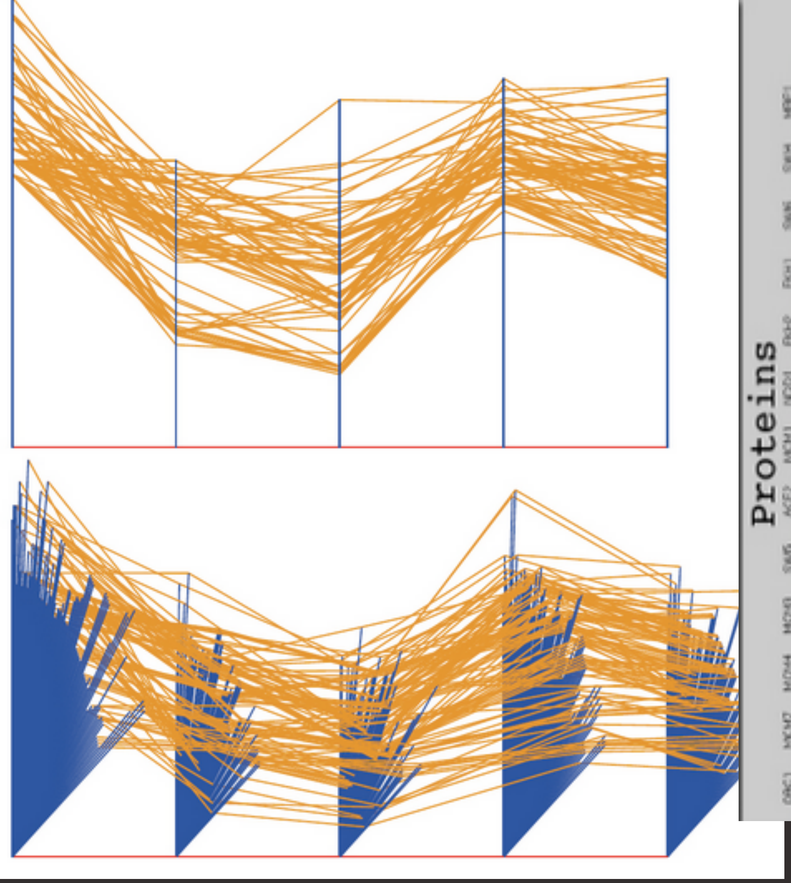
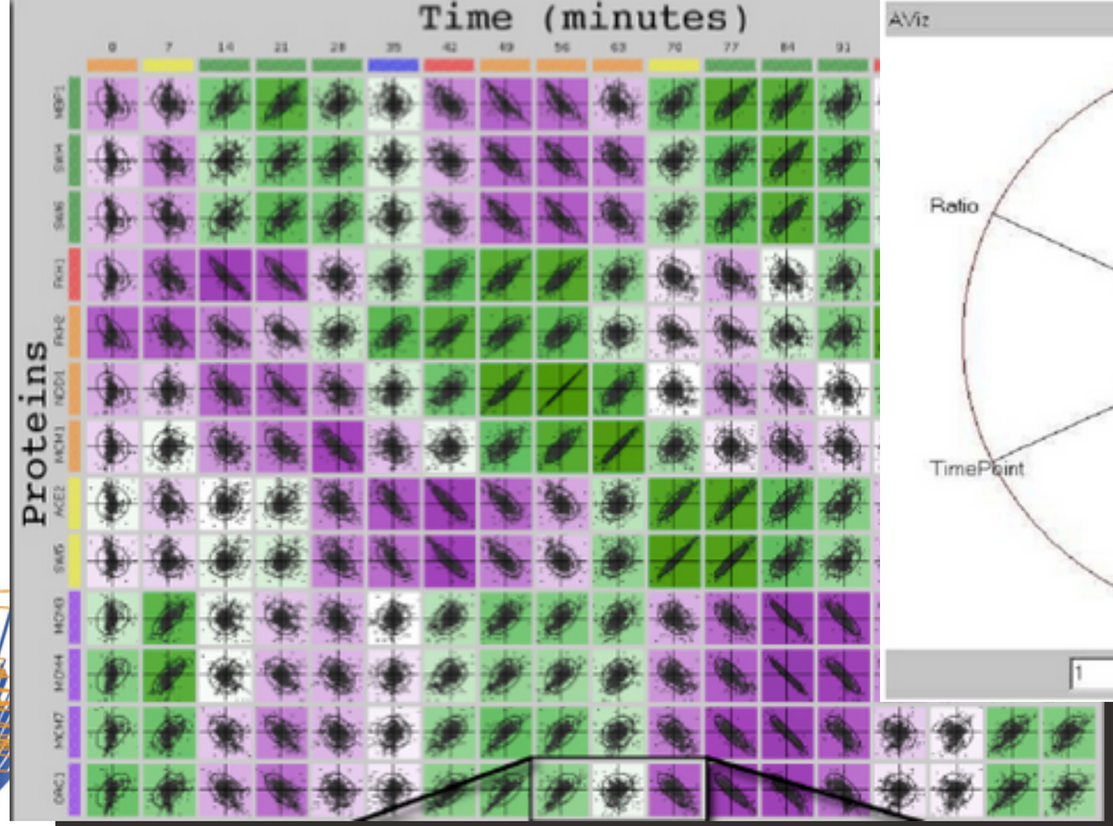
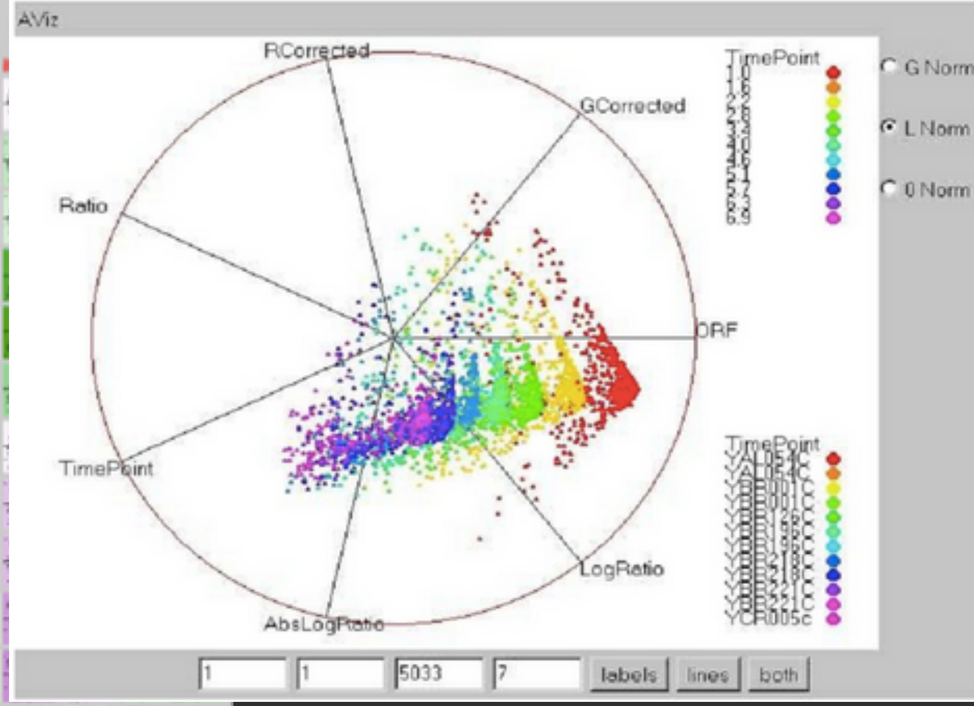
Ranking Visualizations of Correlation using Weber's Law

Lane Harrison, Fumeng Yang, Steven Franconeri, Remco Chang*

*Tufts University, *Northwestern University*

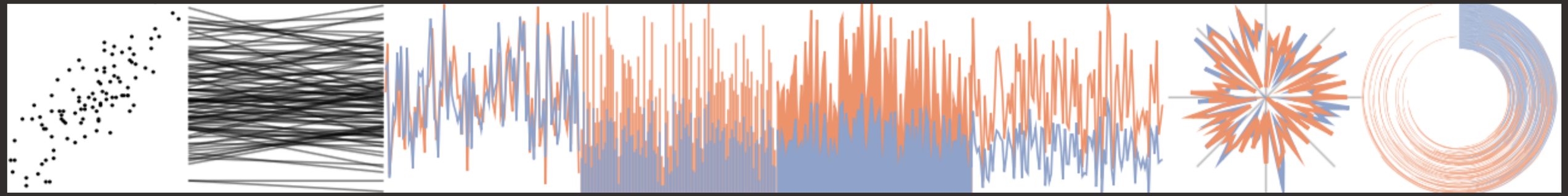




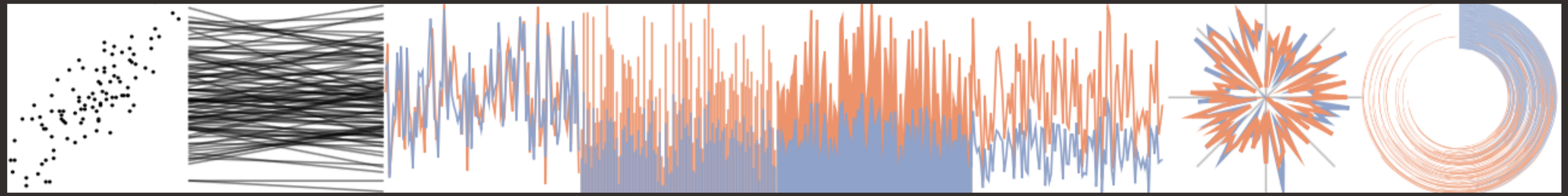


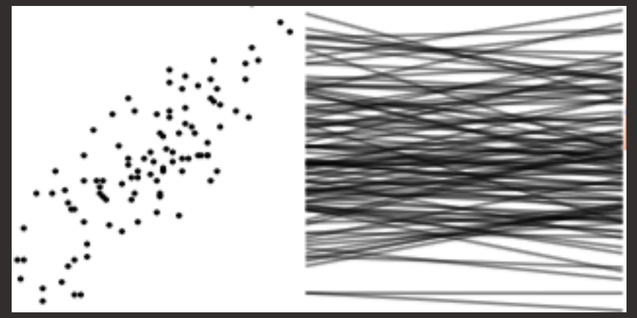
Many techniques for the same data…

Comparative Evaluation

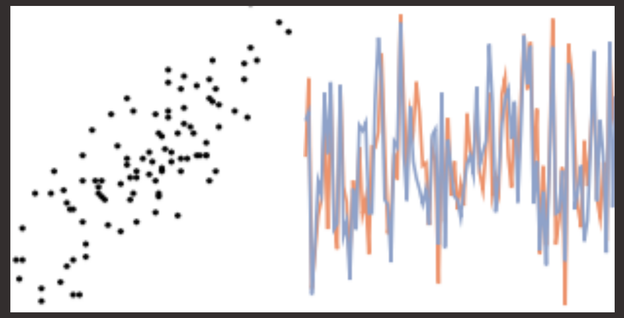


Comparative Evaluation

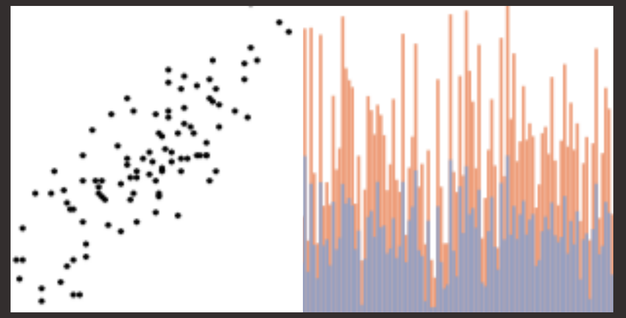




condition 1



condition 2



condition 3

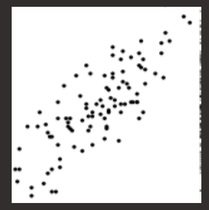
• • •

$_8C_2 = 28$

conditions

Model-based Evaluation

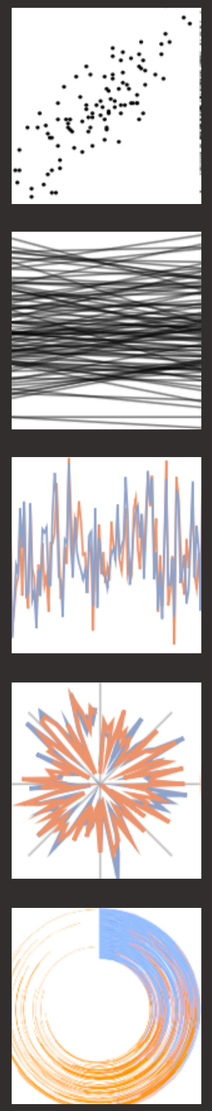
Model-based Evaluation



→ M_1

Model the performance of scatterplots on a task.

Model-based Evaluation



M_1

M_2

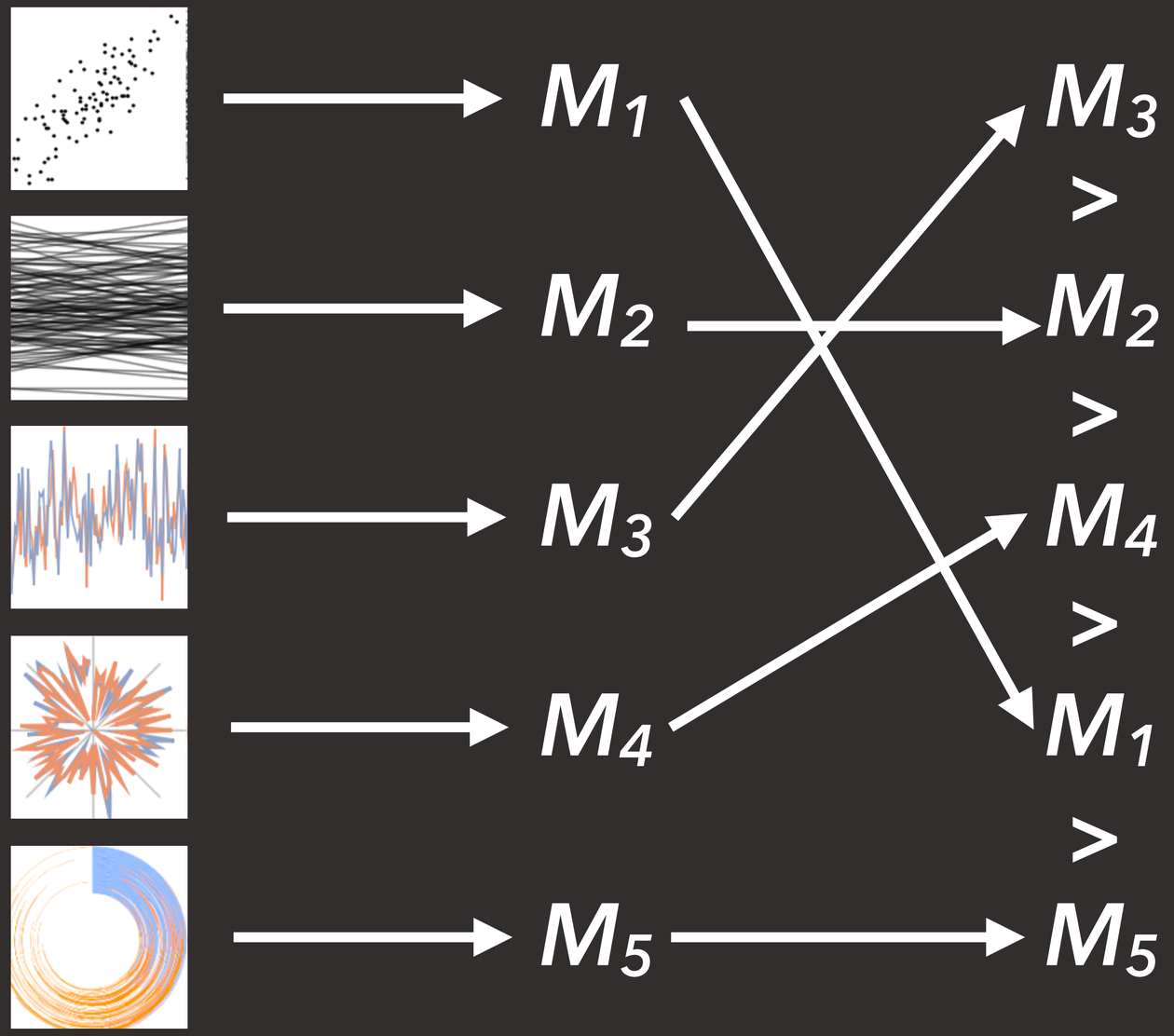
M_3

M_4

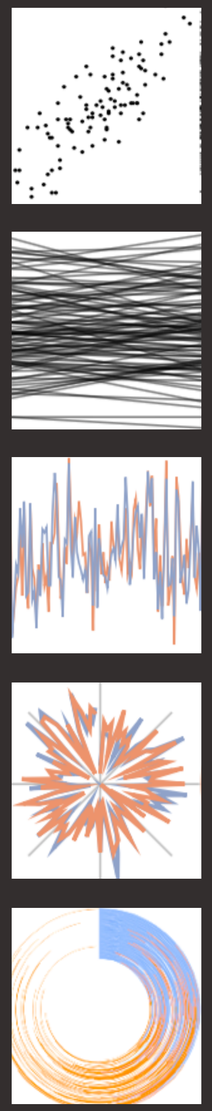
M_5

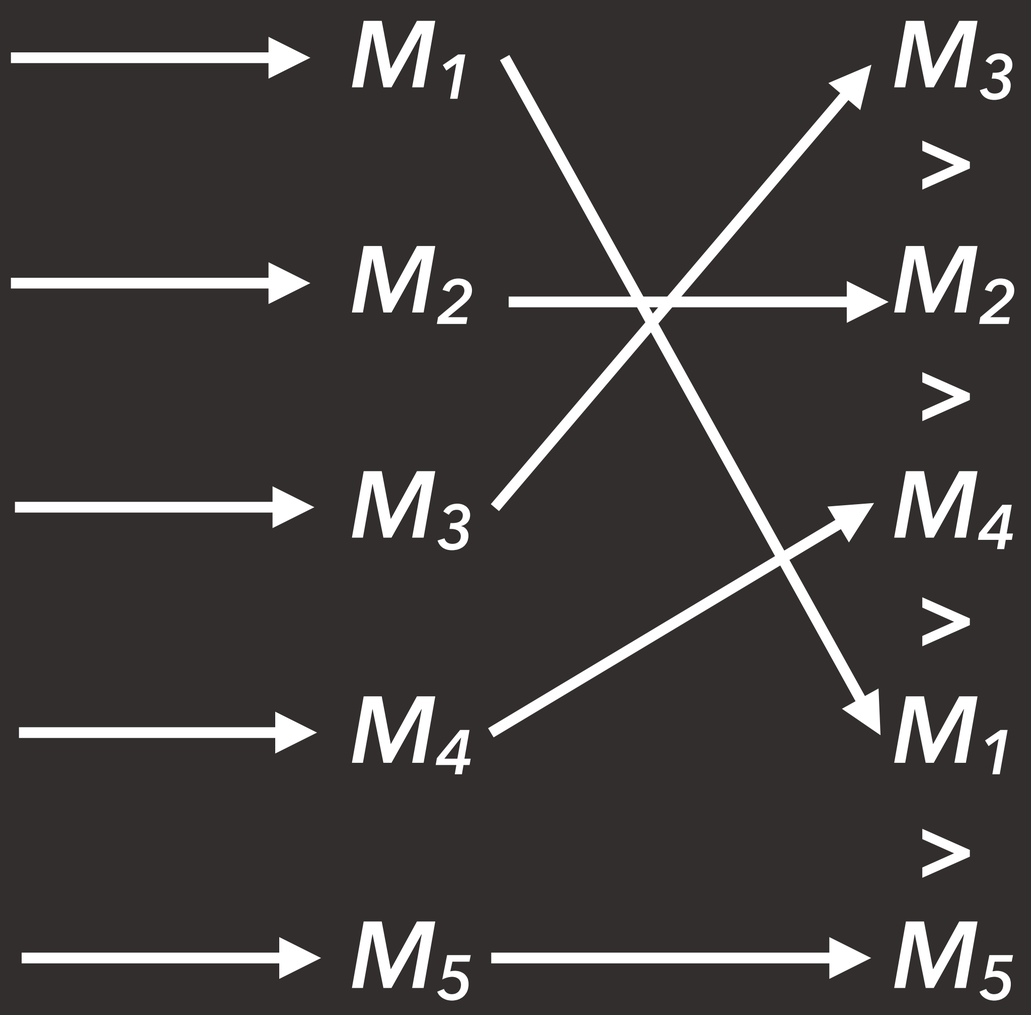
Model the performance of visualizations on a task.

Model-based Evaluation



Model-based Evaluation

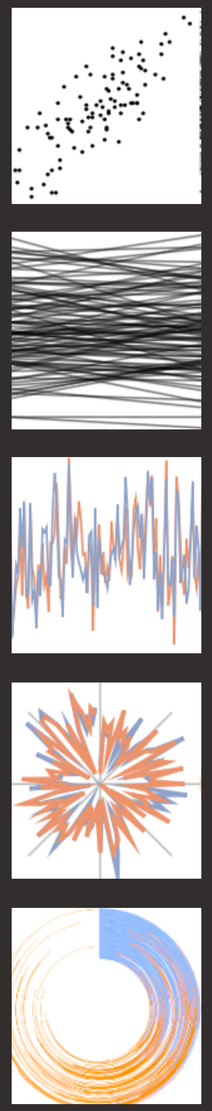


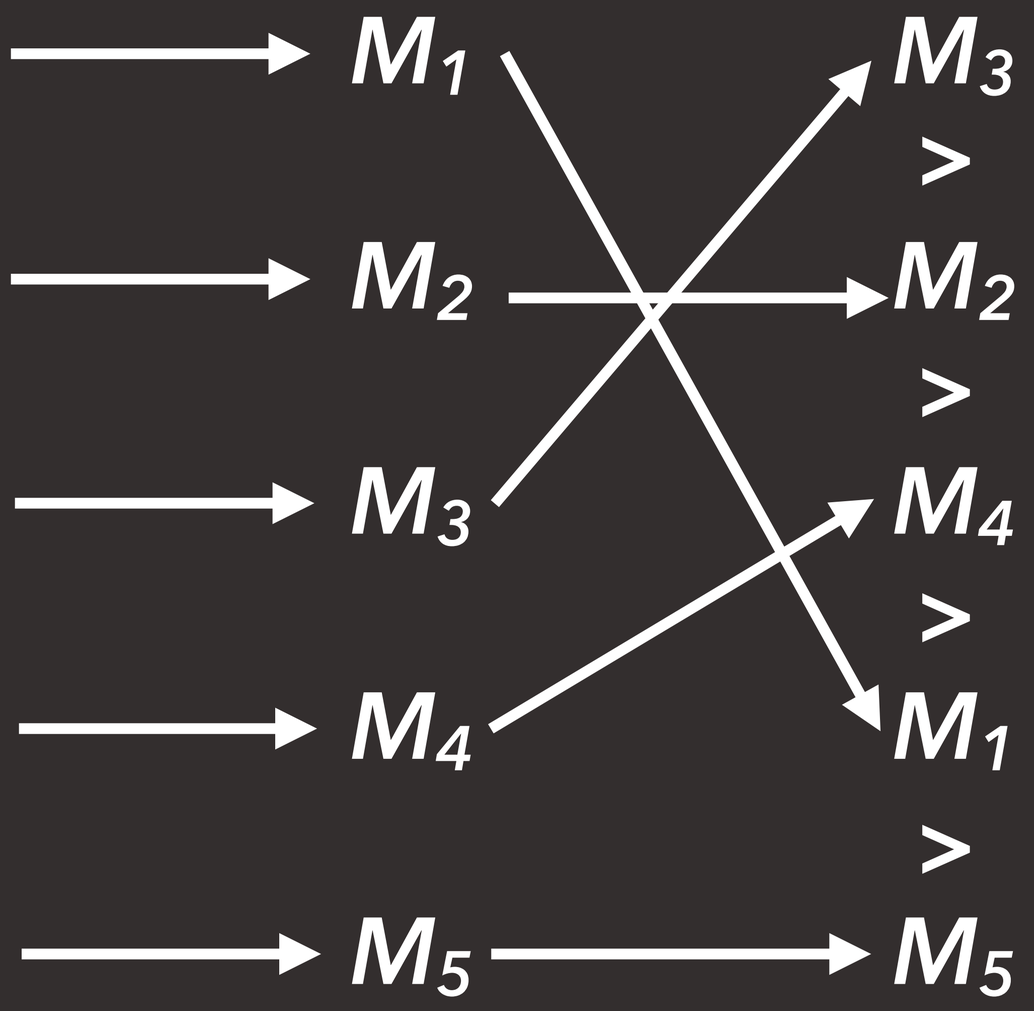


Models of performance can be compared directly and efficiently.

Models are scalable and falsifiable.

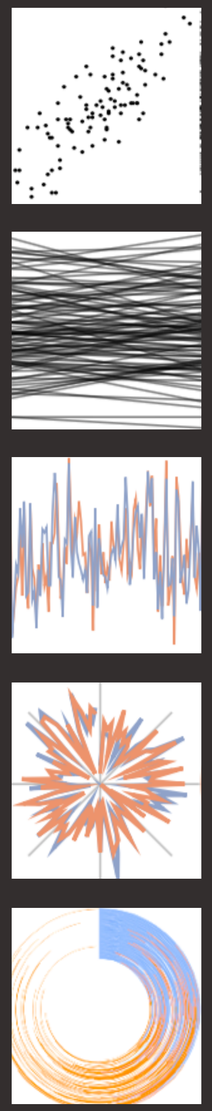
Model-based Evaluation

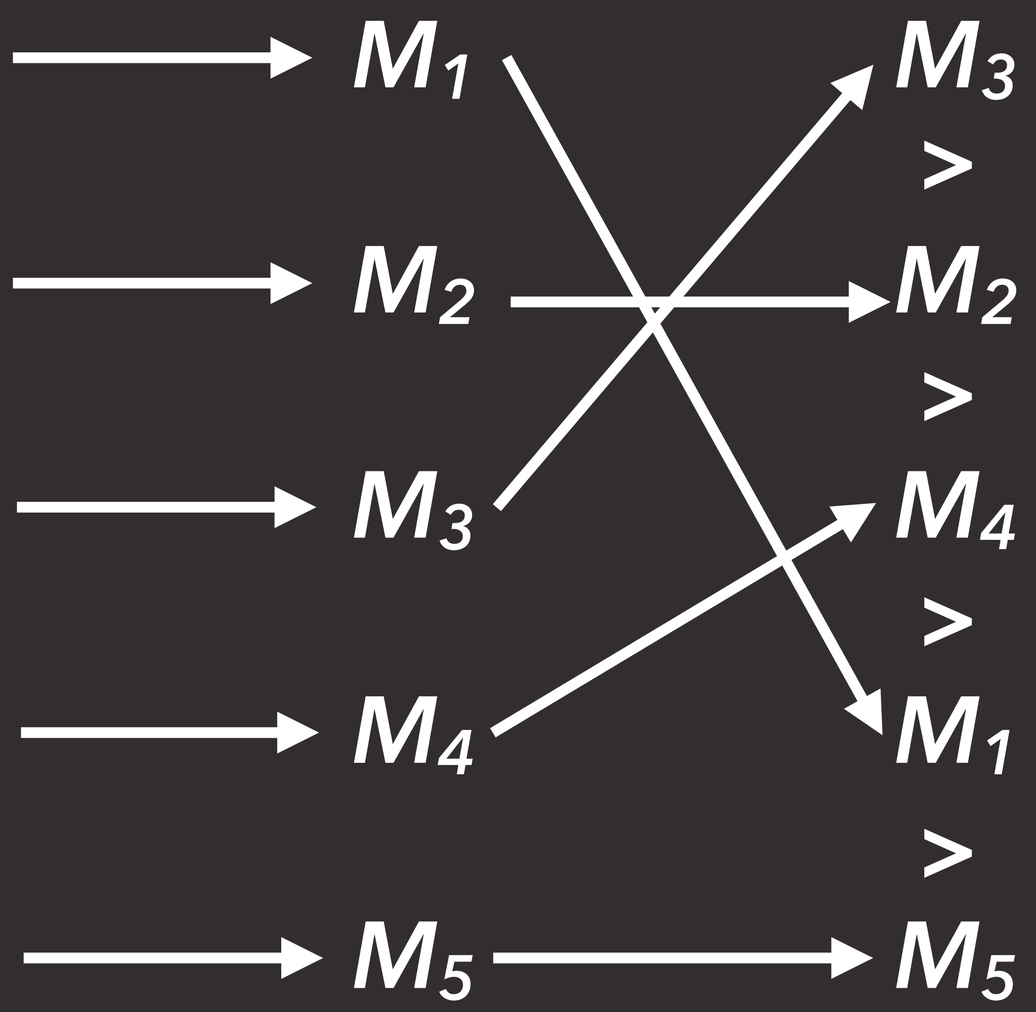




To be effective, models must be grounded in theory.

Model-based Evaluation





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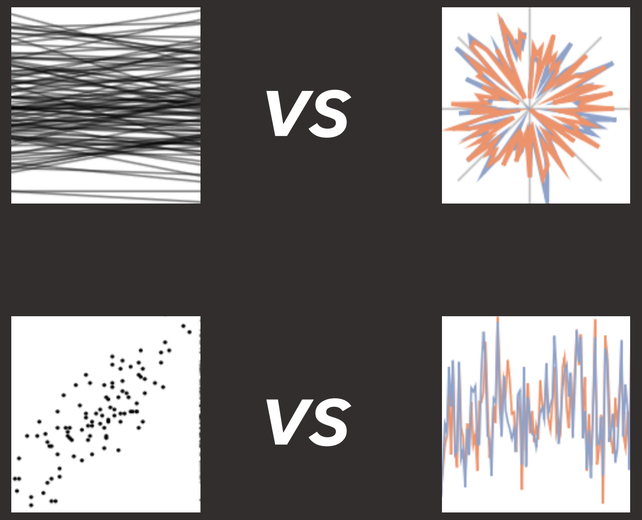
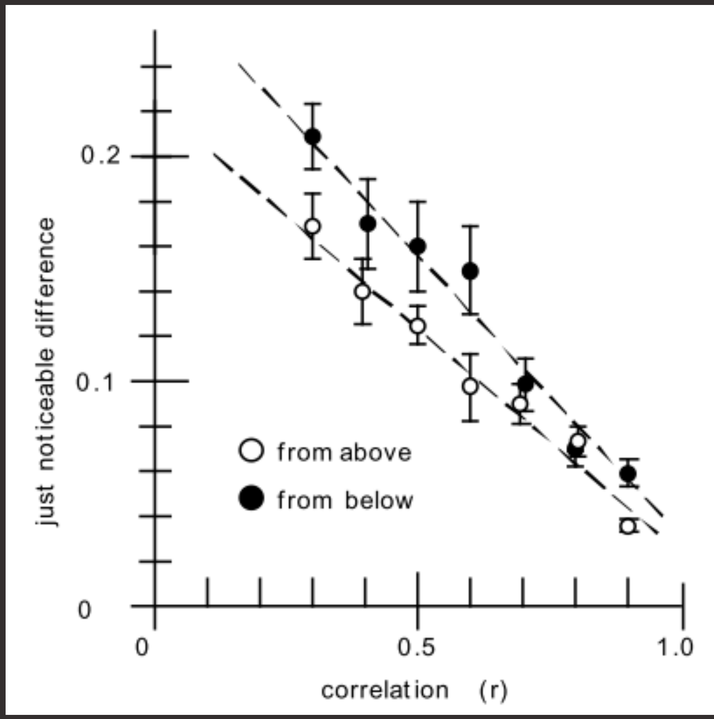


A model grounded in theory:

Ron Rensink, Gideon Baldridge (2010)
The Perception of Correlation in Scatterplots

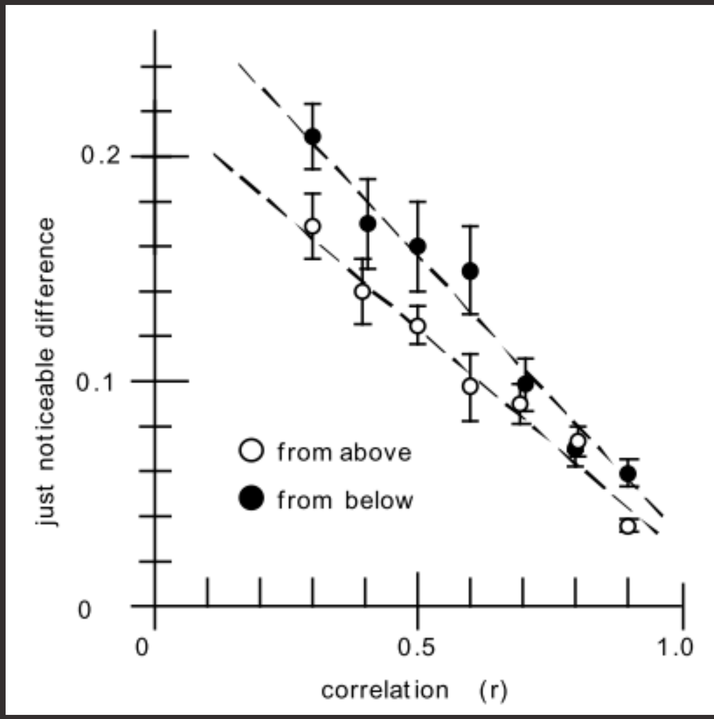
- *Used psychophysiological methodologies.*



A model grounded in theory:

Ron Rensink, Gideon Baldridge (2010)
The Perception of Correlation in Scatterplots

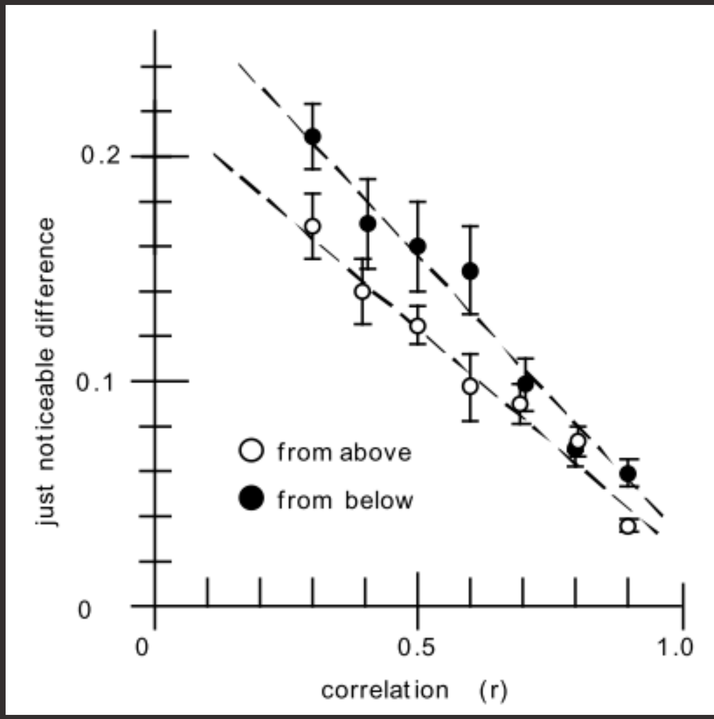
- *Used psychophysiological methodologies.*
- *Inferred just-noticeable differences for scatterplots depicting positive correlations.*



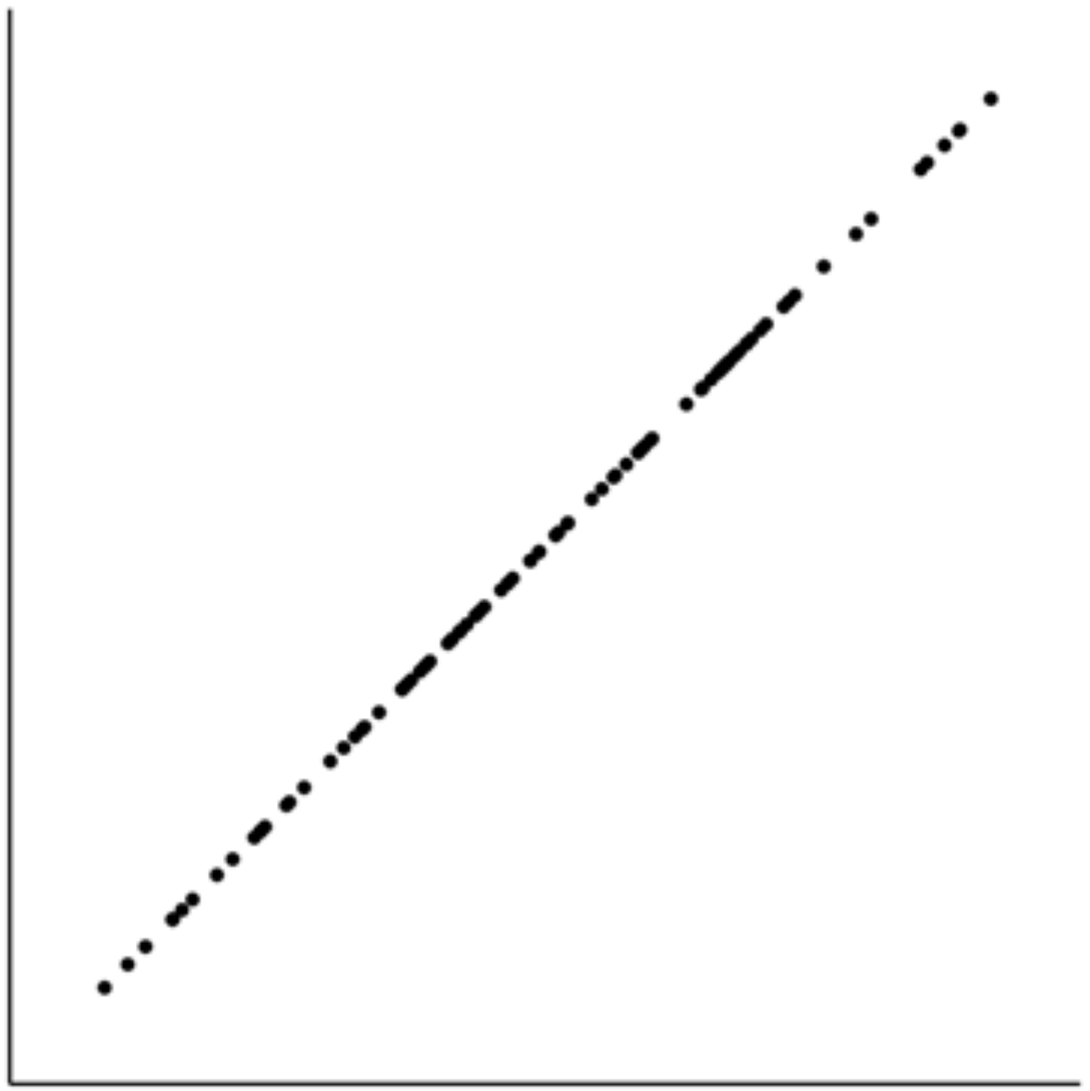
A model grounded in theory:

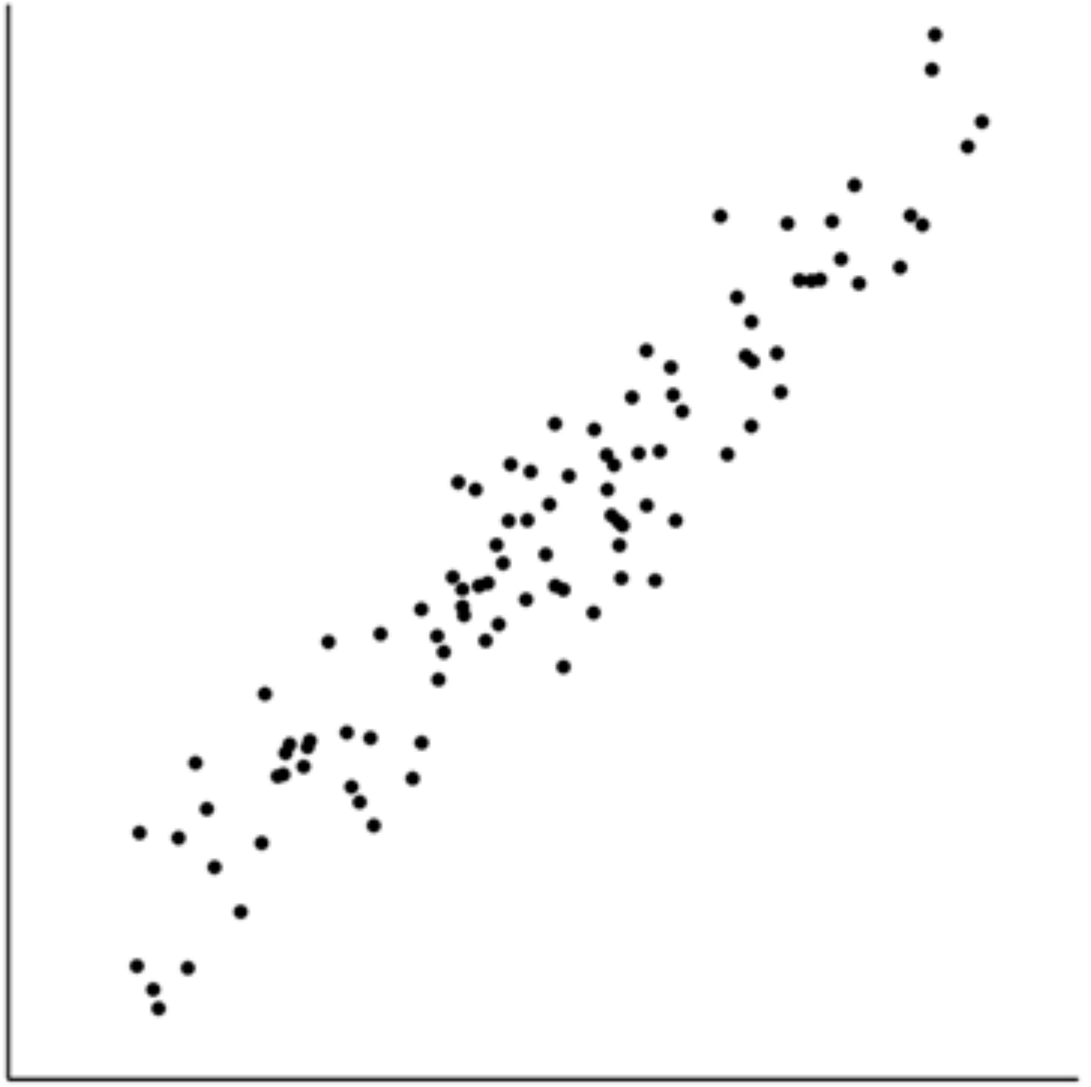
Ron Rensink, Gideon Baldridge (2010)
The Perception of Correlation in Scatterplots

- *Used psychophysiological methodologies.*
- *Inferred just-noticeable differences for scatterplots depicting positive correlations.*
- *Established that the perception of correlation in scatterplots can be modeled using Weber's law.*

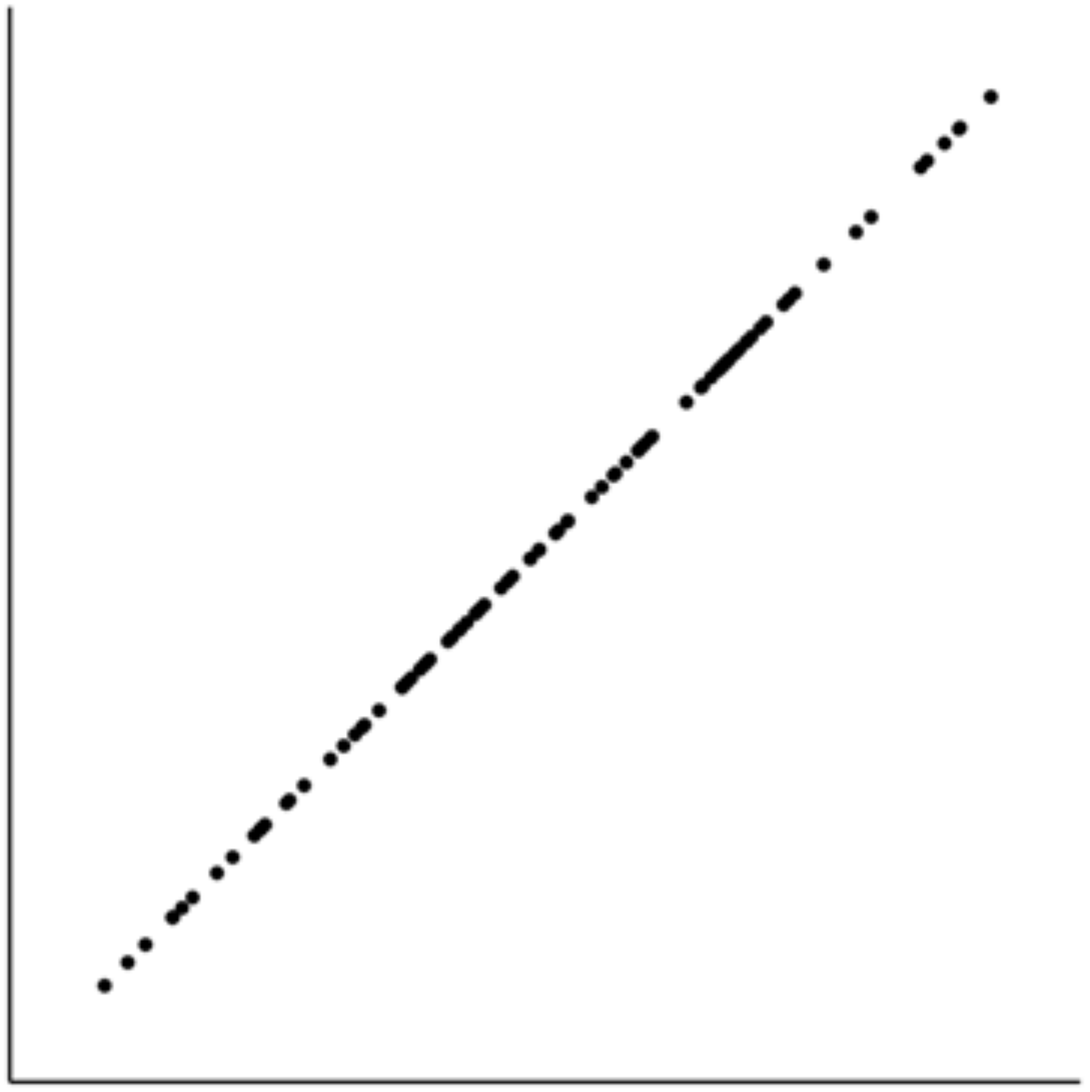


Psychophysiological methodology: Which is more correlated?

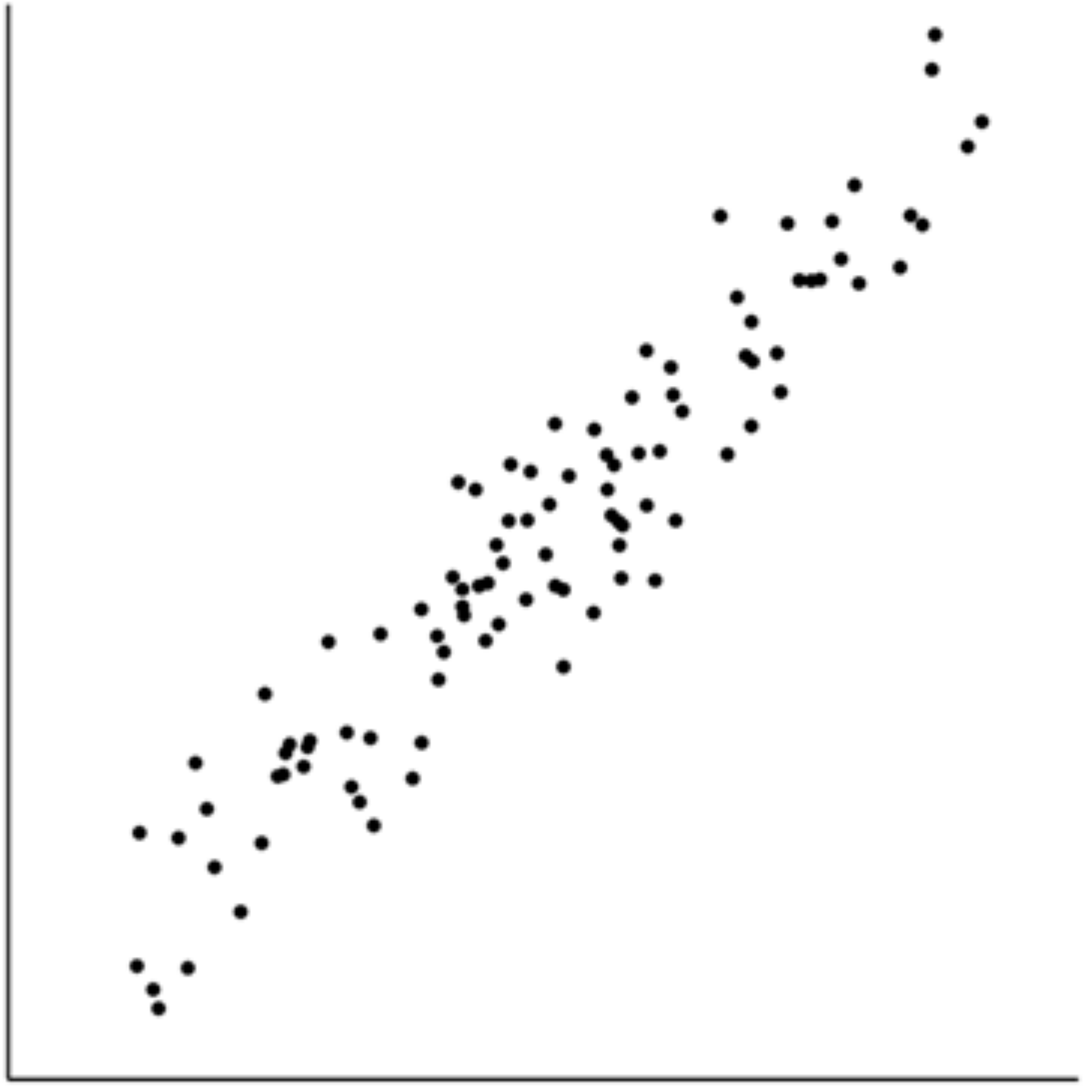


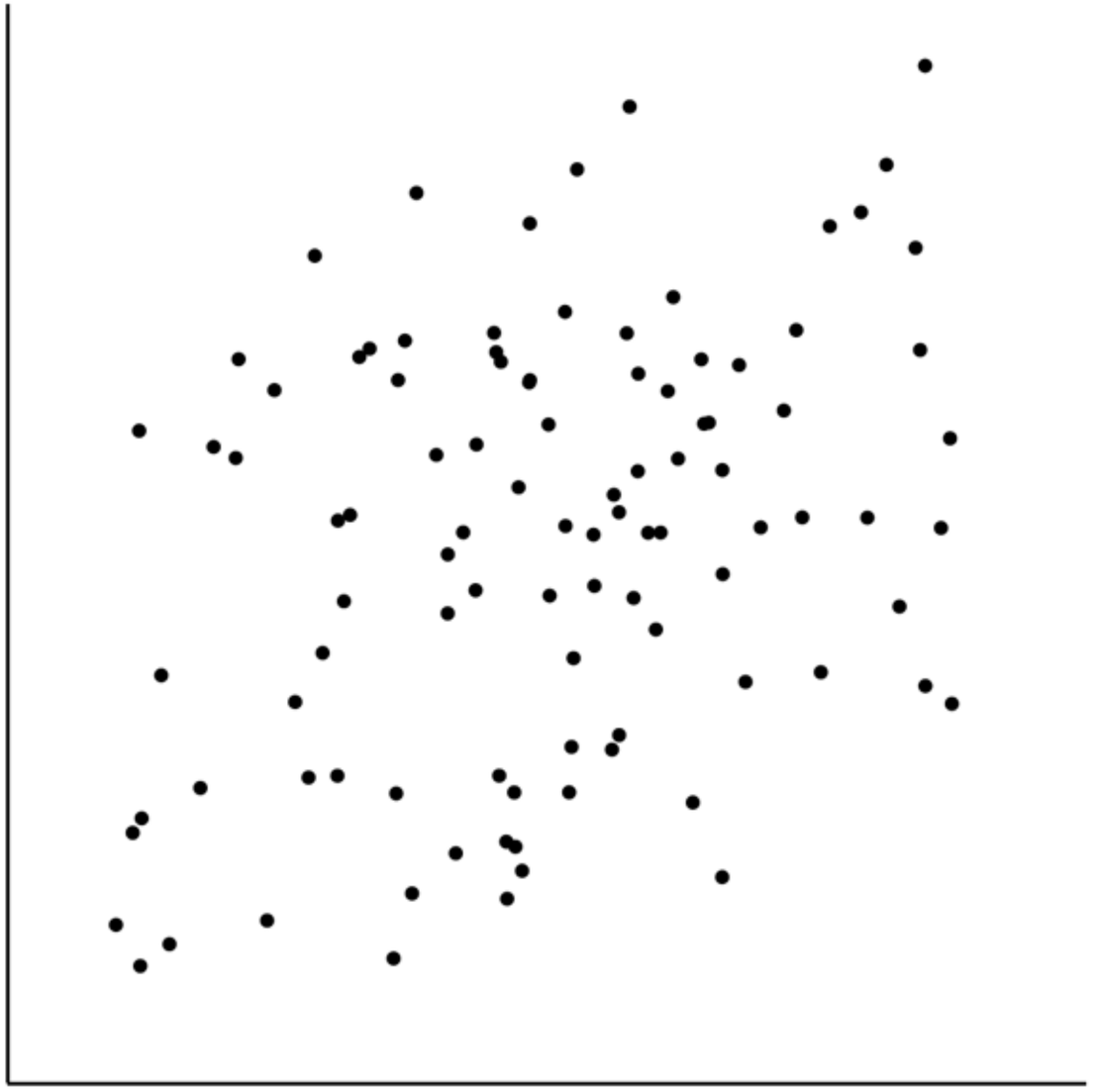


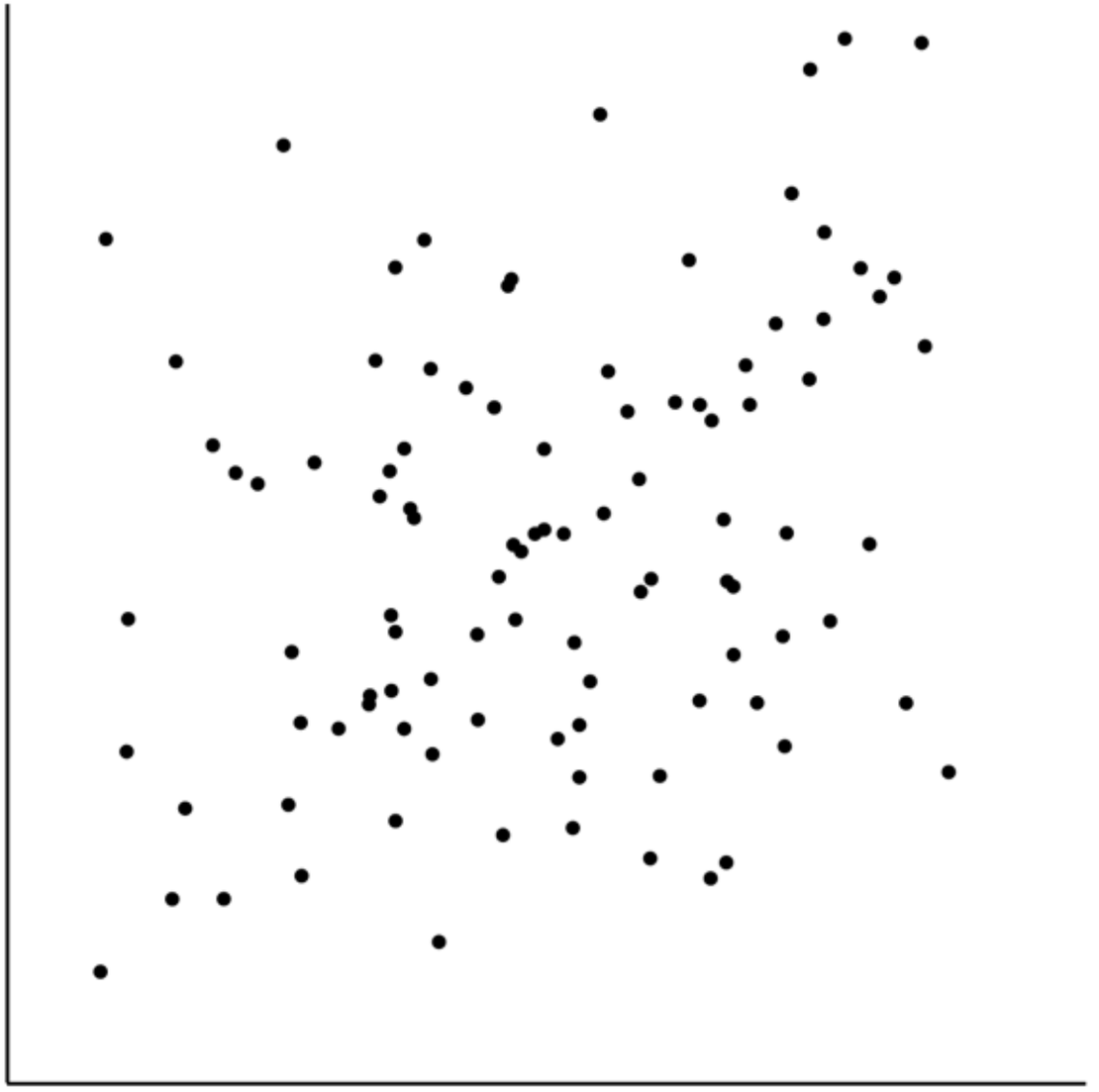
r = 1



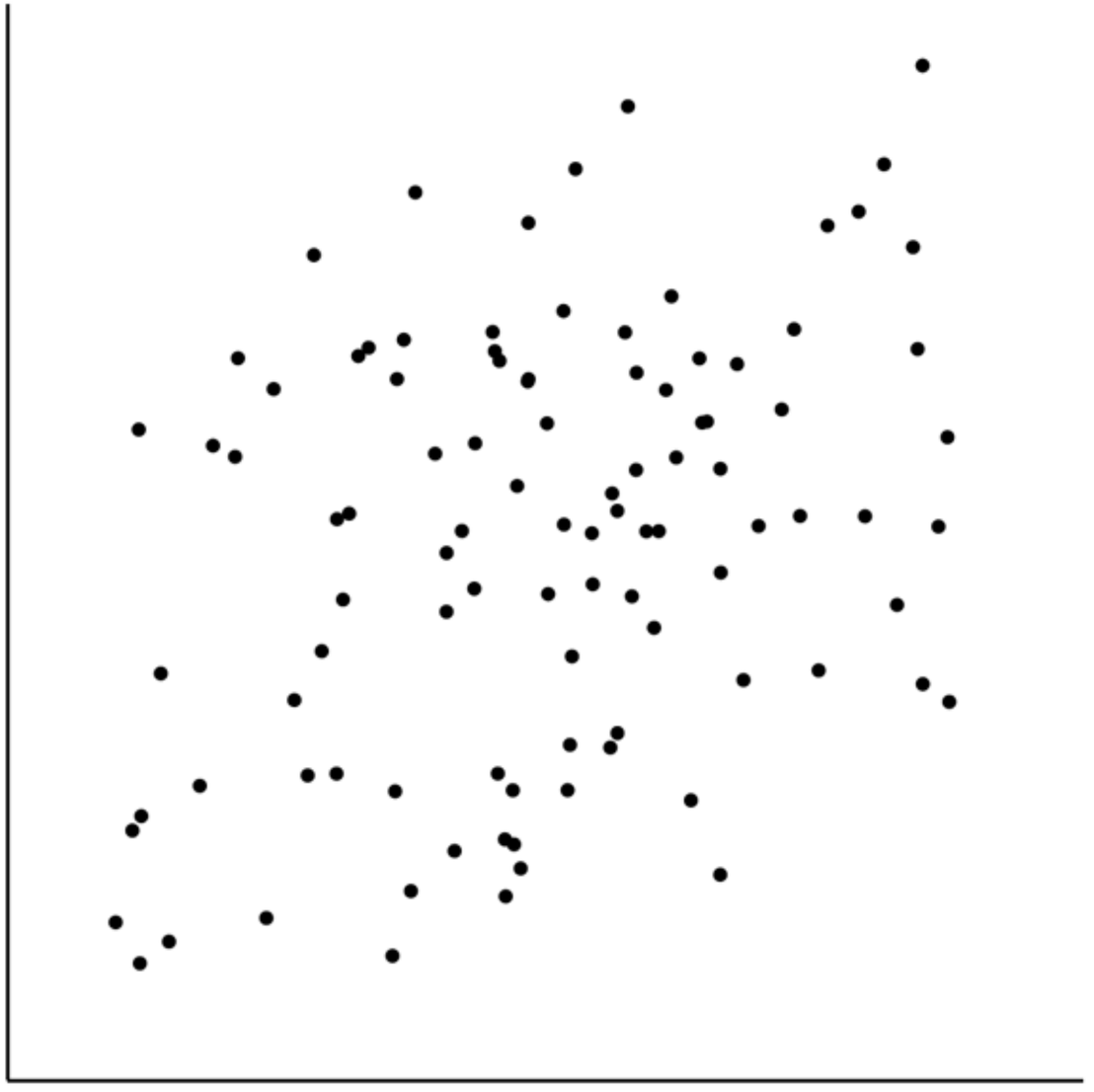
r = 0.95



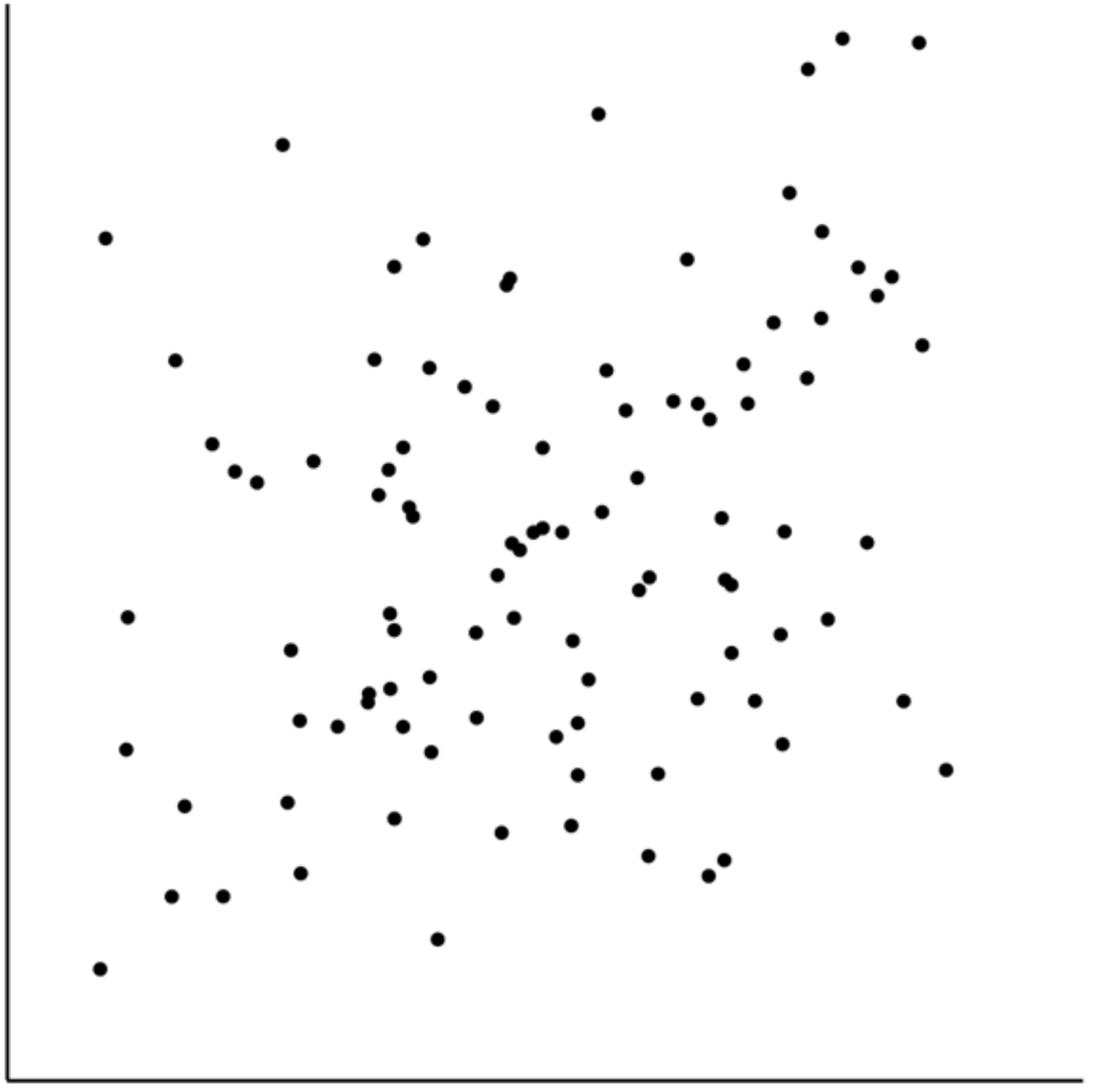




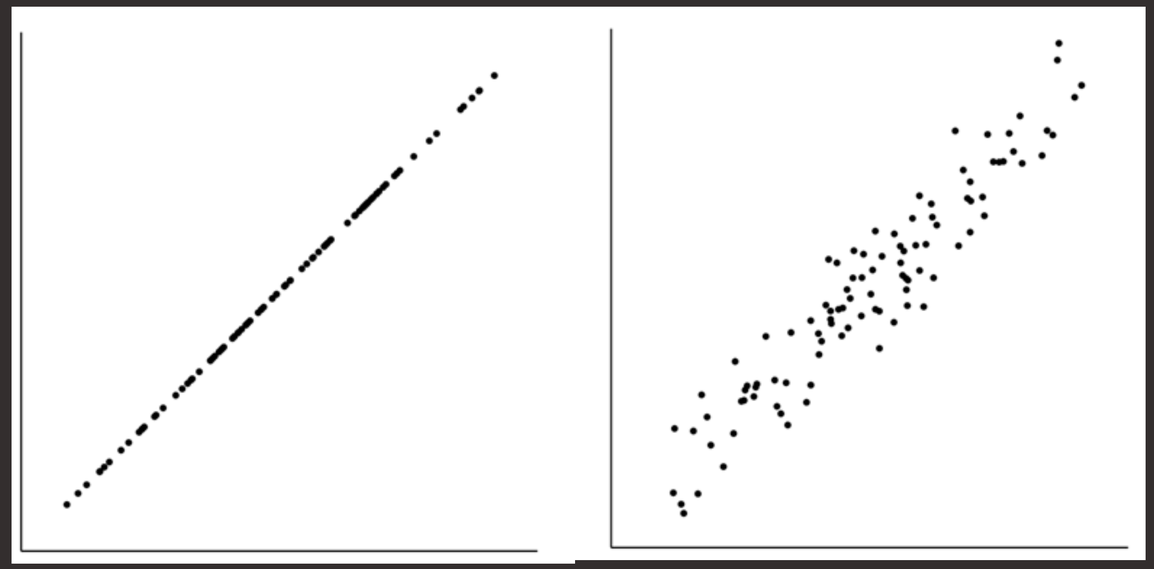
r = 0.35



r = 0.3

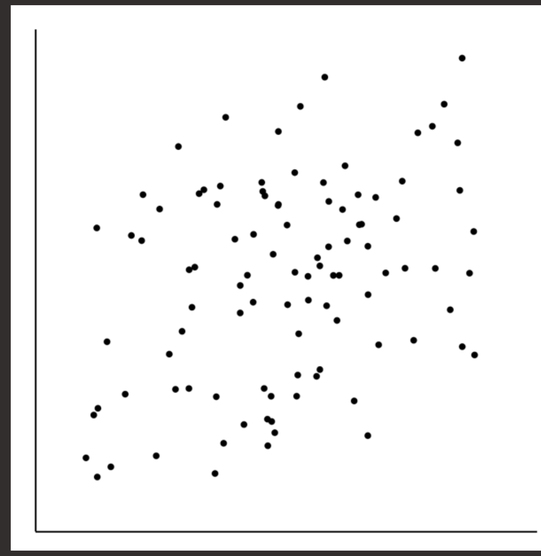


Same difference but harder, why?

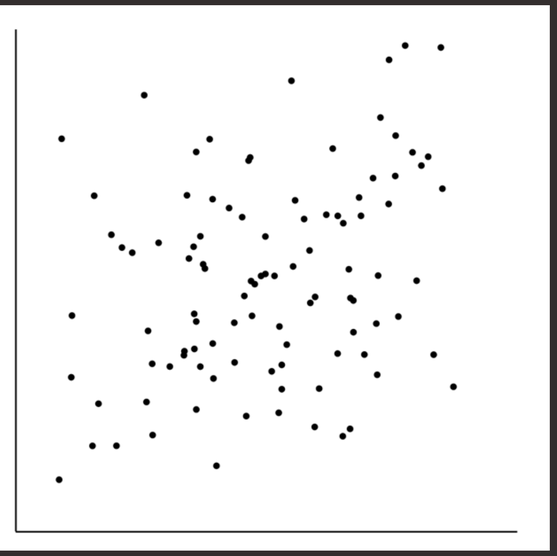


1.0

0.95



0.35



0.3

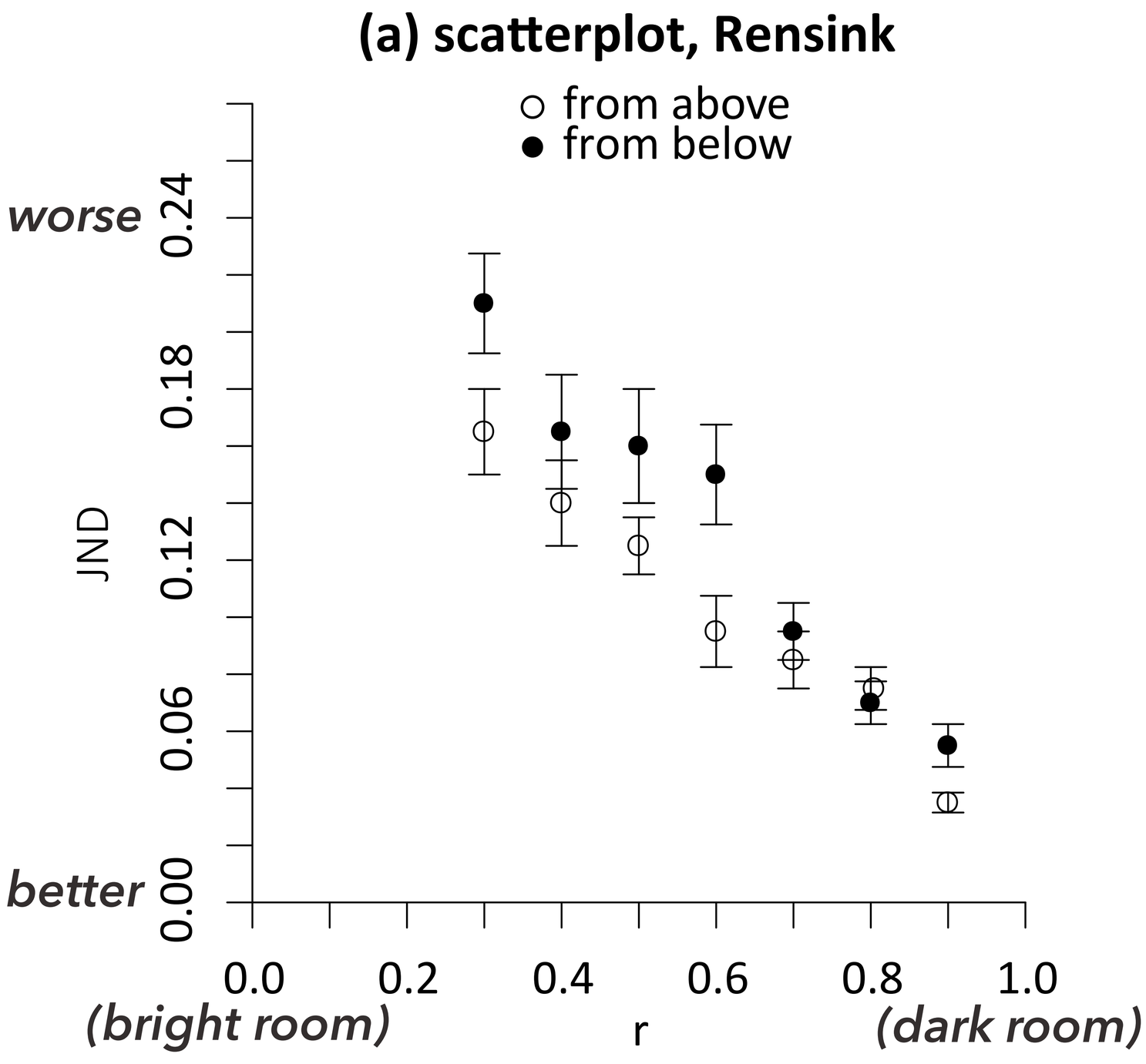
just-noticeable differences (jnd)

imagine yourself in a dark room...

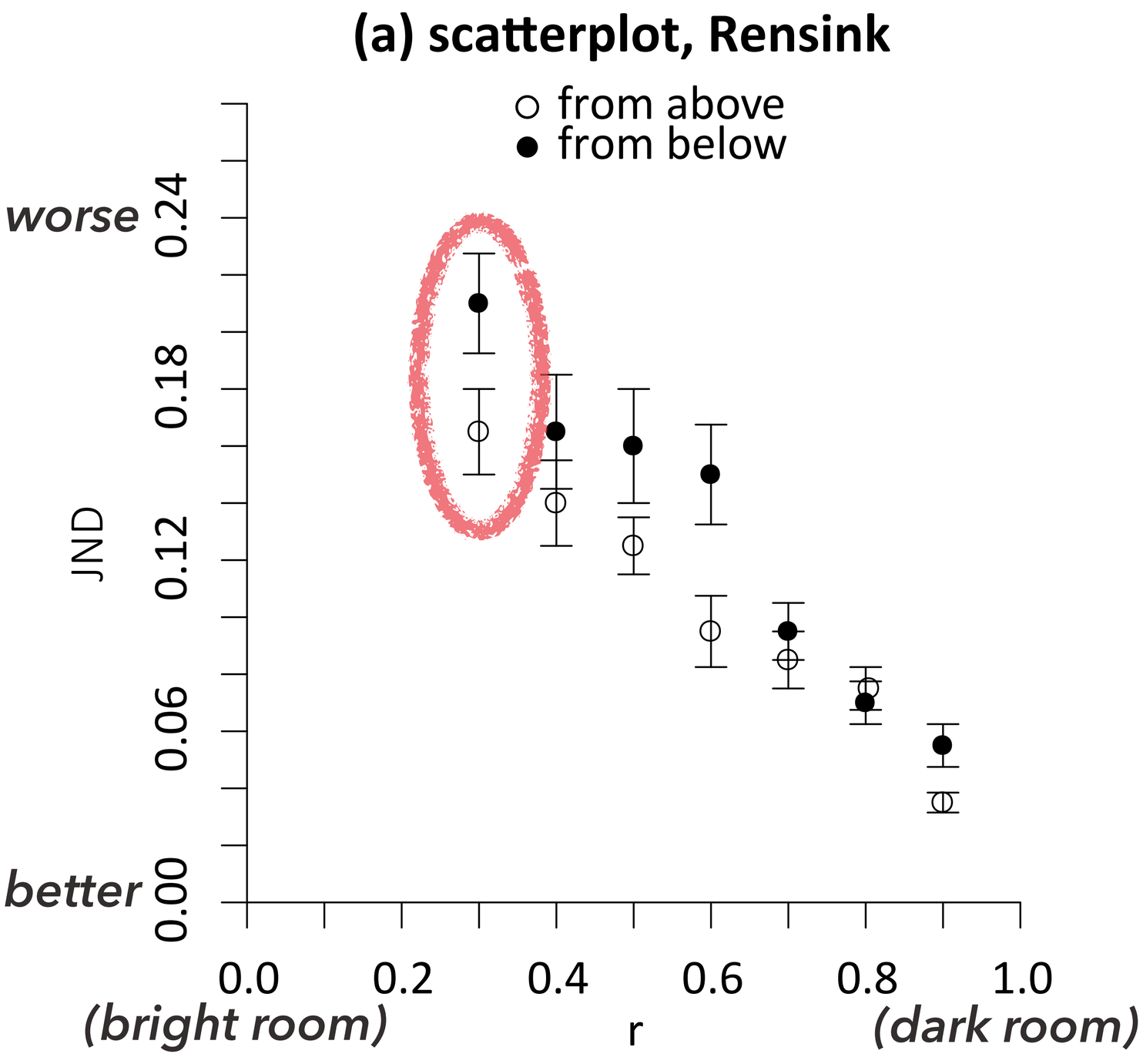
JND: the smallest difference necessary to perceive two stimuli as being different.

after many trials...

Rensink plotted JND as a function of correlation (r)

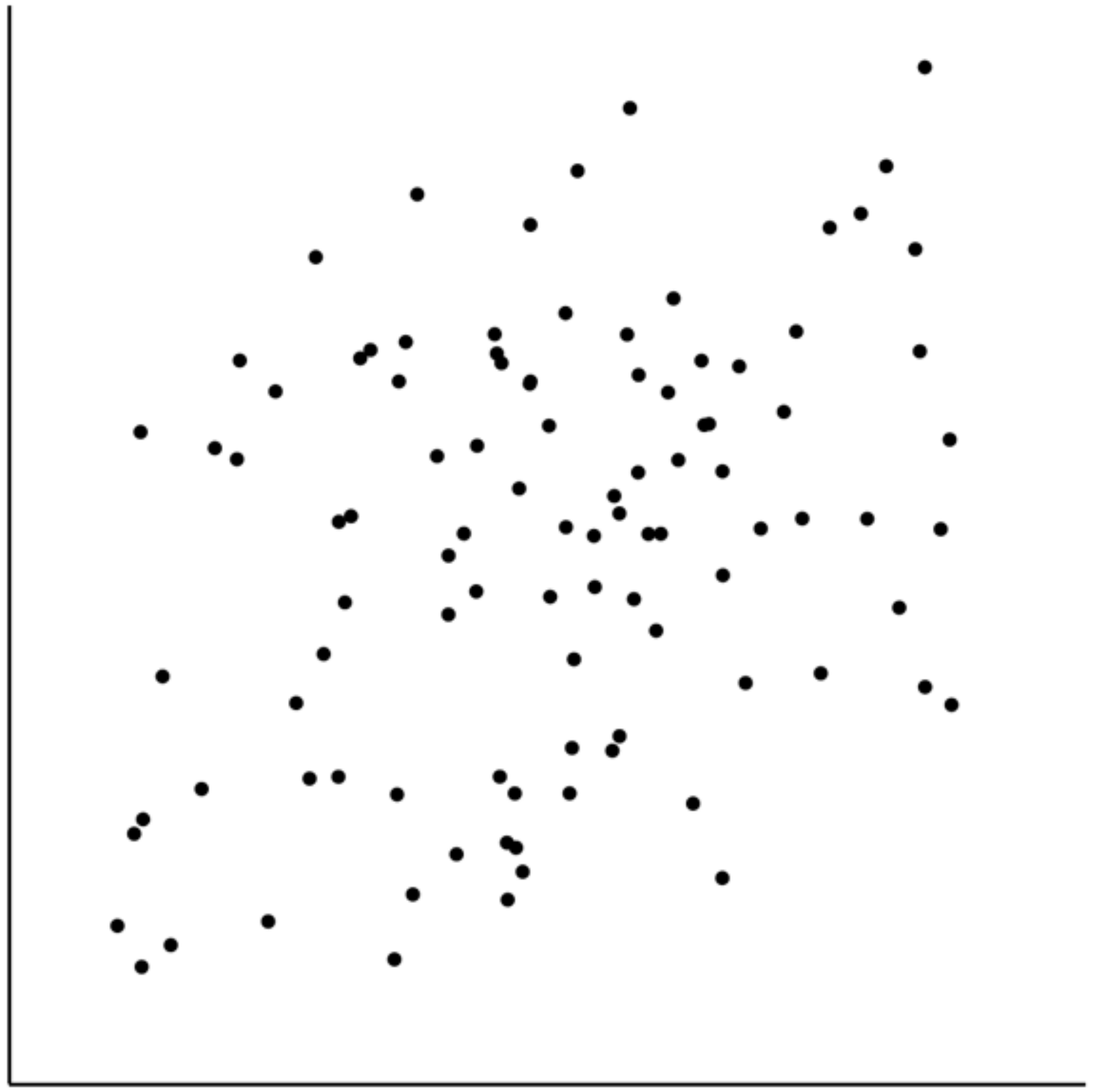


To see a difference in data with correlation of 0.3, the comparison r must be +/- 0.2.

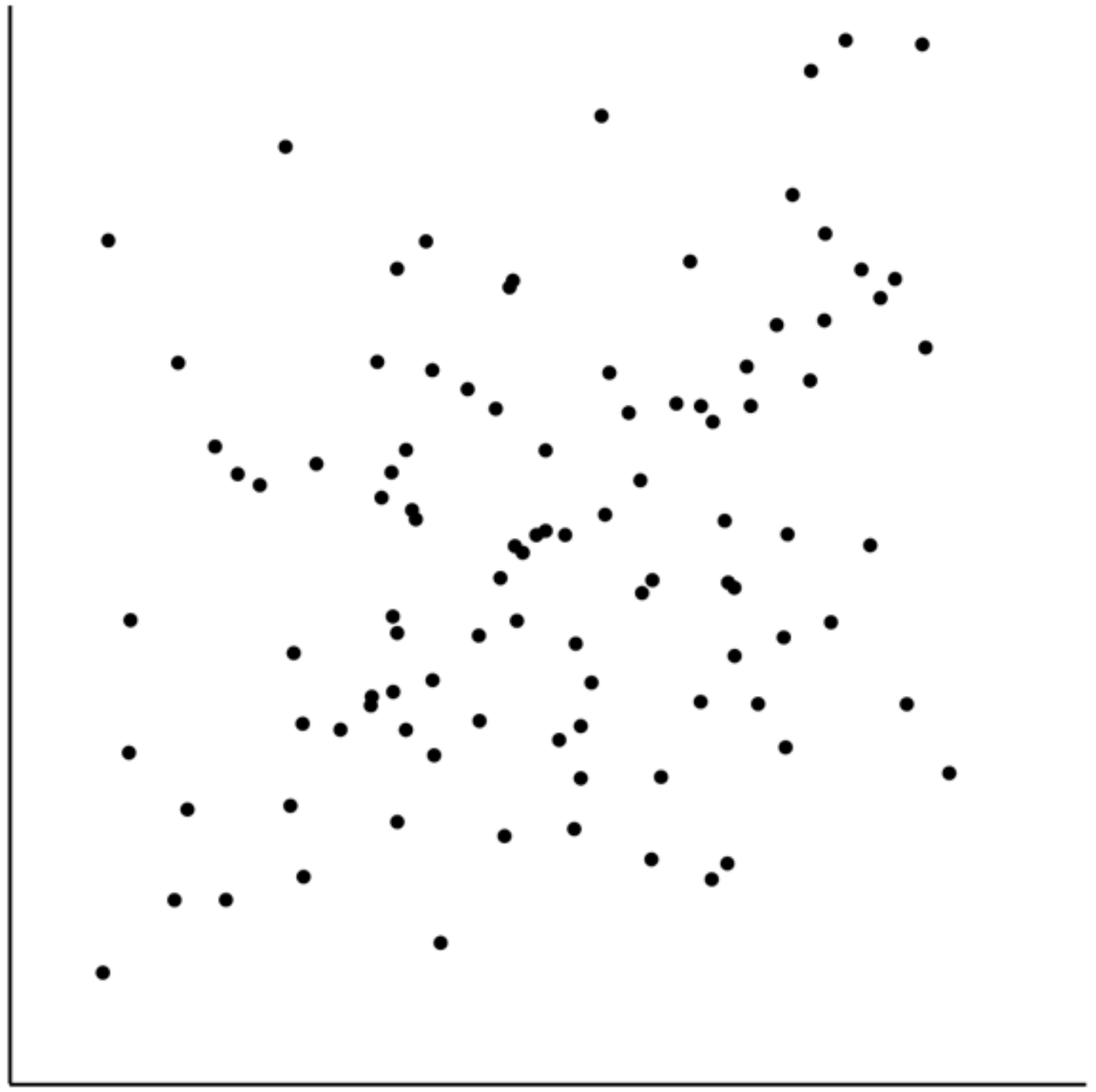


r = 0.35

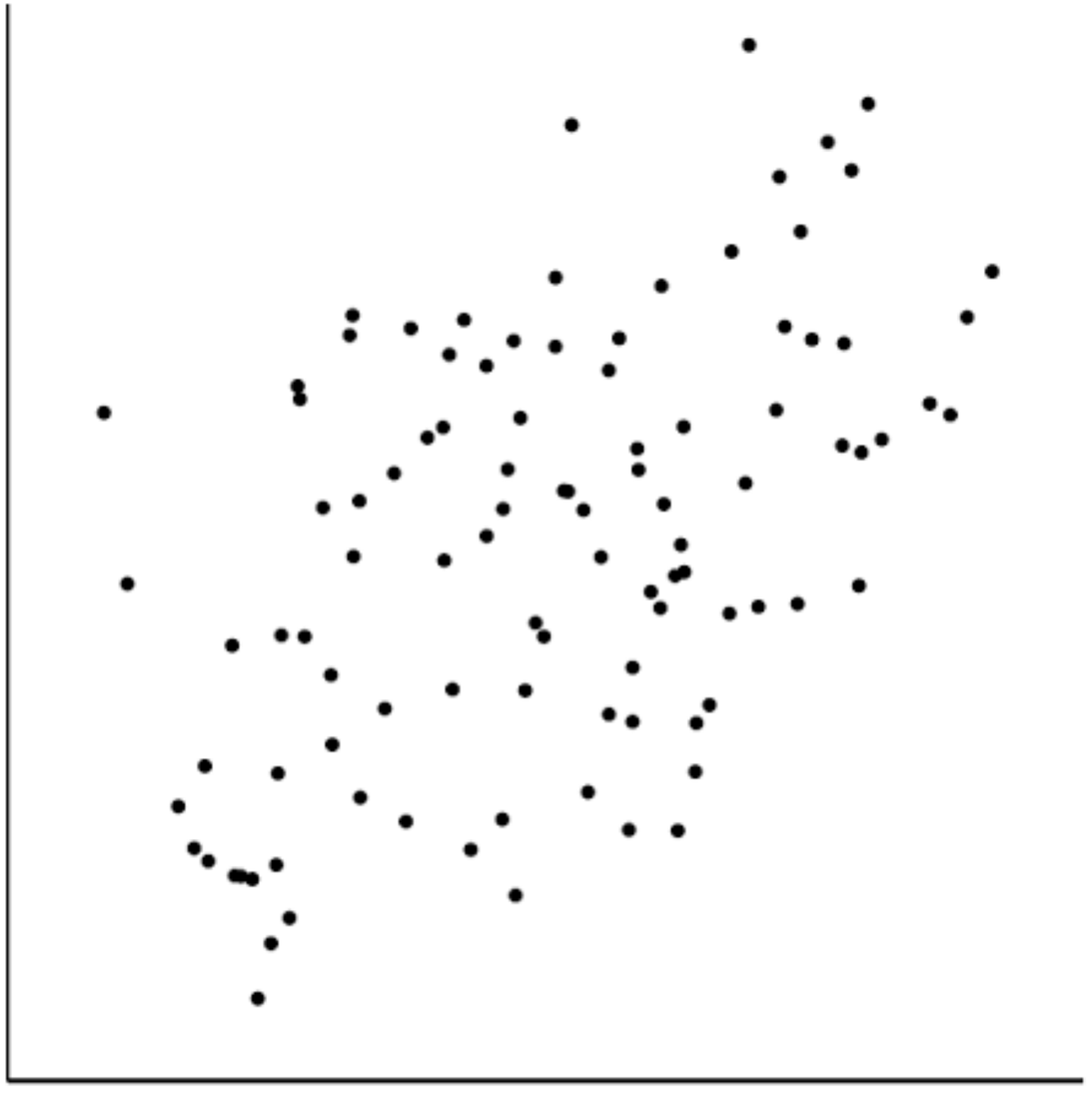
To see a diff, increase to 0.5!



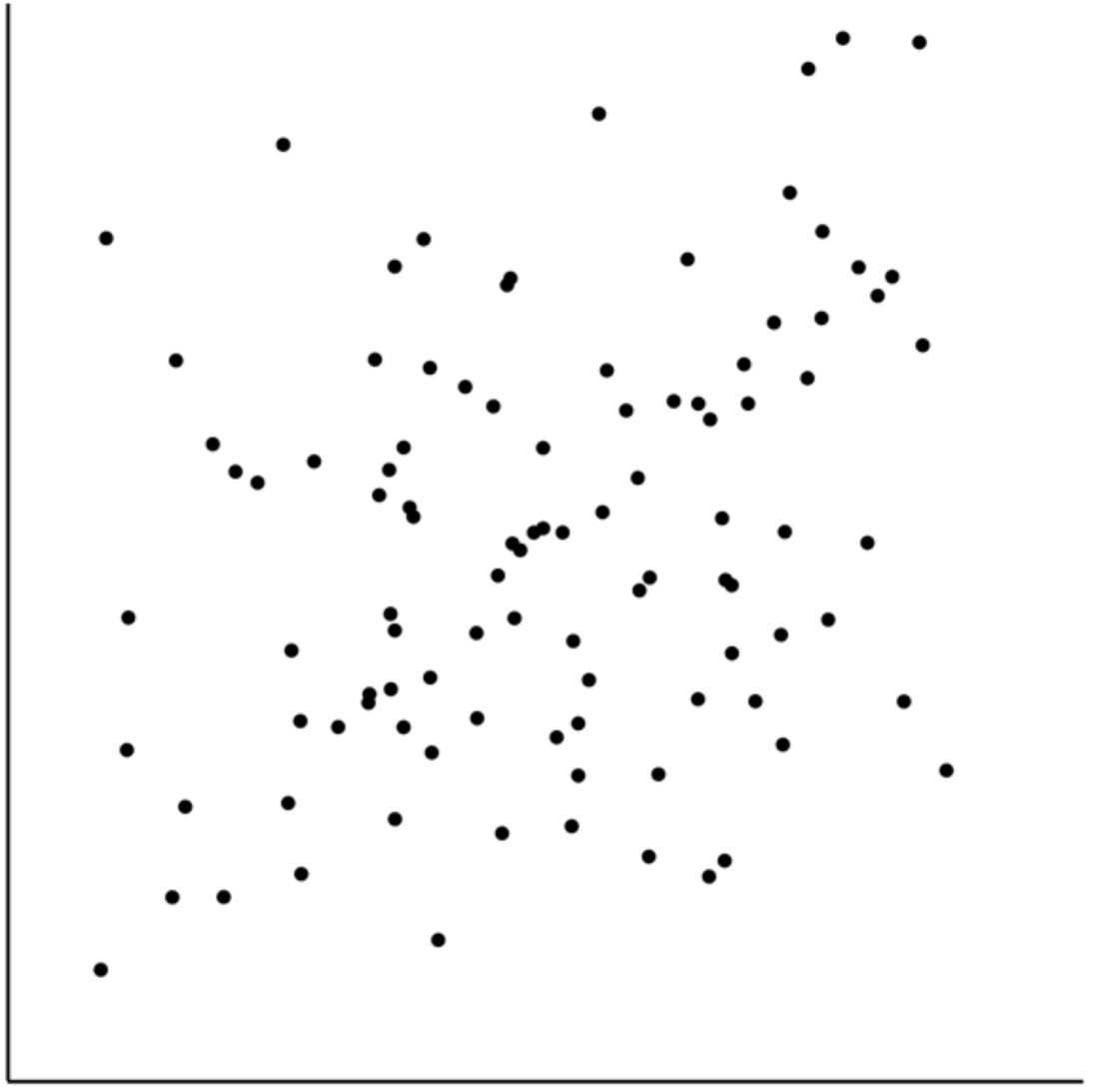
r = 0.3



r = 0.5

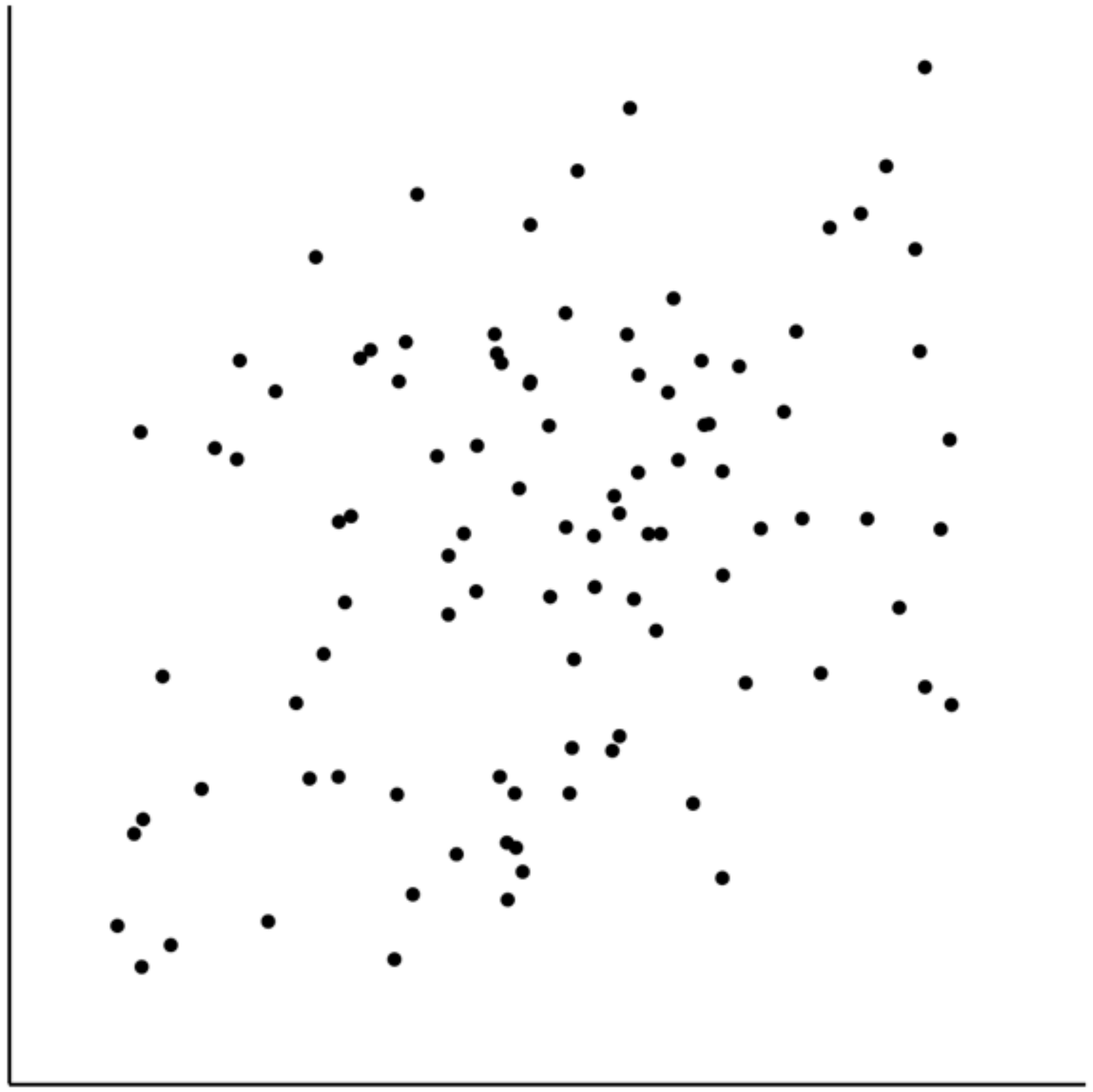


r = 0.3

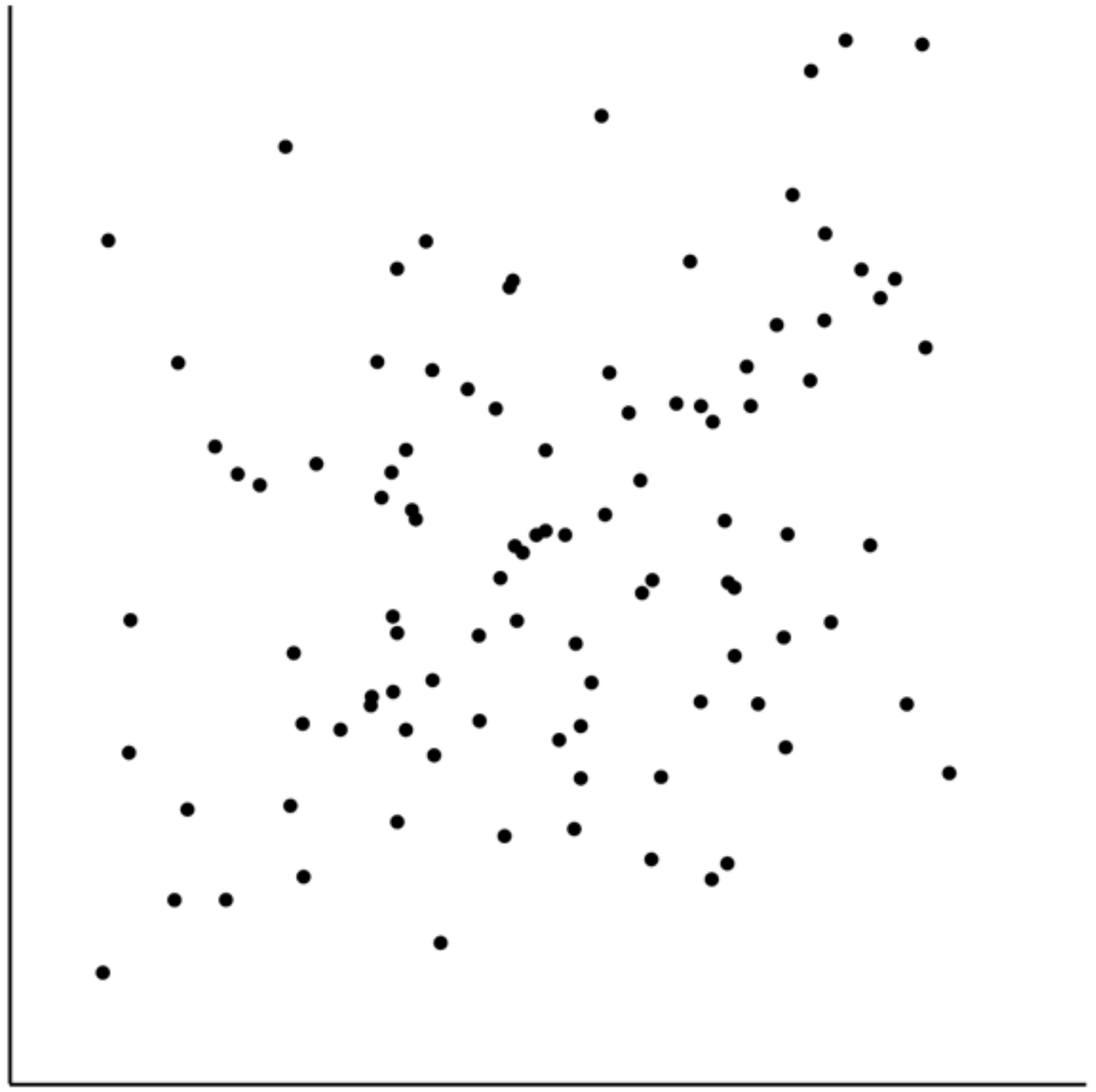


r = 0.35

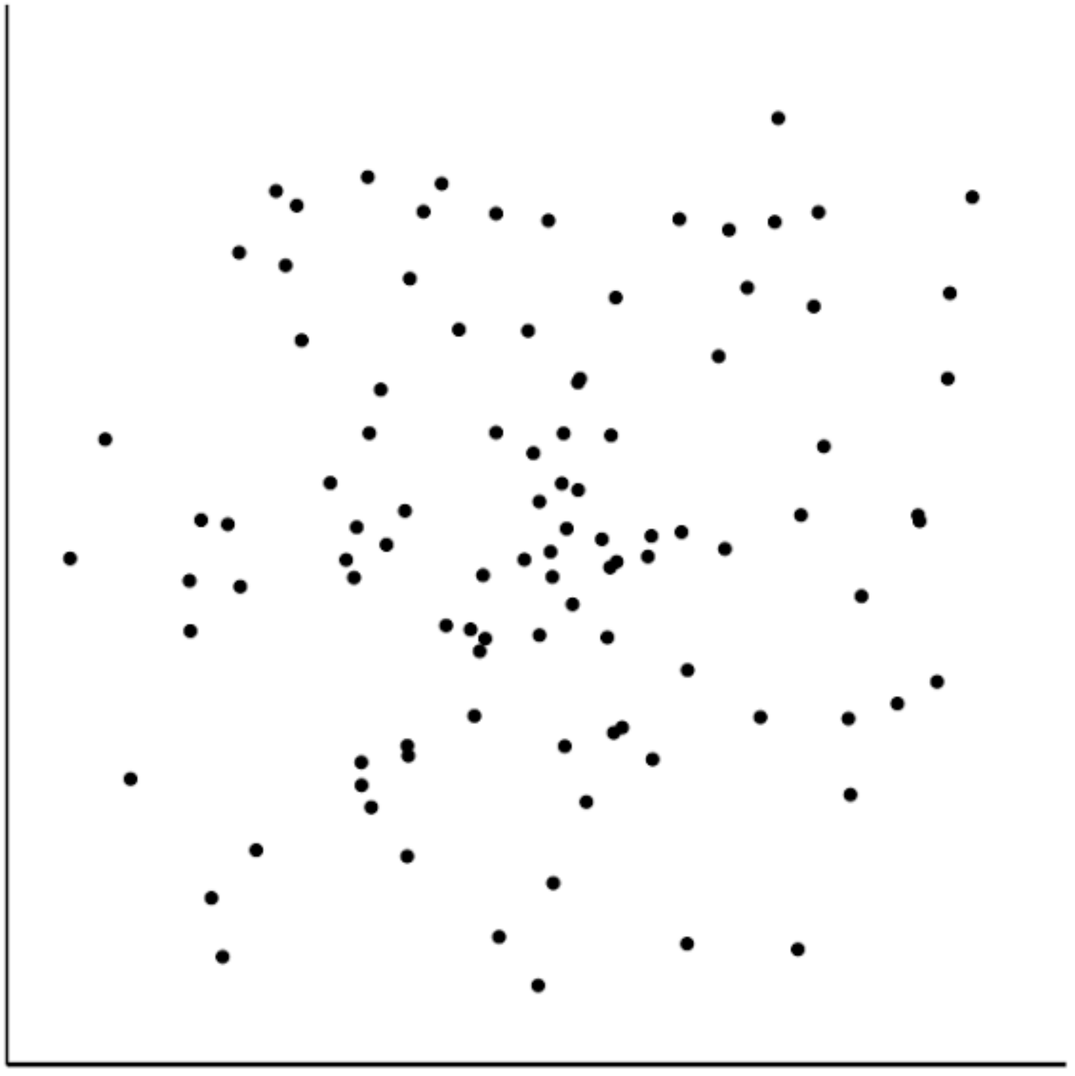
To see a diff, decrease to 0.1!



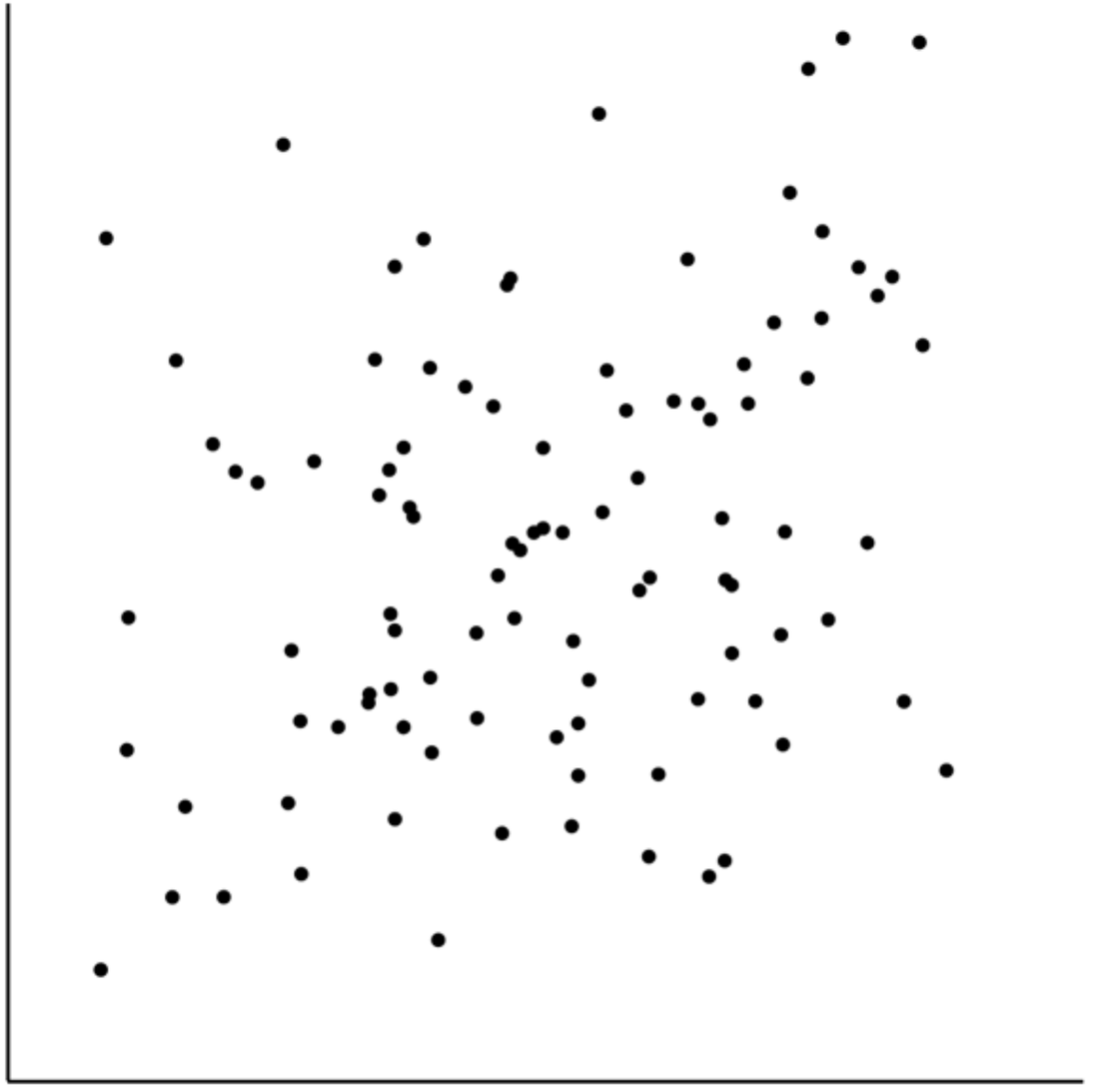
r = 0.3



r = 0.1



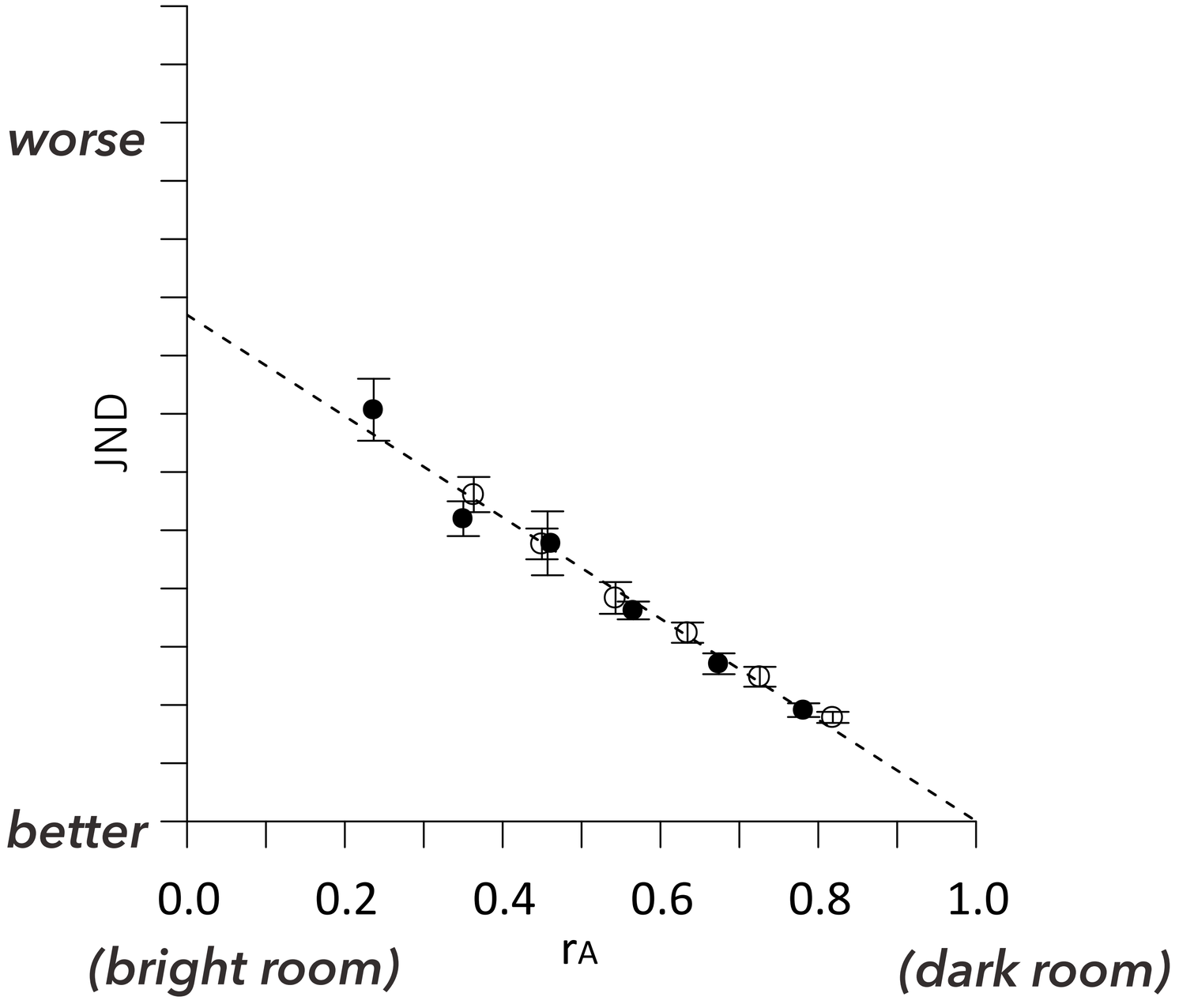
r = 0.3



Rensink's insight...

Because the trend of JND & correlation is linear…

"The perception of correlation in scatterplots can be modeled using Weber's Law."



Weber's Law $\Delta P = k * \frac{\Delta I}{I}$

- model for low-level perceptual discrimination

- sound, taste, weight, brightness, line-length

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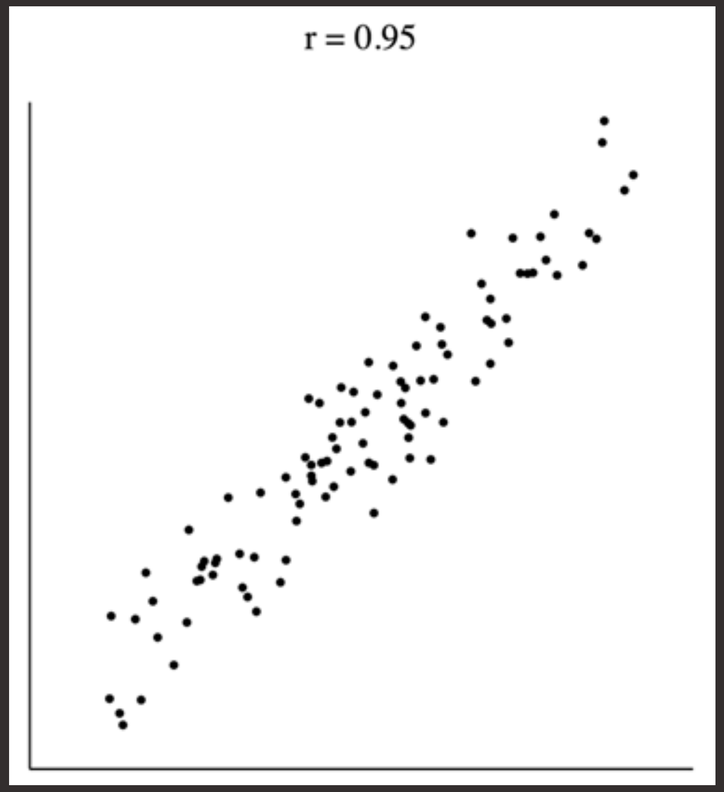


$$\Delta P = k * \frac{\Delta I}{I}$$

Weber's Law

Perceived diff

$$\Delta P = k * \frac{\Delta I}{I}$$

Perceived diff

$$\Delta P = k * \frac{\Delta I}{I}$$

Actual intensity of Stimulus

Perceived diff

Change in Intensity

$$\Delta P = k * \frac{\Delta I}{I}$$

Actual intensity of Stimulus

Perceived diff

Change in Intensity

$$\Delta P = k * \frac{\Delta I}{I}$$

via experiment

Actual intensity of Stimulus

bright room, high intensity

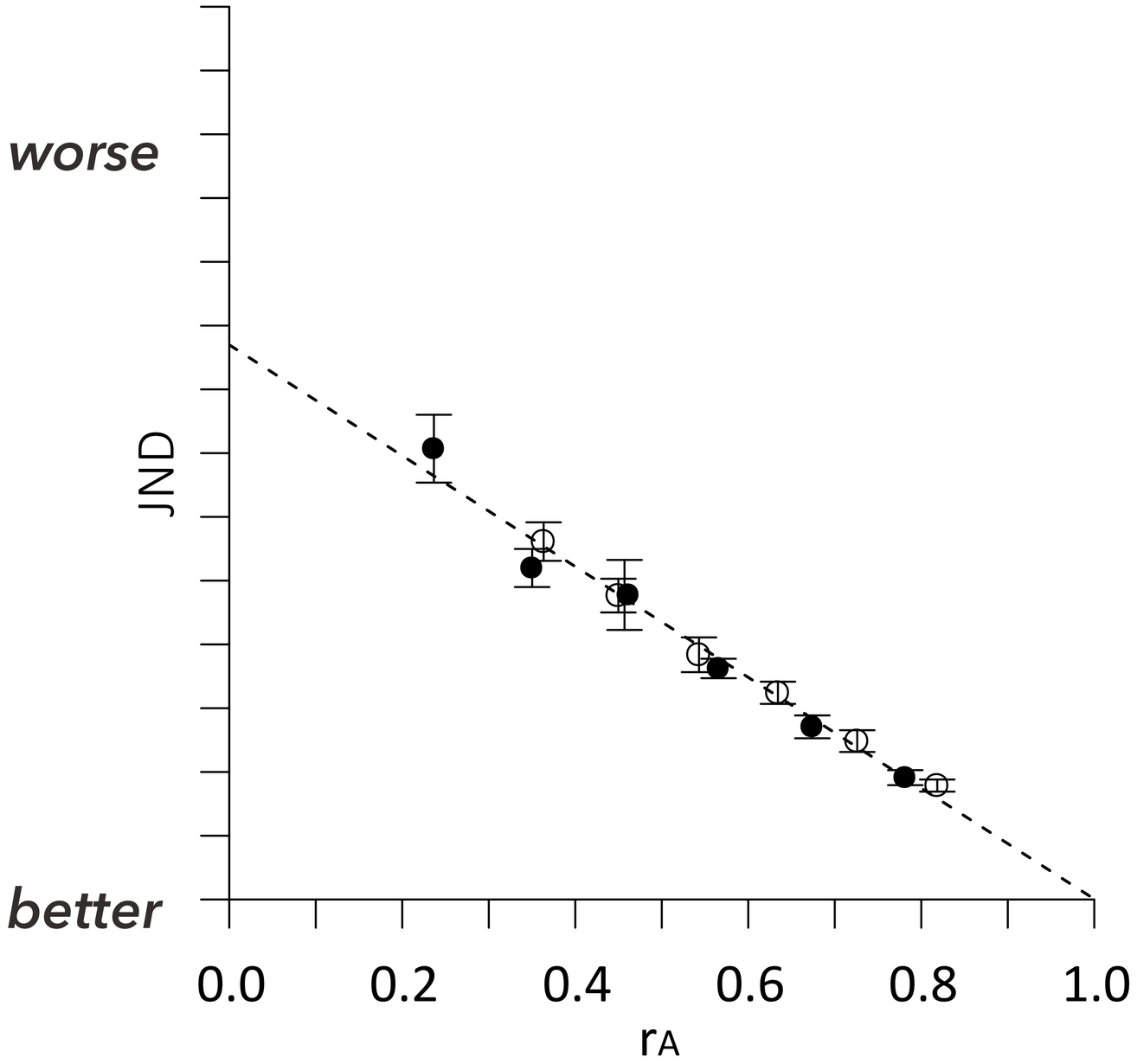
$$\Delta P = k * \frac{\Delta I}{I}$$

super bright light needed

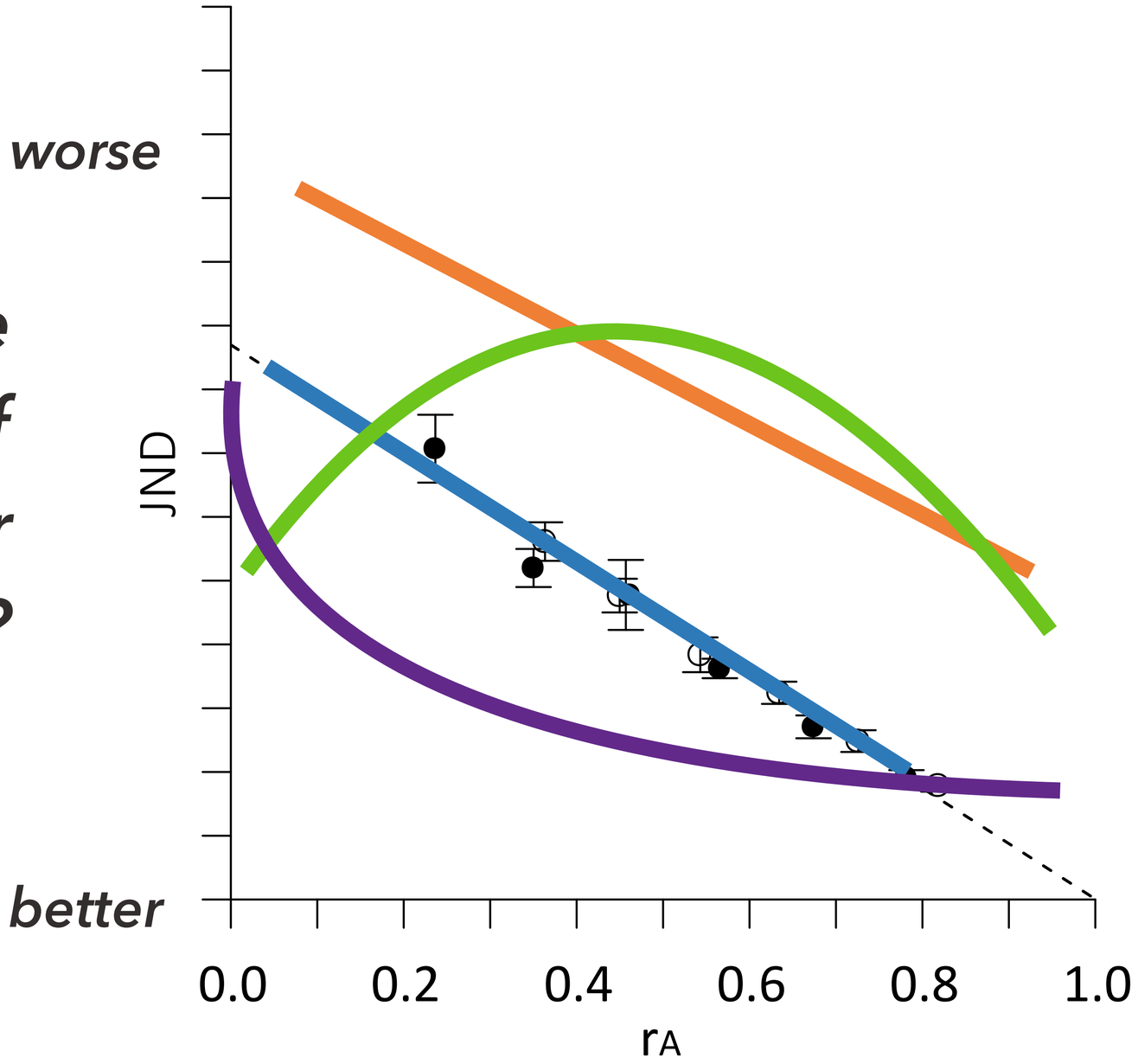
$$\Delta P = k * \frac{\Delta I}{I}$$

Our hypothesis...

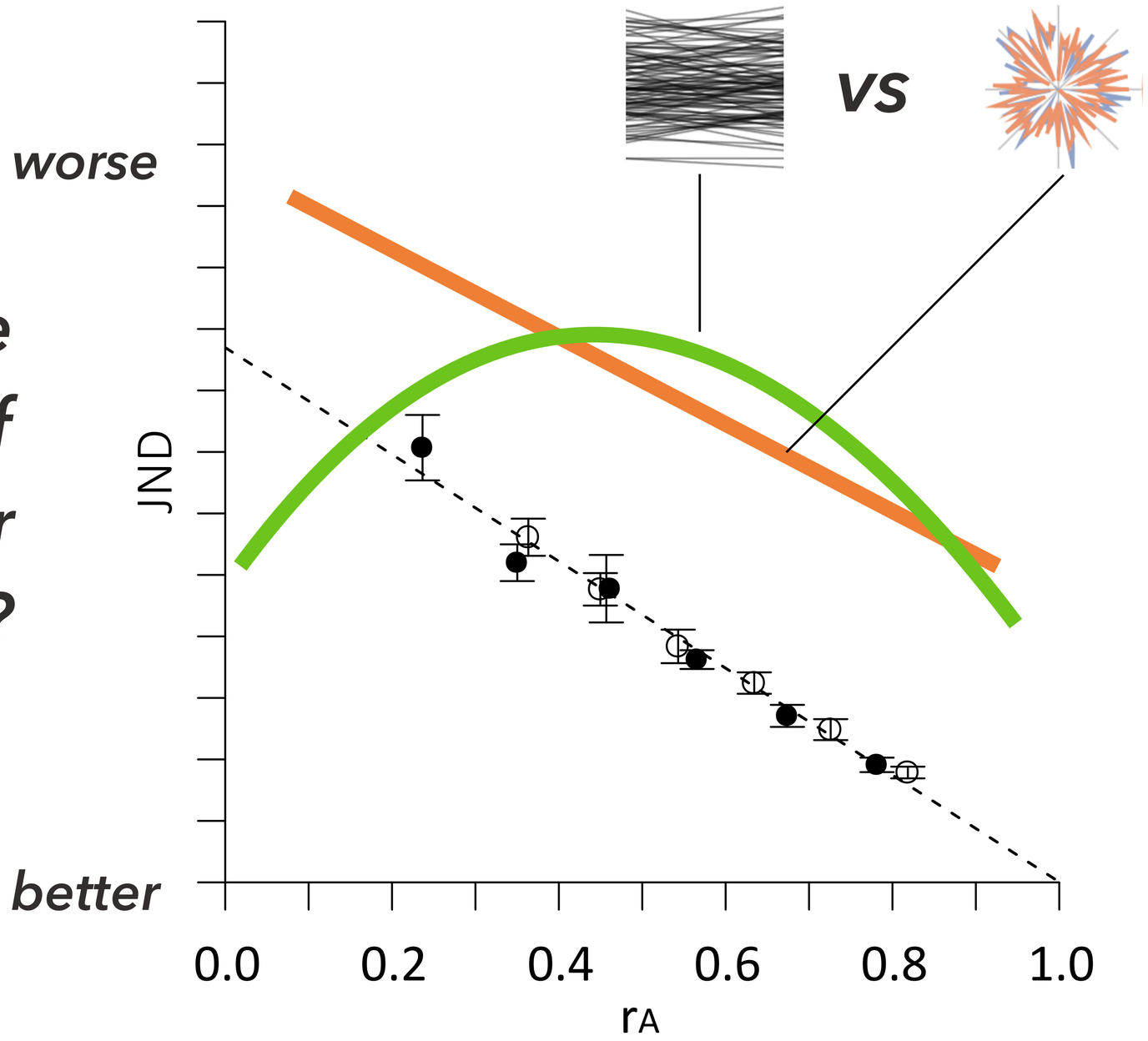
If the perception of correlation in scatterplots follows Weber's law…



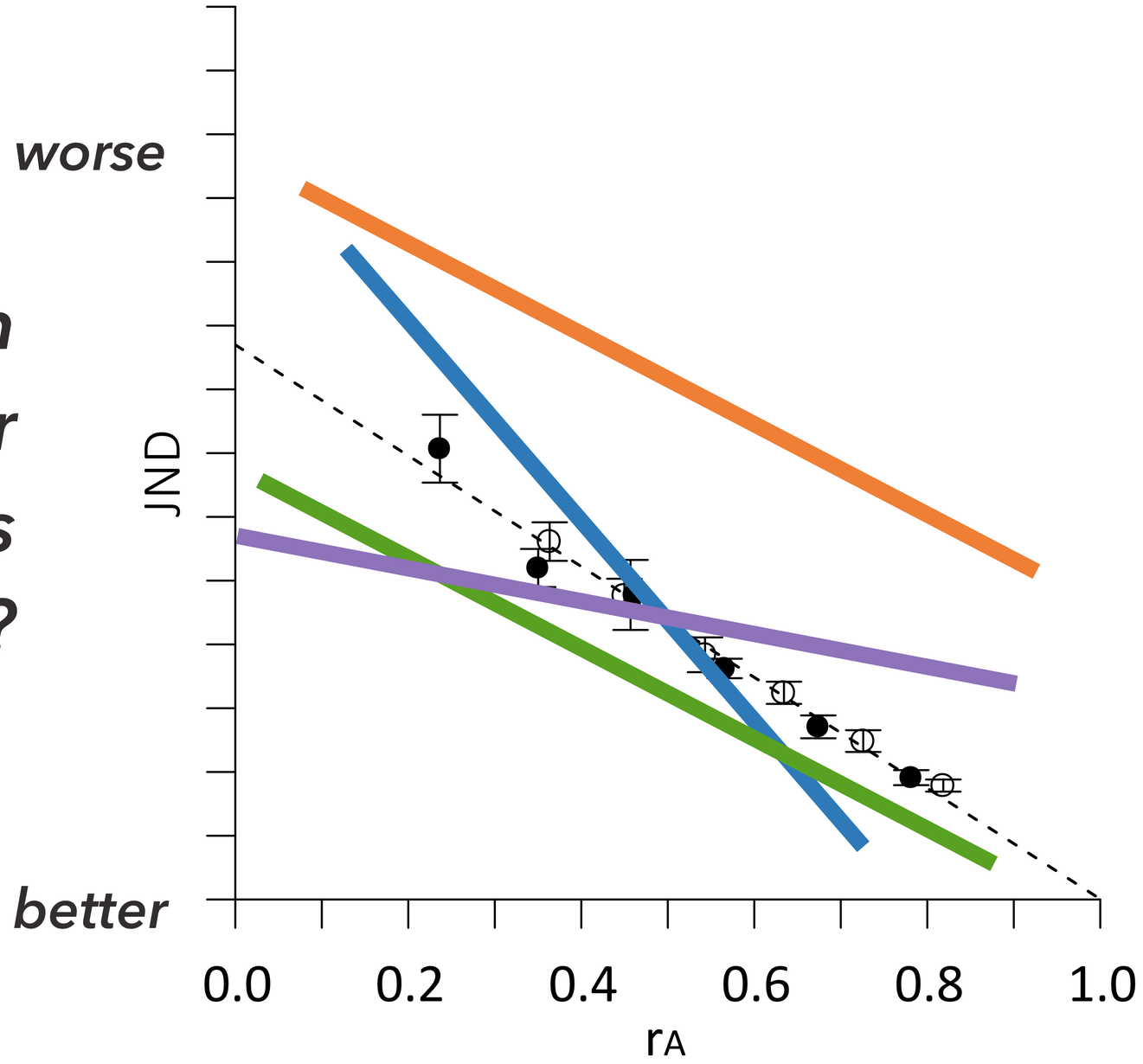
What does the perception of correlation in other charts look like?



What does the perception of correlation in other charts look like?



What if the perception of correlation in other charts also follows Weber's law?



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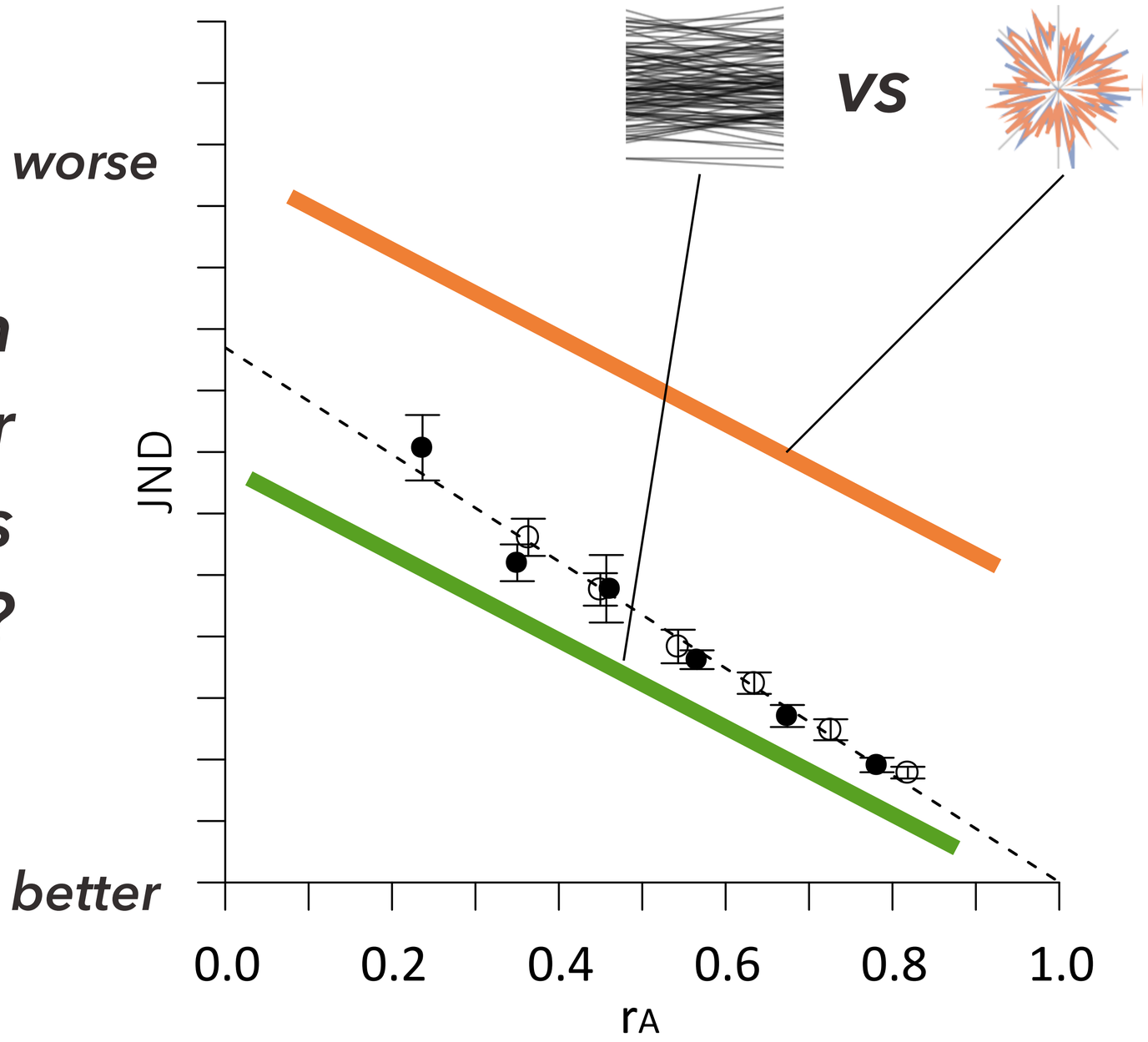
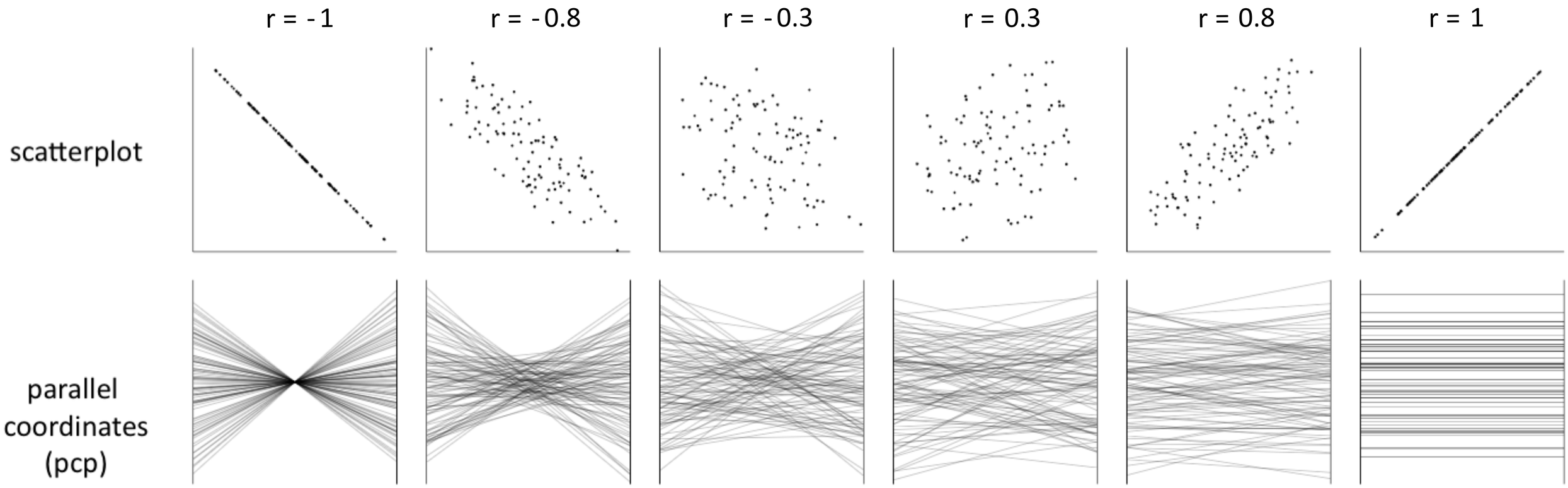
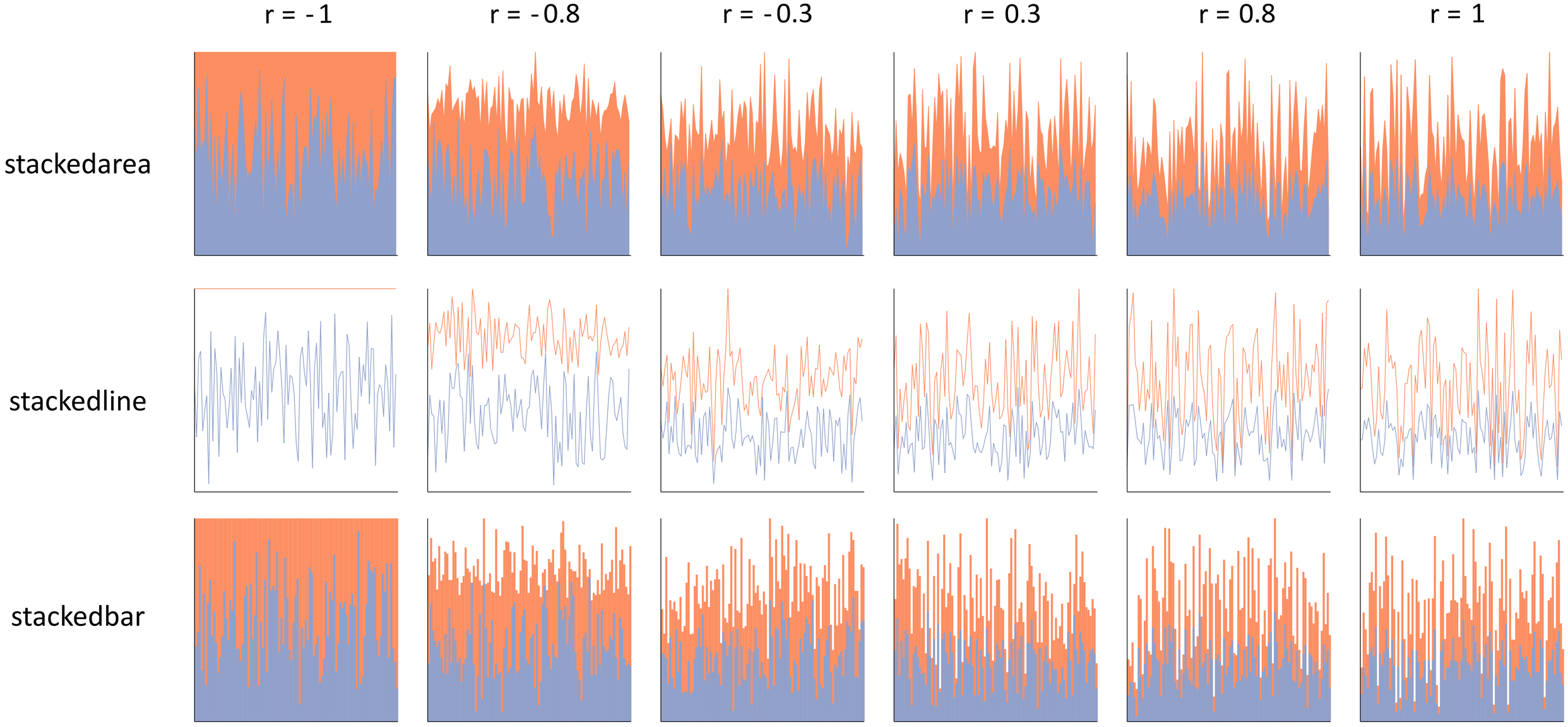


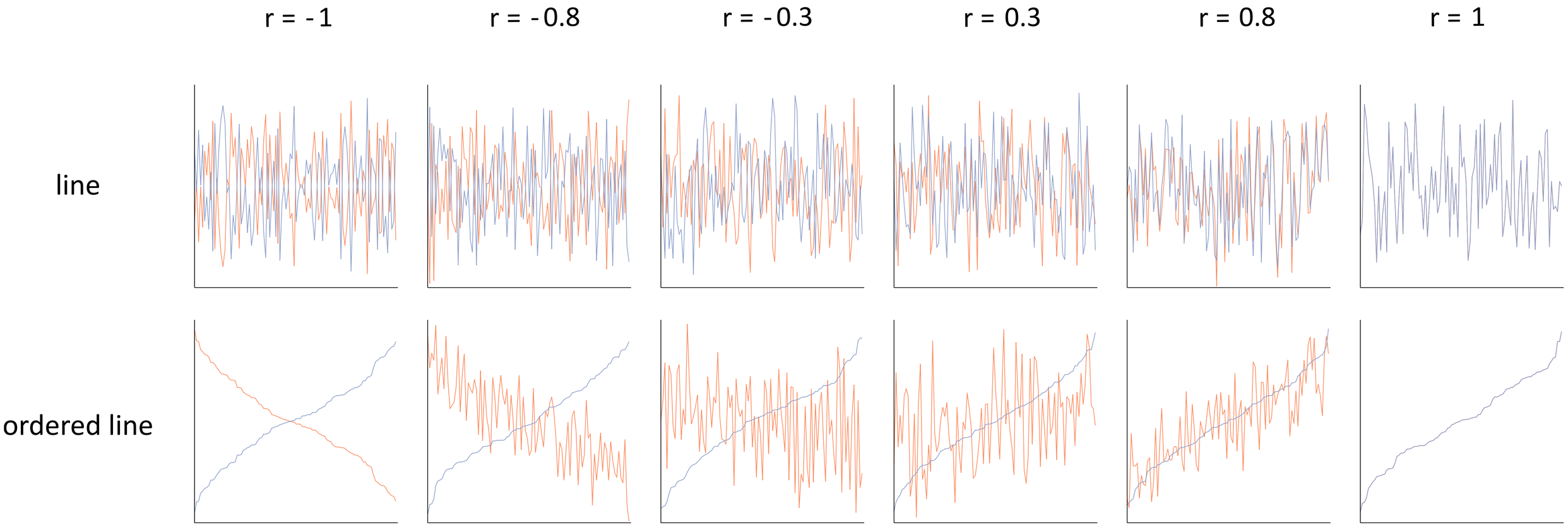
Experiment

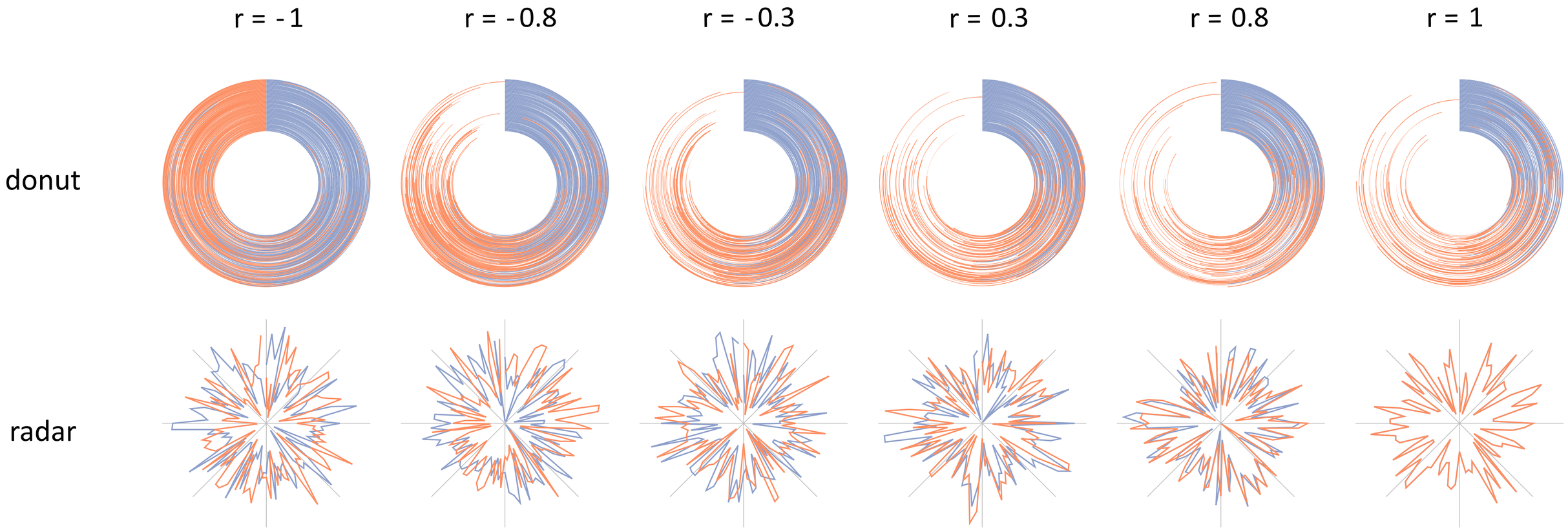
Stimuli:

9 chart types depicting bi-variate data


r = -1
r = -0.8
r = -0.3
r = 0.3
r = 0.8
r = 1
scatterplot
parallel coordinates (pcp)


r = -1
r = -0.8
r = -0.3
r = 0.3
r = 0.8
r = 1
stackedarea
stackedline
stackedbar


r = -1
r = -0.8
r = -0.3
r = 0.3
r = 0.8
r = 1
line
ordered line


r = -1
r = -0.8
r = -0.3
r = 0.3
r = 0.8
r = 1
donut
radar

Methodology: Crowdsourced on Amazon's Mechanical Turk*

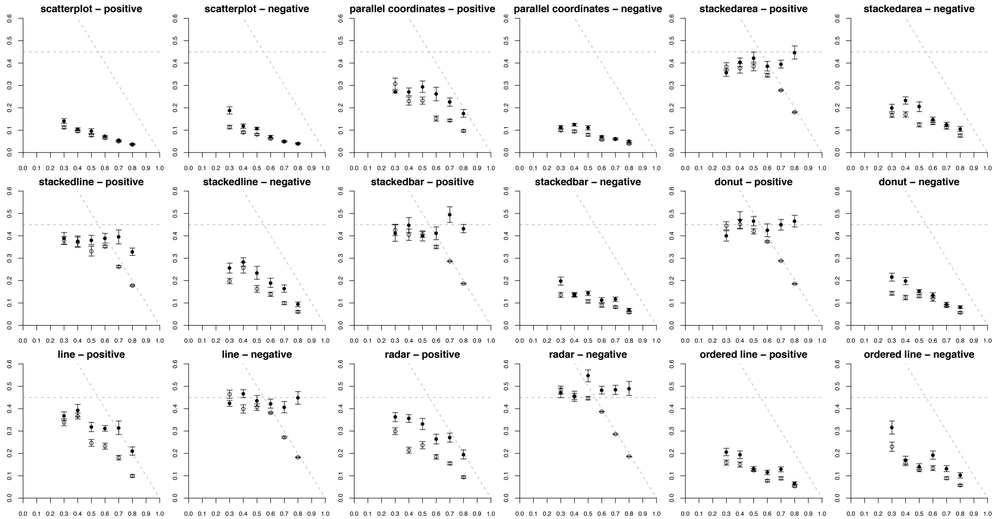
Design

- n=1687 (AMT)
- 9 charts
- Normal data (in charts)
- Between subjects
- "Staircase" methodology

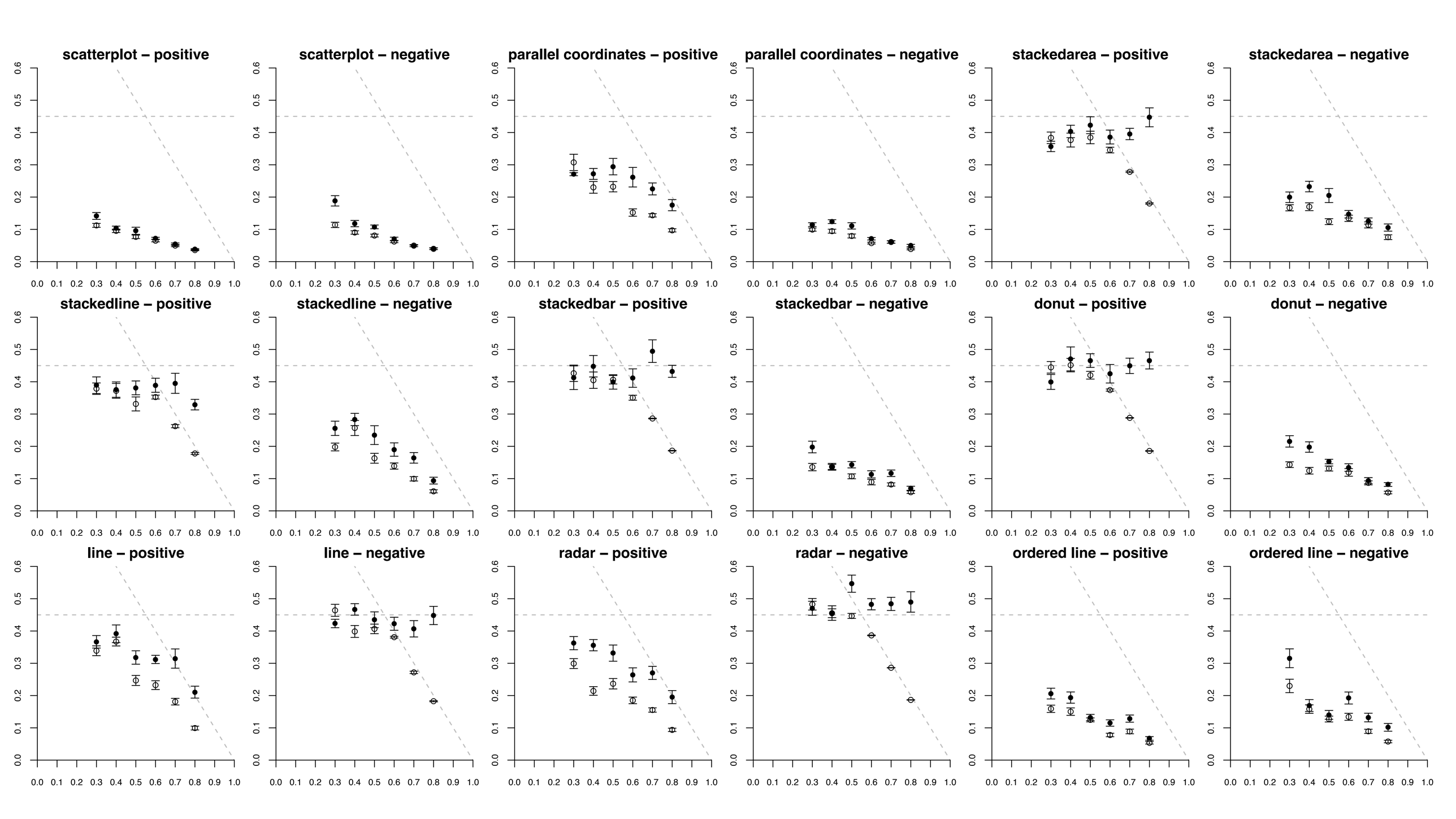
Analyses

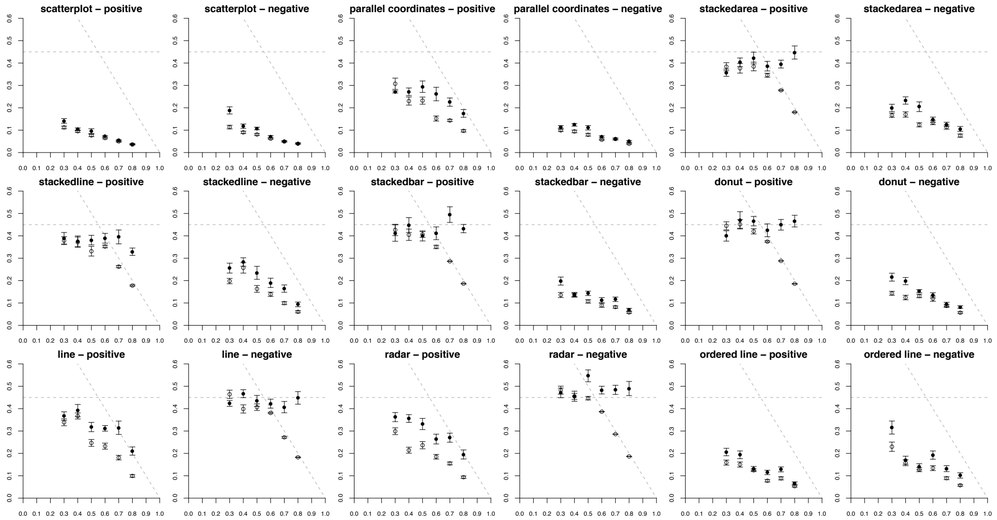
- Kruskal-Wallis (overall)
- Mann-Whitney (post-hoc)
- Bonferonni correction ($p < 0.0036$)

Results

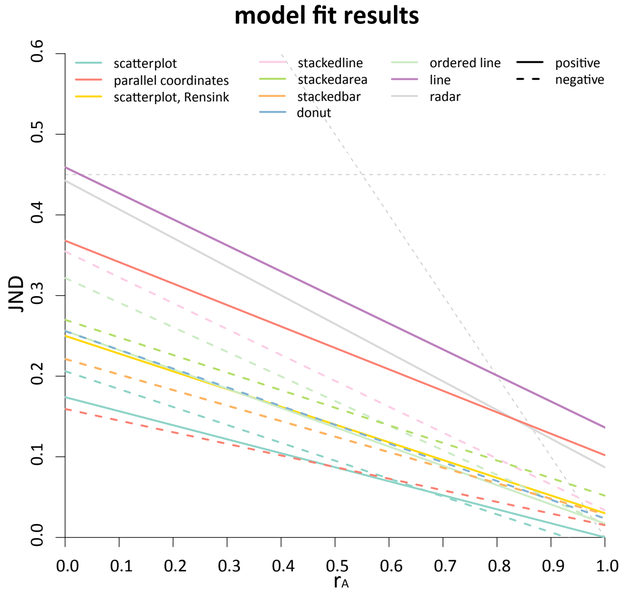


1. Inferred JNDs from experiment data for each chart and for positive/negative correlations.


scatterplot – positive
scatterplot – negative
parallel coordinates – positive
parallel coordinates – negative
stackedarea – positive
stackedarea – negative
stackedline – positive
stackedline – negative
stackedbar – positive
stackedbar – negative
donut – positive
donut – negative
line – positive
line – negative
radar – positive
radar – negative
ordered line – positive
ordered line – negative



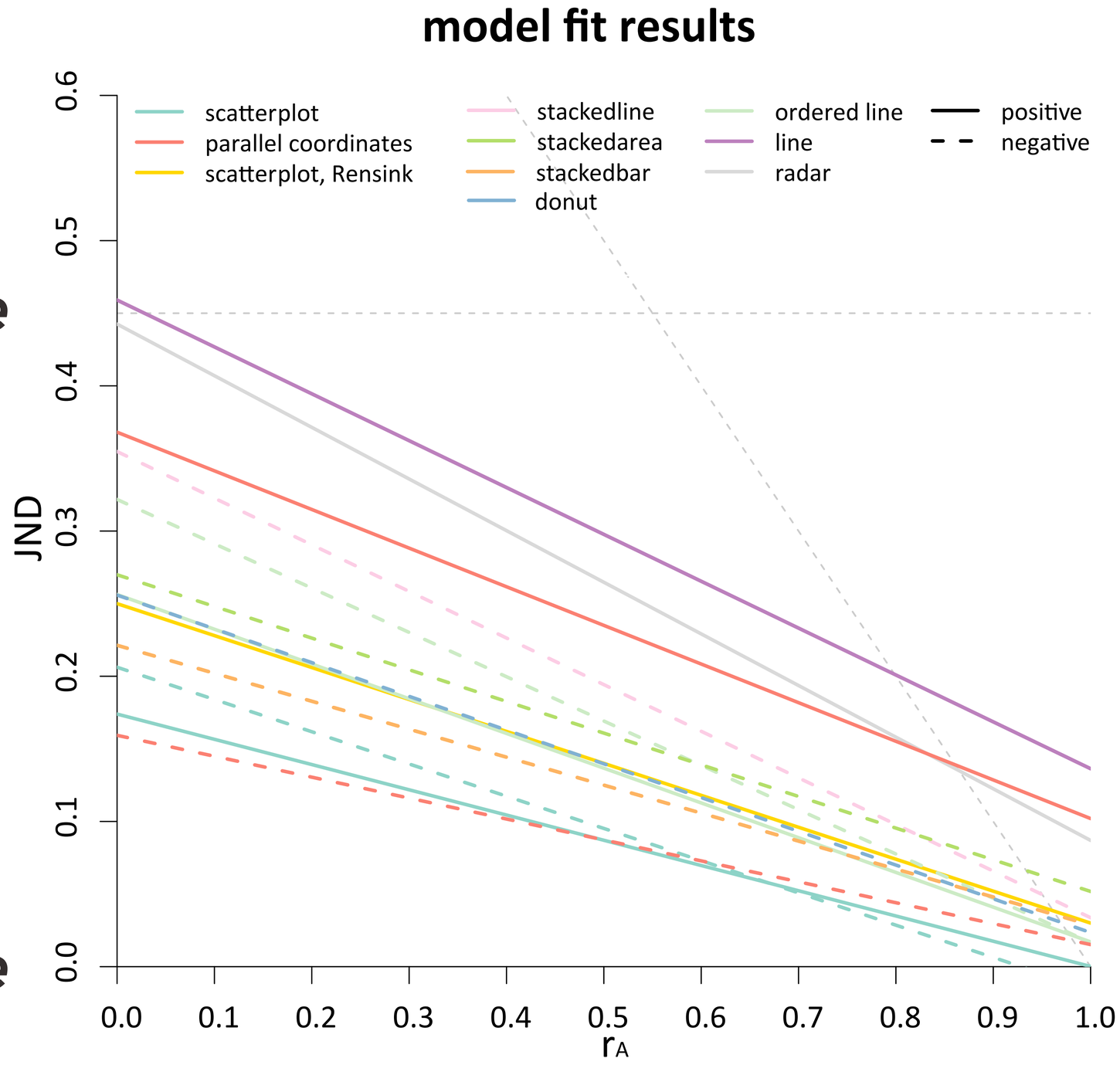
1. Inferred JNDs from experiment data for each chart and for positive/negative correlations.



2. Tested Weber-model fit using previously-established methodologies.

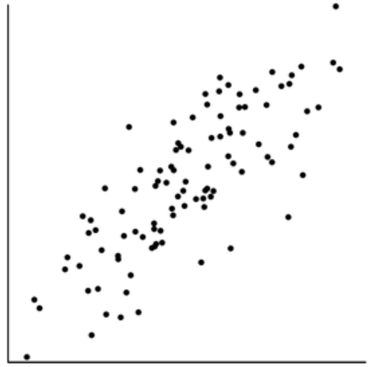
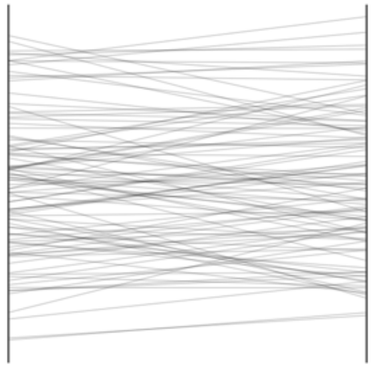
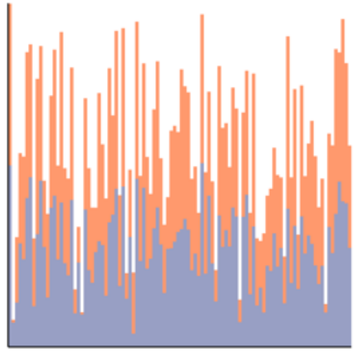
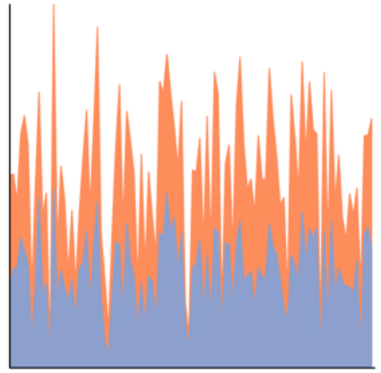
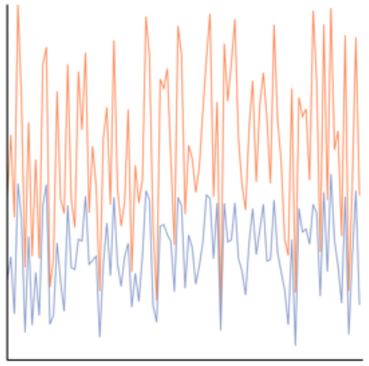
less precise

more precise

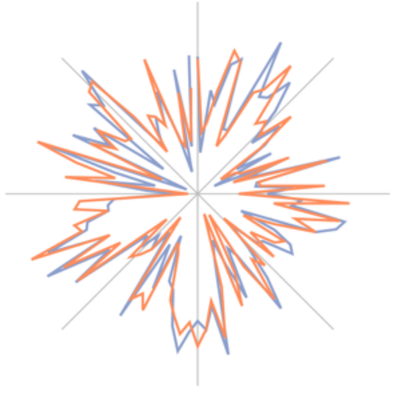
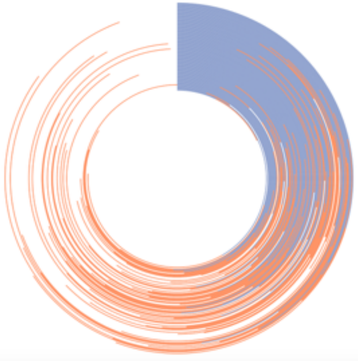
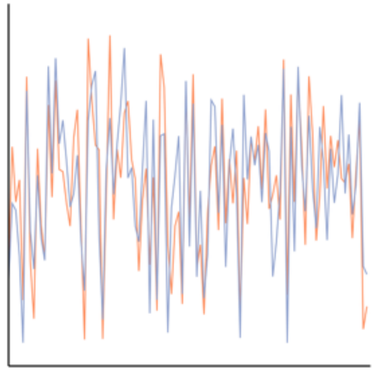
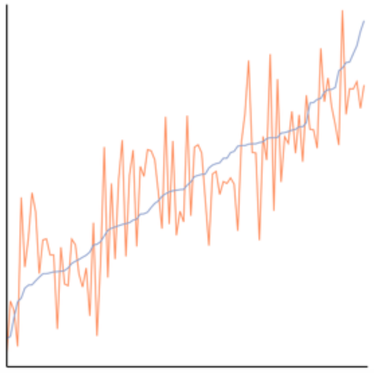


visualization - direction	intercept-b	slope-k	correlation-r	r^2	RMS
scatterplot - positive	0.17	-0.17	-0.99	0.98	0.0041
scatterplot - negative	0.21	-0.22	-0.95	0.90	0.013
parallel coordinates - positive	0.37	-0.27	-0.86	0.74	0.032
parallel coordinates - negative	0.16	-0.14	-0.95	0.90	0.0085
stacked line - negative	0.35	-0.32	-0.92	0.84	0.027
stacked area - negative	0.27	-0.22	-0.93	0.86	0.016
stacked bar - negative	0.22	-0.19	-0.95	0.90	0.011
donut - negative	0.26	-0.23	-0.96	0.93	0.012
line - positive	0.46	-0.32	-0.86	0.74	0.043
radar - positive	0.44	-0.36	-0.95	0.91	0.024
ordered line - positive	0.26	-0.24	-0.95	0.91	0.014
ordered line - negative	0.32	-0.31	-0.88	0.78	0.031

! ! !!!

The perception of correlation in every tested chart can be modeled using Weber's law.

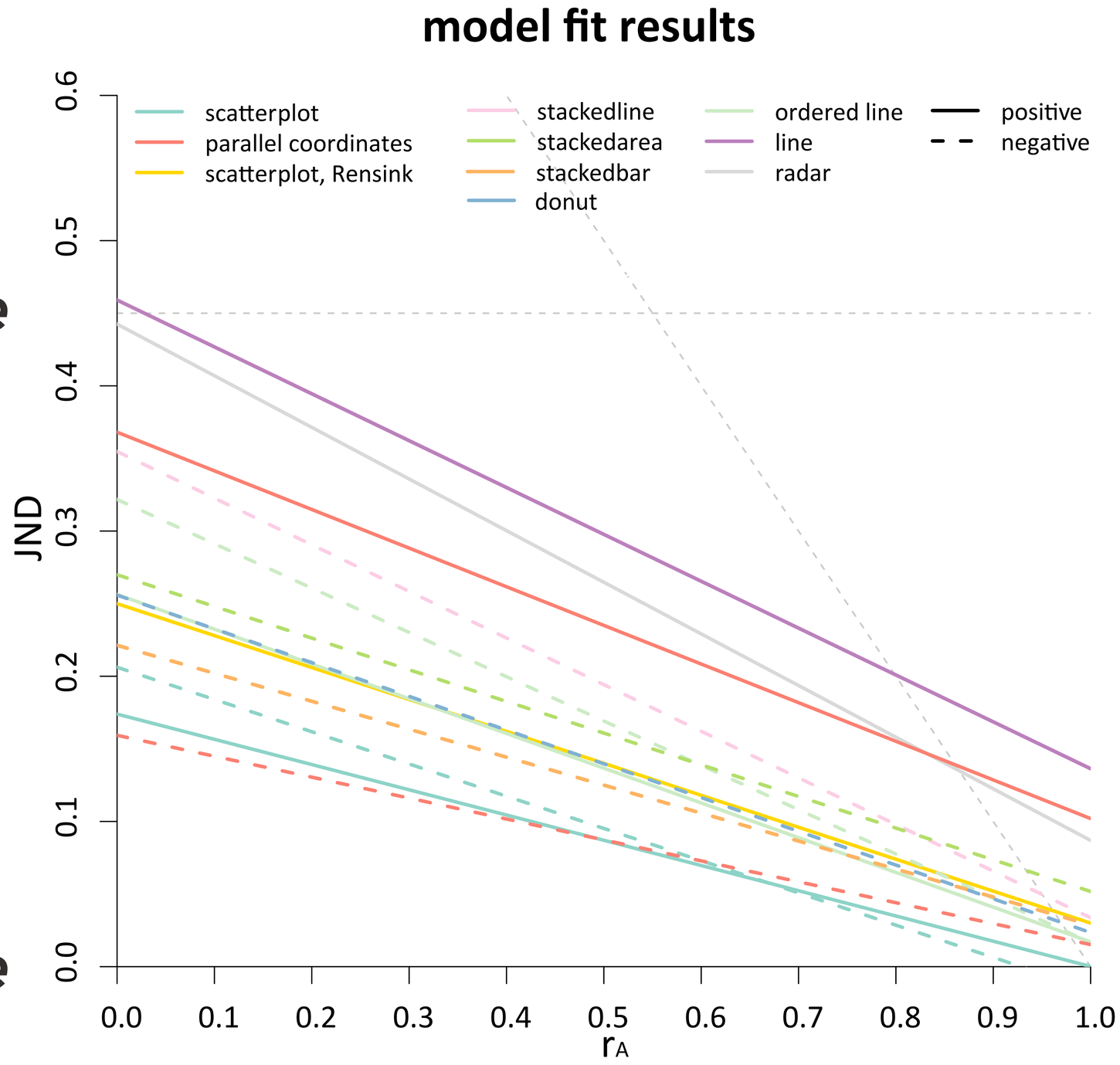





You can do a lot of good with good models.

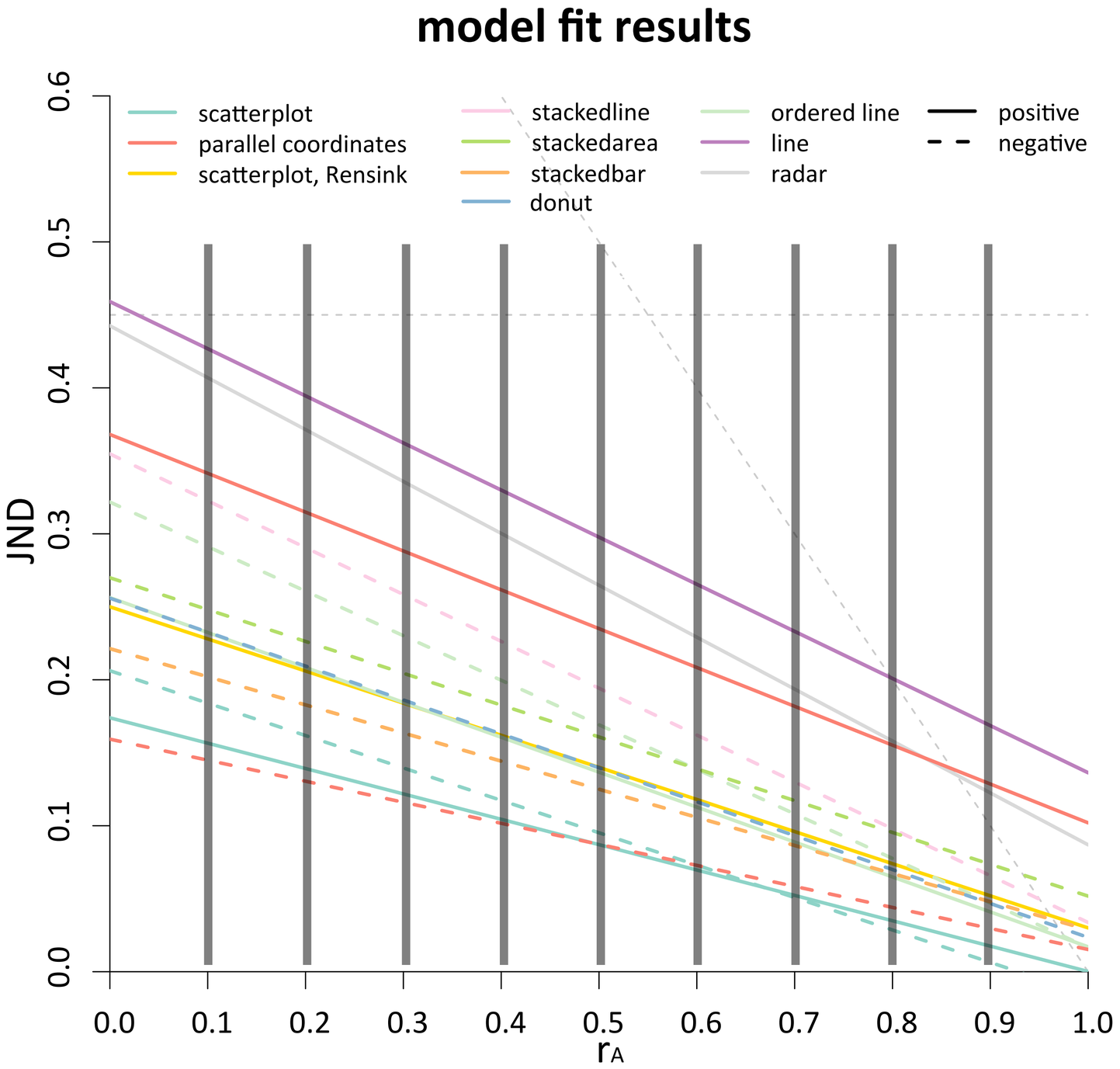
1. Perceptually-backed ranking of precision for judging correlation

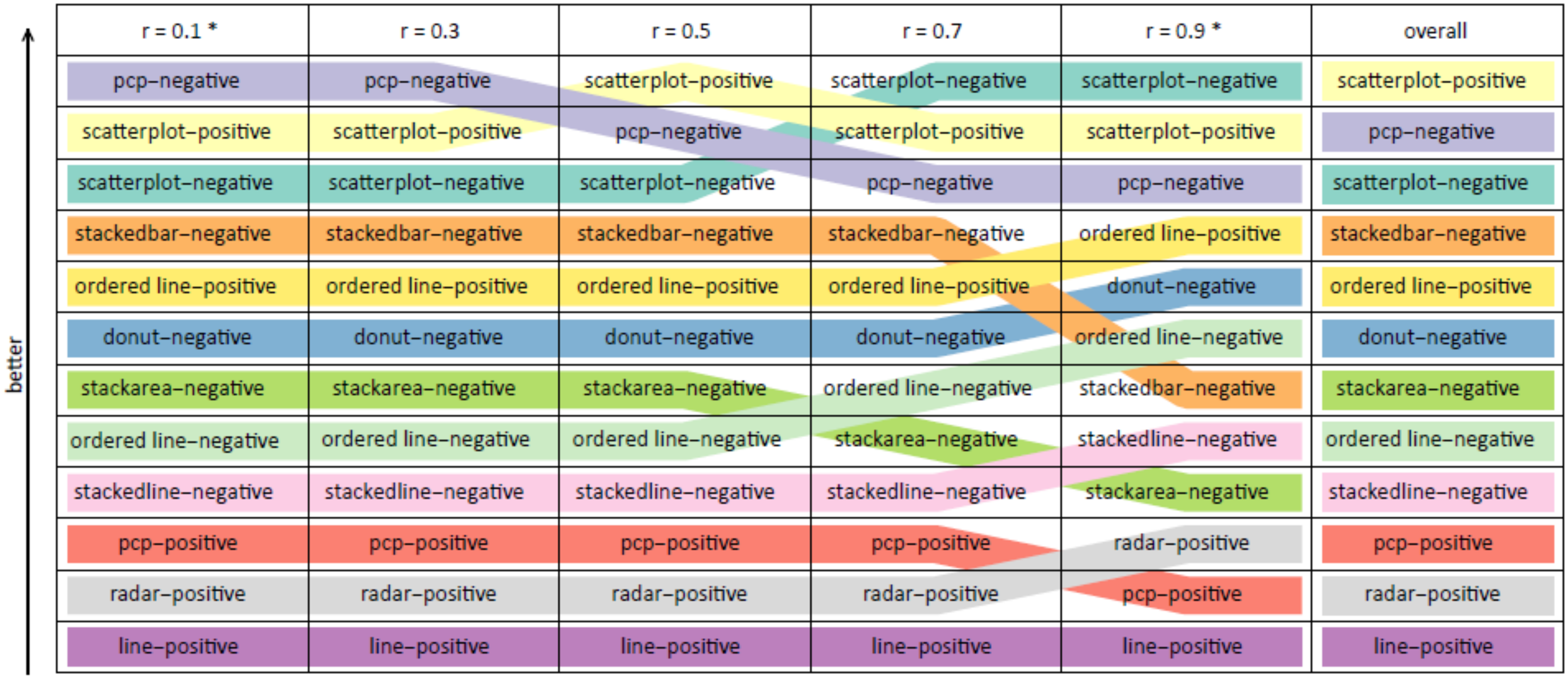
less precise

more precise

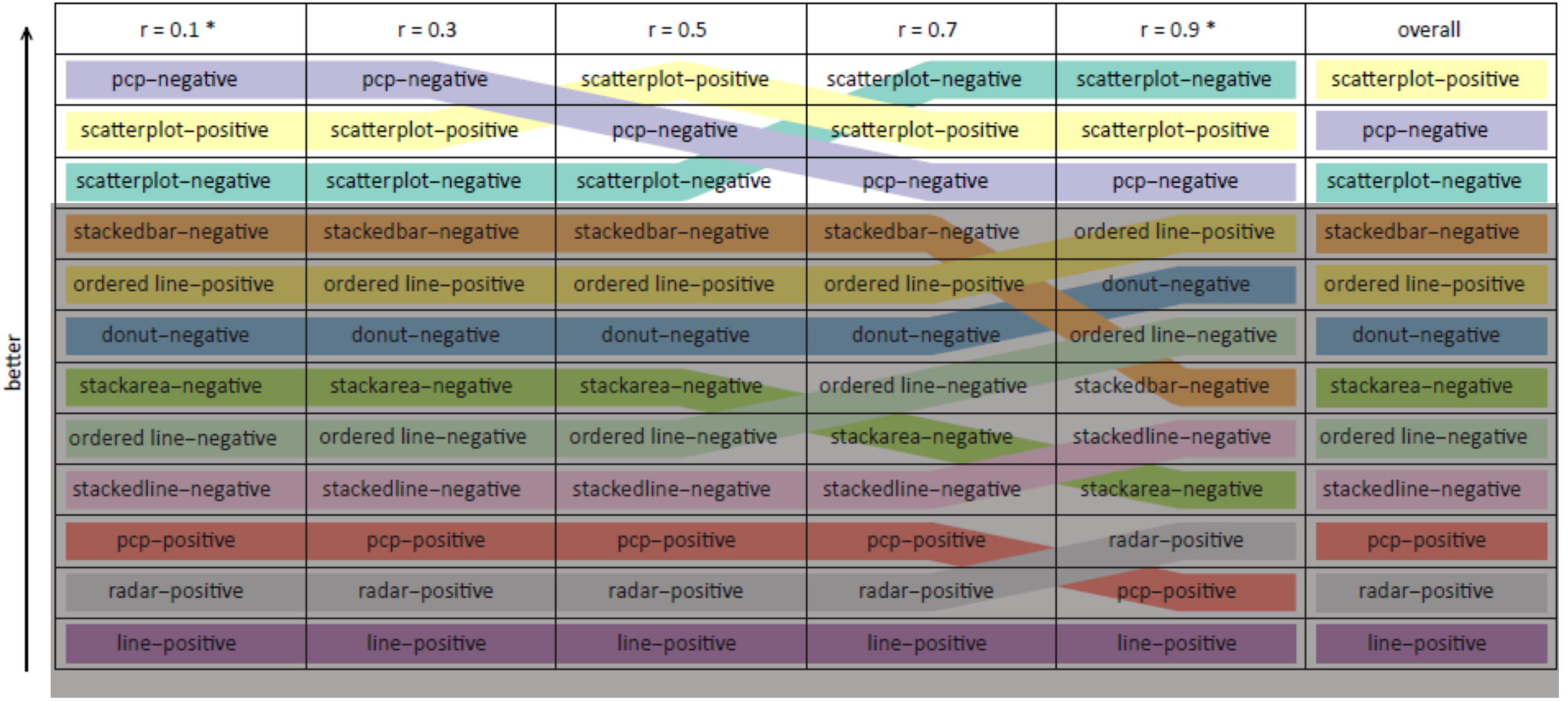


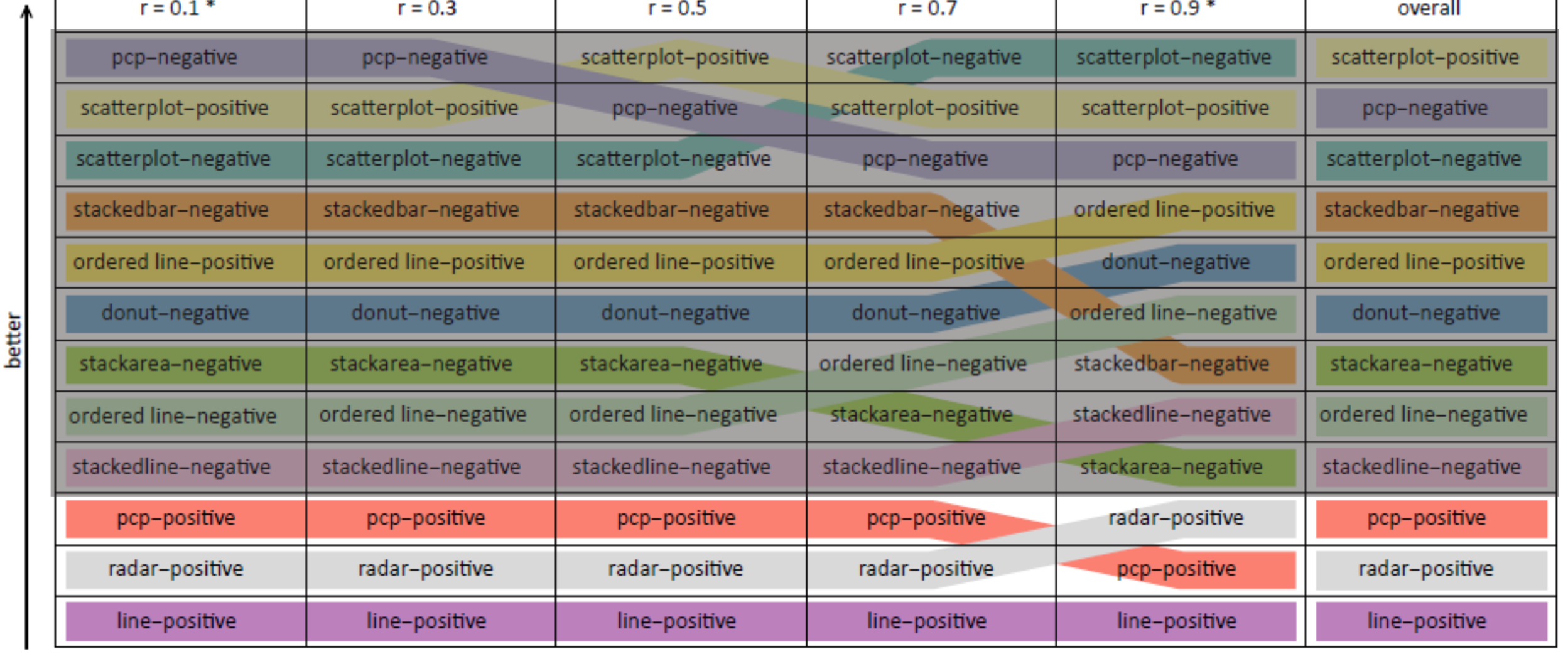
Obtain rankings at each |r|





Perceptually-backed ranking for vis of correlation


r = 0.1 *
r = 0.3
r = 0.5
r = 0.7
r = 0.9 *
overall
pcp–negative
pcp–negative
scatterplot–positive
scatterplot–negative
scatterplot–negative
scatterplot–positive
scatterplot–positive
scatterplot–positive
pcp–negative
scatterplot–positive
scatterplot–positive
pcp–negative
scatterplot–negative
scatterplot–negative
scatterplot–negative
pcp–negative
pcp–negative
scatterplot–negative
stackedbar–negative
stackedbar–negative
stackedbar–negative
stackedbar–negative
ordered line–positive
stackedbar–negative
ordered line–positive
ordered line–positive
ordered line–positive
ordered line–positive
donut–negative
ordered line–positive
donut–negative
donut–negative
donut–negative
donut–negative
ordered line–negative
donut–negative
stackarea–negative
stackarea–negative
stackarea–negative
ordered line–negative
stackedbar–negative
stackarea–negative
ordered line–negative
ordered line–negative
ordered line–negative
stackarea–negative
stackedline–negative
ordered line–negative
stackedline–negative
stackedline–negative
stackedline–negative
stackedline–negative
stackarea–negative
stackedline–negative
pcp–positive
pcp–positive
pcp–positive
pcp–positive
radar–positive
pcp–positive
radar–positive
radar–positive
radar–positive
radar–positive
pcp–positive
radar–positive
line–positive
line–positive
line–positive
line–positive
line–positive
line–positive
better


r = 0.1 *
r = 0.3
r = 0.5
r = 0.7
r = 0.9 *
overall
pcp–negative
pcp–negative
scatterplot–positive
scatterplot–negative
scatterplot–negative
scatterplot–positive
scatterplot–positive
scatterplot–positive
pcp–negative
scatterplot–positive
scatterplot–positive
pcp–negative
scatterplot–negative
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scatterplot–negative
pcp–negative
pcp–negative
scatterplot–negative
stackedbar–negative
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ordered line–positive
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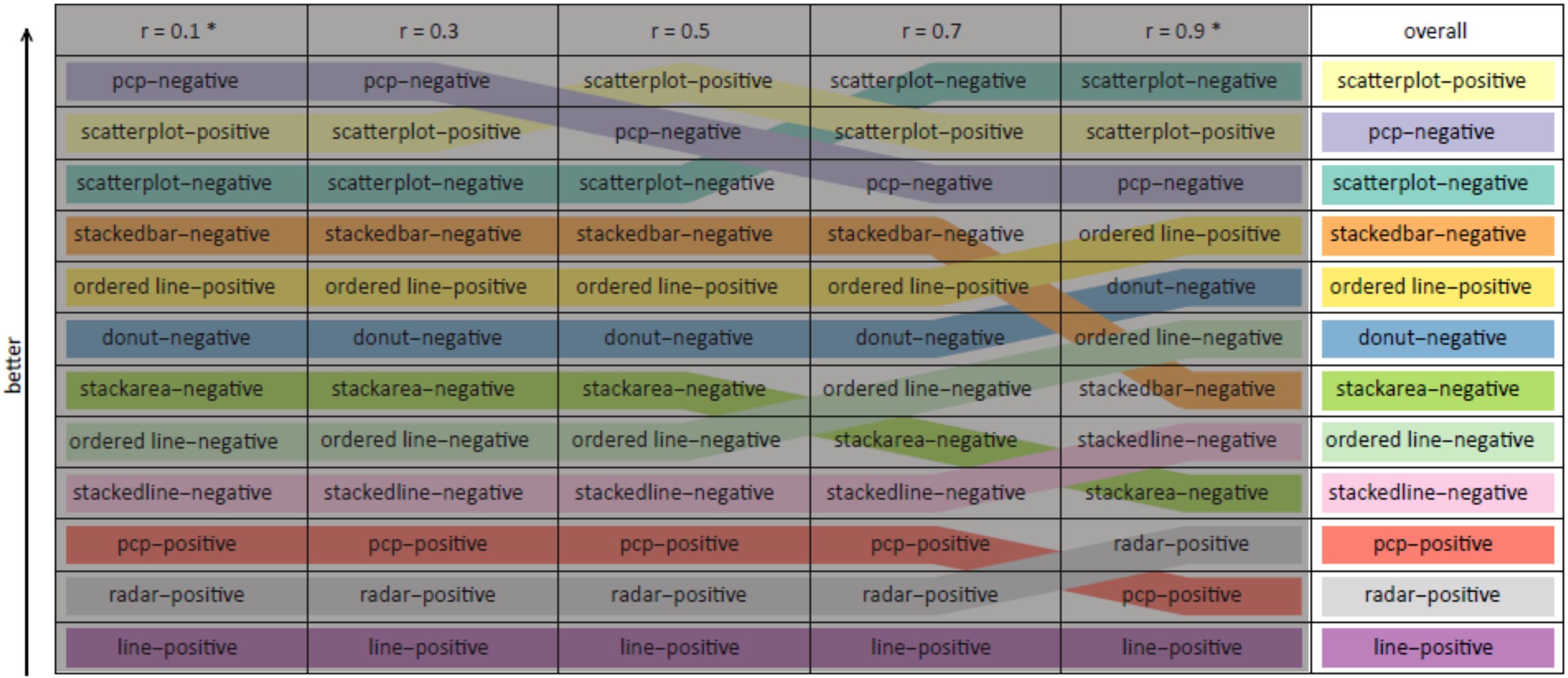
pcp–positive
pcp–positive
pcp–positive
pcp–positive
radar–positive
pcp–positive
radar–positive
radar–positive
radar–positive
radar–positive
pcp–positive
radar–positive
line–positive
line–positive
line–positive
line–positive
line–positive
line–positive
better

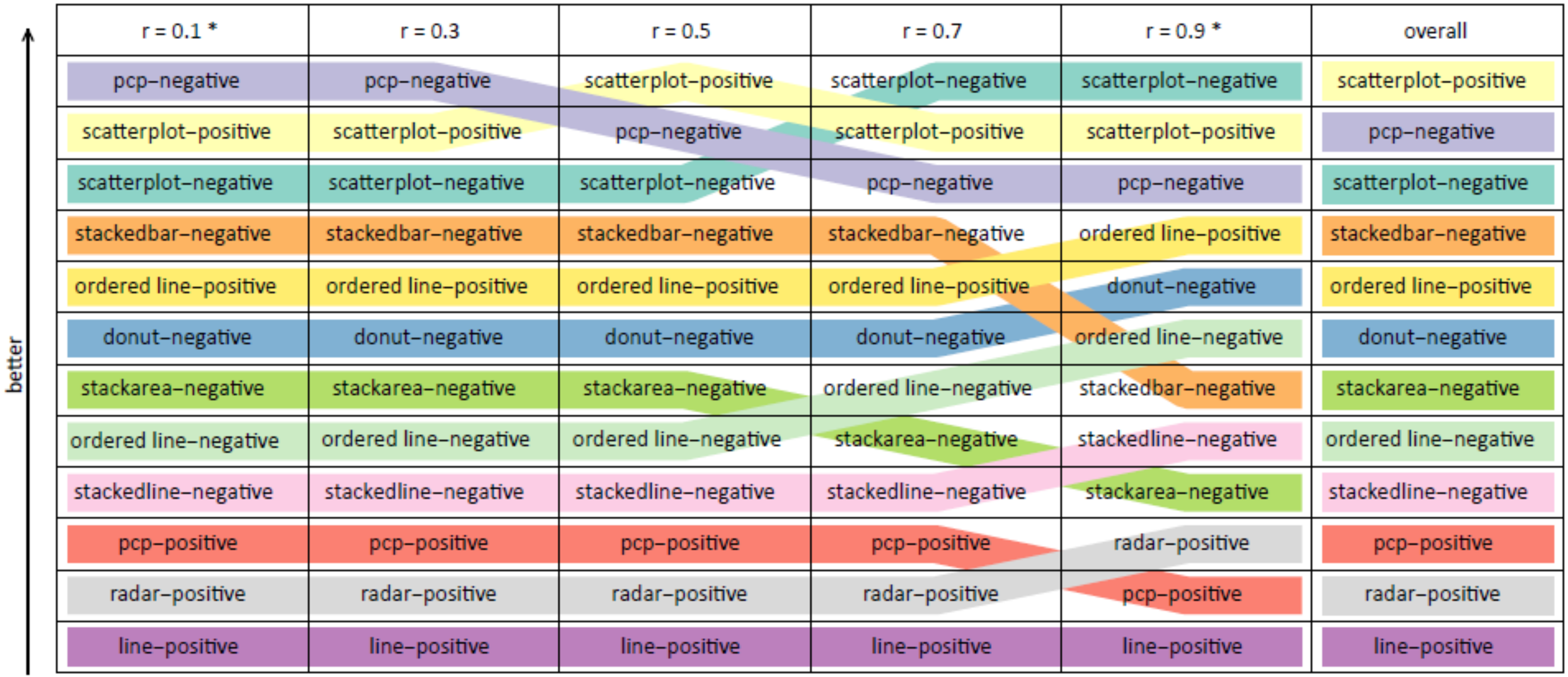
better

r = 0.1 *	r = 0.3	r = 0.5	r = 0.7	r = 0.9 *	overall
pcp–negative	pcp–negative	scatterplot–positive	scatterplot–negative	scatterplot–negative	scatterplot–positive
scatterplot–positive	scatterplot–positive	pcp–negative	scatterplot–positive	scatterplot–positive	pcp–negative
scatterplot–negative	scatterplot–negative	scatterplot–negative	pcp–negative	pcp–negative	scatterplot–negative
stackedbar–negative	stackedbar–negative	stackedbar–negative	stackedbar–negative	ordered line–positive	stackedbar–negative
ordered line–positive	ordered line–positive	ordered line–positive	ordered line–positive	donut–negative	ordered line–positive
donut–negative	donut–negative	donut–negative	donut–negative	ordered line–negative	donut–negative
stackarea–negative	stackarea–negative	stackarea–negative	ordered line–negative	stackedbar–negative	stackarea–negative
ordered line–negative	ordered line–negative	ordered line–negative	stackarea–negative	stackedline–negative	ordered line–negative
stackedline–negative	stackedline–negative	stackedline–negative	stackedline–negative	stackarea–negative	stackedline–negative
pcp–positive	pcp–positive	pcp–positive	pcp–positive	radar–positive	pcp–positive
radar–positive	radar–positive	radar–positive	radar–positive	pcp–positive	radar–positive
line–positive	line–positive	line–positive	line–positive	line–positive	line–positive

Interpolated (predicted) performance from models

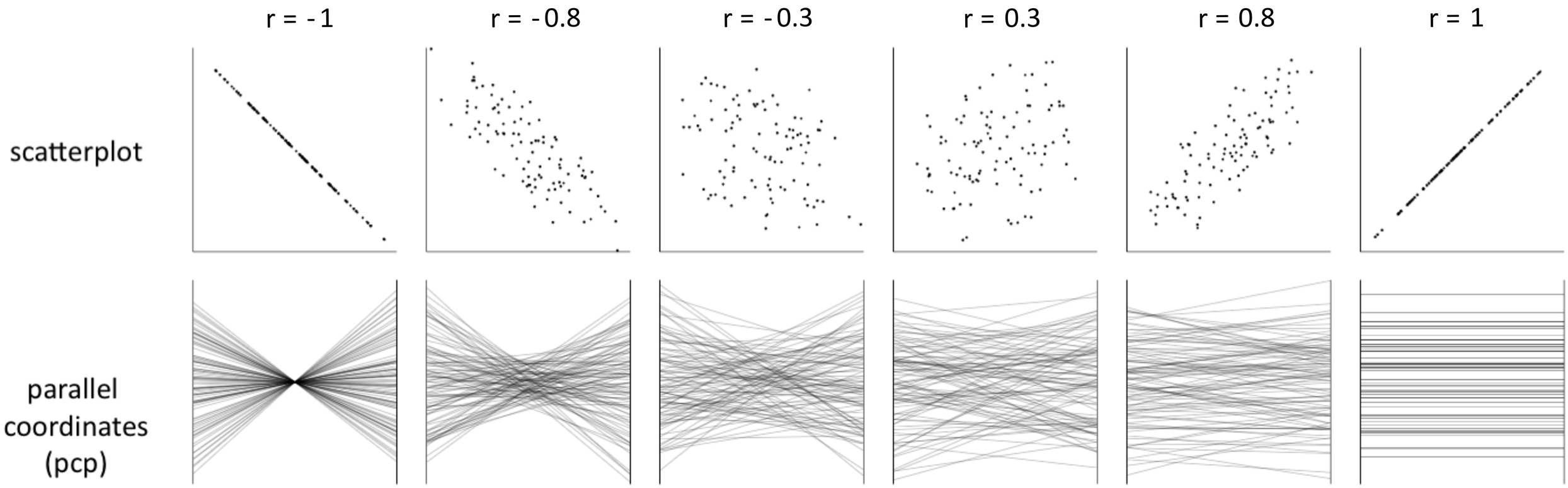


Overall ranking

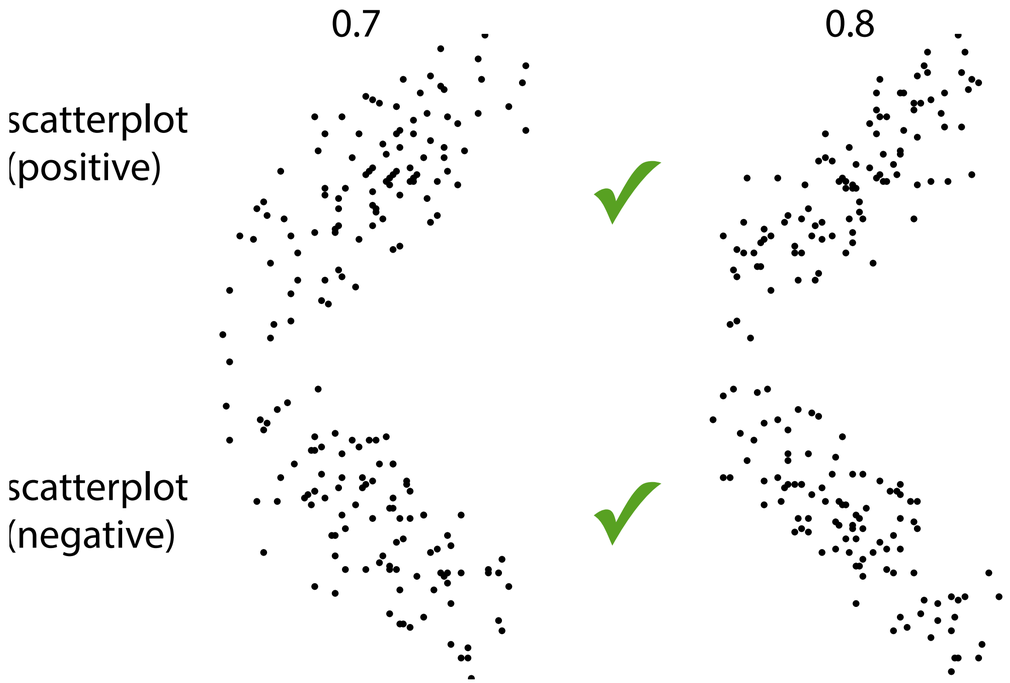


Perceptually-backed ranking for vis of correlation

2. Explore properties of the perceptual space of correlation.

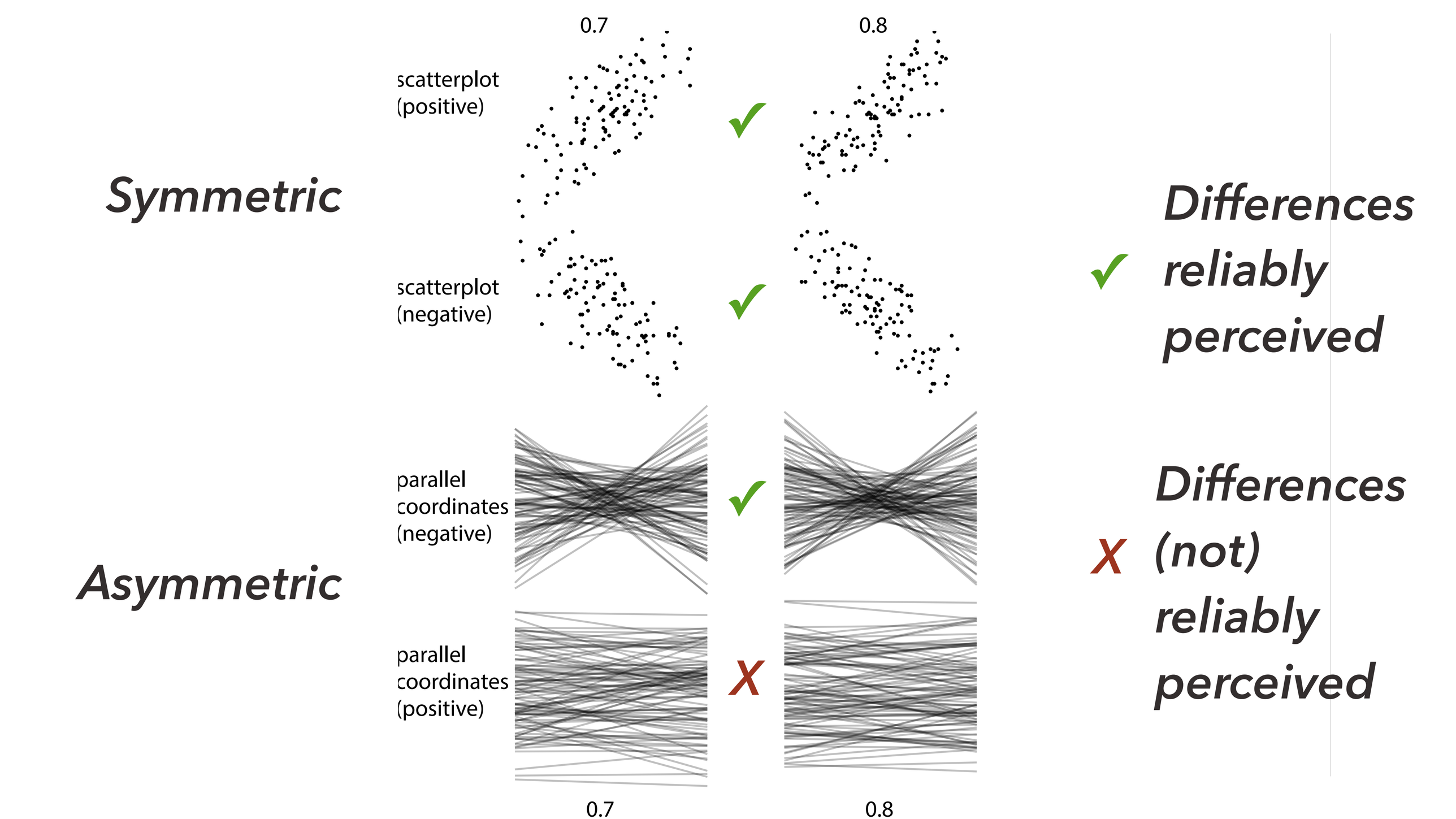

r = -1
r = -0.8
r = -0.3
r = 0.3
r = 0.8
r = 1
scatterplot
parallel coordinates (pcp)

Symmetric



✓ *Differences reliably perceived*

✗ *Differences (not) reliably perceived*



Symmetric

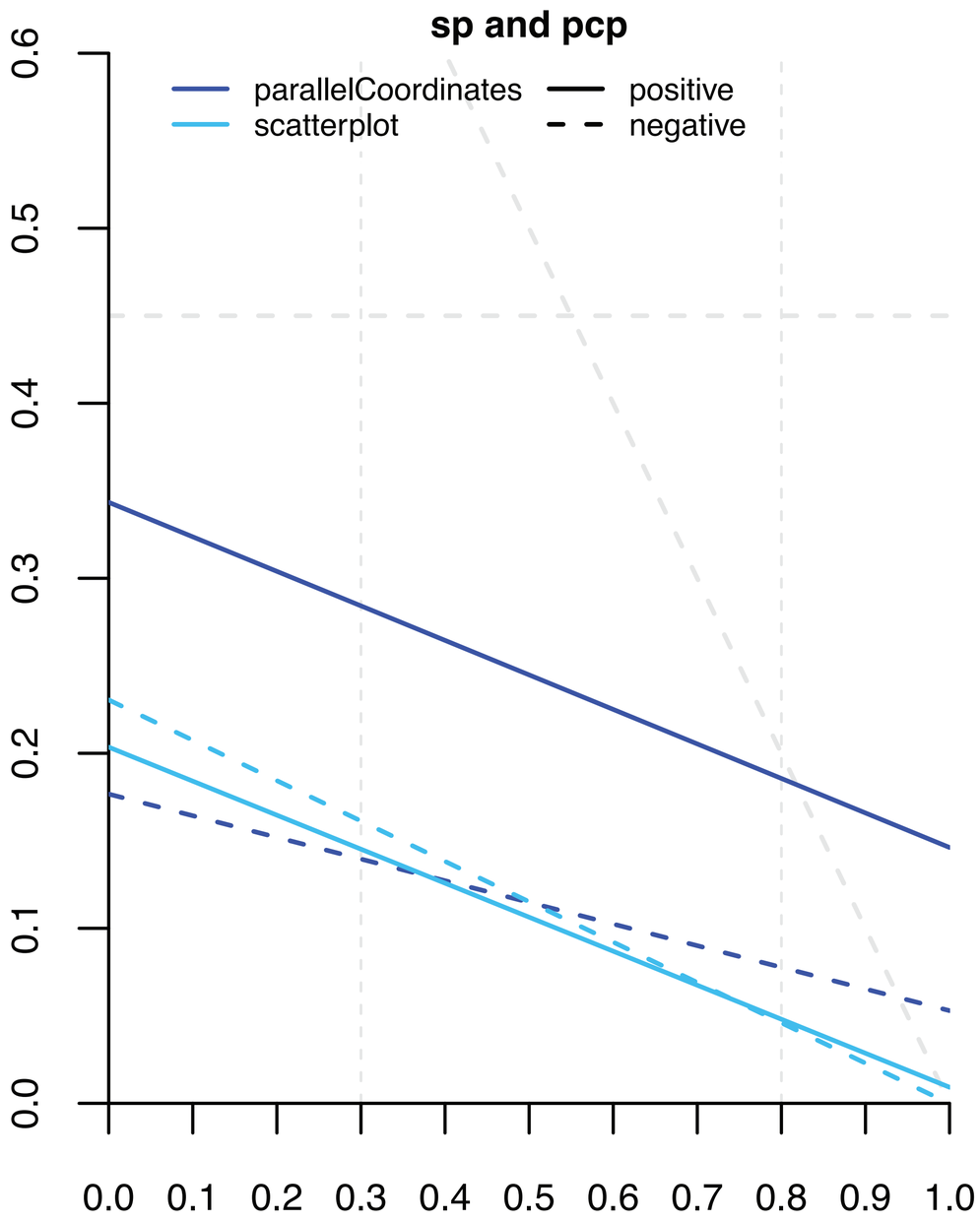
Asymmetric

✓ *Differences reliably perceived*

✗ *Differences (not) reliably perceived*

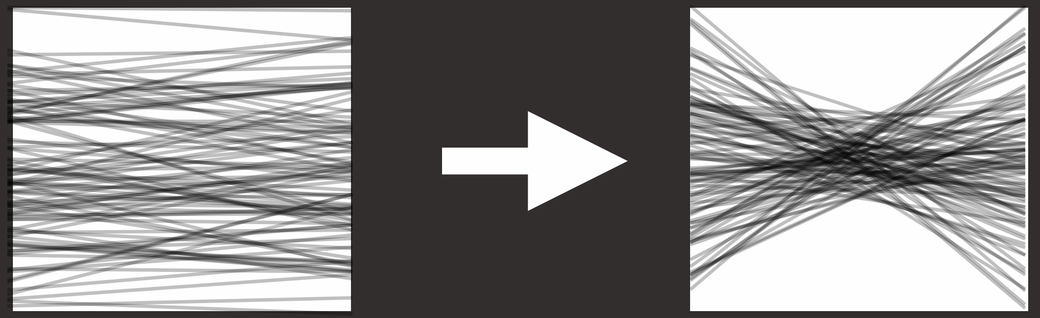
+PCP terrible

-PCP as good as scatterplots

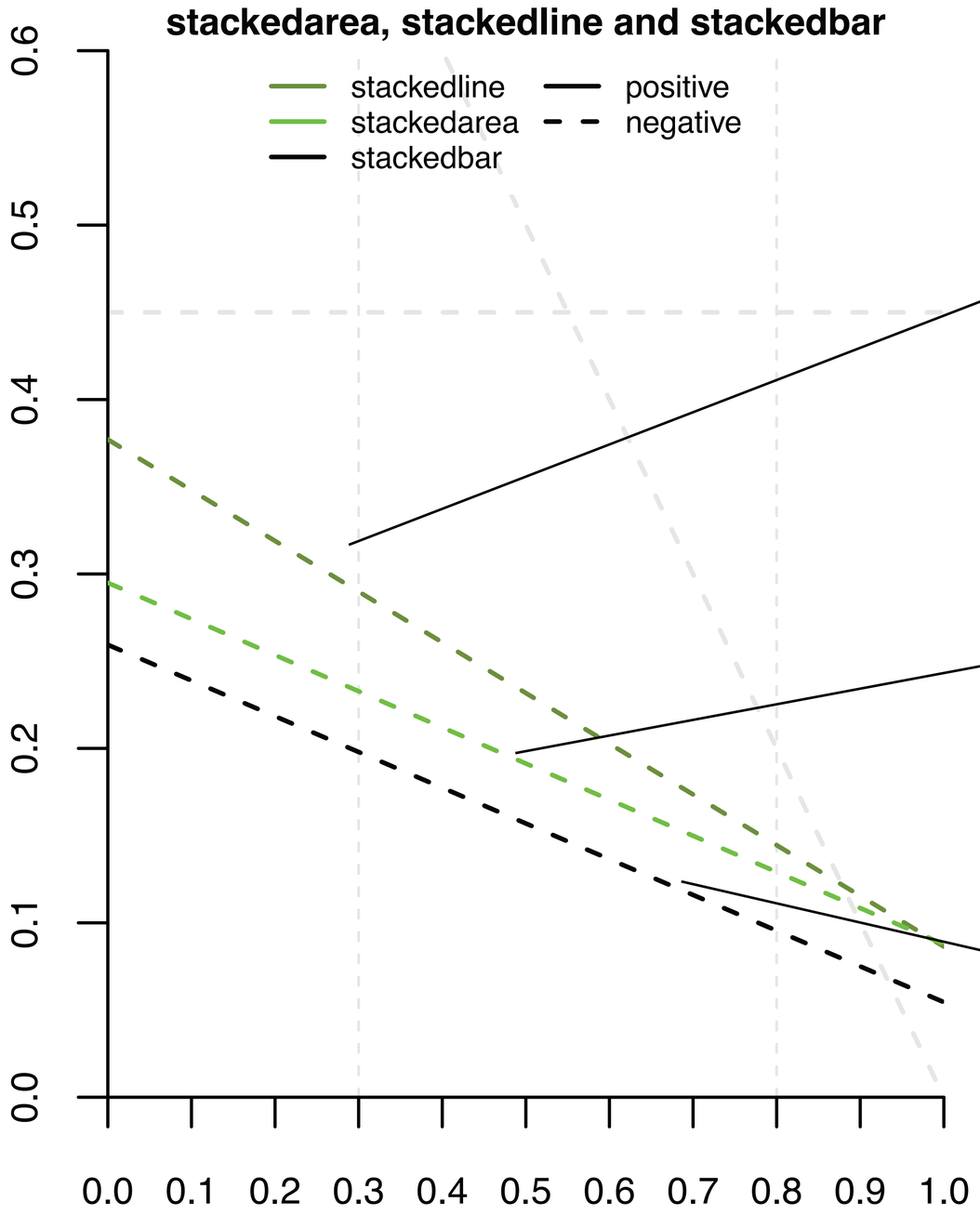


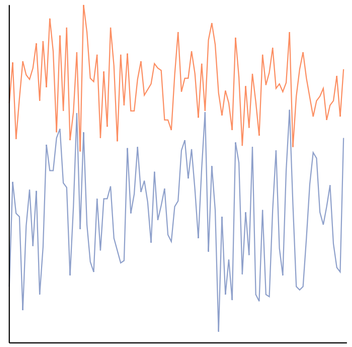
Design implication:

To show correlations precisely in parallel coordinates plots, flip the axes to show as many negative correlations as possible.

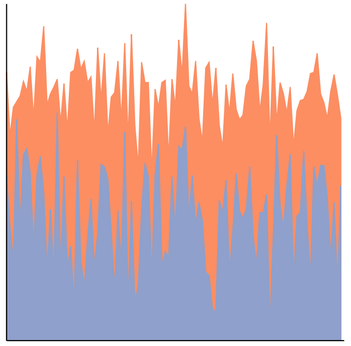


3. Guide the novice user in depicting correlation.

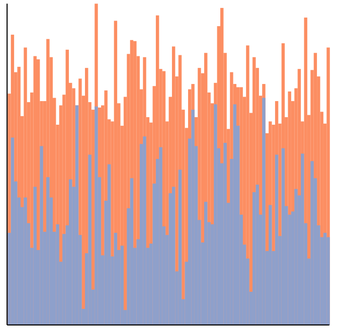




Worst



OK



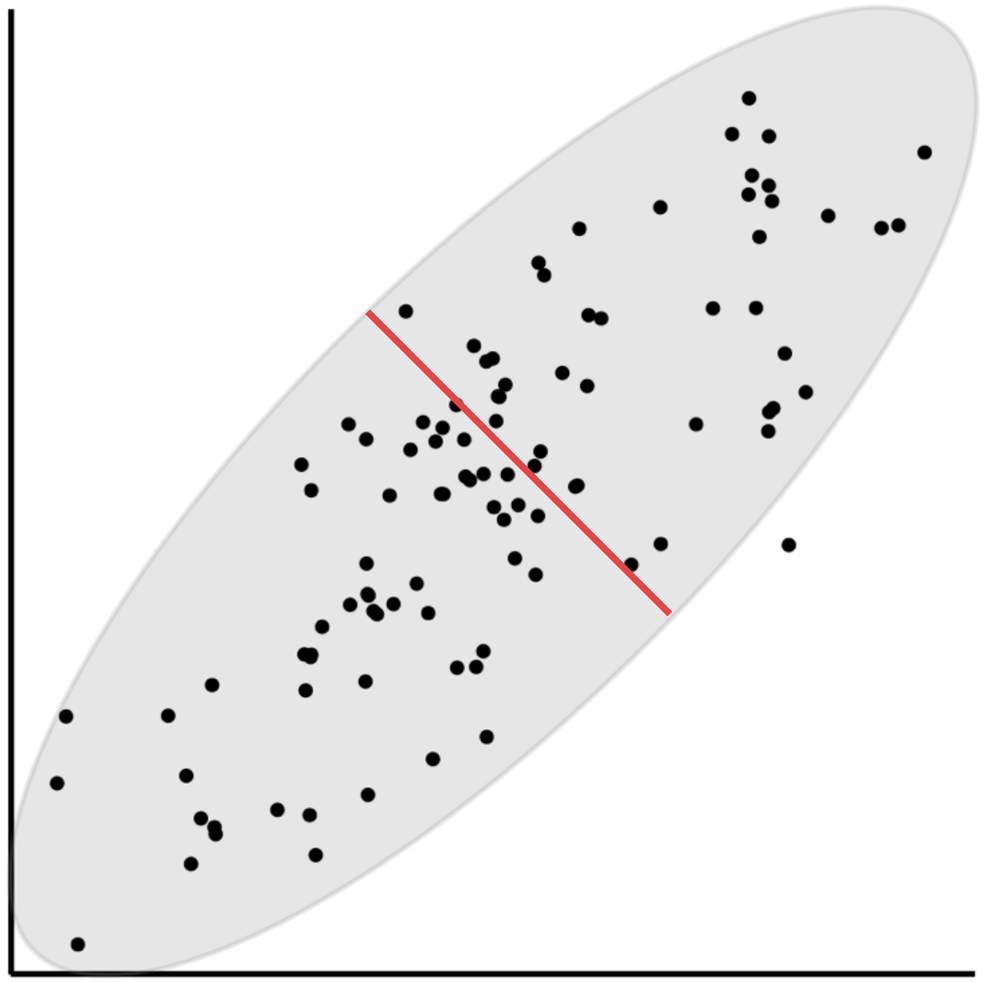
Best

Future Work

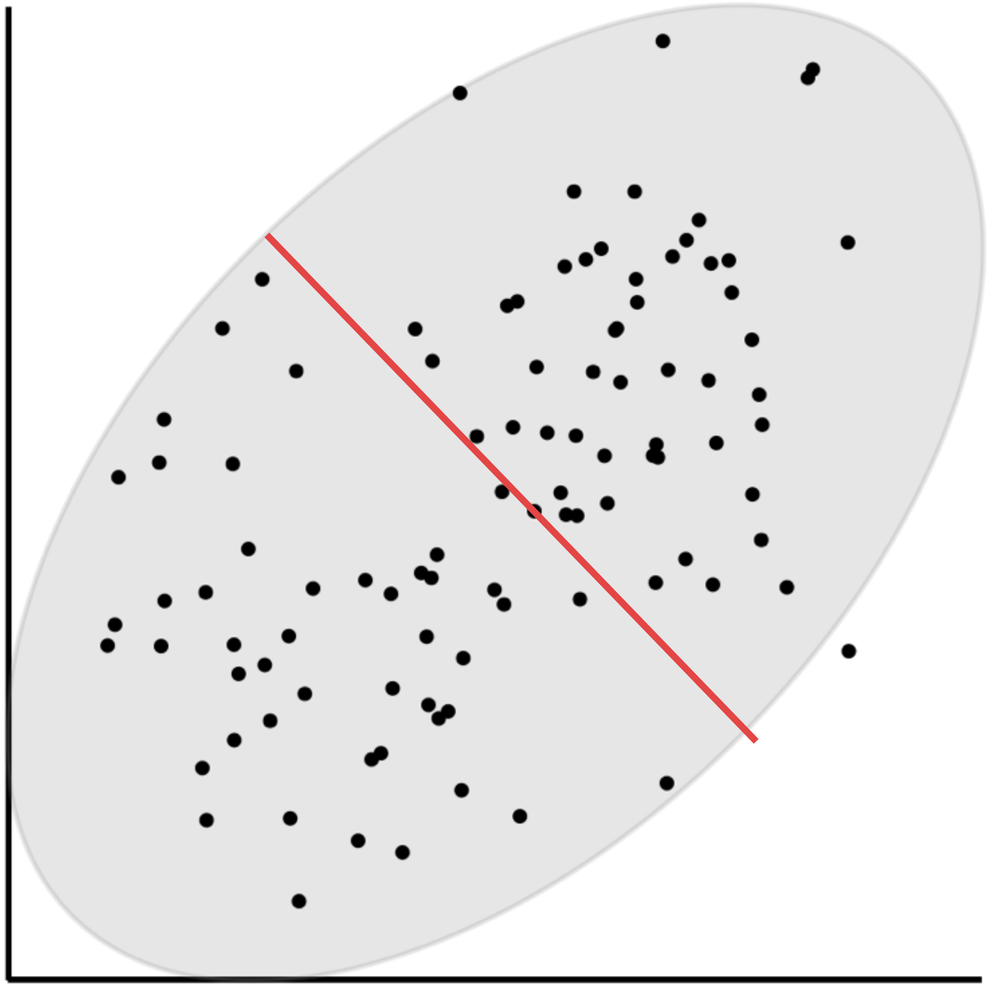
Why does Weber's law, which typically applies to low-level aspects of perception, work so well for modeling correlation?

conj: People aren't perceiving correlation, but the visual features related to correlation.

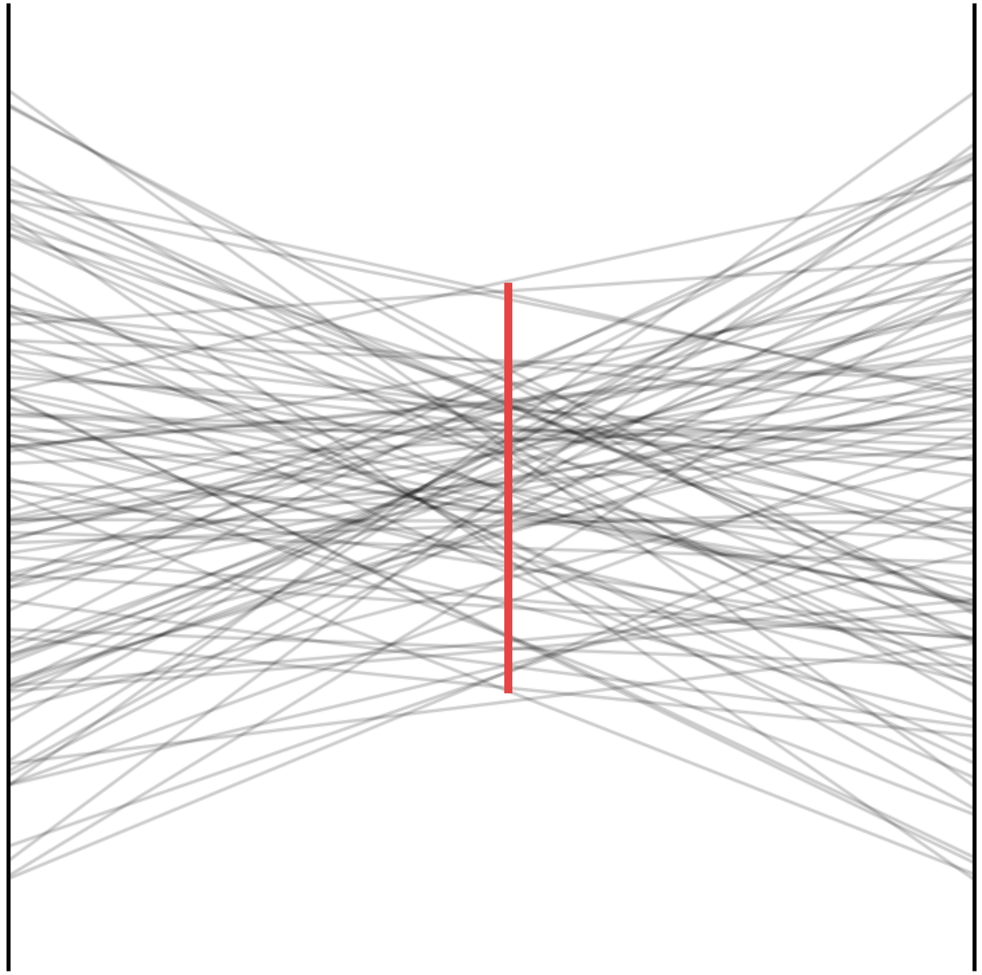
r = 0.8



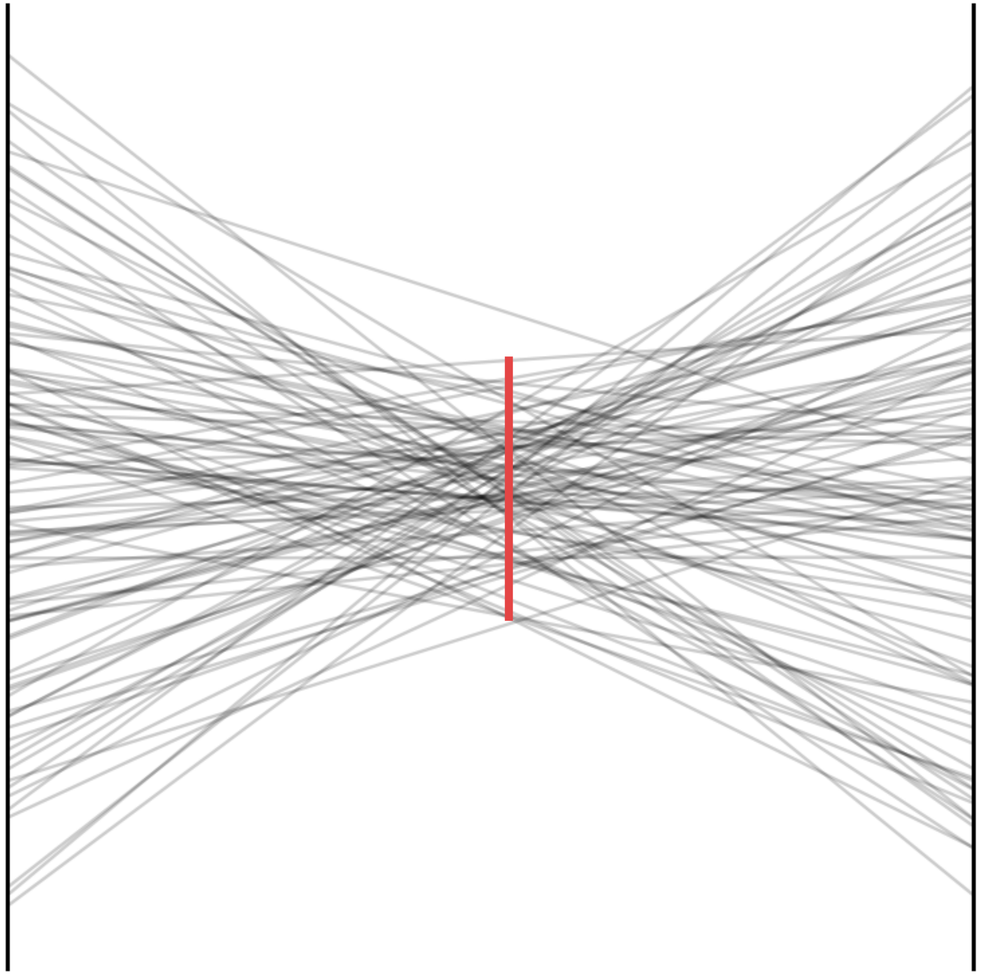
r = 0.5



r = -0.8



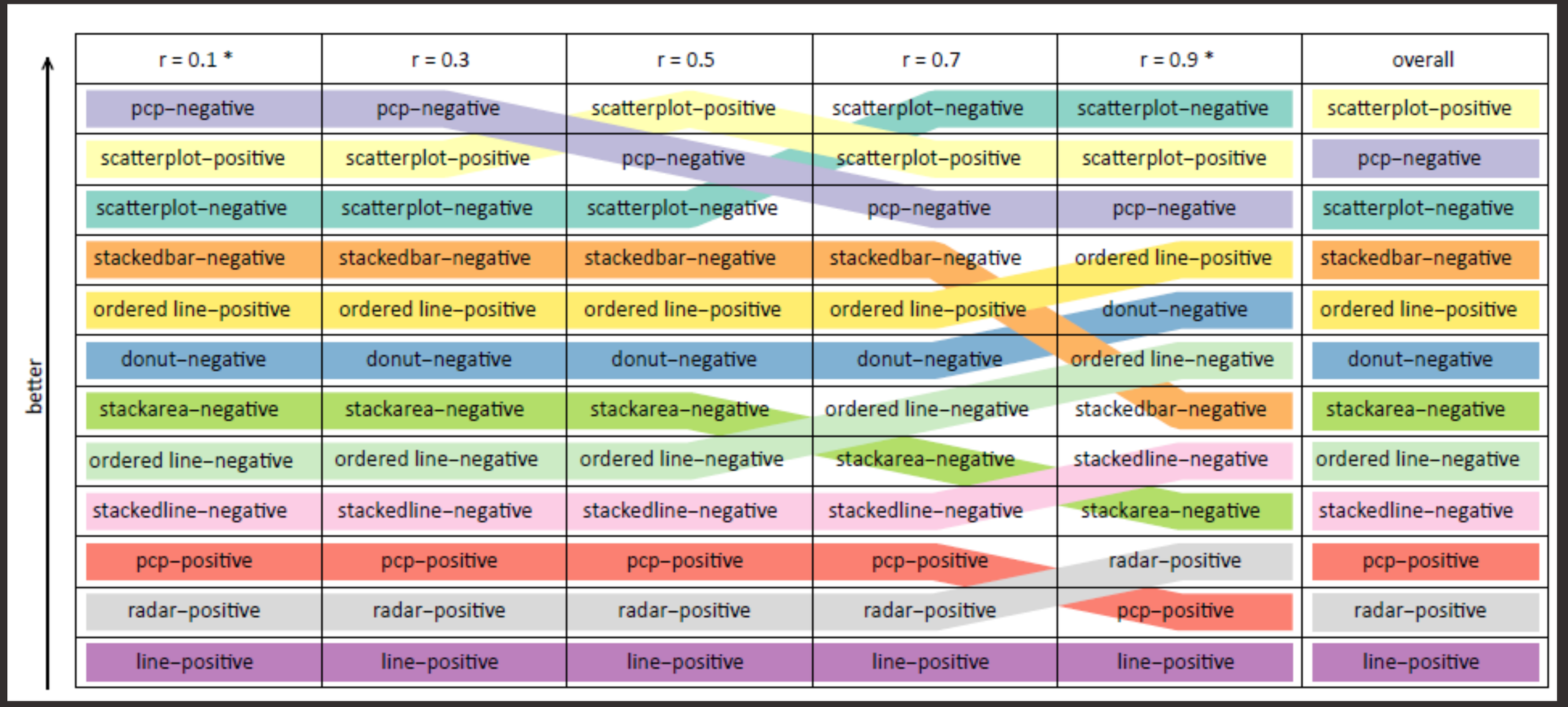
r = -0.5



To summarize:

Theory-grounded models help build the science of visualization while providing actionable information to inform visualization design.

Lane Harrison (lane@cs.tufts.edu)



Data, Code, Analysis Scripts, Paper:
github.com/TuftsVALT/ranking-correlation