Data Visualization & Design

Week 2

This week in **visualization**…

[Source]

1. Assignment **Review**
2. Principles of **Design**
3. **Gestalt Principles** for Data Visualization
4. **Introduction** to **Visual Variables**
5. **Applying Visual Variables**
6. **Tips** & **Best Practices**

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Homework:

Thinking Visually

Description → Visual representation

Description → Visual representation

(**Written** relationships) (**Visual** relationships)

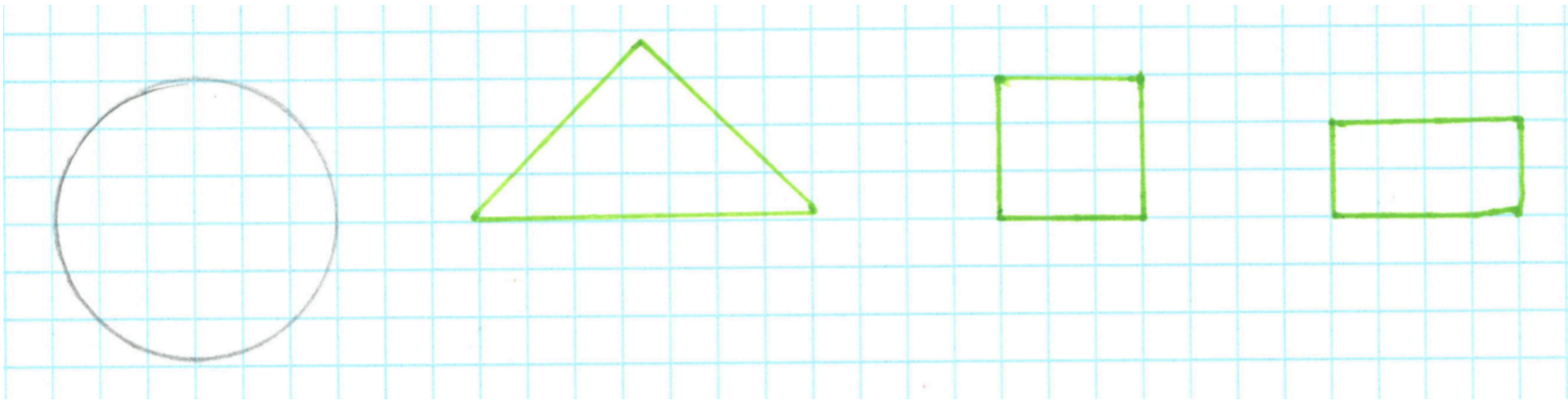
Terms that suggest ***similarity***

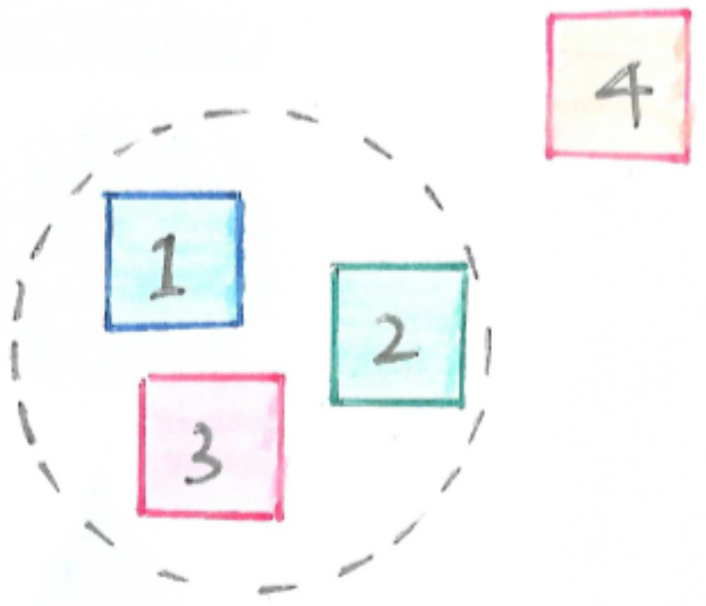
- Two ideas ***overlap*** conceptually
- Three ideas ***relate to each other*** but one does not
- Four ***equal*** concepts which need to be addressed in order

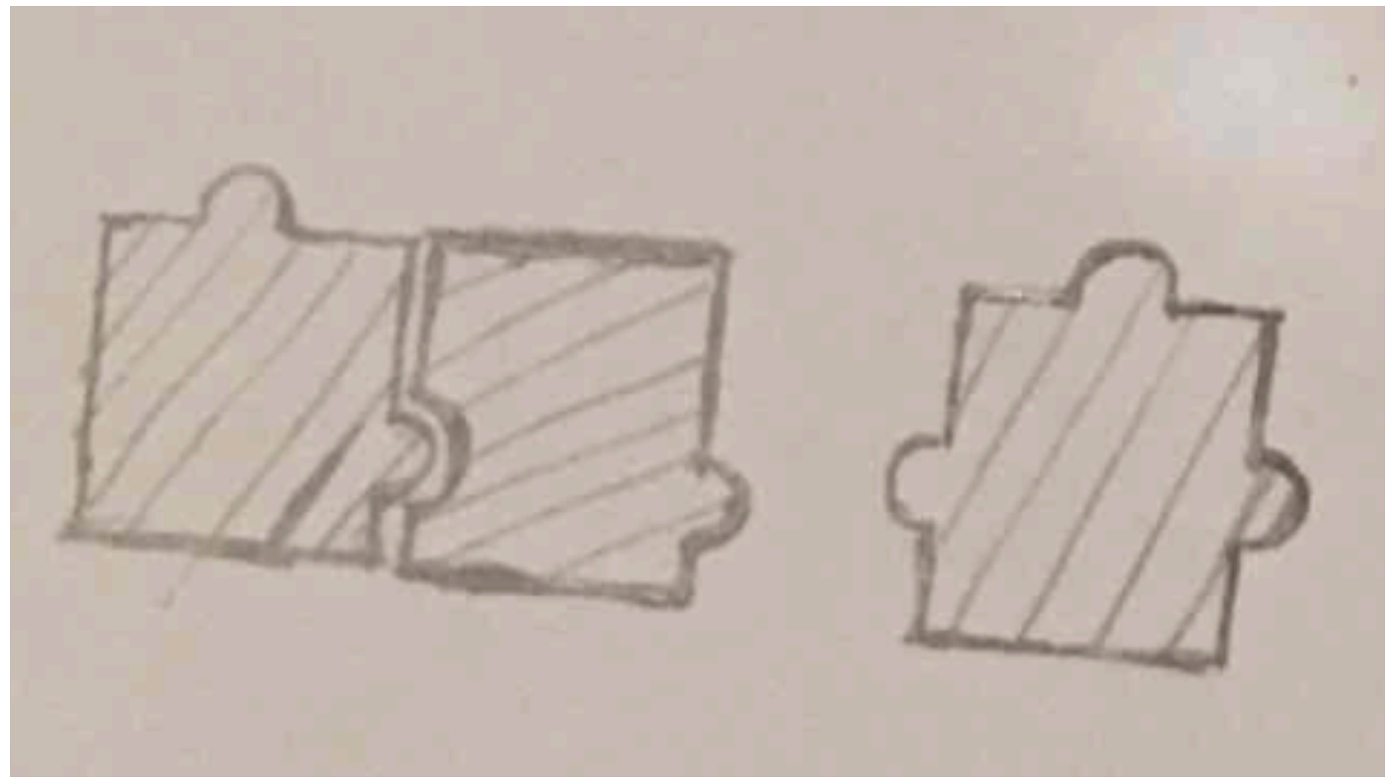
Visual methods that suggest ***similarity***

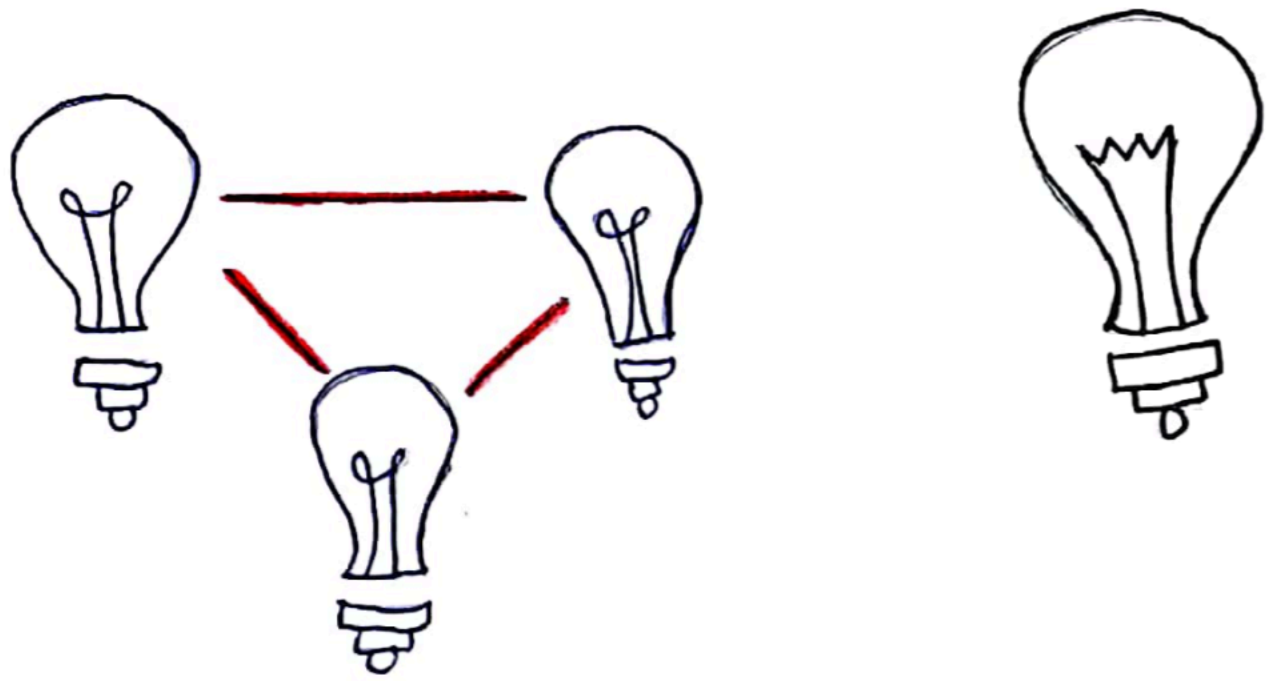
- Sharing the same **color**
- Sharing the same **shape**
- Sharing the same **pattern**
- Being the same **size**
- **Overlapping** in space

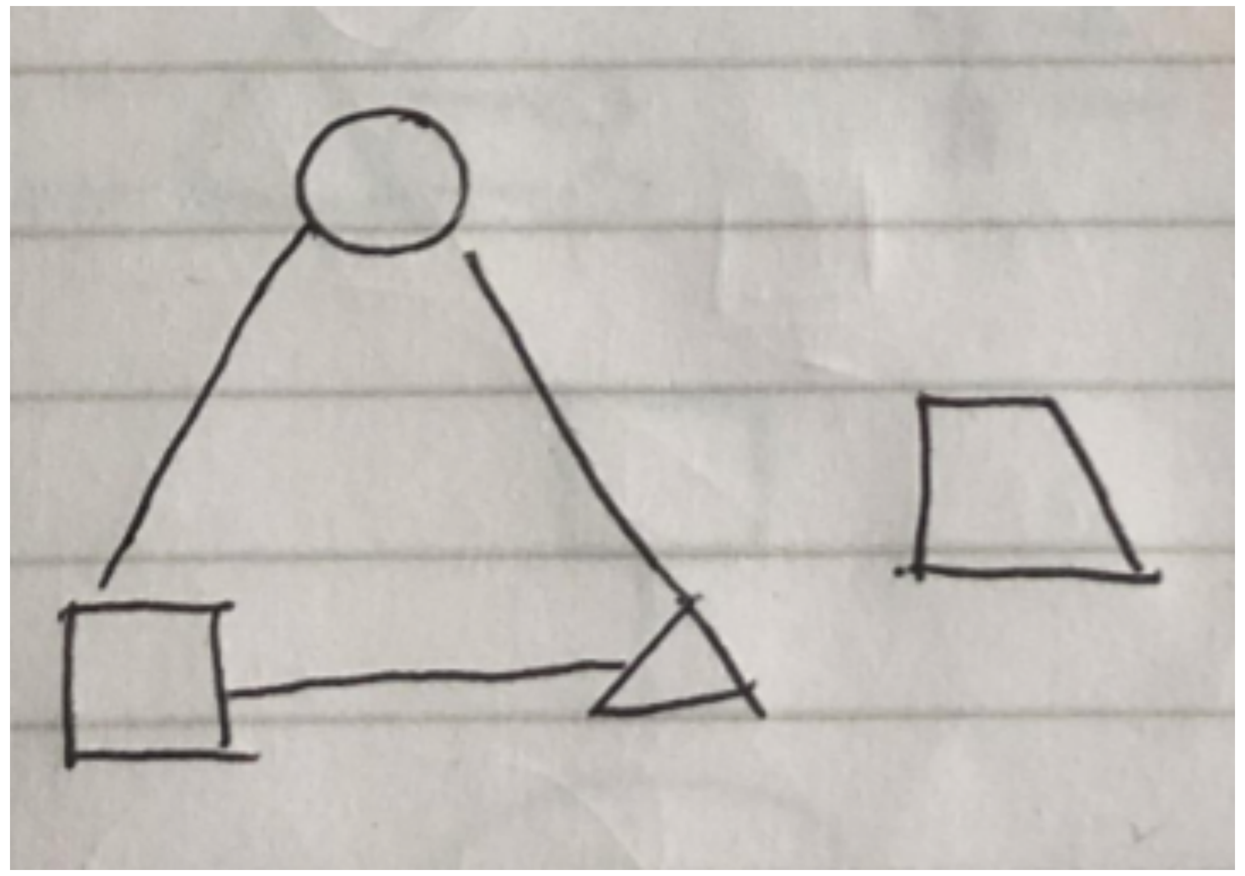
“Three ideas relate to each other but one does not”

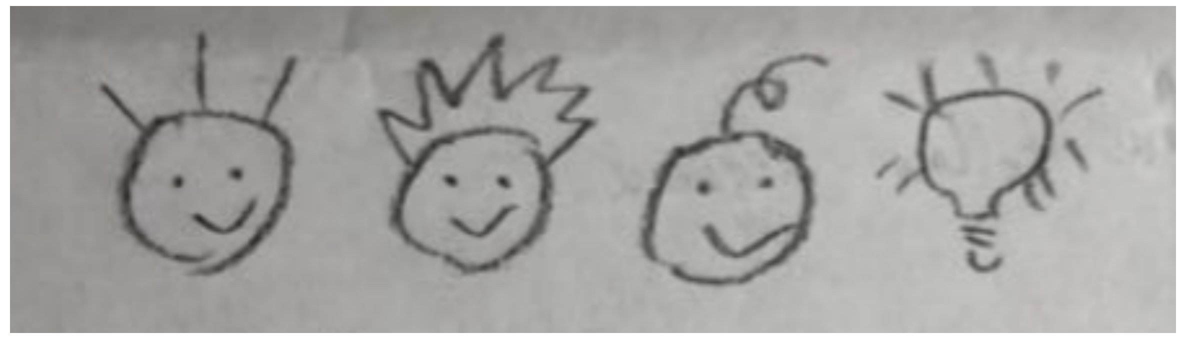












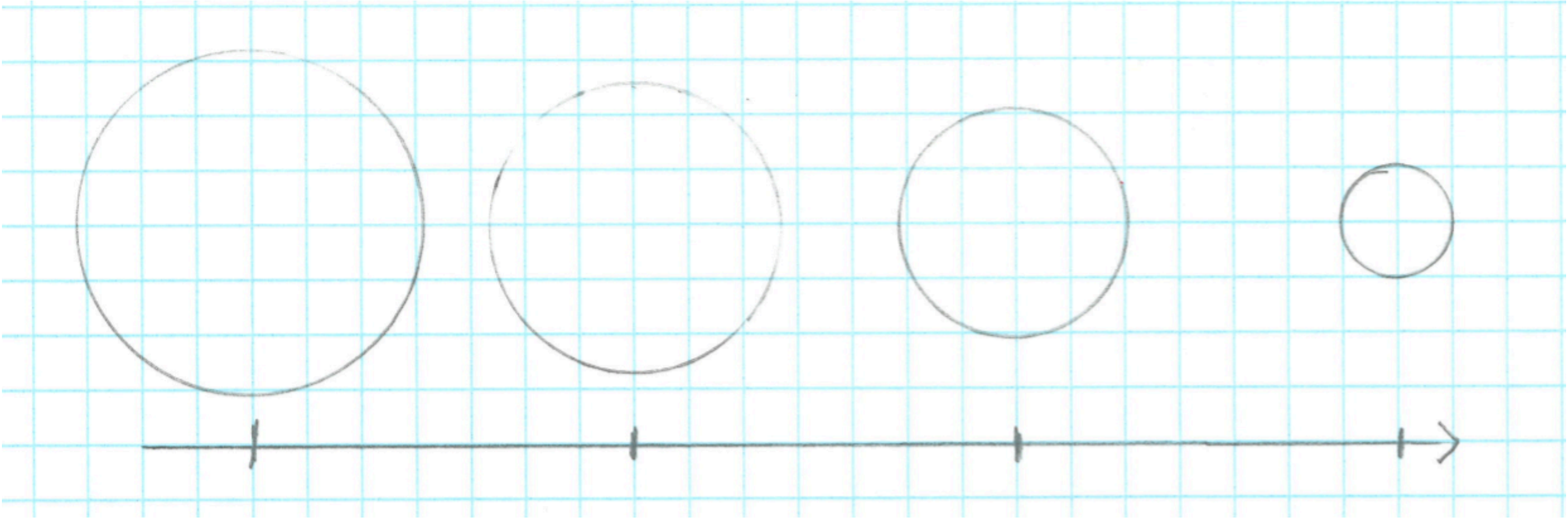
Terms that suggest ***evolution***

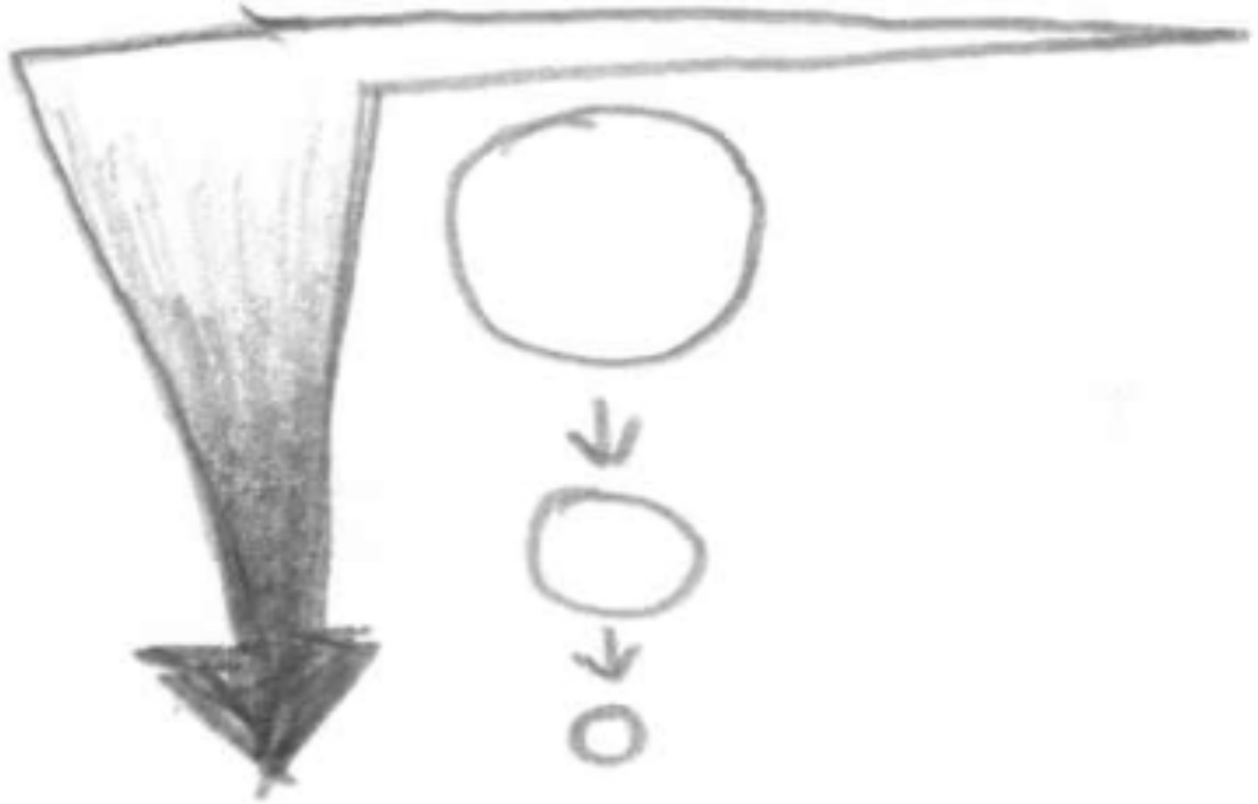
- It ***used to be*** bigger
- The concept is ***gaining impact*** over time
- Four concepts are ***diminishing*** at different rates
- The concept is ***morphing into*** another concept over time
- This idea ***gave rise to*** three new and different ideas

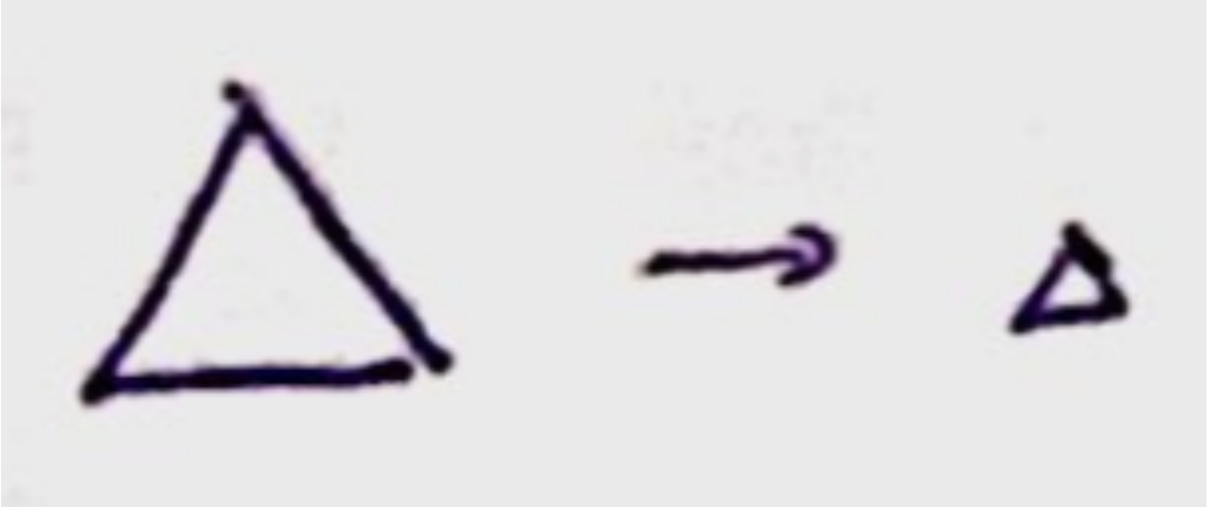
Visual methods that suggest ***evolution***

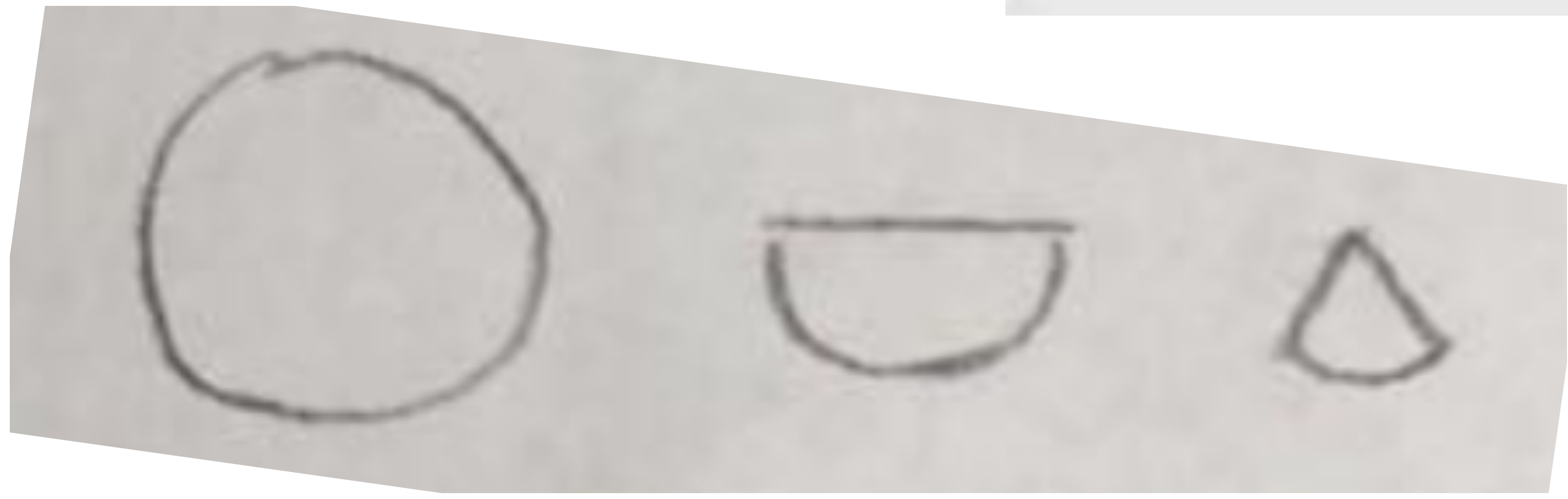
- **Arrows** (before → after)
- **Axes** (scale to mark change)

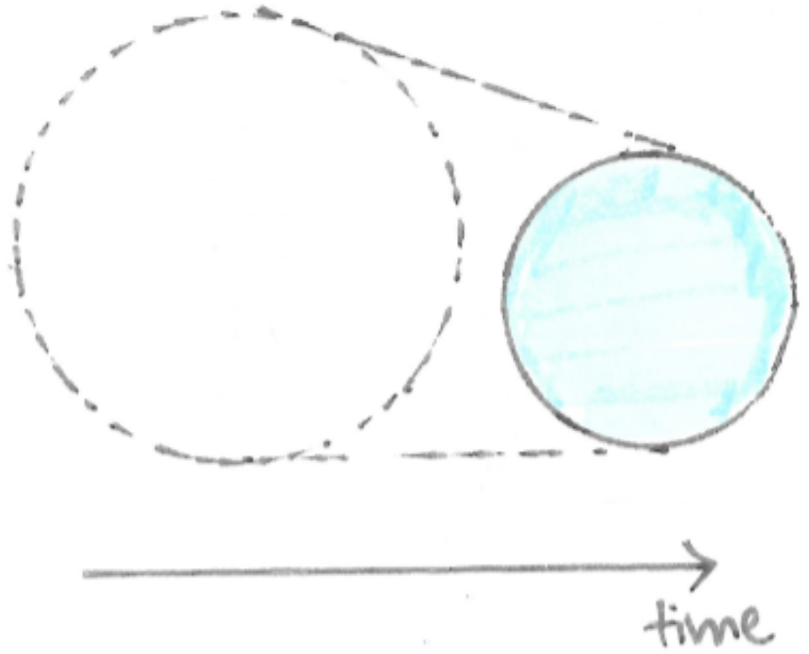
“It used to be bigger”

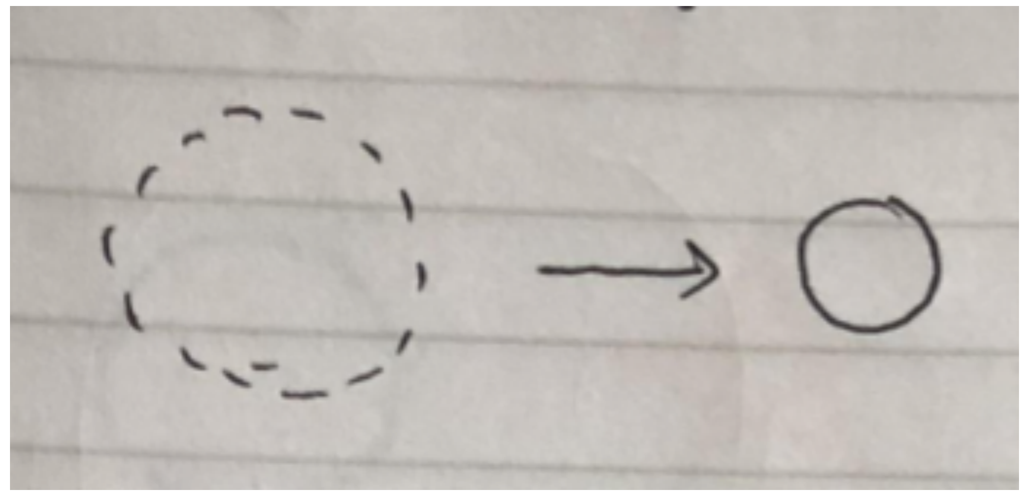


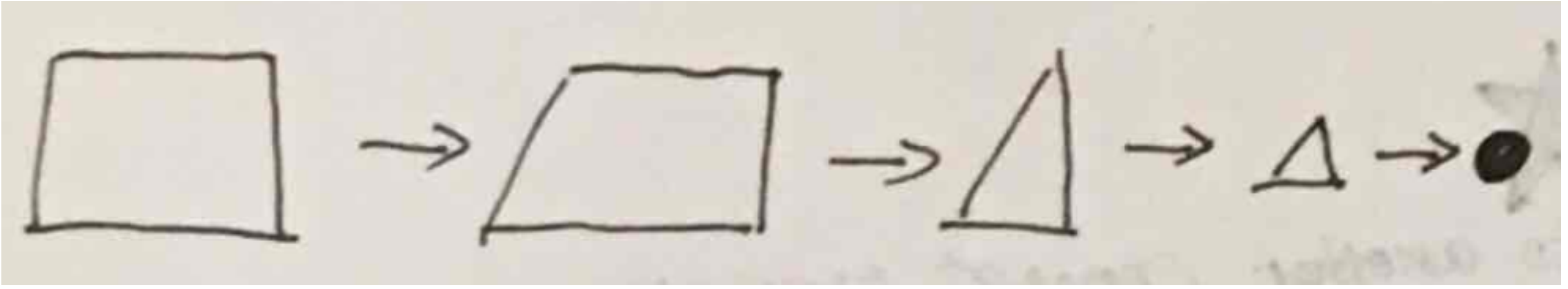












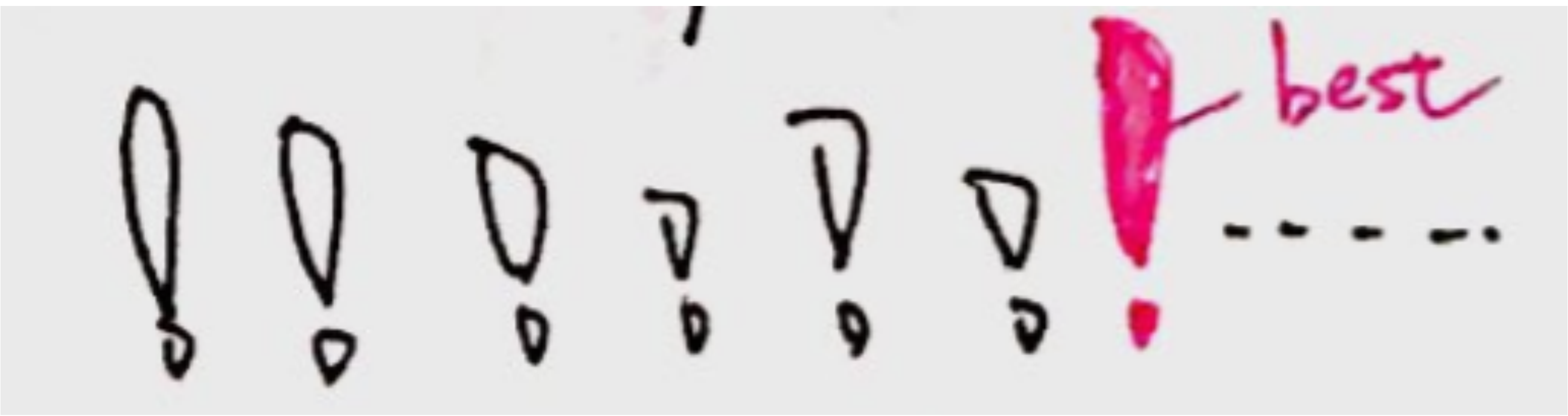
Terms that suggest ***individuality***

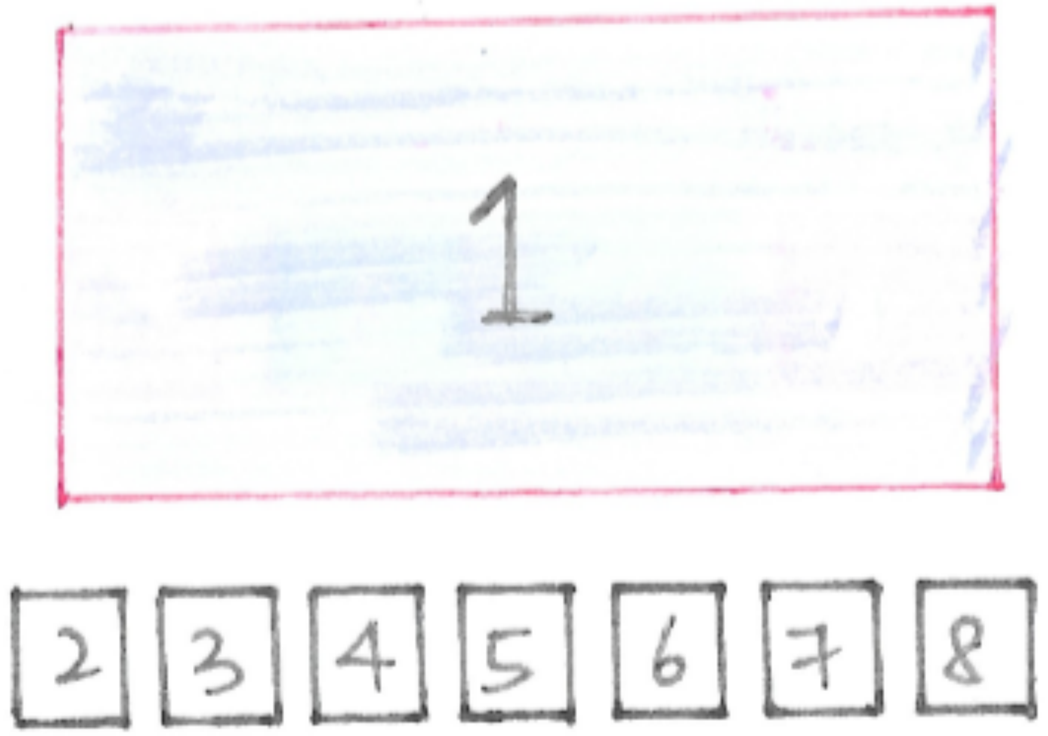
- There is one ***big*** idea
- There are two ideas, but one is ***more important*** than the other
- Three ideas relate to each other but ***one does not***
- There are many ideas, but ***one is best***
- …half in each group are ***special***

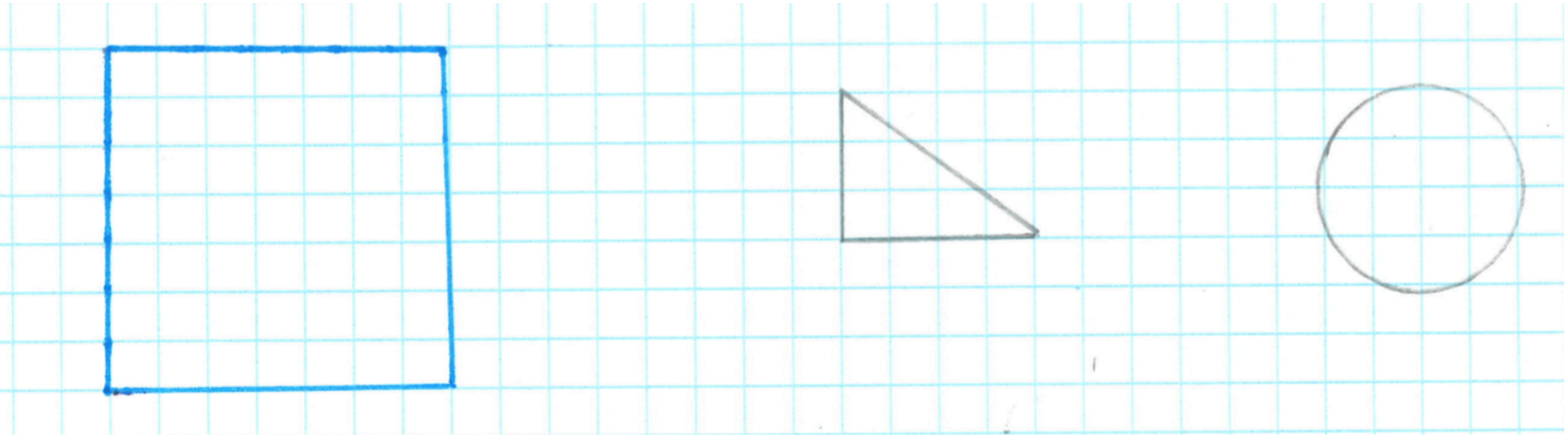
Visual methods that suggest ***individuality***

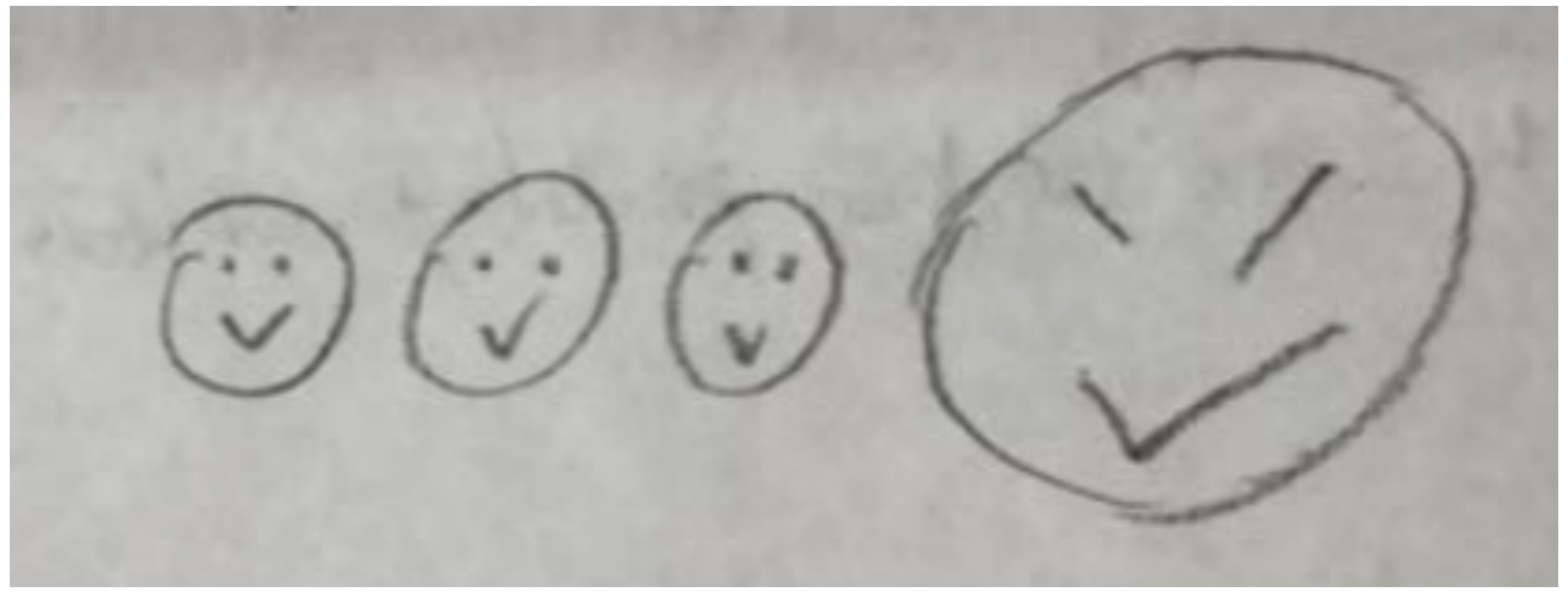
- Having a unique **shape**
- Having a unique **color**
- Having a unique **size**
- Having a unique **pattern**

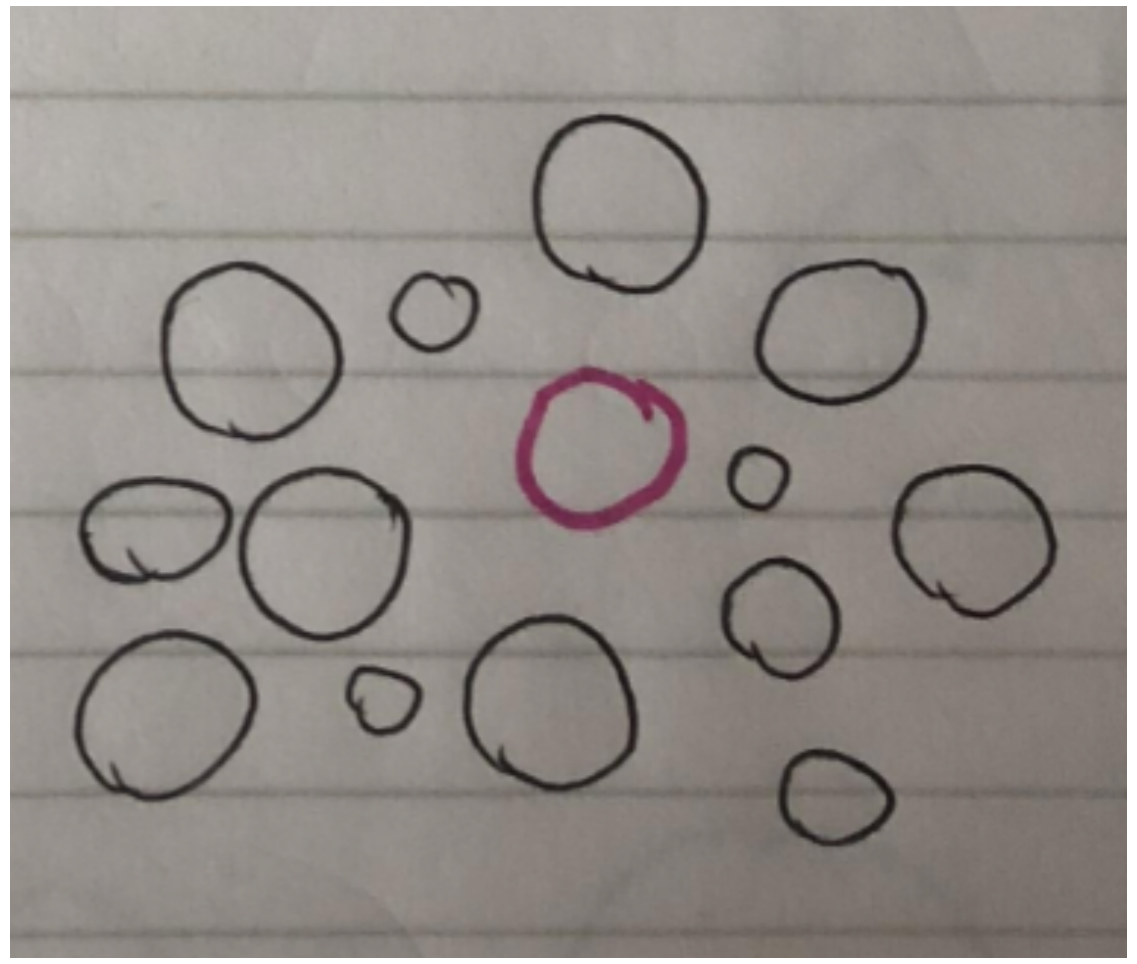
“There are many ideas, but one is best”

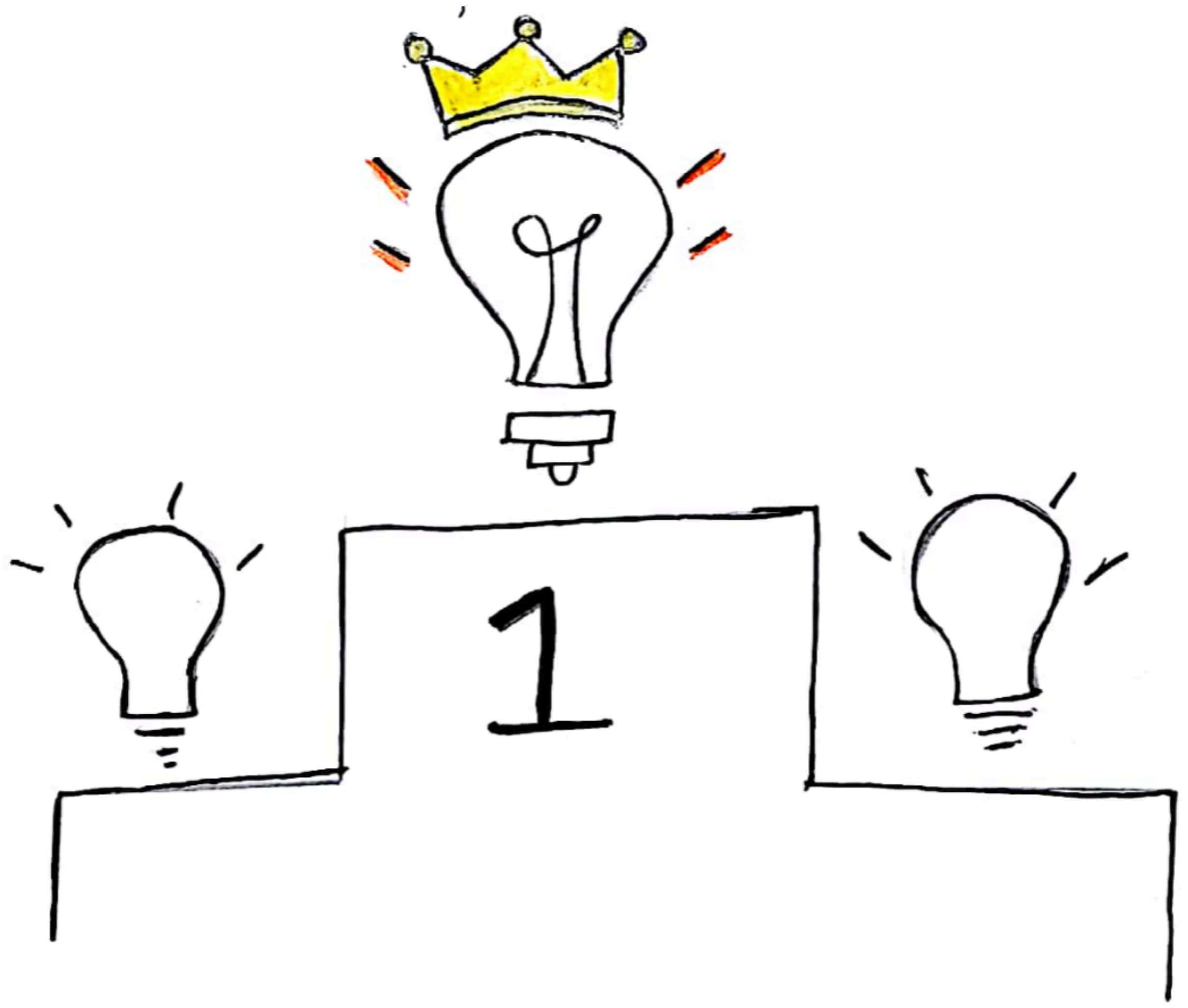












Assignment 1:
Visual Semantics

First draft: **9/16**
Final: **9/22, 11:59PM**

- Qualitative data
- **“Take-home-message”**
- Grouping, hierarchy, connection
- Visual metaphor
- Cite all sources
- ***Original work only***

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Attention is your most valuable resource.
Your **medium** is human perception.

Good design makes perception **easy**.

Affordance —

The physical characteristics of an object or environment influence its function.

ex. A door with a handle “affords” pulling.

Entry point —

A point of physical or attentional entry into a design.

ex. Store entrances that reduce the barrier to entry (lures).

Figure-ground relationship —

Elements are perceived as either figures (objects of focus) or ground (the rest of the perceptual field).

ex. On a simple map, land is the object of focus, and water is the background.

Highlighting —

A technique for bringing attention to an area of text or image.

ex. **Bold**, *italics*, or <u>underline</u>.

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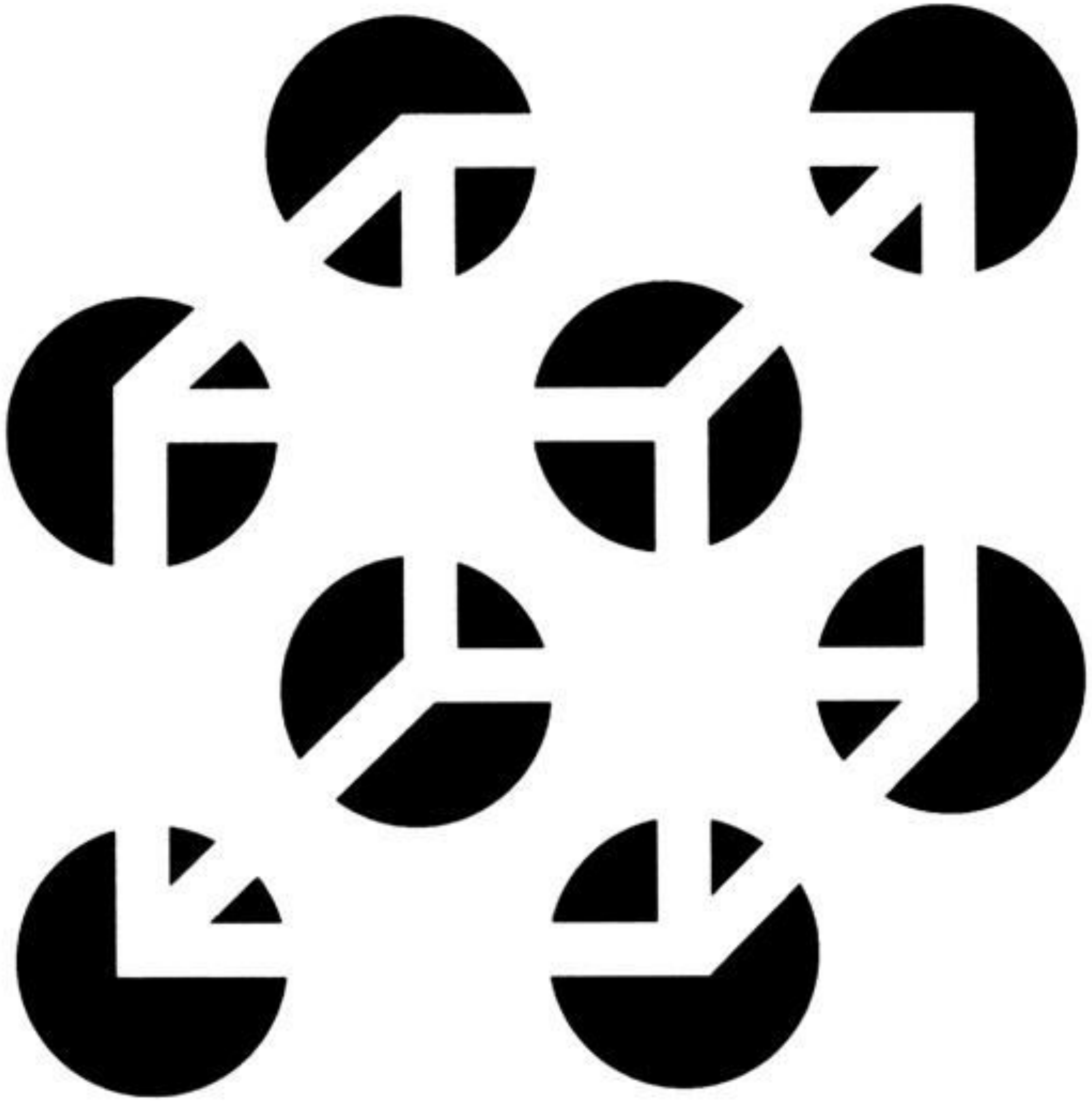
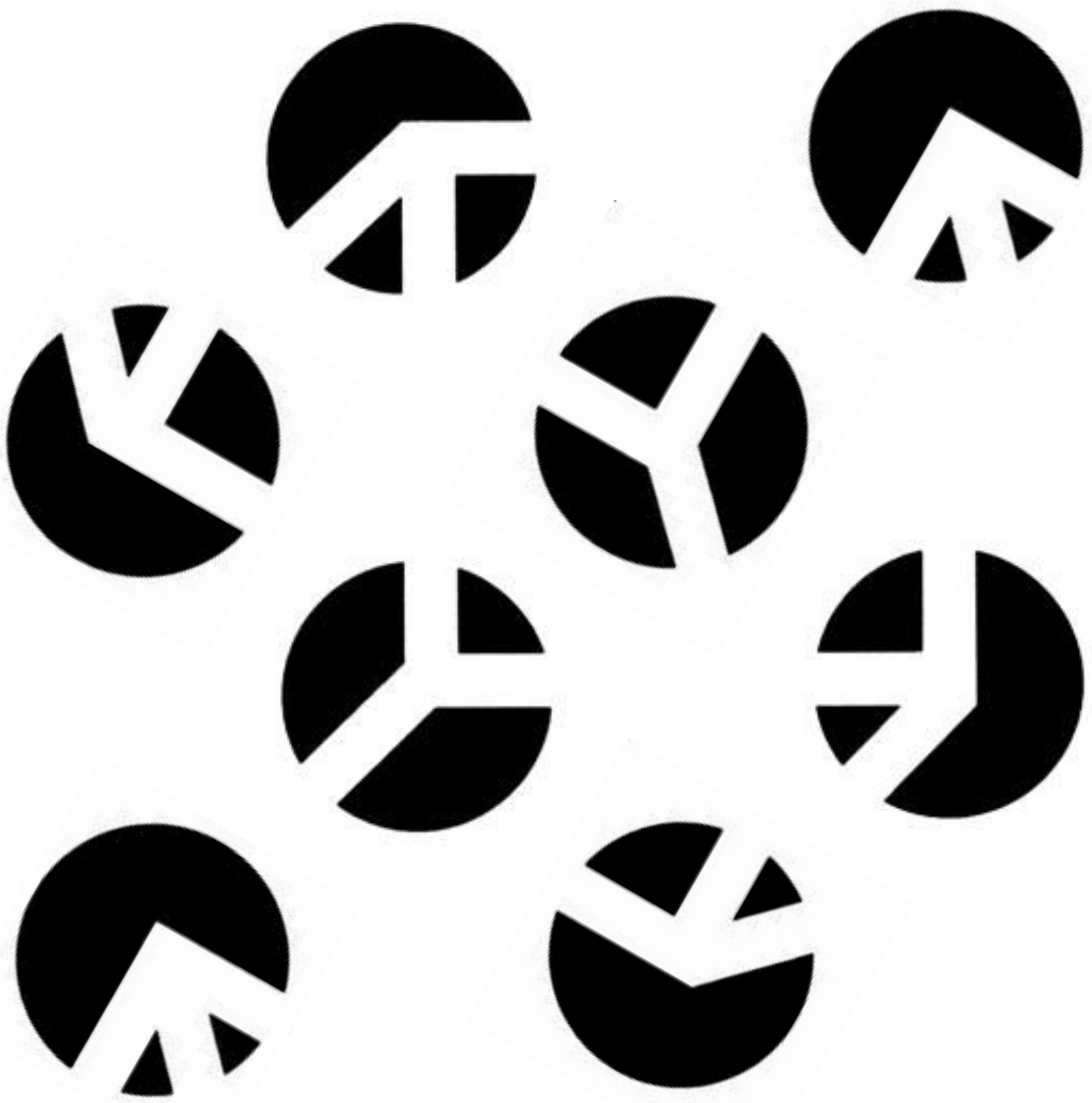
Gestalt principles account for the ***organized patterns and objects*** humans naturally perceive when presented with graphical elements.





Gestalt principles underlie the simplest graphics…

I ♥ NY®

…as well as the most **complex**.

WORLD MAP
A R C T I C O C E A N
N
Greenland (Denmark)
Svalbard (Norway)
Franz Josef Land
October Revolution
Prime Meridian
W 0° E
Baffin Bay
Beaufort Sea
Jan Mayen (Norway)
Norwegian Sea
Barents Sea
Kara Sea
Novaya Zemlya
Laptev Sea
Kotelny
East Siberian Sea
Wrangel
Arctic Circle
Alaska (USA)
Canada
Hudson Bay
Labrador Sea
Gulf of Alaska
Iceland
Faroe Islands (Denmark)
Finland
Sweden
Norway
Russia
Bering Sea
Sea of Okhotsk
United Kingdom
North Sea
Ireland
Denmark
Estonia
Latvia
Lithuania
Belarus
Poland
Germany
Ukraine
France
Black Sea
Aral Sea
Caspian Sea
Kazakhstan
Mongolia
San Marino
Monaco
Andorra
Spain
Portugal
Vatican City
Italy
Romania
Bulgaria
Greece
Turkey
Georgia
Azerbaijan
Armenia
Uzbekistan
Turkmenistan
Kyrgyzstan
Tajikistan
Afghanistan
Pakistan
North Korea
Sea of Japan (East Sea)
South Korea
Japan
China
NORTH PACIFIC OCEAN
United States of America
NORTH ATLANTIC OCEAN
Bermuda (U.K.)
Mediterranean Sea
Malta
Tunisia
Morocco
Canary Islands (Spain)
Algeria
Libya
Egypt
Israel
Jordan
Syria
Iraq
Iran
Kuwait
Bahrain
Qatar
U.A.E.
Saudi Arabia
Nepal
Bhutan
India
Myanmar (Burma)
East China Sea
Taiwan
PACIFIC OCEAN
Tropic of Cancer
Mexico
Gulf of Mexico
The Bahamas
Haiti
Dominican Rep.
Puerto Rico (U.S)
St. Kitts & Nevis
Antigua and Barbuda
Dominica
St. Lucia
Barbados
Grenada
Trinidad & Tobago
Cuba
Jamaica
Belize
Guatemala
Honduras
El Salvador
Nicaragua
Costa Rica
Caribbean Sea
Hawaii Islands (U.S.)
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Yemen
Oman
Arabian Sea
Bangladesh
Laos
Bay of Bengal
Thailand
Vietnam
Philippine Sea
Philippines
Northern Mariana Islands (U.S)
Guam (U.S)
Marshall Islands
Cabo Verde
Senegal
The Gambia
Burkina Faso
Nigeria
Djibouti
Ethiopia
Sierra Leone
Liberia
Côte d'Ivoire
Central African Rep.
South Sudan
Somalia
Maldives
Sri Lanka
Brunei
Malaysia
Palau
Federated States of Micronesia
Venezuela
Suriname
French Guiana (Fr.)
Colombia
Guyana
Kiribati
Equator
Ecuador
Galapagos (Ecuador)
Gabon
Congo
Uganda
Kenya
Dem. Rep. of the Congo
Burundi
Andaman & Nicobar Is. (India)
Sumatra
Indonesia
Papua New Guinea
Nauru
São Tomé and Principe
Ascension (U.K.)
Tanzania
Seychelles
Singapore
Java
Timor-Leste
Solomon Islands
Tuvalu
Wallis and Futuna (Fr.)
Samoa
French Polynesia
Peru
Brazil
Angola
Zambia
Comoros
Mayotte (Fr.)
Cocos Is. (Aus.)
Christmas (Aus.)
Coral Sea
Vanuatu
Fiji
Bolivia
Paraguay
Trindade (Brazil)
St Helena (U.K.)
Namibia
Zimbabwe
Madagascar
Mauritius
Réunion (Fr.)
Botswana
Mozambique
New Caledonia (Fr.)
Tonga
Tropic of Capricorn
Easter (Chile)
Swaziland
INDIAN OCEAN
Australia
South Africa
Lesotho
Chile
Uruguay
Argentina
SOUTH ATLANTIC OCEAN
Great Australian Bight
Tasman Sea
Tasmania
New Zealand
North Island
South Island
SOUTH PACIFIC OCEAN
Falkland Islands (U.K.)
South Georgia (U.K.)
South Sandwich (U.K.)
1. Netherlands
2. Belgium
3. Luxembourg
4. Switzerland
5. Slovenia
6. Croatia
7. Bosnia and Herzegovina
8. Czech Republic
9. Slovakia
10. Austria
11. Hungary
12. Serbia
13. Moldova
14. Macedonia (FYROM)
15. Albania
16. Cyprus
17. Lebanon
18. Guinea-Bissau
19. Guinea
20. Ghana
21. Togo
22. Benin
23. Cameroon
24. Equatorial Guinea
25. Rwanda
26. Cambodia
27. Panama
28. Malawi
29. Liechtenstein
30. Montenegro
31. Kosovo
32. Palestinian Territories
33. St. Vincent & the Grenadines
0 2,000 4,000 Miles
0 2,000 4,000 6,000 8,000 Kilometers
S O U T H E R N O C E A N
Antarctic Circle
Weddell Sea
A N T A R C T I C A
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Gestalt theories can be broken down into two underlying principles:

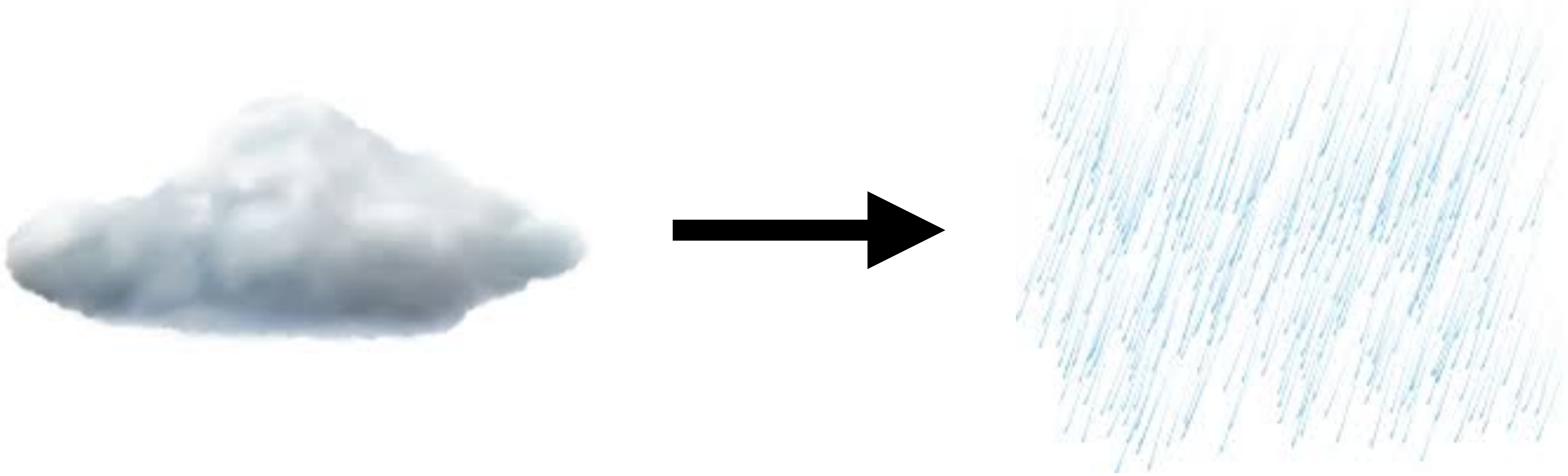
1. **Mosaic, or ‘bundle’ hypothesis**
2. **Association hypothesis**

1. Mosaic, or ‘bundle’ hypothesis —

Every complex consists of elementary contents or pieces

2. Association hypothesis —

If any object or scenario is frequently experienced alongside another, there is a tendency for one to “call up” the other

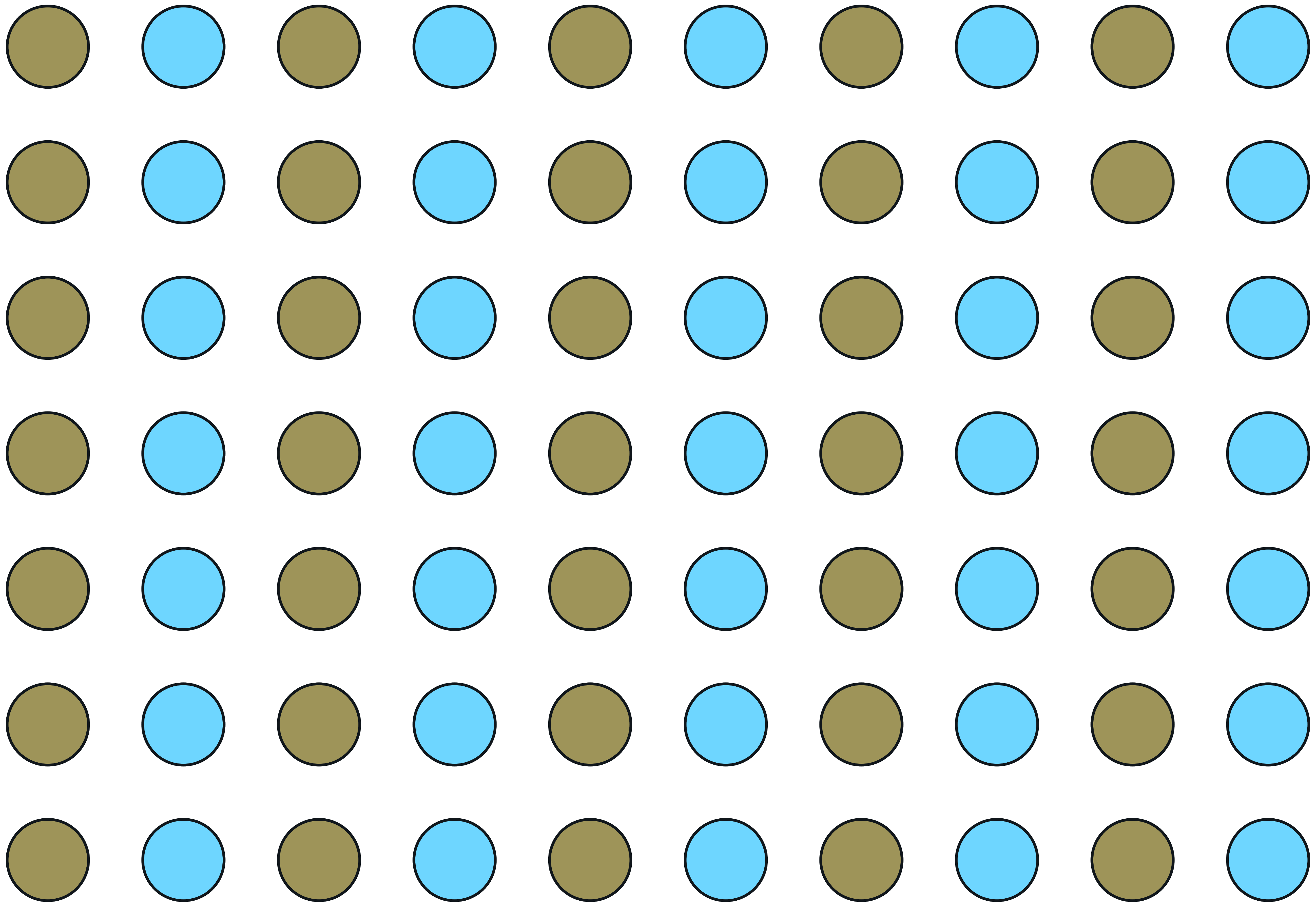


Principles of perception are useful for improving traditional bar and line charts…

…but are **crucial** to understand when building more complex visualizations, like networks or hierarchical diagrams.

3 Gestalt Principles

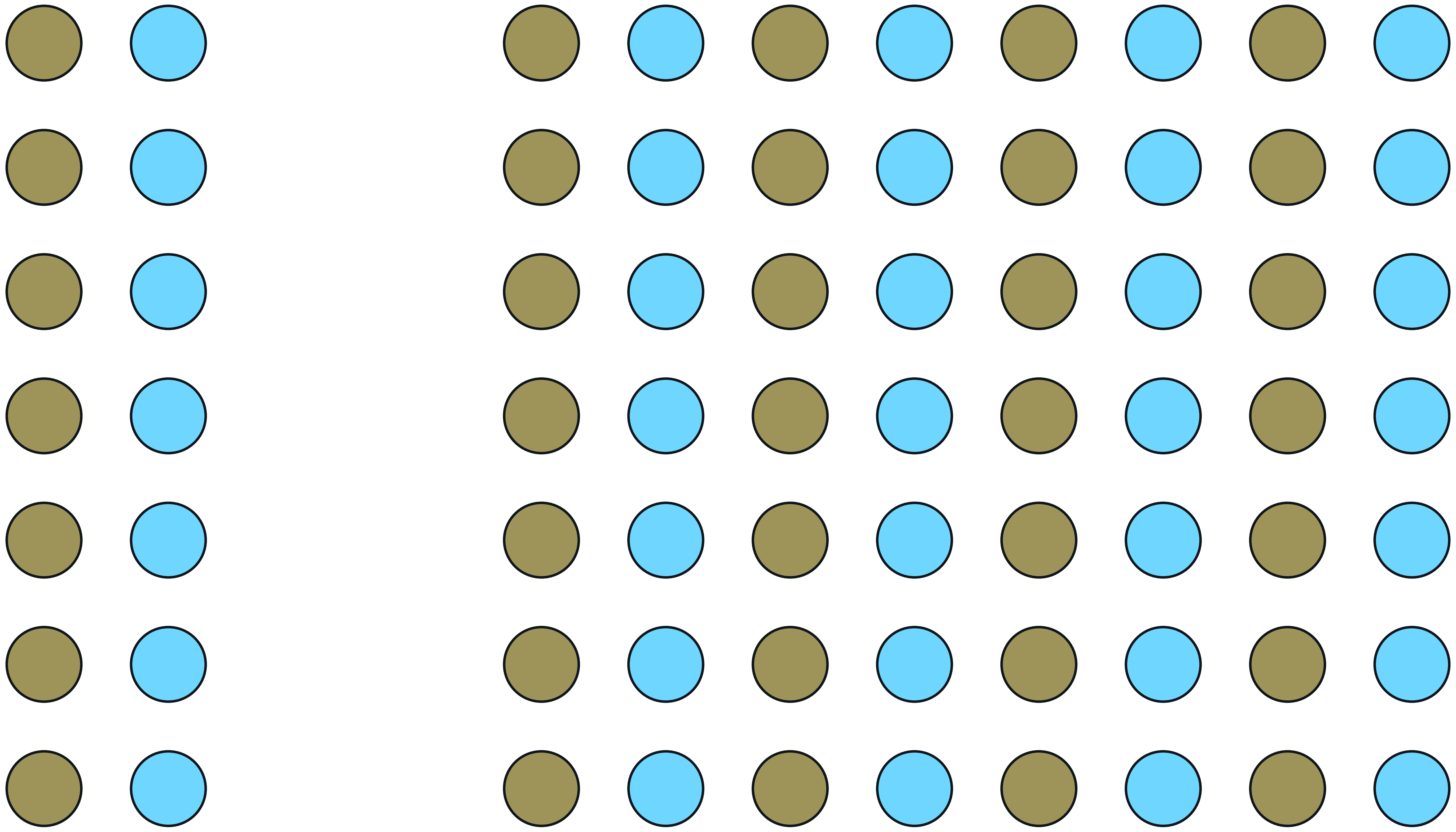
Gestalt Principle 1: **Similarity**



Gestalt Principle 1: **Similarity**

- The most intuitive (+ principle by which **color-coding** works)
- Graphical elements with shared visual properties are perceived as belonging to the same group
- In the previous image, we detect two classes of objects, denoted by **gold** and **blue**

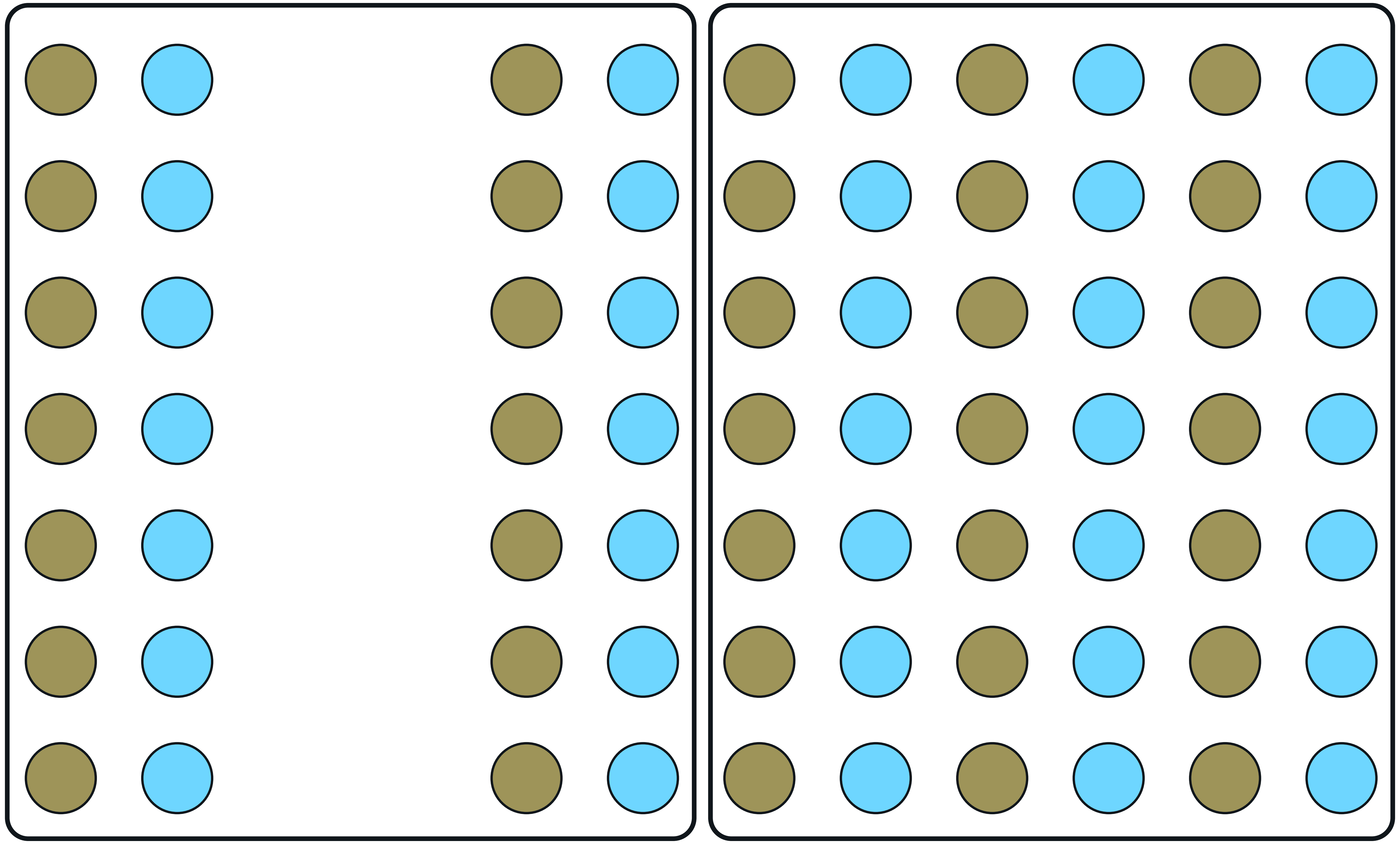
Gestalt Principle 2: **Proximity**



Gestalt Principle 2: **Proximity**

- ***Always*** **present** in data visualization charts
- A graphical element being close to another graphical element is a strong indicator of similarity (ex. pie charts, bar charts)
- In the previous image, we detect **two groups of objects**, because the two columns of circles on the left are closer to each other than to the eight columns of circles on the right

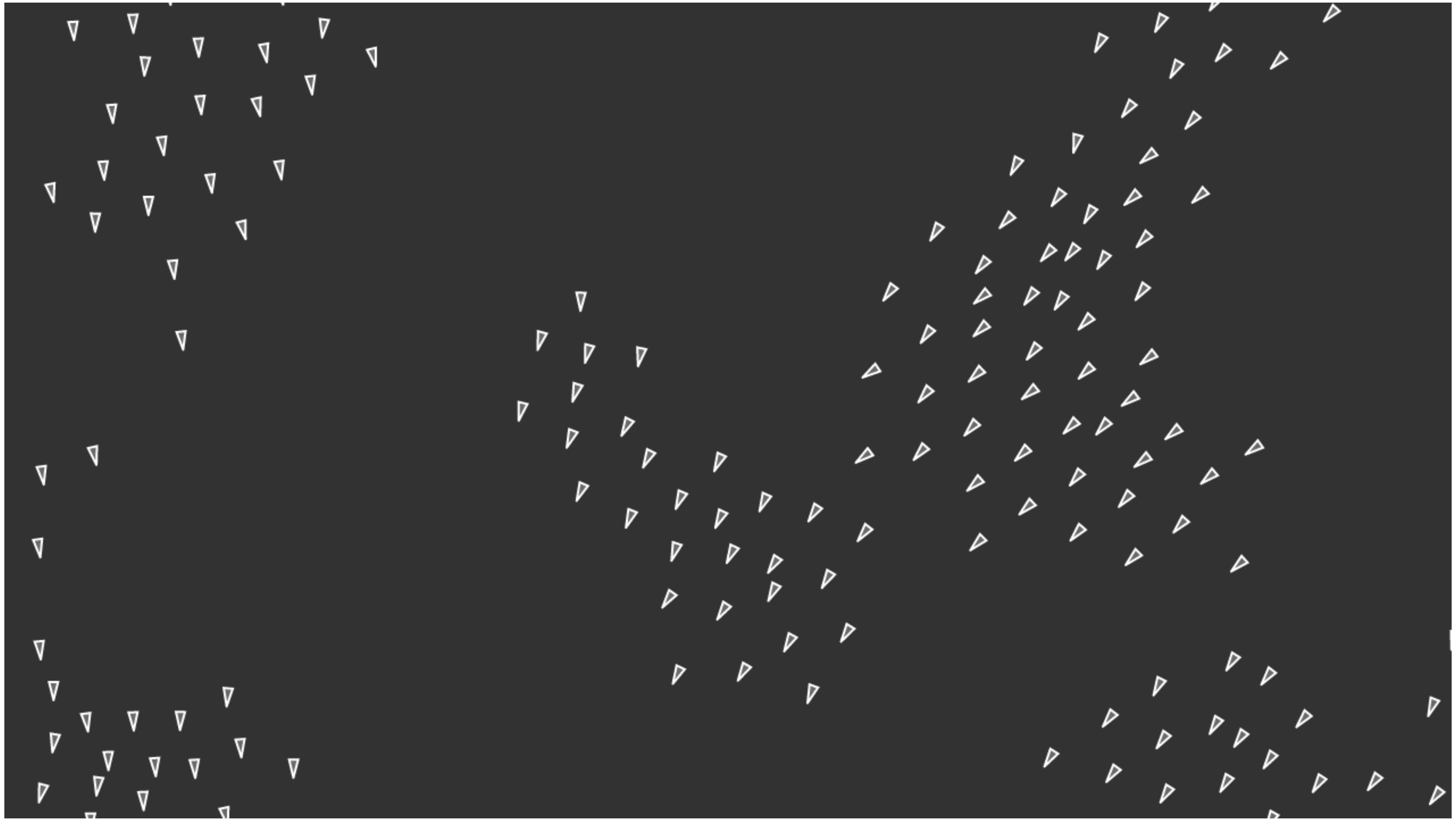
Gestalt Principle 3: **Enclosure**



Gestalt Principle 3: **Enclosure**

- Surrounding a group of elements with a visual element
- Uncommon, but very powerful (correlated with annotations)
- In the previous image, we detect **two groups of objects** that override the two groups of objects we discerned through the principle of proximity

Honorable mention: **Uniform destiny (“common fate”)**



Honorable mention: **Uniform destiny (“common fate”)**

- Elements tend to be perceived as grouped together if they move together. (Link: **flocking**)

Visualization designers can **leverage perceptual tendencies** to better express meaning.

- We make many implicit assumptions when interpreting and constructing graphics
- Effective communication relies on understanding what these principles and tendencies are, and leveraging them for easier readability
- Our job is **not to *persuade*, but to *show*** (persuasion is sinister, showing is honest)
- Strive for ***honesty*** in graphics, by way of transparency

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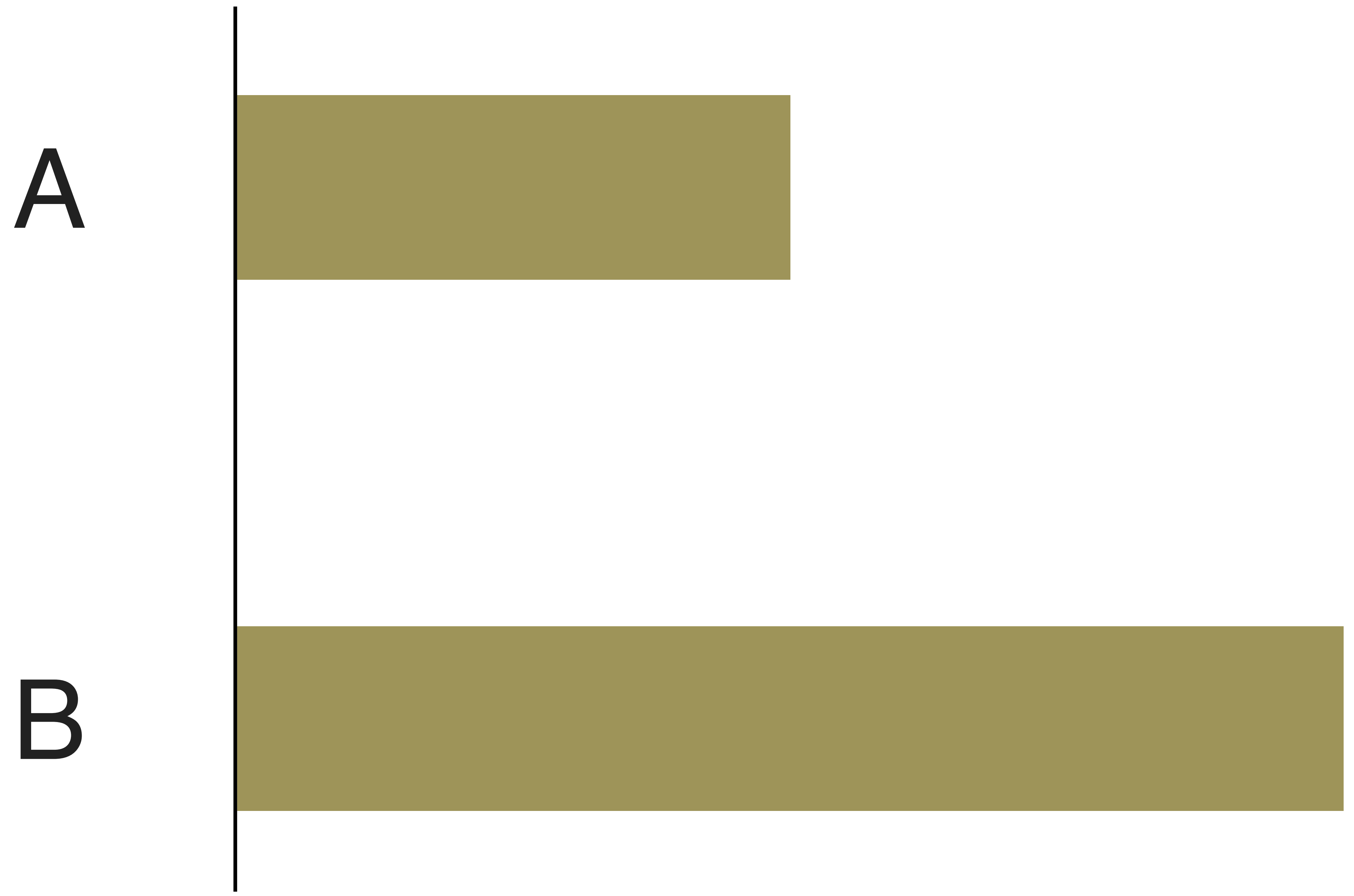
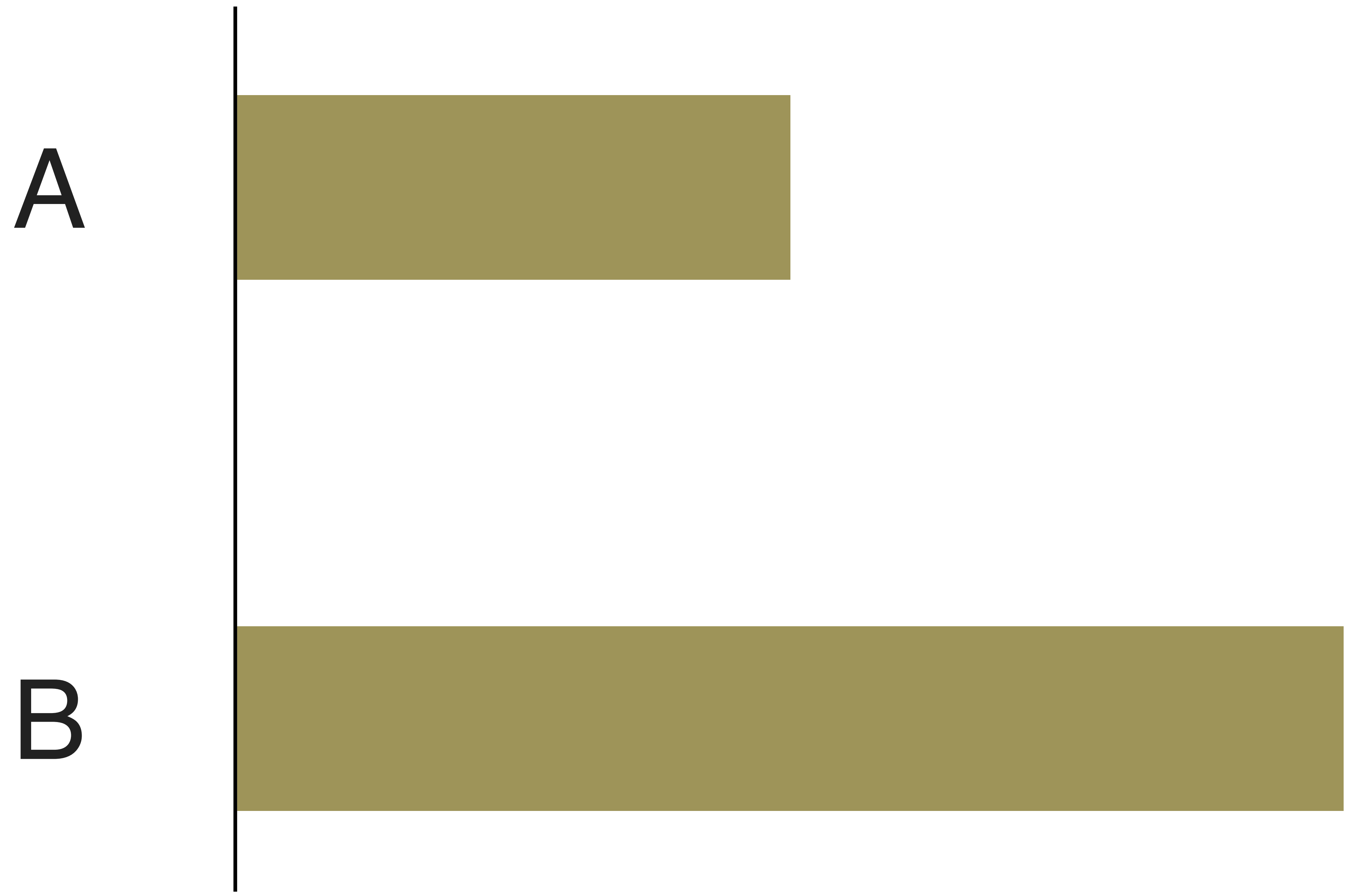
Perception Test

Test: **How much longer?**



Test: **How much longer?**

2X

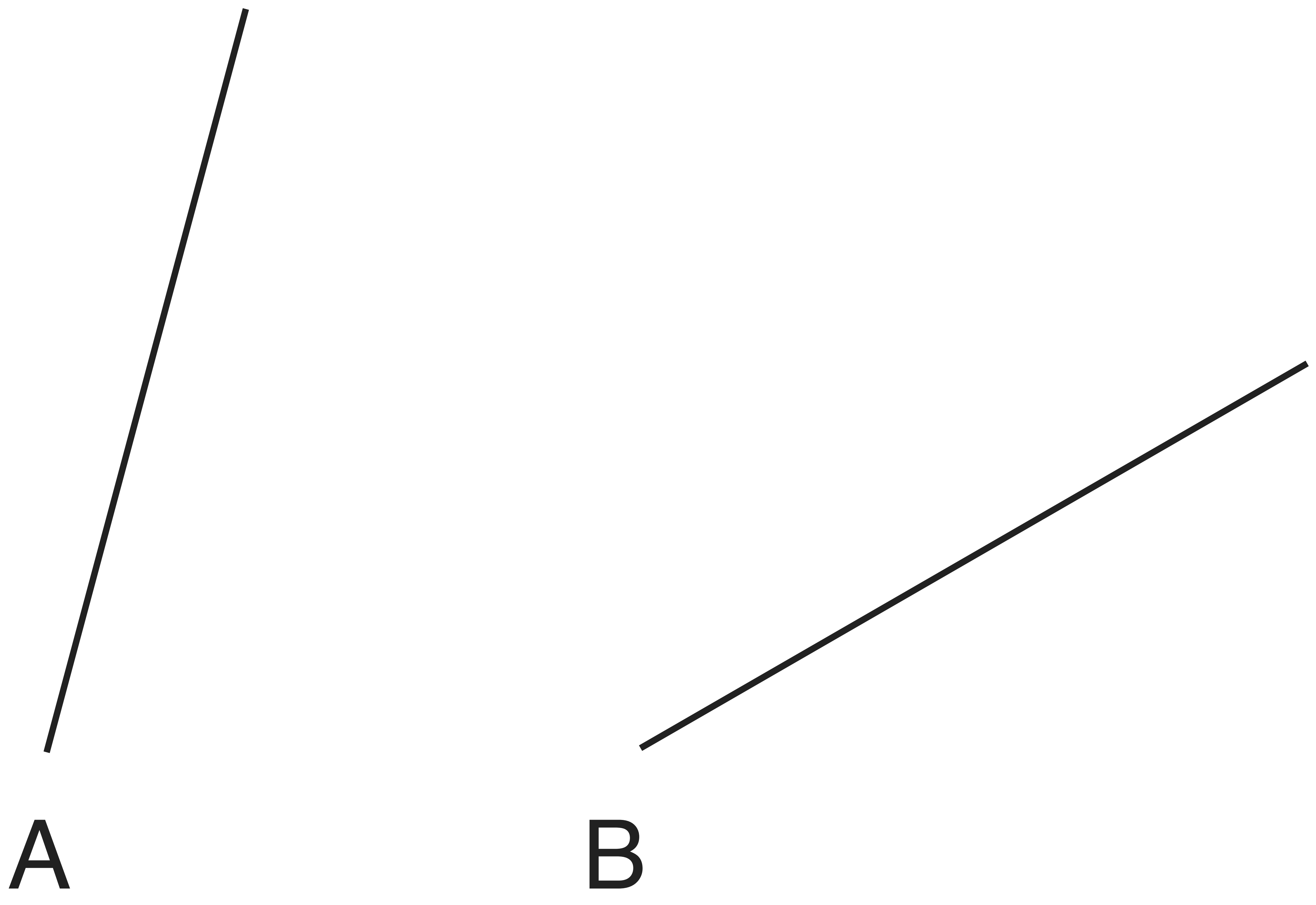


Test: **How much longer?**

Test: **How much longer?**

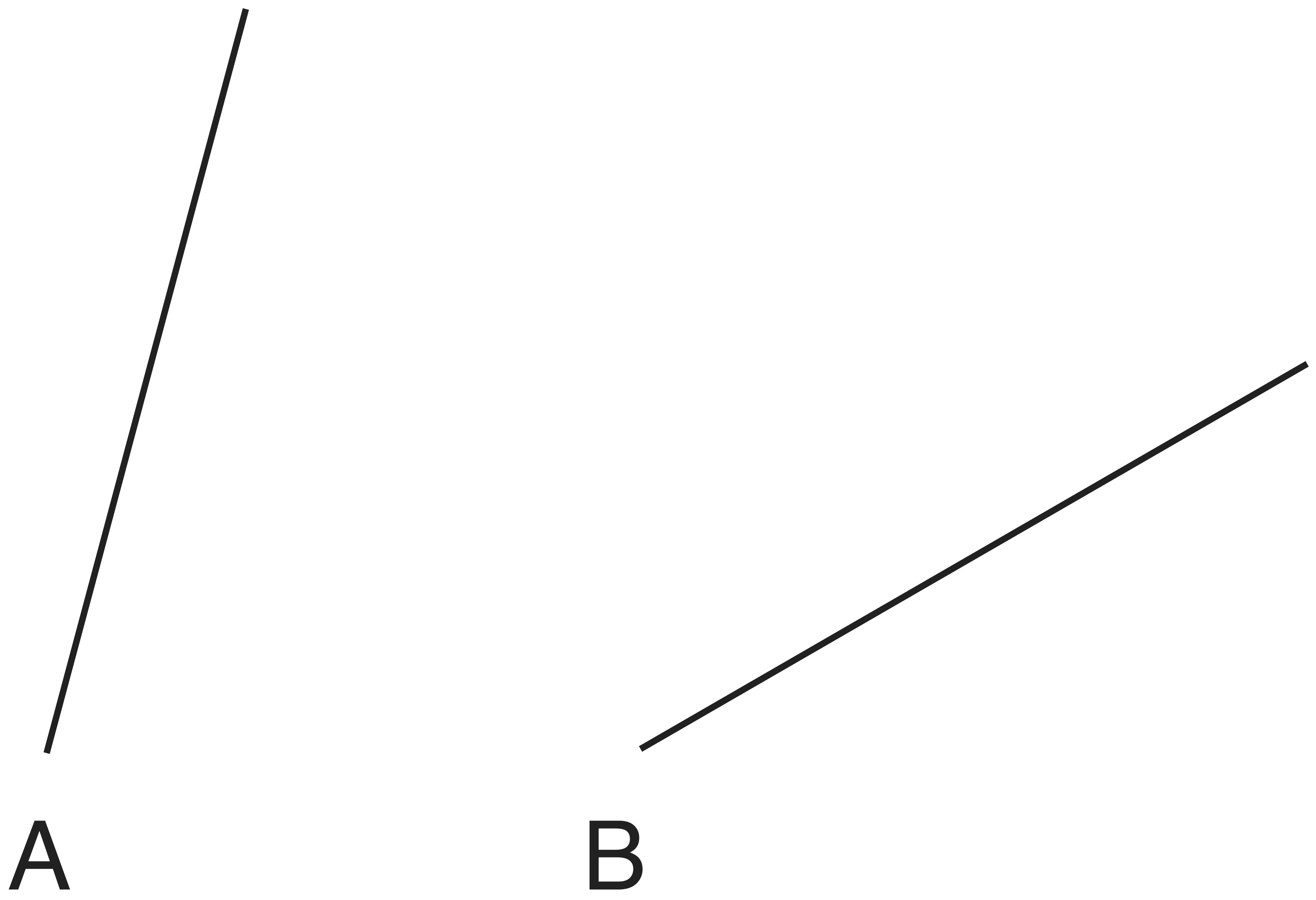
4X

Test: **How much steeper?**

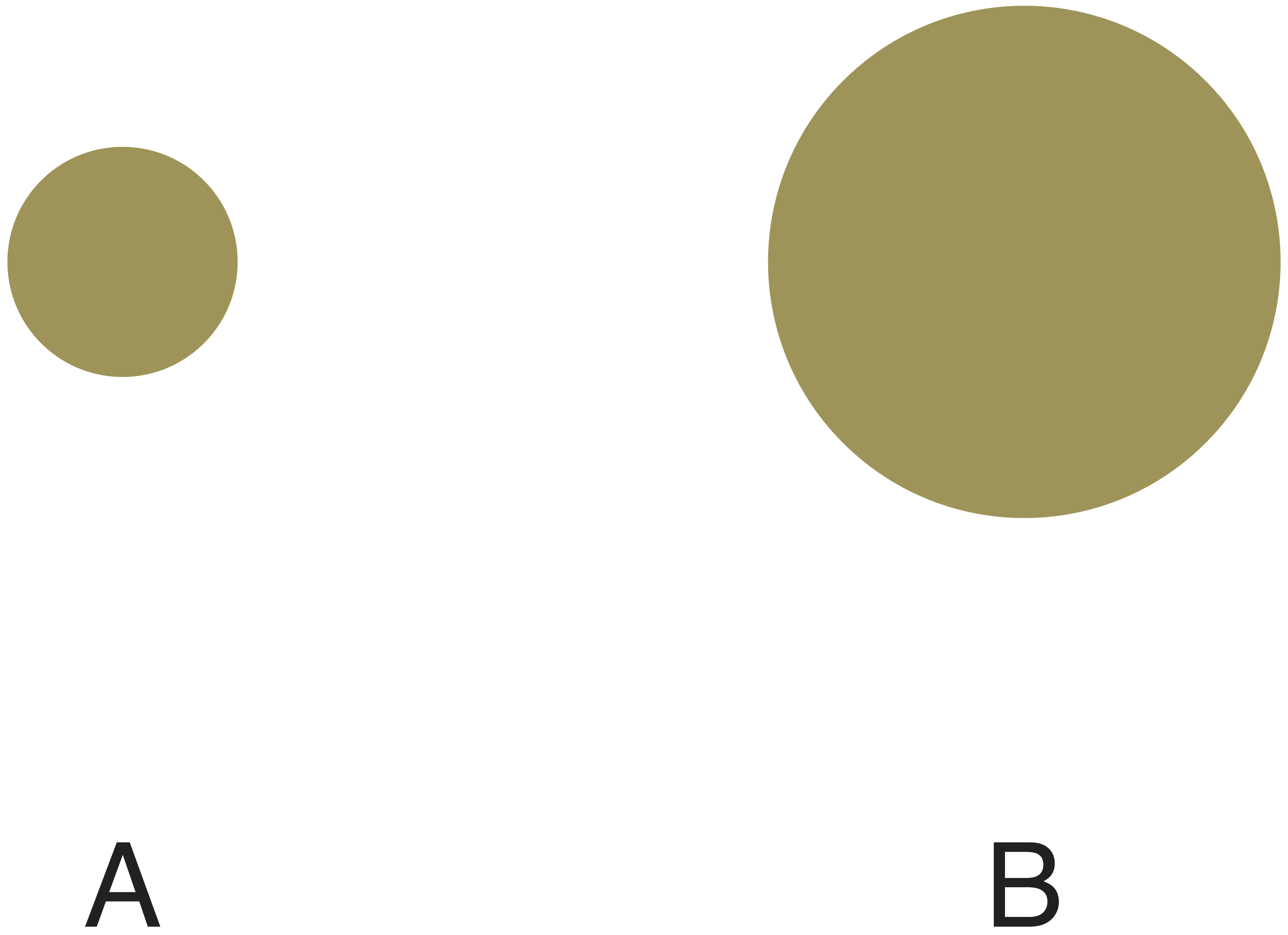


Test: **How much steeper?**

4X



Test: **How much larger (area)?**

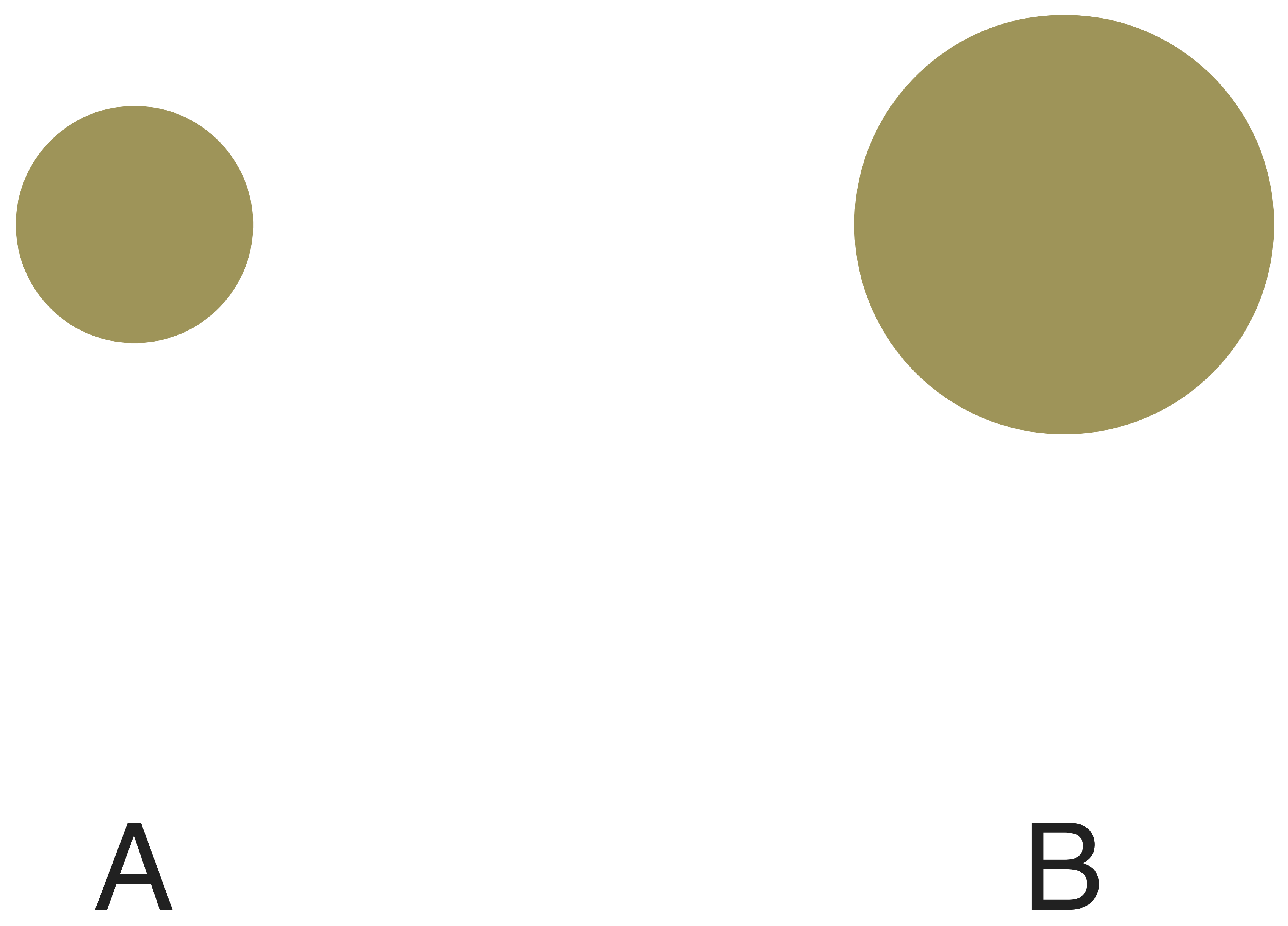


Test: **How much larger (area)?**

5X

A B

Test: **How much larger (area)?**

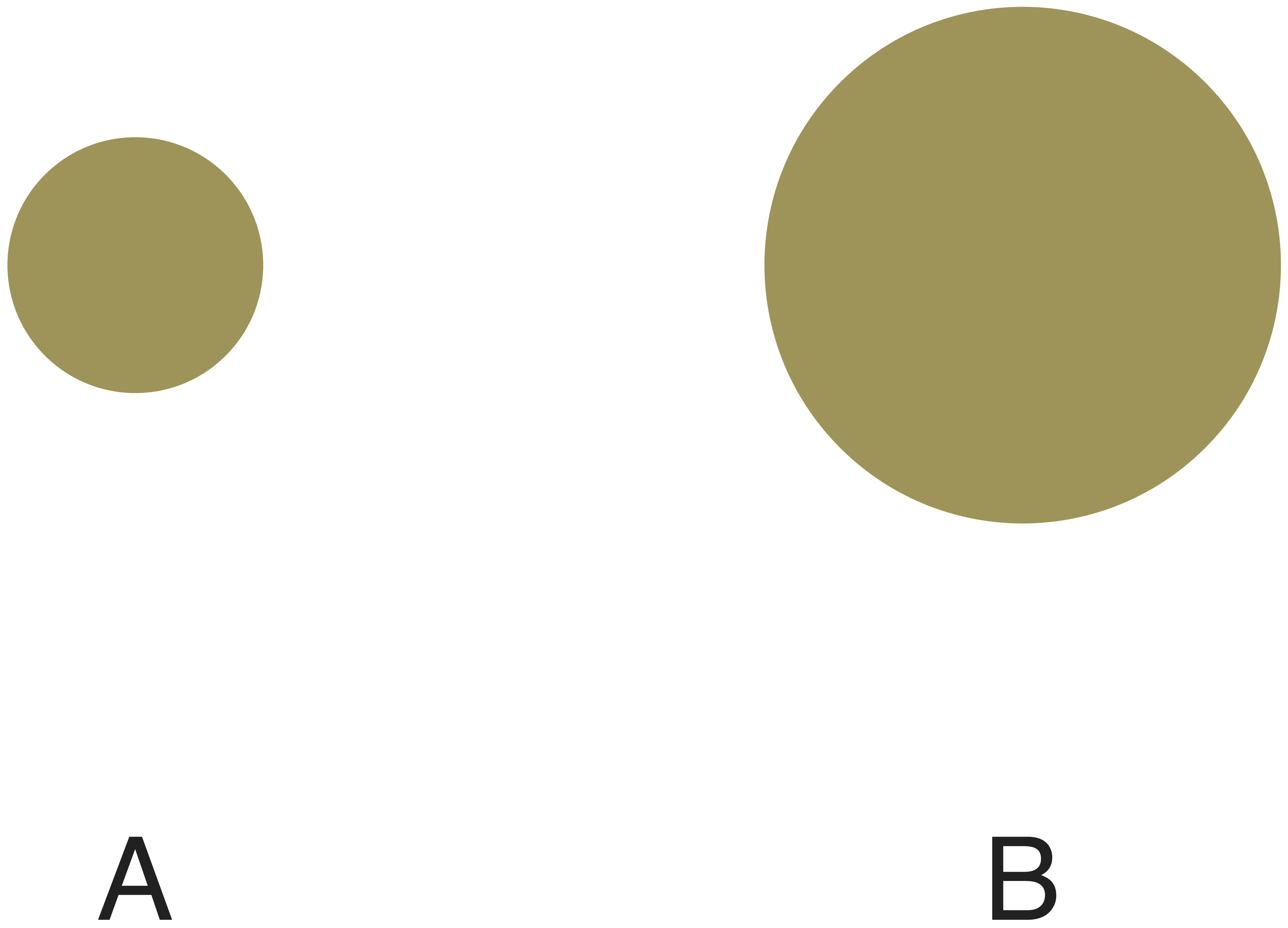


Test: **How much larger (area)?**

3X

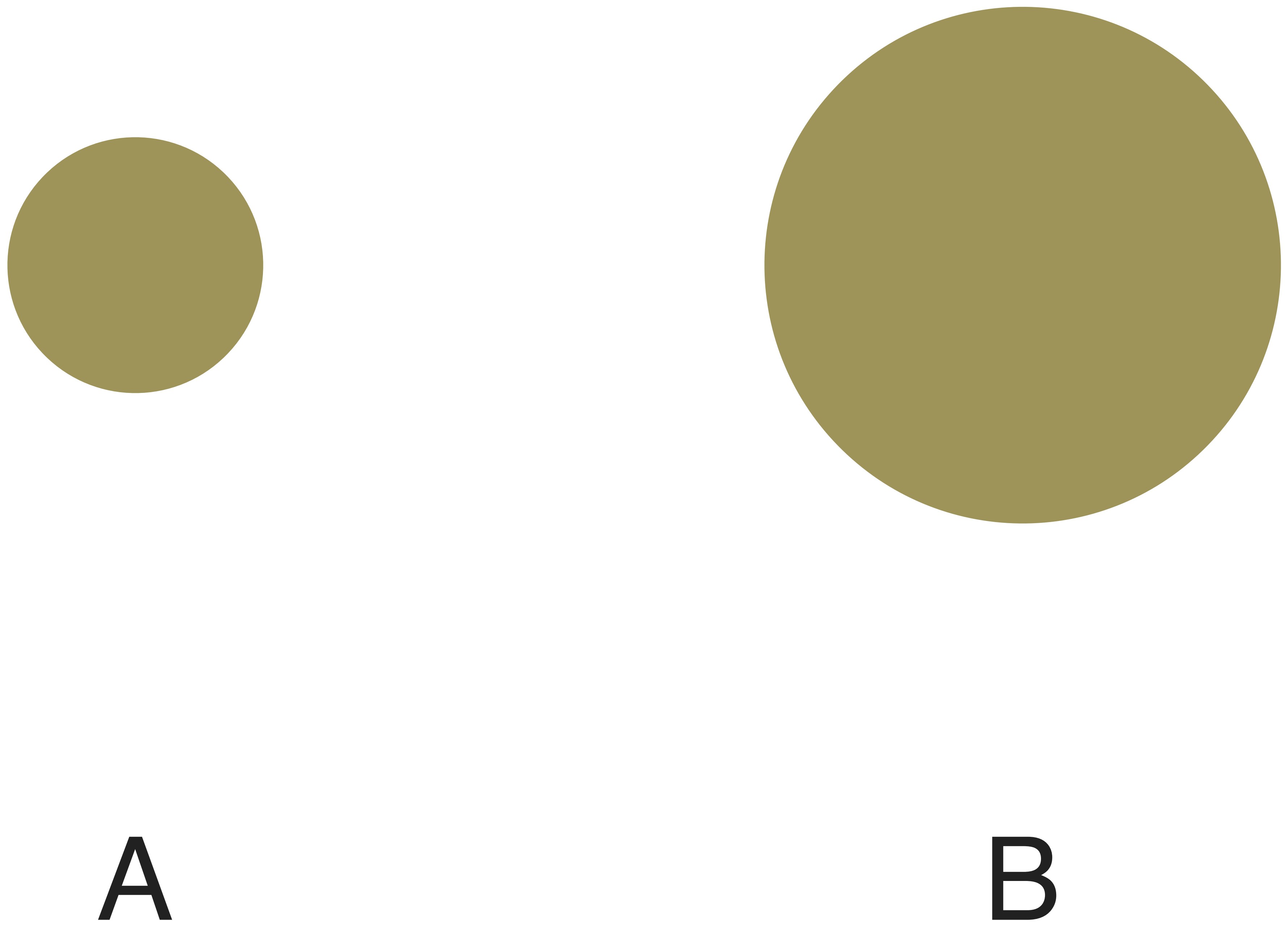
A B

Test: **How much larger (diameter)?**

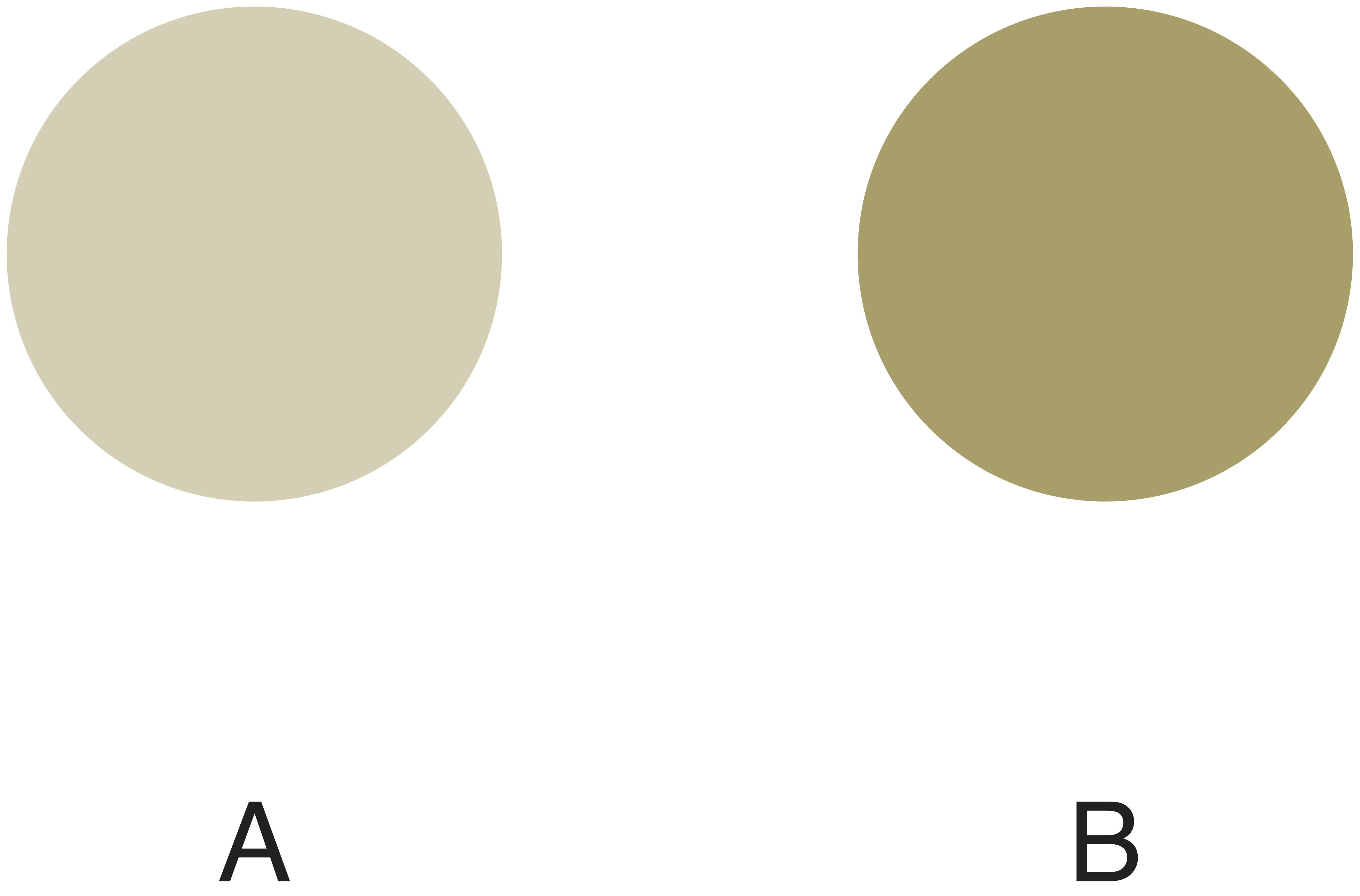


Test: **How much larger (diameter)?**

2X



Test: **How much darker?**



Test: **How much darker?**

2X

A B

Each of these asks you to ***interpret differences*** encoded by visual attributes.

Some attributes (like length) are **easier to read** than others (like saturation).

An active area of **visualization research** addresses the relative strengths and weaknesses of these attributes.

Two visualization theorists:

Jacques Bertin & **Jock Mackinlay**

VP Design, Tableau

1952 – present

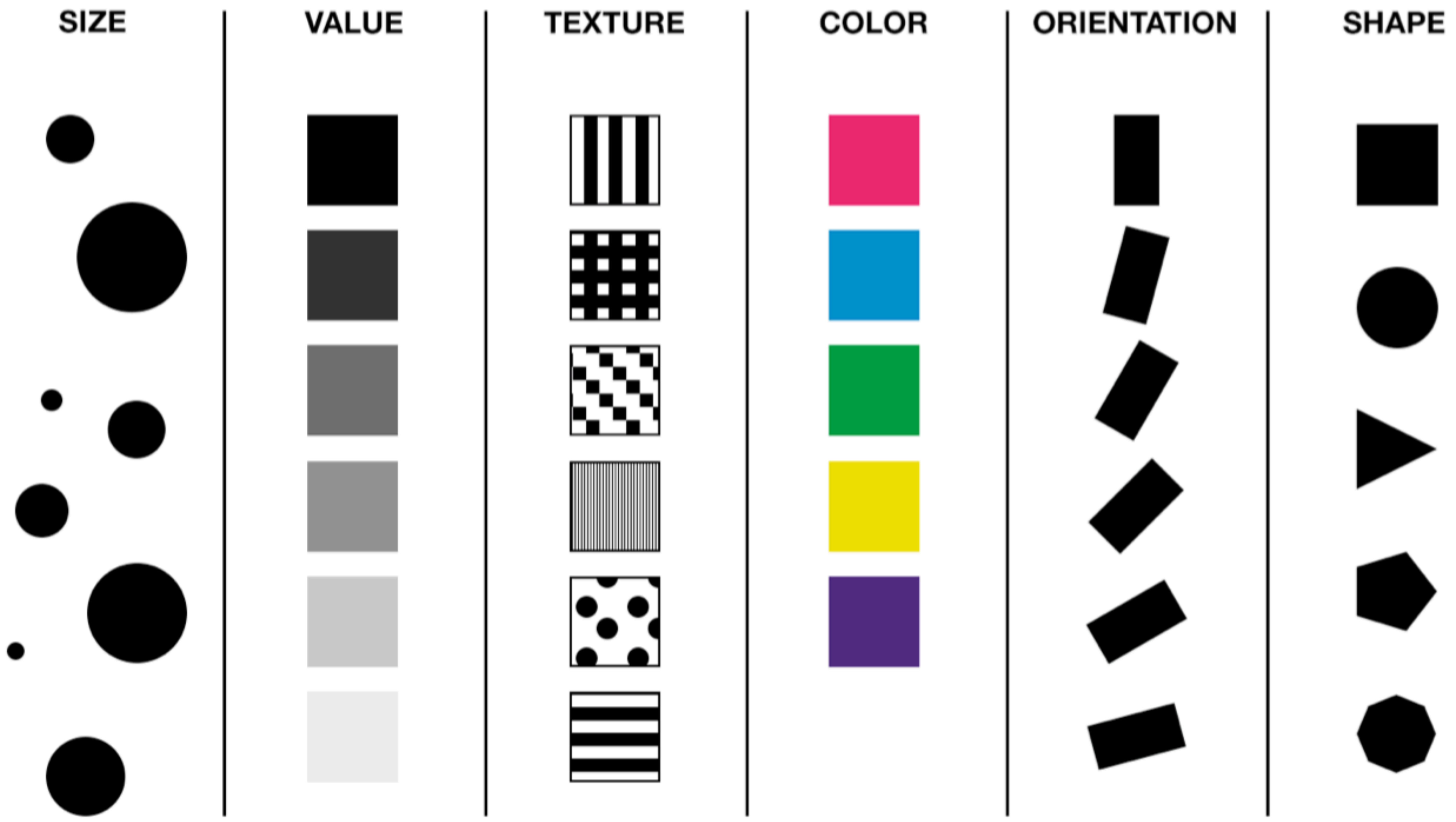
Two visualization theorists:

Jacques Bertin & **Jock Mackinlay**

Cartographer

1918 – 2010

In ***The Semiology of Graphics* (1967)**, Bertin defines six different ways to visually differentiate symbols from one another.

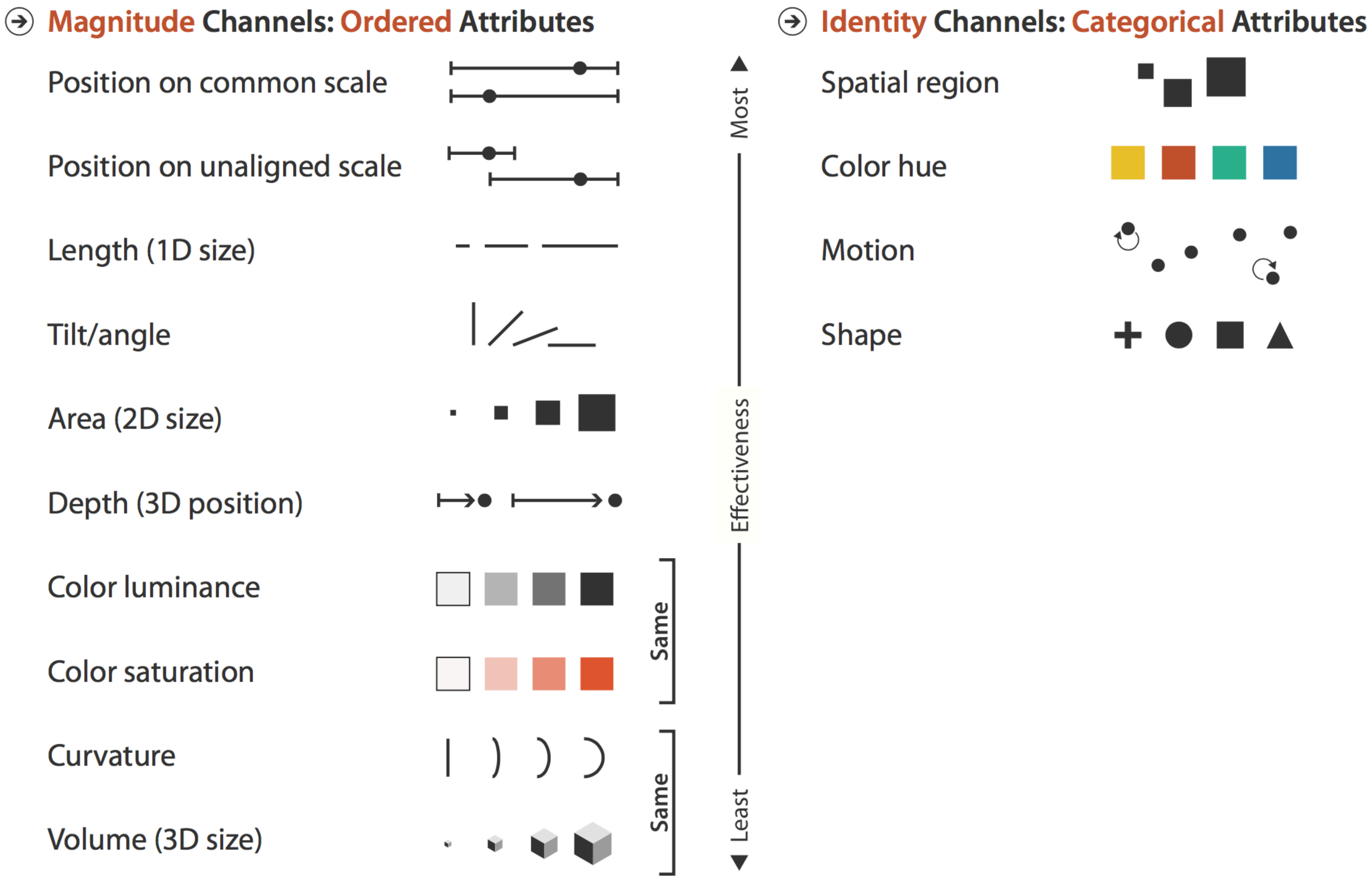

SIZE
VALUE
TEXTURE
COLOR
ORIENTATION
SHAPE

Bertin defines ***marks*** and ***channels*** as the primary components of a visualization.

In his terms, each **channel *(= visual variable)*** modifies a **mark**, based on a given attribute.

Building on Bertin's research, Mackinlay ranks channels in terms of **effectiveness**.

He also delineates the **different data types** that correspond to different channels.



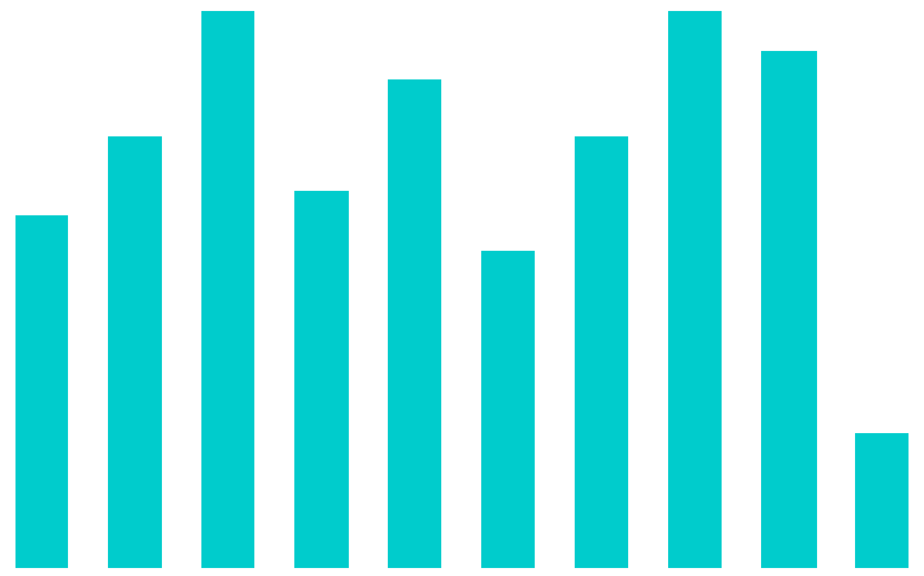
Magnitude Channels: Ordered Attributes
Position on common scale
Position on unaligned scale
Length (1D size)
Tilt/angle
Area (2D size)
Depth (3D position)
Color luminance
Color saturation
Curvature
Volume (3D size)
Same
Same
Most
Effectiveness
Least
Identity Channels: Categorical Attributes
Spatial region
Color hue
Motion
Shape

Effectiveness criterion: **Selectivity**

- Is a mark distinct from other marks?
- Can we make out the difference between two marks?

Effectiveness criterion: **Quantifiability**

- Can we reliably compute the difference between marks?

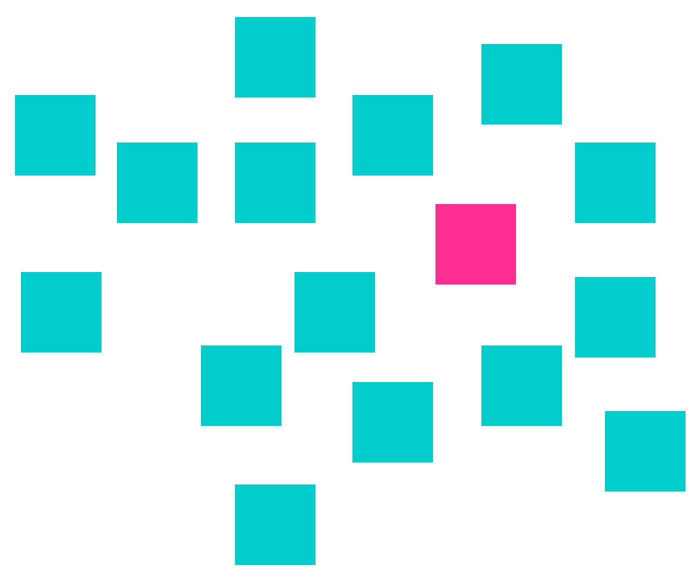


Effectiveness criterion: **Discriminability**

- How many usable steps? (Few for line width)

Effectiveness criterion: **Popout**

- Can a different item be noticed immediately?



Mackinlay's ***effectiveness principle*** —

The most important attributes in a visualization should be encoded with the highest-ranked channels.

Within this framework, **position** emerges as the strongest channel (= *visual variable*), and is suitable for **all data types**.

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6. **Tips** & **Best Practices**

Perception Test

Women’s Olympic Giant Slalom

1952 – 2018

Sample Dataset: **Winter Olympics 1952-2018: Women's Giant Slalom**

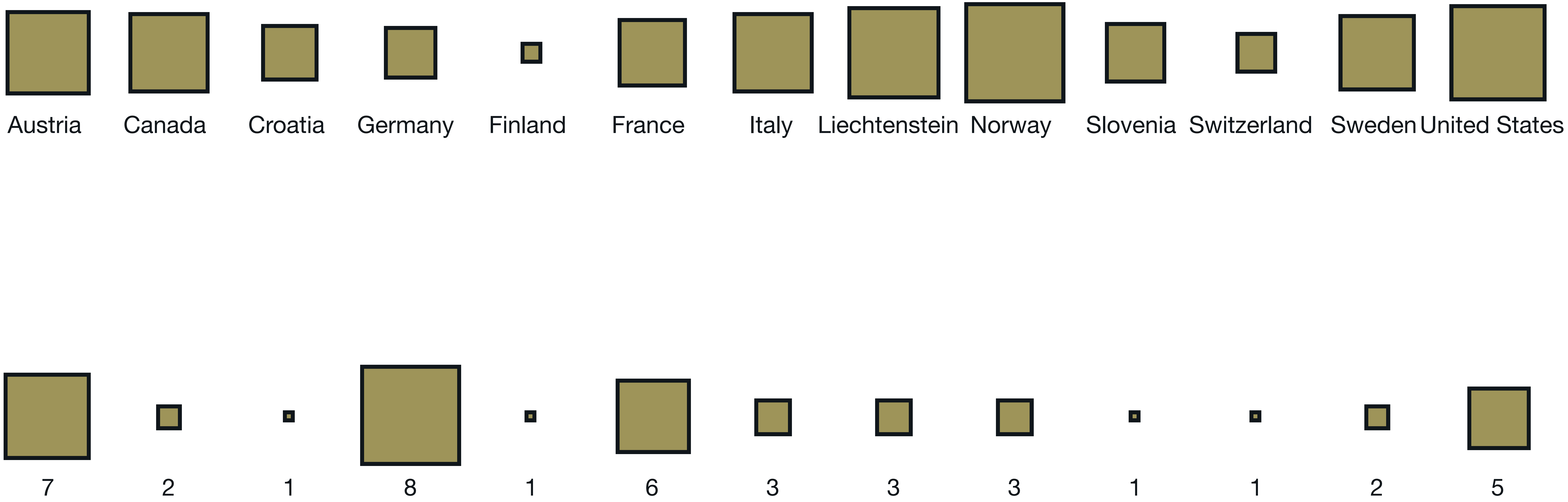
- Lists *all countries* that have won medals in the Women's Giant Slalom, for all games that took place between 1952-2018
    - Country abbreviation
    - Country name
    - Country medal count

country	country_full	country_COUNT
AUT	Austria	7
CAN	Canada	2
CRO	Croatia	1
EUA	Germany	2
FIN	Finland	1
FRA	France	6
FRG	Germany	3
GER	Germany	3
ITA	Italy	3
LIE	Liechtenstein	1
NOR	Norway	1
SLO	Slovenia	2
SUI	Switzerland	5
SWE	Sweden	3
USA	United States	8

(Undifferentiated marks)

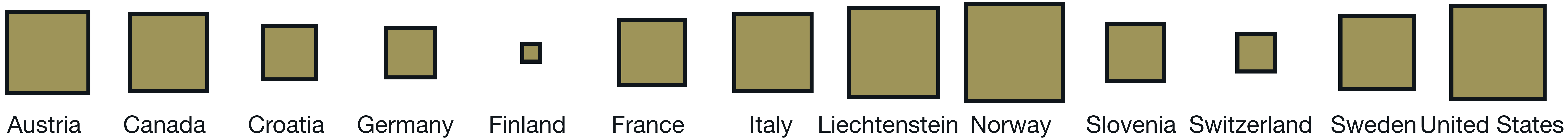
Which is more effective?

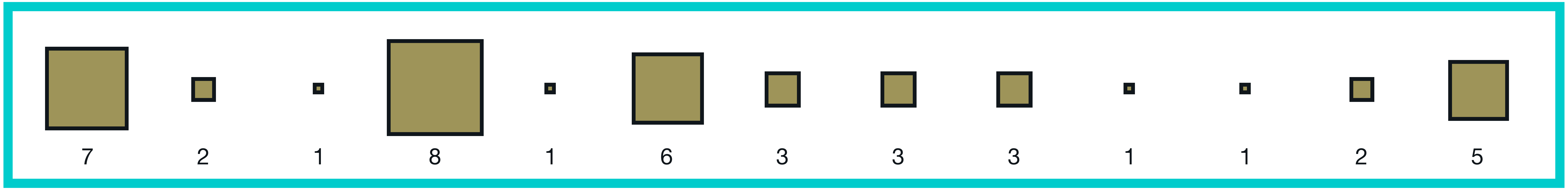
Channel: ***Area (2D Size)***



Which is more effective?

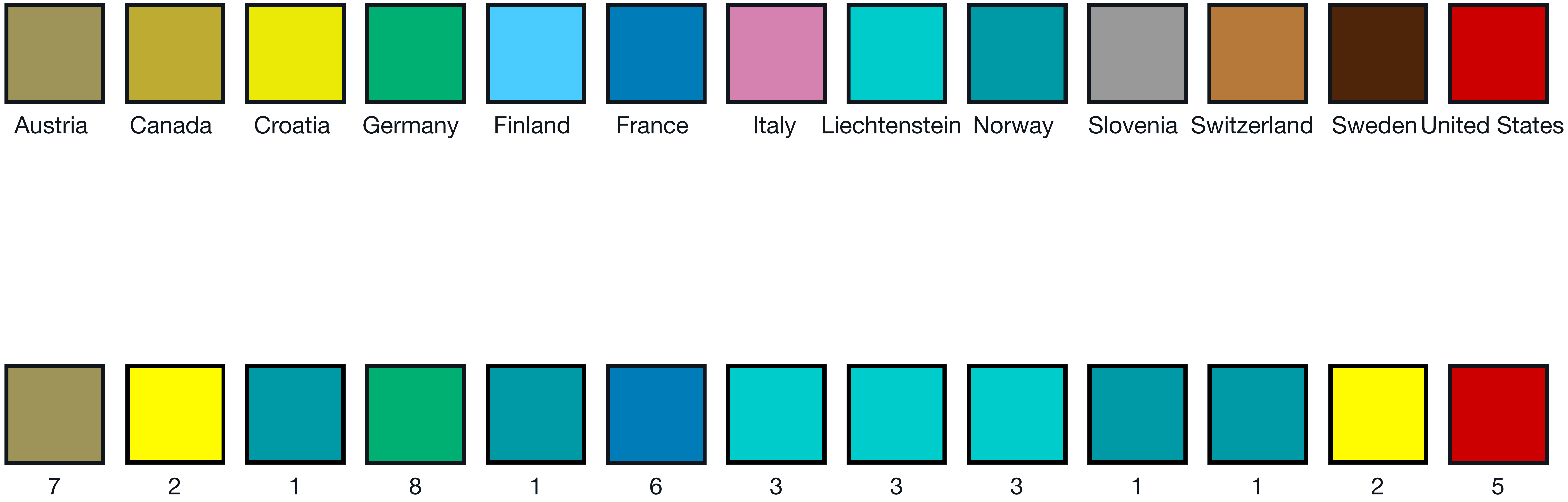
Channel: ***Area (2D Size)***





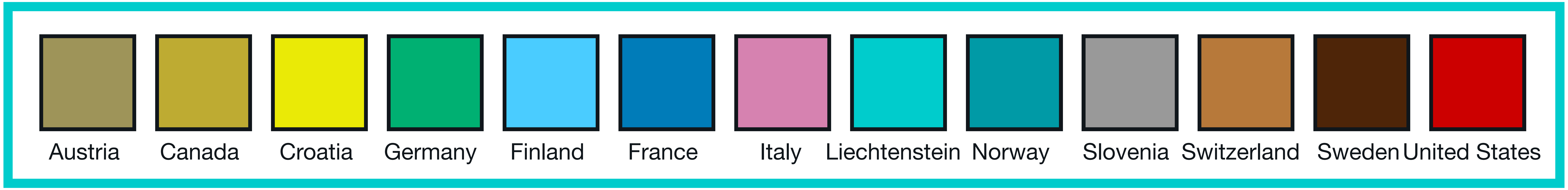
Which is more effective?

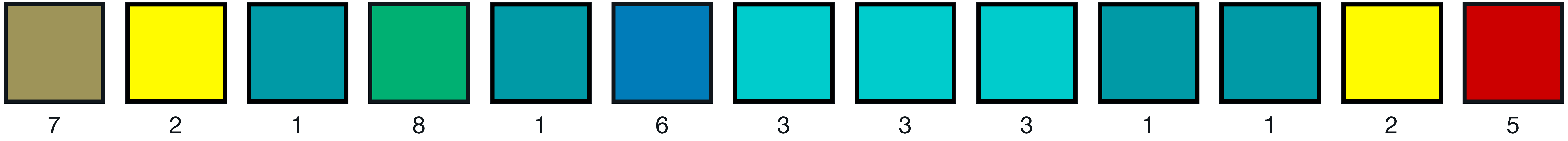
Channel: ***Color***



Which is more effective?

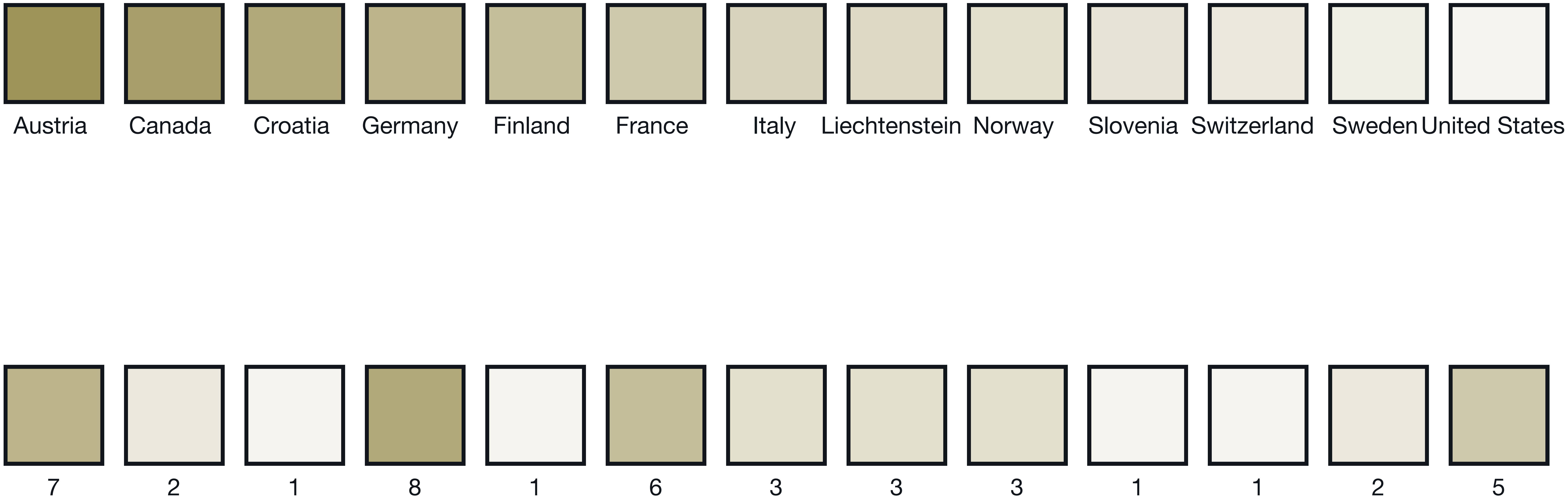
Channel: ***Color***





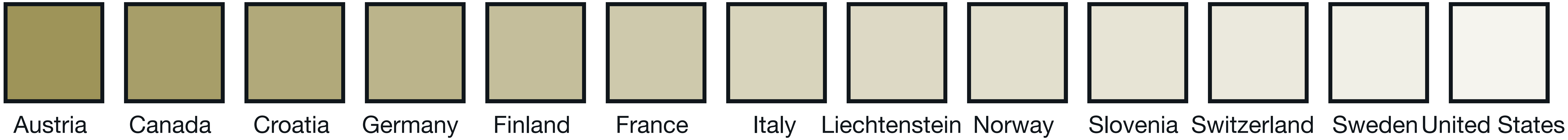
Which is more effective?

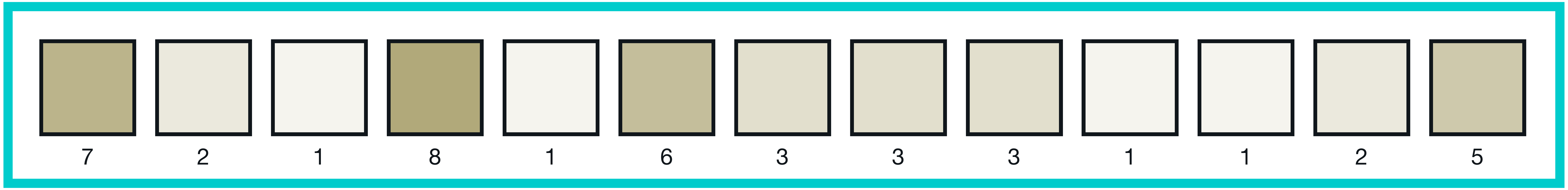
Channel: ***Value (Luminance, Saturation)***



Which is more effective?

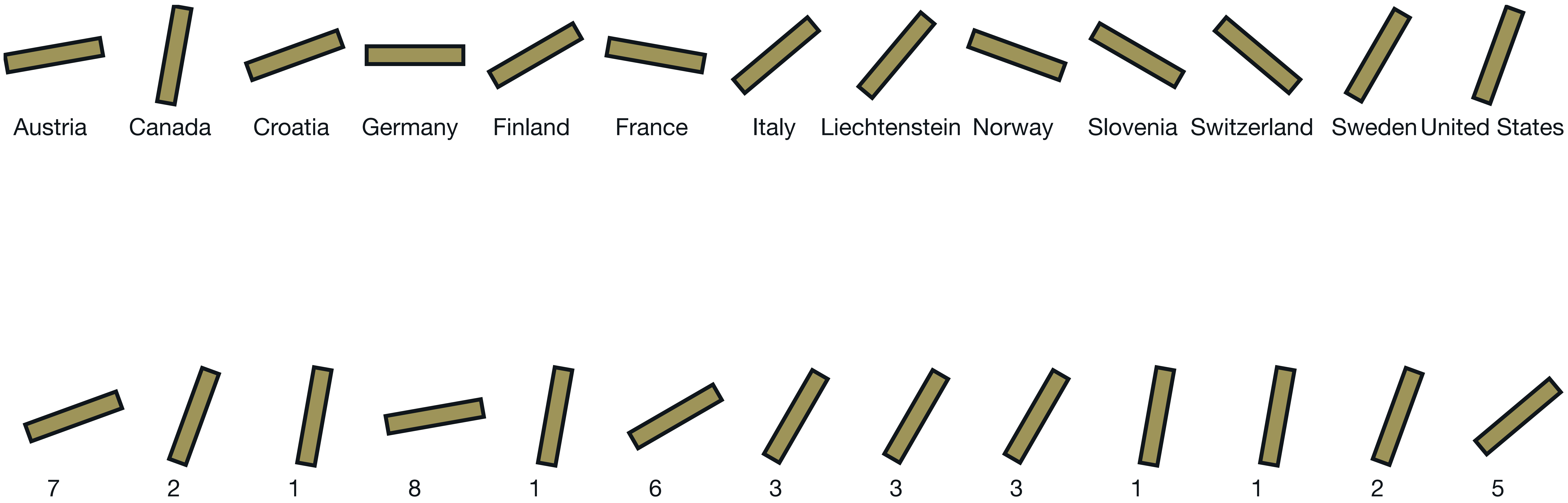
Channel: ***Value (Luminance, Saturation)***





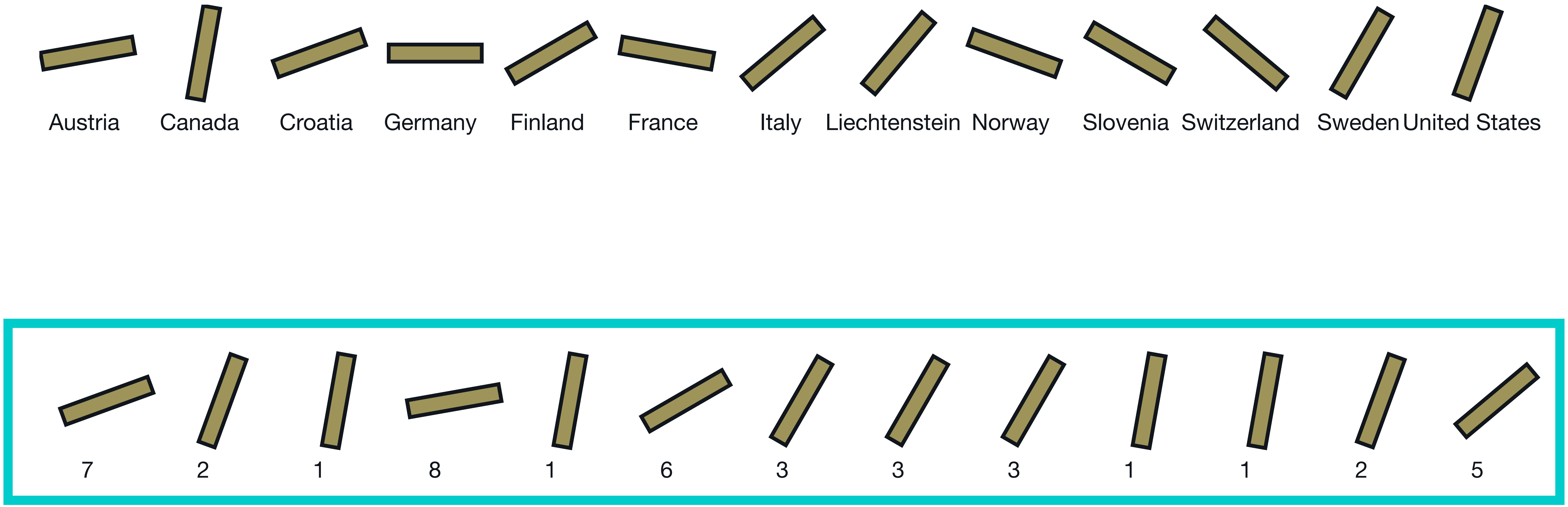
Which is more effective?

Channel: ***Orientation***



Which is more effective?

Channel: ***Orientation***




2.1.0
PROJECT
Ukko
Nicaragua
Costa Rica
Panama
Colombia
Ecuador

Case study:

Women’s Olympic Giant Slalom

1952 – 2018

Sample Dataset: **Winter Olympics 1952-2018: Women's Giant Slalom**

- Lists *all women* who placed in the Winter Olympics Women's Giant Slalom, for all games that took place between 1952-2018
    - Name
    - Games
    - Rank
    - Country
    - Times
        - (incl.) Difference from Mikaela Shiffrin, 2018 gold medalist (USA)
        - (incl.) Difference from Kathy Kreiner, 1976 gold medalist (CAN)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	year	games	rank	country	name_first	name_last	time	time_minute	time_seconc	difference	total_time	difference_fr		
2	2018	Peongchang	1	USA	Mikaela	SHIFFRIN	2:20.02	2	20.02	0.00	140.02	50.89		
3	2018	Peongchang	2	NOR	Ragnhild	MOWINCKEL	2:20.41	2	20.41	0.39	140.41	51.28		
4	2018	Peongchang	3	ITA	Federica	BRIGNONE	2:20.48	2	20.48	0.46	140.48	51.35		
5	2014	Sochi	1	SLO	Tina	MAZE	2:36.87	2	36.87	0.00	156.87	67.74		
6	2014	Sochi	2	AUT	Anna	FENNINGER	2:36.94	2	36.94	0.07	156.94	67.81		
7	2014	Sochi	3	GER	Viktoria	REBENSBURG	2:37.14	2	37.14	0.27	157.14	68.01		
8	2010	Vancouver	1	GER	Viktoria	REBENSBURG	2:27.11	2	27.11	0.00	147.11	57.98		
9	2010	Vancouver	2	SLO	Tina	MAZE	2:27.15	2	27.15	0.04	147.15	58.02		
10	2010	Vancouver	3	AUT	Elisabeth	GEORGL	2:27.25	2	27.25	0.14	147.25	58.12		
11	2006	Turin	1	USA	Julia	MANCUSO	2:09.19	2	9.19	0.00	129.19	40.06		
12	2006	Turin	2	FIN	Tanja	POUTIAINEN	2:09.86	2	9.86	0.67	129.86	40.73		
13	2006	Turin	3	SWE	Anna	OTTOSSON	2:10.33	2	10.33	1.14	130.33	41.20		
14	2002	Salt Lake City	1	CRO	Janica	KOSTELIC	2:30.01	2	30.01	0.00	150.01	60.88		
15	2002	Salt Lake City	2	SWE	Anja	PAERSON	2:31.33	2	31.33	1.32	151.33	62.20		
16	2002	Salt Lake City	3	SUI	Sonja	NEF	2:31.67	2	31.67	1.66	151.67	62.54		
17	1998	Nagano	1	ITA	Deborah	COMPAGNONI	2:50.59	2	50.59	0.00	170.59	81.46		
18	1998	Nagano	2	AUT	Alexandra	MEISSNITZER	2:52.39	2	52.39	1.80	172.39	83.26		
19	1998	Nagano	3	GER	Katja	SEIZINGER	2:52.61	2	52.61	2.02	172.61	83.48		
20	1992	Albertville	1	SWE	Pernilla	WIBERG	2:12.74	2	12.74	0.00	132.74	43.61		
21	1992	Albertville	2	AUT	Anita	WACHTER	2:13.71	2	13.71	0.97	133.71	44.58		
22	1992	Albertville	2	USA	Diane	ROFFE	2:13.71	2	13.71	0.97	133.71	44.58		
23	1988	Calgary	1	SUI	Vreni	SCHNEIDER	2:06.49	2	6.49	0.00	126.49	37.36		
24	1988	Calgary	2	FRG	Krista	KINSHOFER-GÜ	2:07.42	2	7.42	0.93	127.42	38.29		
25	1988	Calgary	3	SUI	Maria	WALLISER	2:07.72	2	7.72	1.23	127.72	38.59		
26	1984	Sarajevo	1	USA	Debbie	ARMSTRONG	2:20.98	2	20.98	0.00	140.98	51.85		
27	1984	Sarajevo	2	USA	Christin	COOPER	2:21.38	2	21.38	0.40	141.38	52.25		
28	1984	Sarajevo	3	FRA	Perrine	PELEN	2:21.40	2	21.40	0.42	141.40	52.27		

Charts and graphs should provide an **immediate answer** to an anticipated question.

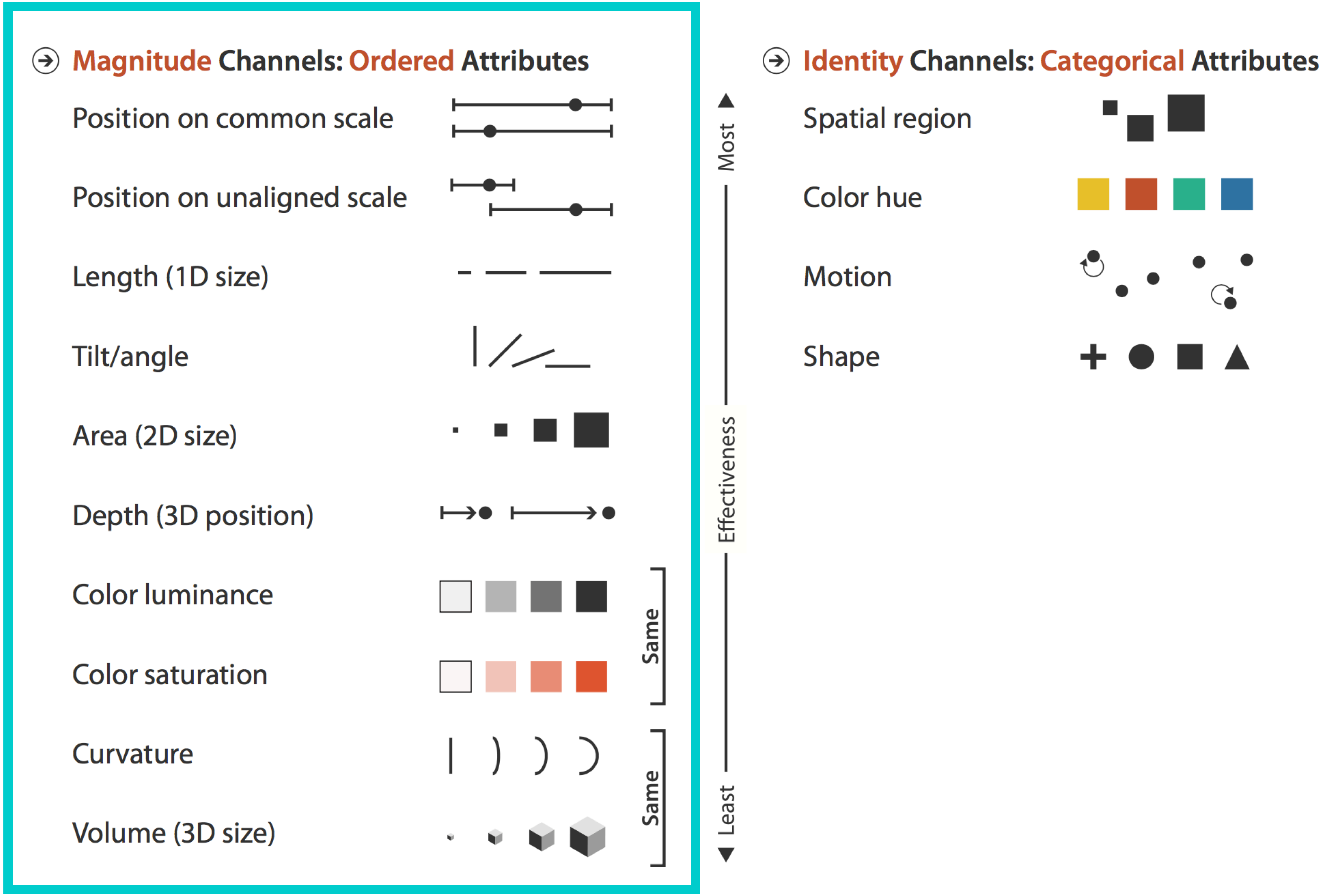
Question:

How fast is Kathy Kreiner compared to other medalists over the years?

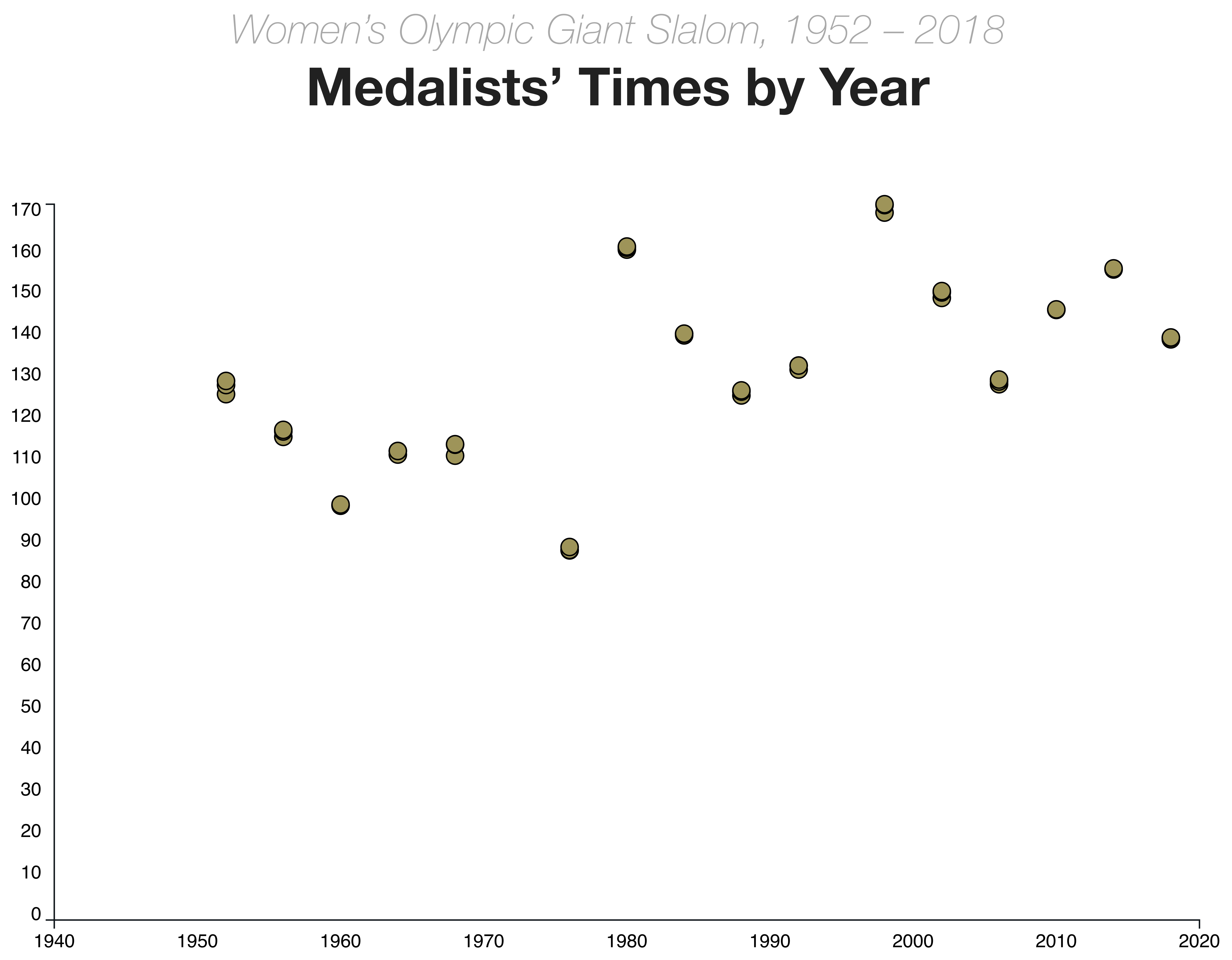
Quantity
(Time)

Question:

How fast is Kathy Kreiner compared to other medalists over the years?



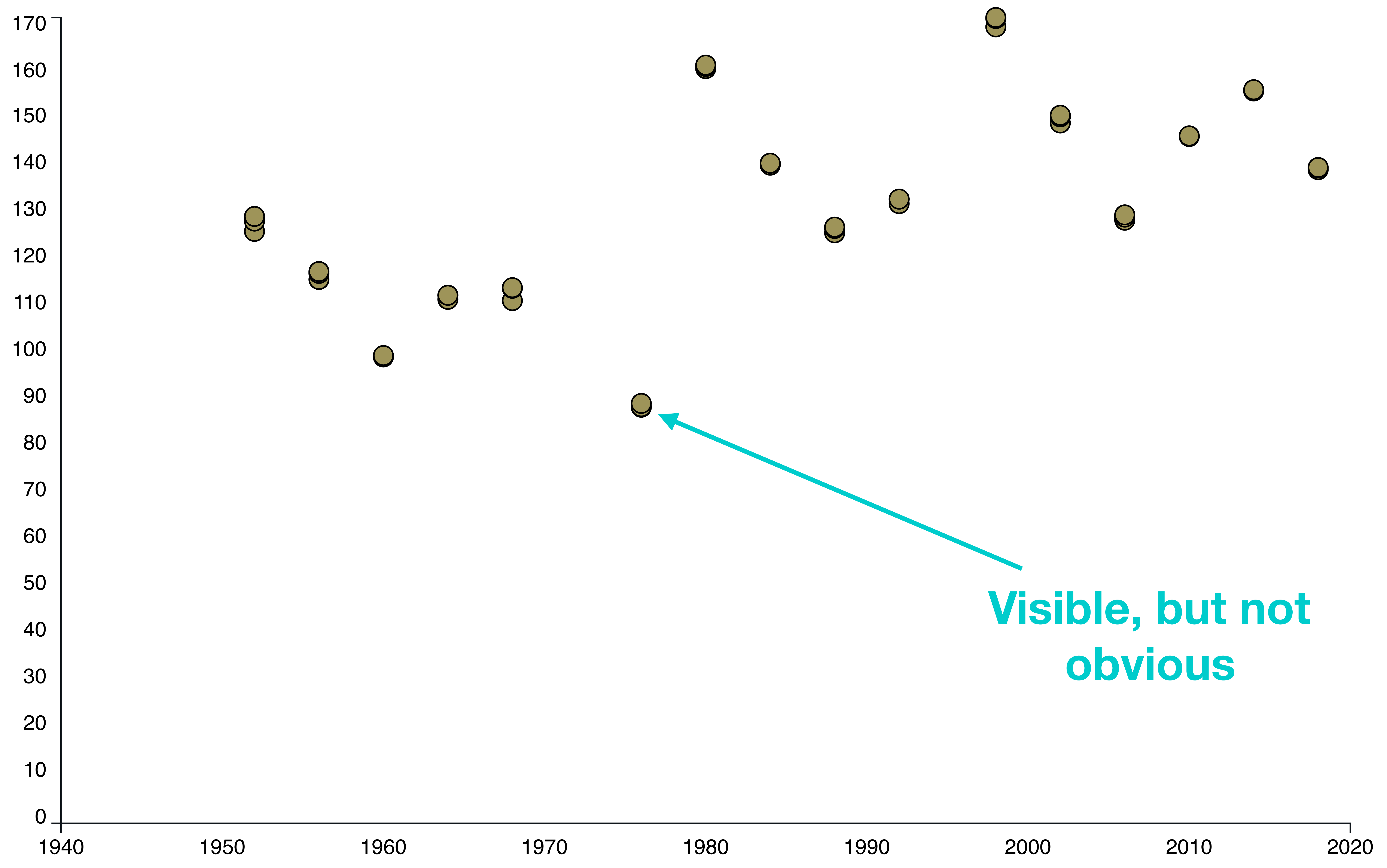
Magnitude Channels: Ordered Attributes
Position on common scale
Position on unaligned scale
Length (1D size)
Tilt/angle
Area (2D size)
Depth (3D position)
Color luminance
Color saturation
Curvature
Volume (3D size)
Same
Same
Most
Effectiveness
Least
Identity Channels: Categorical Attributes
Spatial region
Color hue
Motion
Shape



Women's Olympic Giant Slalom, 1952 – 2018
Medalists' Times by Year
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
1940
1950
1960
1970
1980
1990
2000
2010
2020

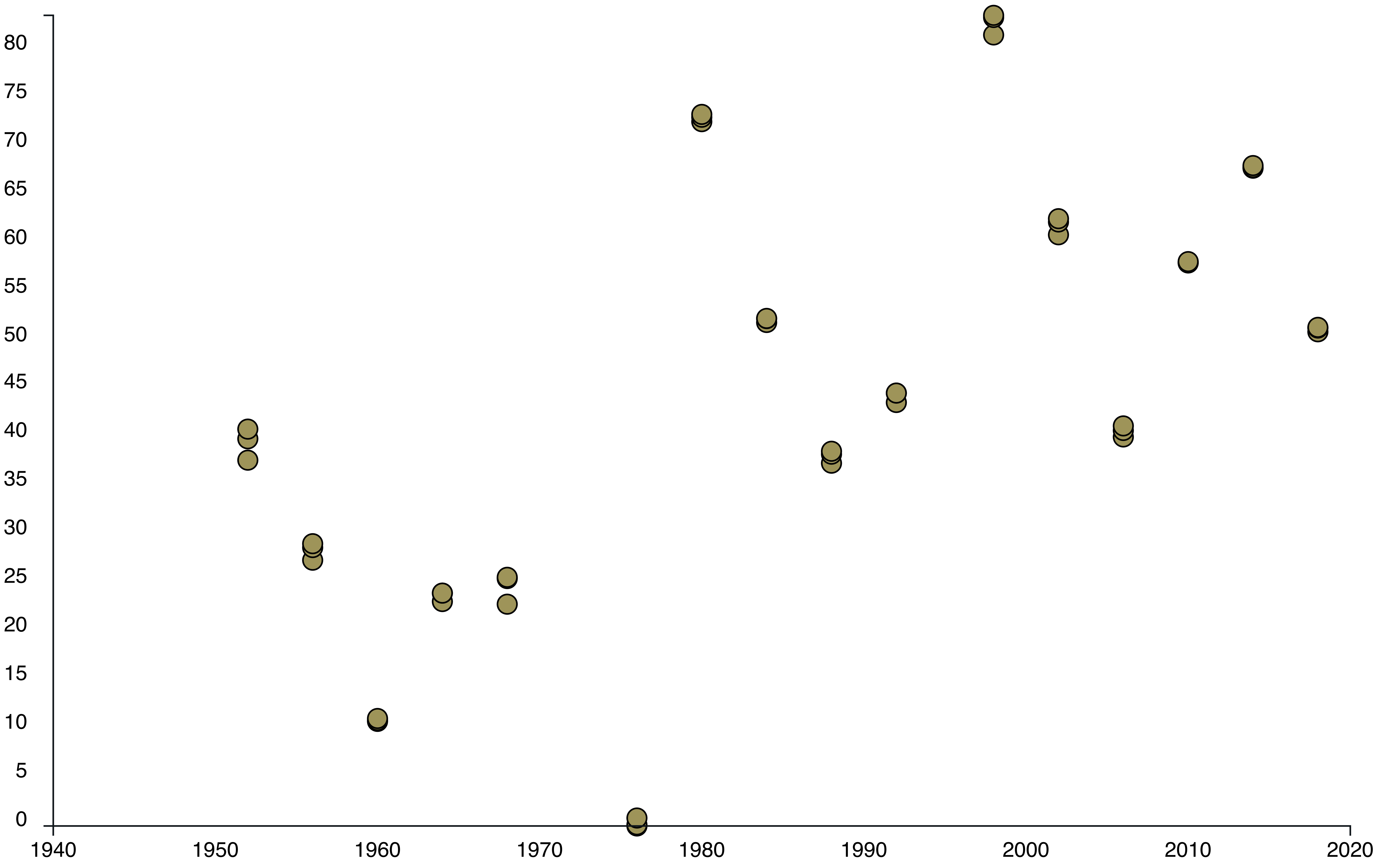
Women's Olympic Giant Slalom, 1952 – 2018

Medalists' Times by Year



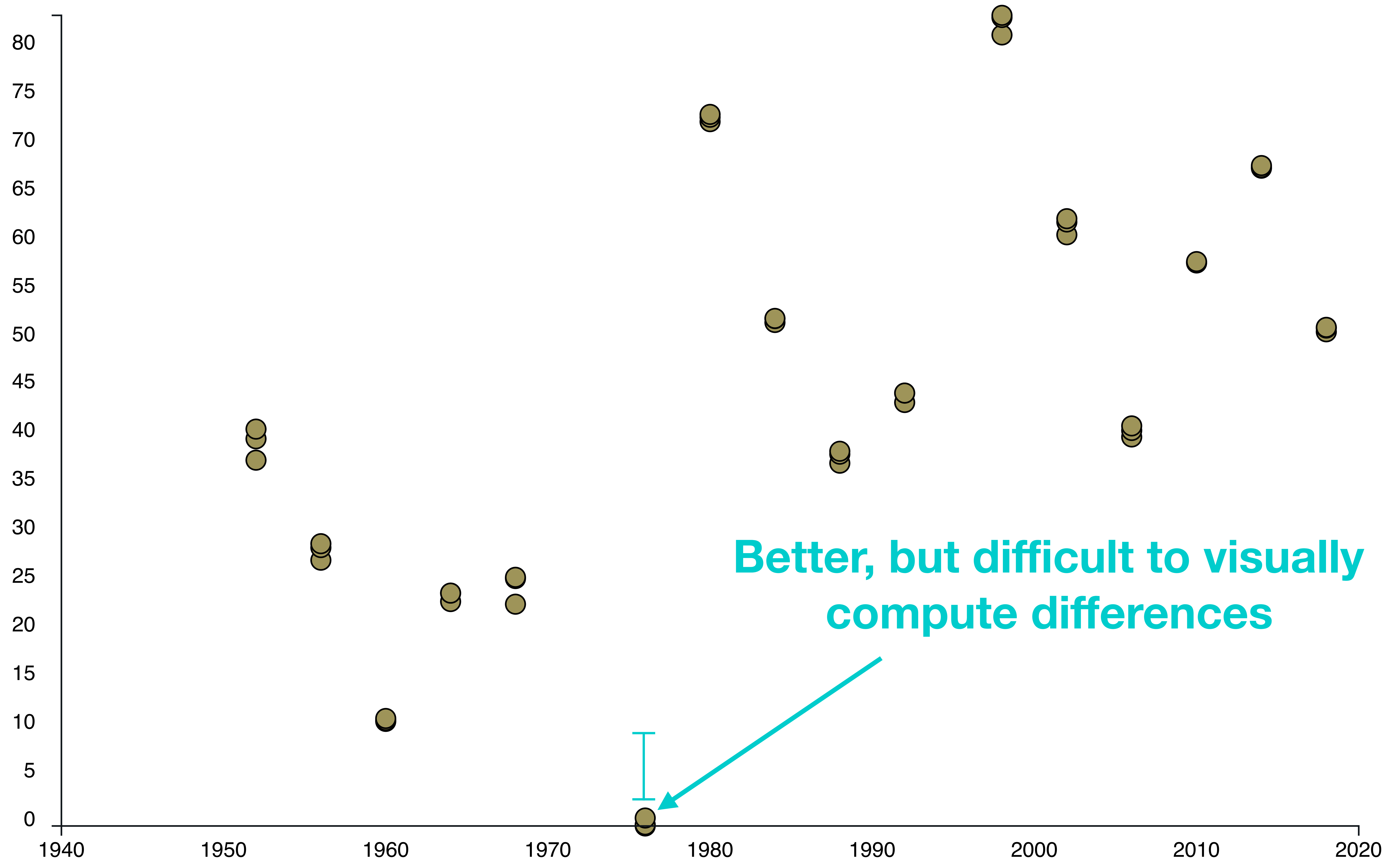
Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year



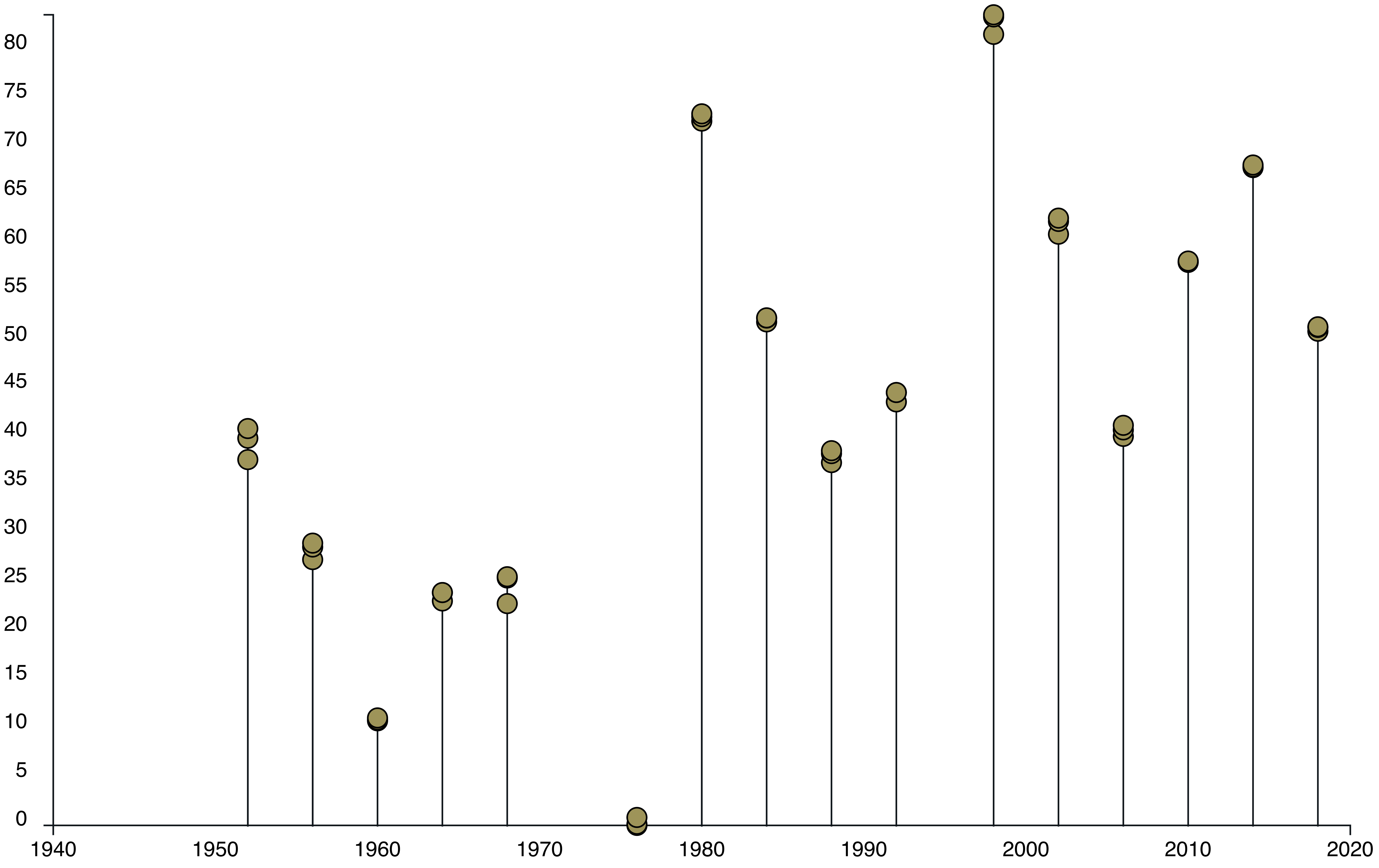
Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year



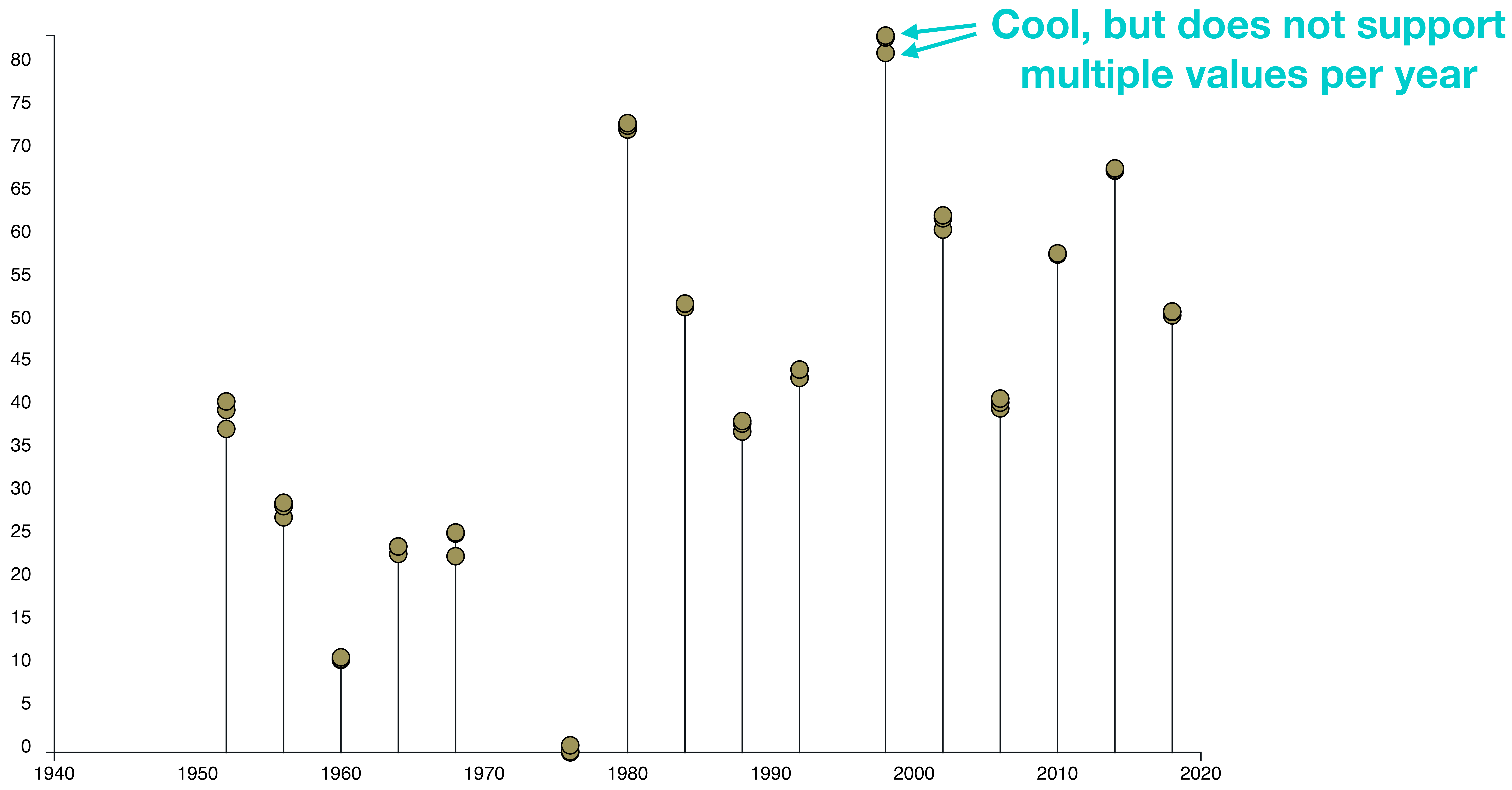
Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year



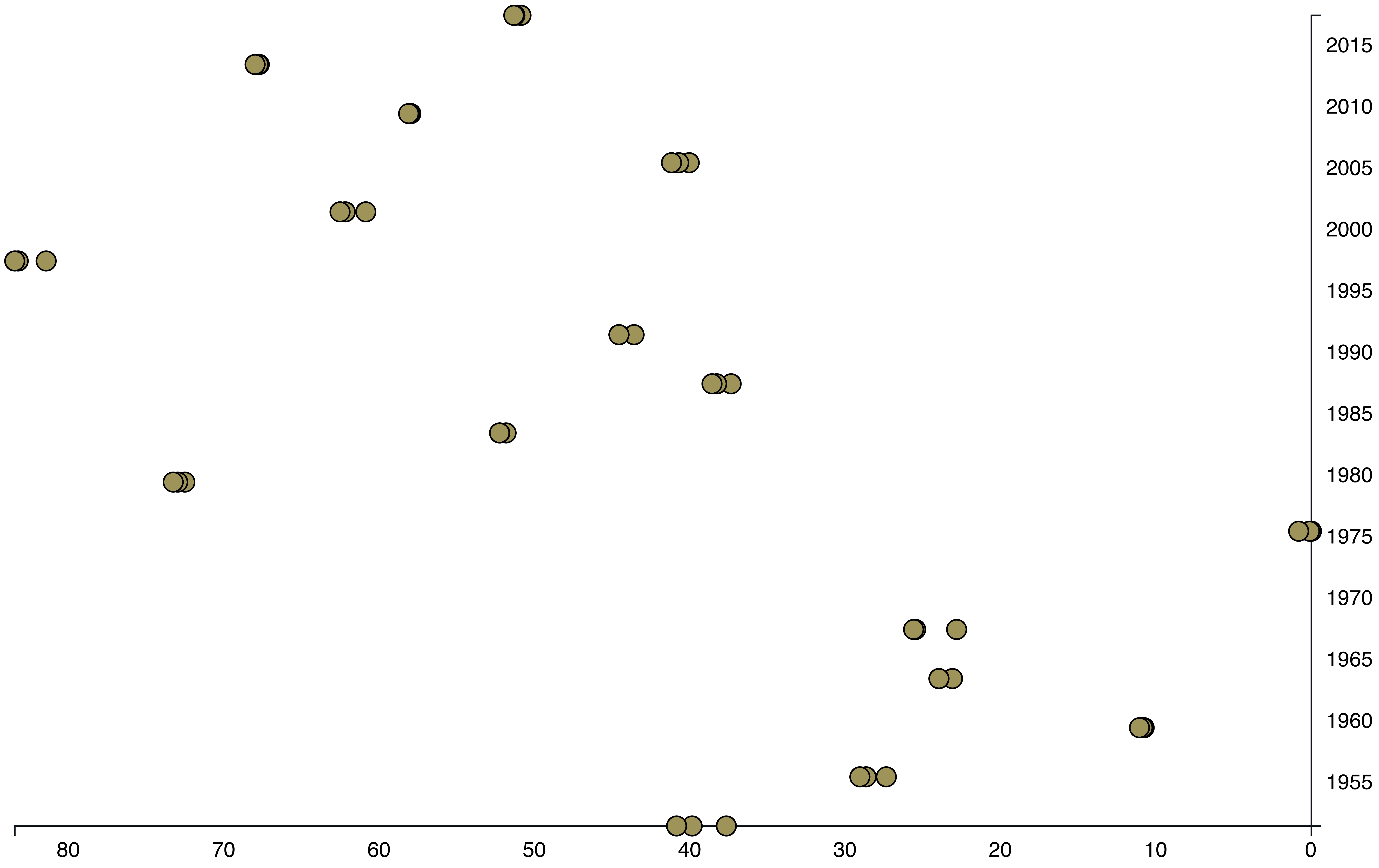
Women’s Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists’ Time and Kreiner’s Time by Year



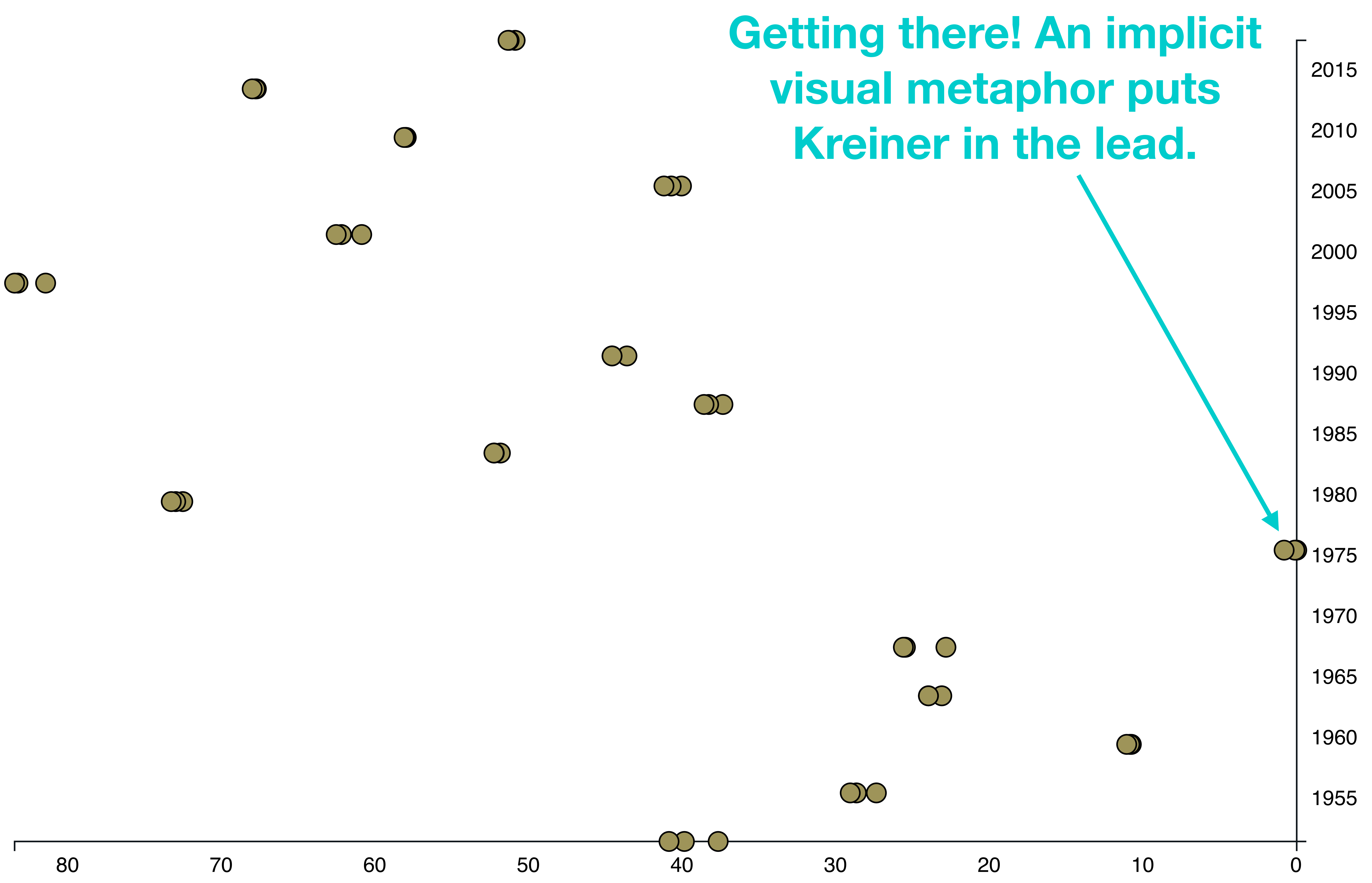
Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year



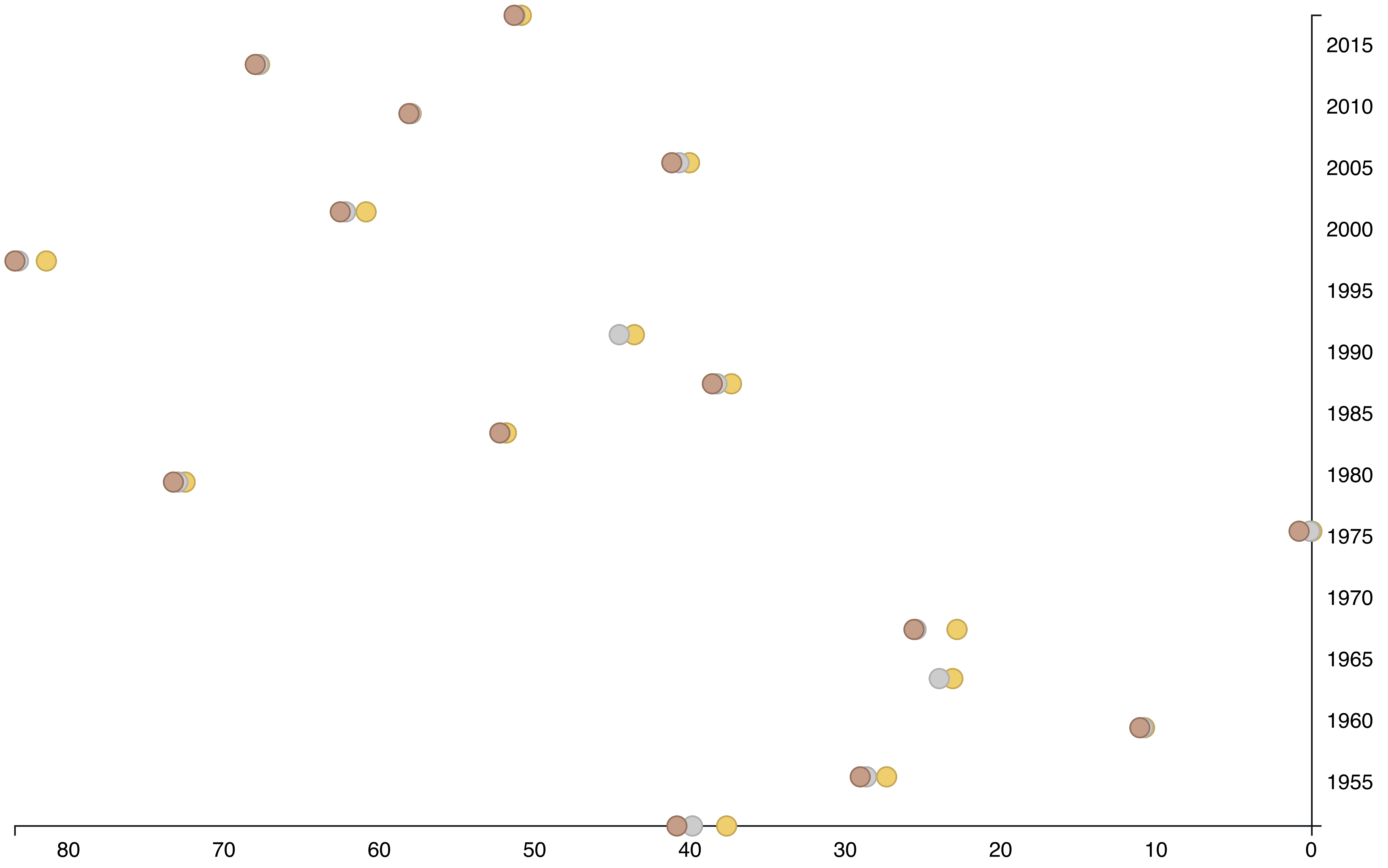
Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year



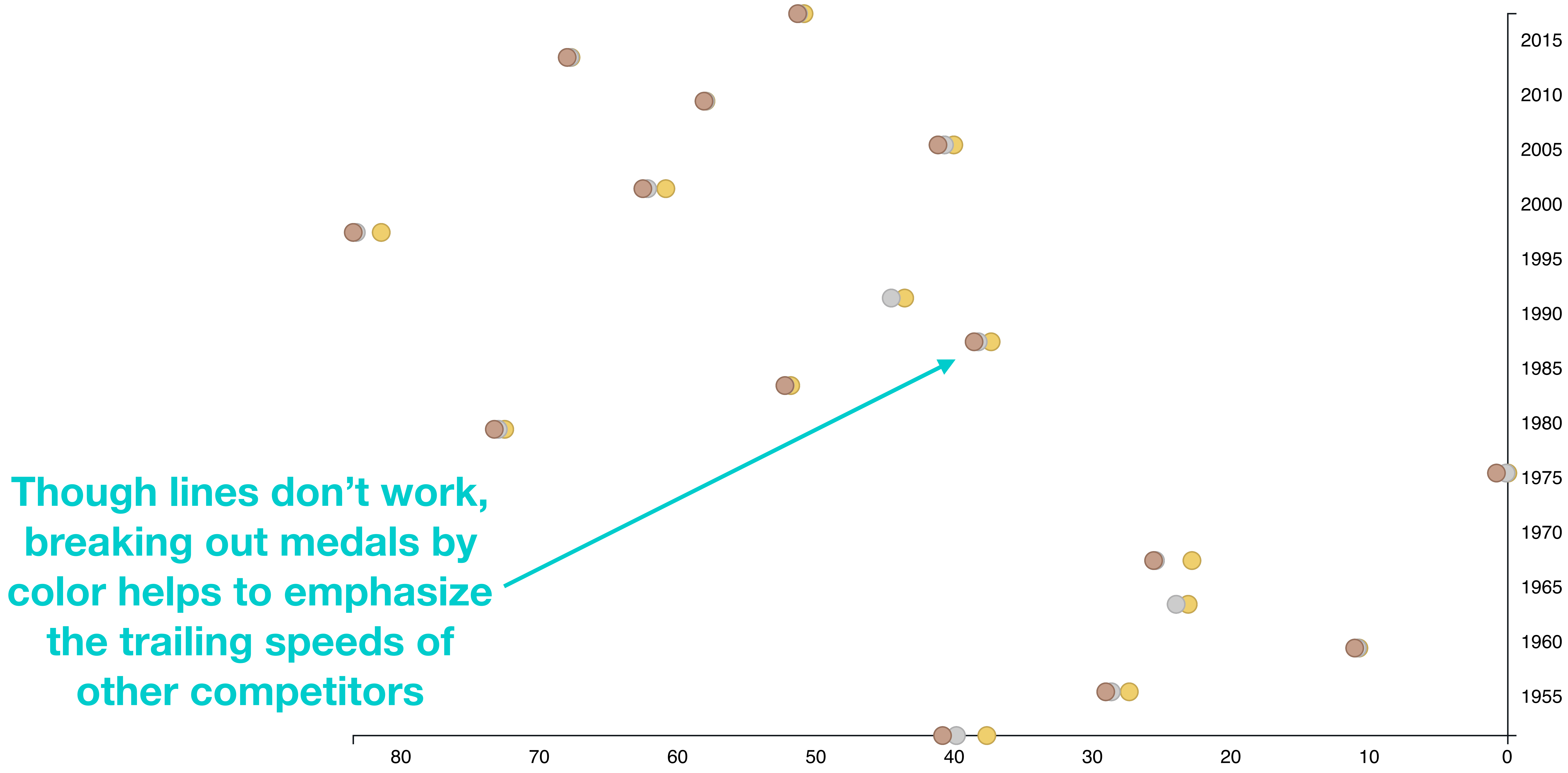
Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year



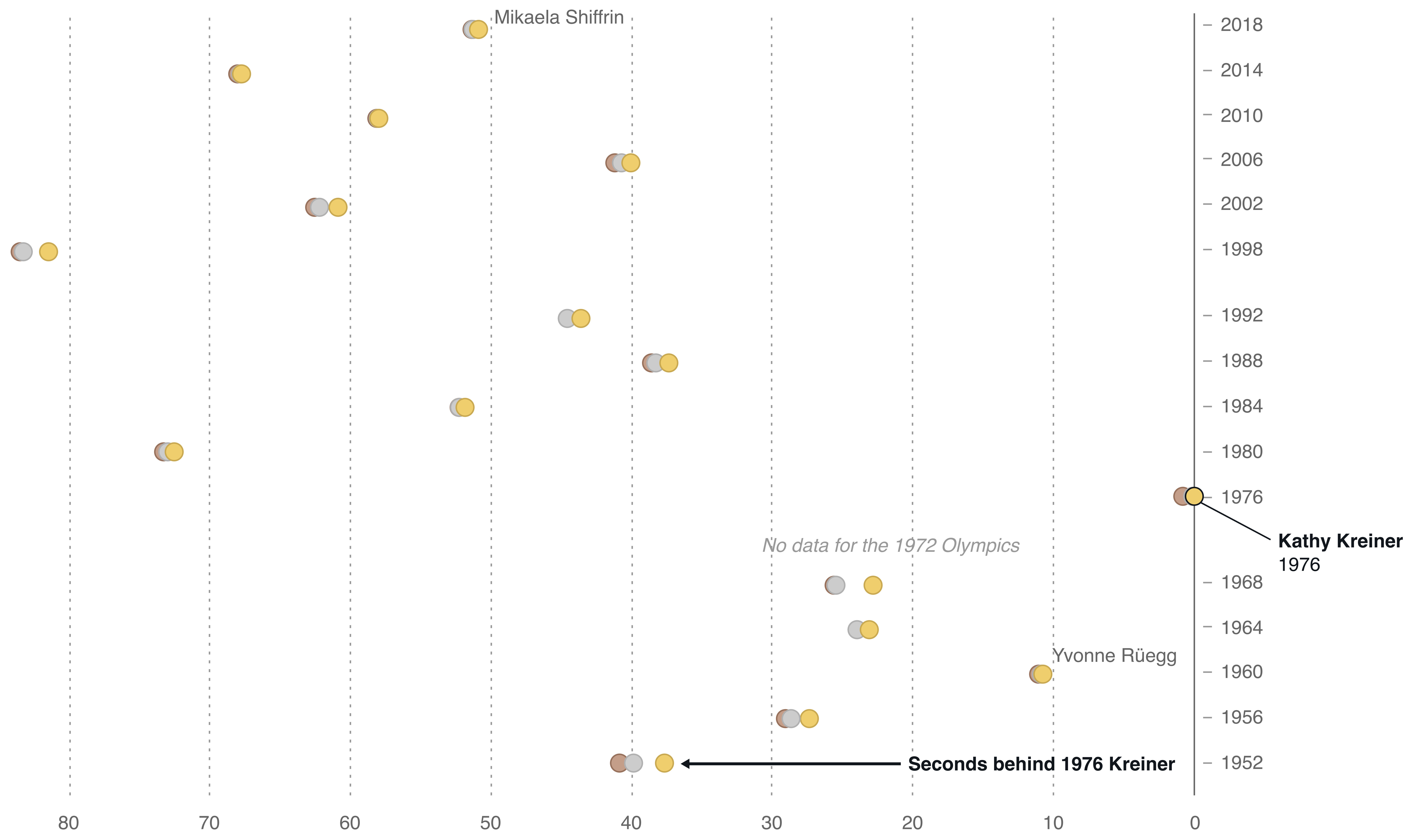
Women's Olympic Giant Slalom, 1952 – 2018

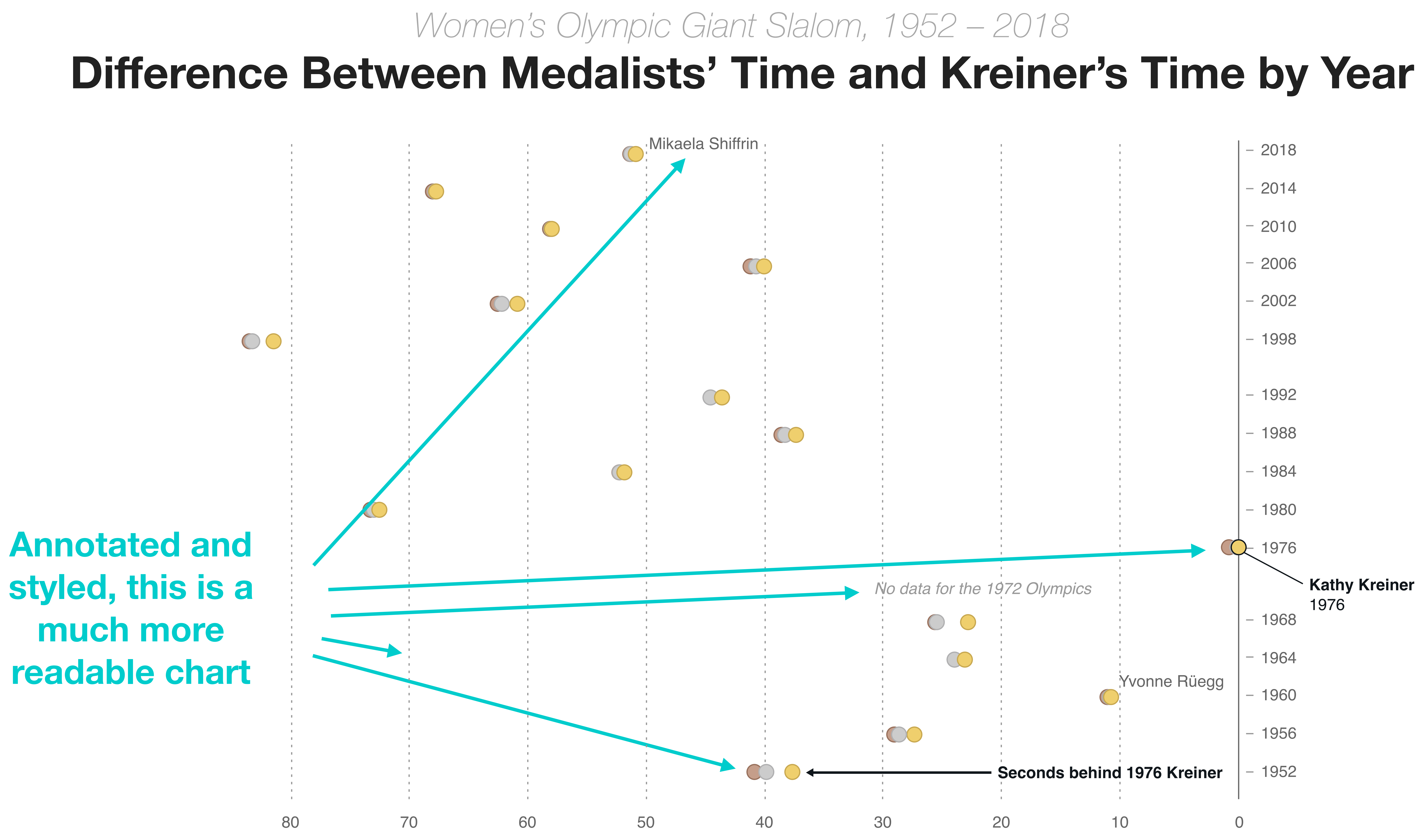
Difference Between Medalists' Time and Kreiner's Time by Year



Women's Olympic Giant Slalom, 1952 – 2018

Difference Between Medalists' Time and Kreiner's Time by Year





Women's Olympic Giant Slalom, 1952 – 2018
Difference Between Medalists' Time and Kreiner's Time by Year
Mikaela Shiffrin
2018
2014
2010
2006
2002
1998
1992
1988
1984
1980
1976
Kathy Kreiner
1976
No data for the 1972 Olympics
1968
1964
Yvonne Rüegg
1960
1956
1952
Seconds behind 1976 Kreiner
80
70
60
50
40
30
20
10
0
Annotated and styled, this is a much more readable chart

Case study:

Theories of Everything, Mapped

Visual variables can help to define the **structure** of larger, more complex visualizations.

Theories of Everything, Mapped

← BACK TO ARTICLE

INDEX

12 TOPICS
41 THEORIES

Kicker (link to multimedia tag): Physics Interactive

Theories of Everything, Mapped

SEO hed: Frontier of Physics: Interactive Map

Teaser/subtitle: Explore the deepest mysteries at the frontier of fundamental physics, and the most promising ideas put forth to solve them.

Categories: physics, multimedia

Tags: physics, fundamental physics, theoretical physics, multiverse, space-time, quantum gravity, quantum mechanics, general relativity, particle physics, cosmology, multimedia

Keywords: tags + physics map

By Natalie Wolchover

"Ever since the dawn of civilization," Stephen Hawking wrote in his international bestseller *A Brief History of Time*, "people have not been content to see events as unconnected and inexplicable. They have craved an understanding of the underlying order in the world."

In the quest for a unified, coherent description of all of nature — a "theory of everything" — physicists have unearthed the taproots linking ever more disparate phenomena. With the law of universal gravitation, Isaac Newton wedded the fall of an apple to the orbits of the planets. Albert Einstein, in his theory of relativity, wove space and time into a single fabric, and showed how apples and planets fall along the fabric's curves. And today, all known elementary particles plug neatly into a mathematical structure called the Standard Model. But our physical theories remain riddled with disunions, holes and inconsistencies. These are the deep questions that must be answered in pursuit of the theory of everything.

Our map of the frontier of fundamental physics, built by the interactive developer Emily Fuhrman, weights questions roughly according to their importance in advancing the field. It seemed natural to give greatest weight to the quest for a theory of quantum gravity, which would encompass general relativity and quantum mechanics in a single framework. In their day-to-day work, though, many physicists focus more on rooting out dark matter, solving the Standard Model's hierarchy problem, and pondering the goings-on in black holes, those mysterious swallowers of space and time. For each question, the map presents several proposed solutions. Relationships between these proposals form a network of ideas.

The map provides concise descriptions of highly complex theories; learn more by exploring the links to dozens of articles and videos, and vote for the ideas you find most elegant or promising. Finally, the map is extensive, but hardly exhaustive; proposed additions are welcome below.

Map text:

Black Hole Information Paradox
What happens to information that falls into a black hole?

Quantum mechanics says that information can be hidden or scrambled, but never destroyed. So what happens to information carried by objects that fall into black holes, those inescapable sinkholes in space-time? According to general relativity, infalling objects will forever plunge toward the singularity at the black hole's center. But Stephen Hawking showed in the 1970s that quantum fluctuations at the black hole's horizon will cause it to radiate, lose mass in the process, and eventually evaporate. So, what happens to the information that fell in?

- **Information loss**

  The position originally espoused by Stephen Hawking is that the information gets destroyed along with the black hole, violating quantum mechanics. Information must be preserved in order for quantum mechanics to work — otherwise, the probabilities of different states of a system, given by a quantum mechanical "wave function," won't add up. Thus, information loss could mean the fundamental laws of physics must be reformulated.

- **Firewalls** (sibling of fuzzballs)

  The "firewall" argument, raised in 2012 by a group of physicists known as AMPS, asserts that there is no inside of a black hole; all the stuff that appears to fall in actually becomes part of the fiery shell of entangled particles on its horizon. Firewalls are a dramatic departure from the tenets of Einstein's theory of general relativity, in which space-time curves steeply, but never suddenly stops.

- **Fuzzballs** (child of string theory, sibling of firewalls)

  The fuzzball proposal, from string theorist Samir Mathur, replaces the singularity at the black hole's center with a complicated configuration of strings (which are the basic building blocks of nature in string theory). When information appears to fall into a black hole, it actually becomes part of this fuzzball, which radiates the information back out.

- **Duality** (sibling of holography)

  The black hole interior might be constructed out of stuff that is far from the black hole — namely the particles that have radiated away. The ER = EPR proposal suggests that a wormhole connects each particle of this outgoing radiation to an entangled particle in the black hole interior. Meanwhile, the Horowitz-Maldacena approach links the interior and exterior by proposing that time flows backward inside black holes. The Papadodimas-Raju proposal holds that infalling objects are holographically encoded in the outgoing radiation.

Matter-Antimatter Asymmetry
Why does the universe contain so much more matter than antimatter?

The Standard Model of particle physics treats matter and antimatter nearly equivalently, respecting (with minor exceptions) "CP symmetry." But it's clear that much more matter than antimatter must have been created during the Big Bang; matter and antimatter annihilate each other upon contact, so producing equal amounts of each would have meant the wholesale annihilation of both, resulting in an empty universe. Which CP-violating process produced the surplus of baryons — matter particles that include the protons and neutrons of atomic nuclei — over antibaryons in the early universe, a process known as baryogenesis?

- **Leptogenesis** (sibling of sterile neutrinos)

  This popular hypothesis claims that heavier cousins of neutrinos filled the hot early universe. These would have decayed more often into antileptons than into leptons. (Leptons are the particle category that includes electrons.) Through high-temperature quantum tunneling events known as sphaleron processes, the surplus of antileptons would then have converted into the baryon surplus we see today. Experimental searches are underway for rare particle decays that would point to the existence of the heavy neutrinos.

- **Electroweak baryogenesis**

  The baryon surplus might have come about during a phase transition soon after the birth of the cosmos called electroweak symmetry breaking (EWSB), but only if EWSB was a first-order transition, akin to evaporating water. Bubbles of energy in a field permeating all of space, called the Higgs field, were needed to create two environments: the space outside the bubbles where antileptons could morph into baryons via quantum tunneling events called sphaleron processes, and the space inside the bubbles where they couldn't. The mass of the Higgs boson suggests that the temperature of EWSB was too low for a first-order transition. However, if additional Higgs-like particles are found at higher energies, this theory becomes viable.

- **Asymmetric dark matter** (sibling of asymmetric dark matter, in dark matter problem)

  The universe contains roughly five parts dark matter for every part visible matter — similar abundances that may point to a connection between the two. Accordingly, this proposal tries to pass the buck by attributing the matter-antimatter asymmetry to an earlier asymmetry between the production of dark matter and dark antimatter, about which nothing is yet known.

- **Planck/GUT-scale baryogenesis** (child of all the grand unification proposals)

  Baryogenesis may have occurred very near the beginning of time and at unreachably high energies known as the GUT (grand unified theory) scale or the Planck scale, where the Standard Model rules probably break down. Measurements of proton decay could someday provide a window onto the GUT-scale laws of physics, but if baryogenesis occurred at the Planck scale, we may never experimentally discover or verify the mechanism behind it.

- **Affleck-Dine mechanism** (child of supersymmetry, child of cosmic inflation)

  Supersymmetry posits the existence of a hypothetical twin for each known elementary particle. If the theory is correct, then during cosmic inflation, the supersymmetric partners of the known particles might have undergone CP-violating decays that produced an excess of baryons. No supersymmetric particles have shown up in searches at the Large Hadron Collider, but they could nonetheless exist at higher energies beyond the collider's reach.

Grand Unification
Do the three quantum forces unite into a single force at high energies?

When extrapolated to high energies corresponding to those in the universe's first fraction of a second, the curves representing the strengths of the electromagnetic, weak and strong forces nearly converge. (Adding supersymmetry to the equations makes the convergence exact — one of the main motivations for the theory.) Was there just one unified "electronuclear force" at this grand unified theory (GUT) scale? Did the mathematical form of the forces at more familiar energies — represented by the symmetry group SU(3) x SU(2) x U(1) — result from the breaking of a larger symmetry? Physicists hope to discover this higher symmetry group, as well as the missing particles that bring the strengths of the three forces exactly together at the GUT scale. (The fourth fundamental force, gravity, could unite with the others at a still higher energy called the Planck scale, corresponding to an even earlier moment — possibly the Big Bang.)

- **SU(5)** (parent of low-energy supersymmetry, child of SO(10))

  The SU(5) symmetry group includes SU(3) x SU(2) x U(1) as a subgroup. In models based on this symmetry group, all the known quarks and leptons are low-energy manifestations of only two fundamental particles that existed at the GUT scale. When the universe cooled past this scale, the SU(5) symmetry broke into SU(3) x SU(2) x U(1), introducing differences between the quarks and leptons. Like other GUT models, this one implies that quarks can become leptons and vice versa (albeit very rarely at low energies), an idea that is being tested in experimental searches for proton decay.

- **SO(10)** (parent of low-energy supersymmetry, child of SU(6), E(6), E(8), etc.)

  The symmetries of the Standard Model, SU(3) x SU(2) x U(1), are part of the SU(5) symmetry group, and SU(5) is part of SO(10). Grand unification theories based on SO(10) hold that all the quarks and leptons were fused into a single fundamental particle at the GUT scale. Like other GUT models, SO(10) models imply that quarks can become leptons and vice versa (albeit very rarely at low energies), an idea that is being tested in experimental searches for proton decay.

- **SU(6), E(6), E(8), etc.** (child of string theory)

  The SU(5) and SO(10) symmetry groups (and their Standard Model subgroup) can be embedded into even larger symmetric structures, some of which show up in string theory. Grand unified theories based on these symmetry groups

All three species of neutrinos in the Standard Model are the quantum equivalent of left-handed. This asymmetry implies that they should be massless, because massive particles travel slower than the speed of light and anything traveling faster than them would observe them as right-handed. However, in 1998, physicists discovered that neutrinos can spontaneously convert from one species to another, which is only possible if the particles have mass. The mass of neutrinos is at most one ten-thousandth that of electrons, and yet this mass proves that the Standard Model is incomplete. What physics beyond the Standard Model accounts for their mass?

- **Seesaw mechanism** (sibling of sterile neutrinos, sibling of leptogenesis)

  If the left-handed neutrinos of the Standard Model are their own antiparticles, then their tiny masses can be generated through an inverse relationship (like two sides of a seesaw) to the masses of much heavier hypothetical right-handed neutrinos. If these heavy neutrinos aren't too heavy, they could also comprise dark matter. If they are enormous, and if they decayed shortly after the Big Bang, they might have been involved in leptogenesis.

- **Extra dimensions** (sibling of extra dimensions, child of string theory)

  If neutrinos are distinct from antineutrinos, then they can acquire mass through the Higgs mechanism, like the other particles in the Standard Model. But then why are neutrinos so much lighter than these other particles? One theory holds that the hypothetical right-handed partners of neutrinos move around in extra space-time dimensions that are curled up at each point in our 4-D reality. Much of their mass gets hidden in these space-time folds, which in turn renders the left-handed neutrinos lightweight.

Dark Matter

universe, annihilating with its own antiparticles as the universe expanded and cooled; the dark matter that remained still exists today. This thermal picture predicts the particle's mass to be around 1 TeV, consistent with a WIMP. In what's known as the "WIMP miracle," a particle in the same mass range also arises in many popular attempts to solve the hierarchy problem, such as supersymmetry. Searches for WIMPs over the past decade have so far come up empty, however, and the absence of evidence for supersymmetry from the Large Hadron Collider also slightly weakens their case.

- **Sterile neutrinos** (sibling of seesaw mechanism)

  Quarks, electrons and almost all other matter particles exist in both left-handed and right-handed forms. But the three known neutrino species are all left-handed. Many theorists hypothesize that neutrinos have as-yet-undiscovered right-handed counterparts — possibly heavier, less interactive particles that feel neither the strong force nor the weak force, called "sterile" neutrinos. Interacting with regular matter only gravitationally, sterile neutrinos could account for dark matter. Some particle astrophysicists claim to have detected a sterile neutrino decay signal, but the observation is highly uncertain. And even if these right-handed twins of known neutrinos do exist, they don't necessarily have the requisite properties to be dark matter.

- **Axions** (sibling of axions)

  An axion field can be thought of as a 3-D mattress with a spring at every point in space-time. First posited in 1977 to solve the strong CP problem, axion fields also arise in string theory and other attempts to extend the known laws of physics. The quantized vibrations in the mattress springs — particles called axions, which gravity assembles into galaxies along with all other matter — could comprise dark matter. Experimental searches for dark matter axions are

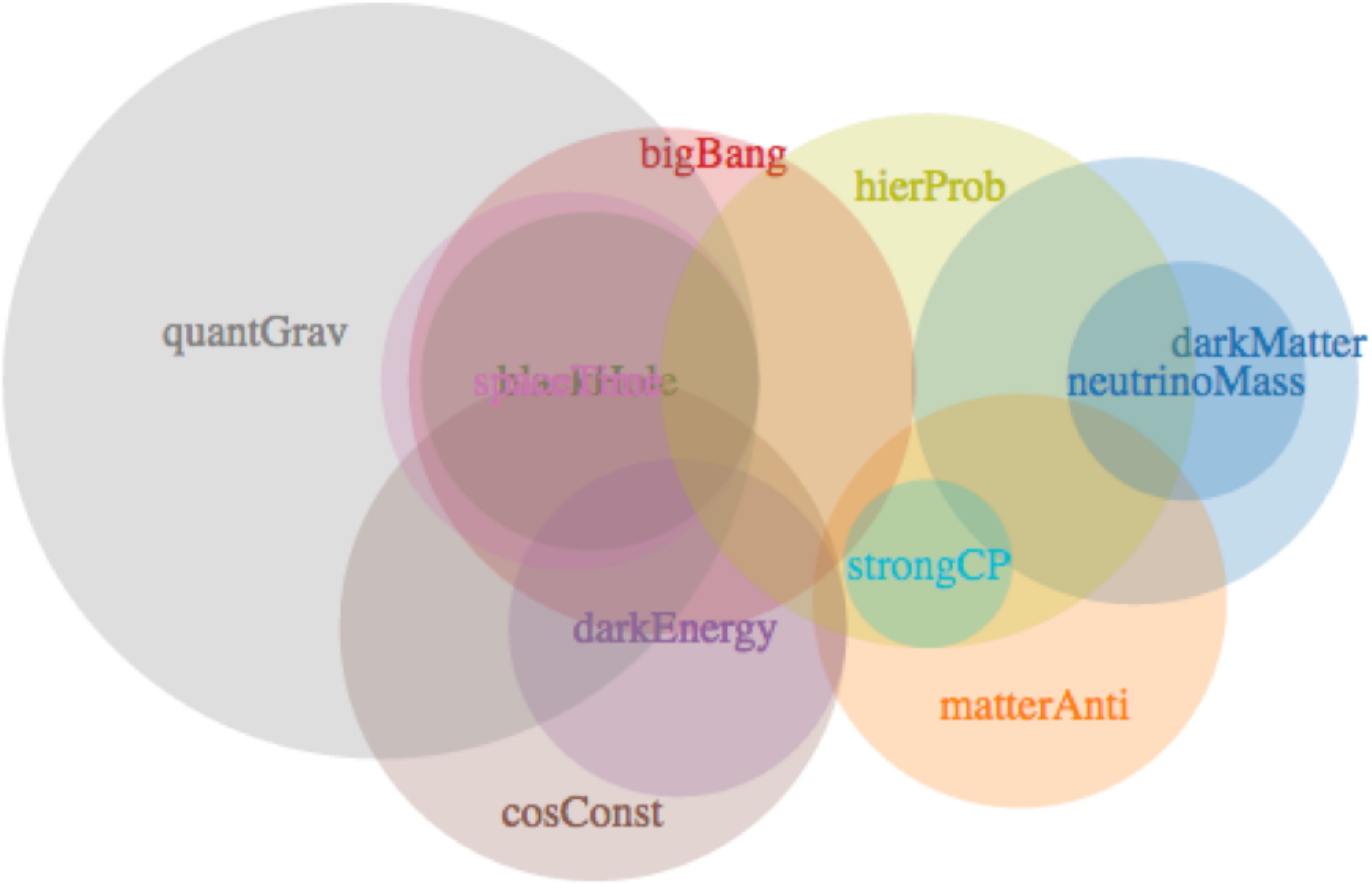
Just as electrons are mutually repulsive and the strong force glues quarks together into protons and neutrons, dark matter particles might feel attracted or repelled by one another. These self-interactions would change dark matter's resulting distribution in the cosmos. Models of self-interacting dark matter may capture the number, size and shape of dwarf galaxies better than some noninteracting models. However, some researchers bristle at the idea of adding extra complications to unknown particles.

- **Kaluza-Klein dark matter** (sibling of extra dimensions)

  In the 1920s, Theodor Kaluza and Oskar Klein tried to unify gravity and electromagnetism by adding a fifth dimension of space curled up at every point in the fabric of our 4-D reality. The theoretical benefits came at a cost: Each particle that propagates in the extra spatial dimension possesses an infinite tower of partner states. Could these "Kaluza-Klein partners" of the known particles — the lightest of which would have a thermal origin, mass and astrophysical signatures much like those of WIMPs — be the constituents of dark matter?

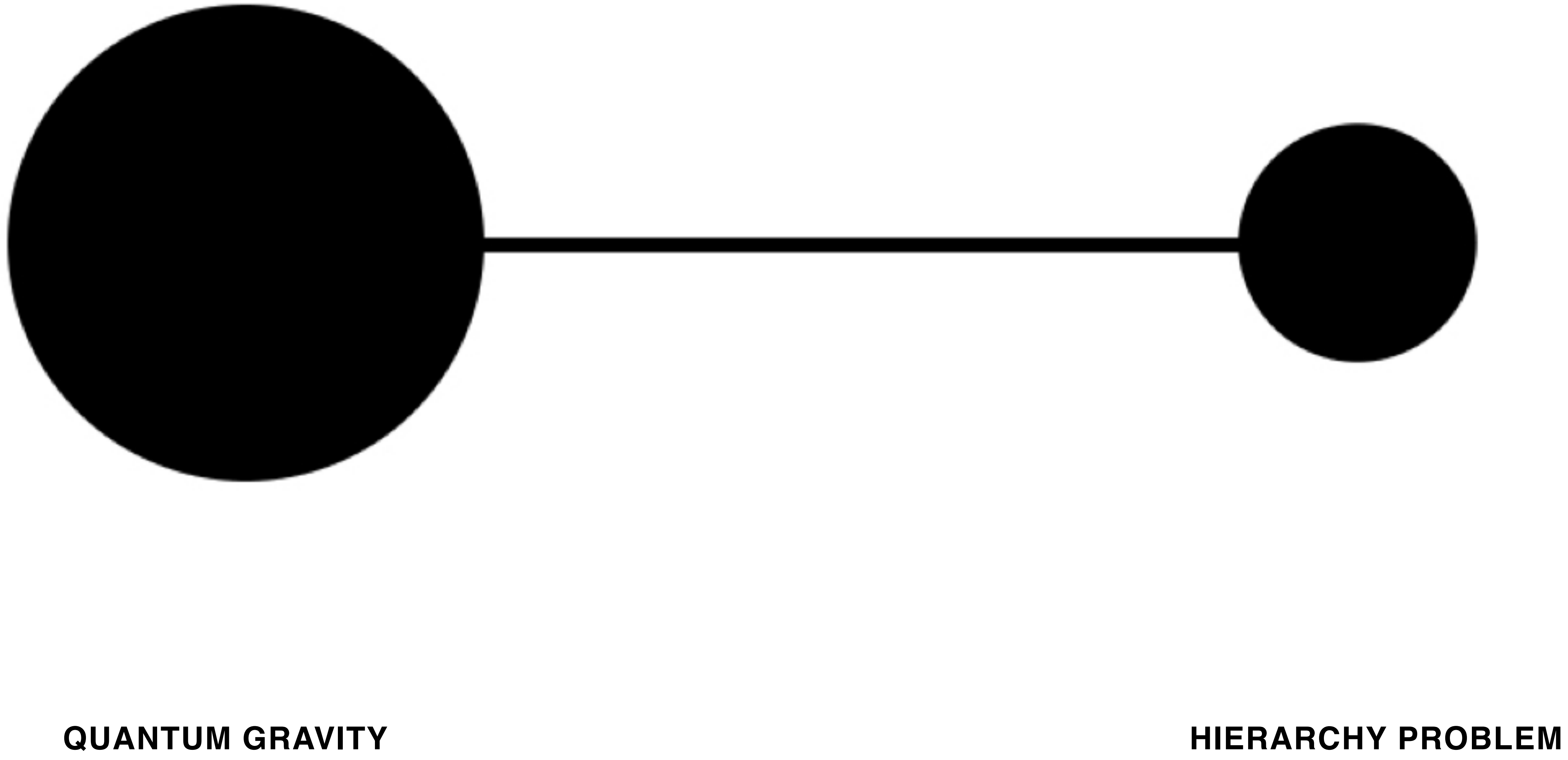
Space-Time
What is the quantum nature of space and time?

The universe appears to have three dimensions of space and one dimension of time. However, in small enough increments — less than a tenth of a trillionth of a trillionth of a trillionth of a meter — our familiar notions of space and time break down. The energy required to peer at such a small patch of space-time would collapse it into an inaccessible black hole. This and other paradoxes imply that space and time emerge from some deeper quantum phenomenon. So, what is the



bigBang
hierProb
quantGrav
darkMatter
neutrinoMass
spaceTime
blackHole
strongCP
darkEnergy
matterAnti
cosConst


QUANTUM GRAVITY
HIERARCHY PROBLEM


QUANTUM GRAVITY
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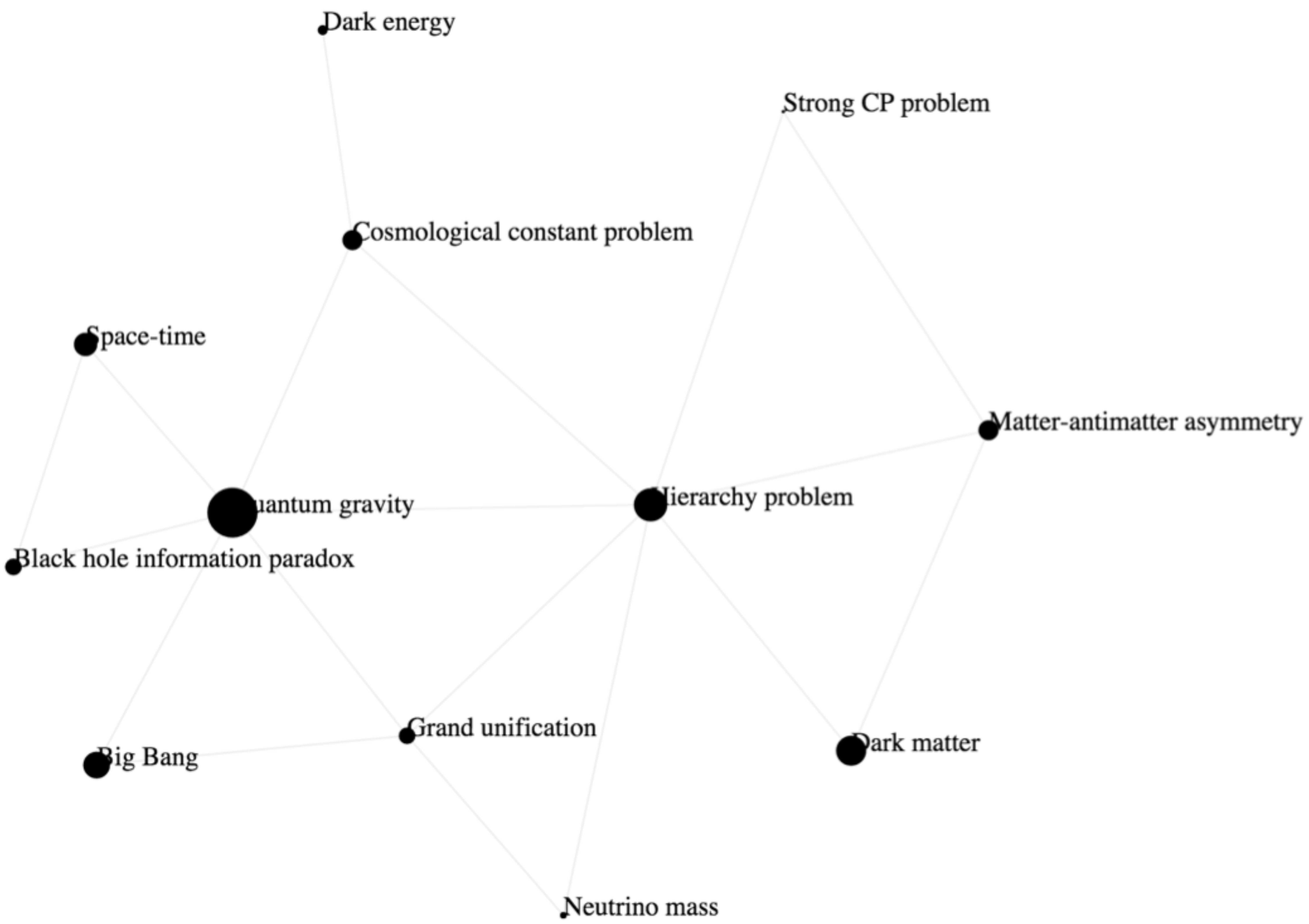
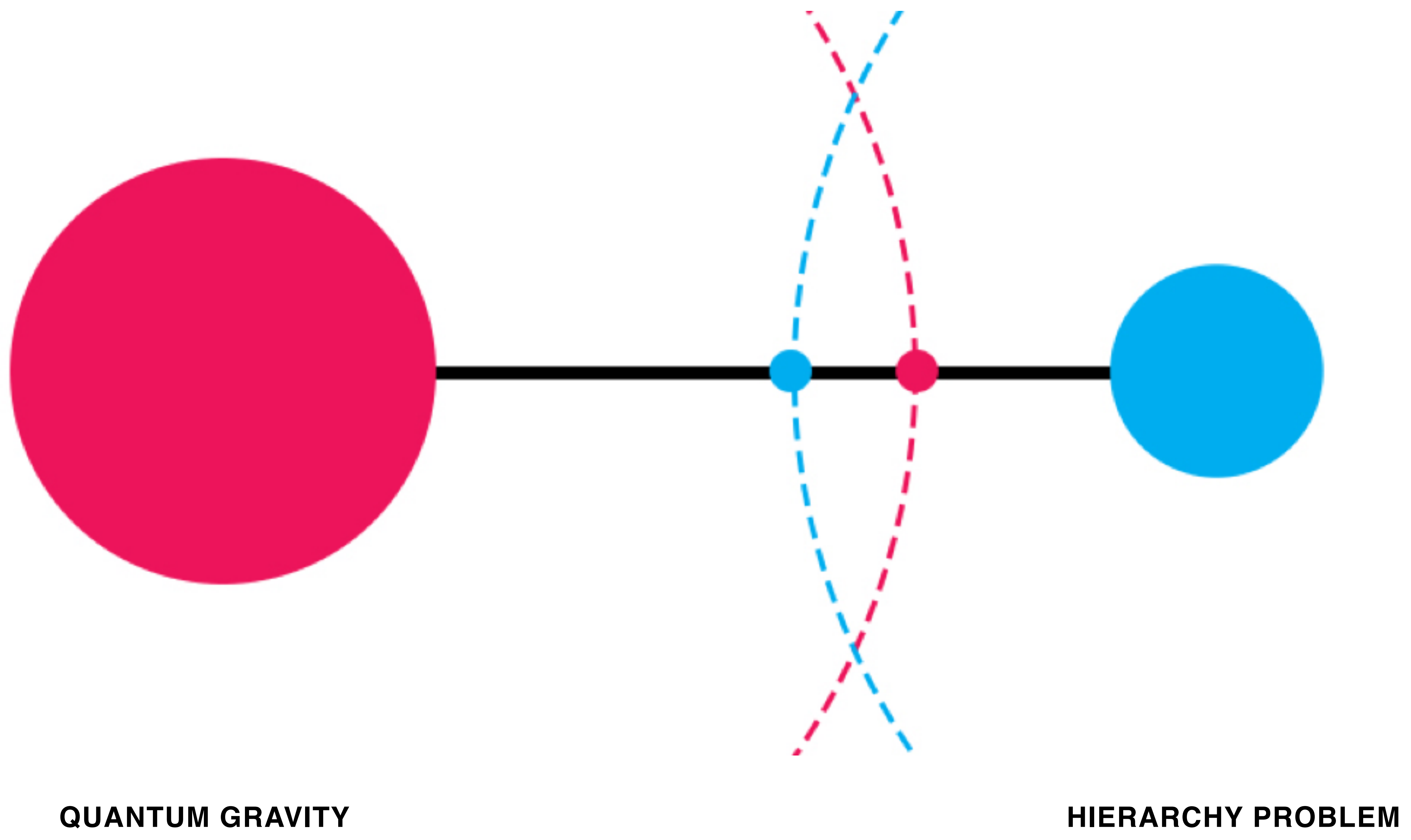


Dark energy
Strong CP problem
Cosmological constant problem
Space-time
Matter-antimatter asymmetry
Quantum gravity
Hierarchy problem
Black hole information paradox
Grand unification
Big Bang
Dark matter
Neutrino mass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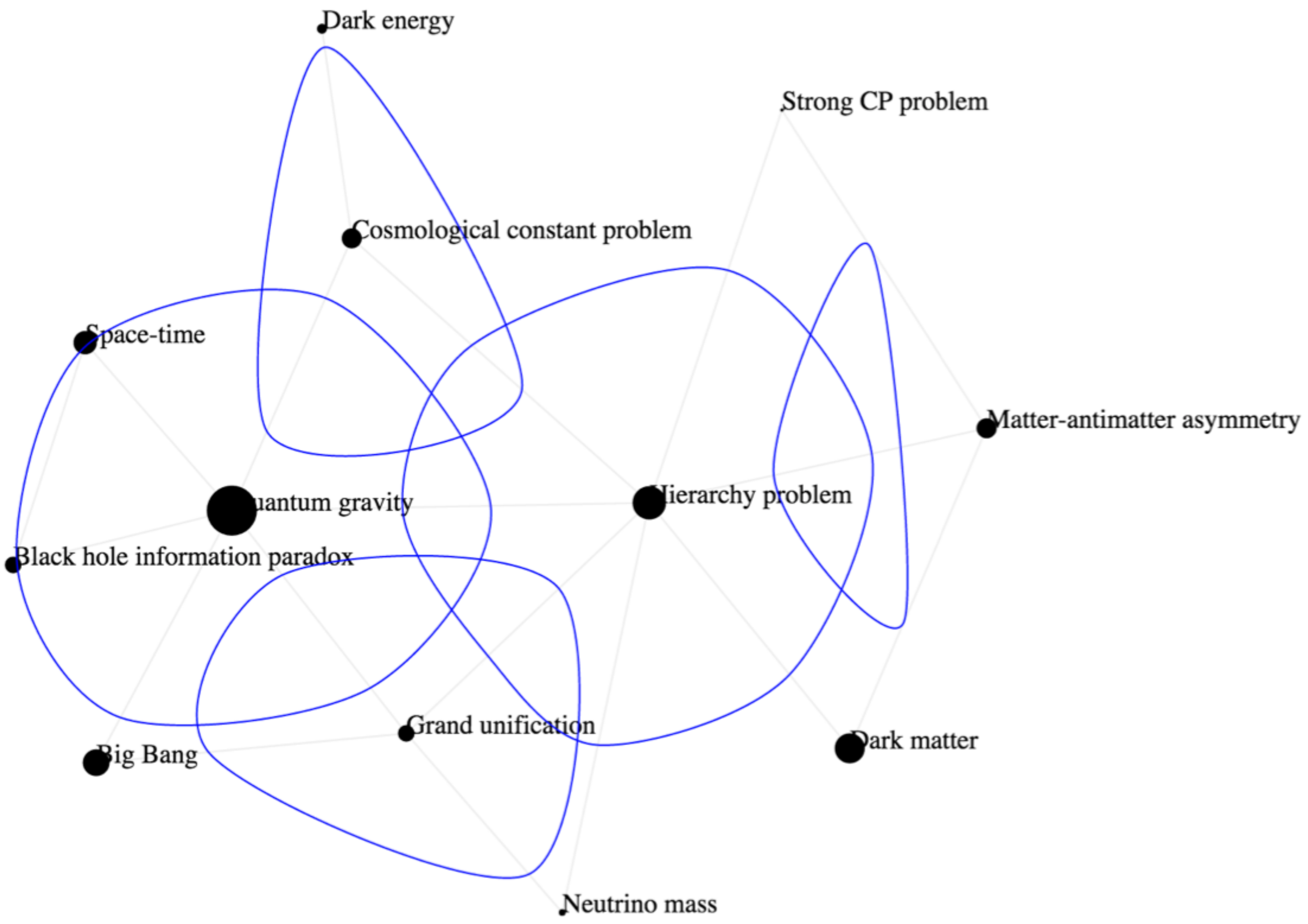

Dark energy
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Grand unification
Dark matter
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Neutrino mass

Theories of Everything, Mapped

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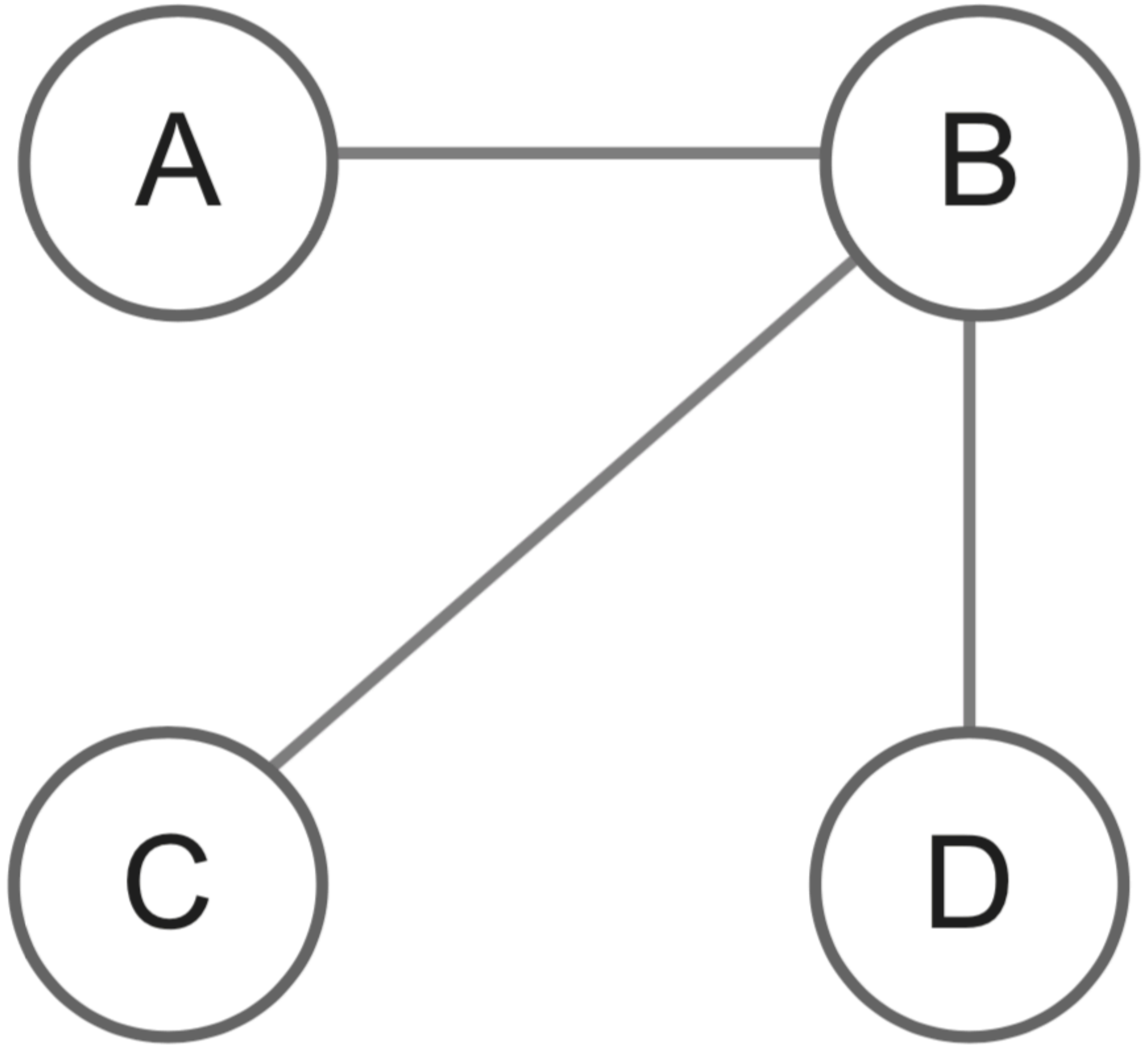
Hierarchy & **Grouping**

Hierarchy —

An arrangement or classification of things according to relative ***importance*** or ***inclusiveness***.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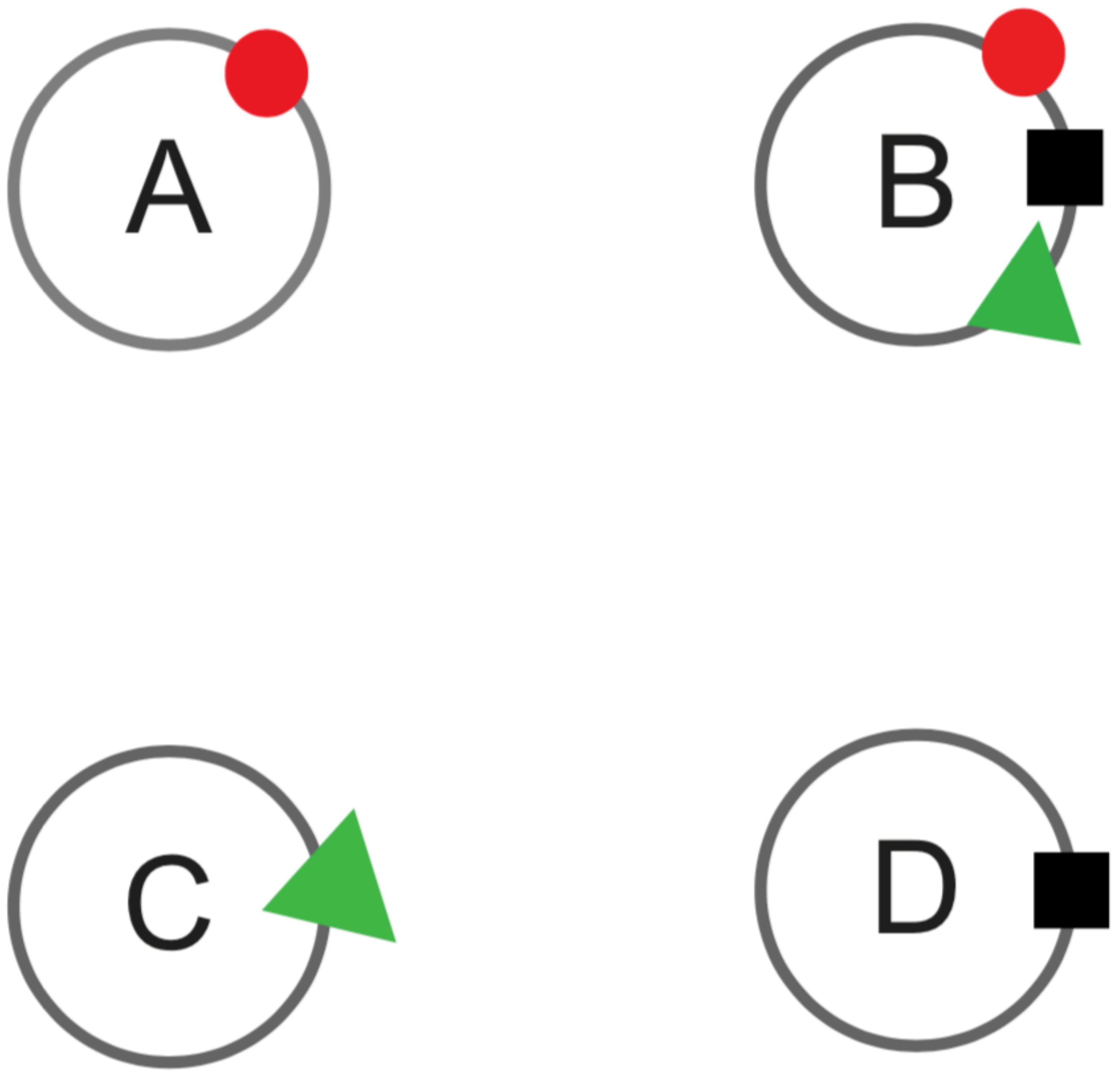
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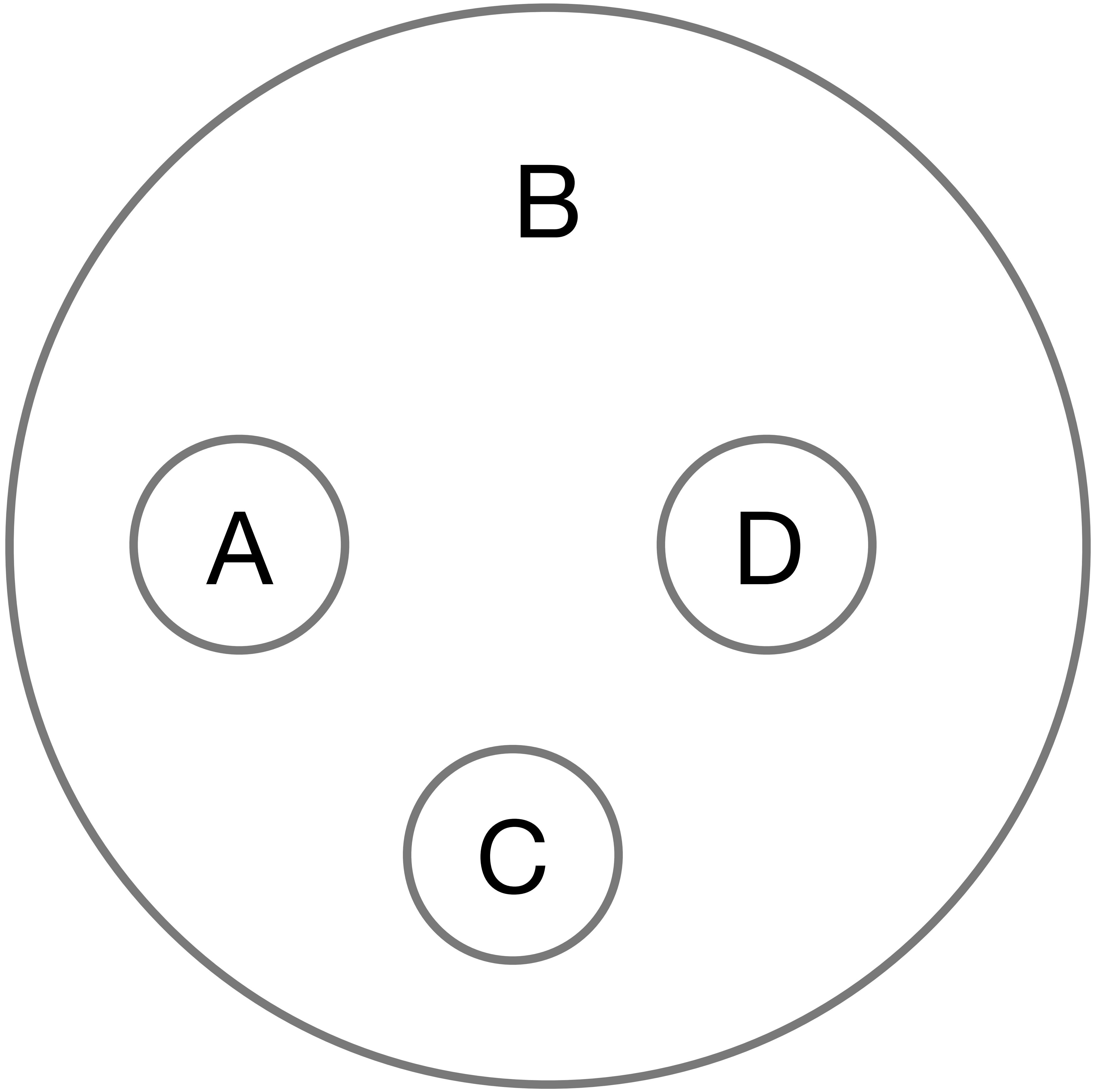
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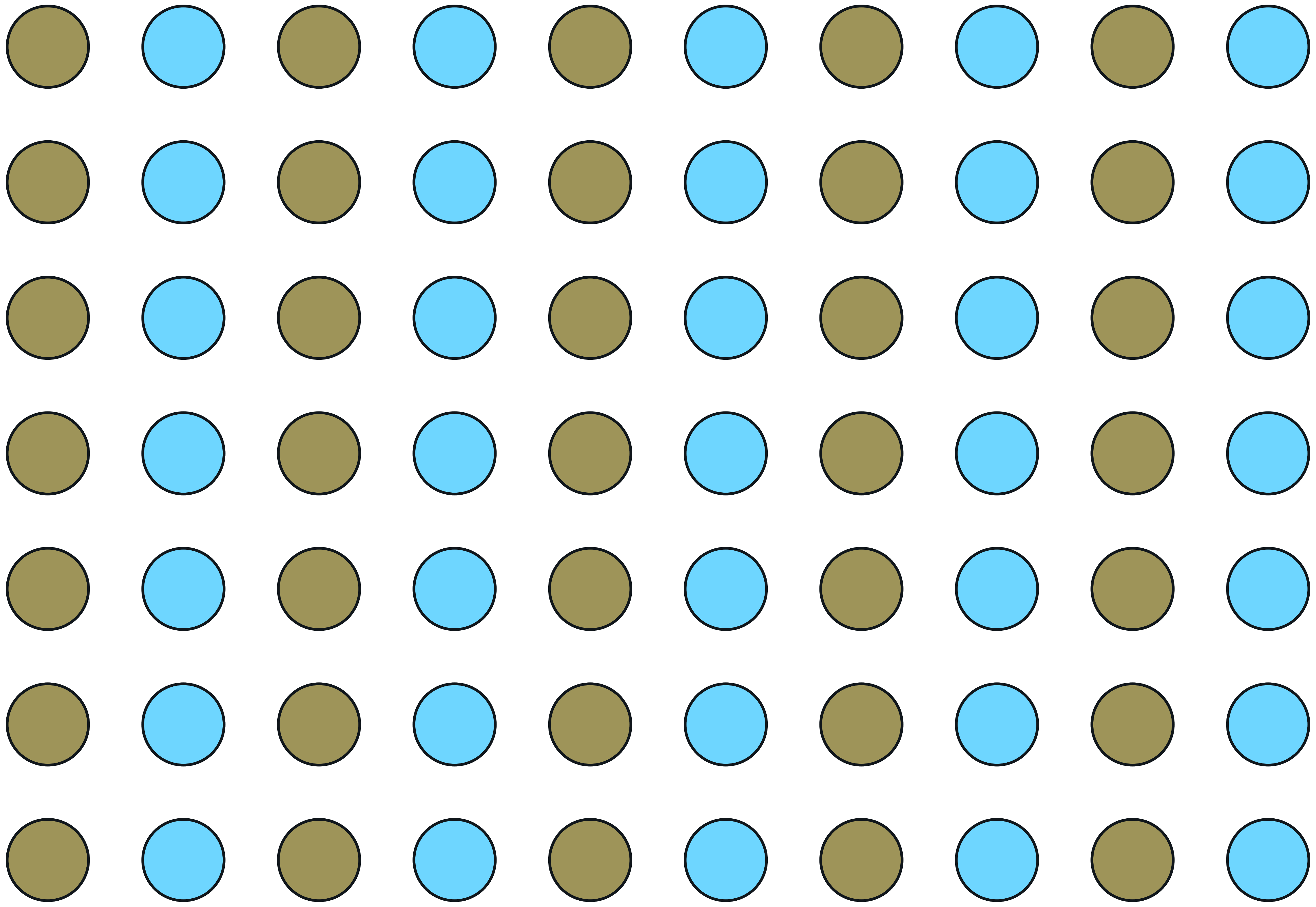
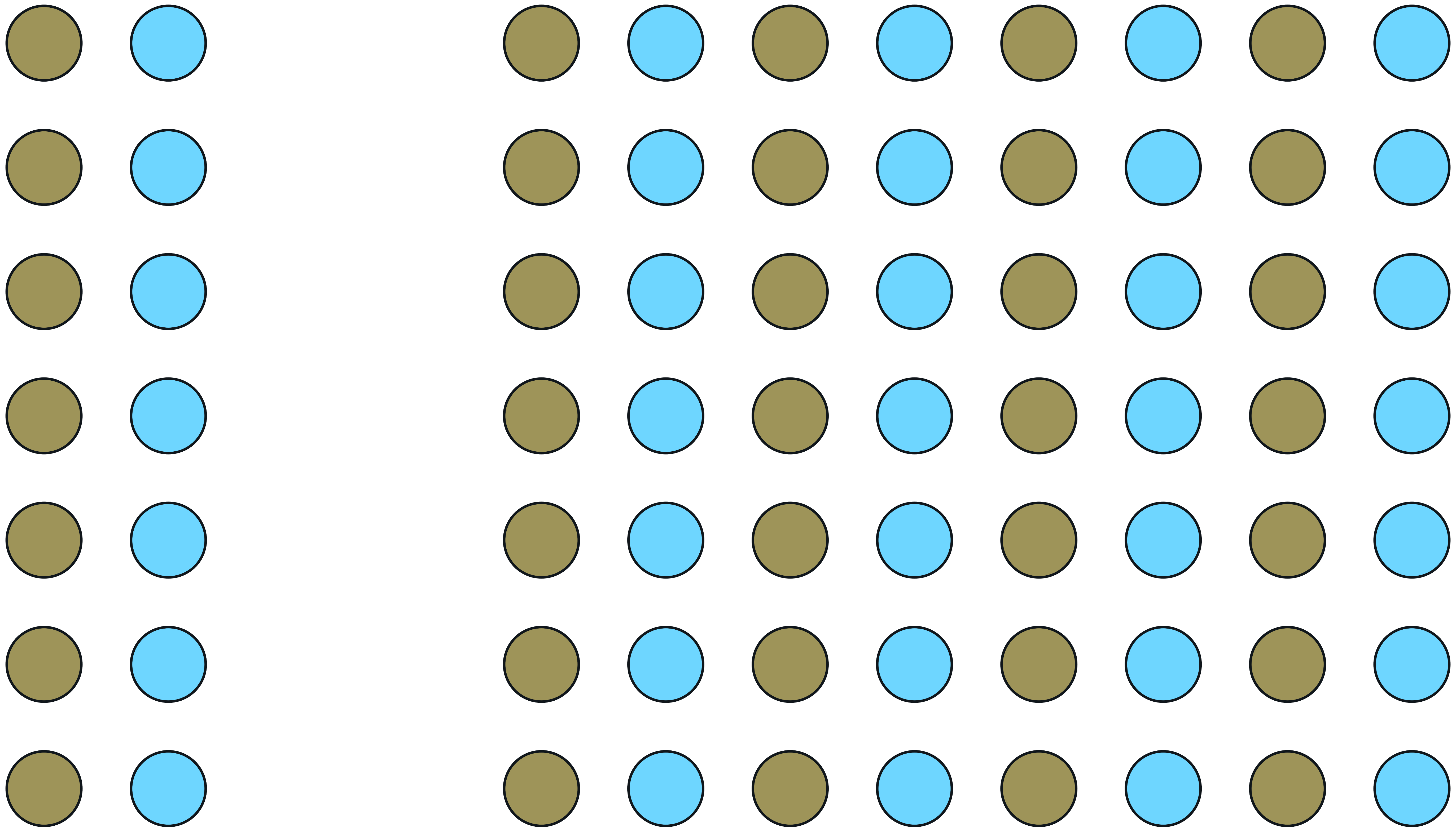
Grouping —

An arrangement of things into ***classes*** or ***categories***.

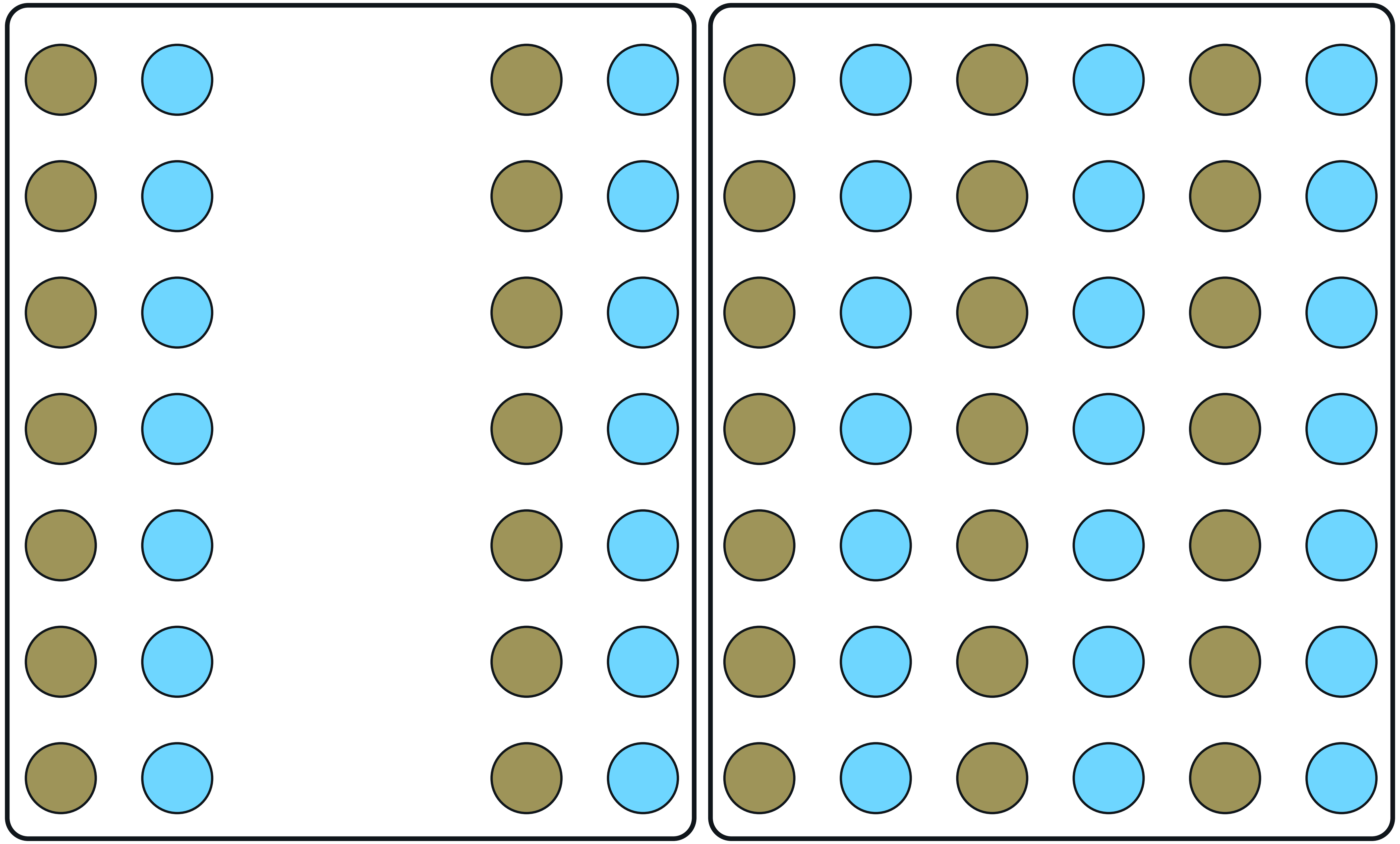
Gestalt Principle 1: **Similarity**



Gestalt Principle 2: **Proximity**



Gestalt Principle 3: **Enclosure**



1. Assignment **Review**
2. Principles of **Design**
3. **Gestalt Principles** for Data Visualization
4. **Introduction** to **Visual Variables**
5. **Applying Visual Variables**
6. **Tips** & **Best Practices**

Simplicity is key.

Only add visual elements that are necessary.

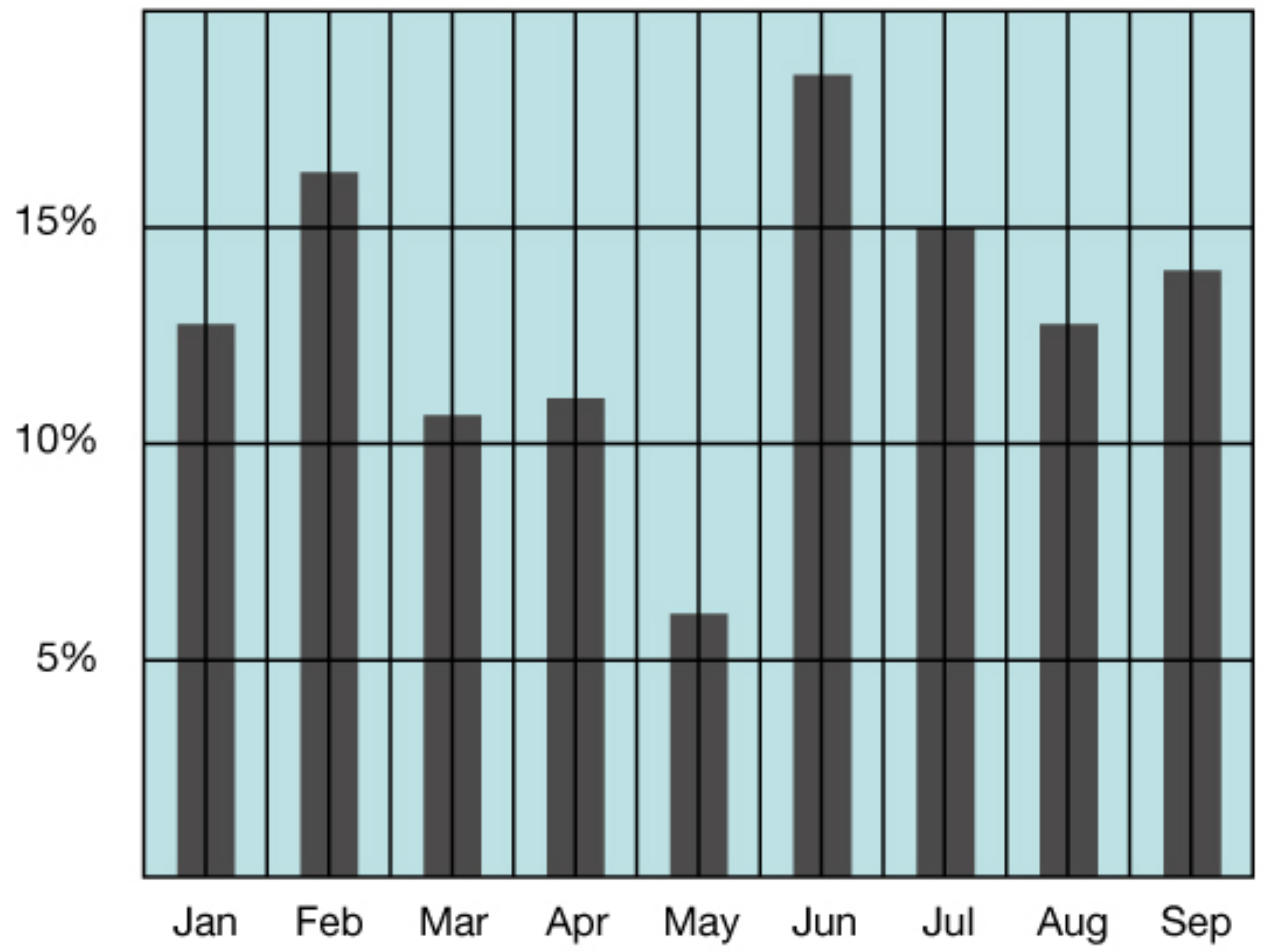
Data-ink—

The non-erasable ink used for the presentation of data

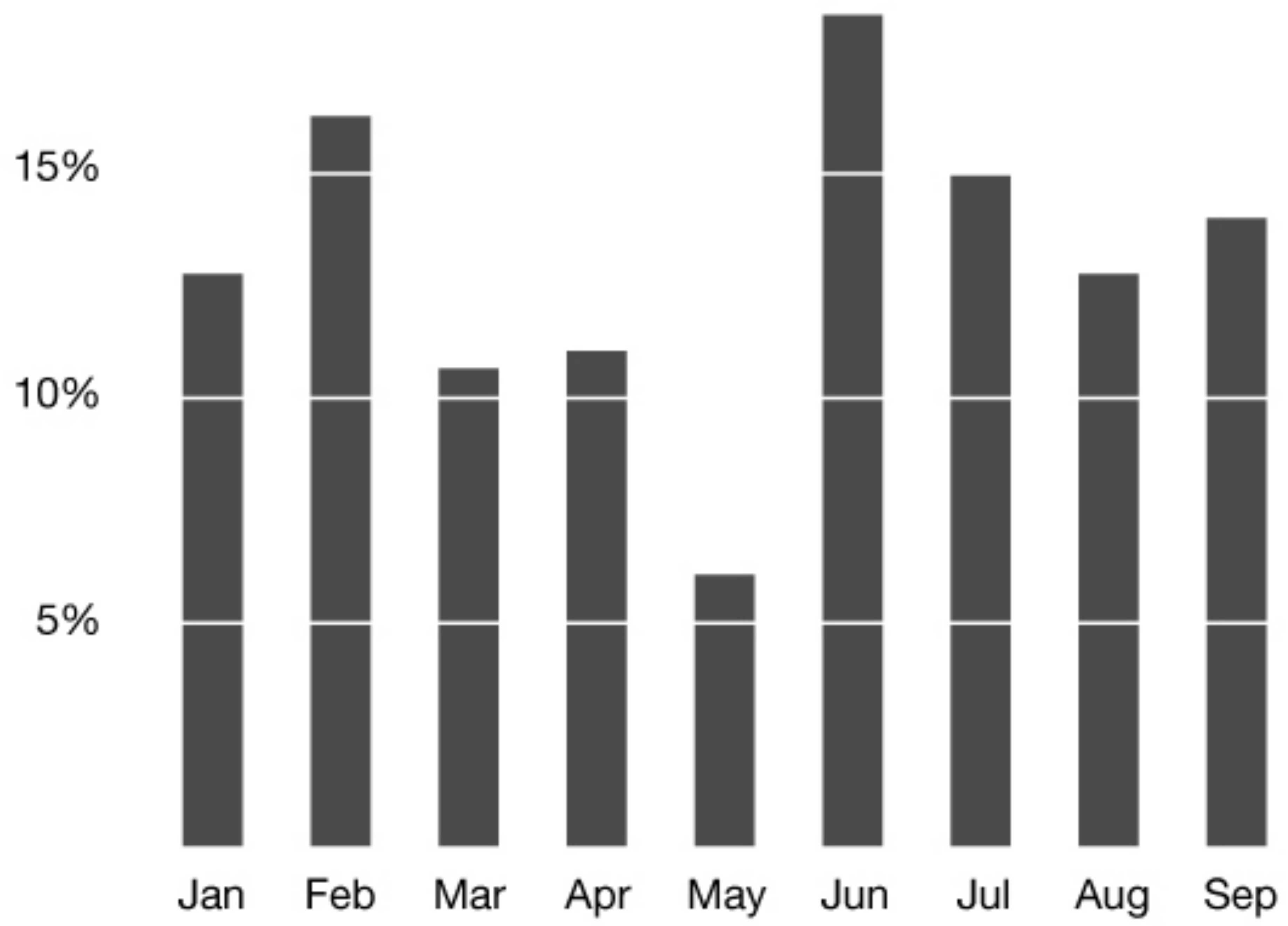
(Edward Tufte)

$$\text{Data-ink ratio} = \frac{\text{Data-ink}}{\text{Total ink used to print graphic}}$$

LOW DATA-INK RATIO



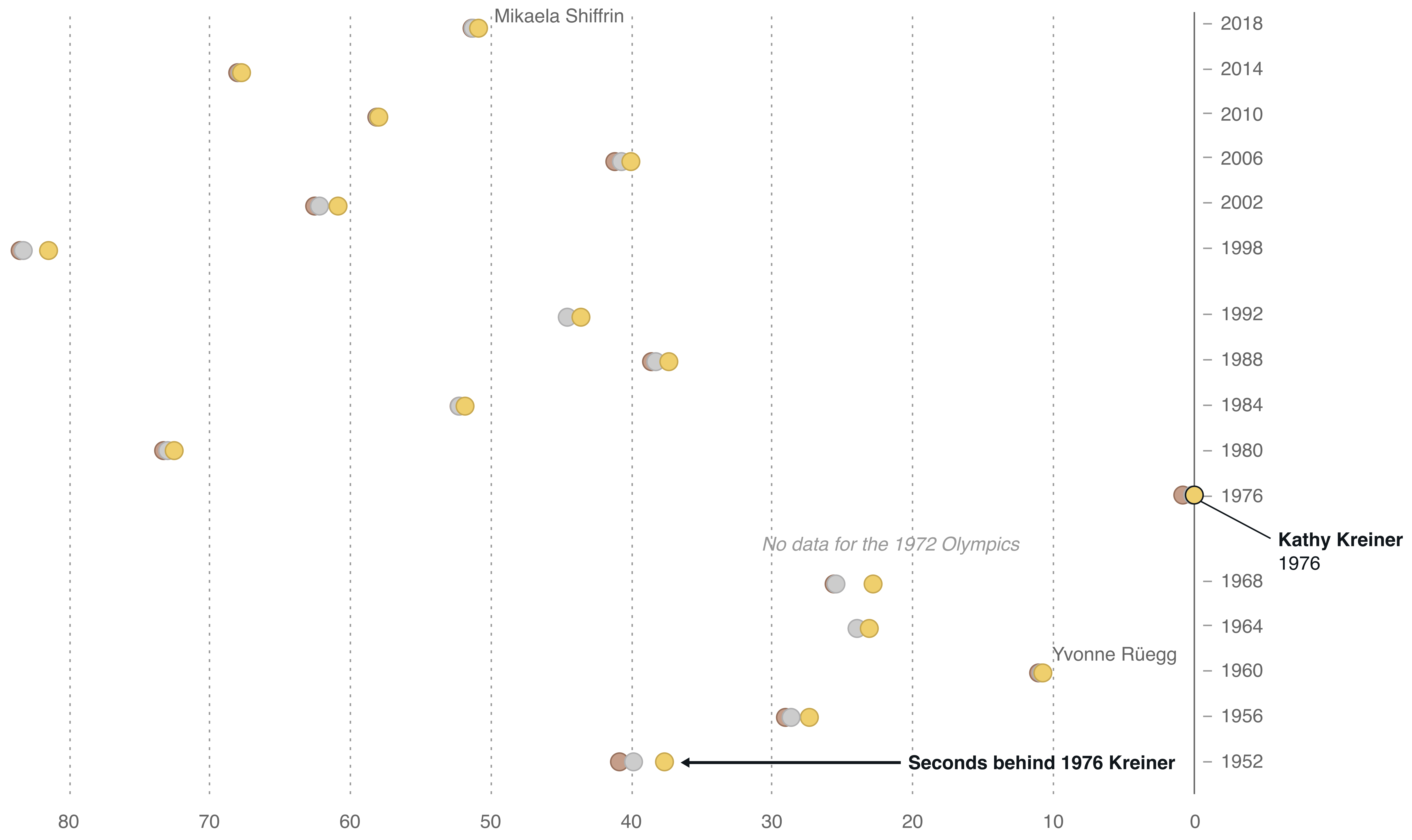
HIGH DATA-INK RATIO




MONSTROUS COSTS
Total House and Senate
campaign expenditures,
in millions
$300
250
200
150
100
50
1972
'74
'76
'78
'80
'82 est.
VOTE

“CHARTJUNK”

Work with **implicit metaphors**.

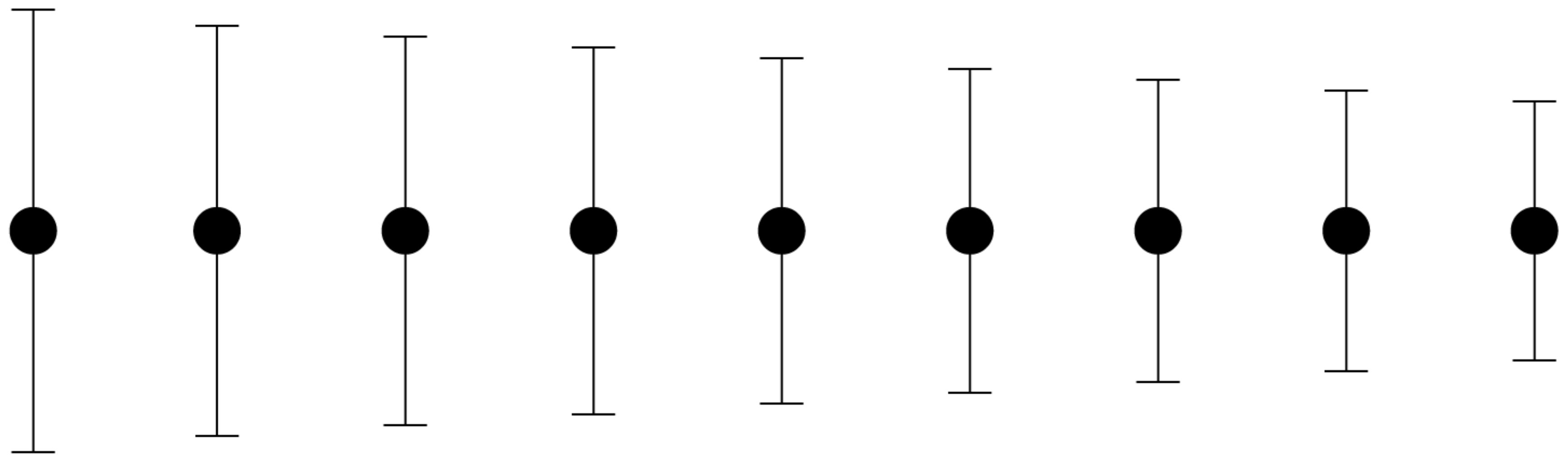


Mikaela Shiffrin
2018
2014
2010
2006
2002
1998
1992
1988
1984
1980
1976
Kathy Kreiner
1976
No data for the 1972 Olympics
1968
1964
Yvonne Rüegg
1960
1956
Seconds behind 1976 Kreiner
1952
80
70
60
50
40
30
20
10
0

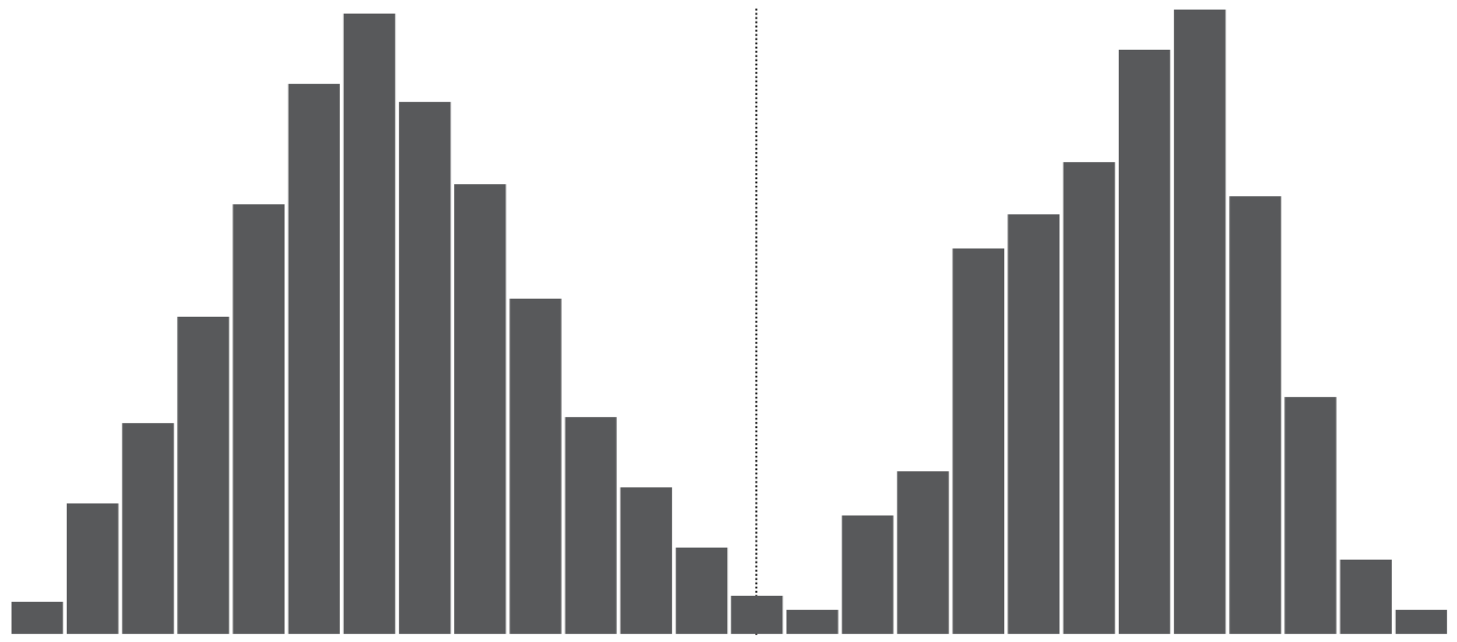
Make **uncertain or missing values apparent** to the viewer.

Use **visual methods** to call out fuzziness, contextual values, or ranges of possibility…

Technique: **Ranges**



Technique: **Distributions**



Technique: **Obscurity**

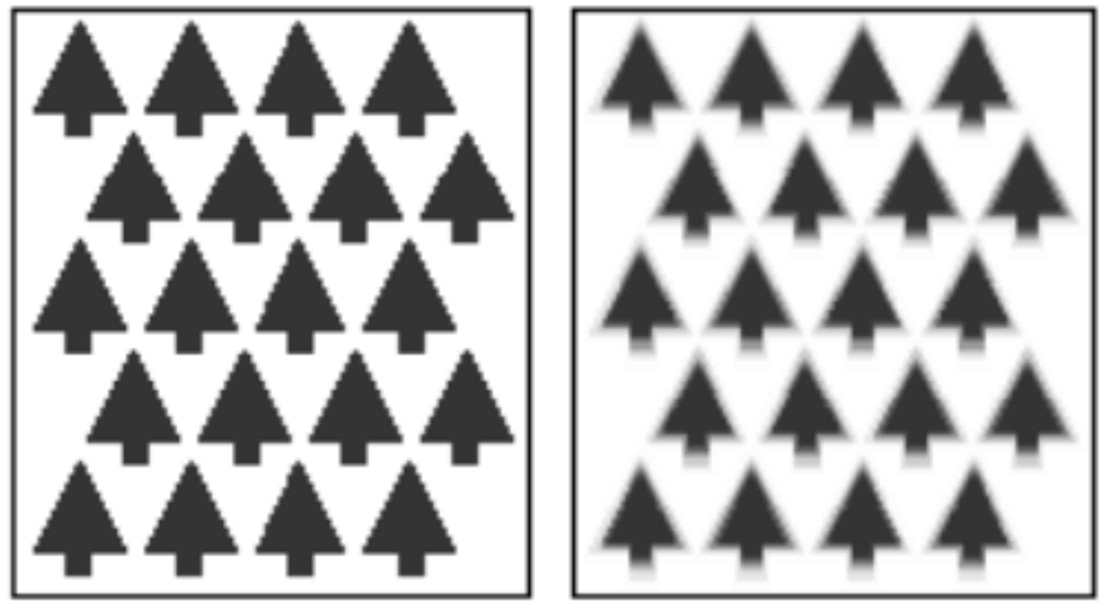
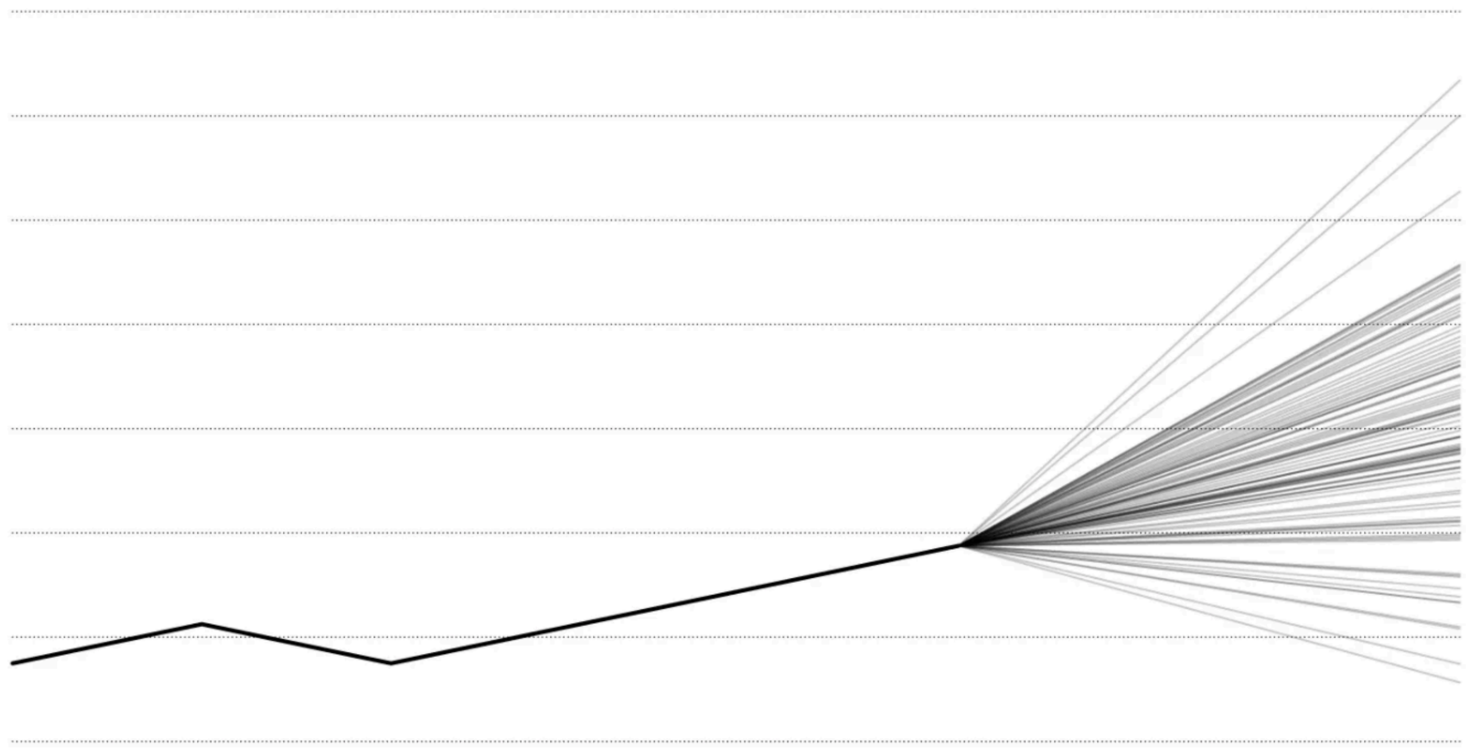


Fig. 5. Certain and uncertain depiction of land cover type.

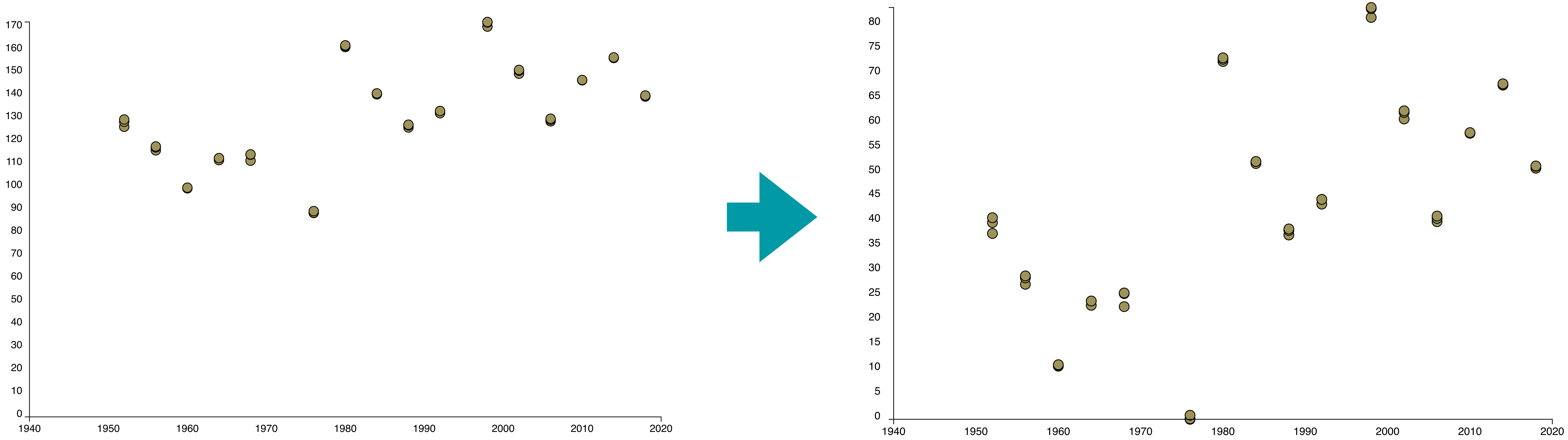
Technique: **Multiple Outcomes**



Source: ***FlowingData***

…or, make uncertainty into an **attribute**.

Don’t make the viewer do math.



170
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2000
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2020

Sometimes, **visualization is not the answer**.

11

slides in this presentation have a teal background.