

Data Visualization & Design

Week 2

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)

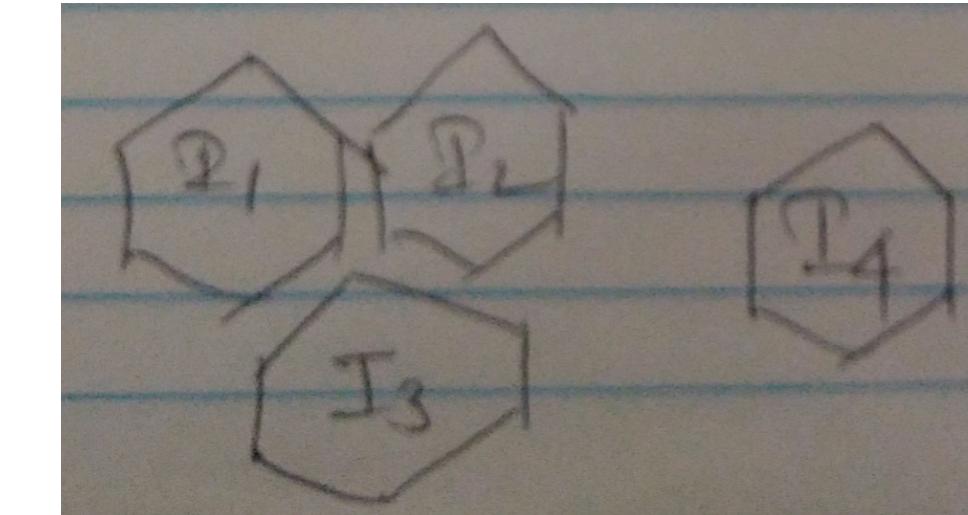
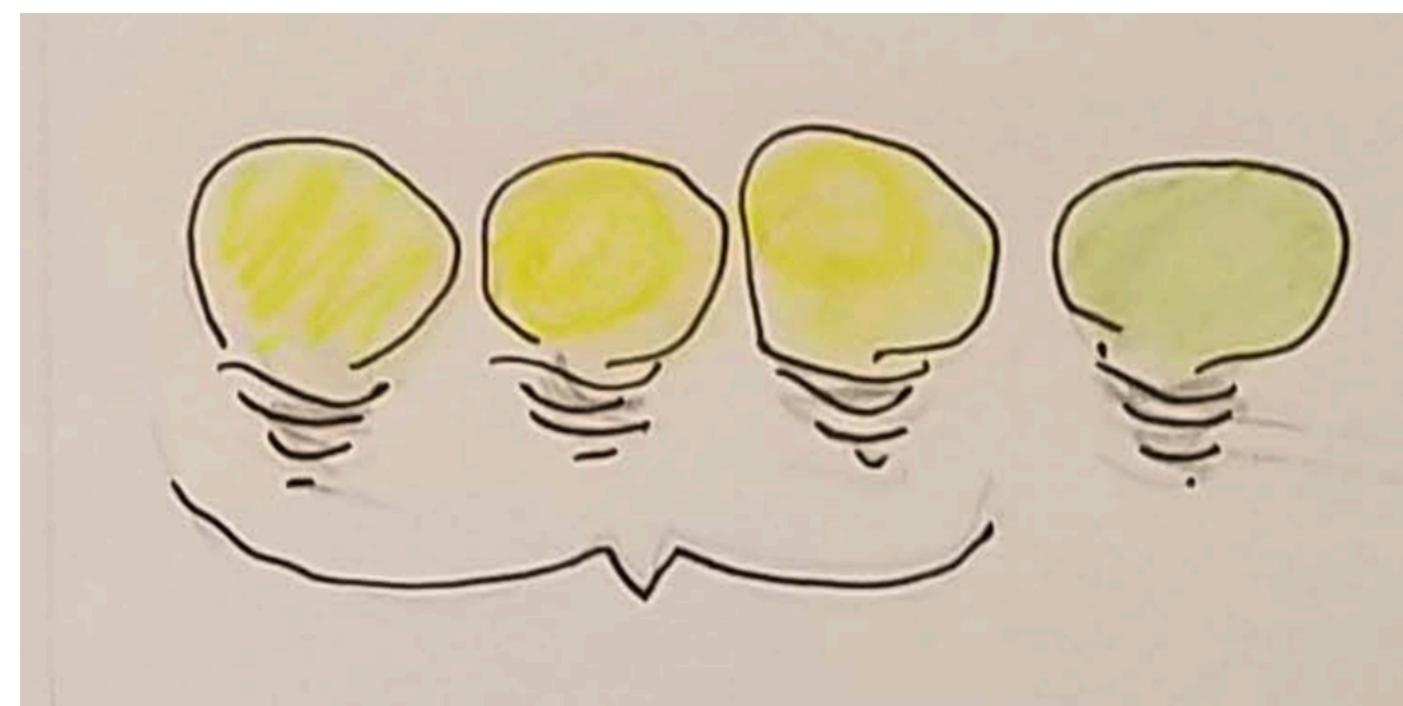
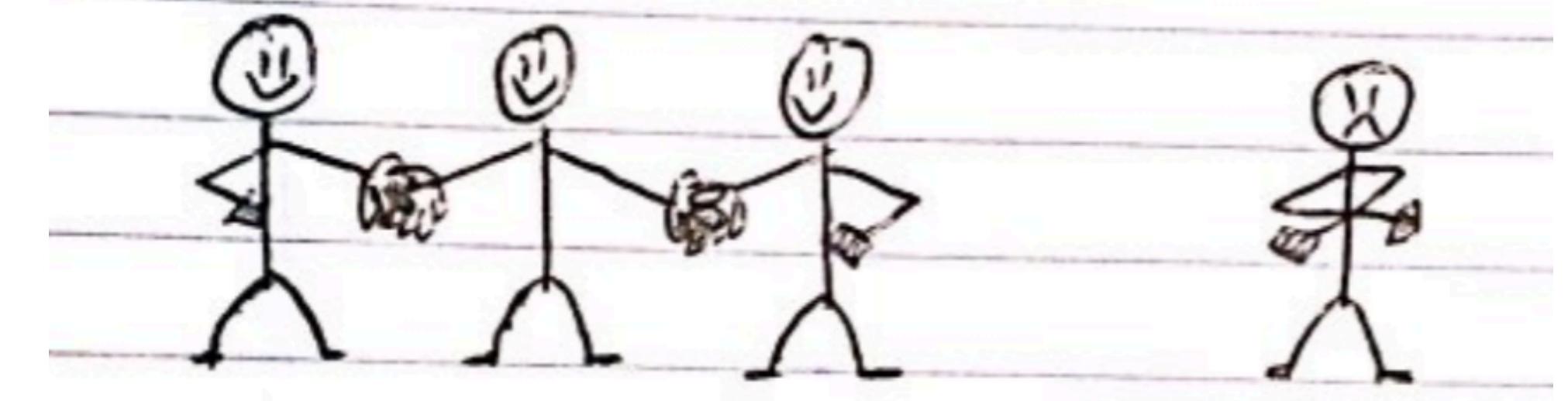
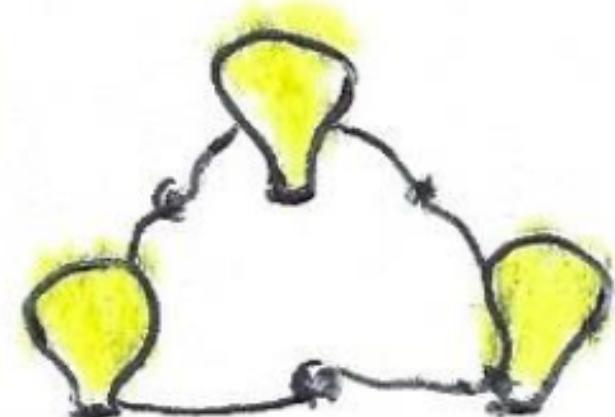
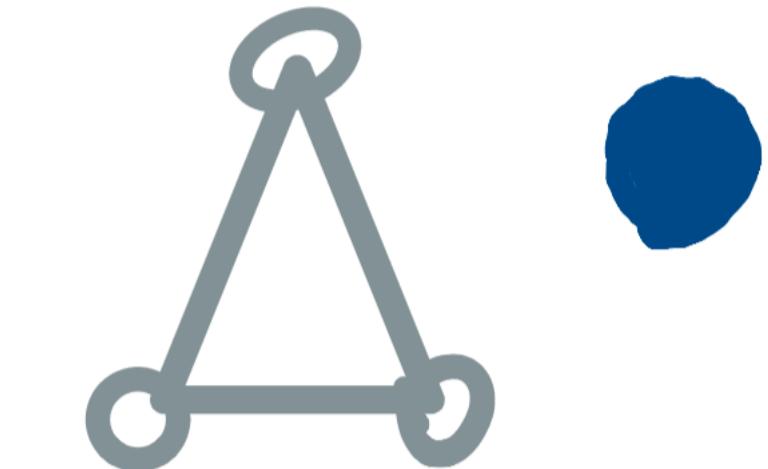
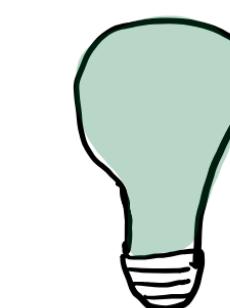
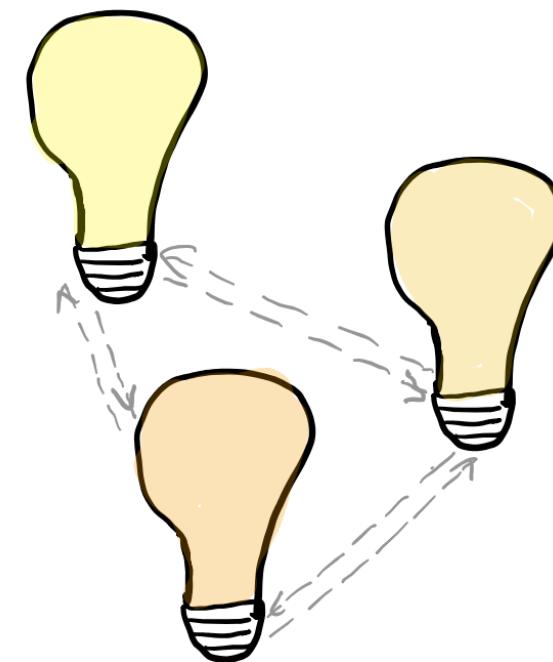
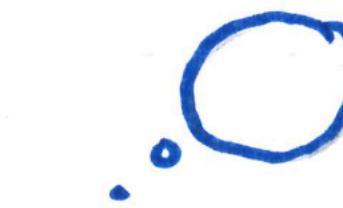
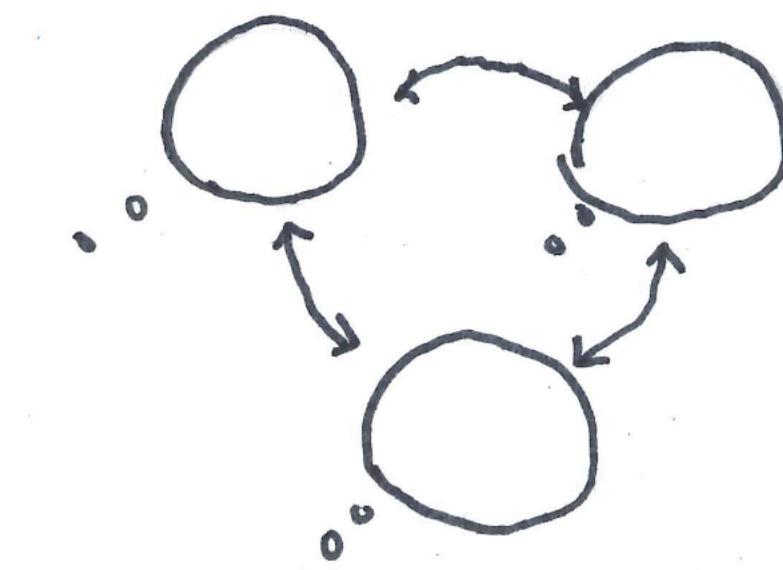
Terms that suggest ***similarity***

- 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
- **Linking** together

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



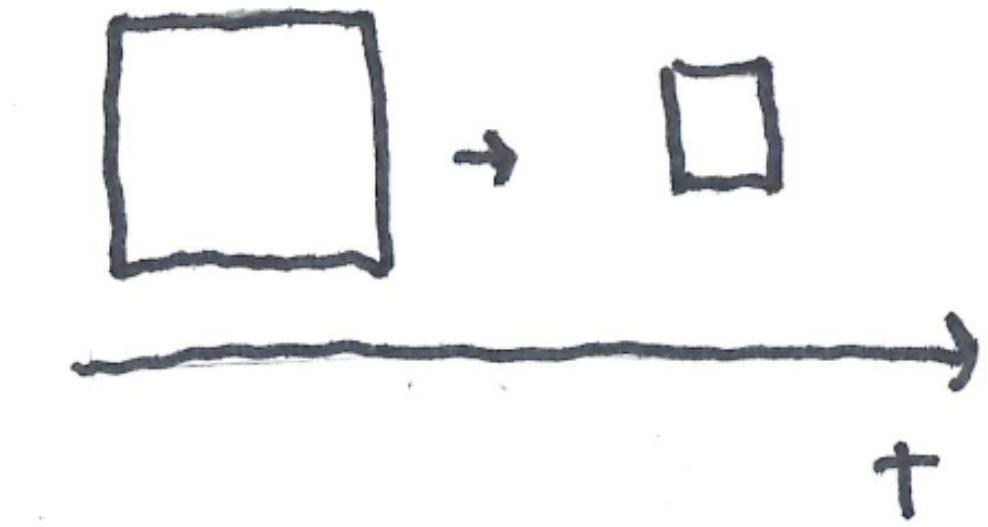
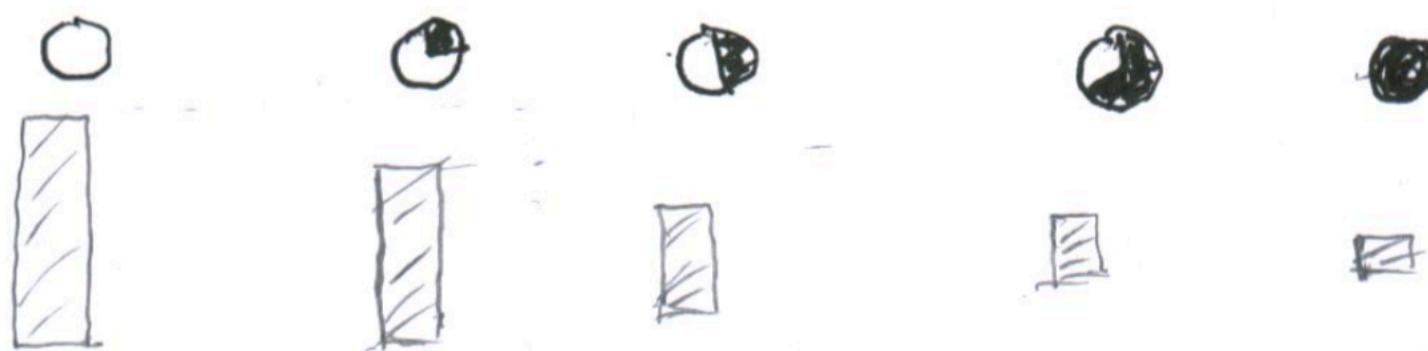
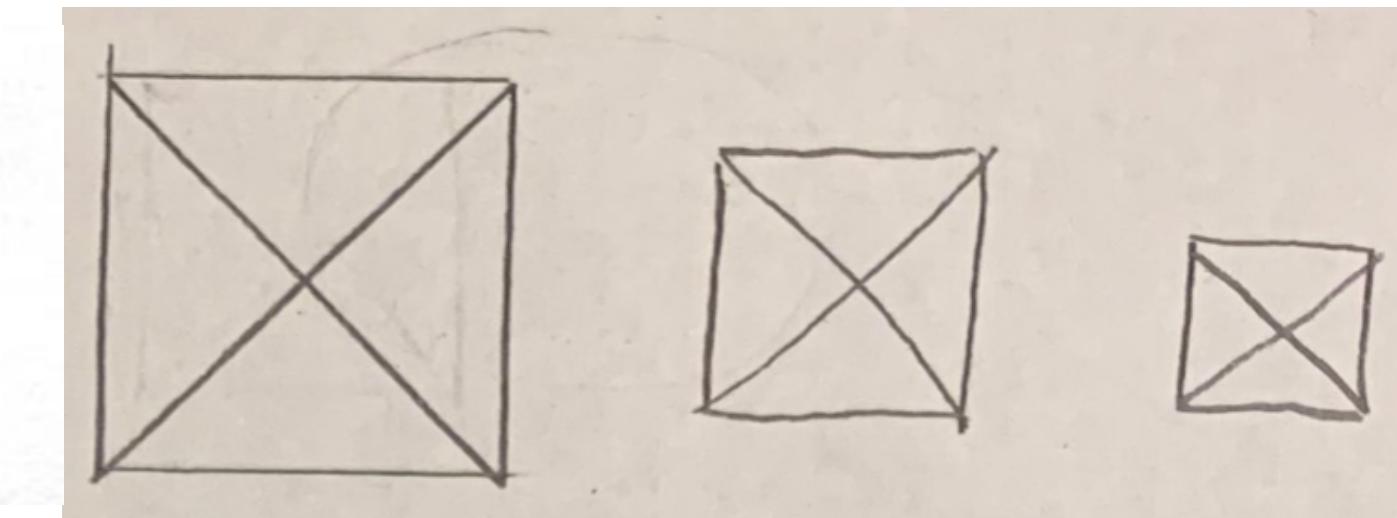
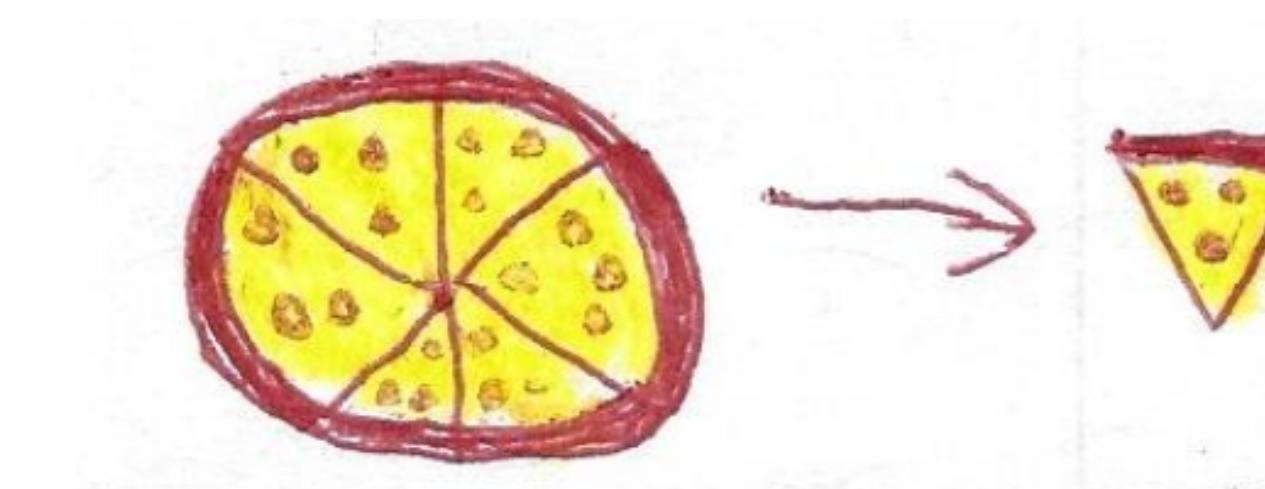
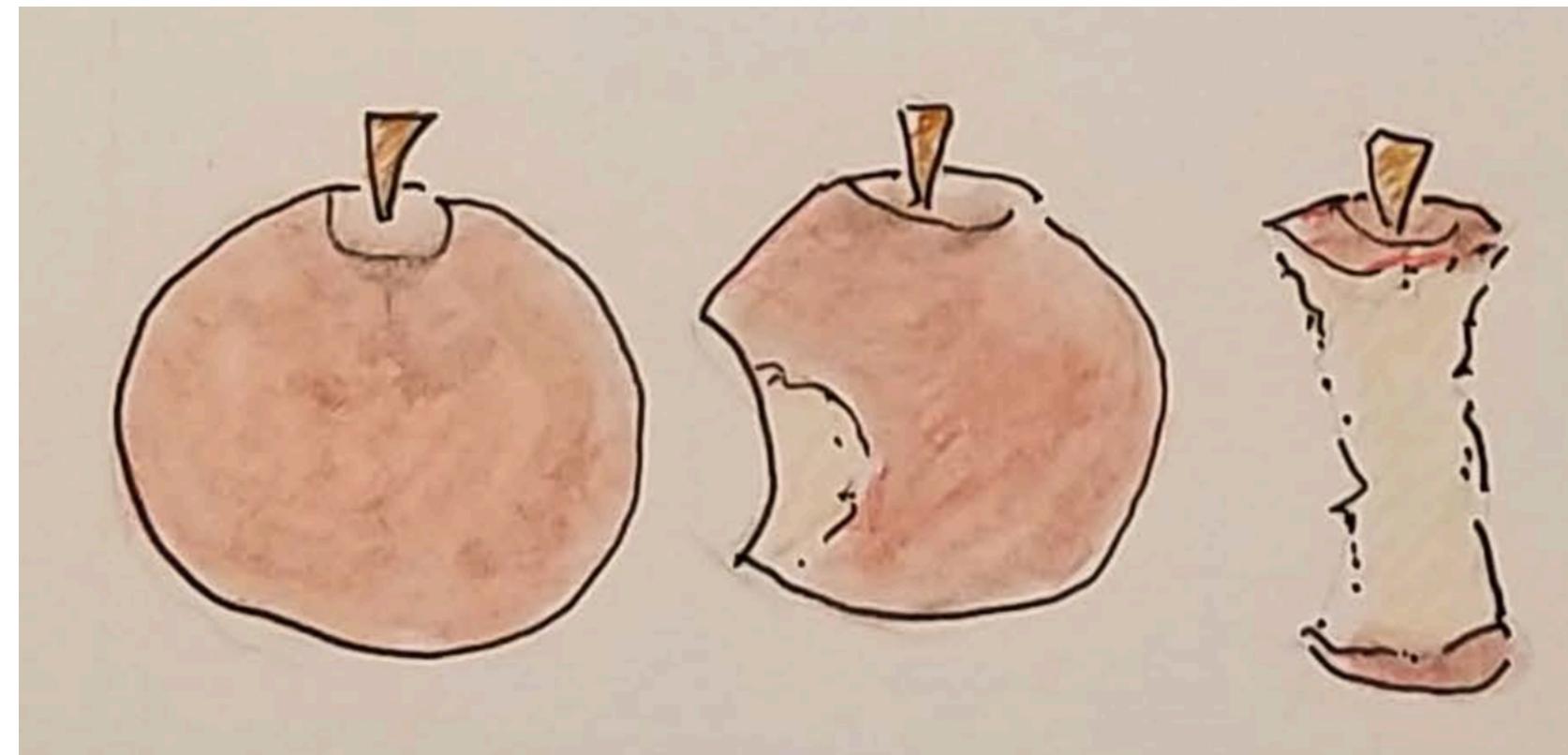
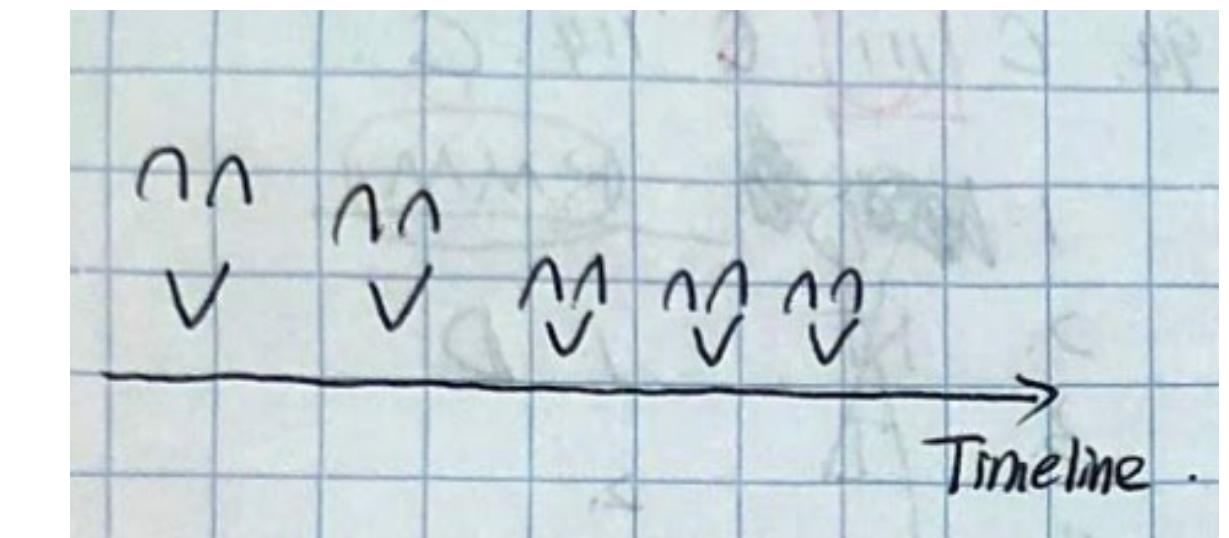
Terms that suggest ***evolution***

- 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)
- **Frame-by-frame**

“It used to be bigger”



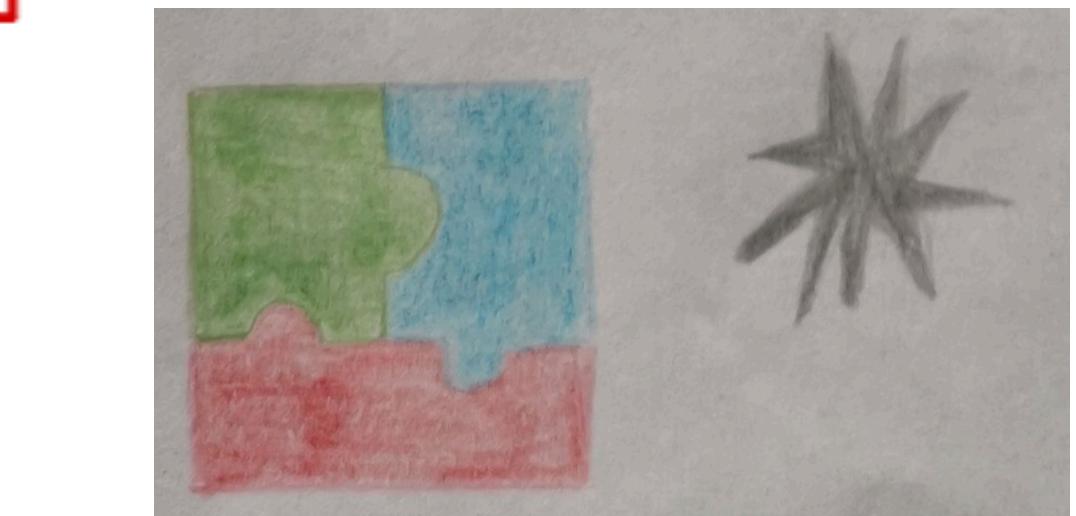
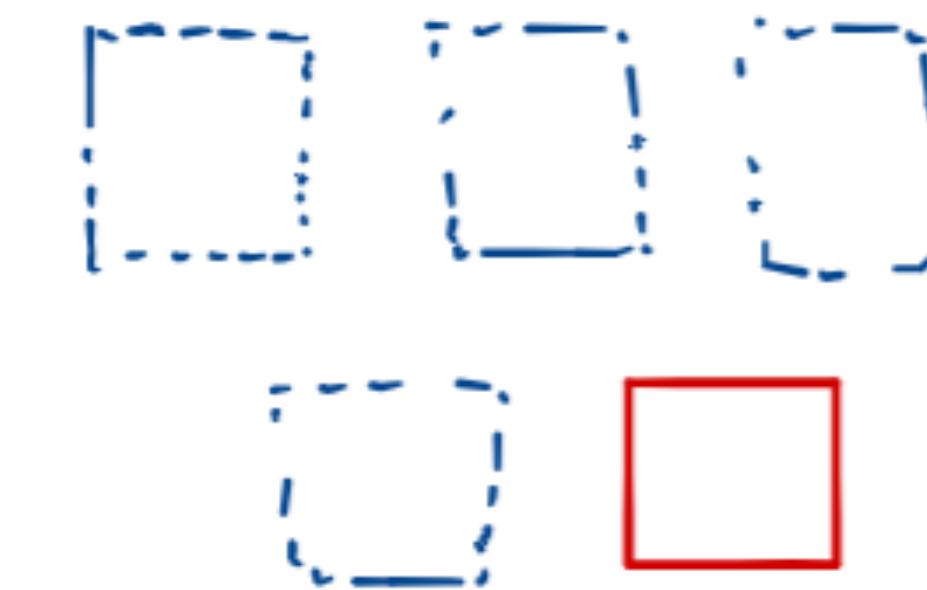
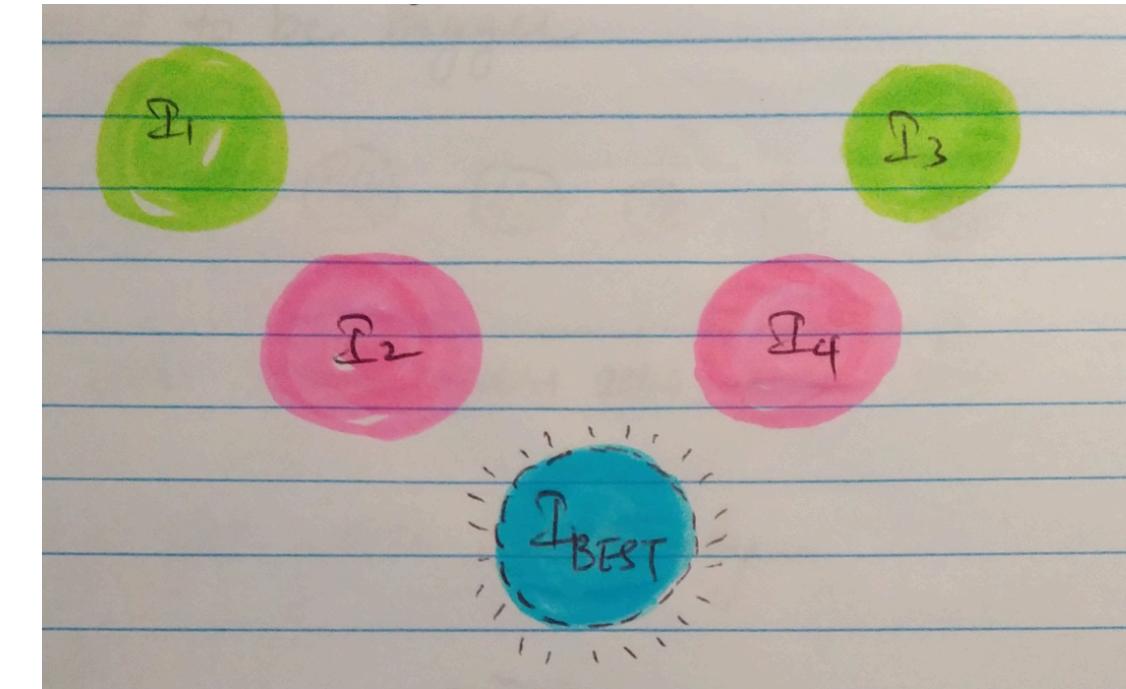
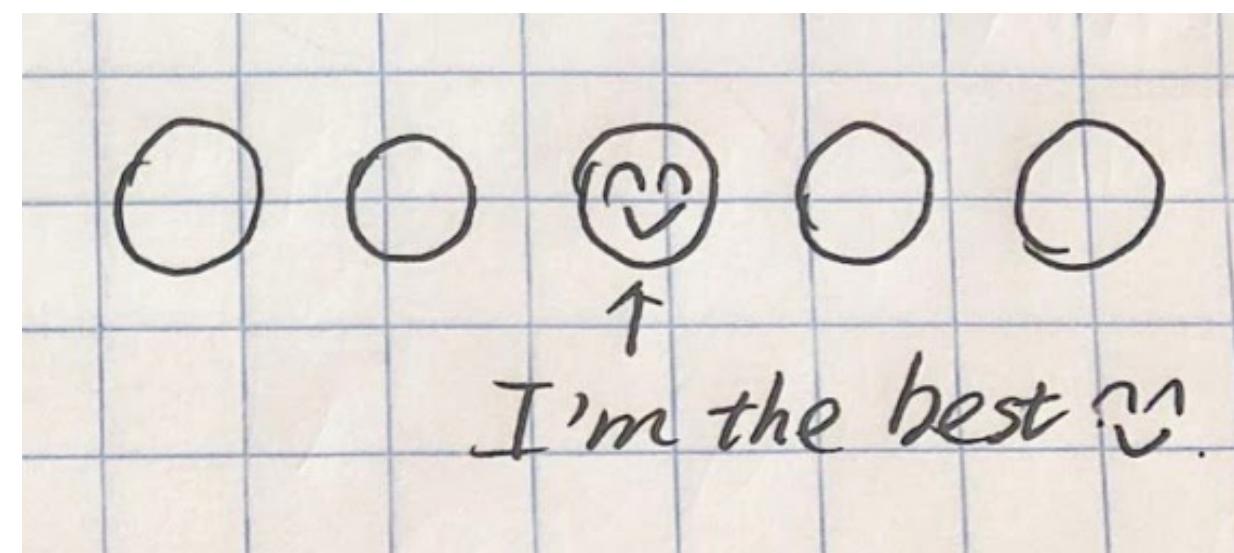
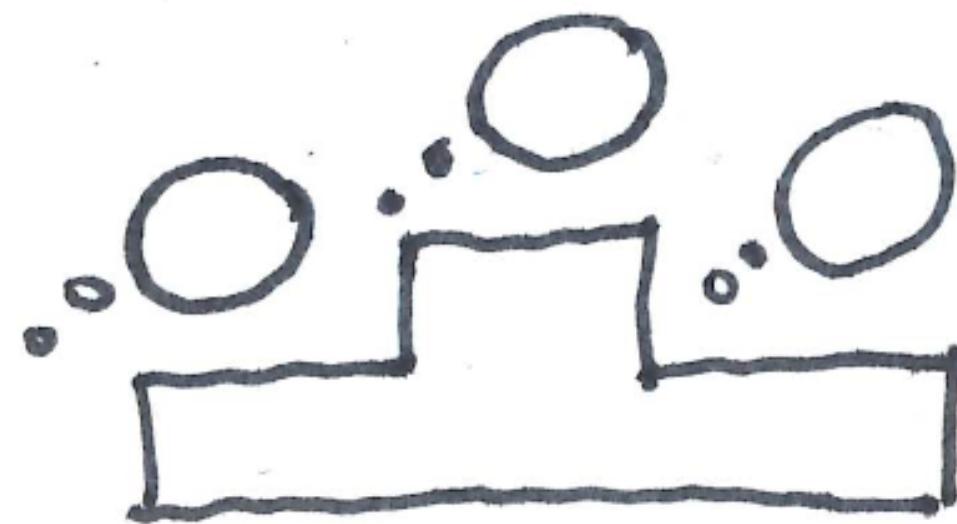
Terms that suggest *individuality*

- 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**
- Having an isolated **position**

“There are many ideas, but one is best”



Assignment 1: **Visual Semantics**

First draft: **2/4**

Final: **2/9, 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.

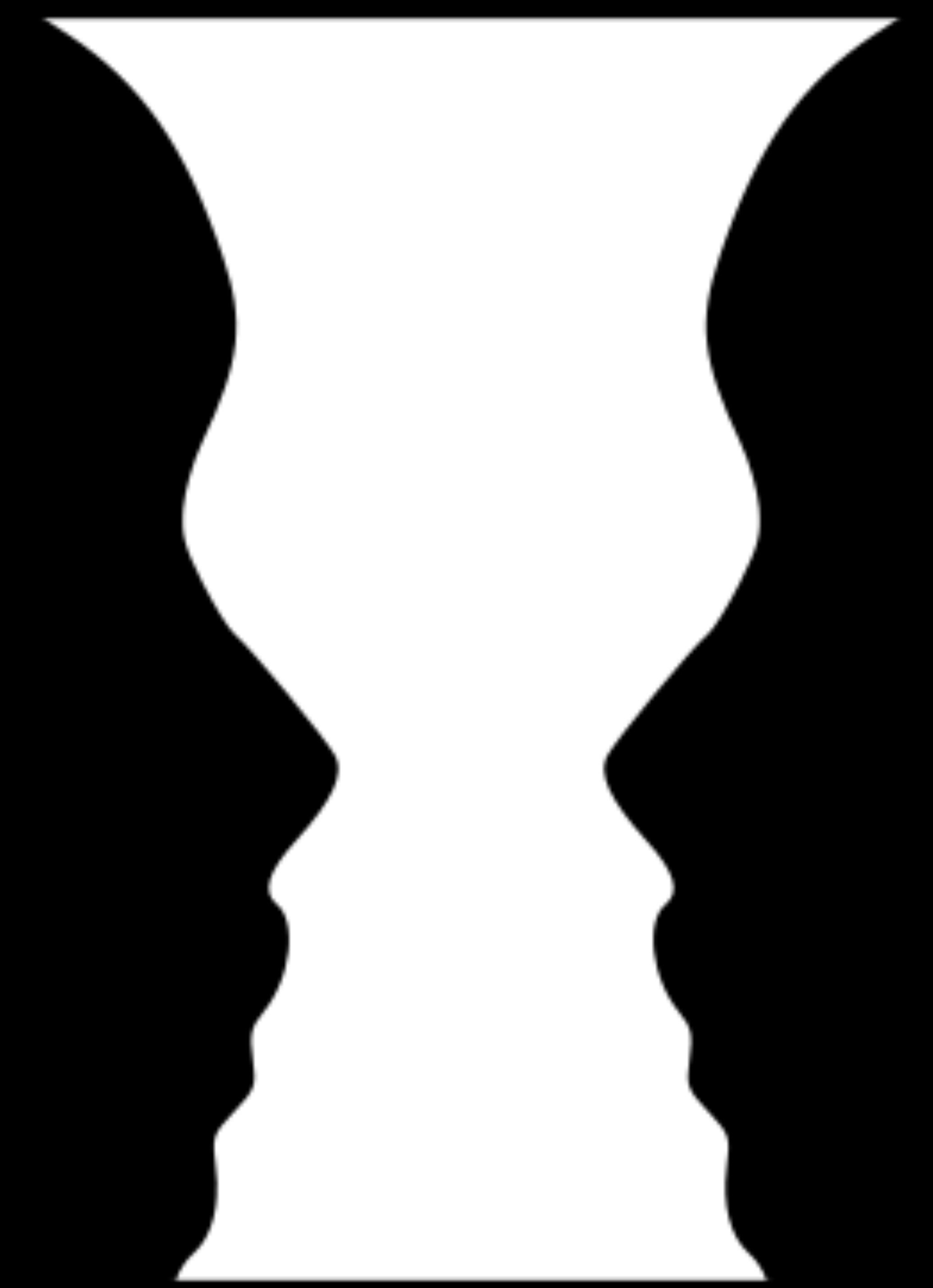
ex. Store entrances that reduce the barrier to entry (lures).



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.



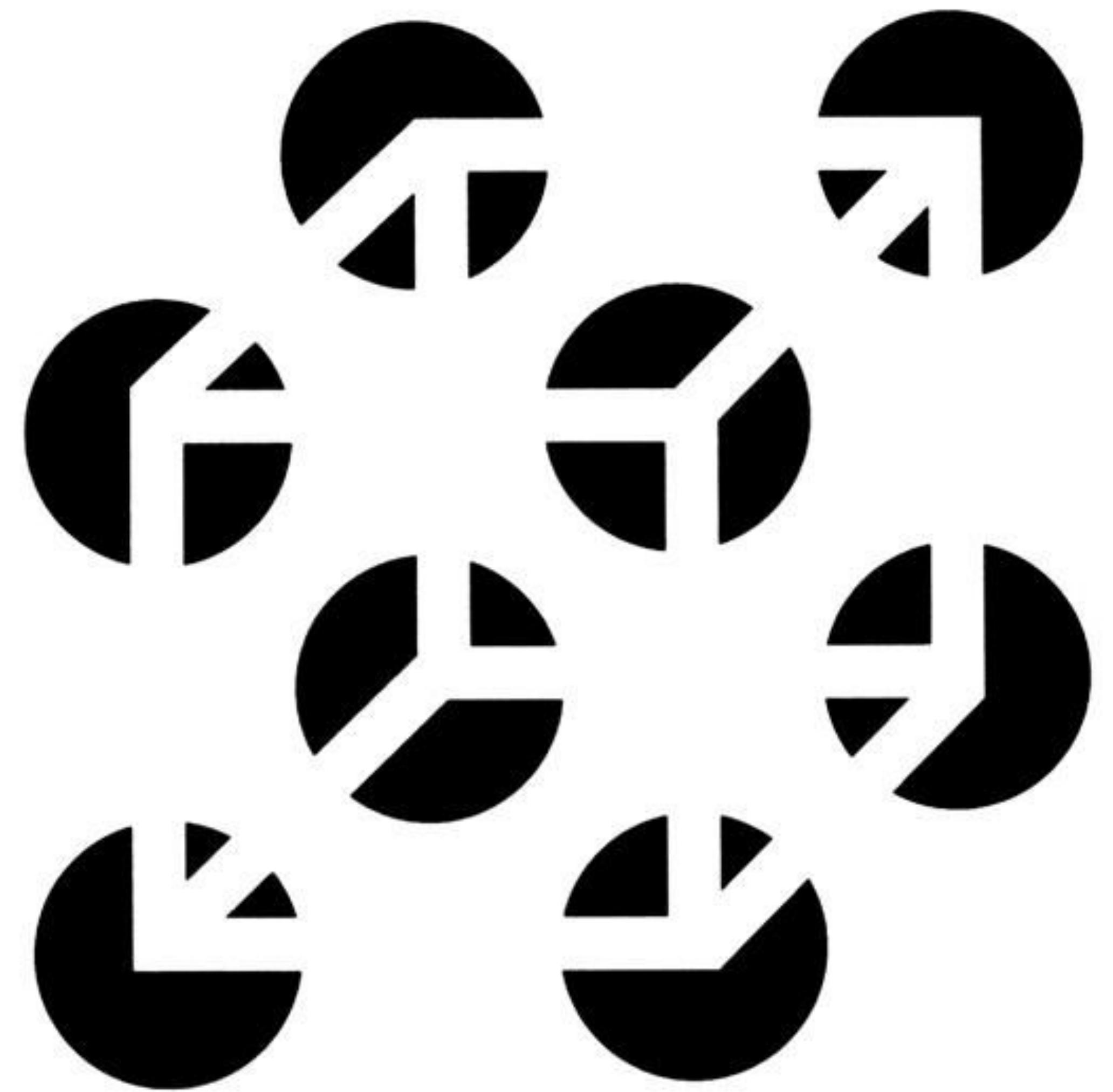
Highlighting –

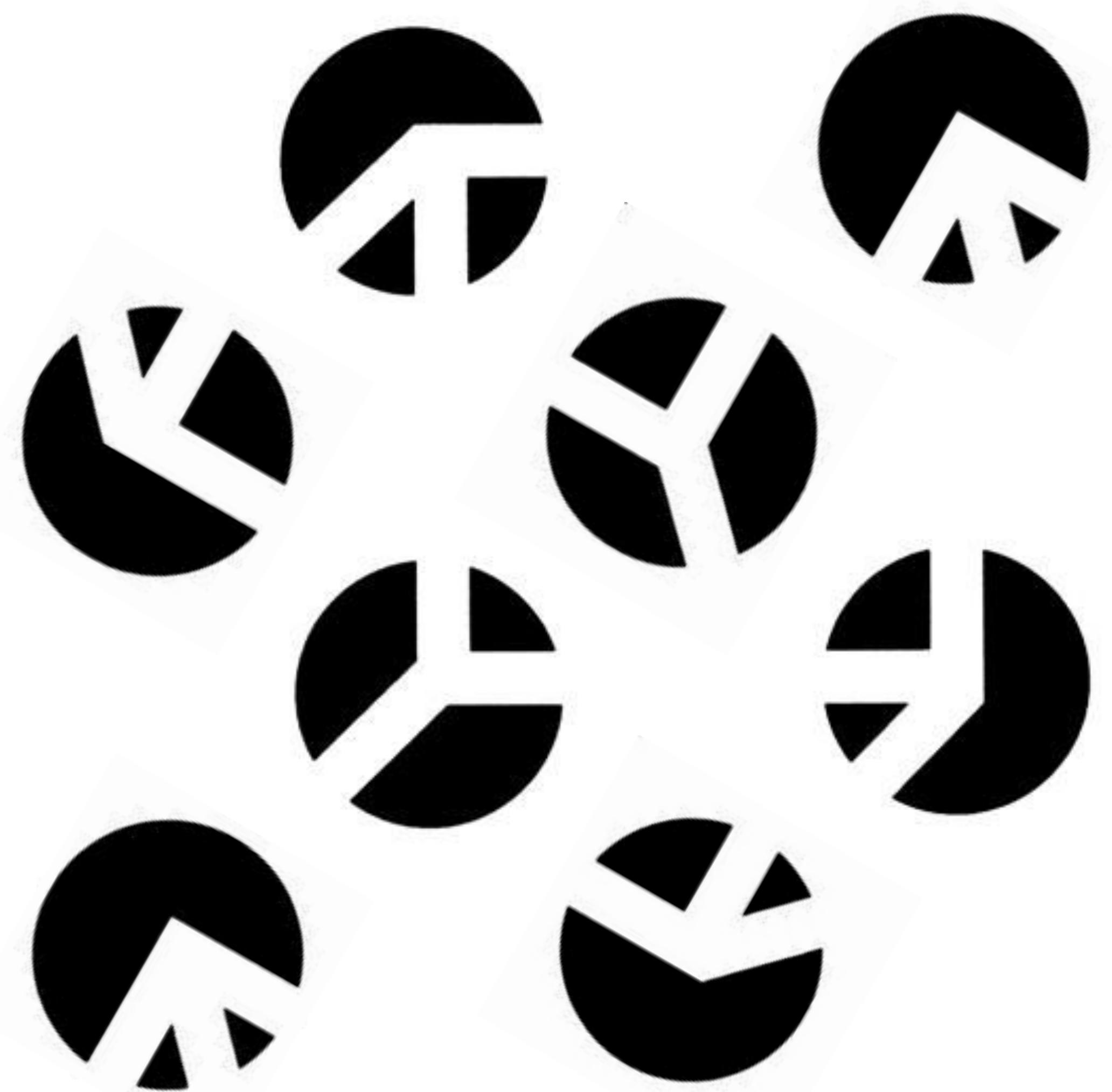
A technique for bringing attention to an area of text or image.

ex. **Bold**, *italics*, or underline.

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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





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

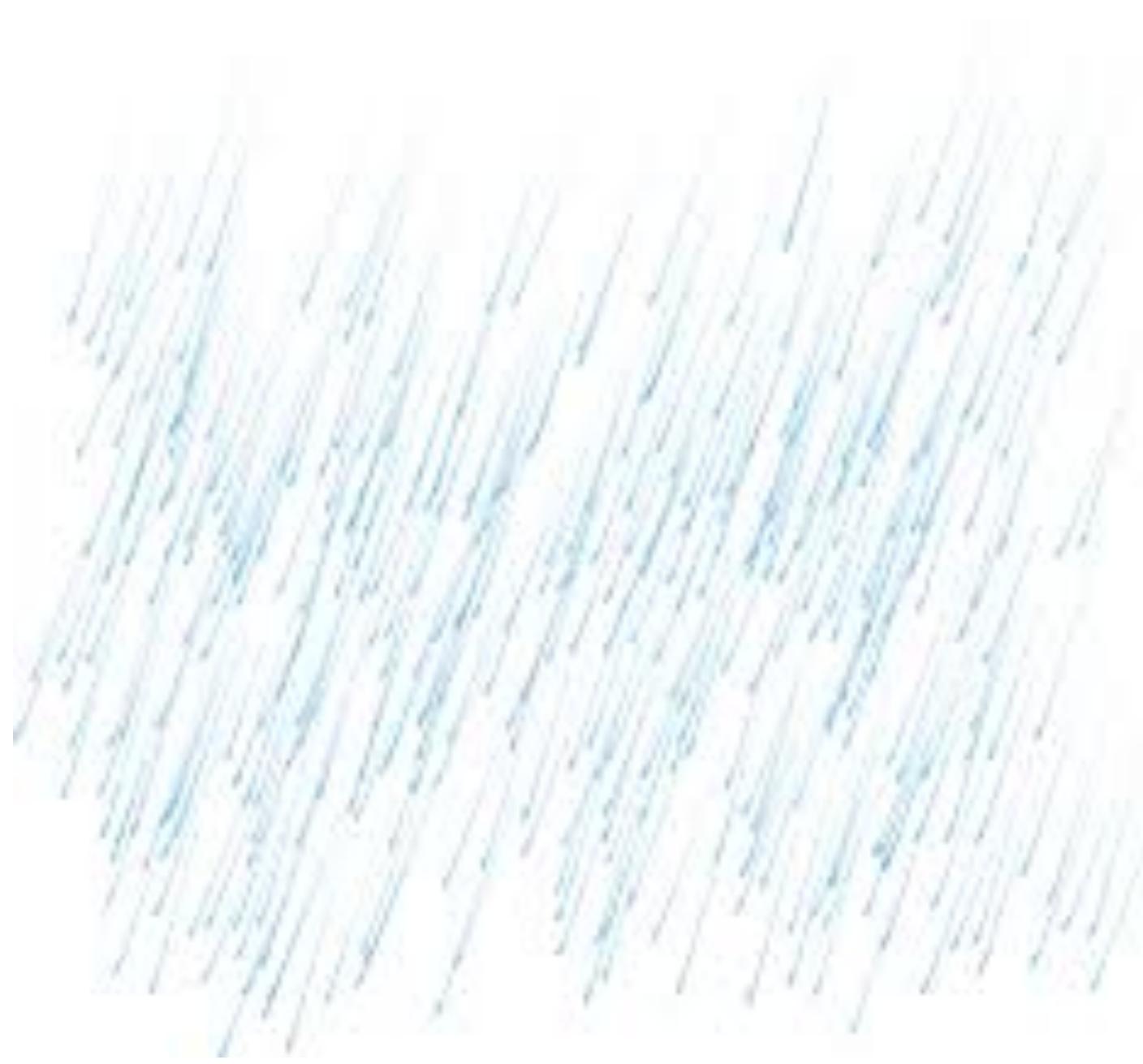




2. Association hypothesis –

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



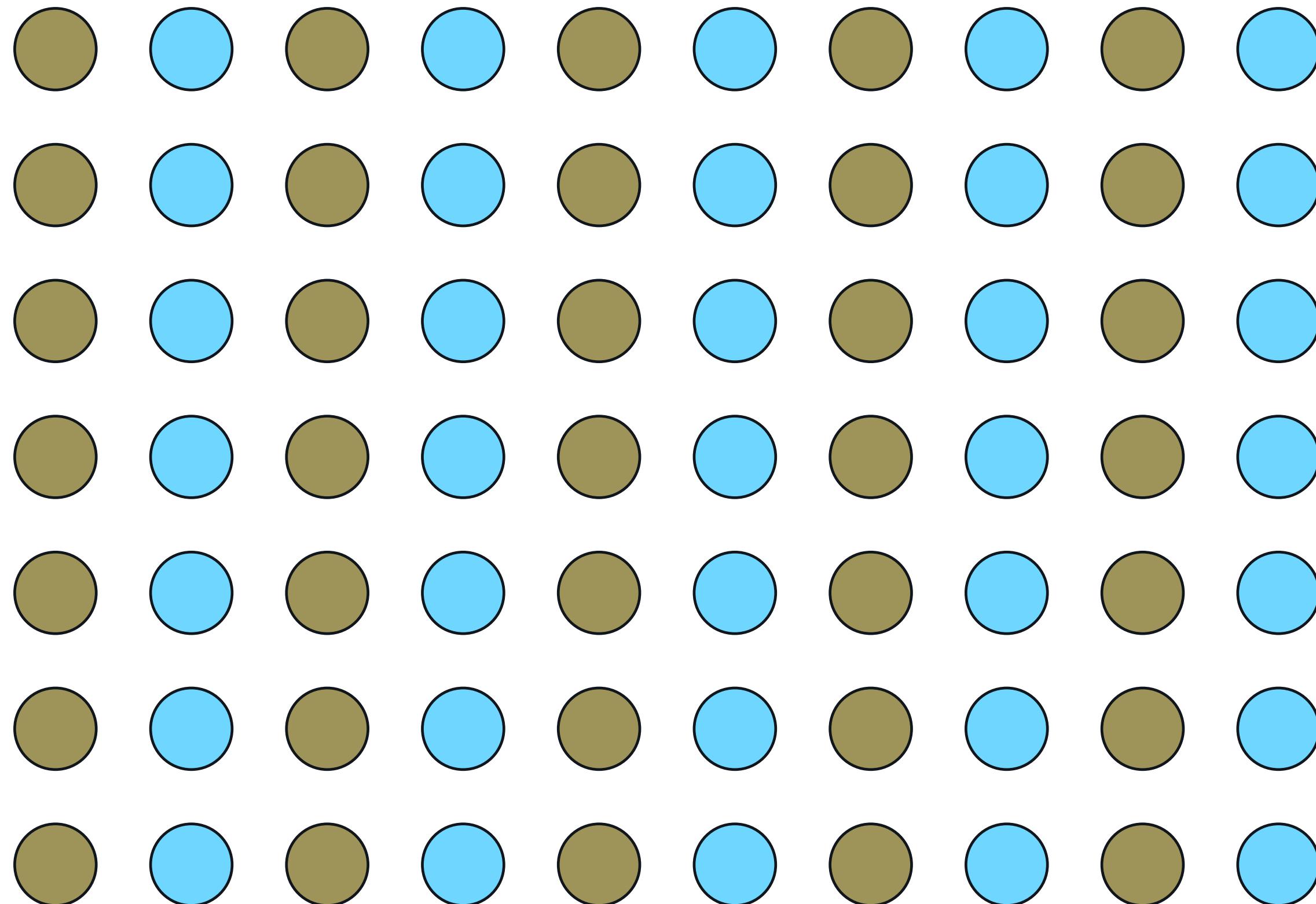


Principles of perception are useful for improving traditional bar and line charts...

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

3 Gestalt Principles

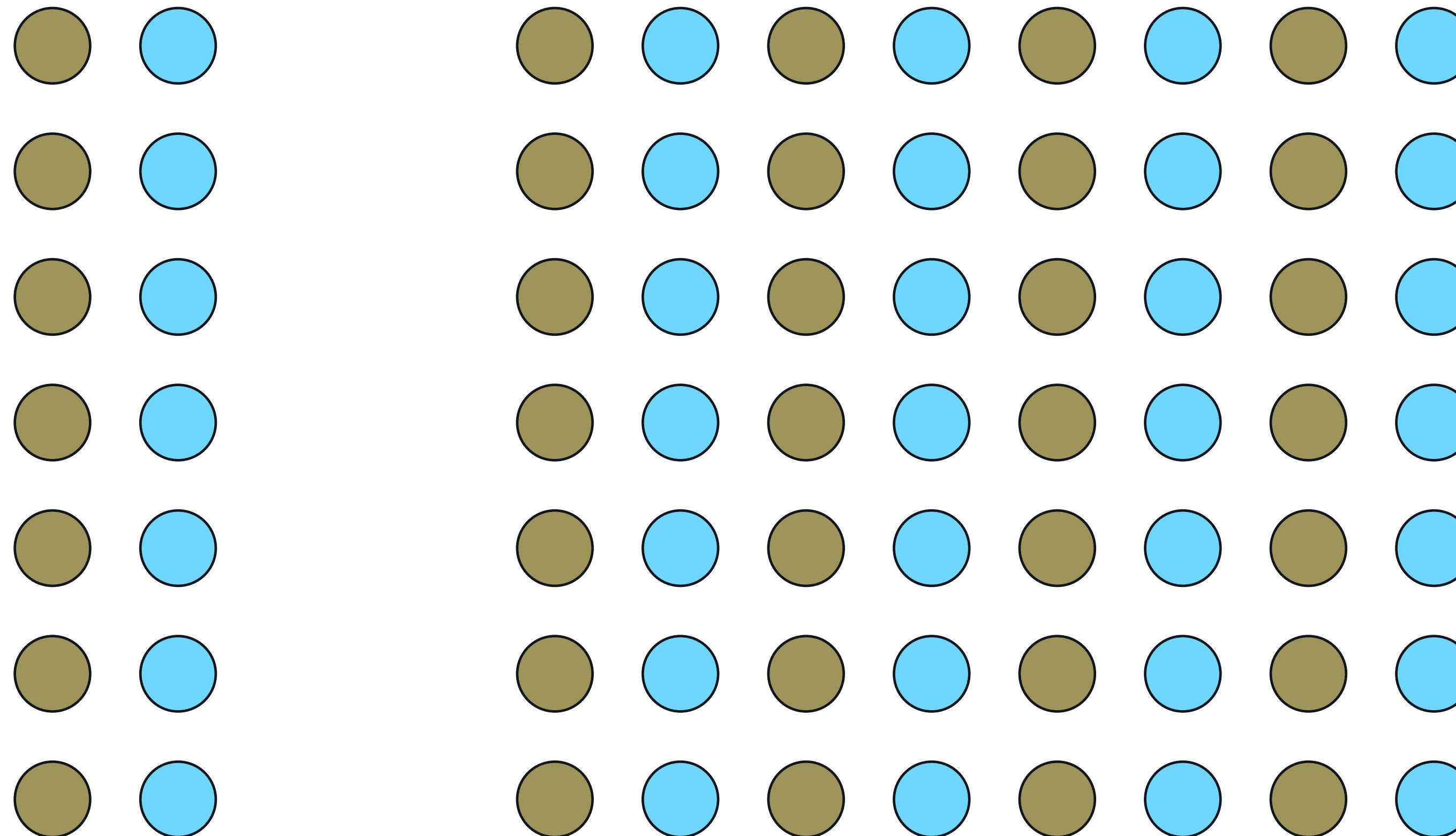
Gestalt Principle 1: **Similarity**



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**

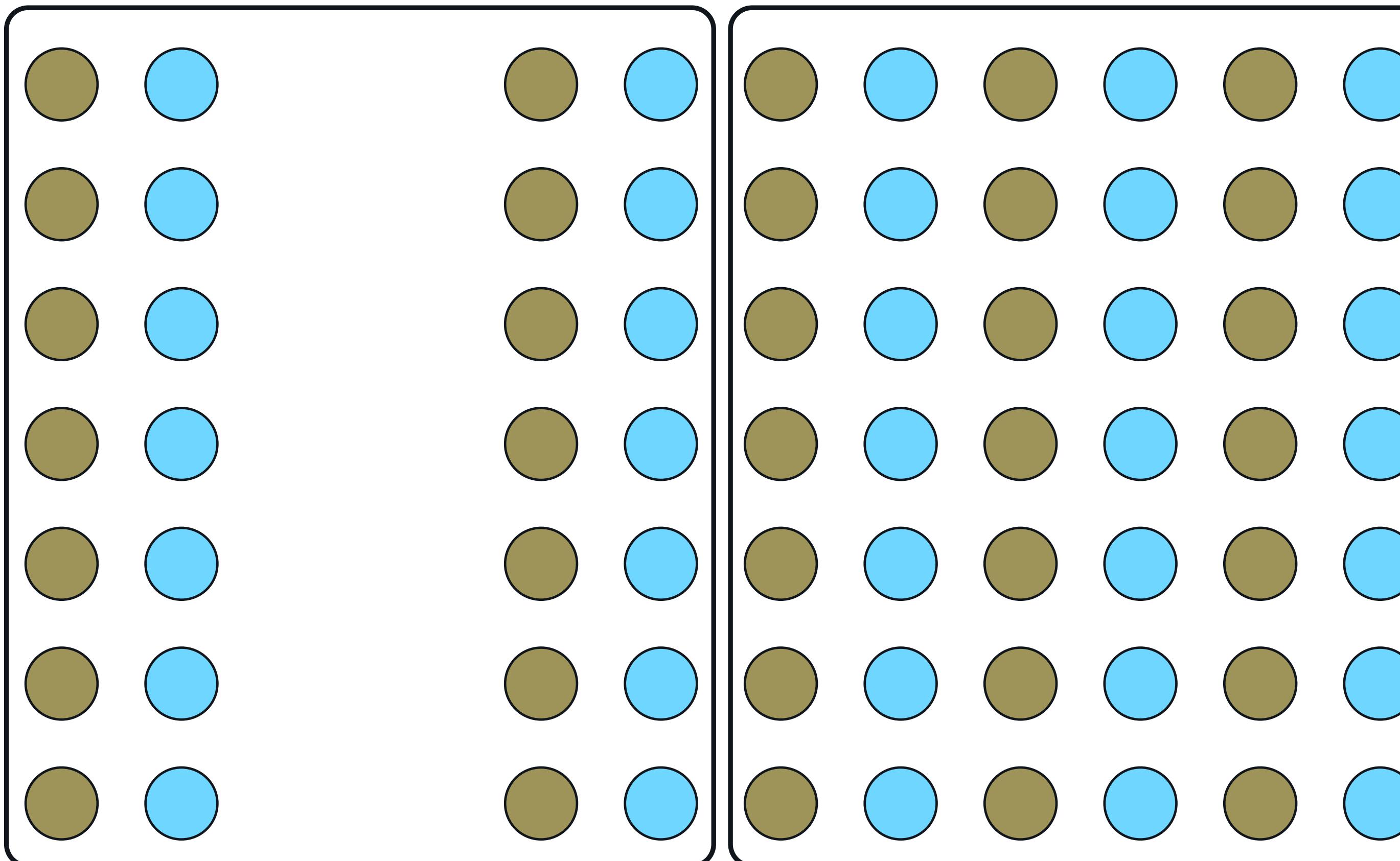
Gestalt Principle 2: **Proximity**



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

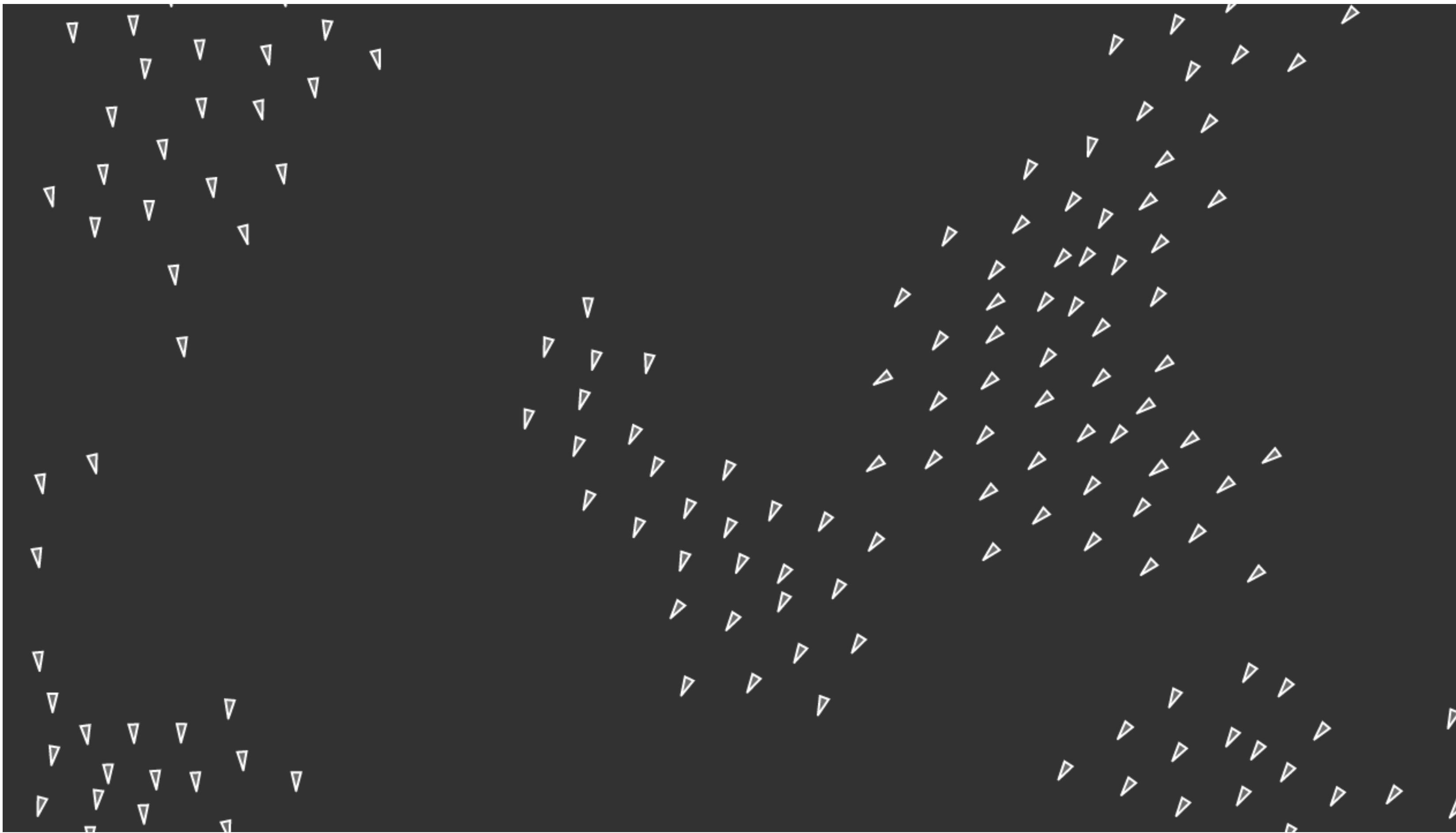
Gestalt Principle 3: **Enclosure**



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?**

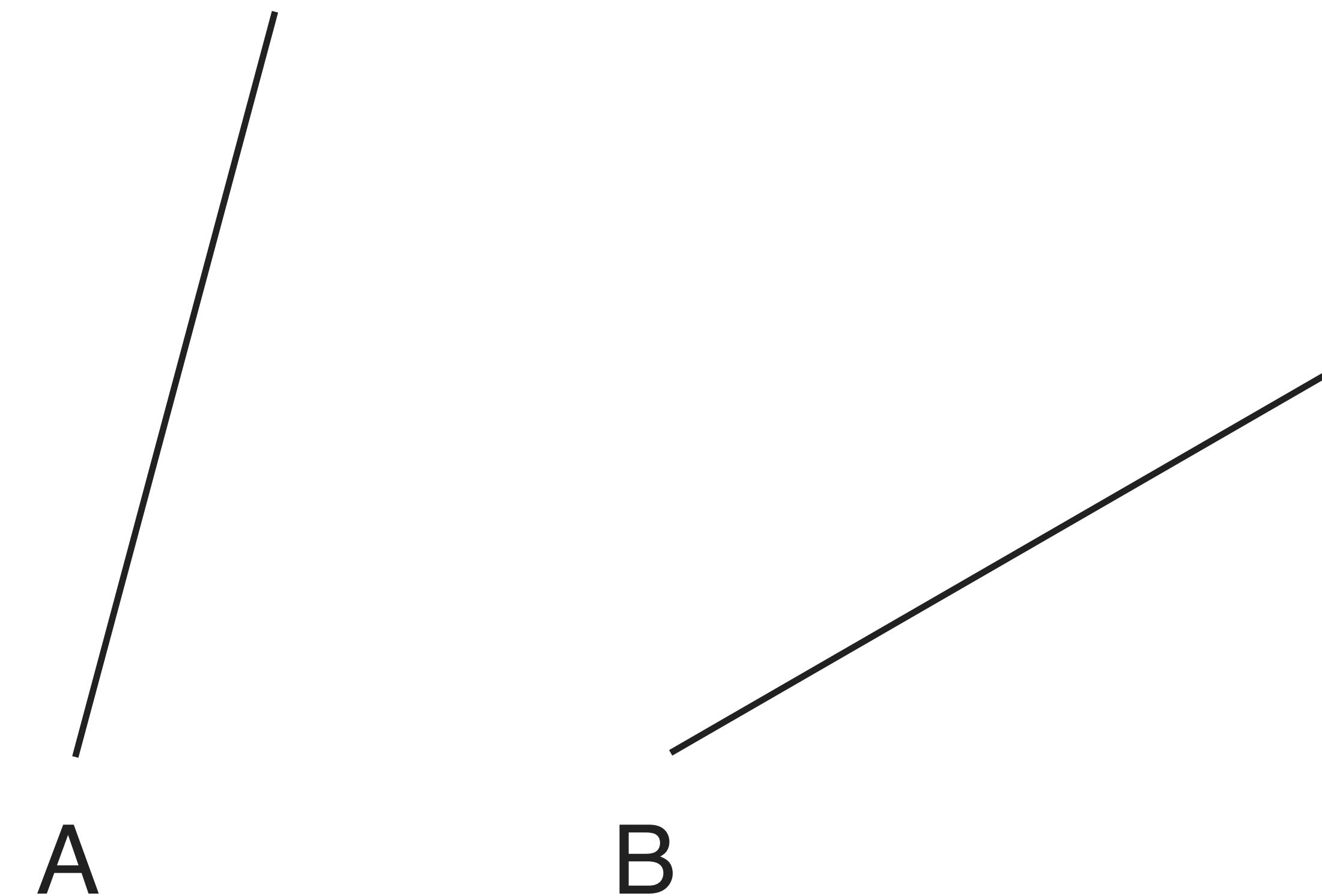


Test: **How much longer?**

4X

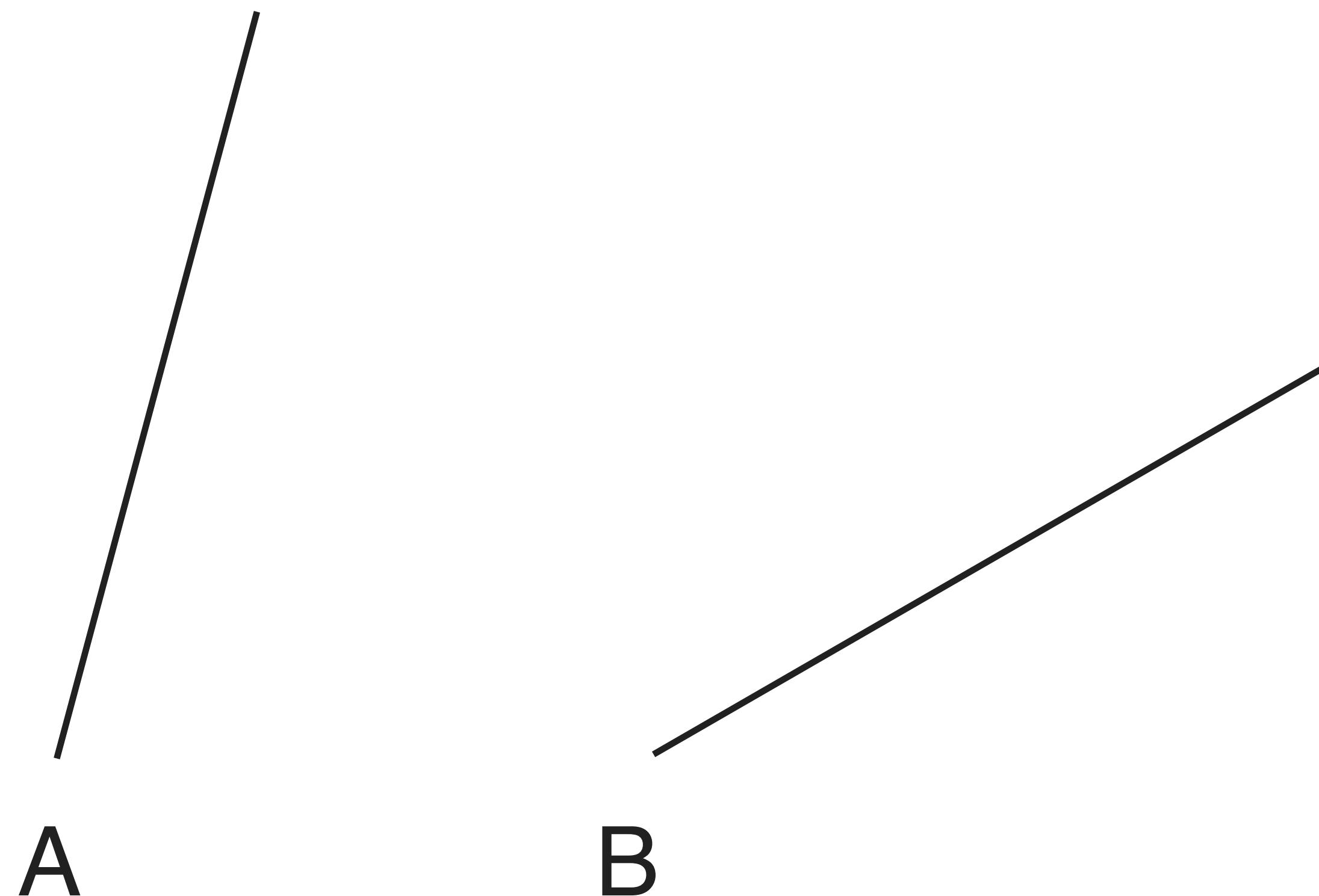


Test: **How much steeper?**

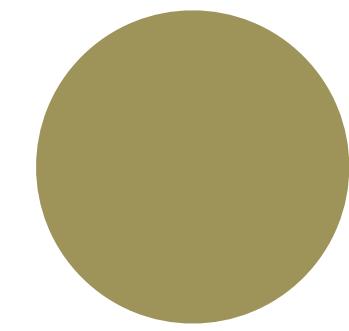


Test: **How much steeper?**

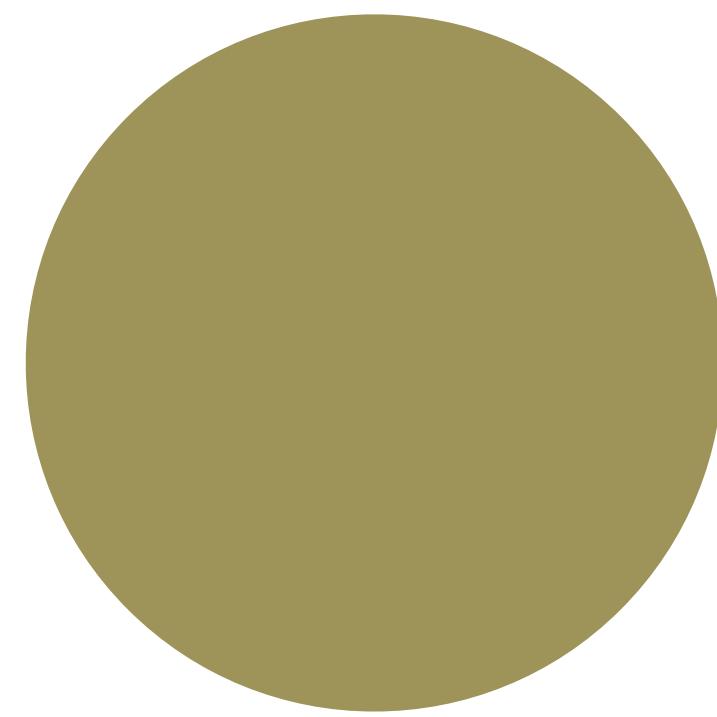
4X



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



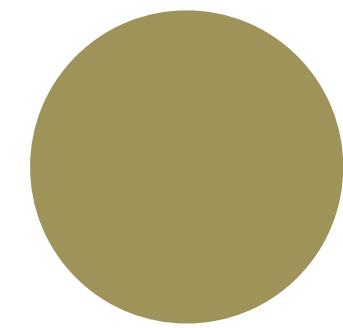
A



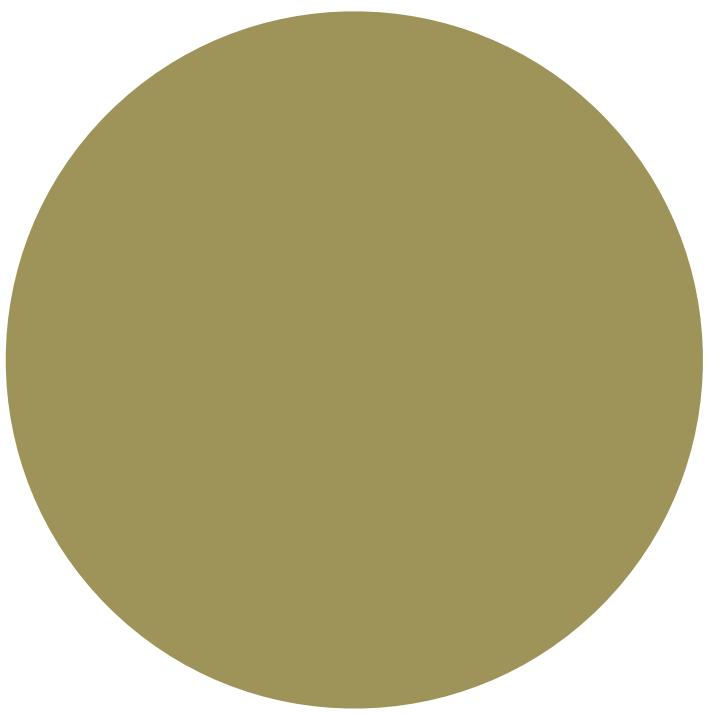
B

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

5X

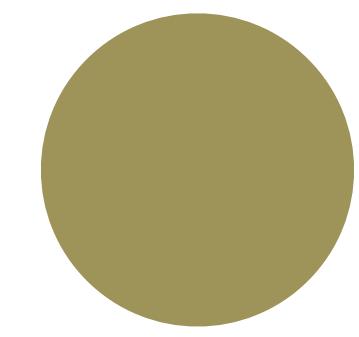


A

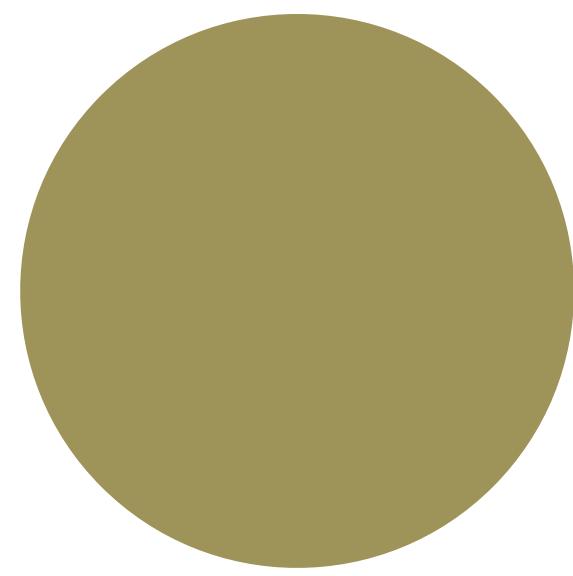


B

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



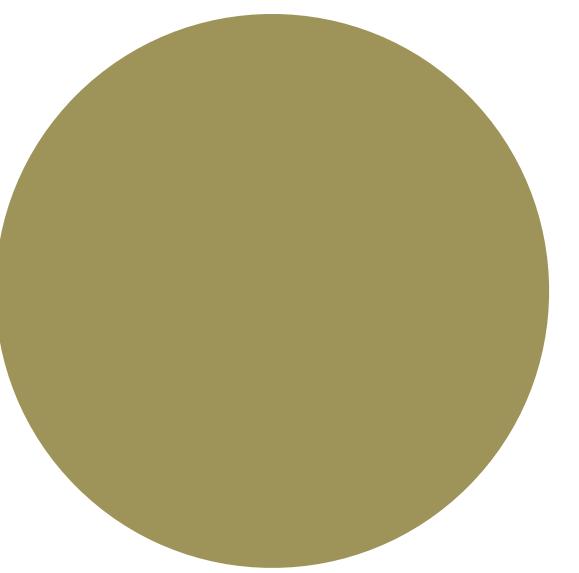
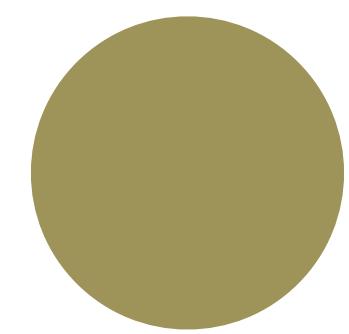
A



B

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

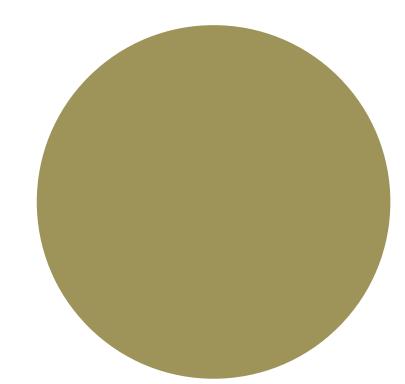
3X



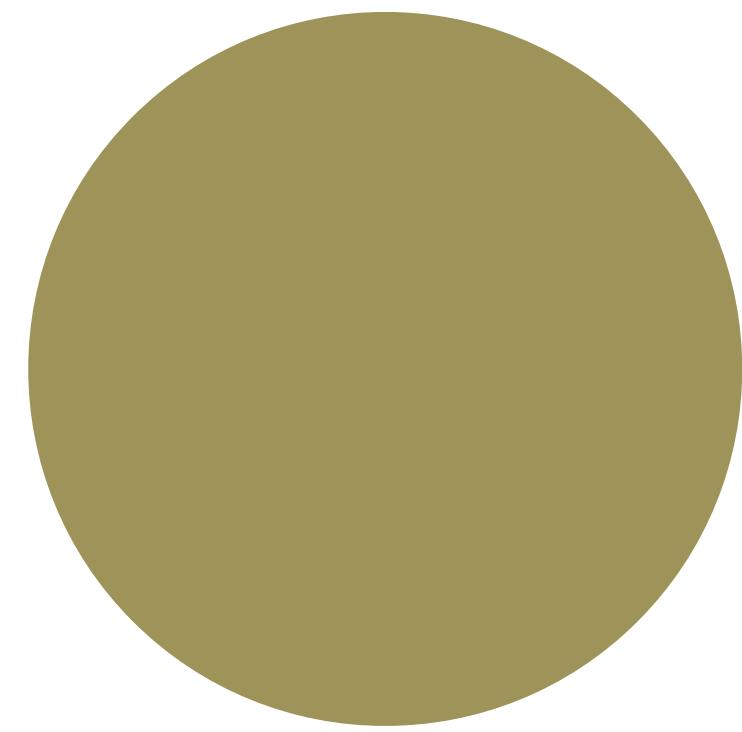
A

B

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



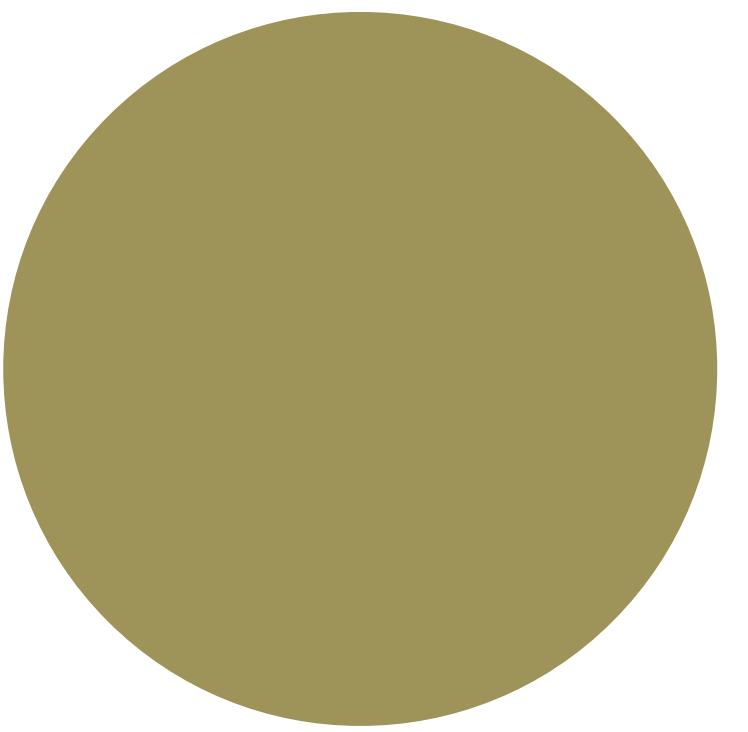
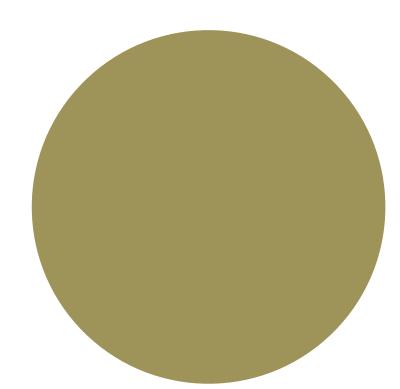
A



B

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

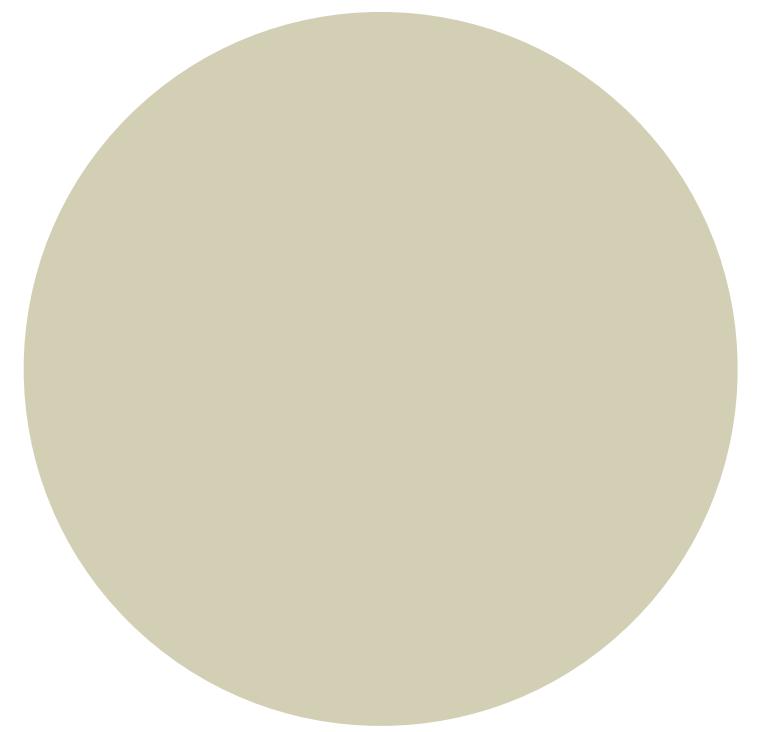
2X



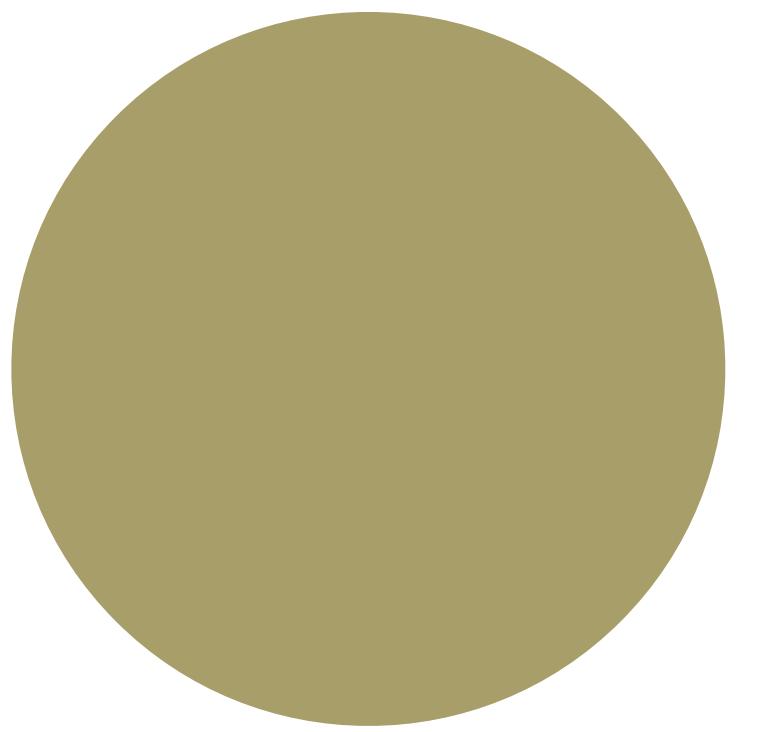
A

B

Test: How much darker?



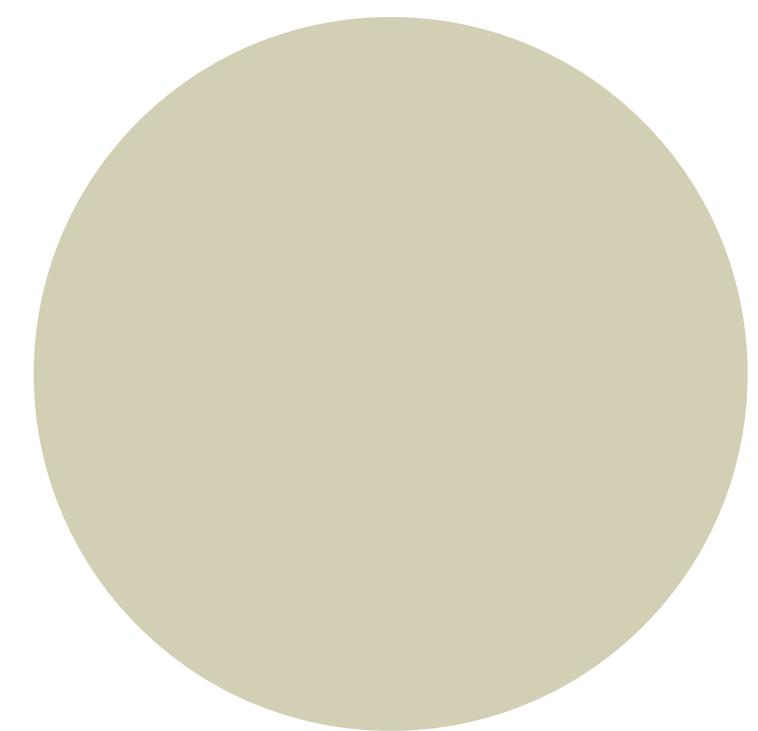
A



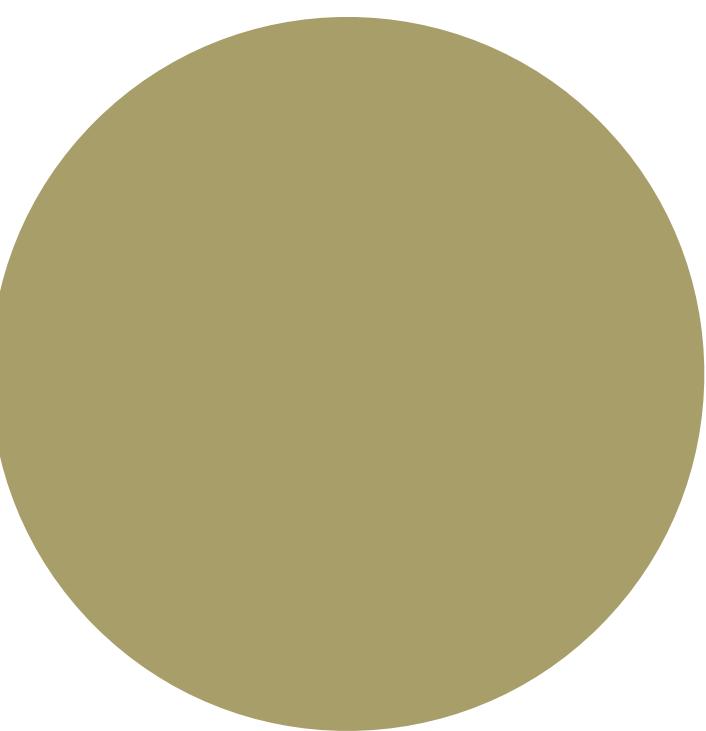
B

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

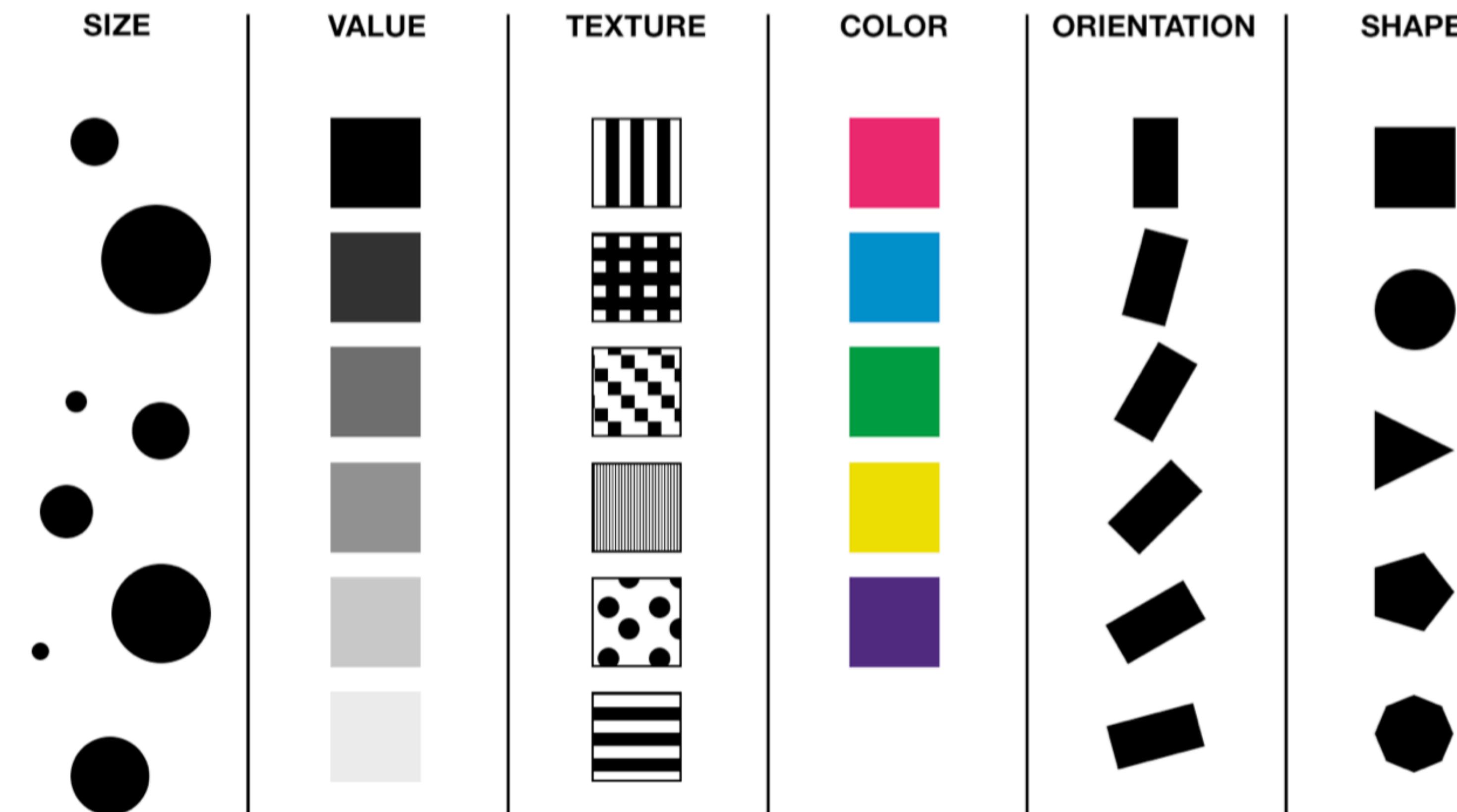
VP Design, Tableau
1952 – present

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.



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



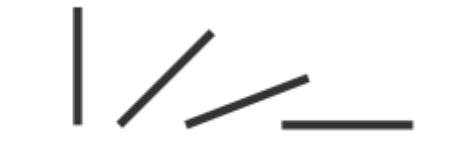
Position on unaligned scale



Length (1D size)



Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



→ **Identity Channels: Categorical Attributes**

Spatial region



Color hue



Motion



Shape



▲ Most

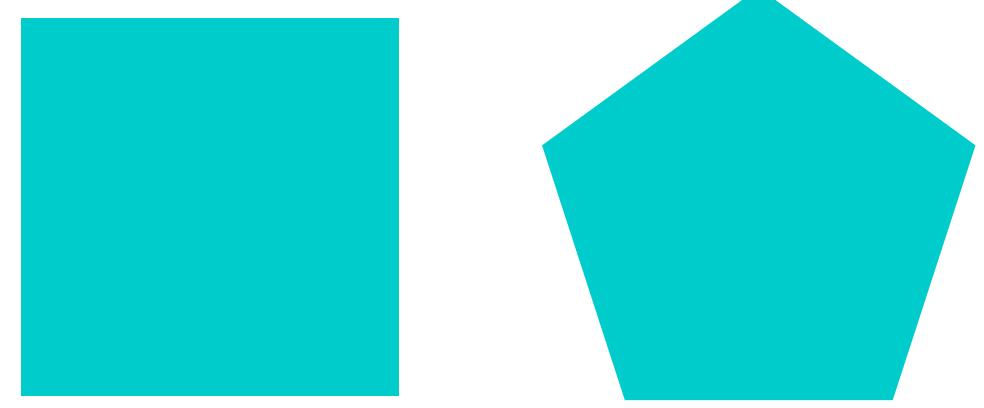
Effectiveness

▼ Least

Same

*Effectiveness criterion: **Selectivity***

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



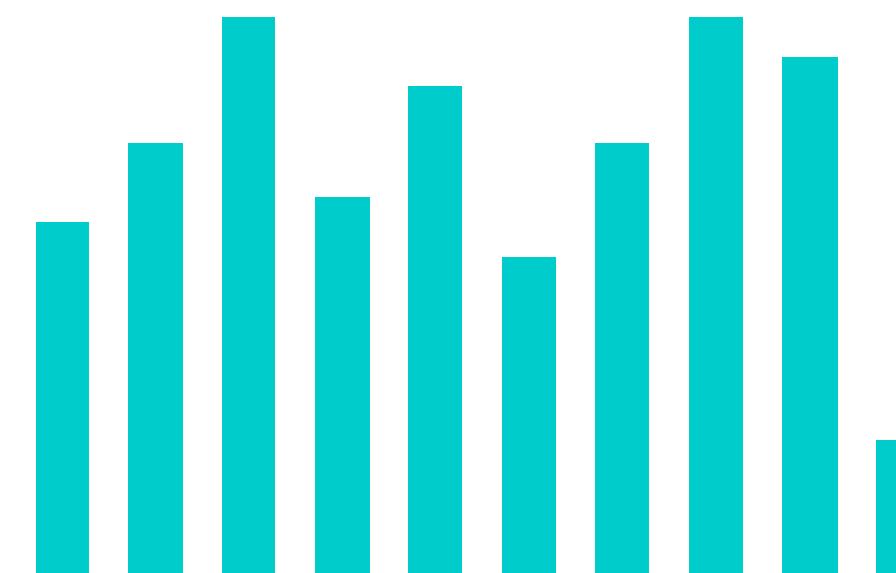
*Effectiveness criterion: **Discriminability***

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



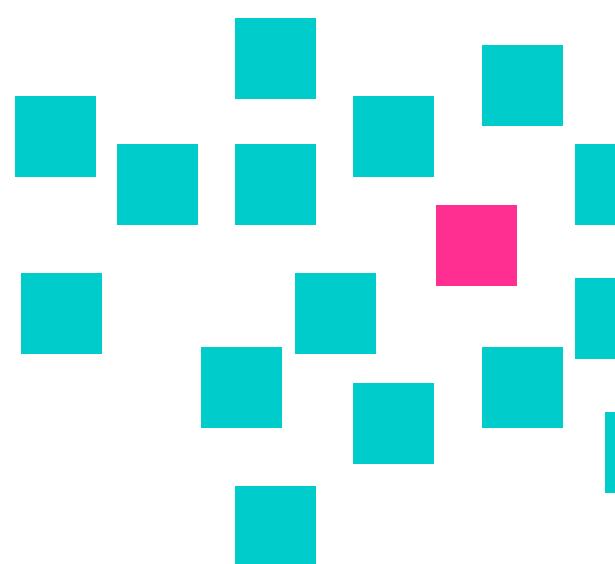
*Effectiveness criterion: **Quantifiability***

- Can we reliably compute the difference between marks?



*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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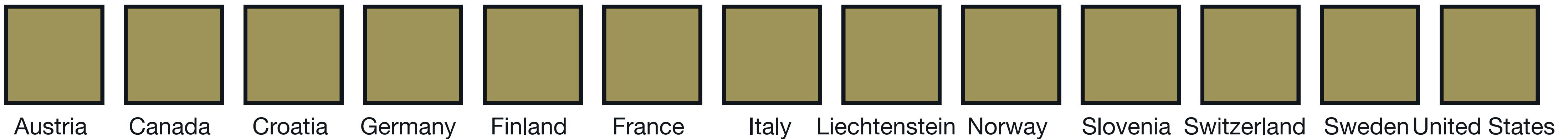
Women's Olympic Giant Slalom

1952 – 2018

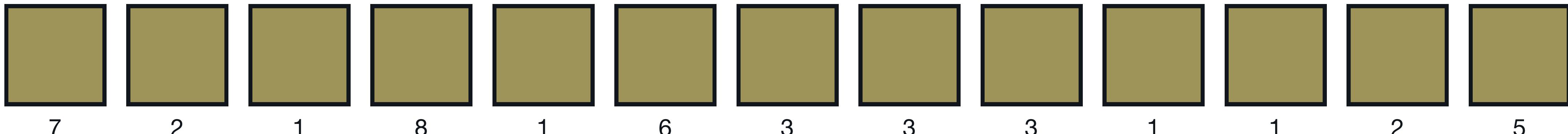
Sample Dataset: **Winter Olympics 1952-2018: Women's Giant Slalom**

- 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

(Undifferentiated marks)



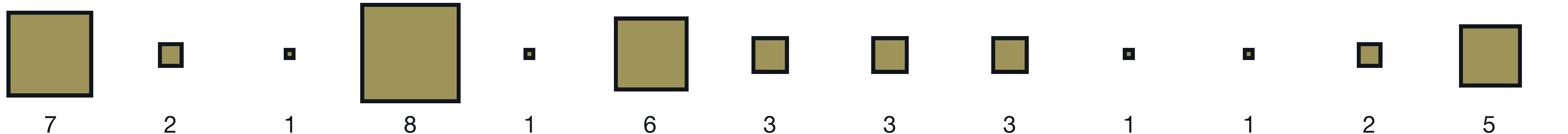
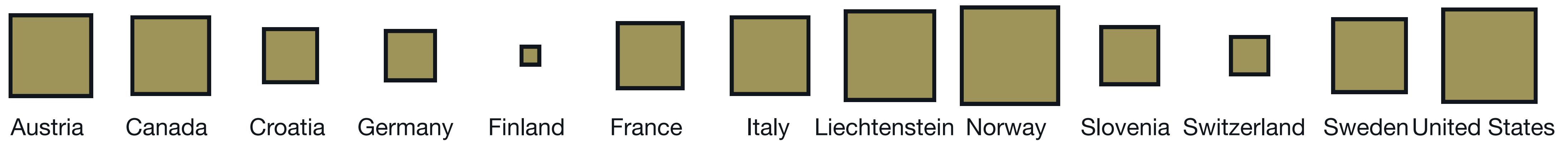
Medalists' nations



Total medal count per nation

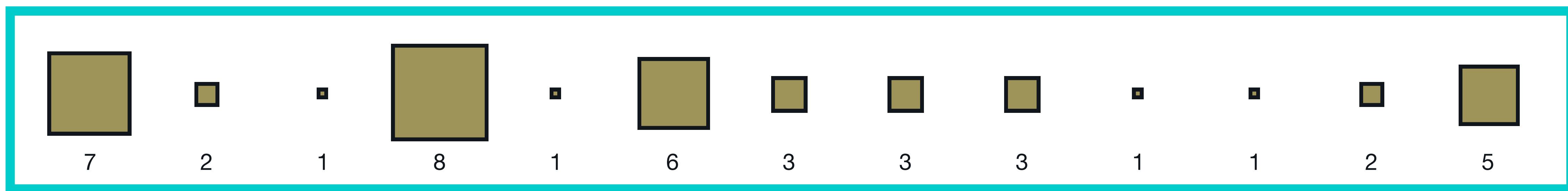
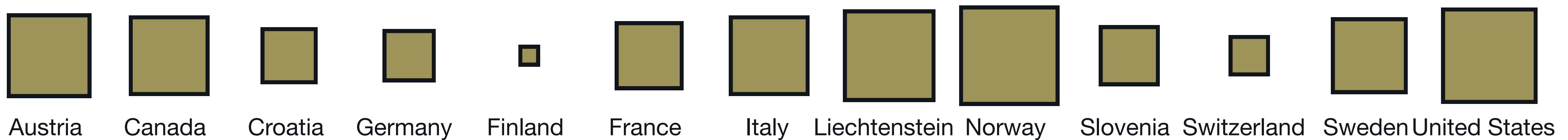
Which is more effective?

Channel: Area (2D Size)



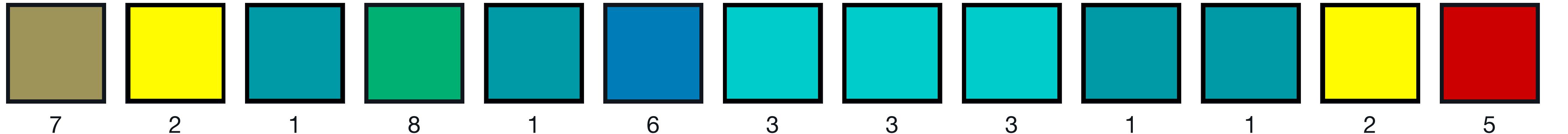
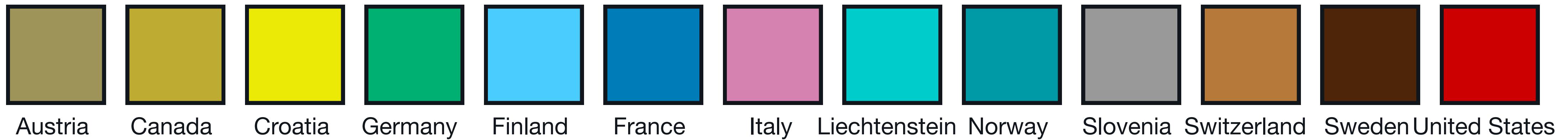
Which is more effective?

Channel: Area (2D Size)



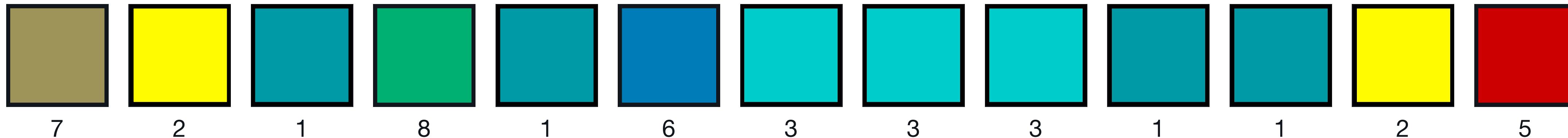
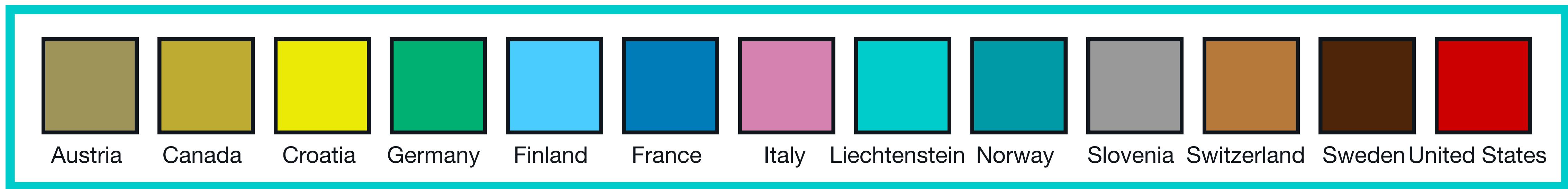
Which is more effective?

Channel: Color



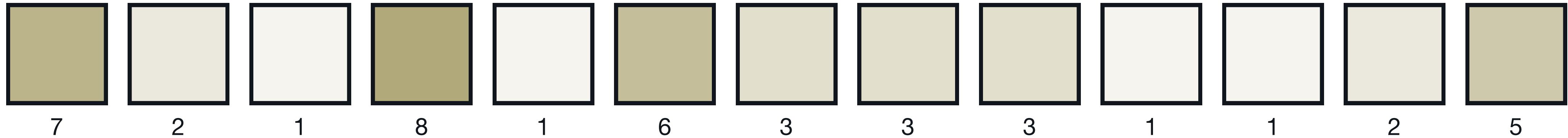
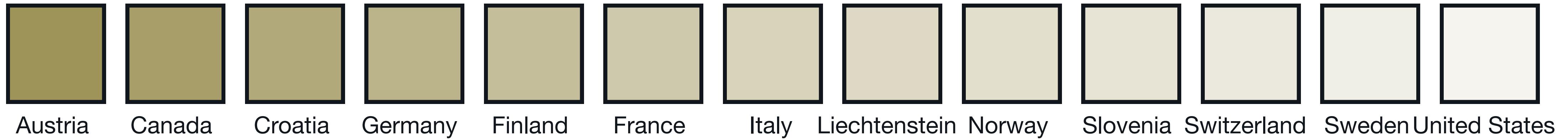
Which is more effective?

Channel: Color



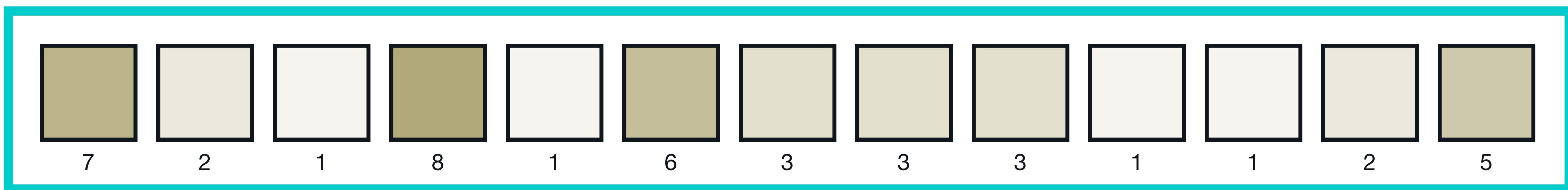
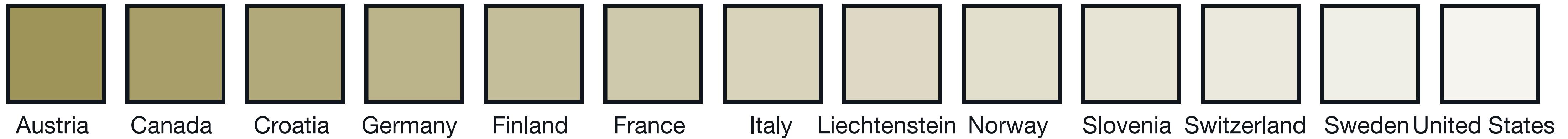
Which is more effective?

Channel: Value (Luminance, Saturation)



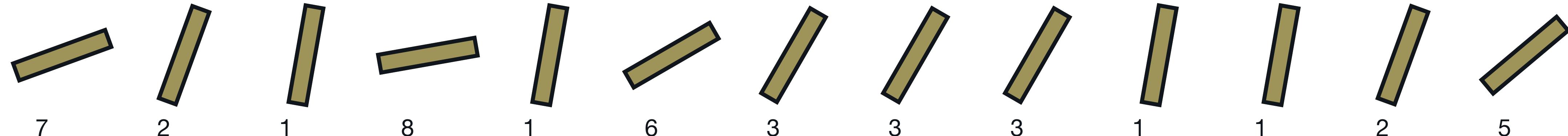
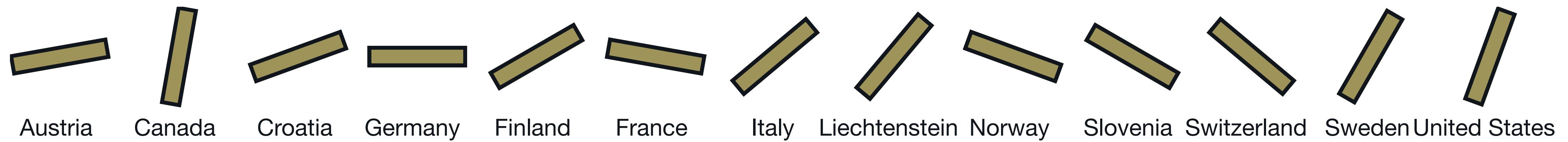
Which is more effective?

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



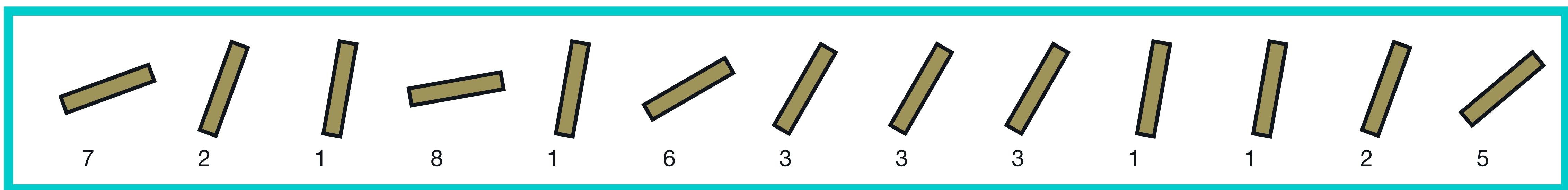
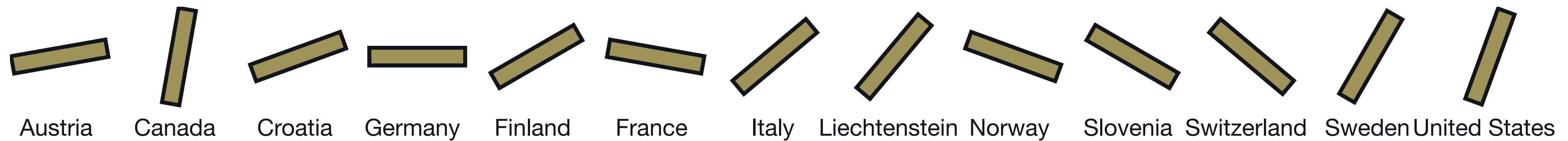
Which is more effective?

Channel: Orientation



Which is more effective?

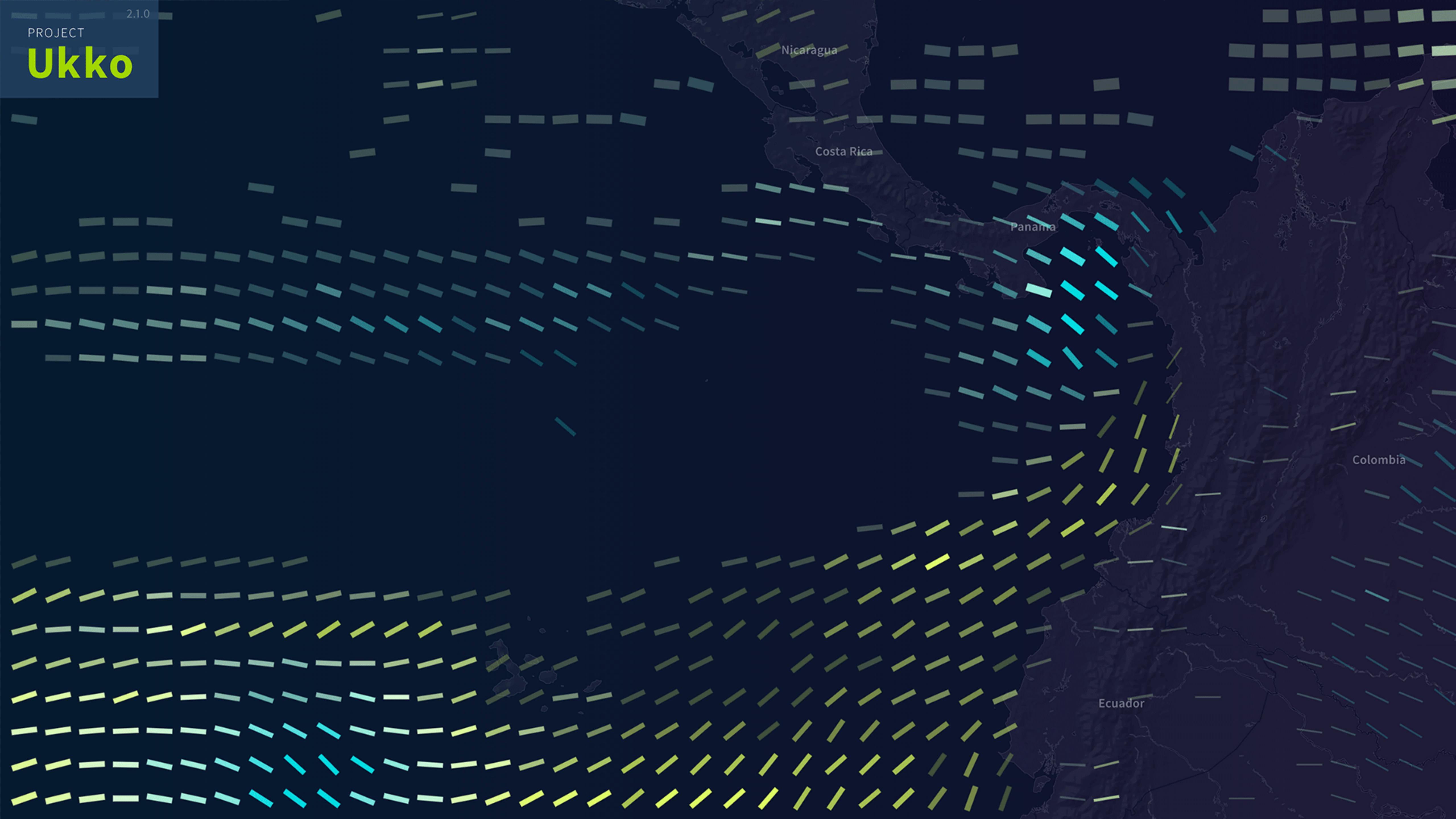
Channel: Orientation



2.1.0

PROJECT

Ukko



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_second	difference	total_time	difference_fi		
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	PFI FN	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?

Question:

Quantity
(Time)



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

→ **Magnitude Channels: Ordered Attributes**

Position on common scale



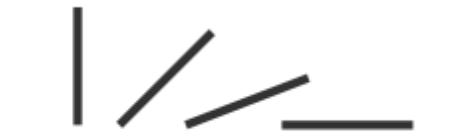
Position on unaligned scale



Length (1D size)



Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



→ **Identity Channels: Categorical Attributes**

Spatial region



Color hue



Motion



Shape



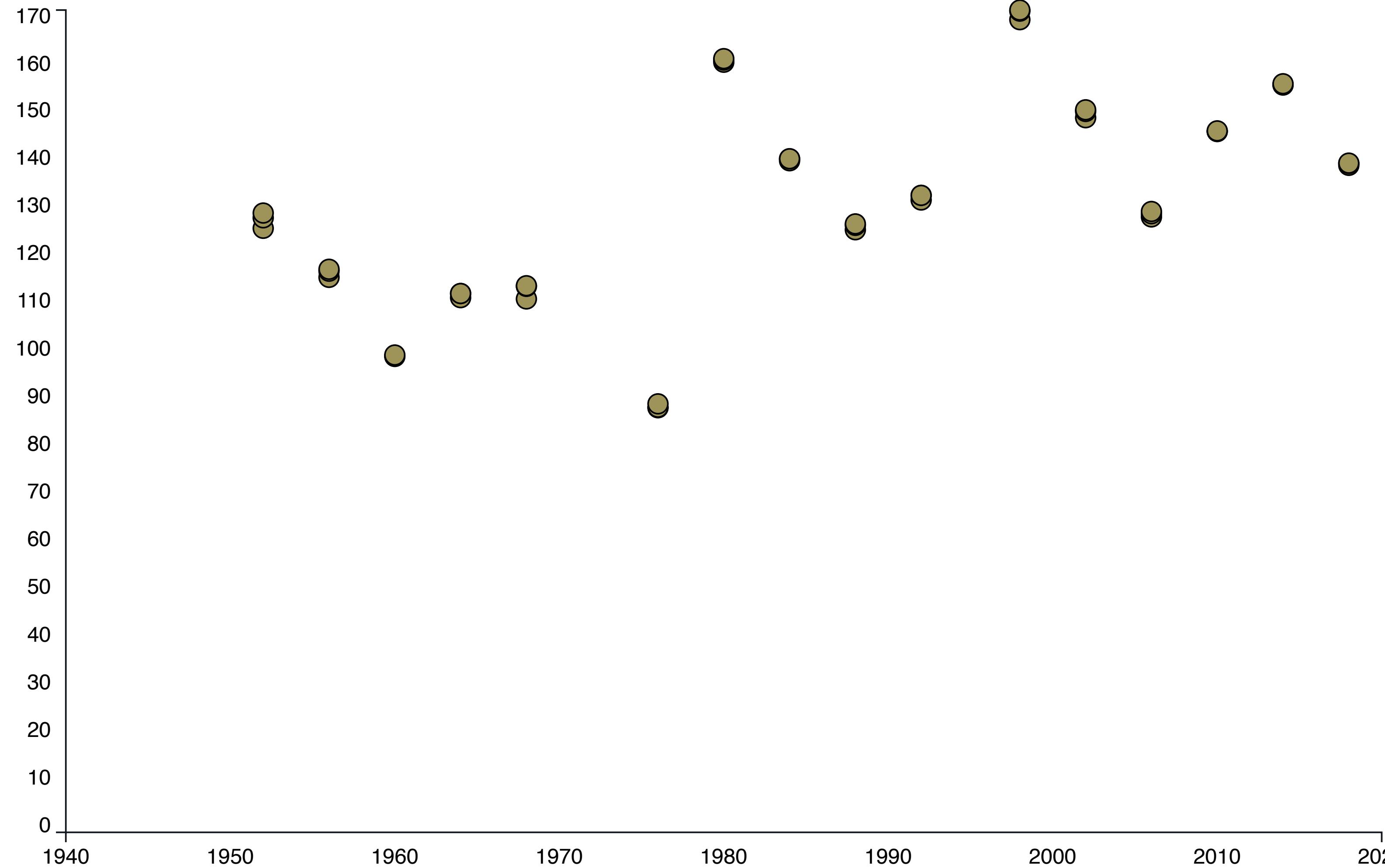
▲ Most

Effectiveness

▼ Least

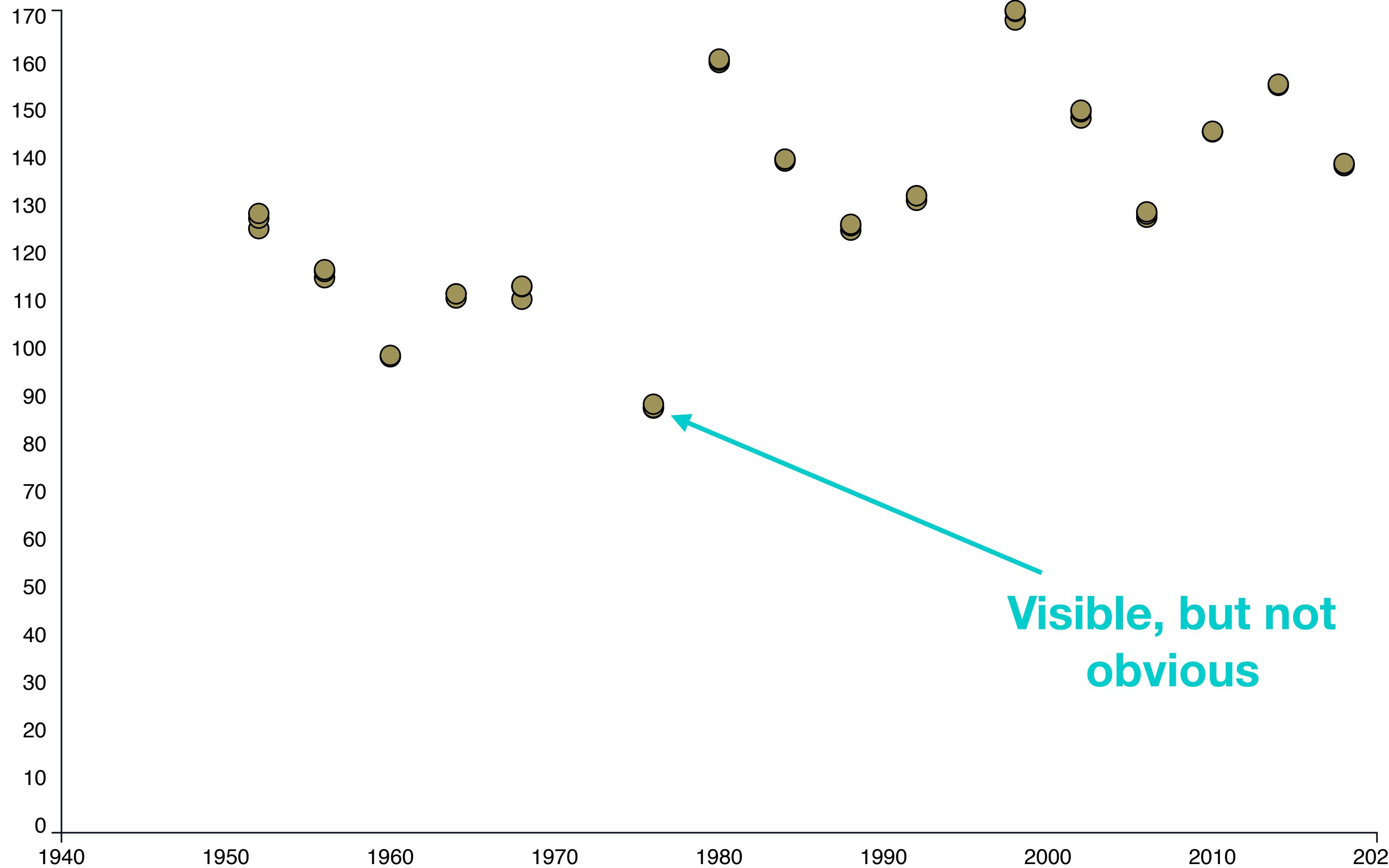
Women's Olympic Giant Slalom, 1952 – 2018

Medalists' Times by Year



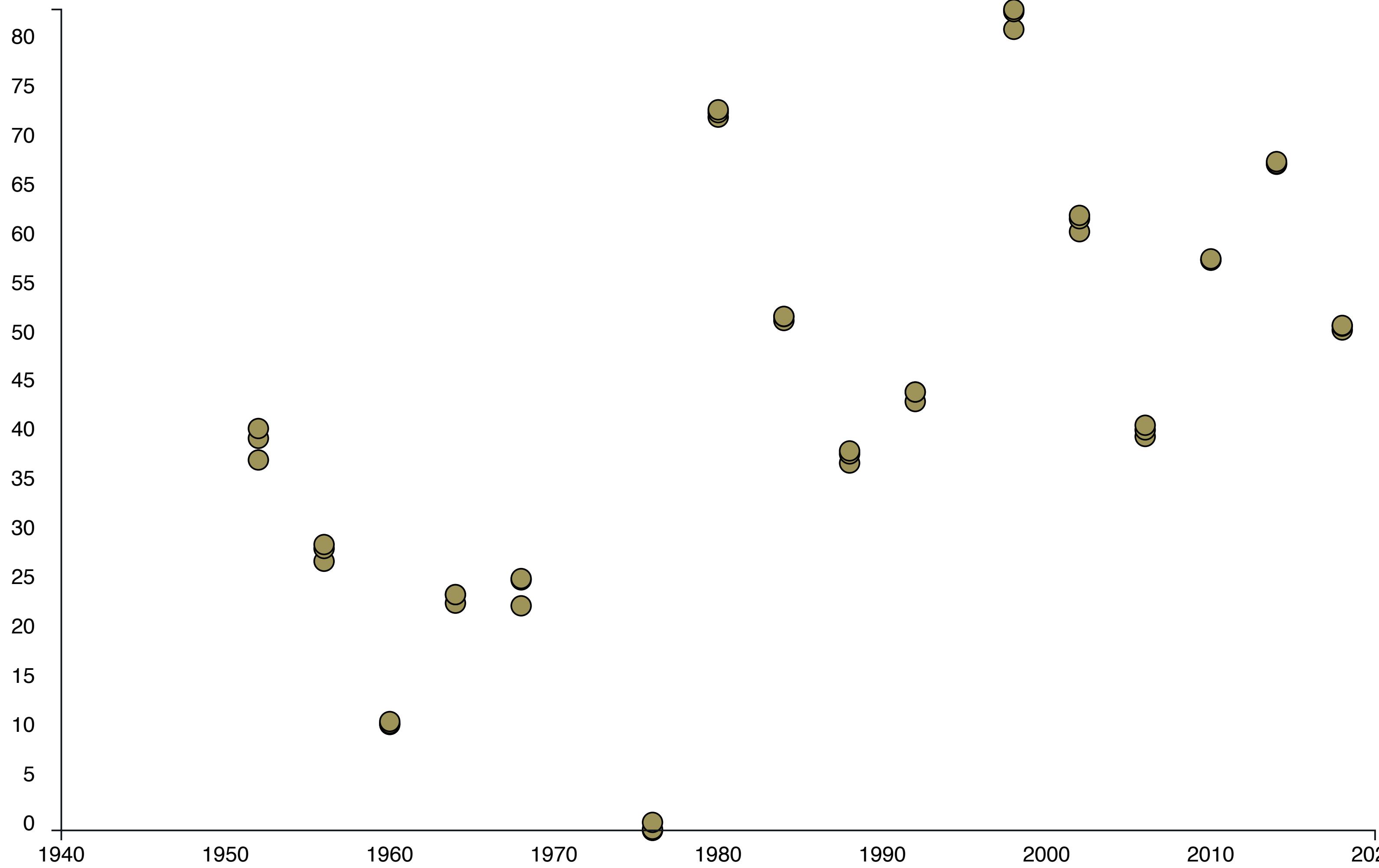
Women's Olympic Giant Slalom, 1952 – 2018

Medalists' Times by Year



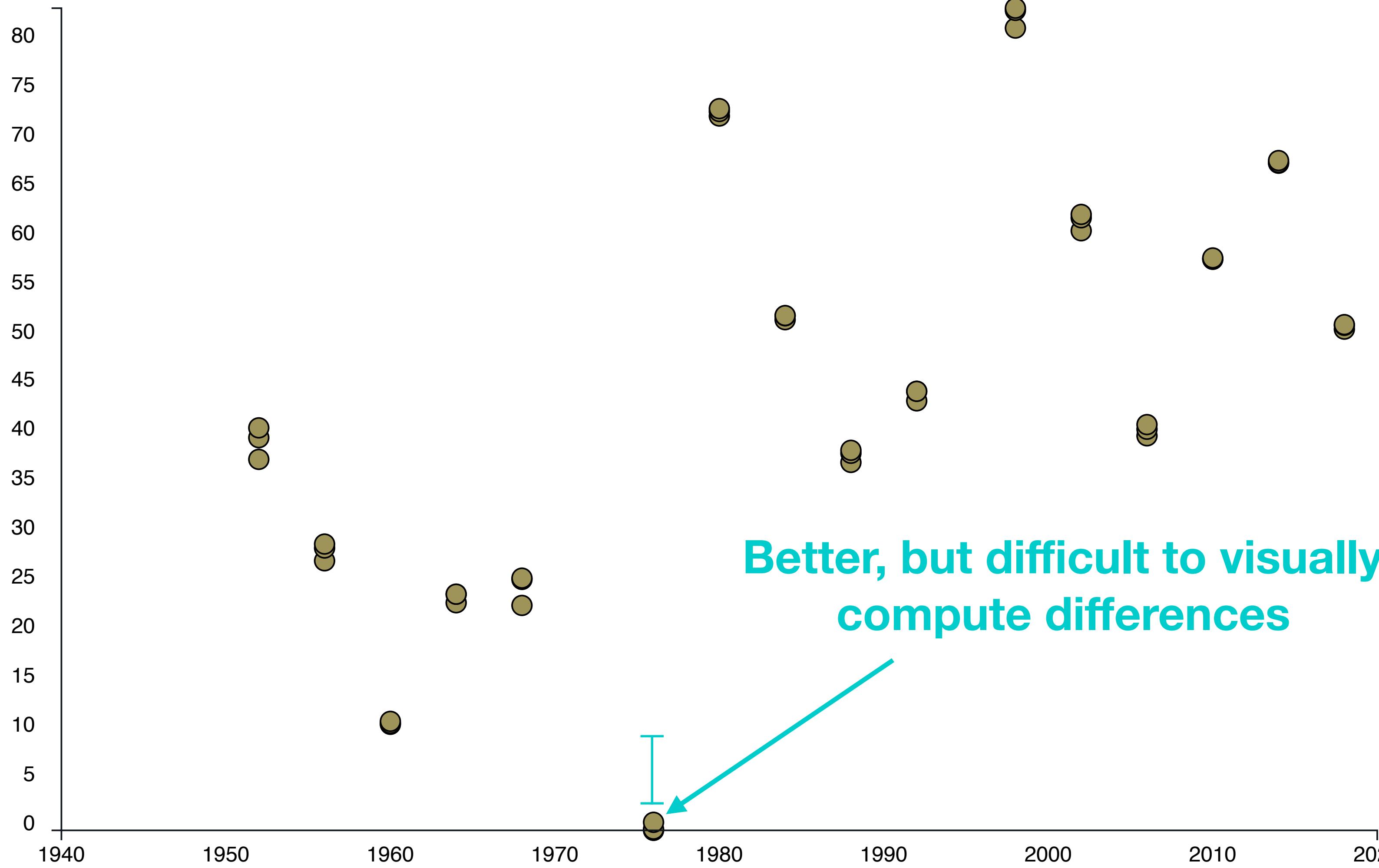
Women's Olympic Giant Slalom, 1952 – 2018

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



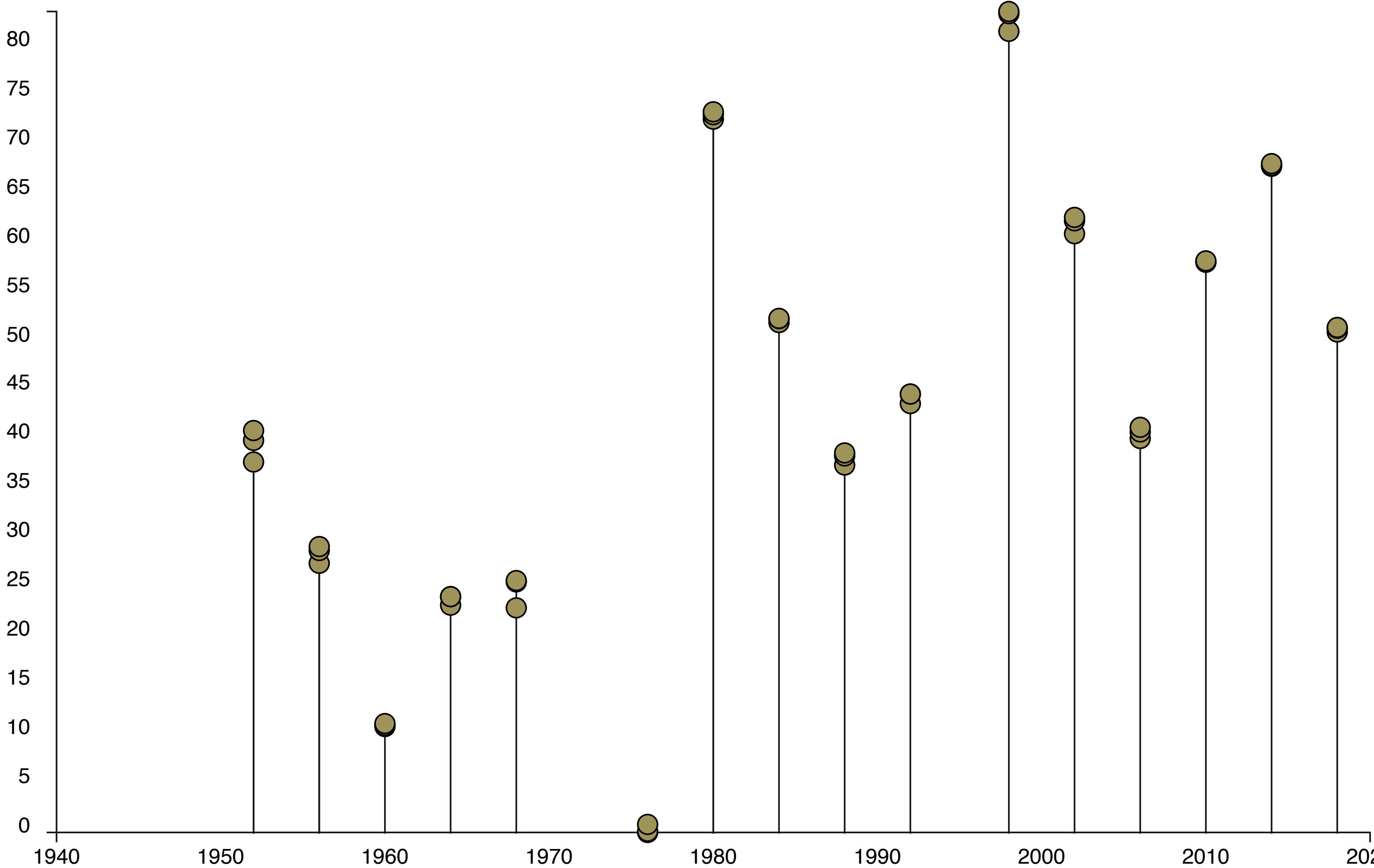
Women's Olympic Giant Slalom, 1952 – 2018

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



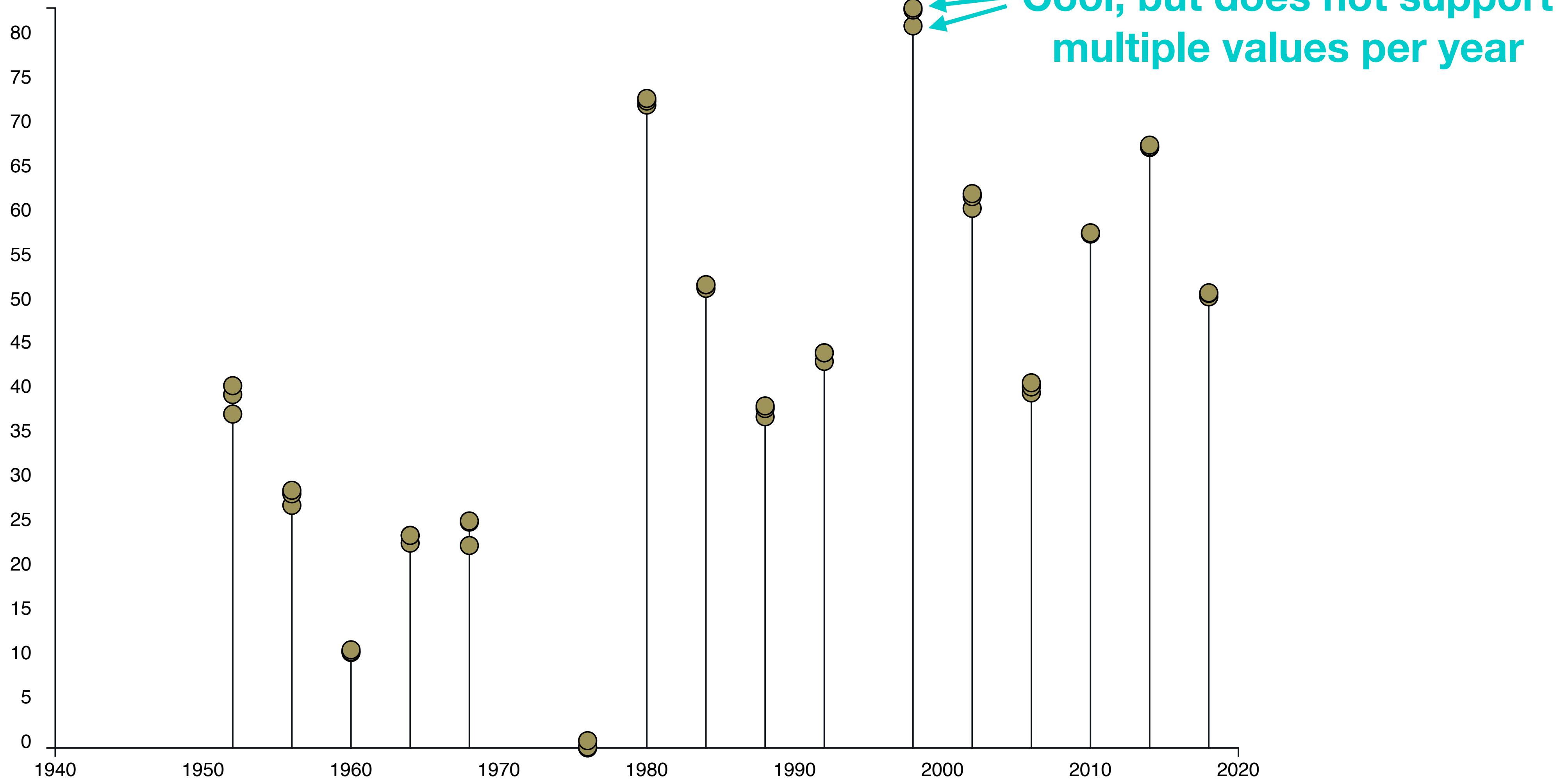
Women's Olympic Giant Slalom, 1952 – 2018

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



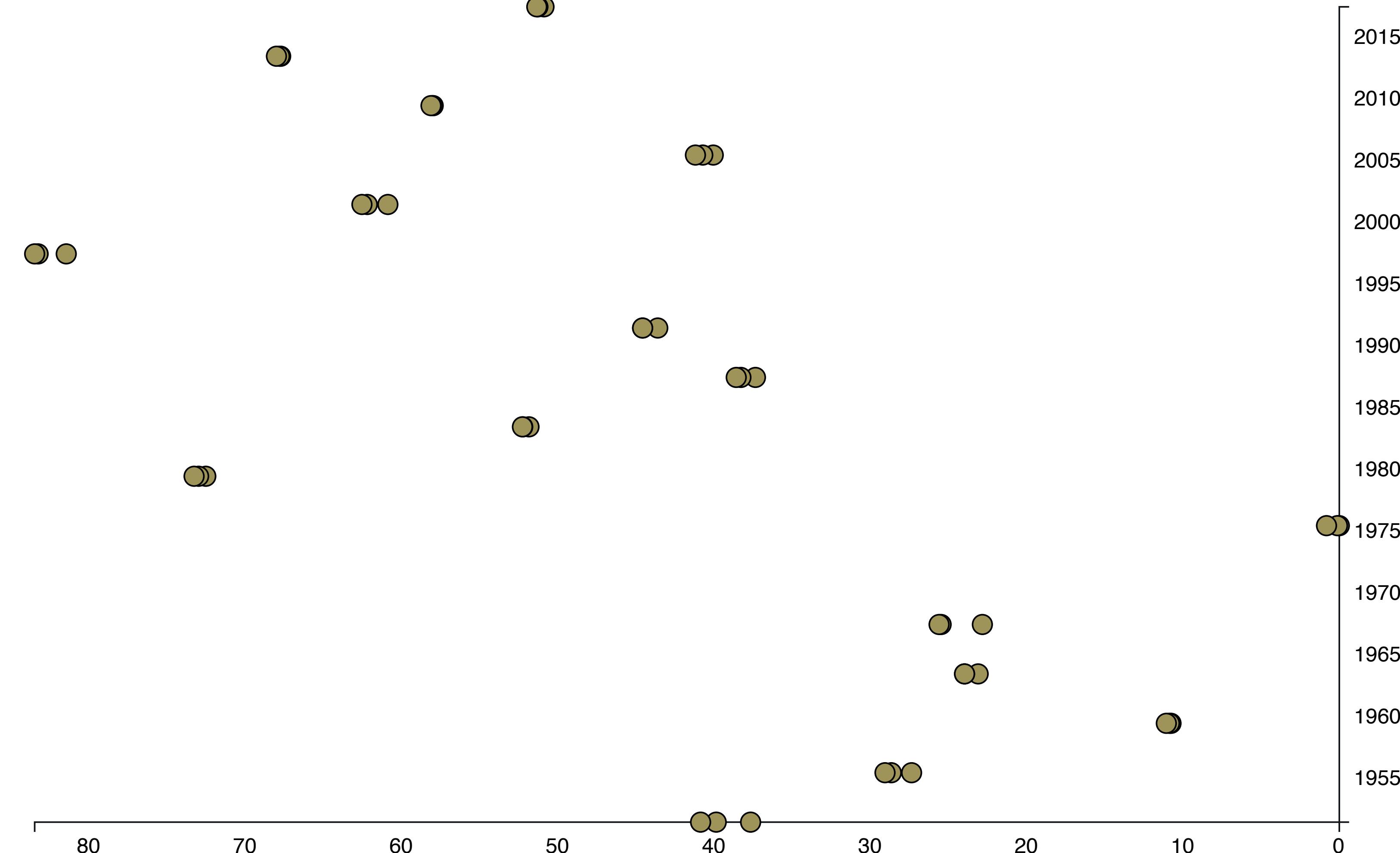
Women's Olympic Giant Slalom, 1952 – 2018

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



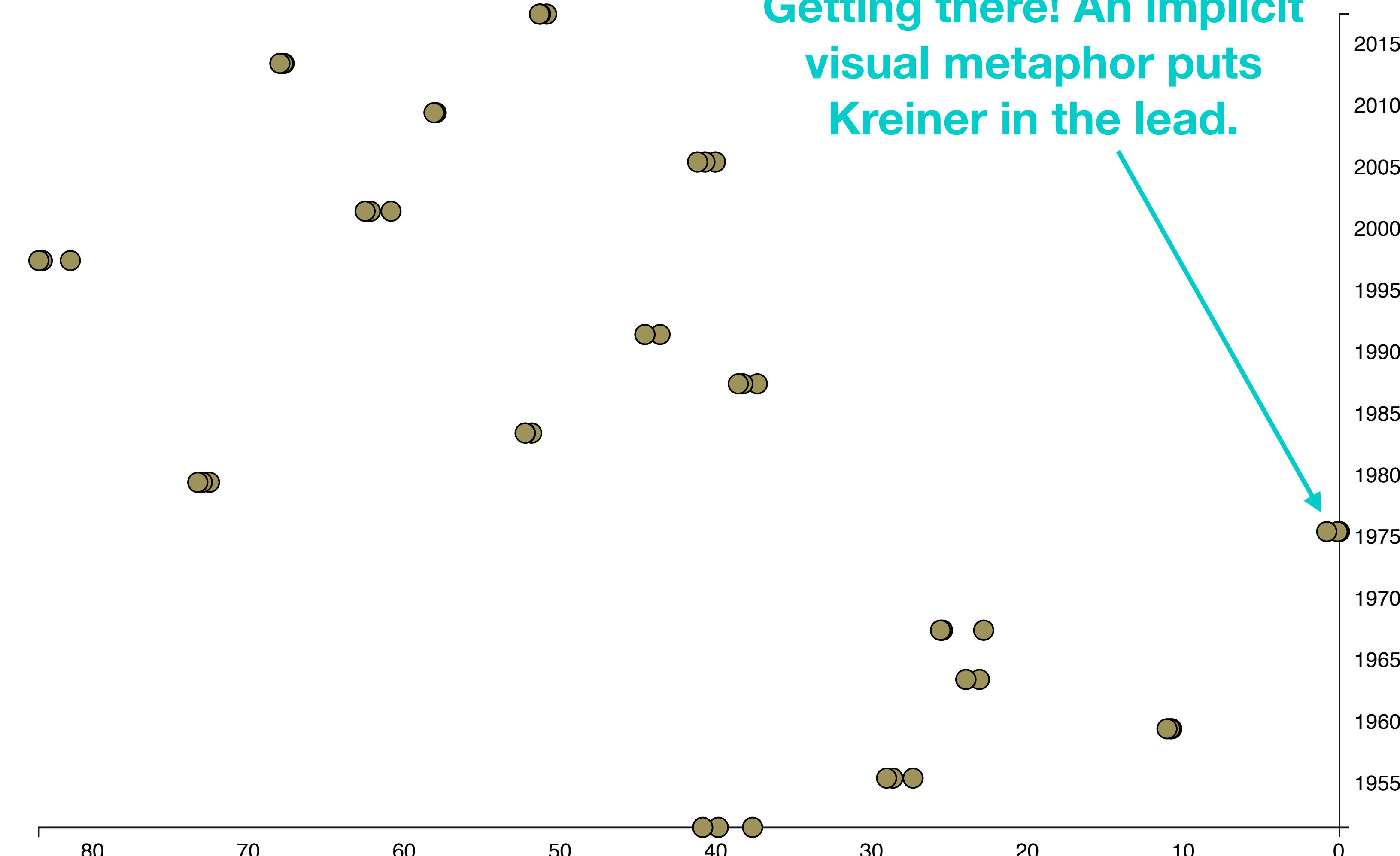
Women's Olympic Giant Slalom, 1952 – 2018

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



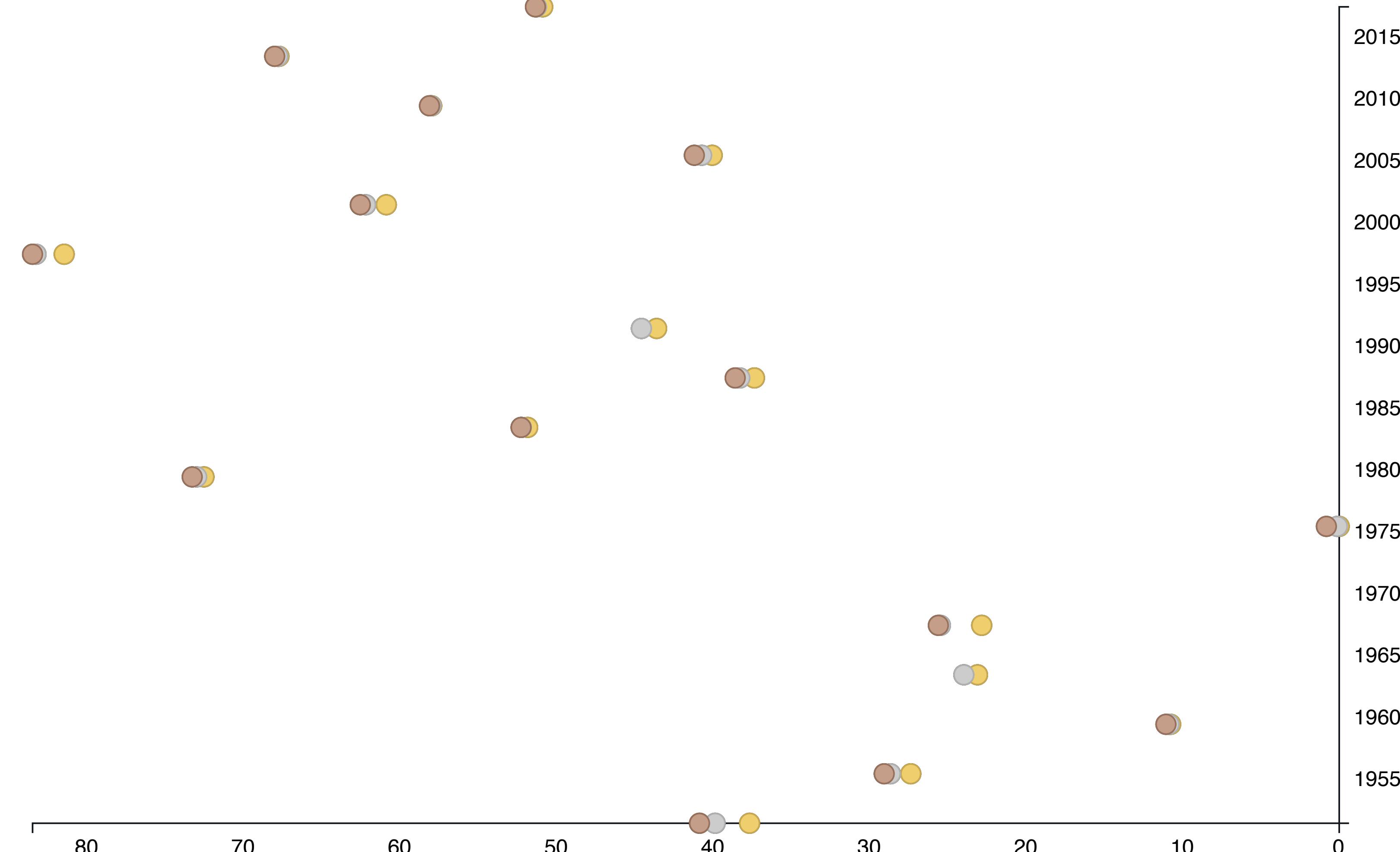
Women's Olympic Giant Slalom, 1952 – 2018

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



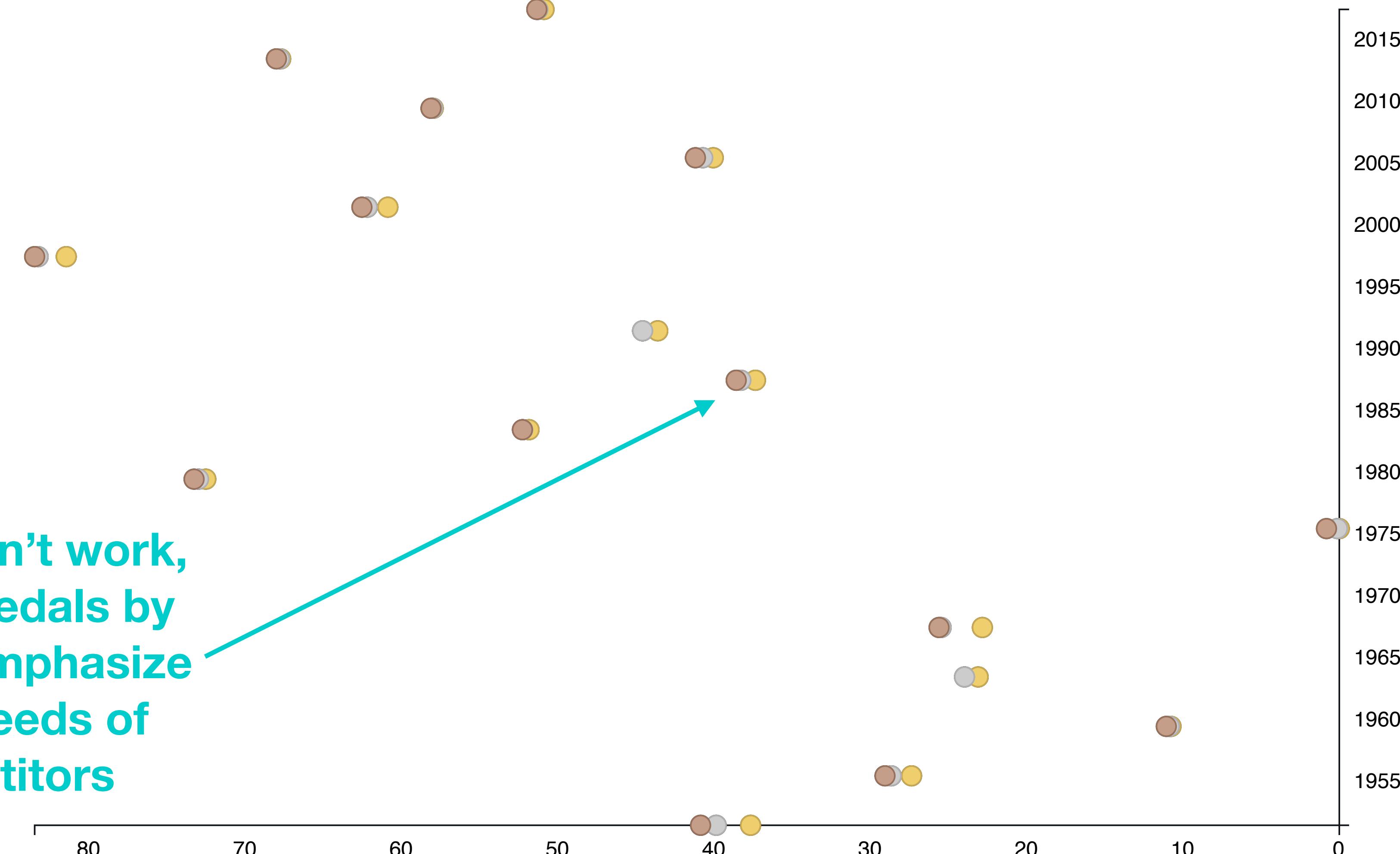
Women's Olympic Giant Slalom, 1952 – 2018

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



Women's Olympic Giant Slalom, 1952 – 2018

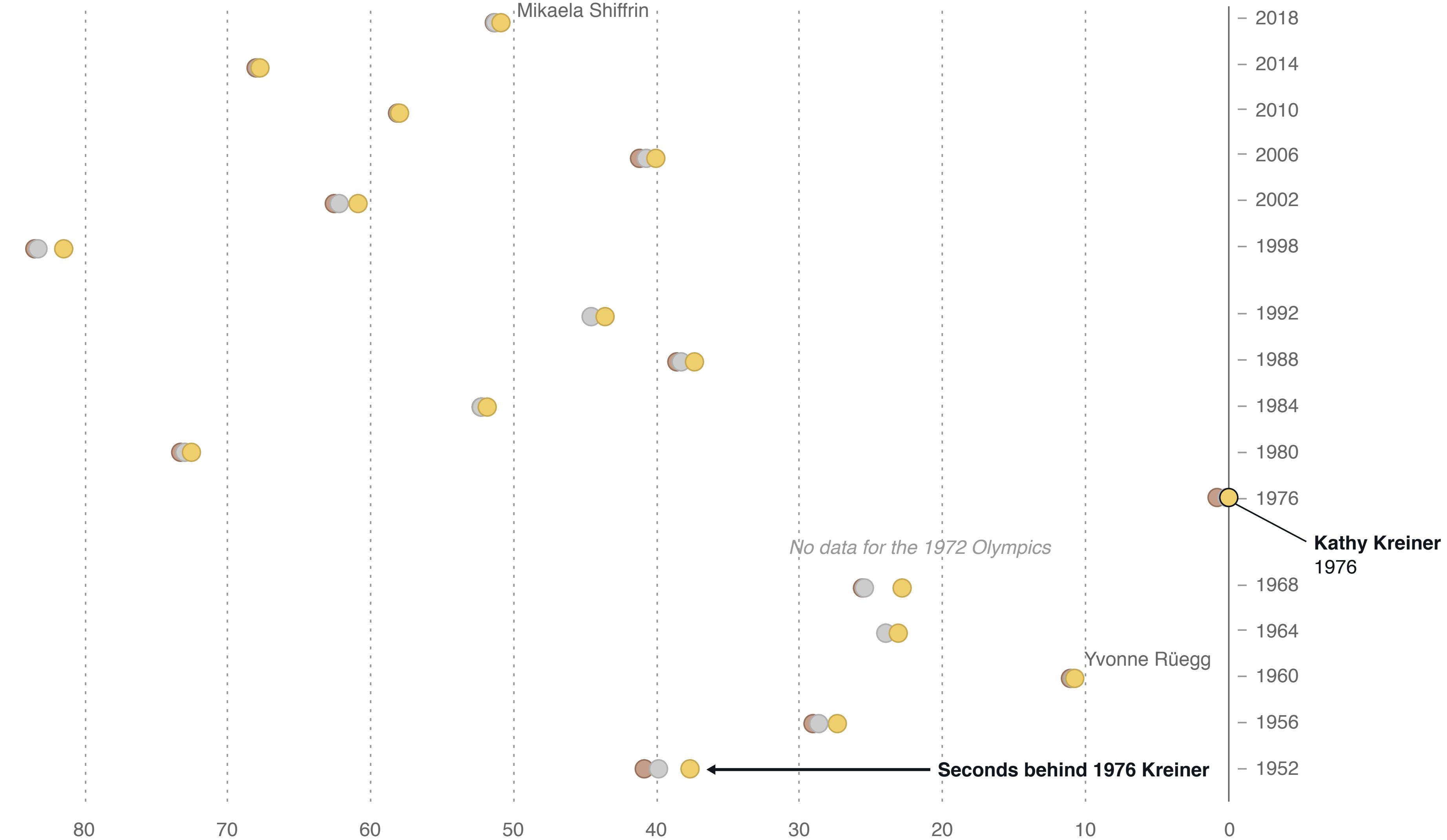
Difference Between Medalists' Time and Kreiner's Time by Year



Though lines don't work,
breaking out medals by
color helps to emphasize
the trailing speeds of
other competitors

Women's Olympic Giant Slalom, 1952 – 2018

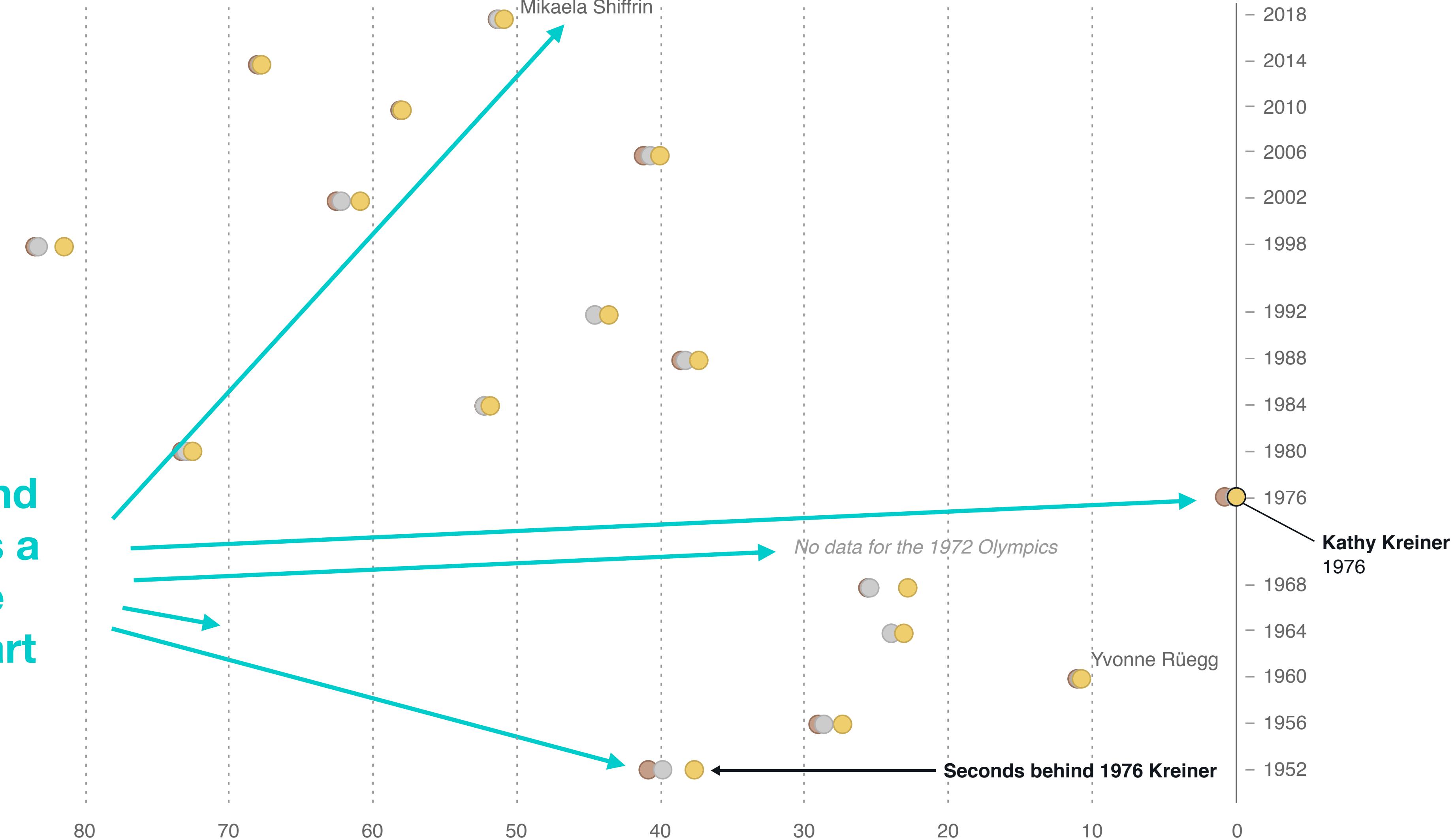
Difference Between Medalists' Time and Kreiner's Time by Year



Women's Olympic Giant Slalom, 1952 – 2018

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

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.

**12 TOPICS
41 THEORIES**

Kicker (link to multimedia tag): Physics Interactive

Theories of Everything, Mapped

SED [map](#): 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 tattered threads linking ever more disparate phenomena. With the law of universal gravitation, Isaac Newton wedged 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 disjunctions, 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 swallows 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 incomparable sinkholes in space-time? According to general relativity, [information](#) 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](#) [Ghawk](#))

The "Hawking evaporation" 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.

• **Bhawkballs** ([child of](#) string theory, [sibling of](#) firewalls)

The "hawkball" proposal, from string theorist Savir Majumdar, 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 [hawkball](#), 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 [Susskind-Susskind](#) proposal holds that [unruled](#) objects are [backphysically](#) 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](#)?

• **Lephogenesis** ([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 [schrodinger](#) 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 [schrodinger](#) processes, and the space inside the bubbles where they couldn't. The

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 "electromagnetic force" at this grand unified theory (GUT) scale? Did the mathematical form of the forces at more familiar energies — represented by the symmetry group $SO(10) \times SU(2) \times U(1)$ — 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.)

• [SO\(10\)](#) ([parent of](#) low-energy [supersymmetry](#), [child of](#) $SO(10)$)

The [SO\(10\)](#) symmetry group includes $SO(3) \times SO(2) \times U(1)$ 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 [SO\(10\)](#) symmetry broke into $SO(3) \times SO(2) \times U(1)$, 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](#) $SO(10)$, $E(6)$, $E(8)$, etc.)

The symmetries of the Standard Model $SO(3) \times SU(2) \times U(1)$, 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.

• [SO\(10\)](#) ([parent of](#) low-energy [supersymmetry](#), [child of](#) string theory)

The [SO\(10\)](#) 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

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 GeV , 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](#) [WIMP](#))

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 [wimps](#) which gravity assembles into galaxies along with all other matter — could comprise dark matter. Experimental searches for dark matter [wimps](#) are

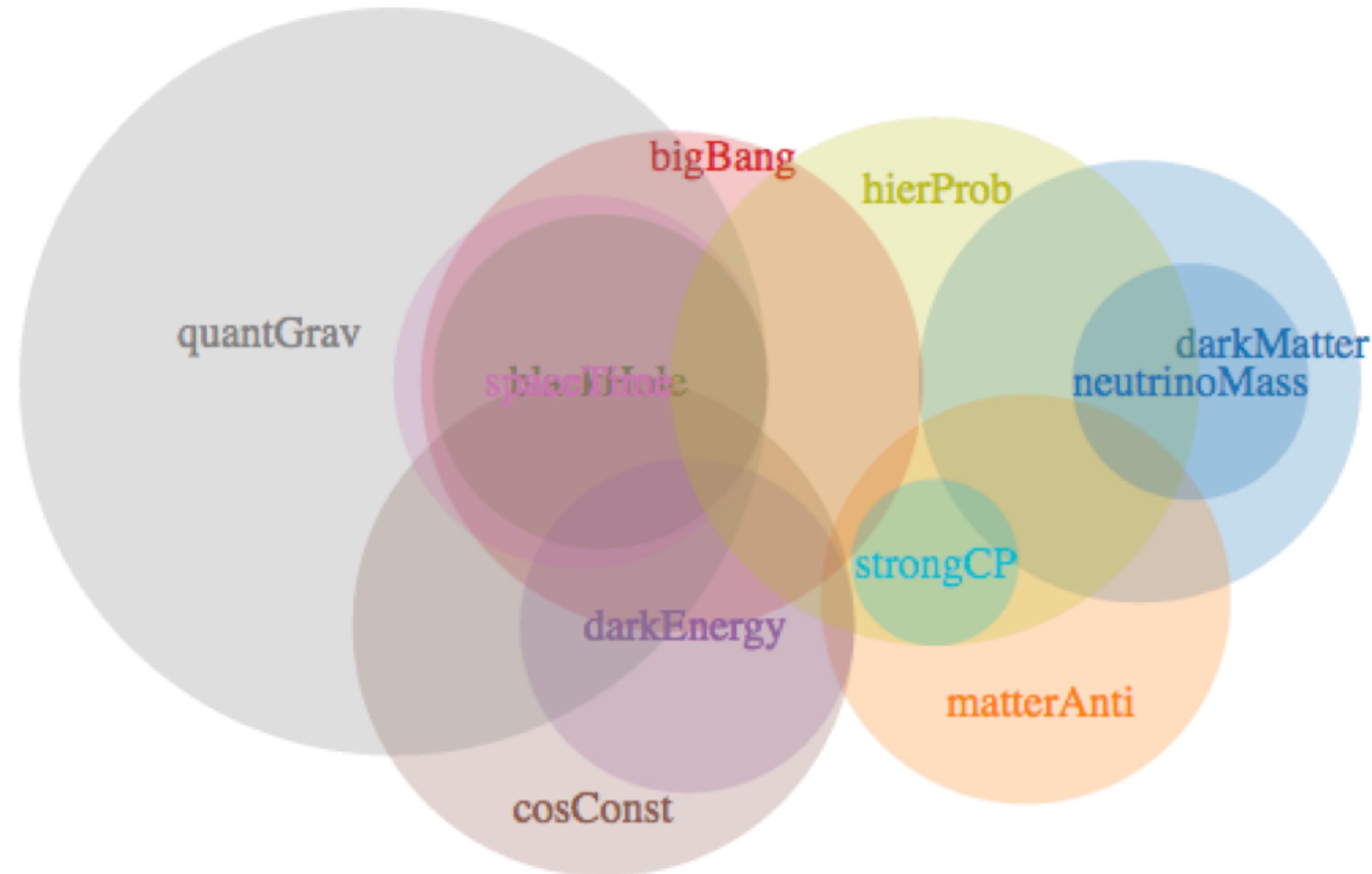
Just as electrons are mutually repulsive and the strong force gives quarks together into protons and neutrons, dark matter particles might feel attracted or repelled by one another. These self-interactions would change dark matter's resulting distribution in the cosmos. Models of self-interacting dark 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.

• **Volume**: Klein dark matter ([sibling of](#) extra dimensions)

In the 1920s, Theodor [Klein](#) 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 [Klein](#)-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?

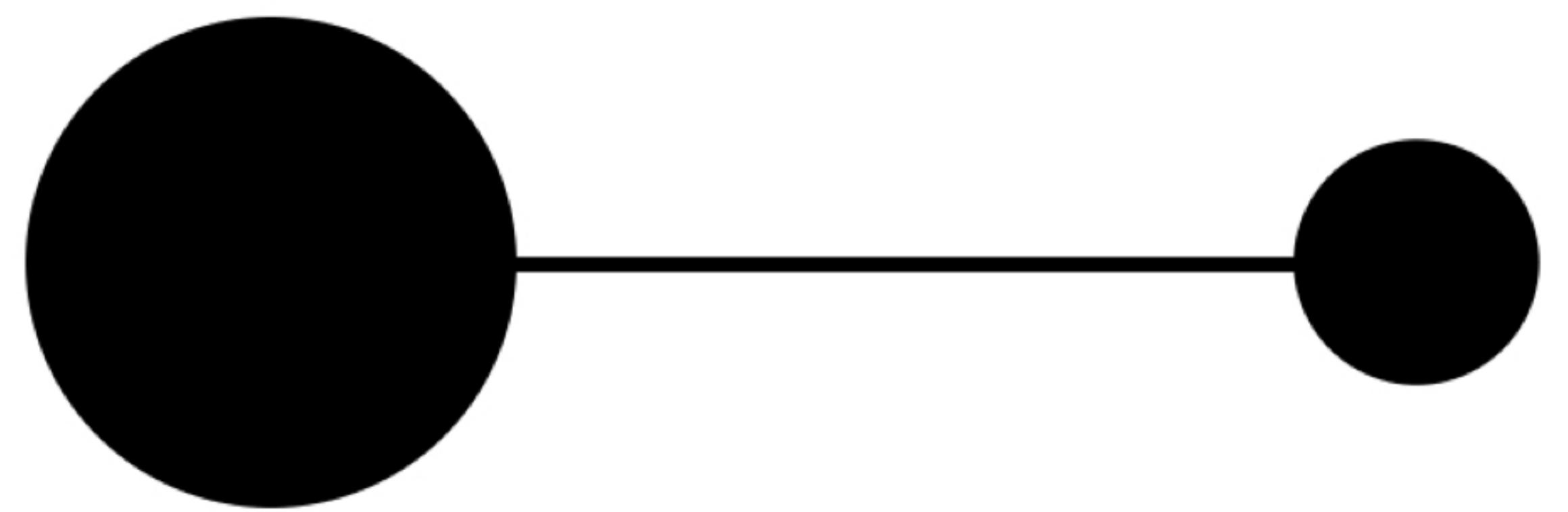
The universe appears to have three dimensions of space and one dimension of time. However, in small enough increments — less than a tenth of a trillionth of a trillionth of a trillionth of a meter — our familiar notions of space and time break down. The energy required to peer at such a small patch of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





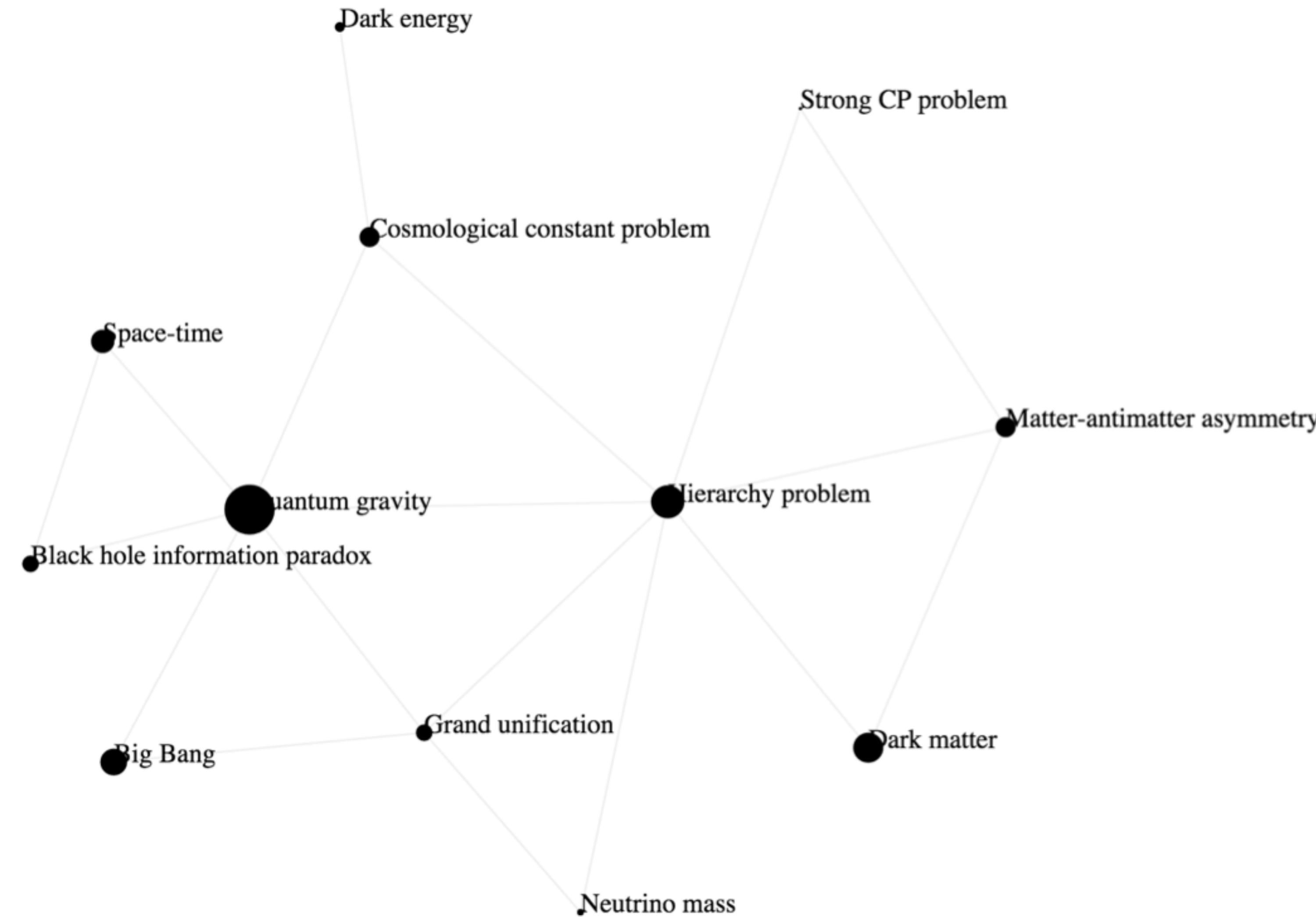
QUANTUM GRAVITY

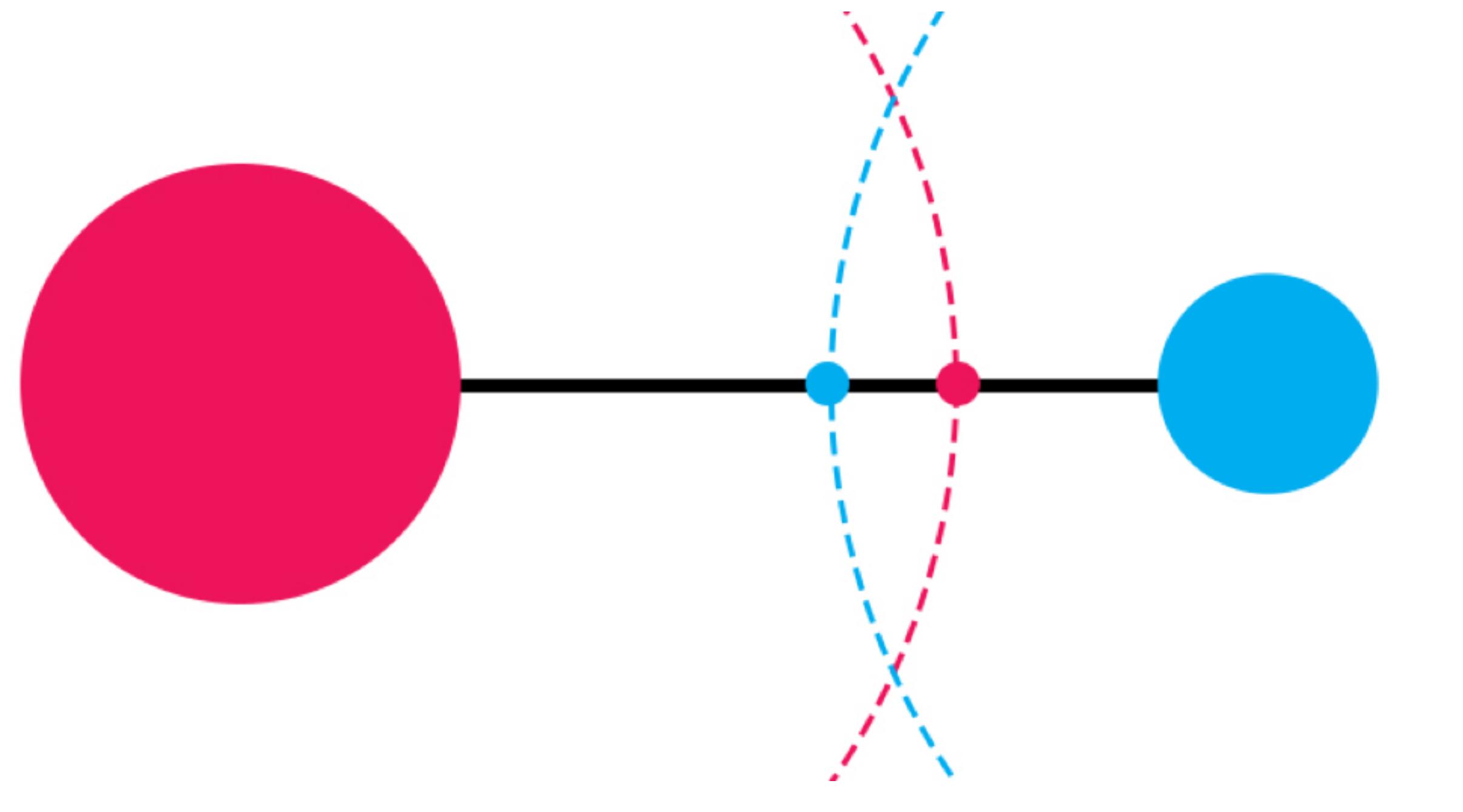
HIERARCHY PROBLEM

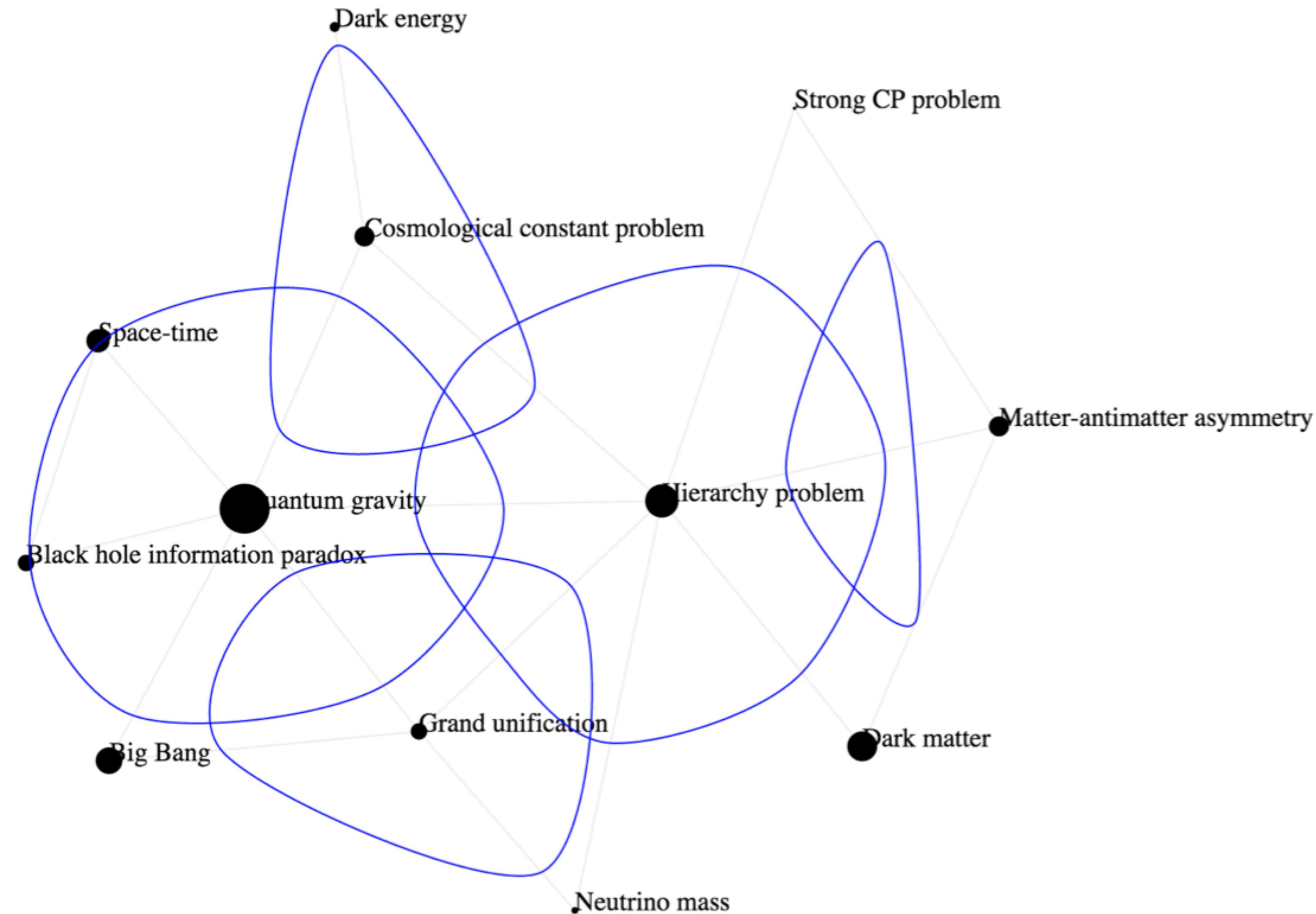


QUANTUM GRAVITY

HIERARCHY PROBLEM







[← BACK TO ARTICLE](#)

Theories of Everything, Mapped

Black hole information paradox

Space-time

Quantum gravity

Big Bang

Grand unification

Dark energy

Strong CP problem

Cosmological constant problem

Matter-antimatter asymmetry

Hierarchy problem

Dark matter

Neutrino mass

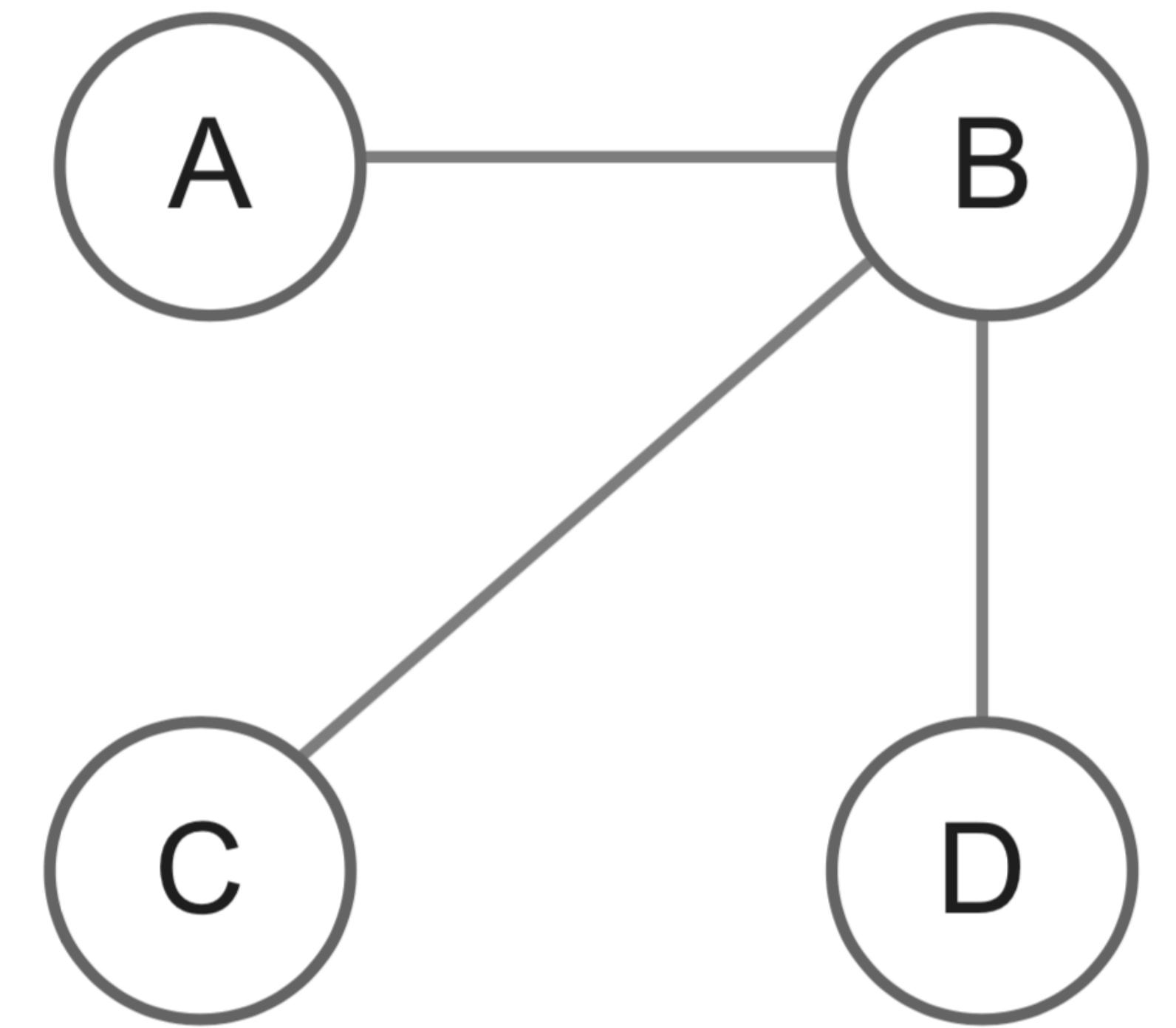


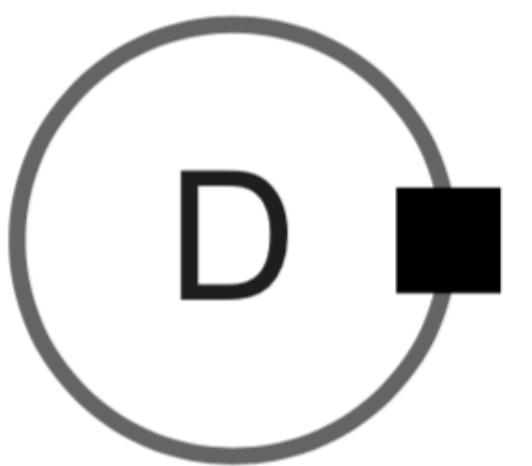
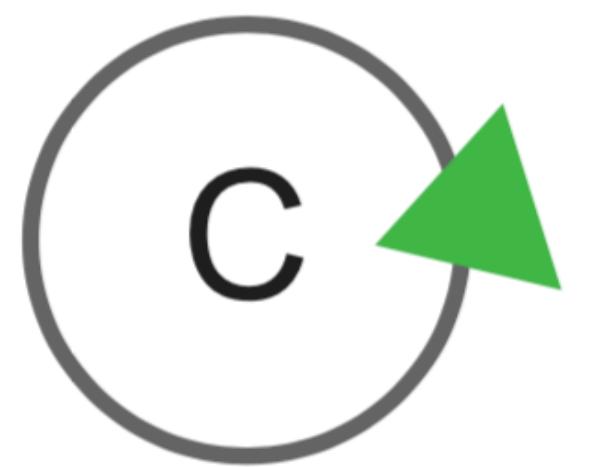
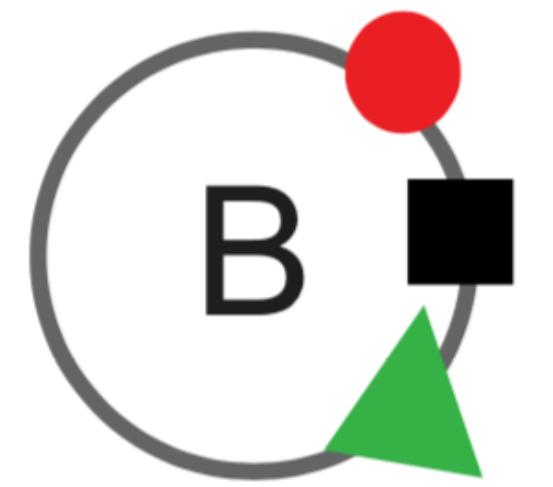
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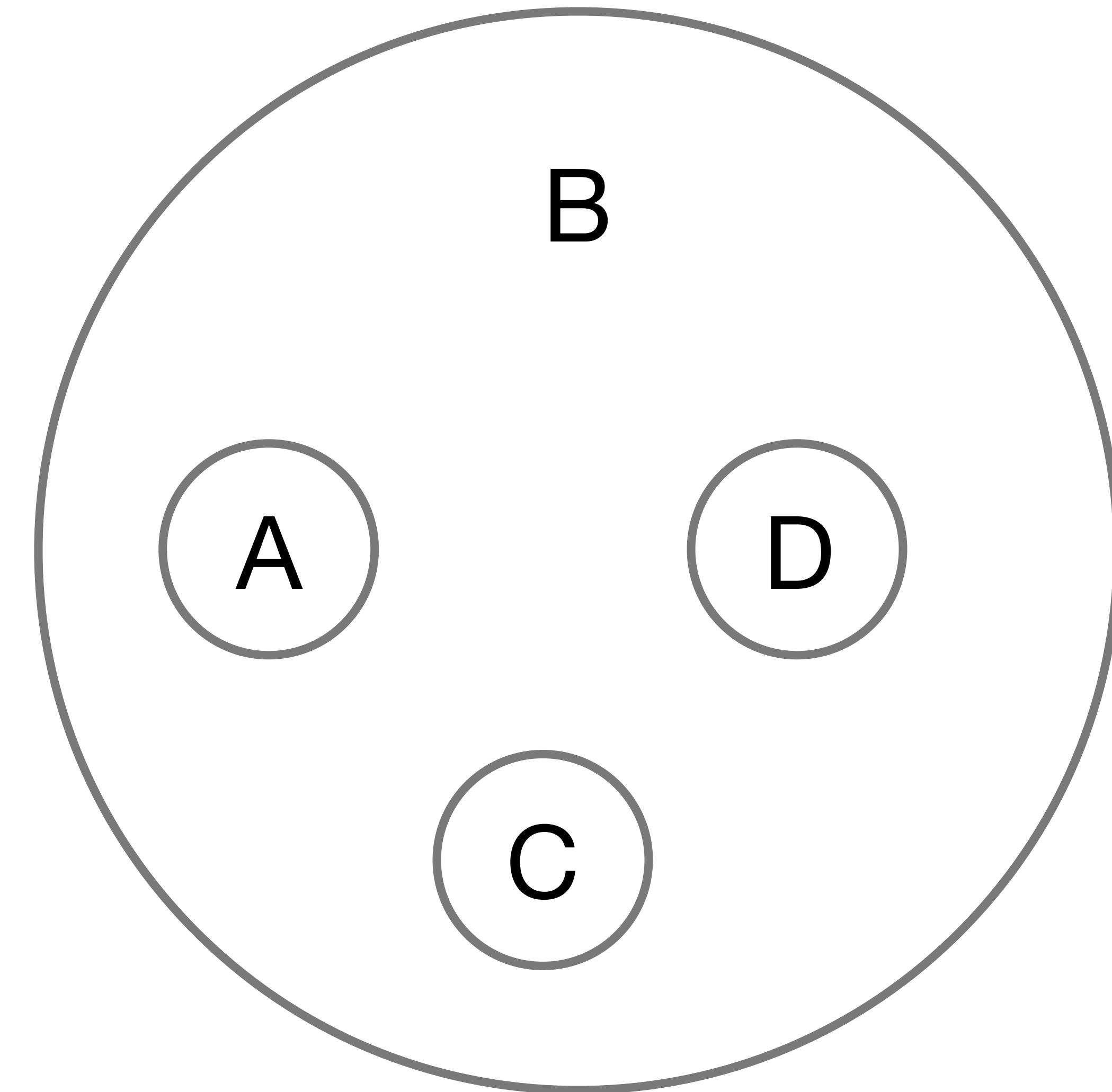
Hierarchy & Grouping

Hierarchy –

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



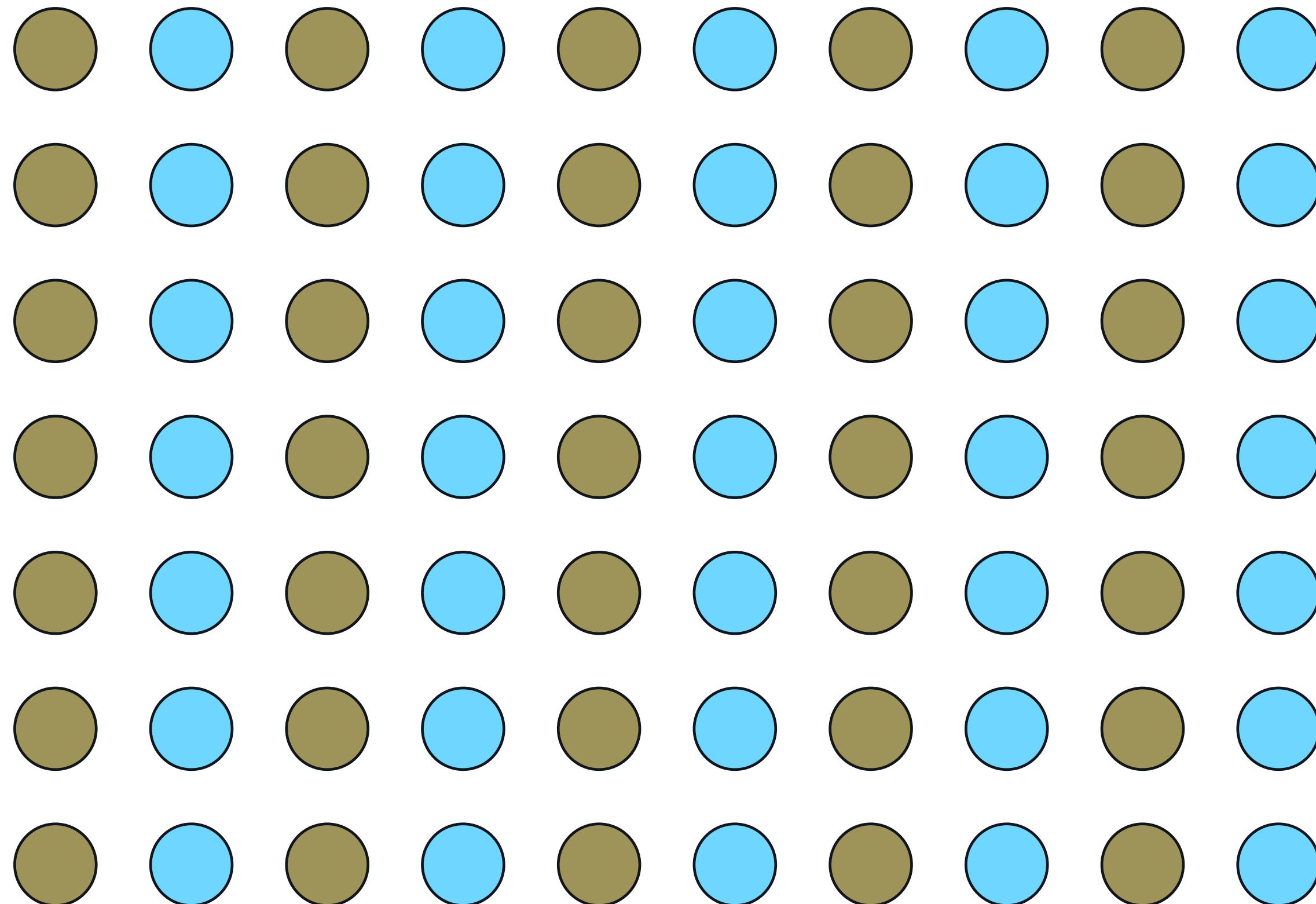




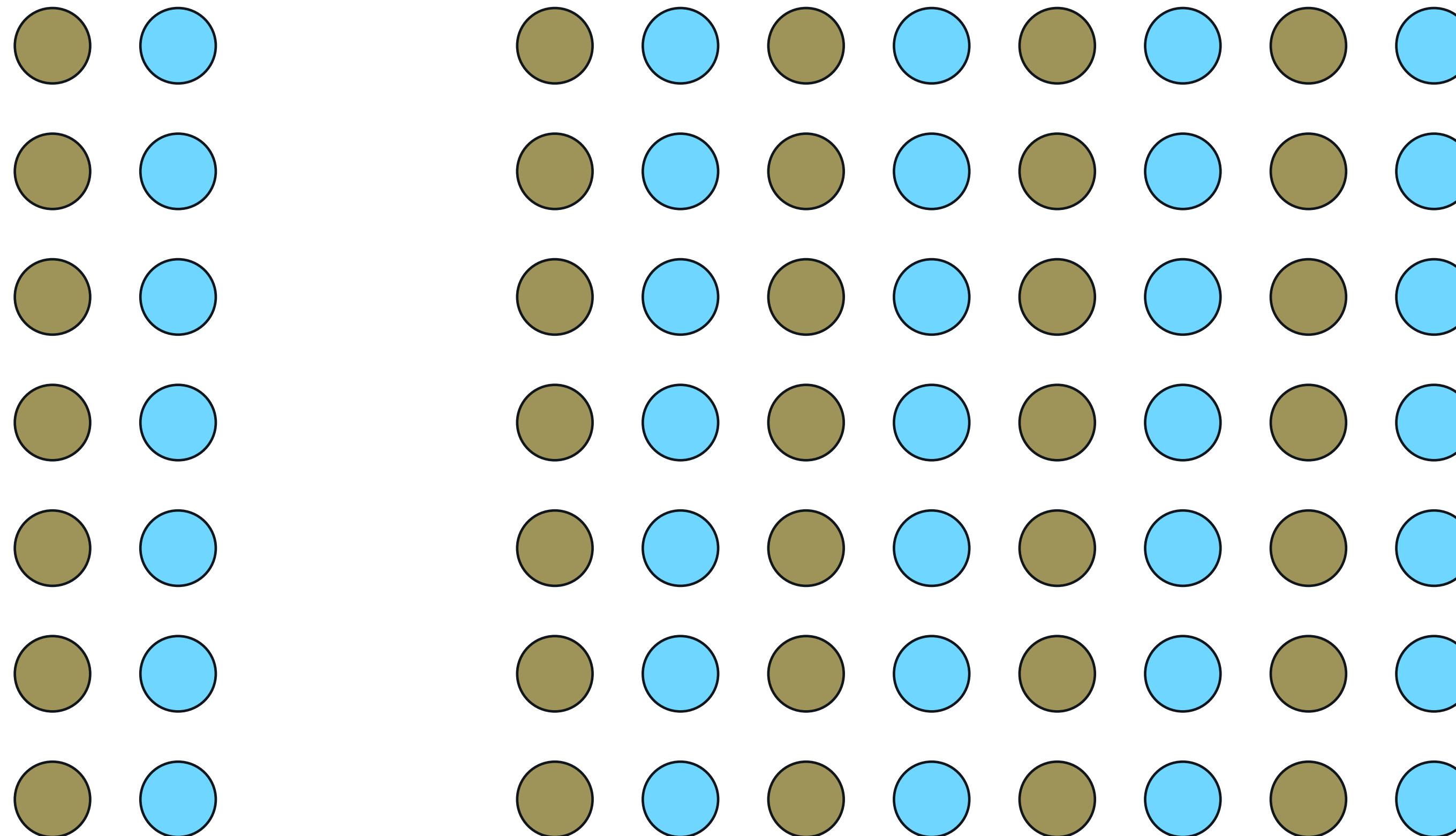
Grouping –

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

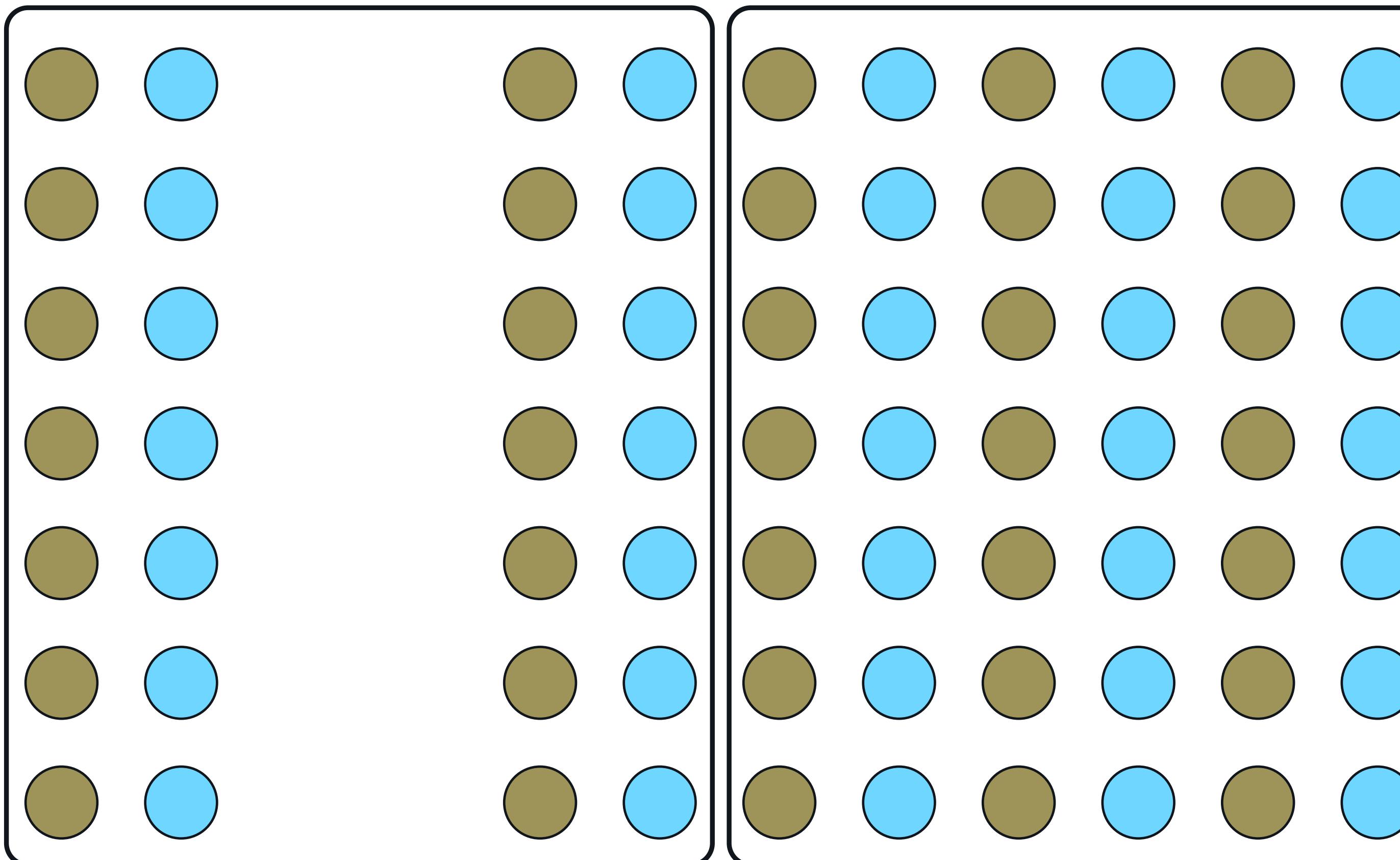
Gestalt Principle 1: **Similarity**



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

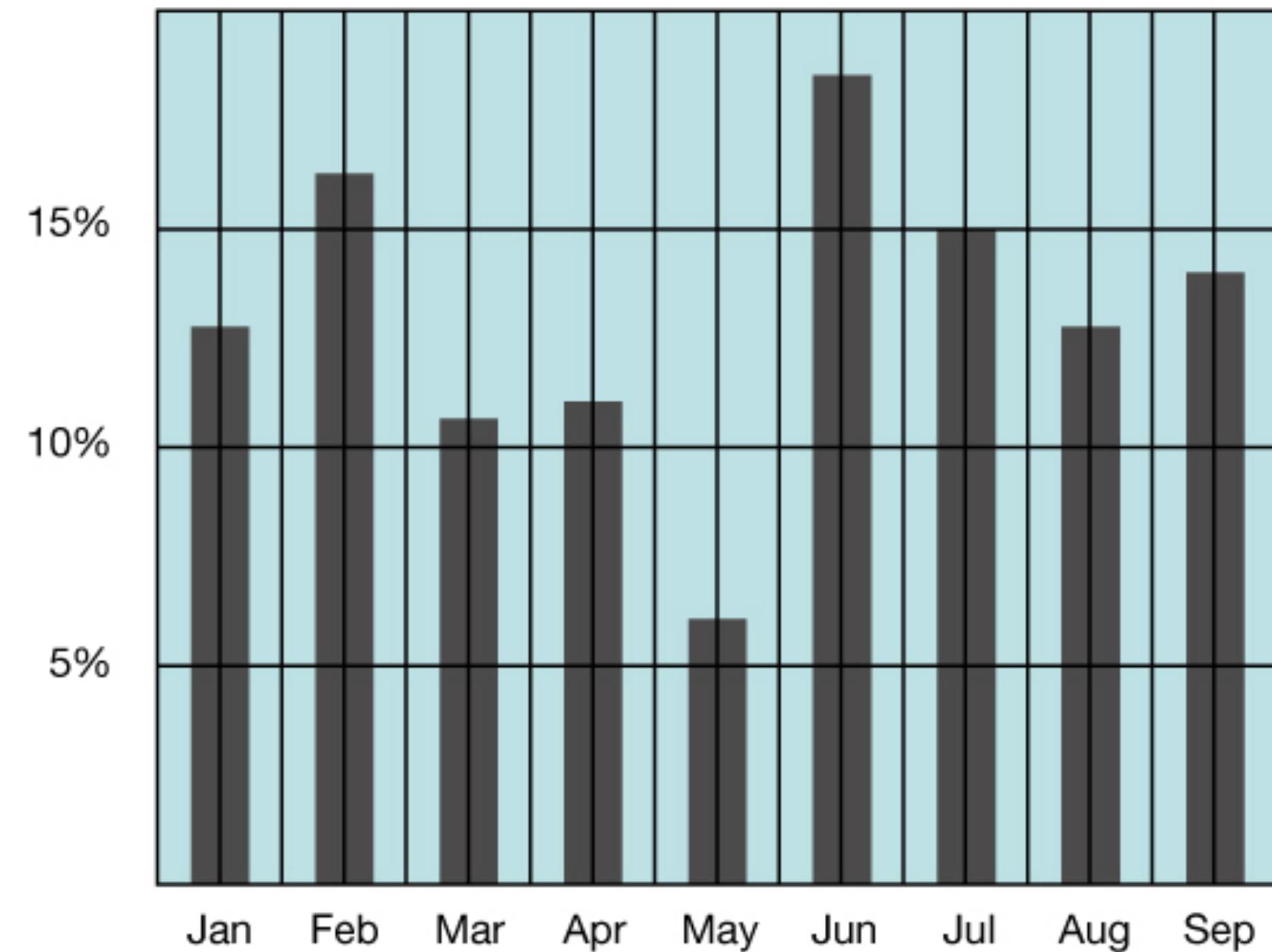
(Edward Tufte)

Data-ink ratio = 

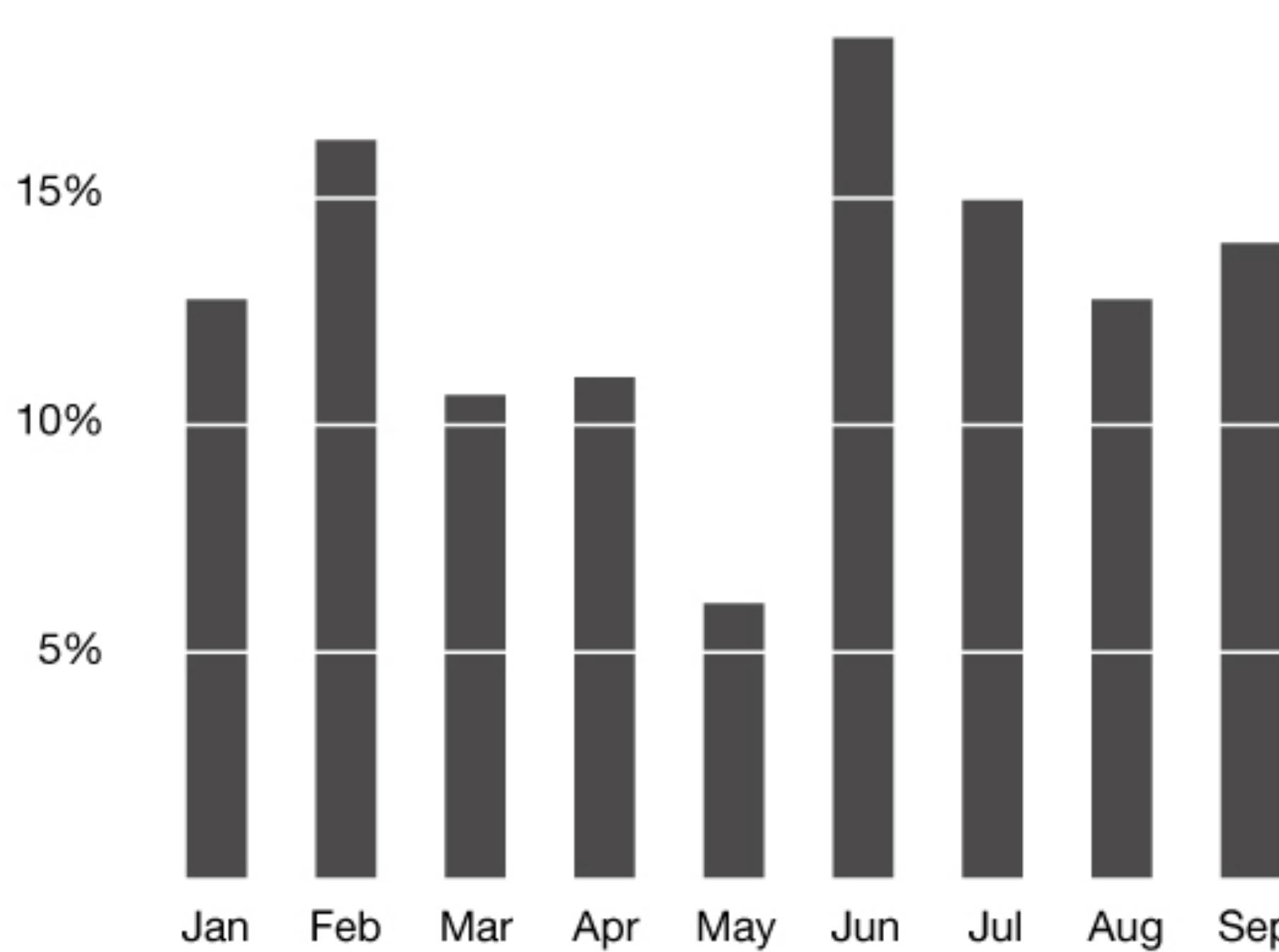
Data-ink

Total ink used to print graphic

LOW DATA-INK RATIO



HIGH DATA-INK RATIO



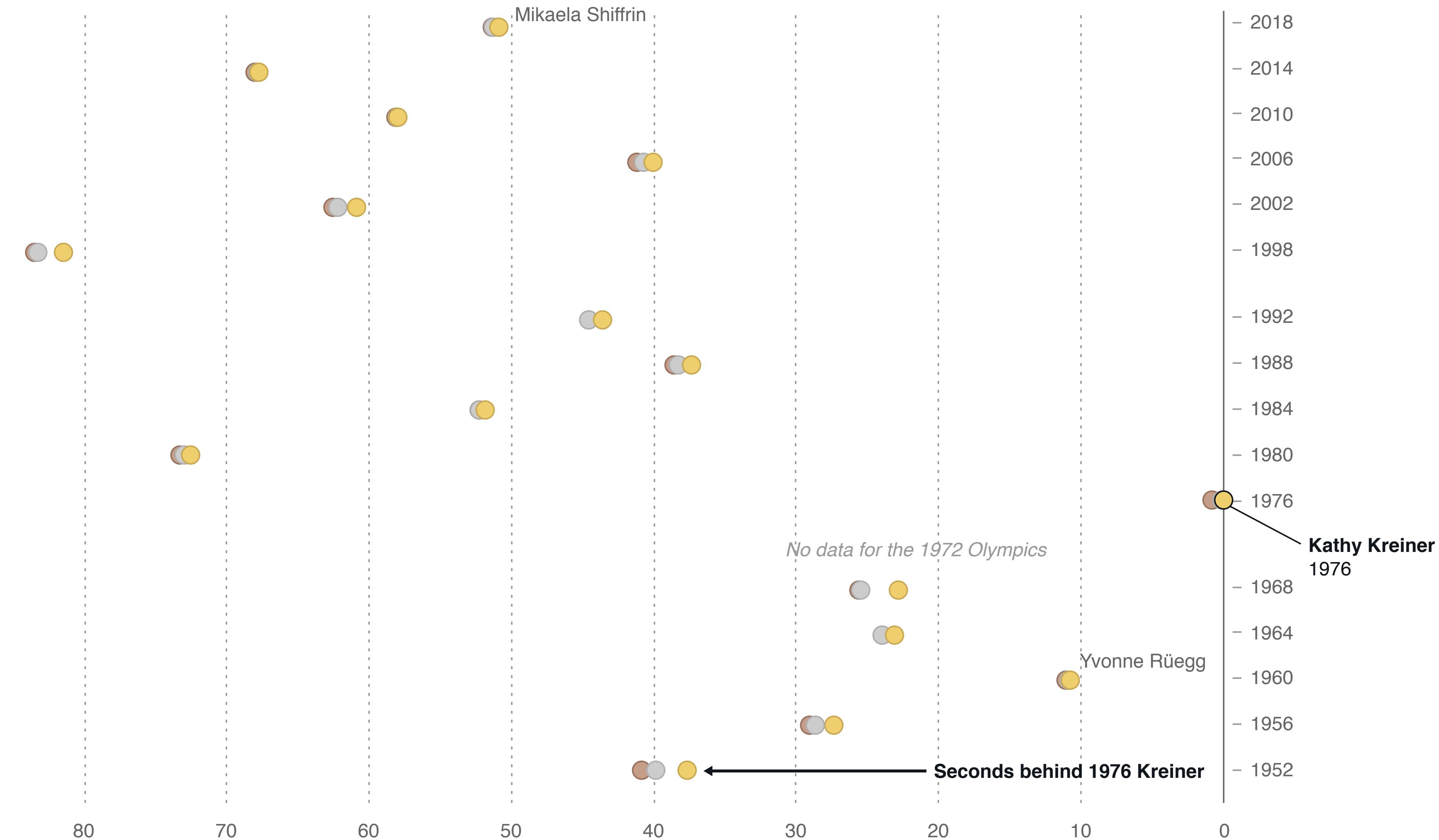
MONSTROUS COSTS

Total House and Senate
campaign expenditures,
in millions



“CHARTJUNK”

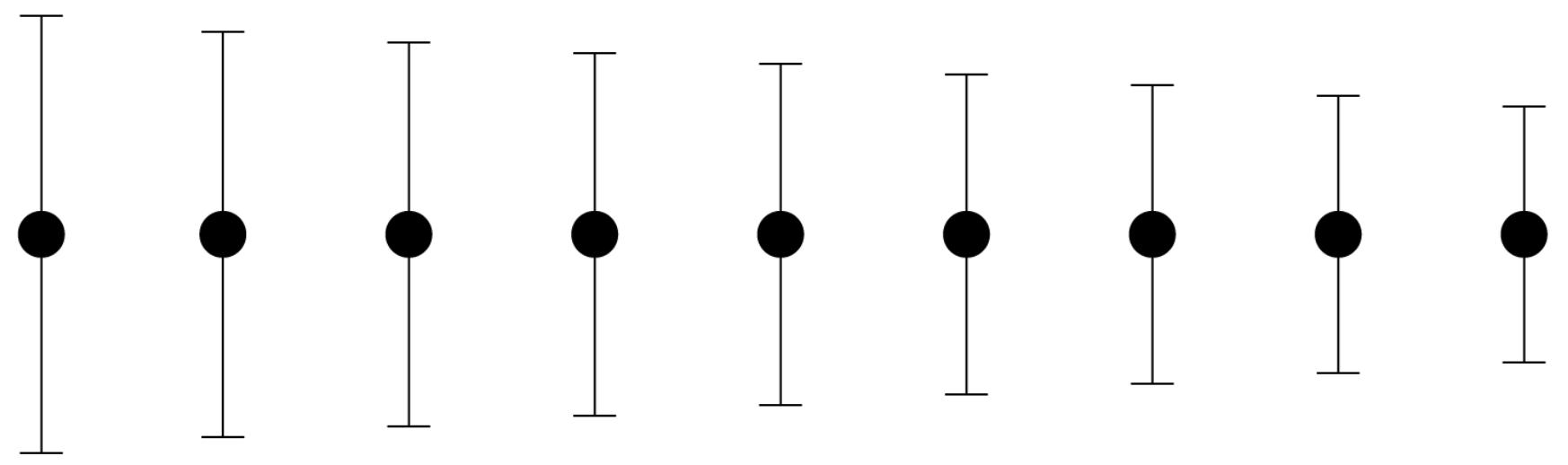
Work with **implicit metaphors**.



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: Obscurity

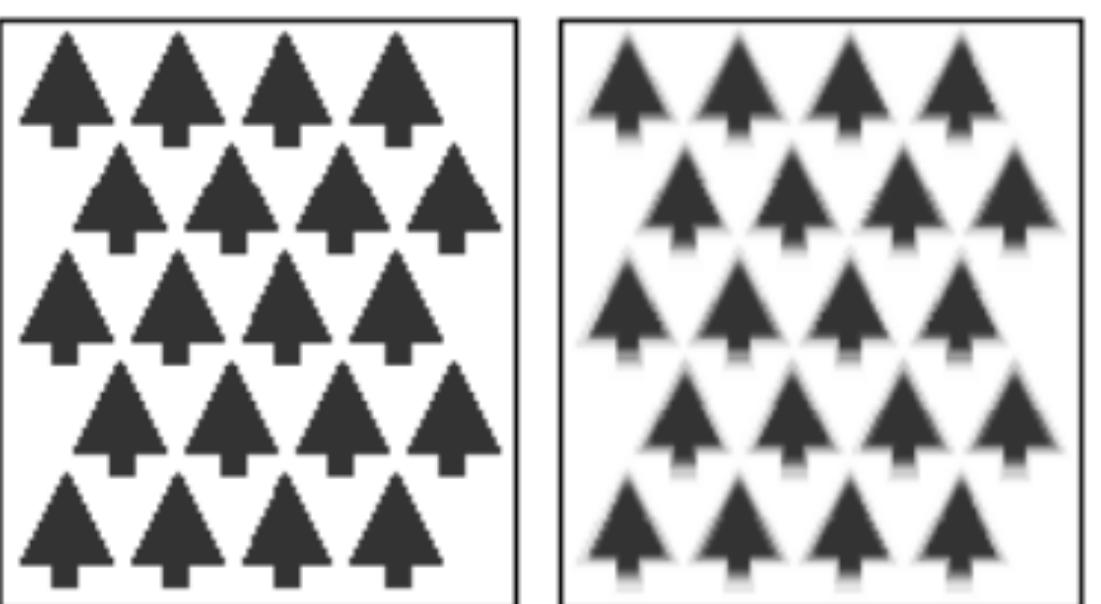
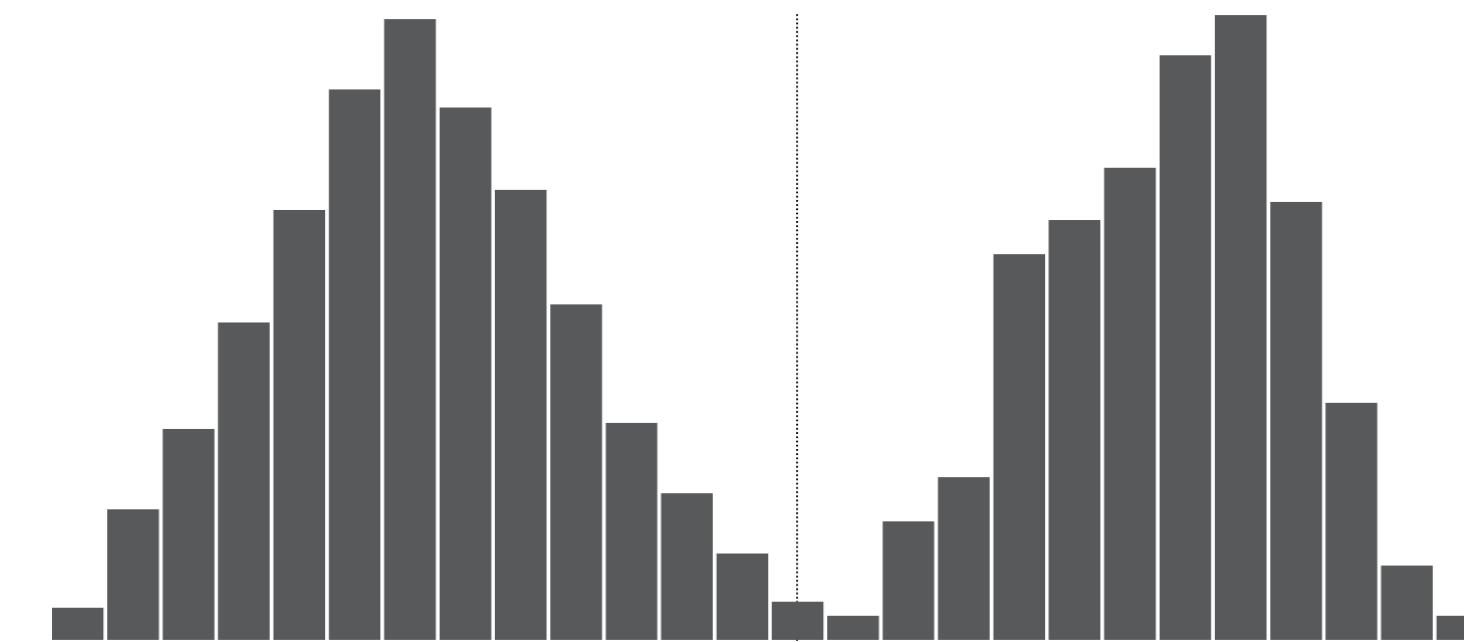
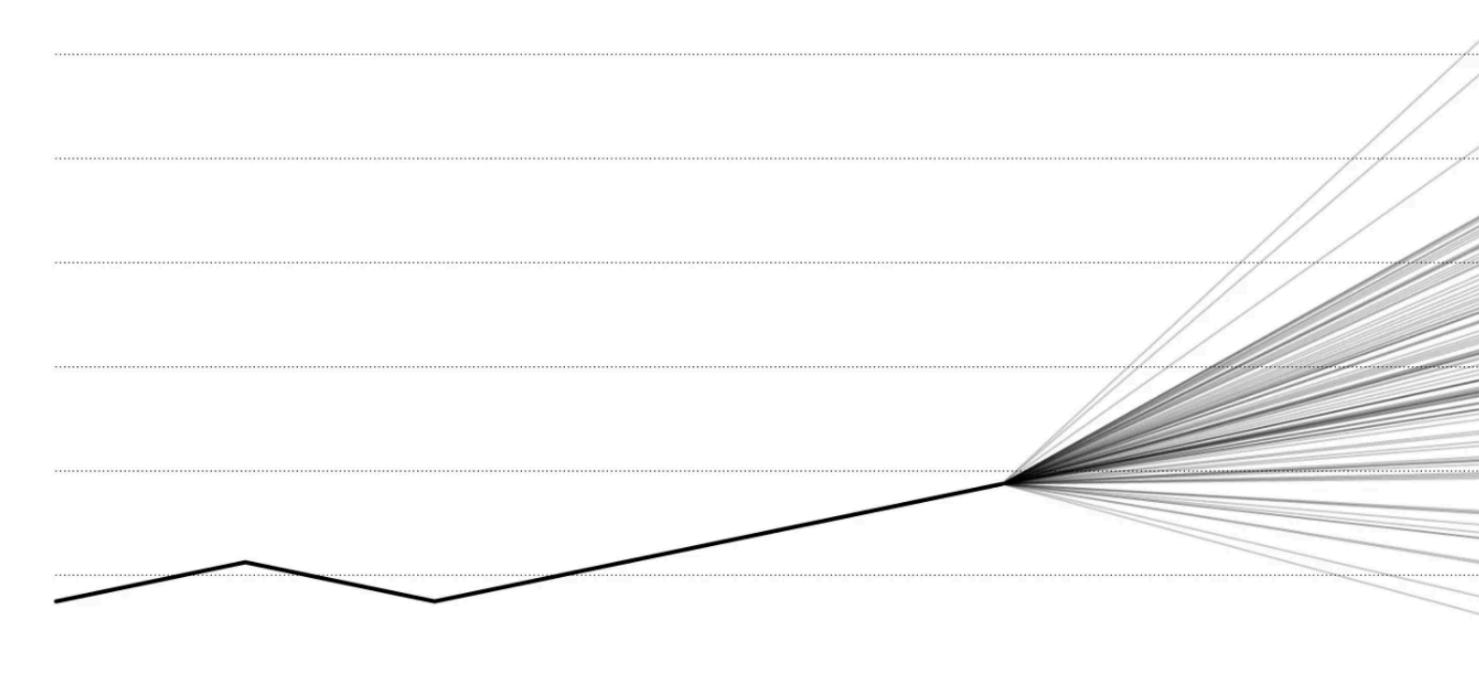


Fig. 5. Certain and uncertain depiction of land cover type.

Technique: Distributions



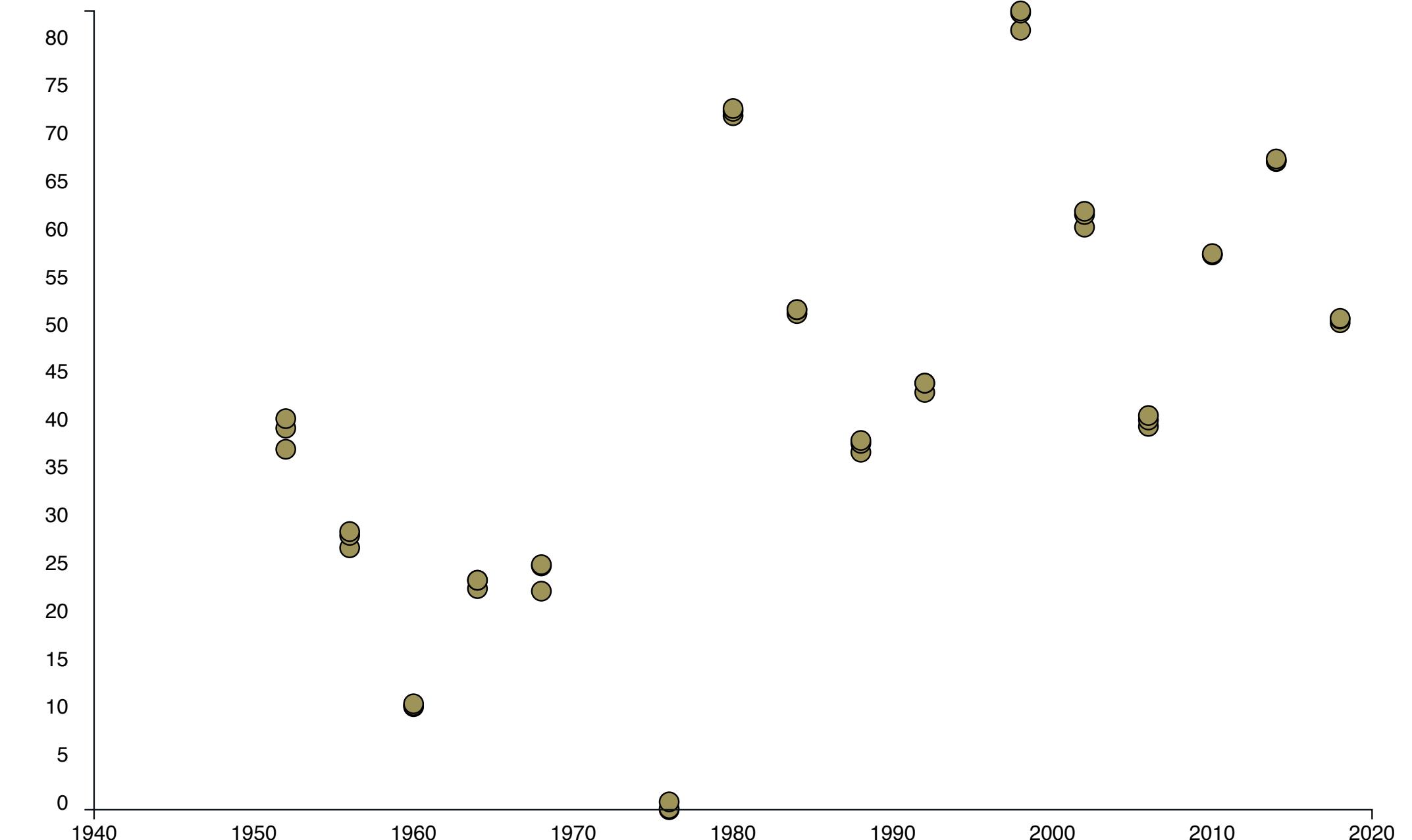
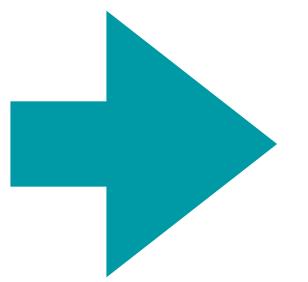
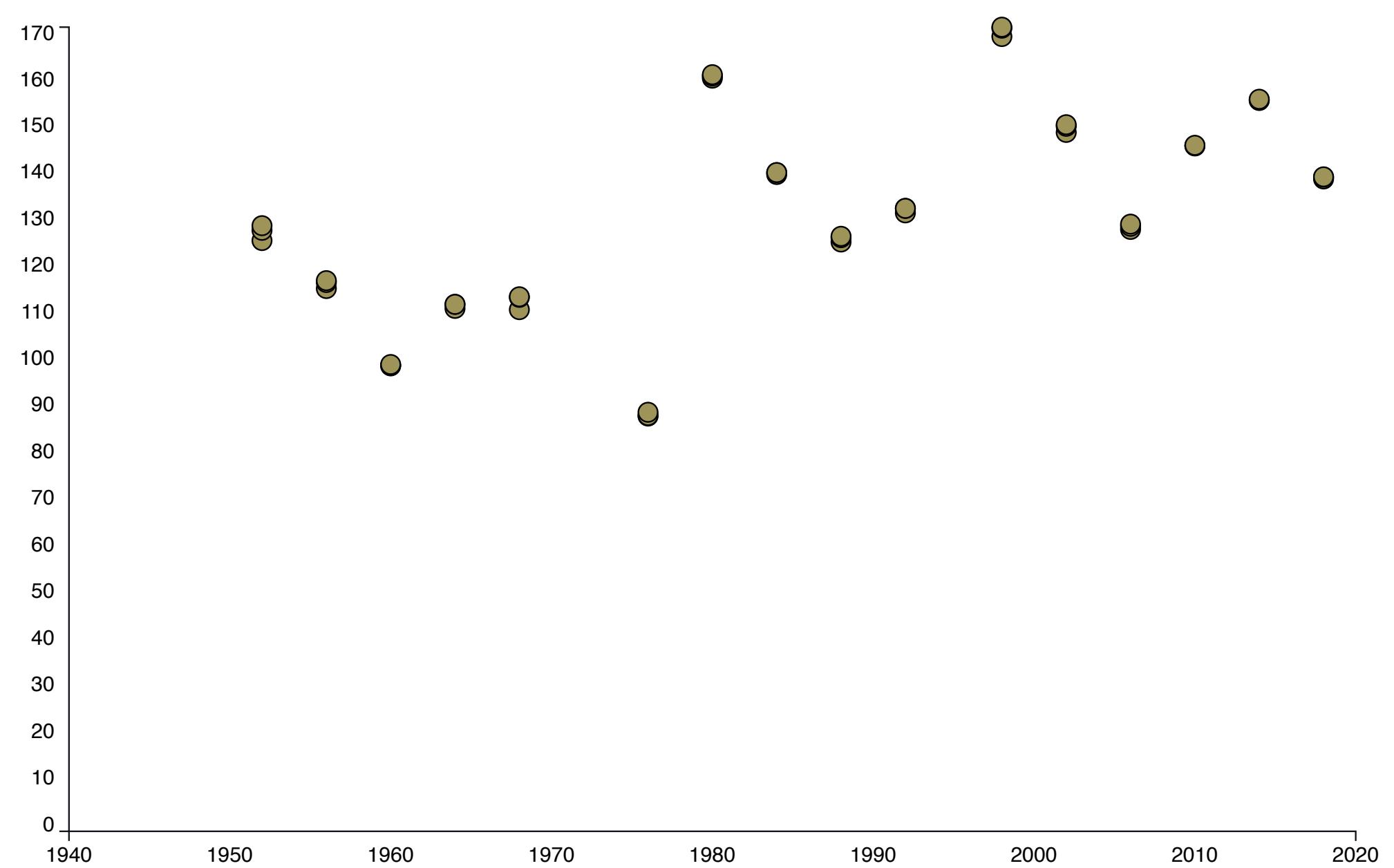
Technique: Multiple Outcomes



Source: [FlowingData](#)

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

Don't make the viewer do math.



Sometimes, visualization is not
the answer.

10

slides in this presentation have a
teal background.

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