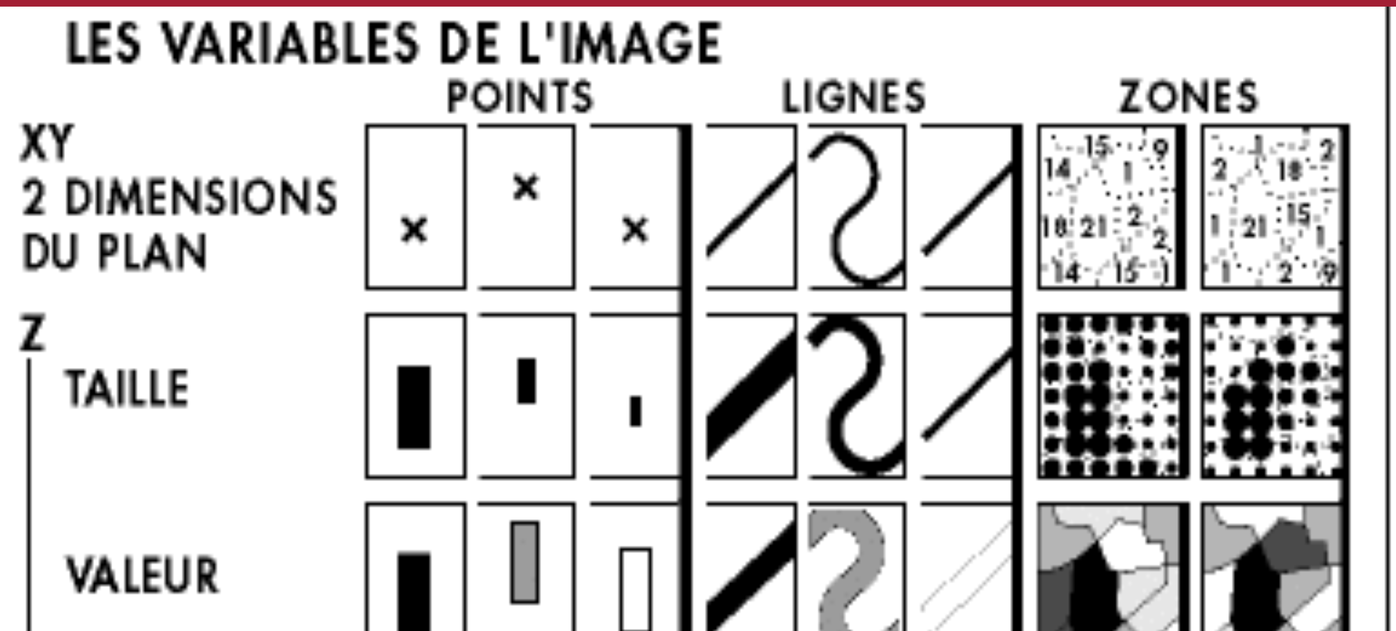
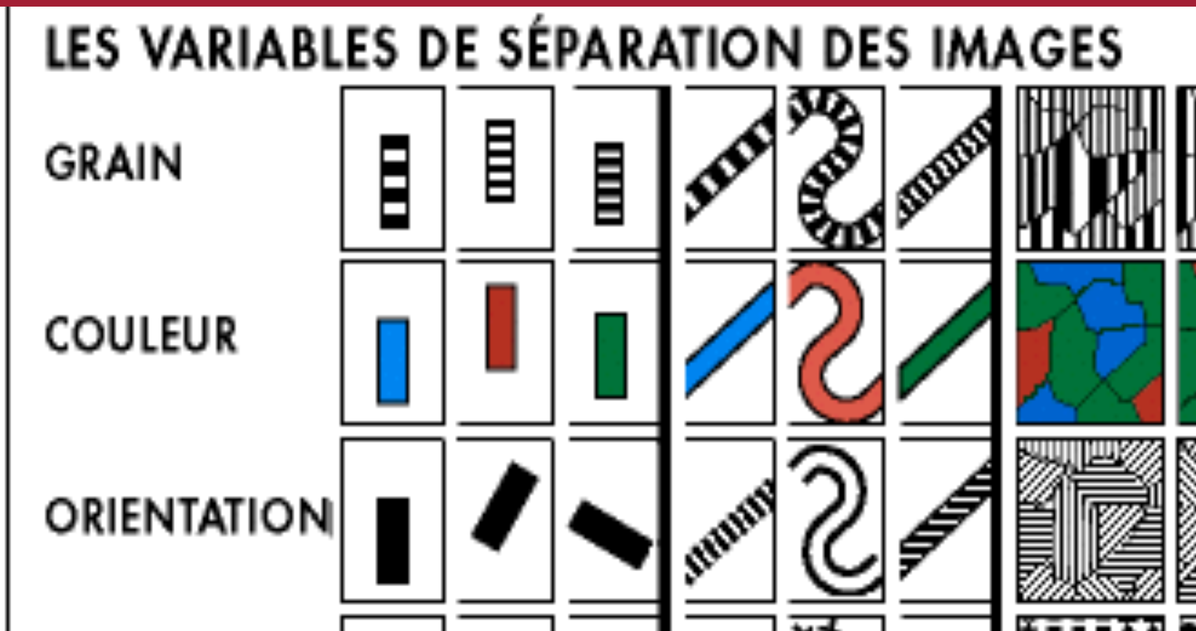
6.859: Interactive Data Visualization

Data & Image Models

Have some paper + pens/ pencils handy!

Arvind Satyanarayan





Course Grading

Class Participation	5%
Reading Commentaries	5%
A0: Sketching Visualizations	2%
A1: Visualization Design	3%
A2: Exploratory Data Analysis	10%
A3: White/Black Hat Visualization	15%
A4: Interactive Narratives	20%
Final Project	40%
Proposal	
MVP + Presentations	
Poster Session + Final Deliverables	

Lectures will be recorded and posted to Canvas.

You may attend asynchronously but we encourage synchronous attendance if you're able to.

Class Participation grade will be primarily determined by activity on **Slack**:

- Introduce yourself in #introductions
- Ask and answer questions
- Post links to + critique interesting visualizations you find online.

Share your work!!

Course Grading

Class Participation	5%	
Reading Commentaries	5%	
A0: Sketching Visualizations	2%	Due 2/22
A1: Visualization Design	3%	Due 3/1
A2: Exploratory Data Analysis	10%	Due 3/9
A3: White/Black Hat Visualization	15%	Due 3/24
A4: Interactive Narratives	20%	Due 4/5, 4/12
Final Project	40%	
Proposal		Due 4/16
MVP + Presentations		Due 5/3
Poster Session + Final Deliverables		Due 5/11

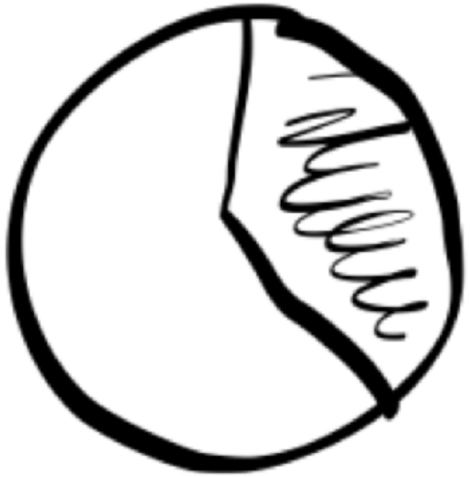
Activity!

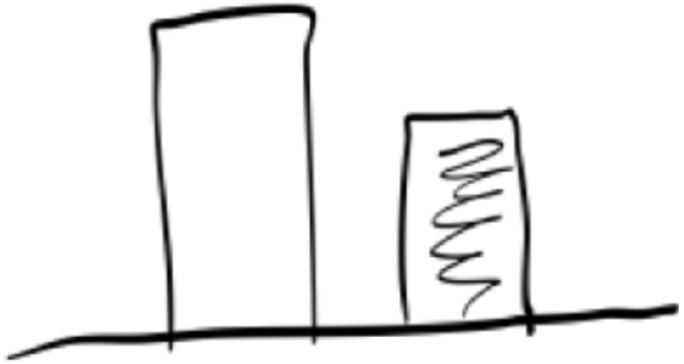
In **1 minute**, sketch as many visualizations as possible of these two numbers:

75 **37**

Most Likely Results

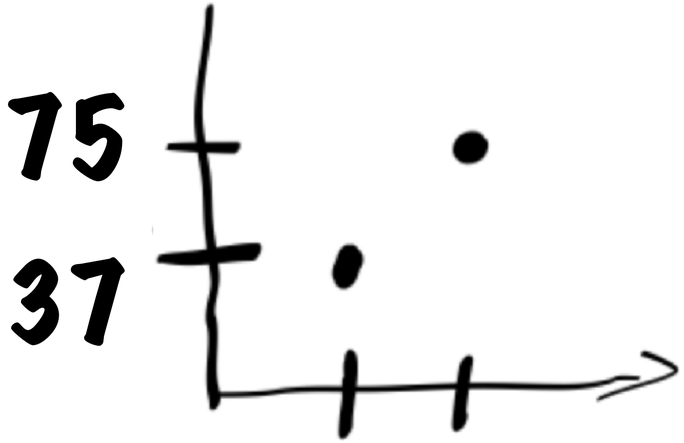
Pie Charts





Bar Charts

Scatterplot



75

37

Arabic Numbers

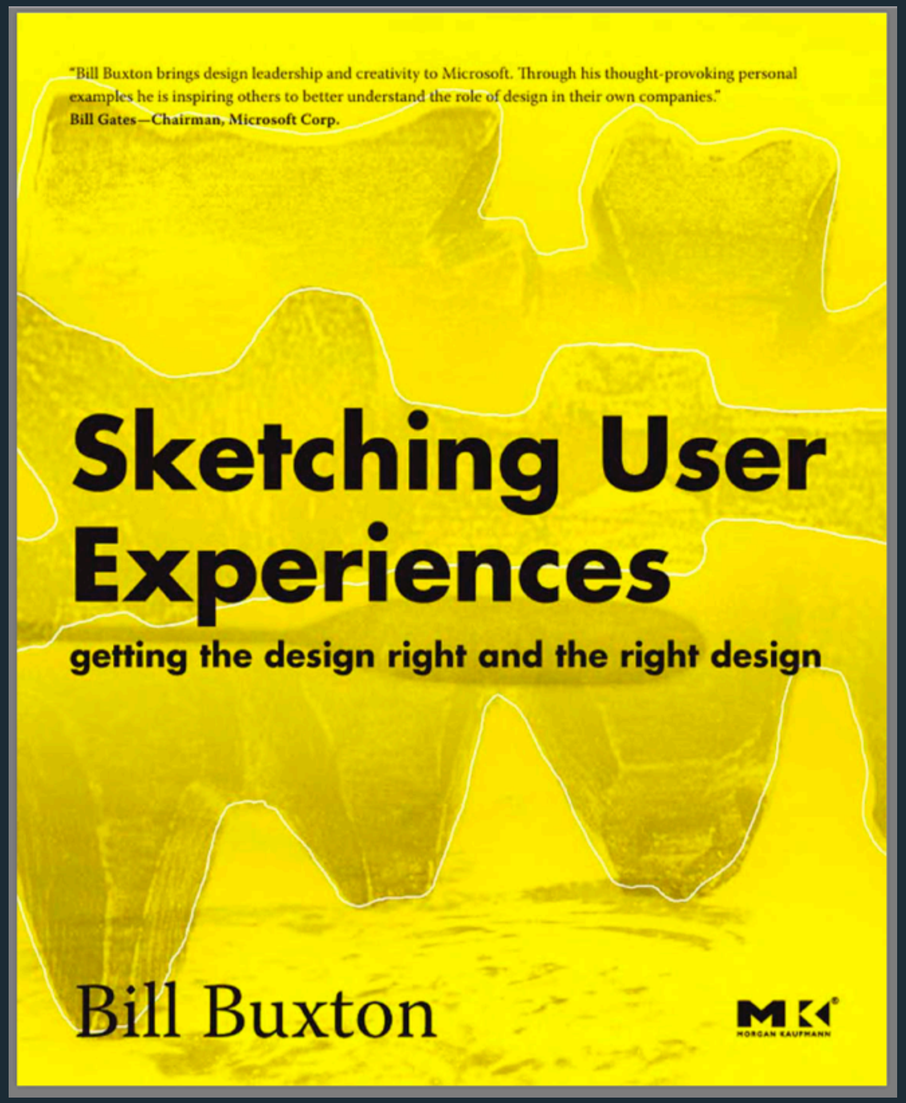
Design Fixation

"A blind adherence to a set of ideas or concepts limiting the output of conceptual design" [Jansson & Smith 1991]

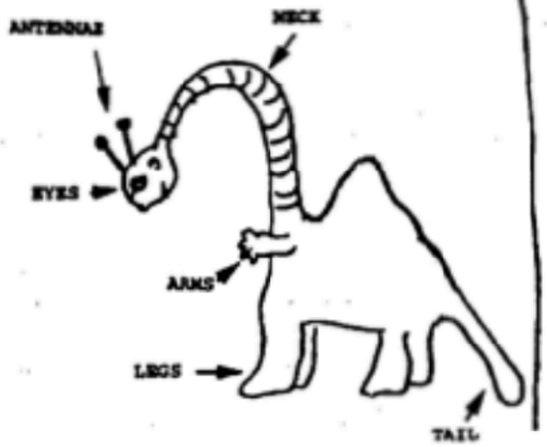
To overcome fixation:

sketch: quick, inexpensive, disposable ways of generating, evaluating, and sharing ideas [Buxton 2007]

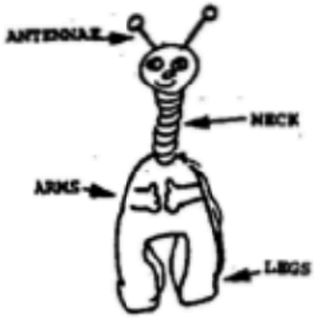
consult examples



FRONT VIEW

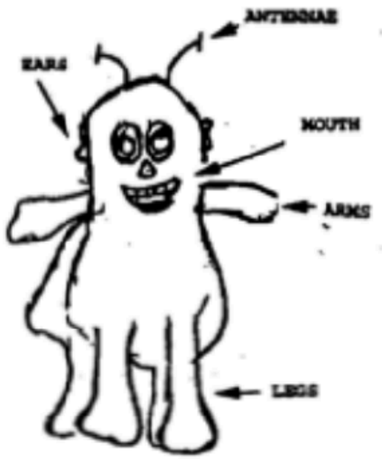


SIDE VIEW

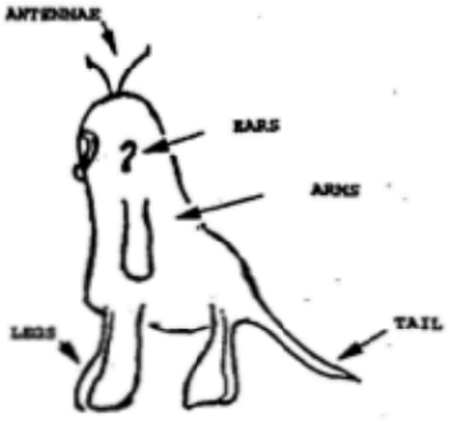


This creature is very friendly and has a retractable neck which helps it to eat off of trees.

FRONT VIEW

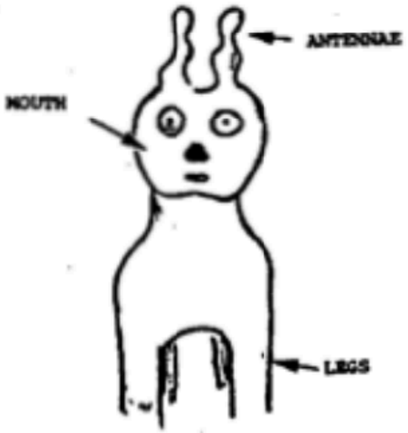


SIDE VIEW

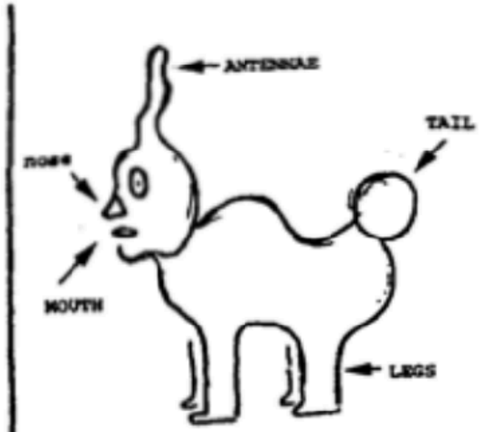


This creature walks tha planet eating all sorts of things like rocks and dirt.

A very fluffy creature that hops from one place to the next using its very strong legs.



FRONT VIEW



SIDE VIEW

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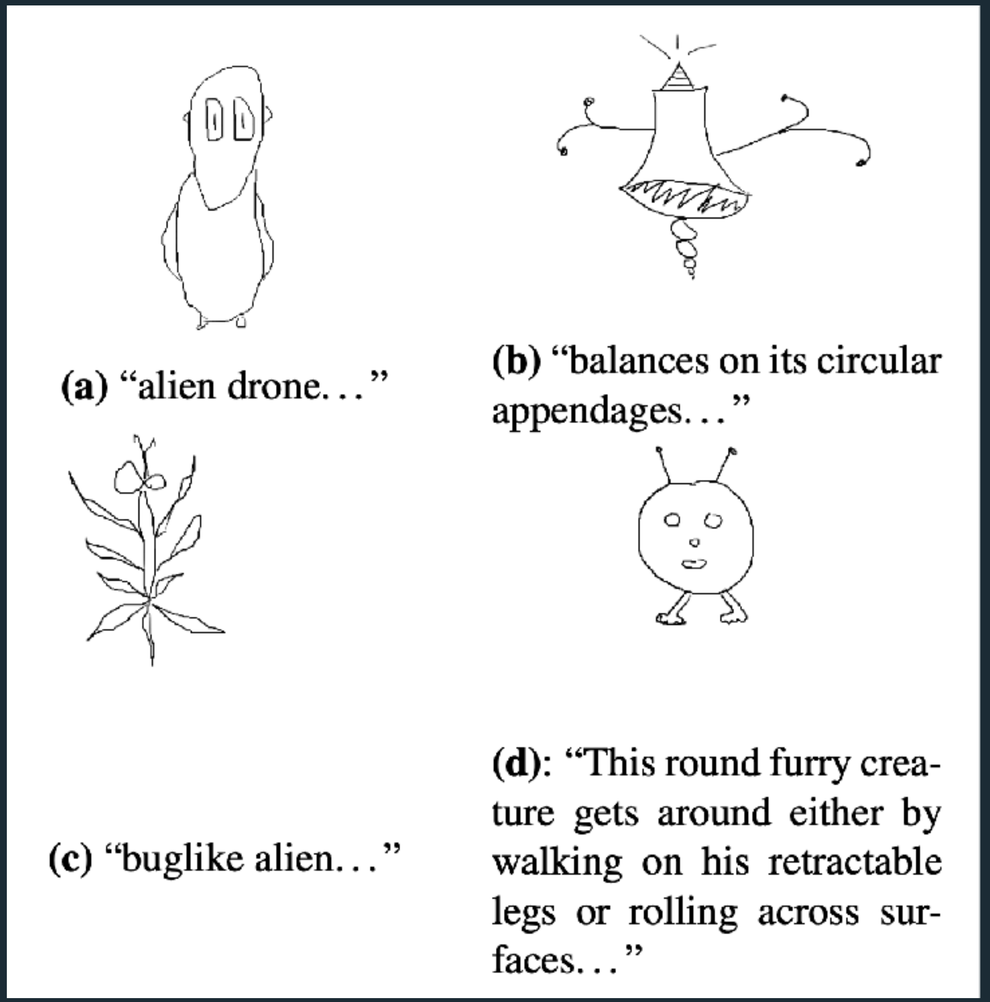
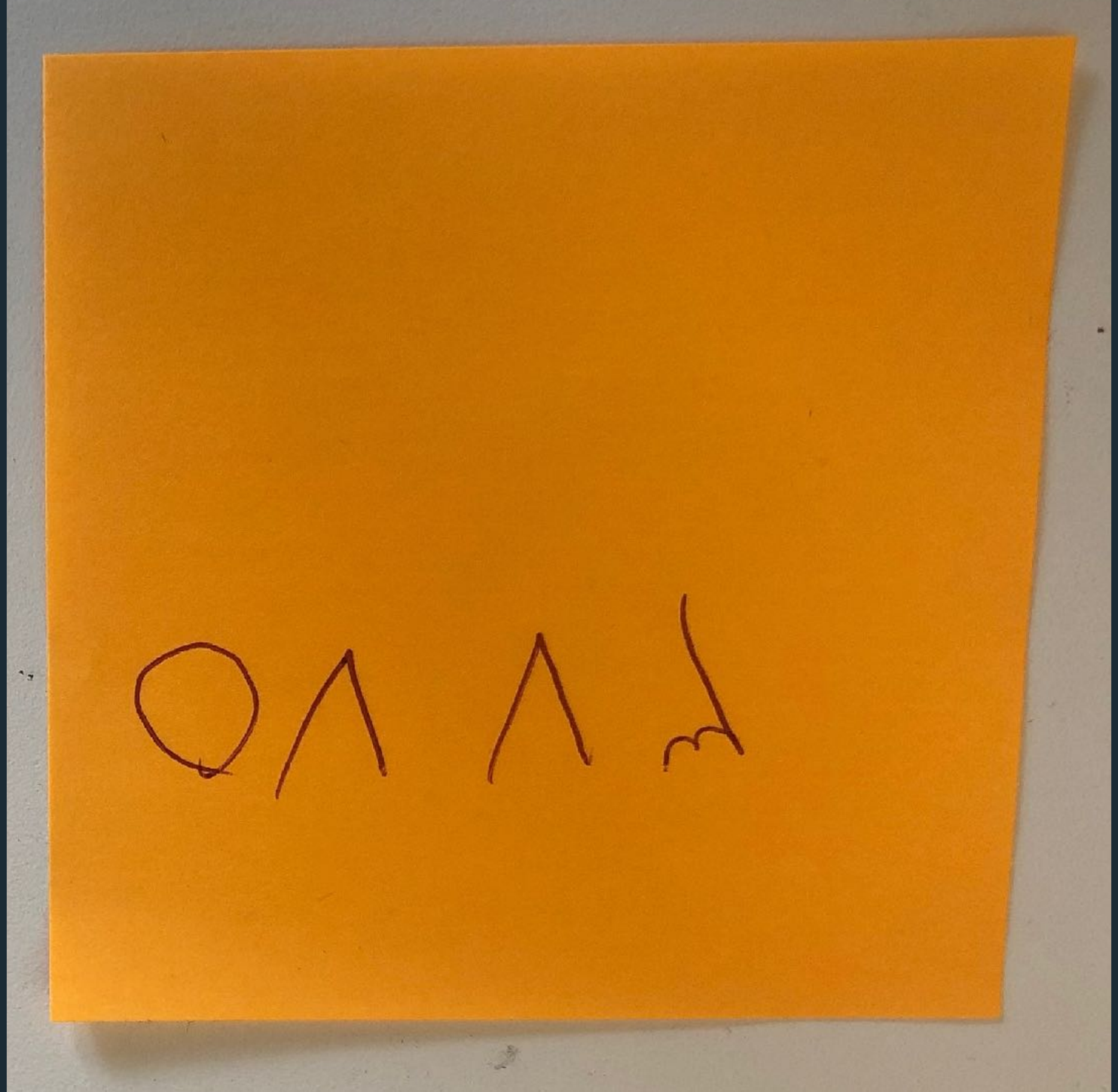


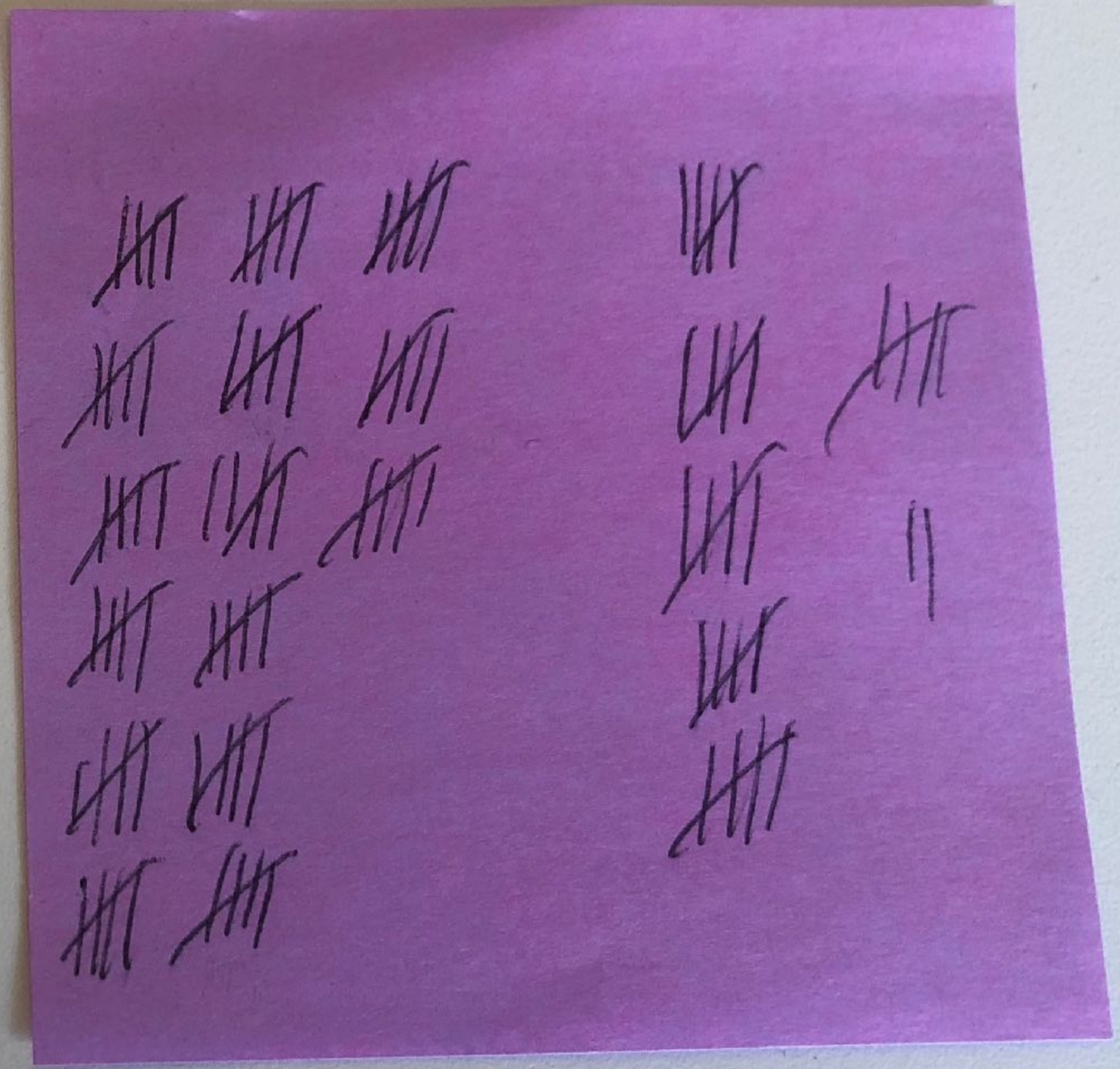
(a) "alien drone…"

(b) "balances on its circular appendages…"

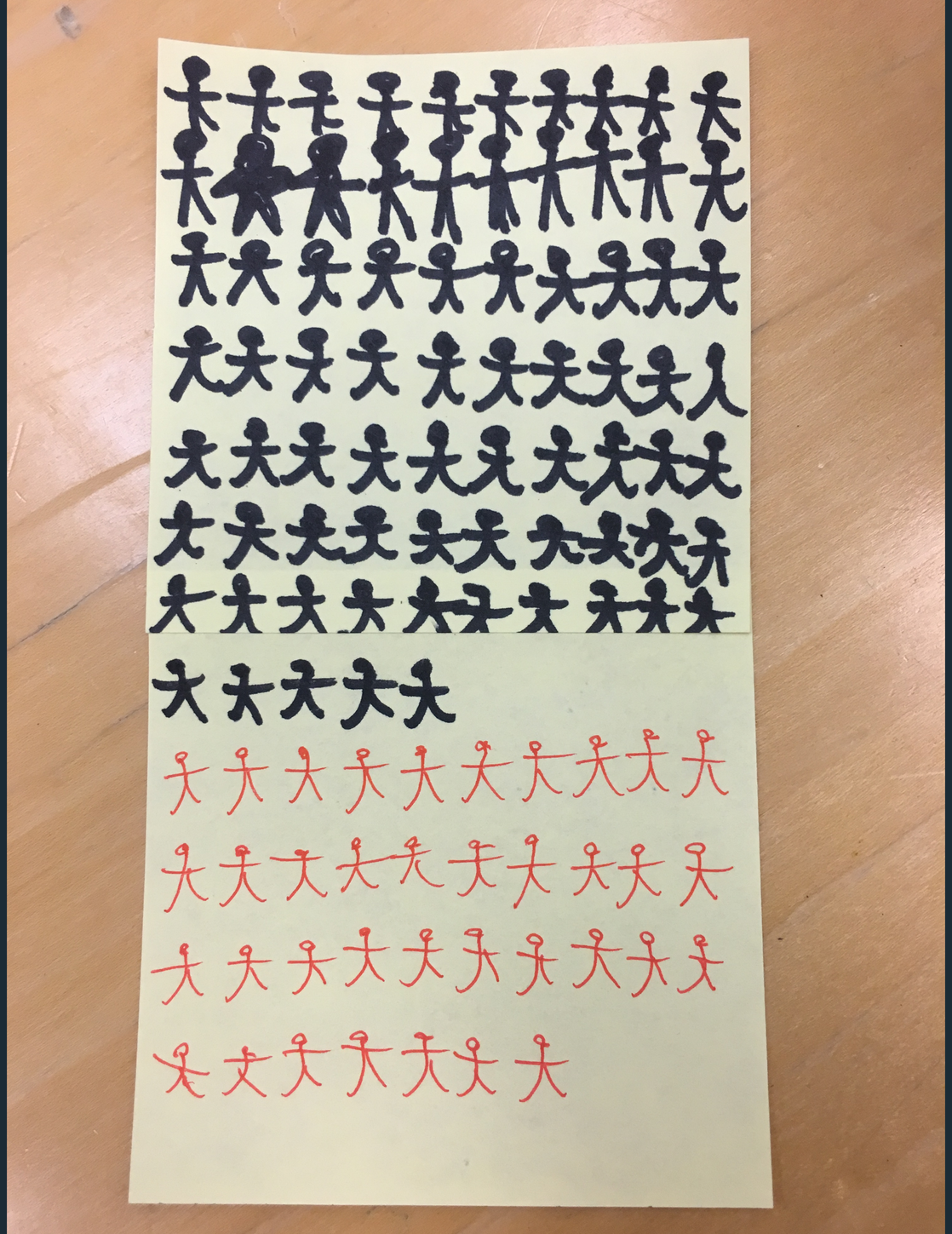
(c) "buglike alien…"

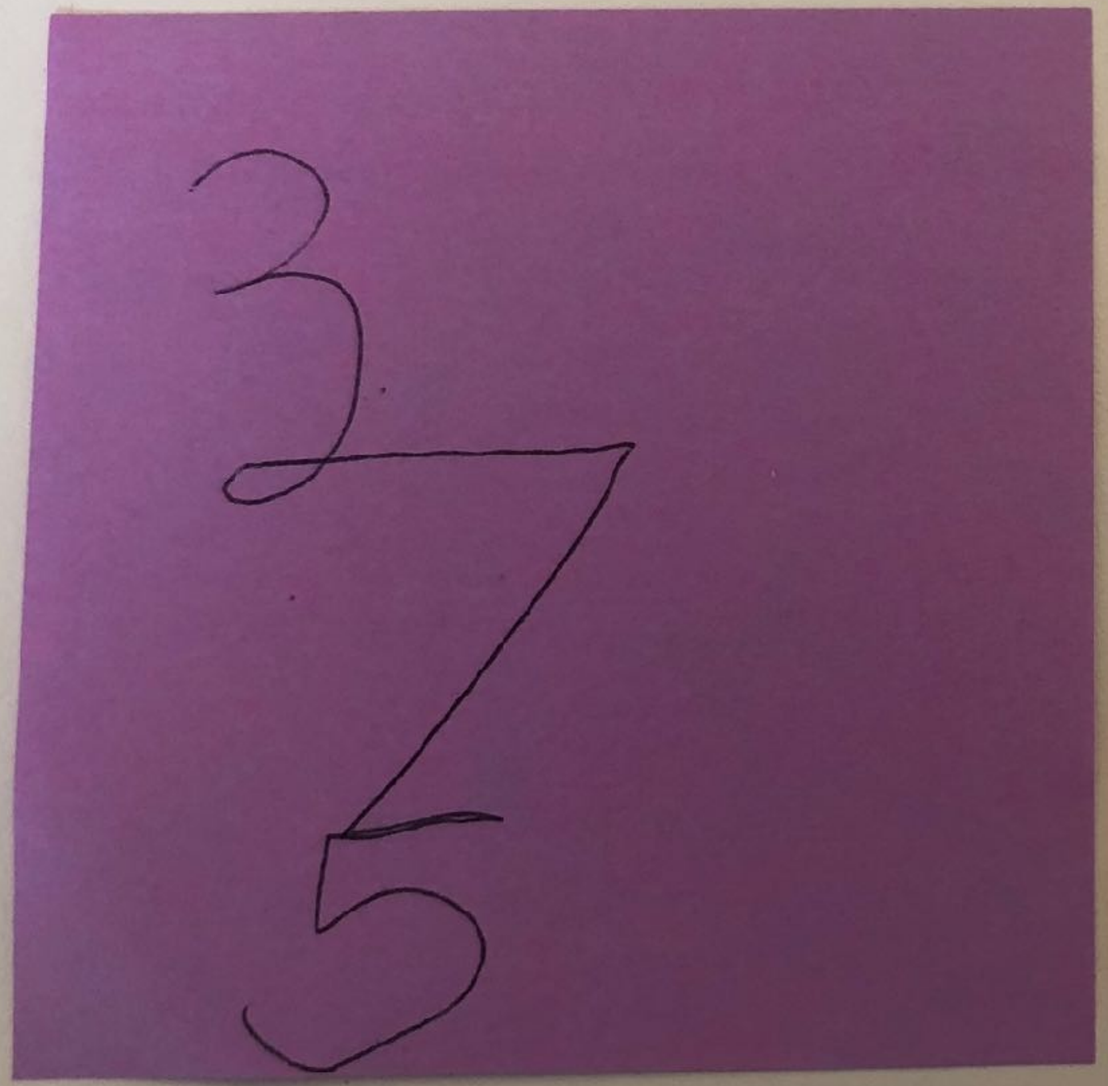
(d): "This round furry creature gets around either by walking on his retractable legs or rolling across surfaces…"

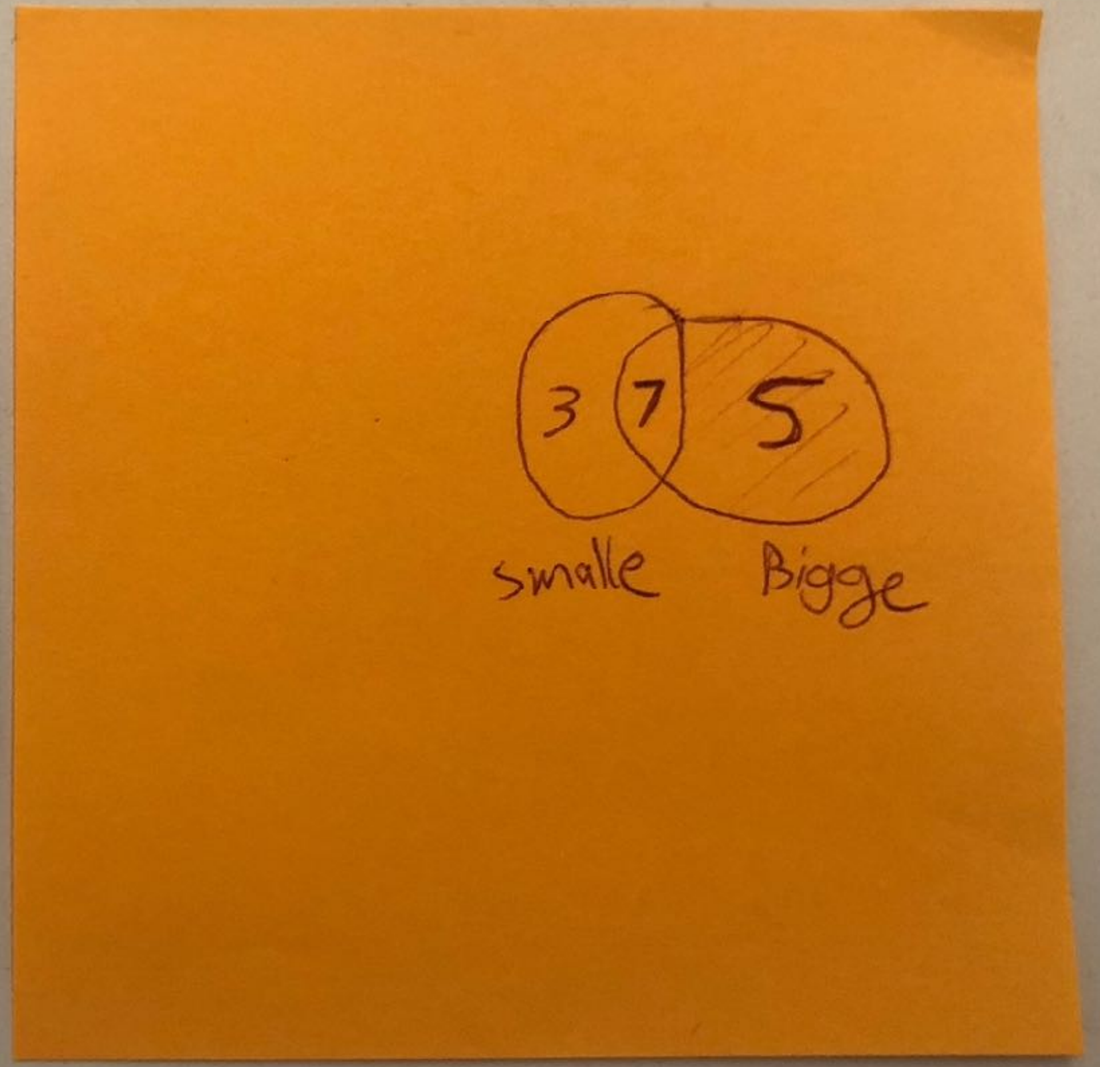




Examples from Jon Schwabish.




3
7
5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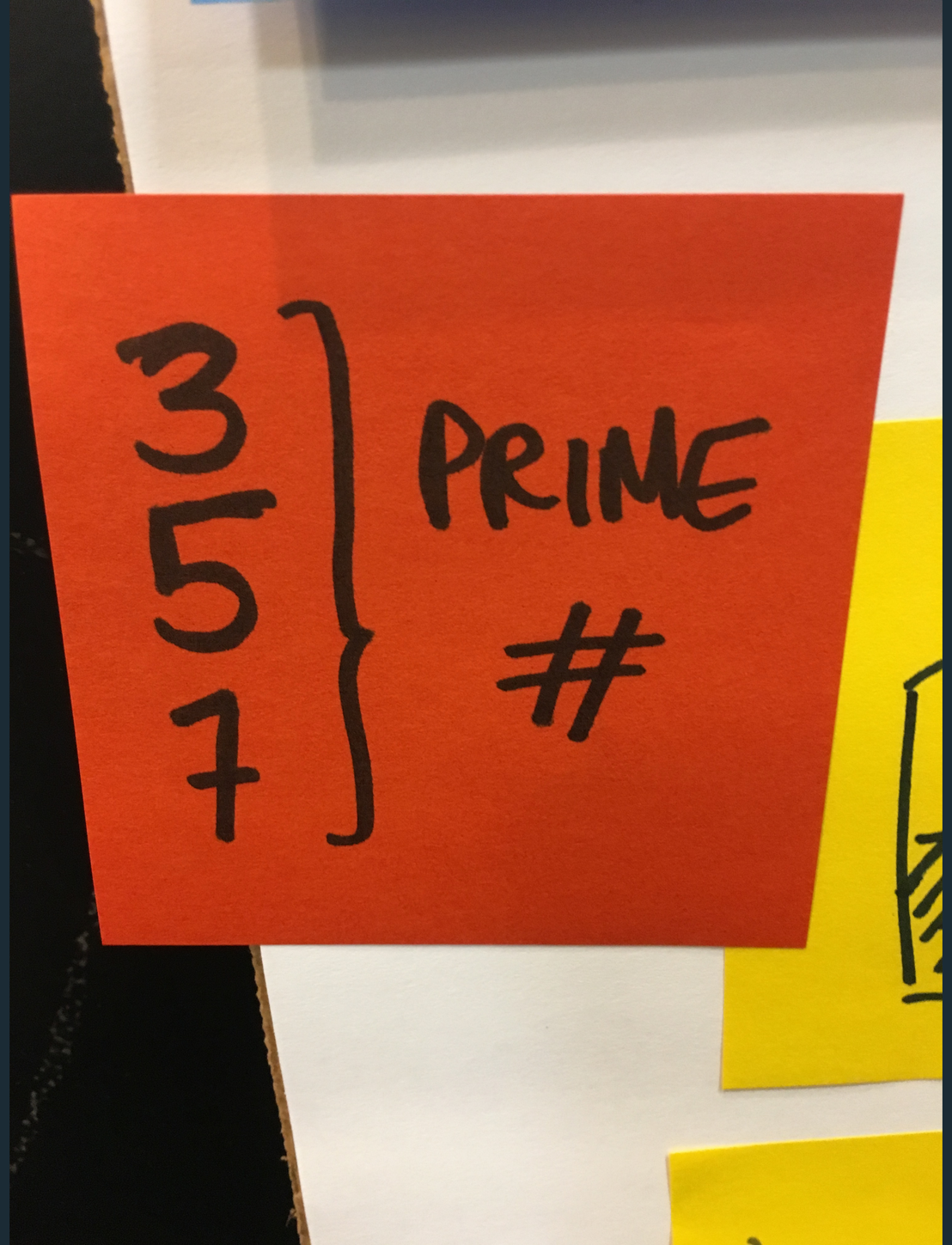
Examples from Jon Schwabish.



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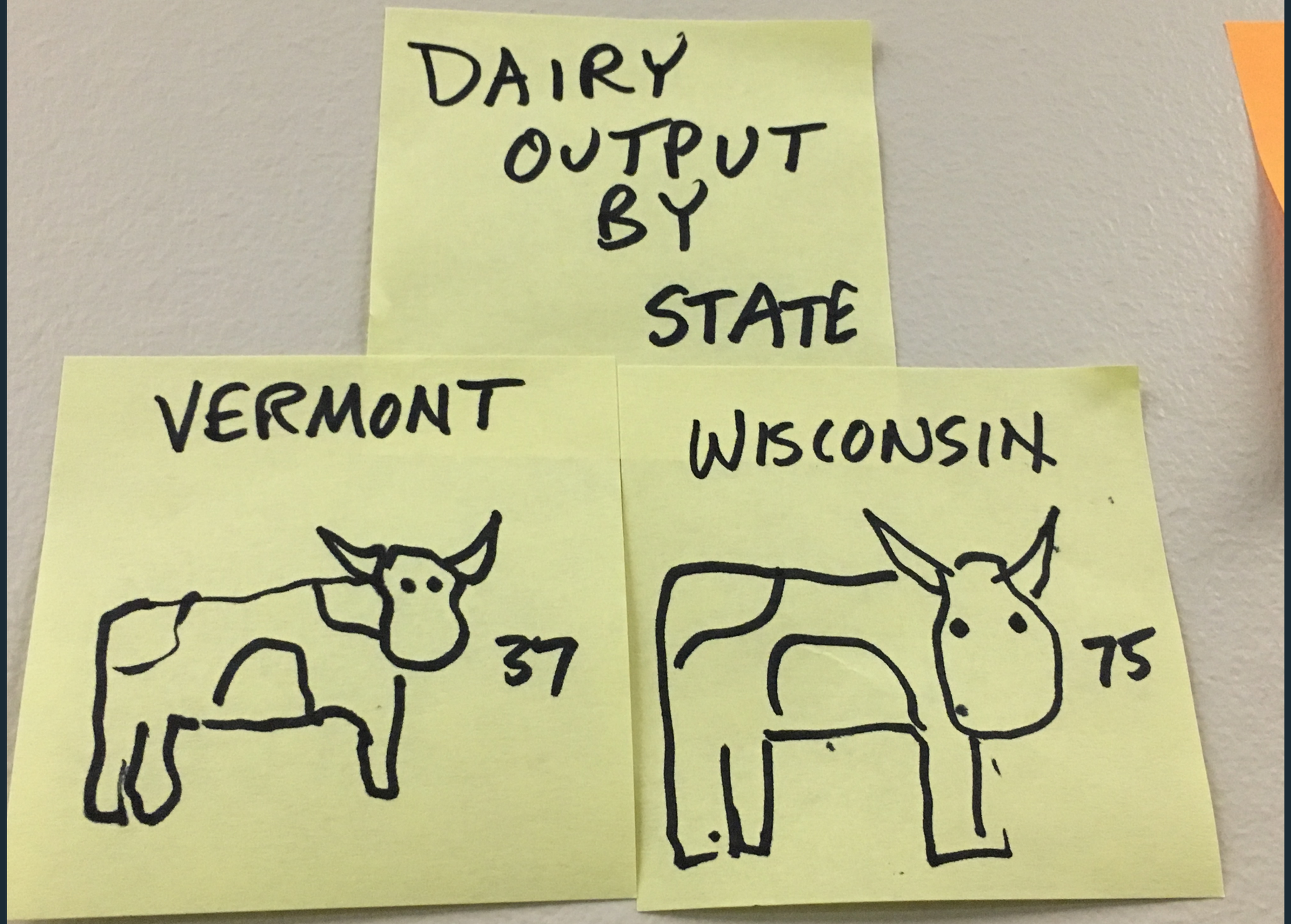

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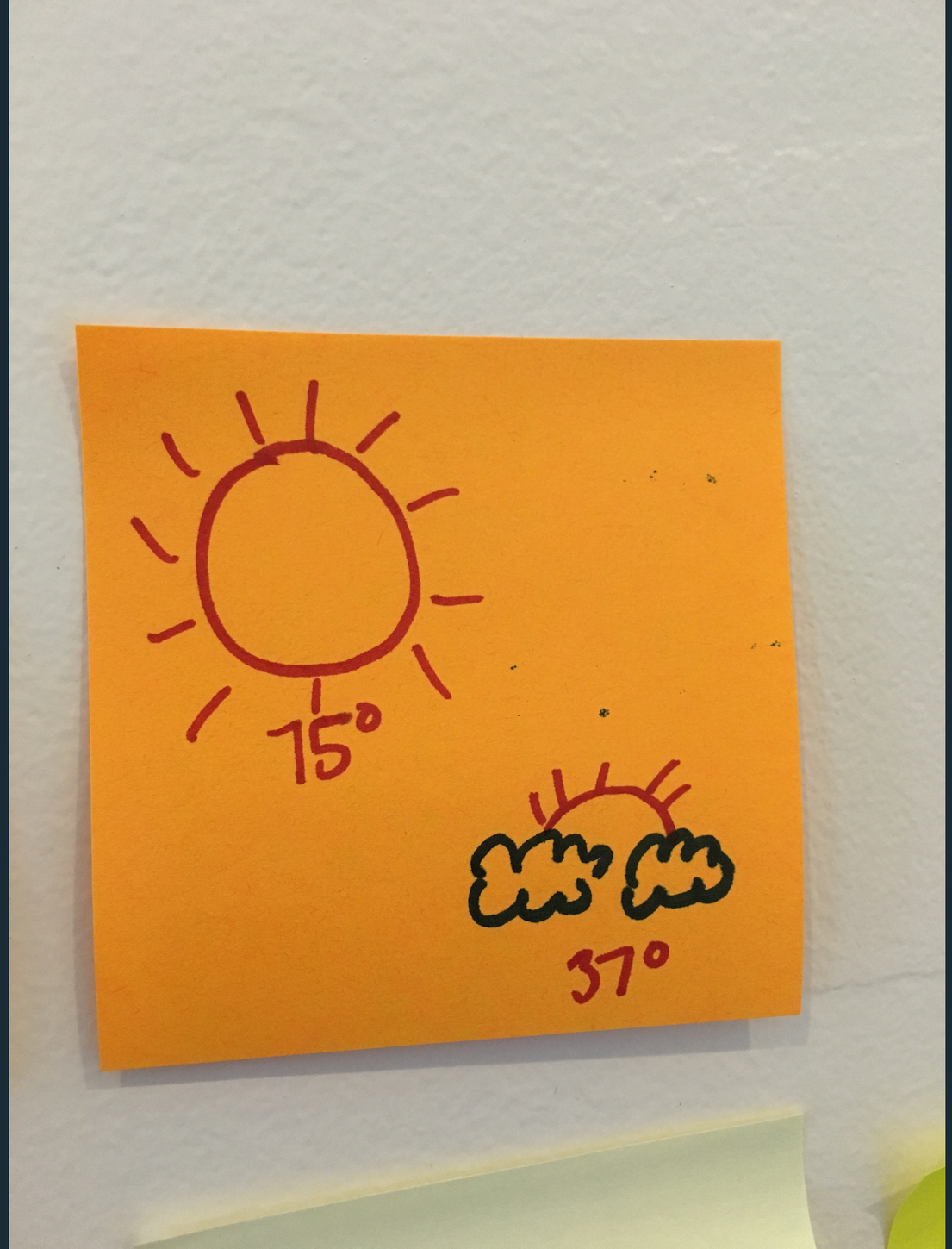

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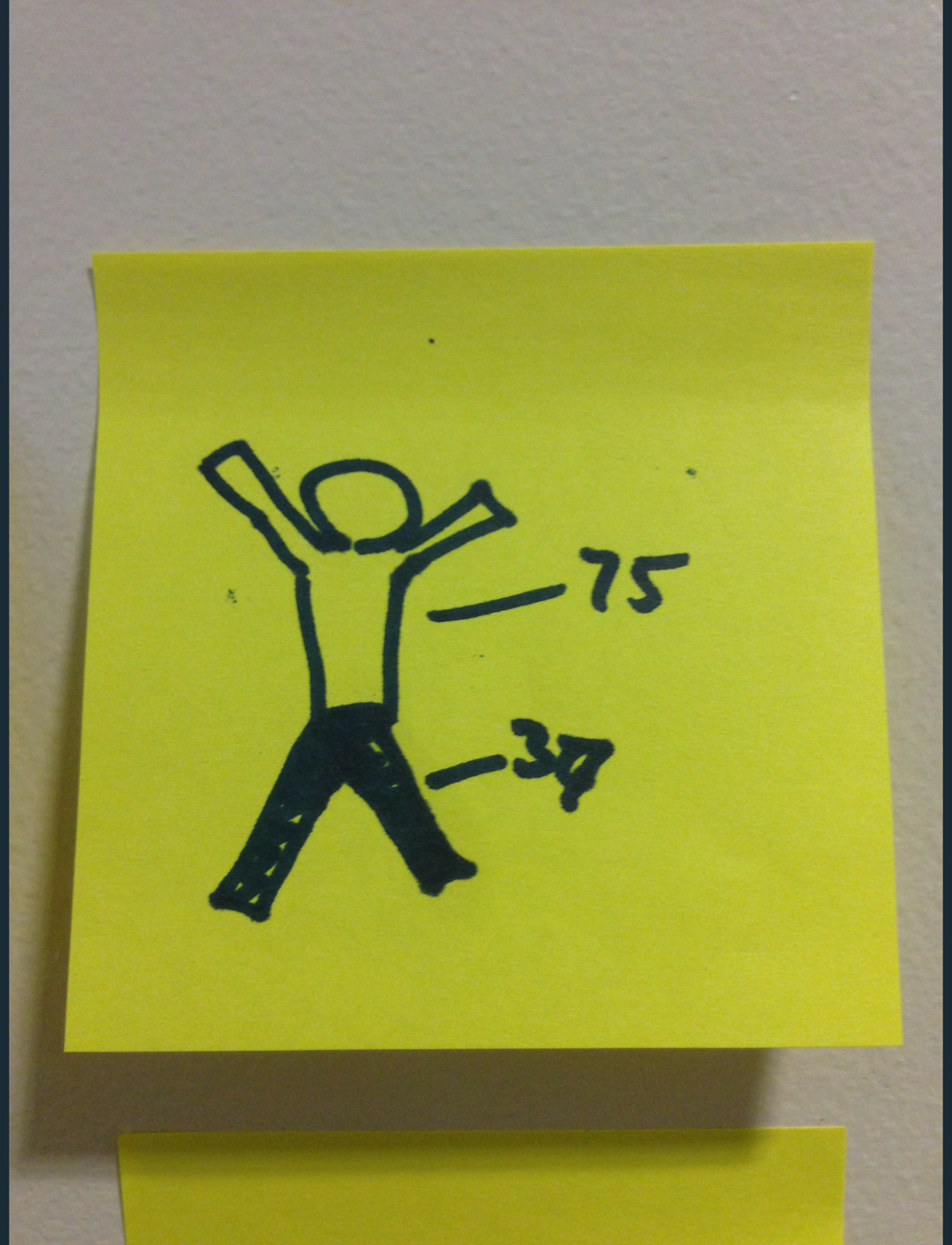

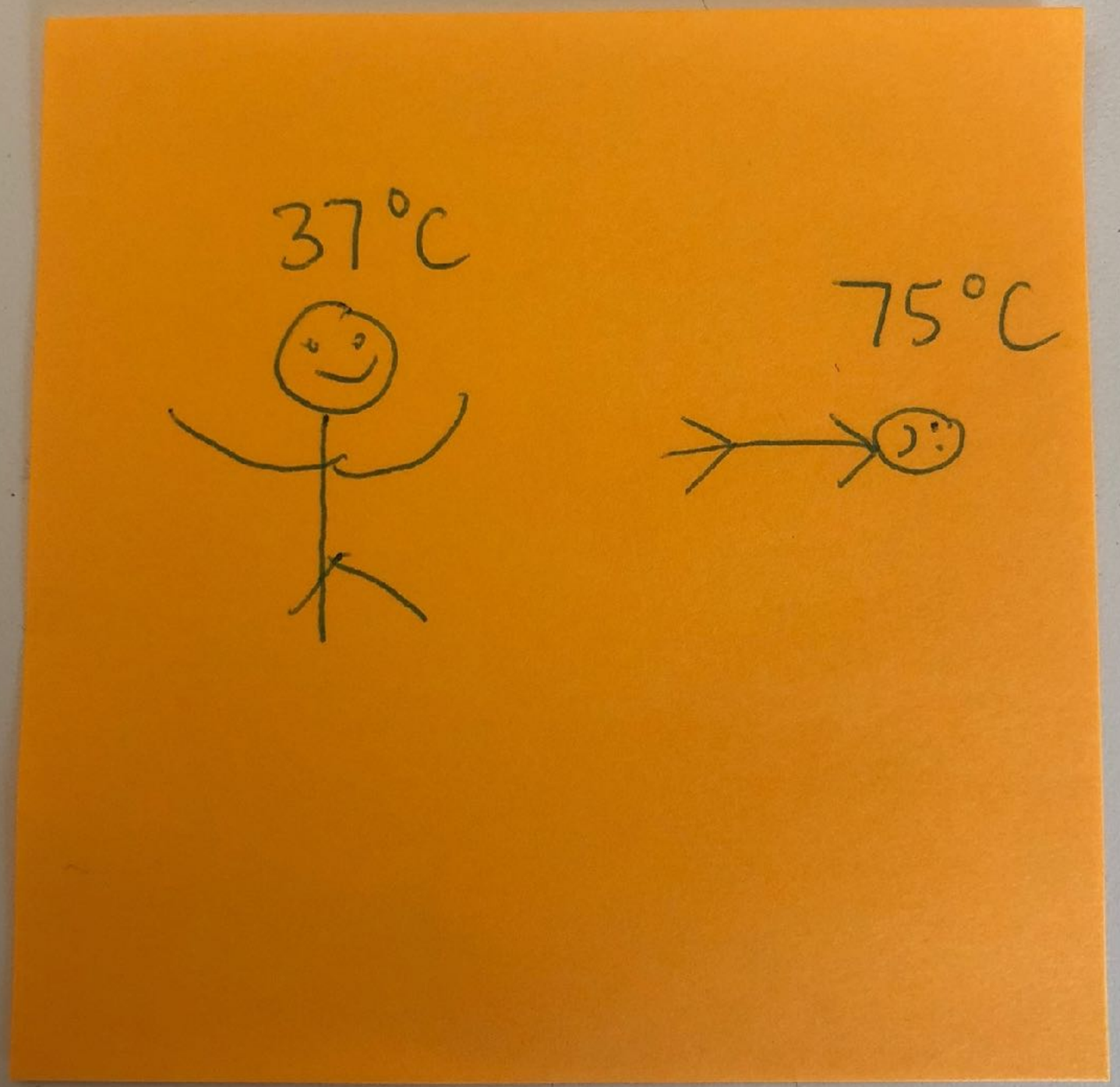
37°C
75°C

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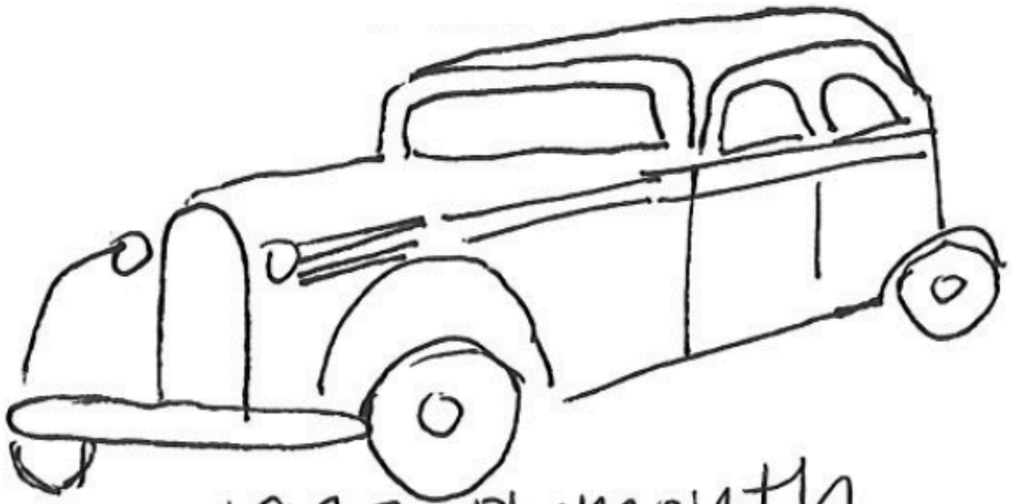
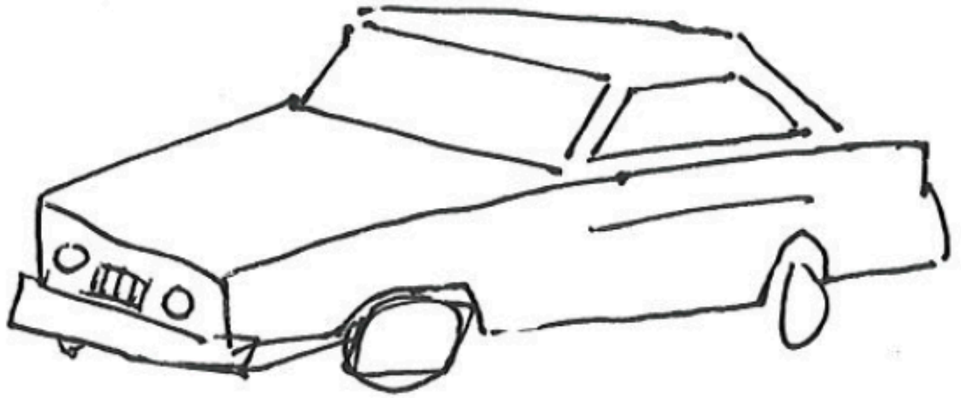
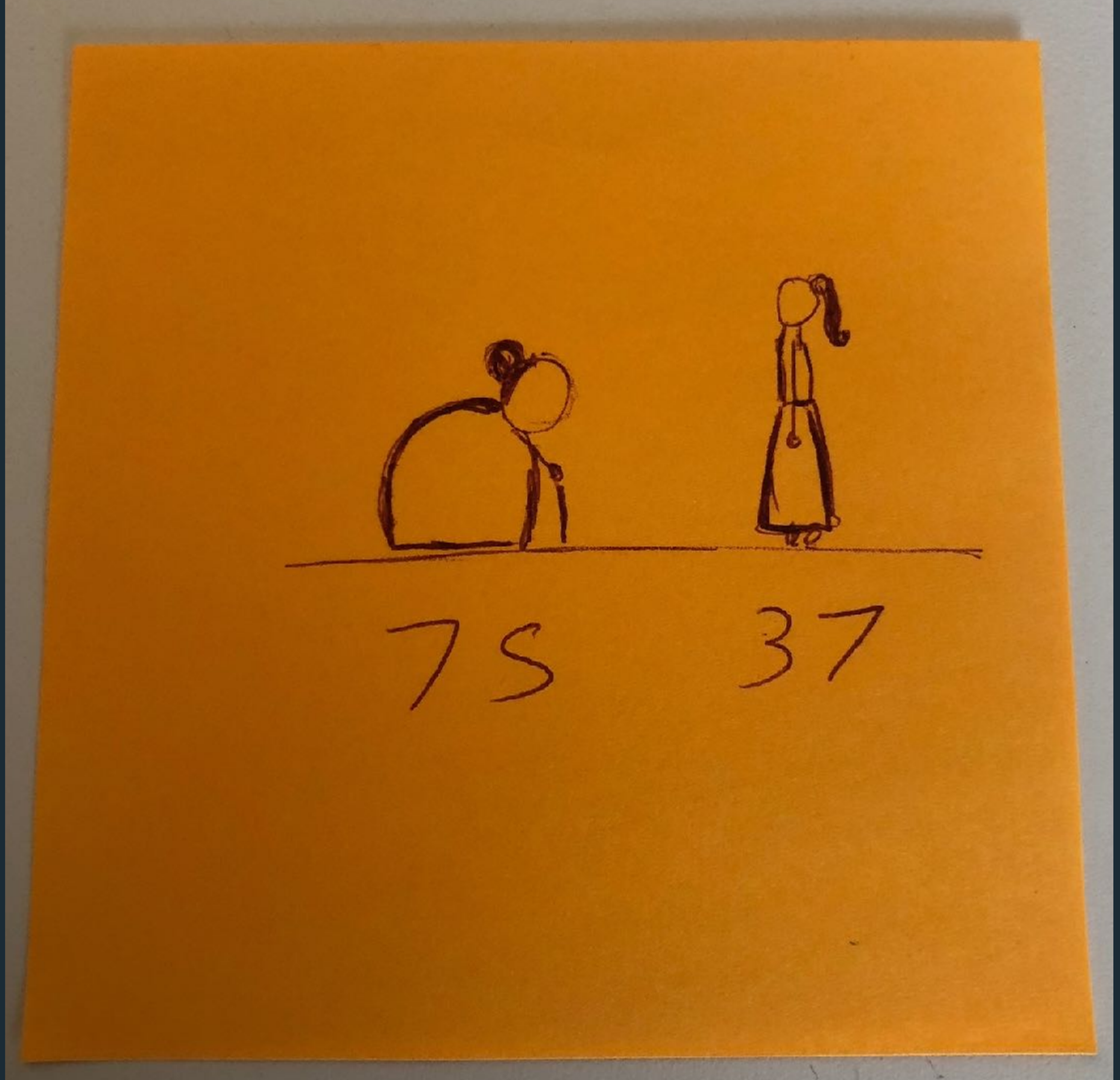
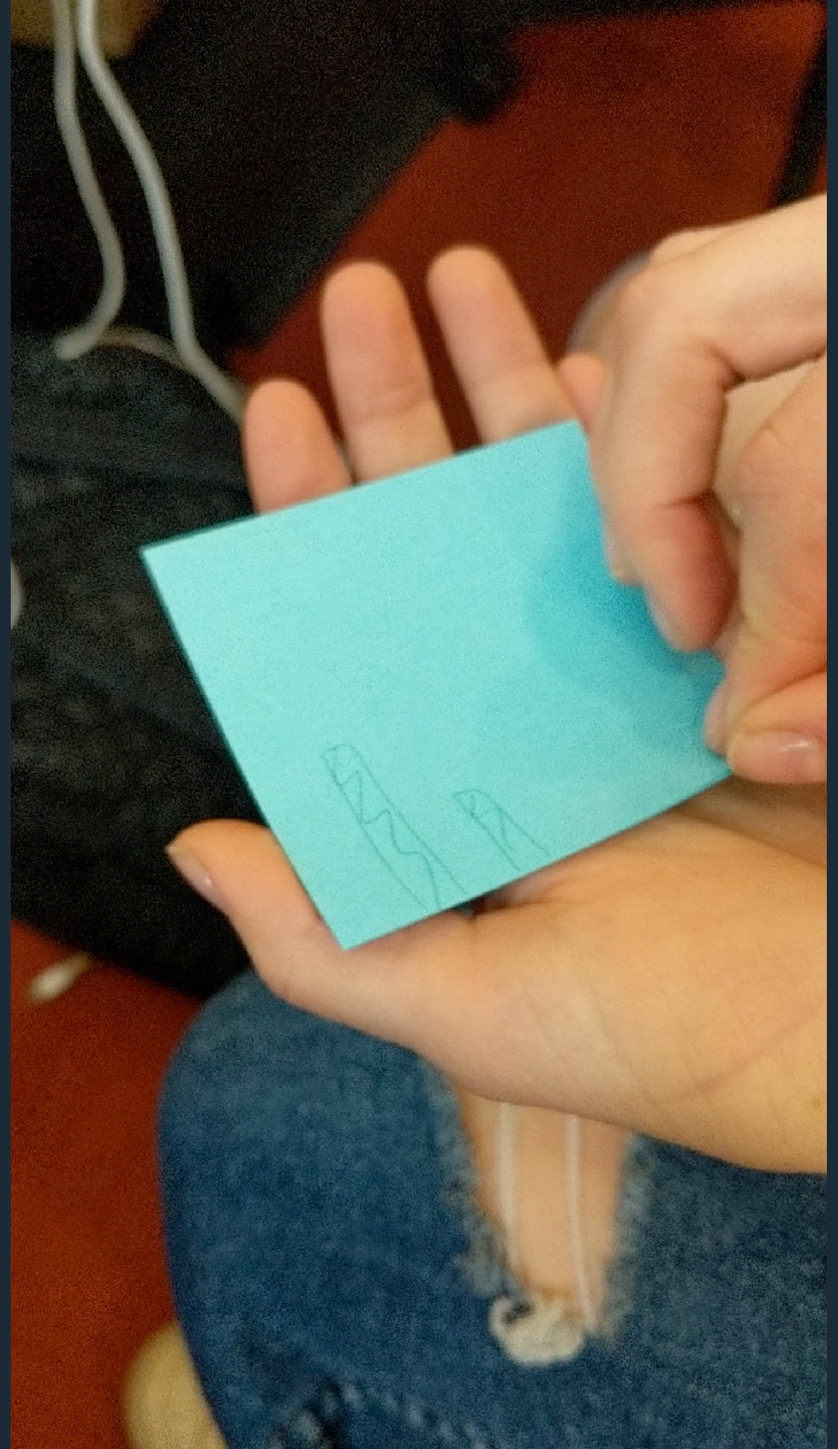


1937 Plymouth



1975 Plymouth


75
37



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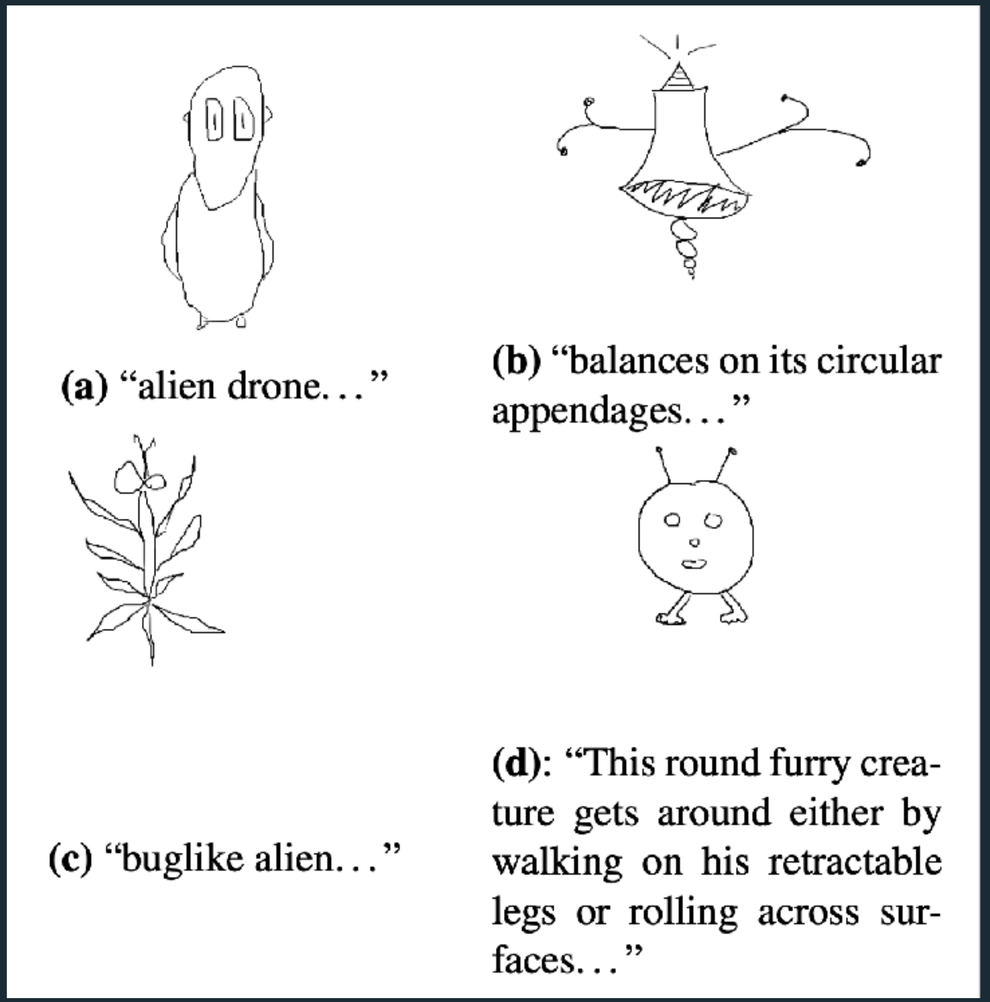

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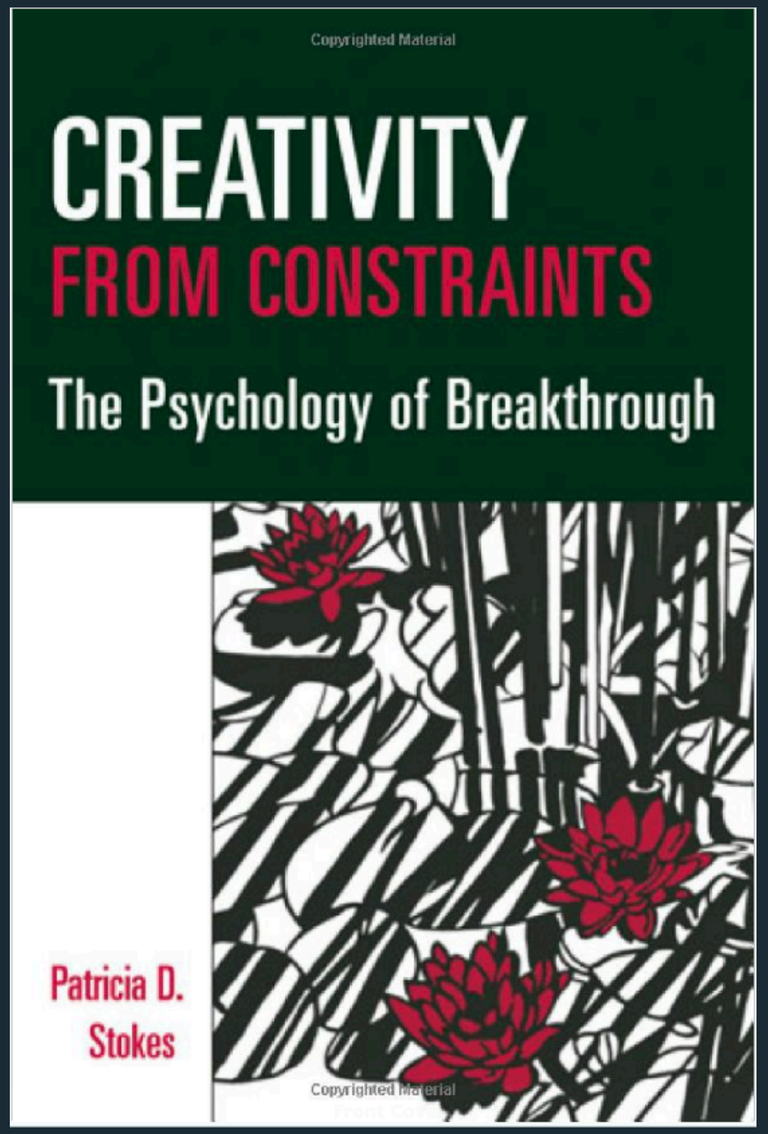
introduce a constraint: impose new structures to the problem to spur creativity [Stokes 2006]



Activity!

Share your work: www.yellkey.com/three

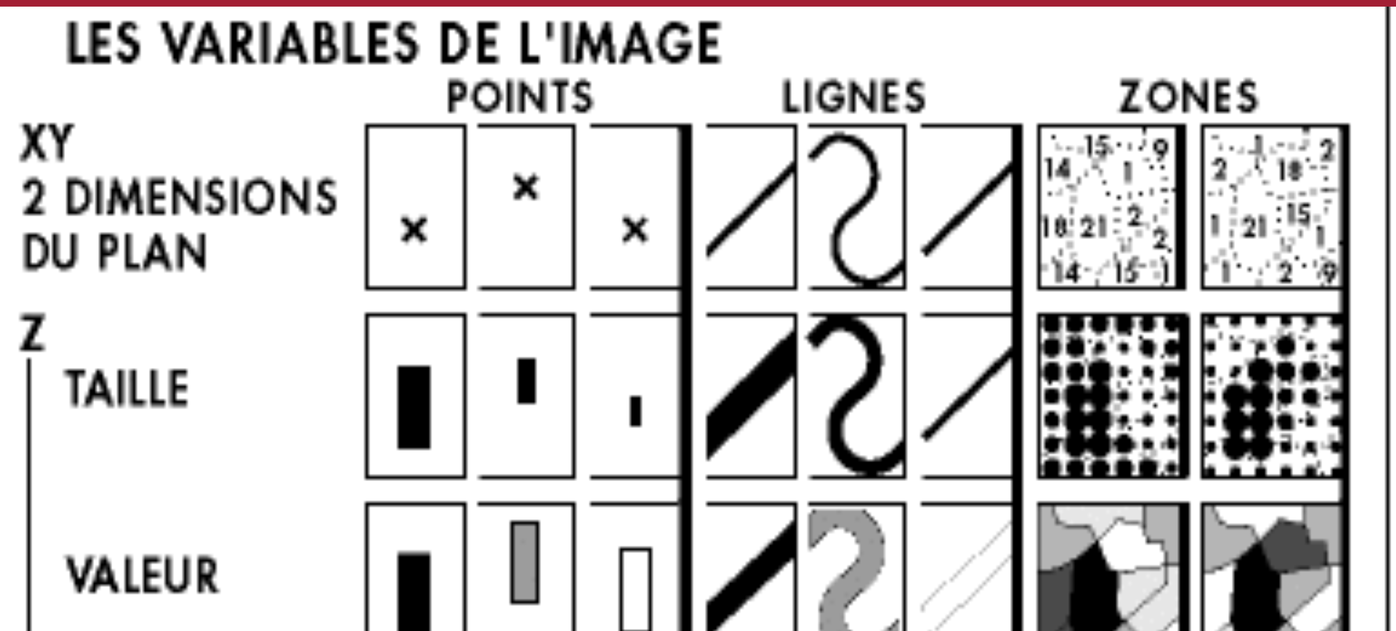
In **3 minutes**, sketch as many **new visualizations** as possible that are different from your previous ideas. If you're stuck, introduce a constraint -- e.g., one line, only black/white, only round objects, etc.

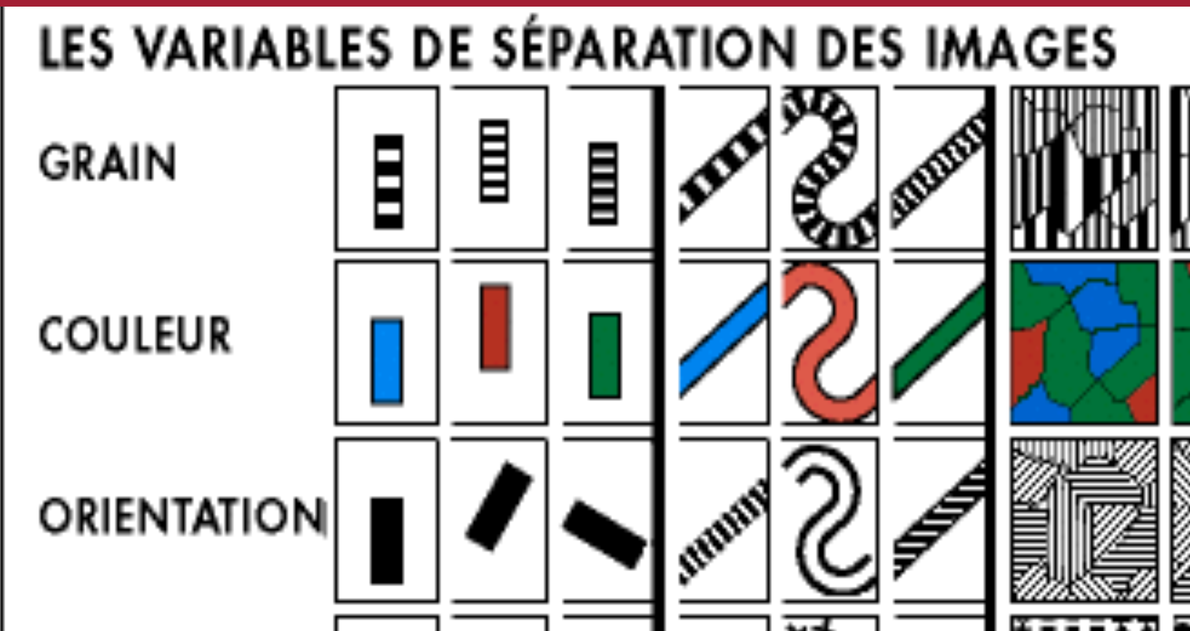
75 37

6.894: Interactive Data Visualization

Data & Image Models

Arvind Satyanarayan





Data Visualization

Mapping or Visual Encoding

Data

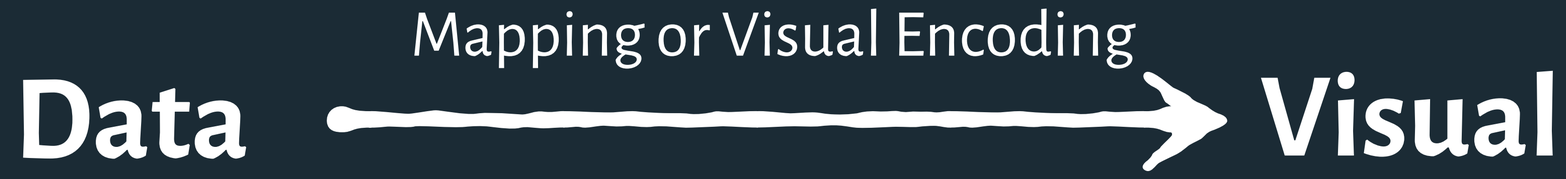
Physical Data Types
`int, float, string`

Conceptual Data Types
`temperature, location`

Visual

Visual **Channels**
`x, y, color, opacity`

Graphical **Marks**
`rect, line, point, area`



Expressiveness

A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

[Mackinlay 1986]

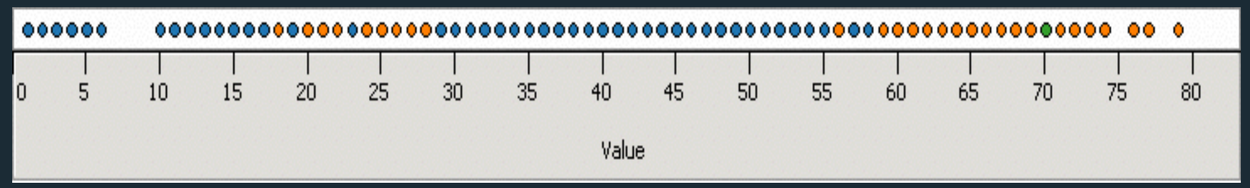
Mapping or Visual Encoding

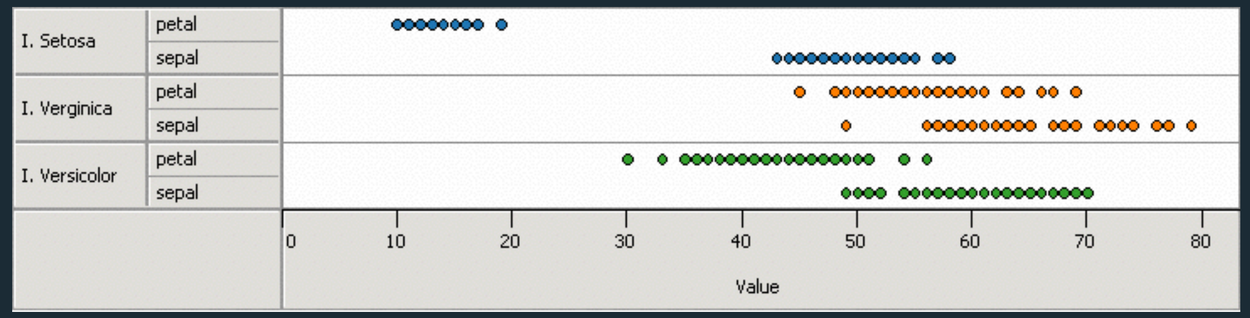
Data → **Visual**

Expressiveness

Cannot express the facts

A multivariate dataset may be *inexpressive* in a single horizontal dot plot because multiple records are mapped to the same position.



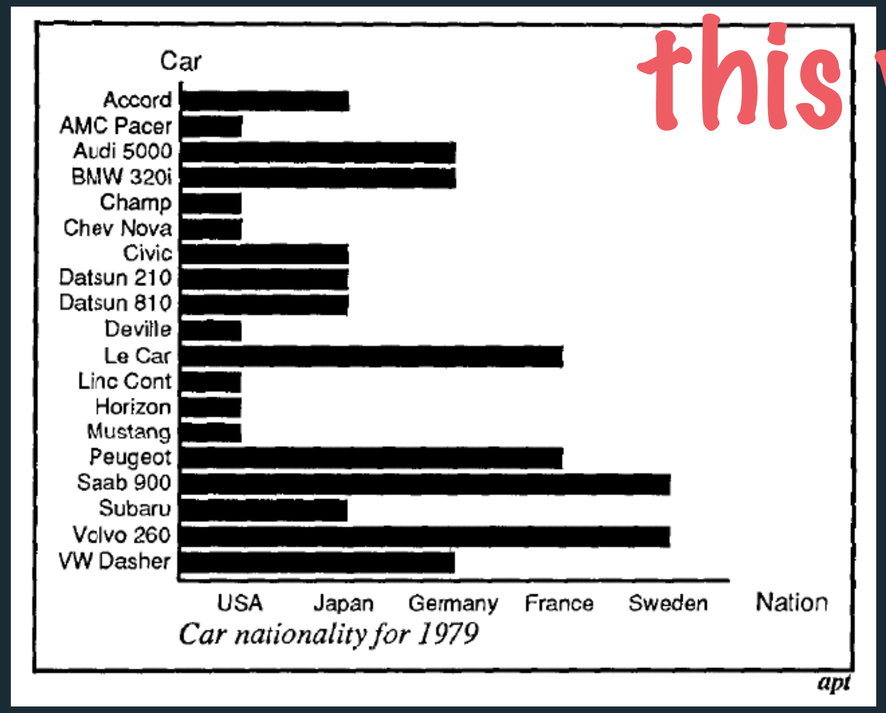


Mapping or Visual Encoding

Data → **Visual**

Expressiveness

What's wrong with this visualization?



Raise your hand

Post in the chat

Mapping or Visual Encoding

Data → **Visual**

Expressiveness

Express facts not in the data

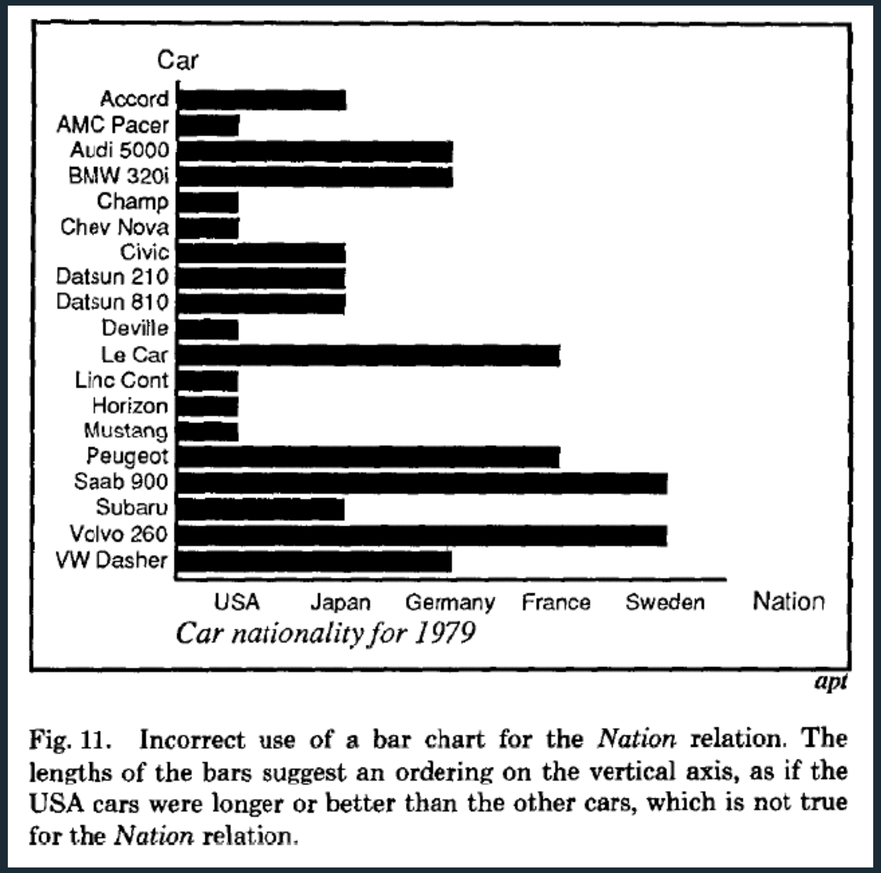
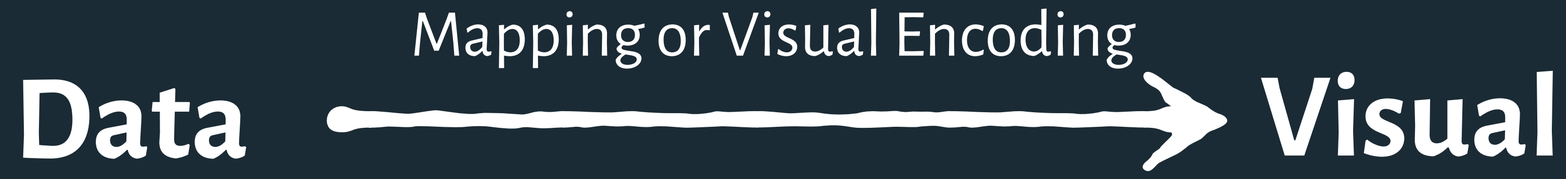


Fig. 11. Incorrect use of a bar chart for the *Nation* relation. The lengths of the bars suggest an ordering on the vertical axis, as if the USA cars were longer or better than the other cars, which is not true for the *Nation* relation.



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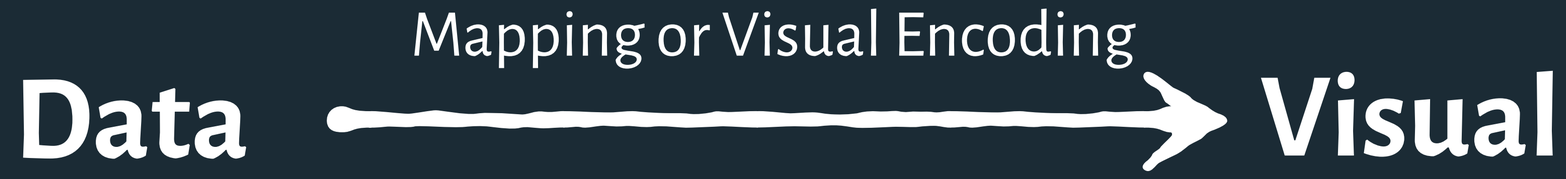


Expressiveness

A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express *all the facts in the set of data, and only the facts in the data*.

Data models give us a way of talking about this.

[Mackinlay 1986]

Data Models

Conceptual Models vs Data Models

By "default", data is described in terms of a specific *domain*.

- E.g., The average amount of *rain* or *snow* in different *towns, cities, countries.*
- E.g., *friends, followers, connections* depending on the social network (or *citations* in academia!).

To effectively map data to visuals, we need a level of *abstraction*.

- Data abstraction allows us to consistently encode the same "types" of data, even if different domains use different terminology to describe it.

Dataset Types

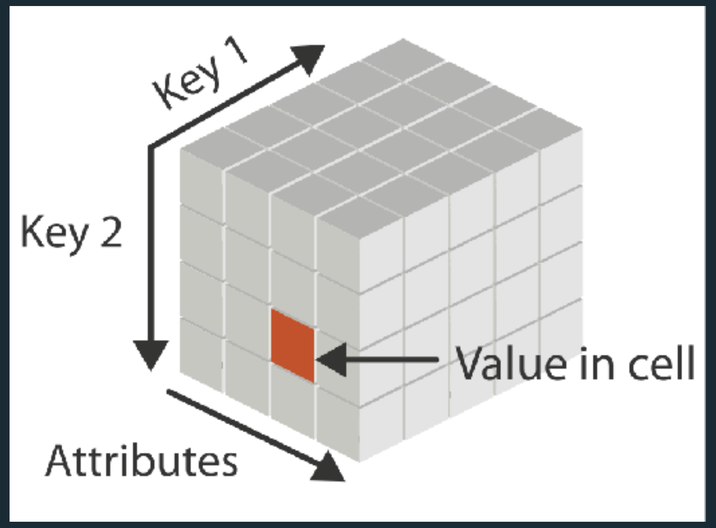
1. Tabular

rows/records/items

columns/attributes/variables

	A	B	C	D	E	F
1	EmployerName	Address	DiffMeanHourlyPercent	DiffMeanBonusPercent	MaleBonusPercent	FemaleBonusPercent
2	1ST CHOICE STAFF RECRUITMENT LIMITED	8, St. Loyes Street, Bedford, MK40 1EP	-4.5	206.9	2	1
3	23.5 DEGREES LIMITED	Charles Watts Way, Hedge End, Southampton,	10	79	4	3
4	A. & B. GLASS COMPANY LIMITED	Chilton Industrial Estate, Sudbury, Suffolk,	15	85	61	32
5	ABACUS HOTELS LIMITED	20 Station Street, Swaffham, Norfolk,	37.8	-6.6	19.2	16.2
6	Abbeyfield Wales Society	24 Gold Tops, Newport, NP20 4PG	21.9	0	0	0
7	ABERDEEN JOURNALS LIMITED	Mastrick, Aberdeen, United Kingdom,	15.7	44.7	17.1	39.7
8	ACCESSIBLE TRANSPORT GROUP CONTRACT SERVICES LIMITED	Birmingham, West Midlands, United Kingdom,		0	0	0
9	ACEGOLD LIMITED	Norcliffe House, Station Road, Wilmslow, SK9 1BU	-5.1	0	0	0
10	Acorns Children's Hospice Trust	Wythall, Birmingham, United Kingdom,	11.2	0	0	0
11	AD Astra Academy Trust	Davison Drive, Hartlepool, Cleveland,	9.5	0	0	0
12	ADAPT BUSINESS SERVICES LIMITED	Drive, Gorseinon, Swansea, SA4 4QN	3.3	0	0	0
13	ADARE INTERNATIONAL LIMITED	Two Colton Square, Leicester, England,	18.8	71.3	11.6	10.5

cell containing value



Tamara Munzner, *Visualization Analysis and Design* (2014).

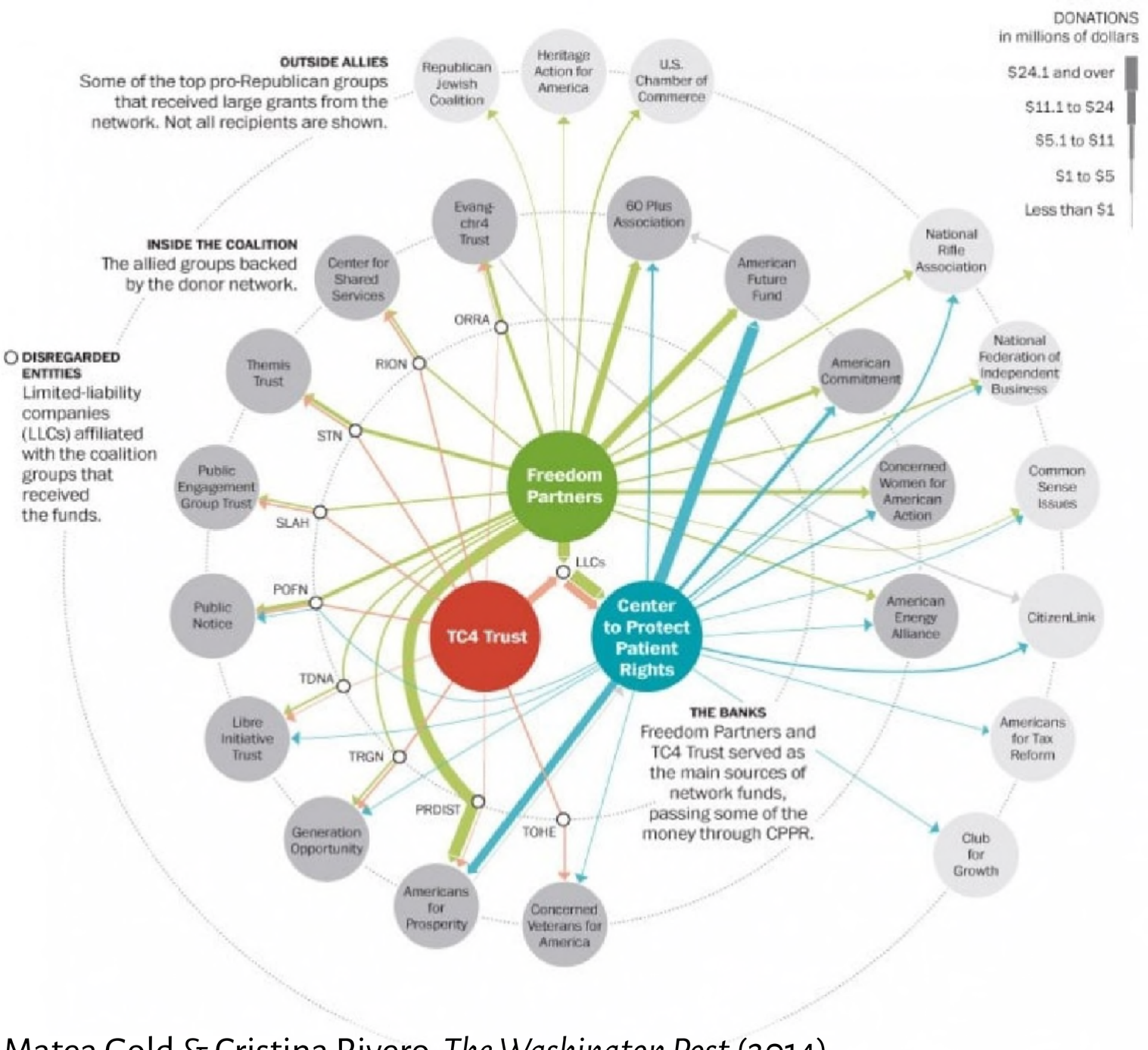
https://gender-pay-gap.service.gov.uk

Dataset Types

1. **Tabular**
   A collection of records with named attributes.

2. **Networks**
   Nodes and links can also have attributes (e.g., size of nodes, thickness/directionality of links).

   Trees are special networks where each node has only one parent.



Matea Gold & Cristina Rivero, *The Washington Post* (2014).

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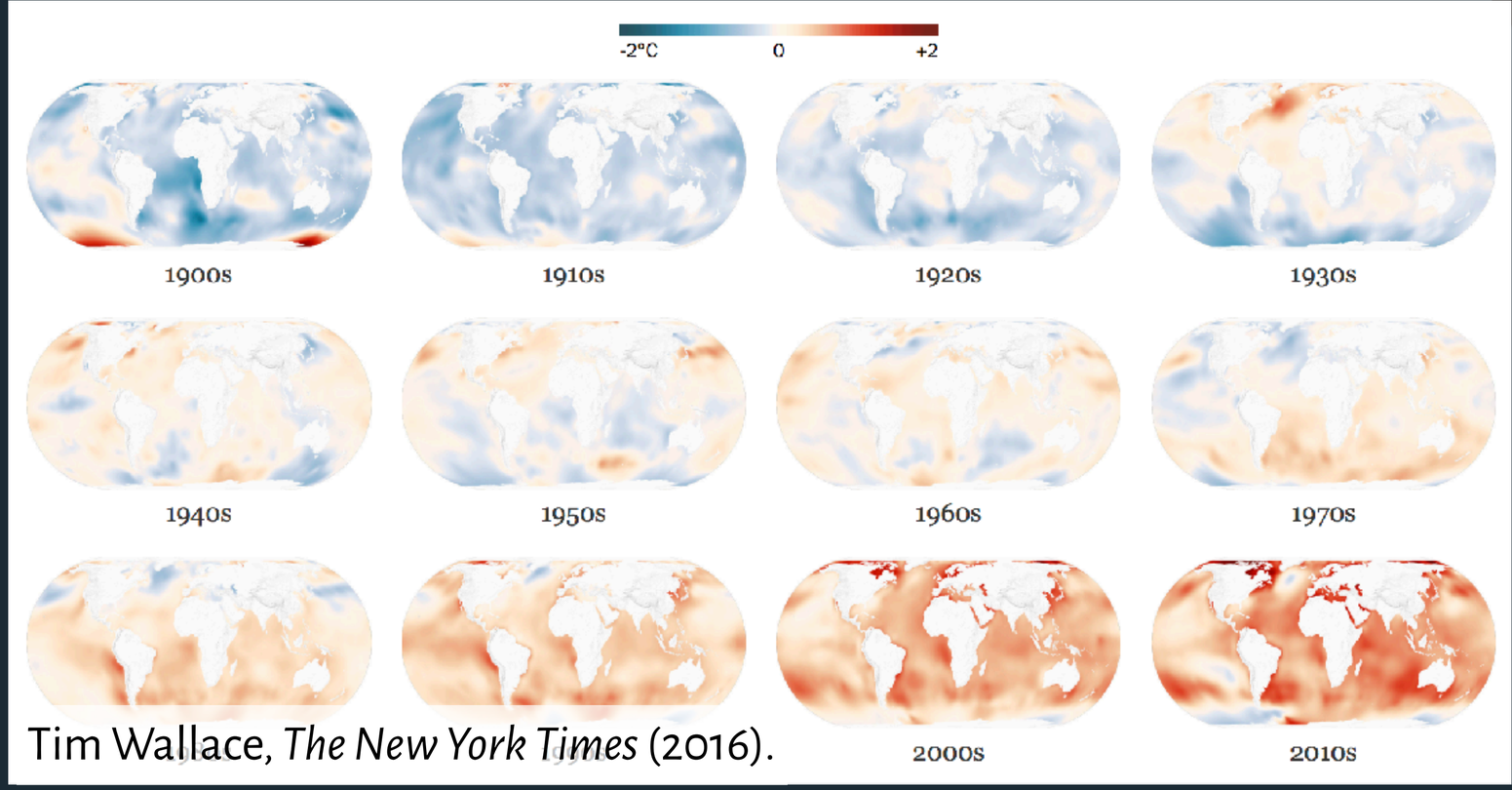
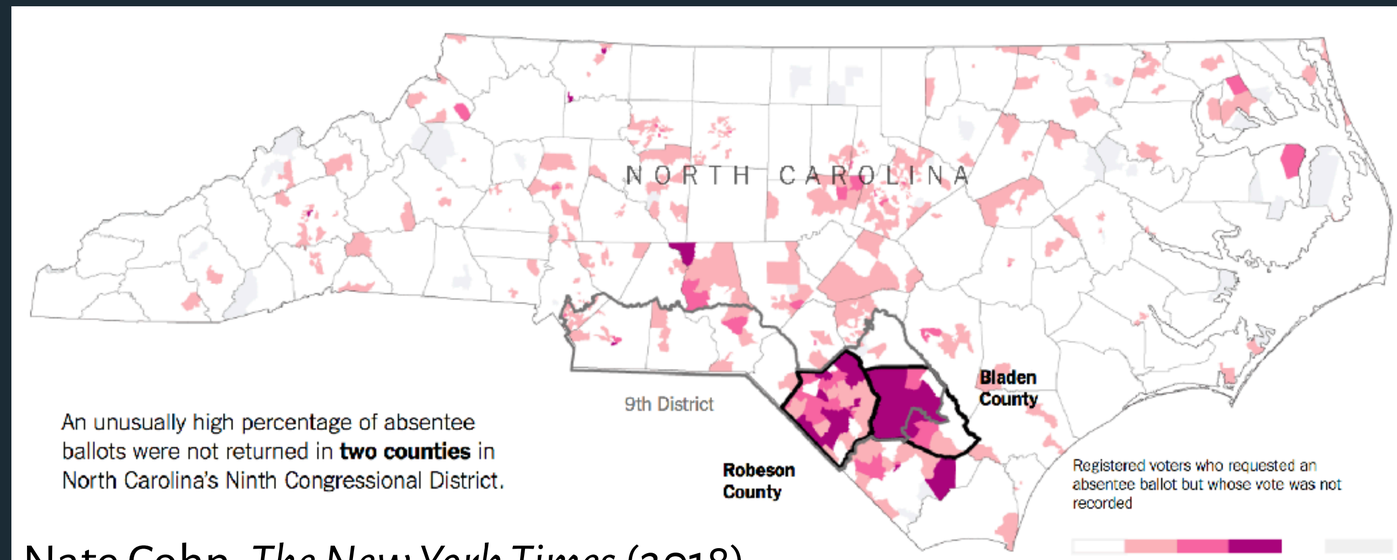
3. **Spatial**
   Continuous "fields" vs discrete "positions"



Tim Wallace, *The New York Times* (2016).



Nate Cohn, *The New York Times* (2018).

Attribute Types

Dimensions

~ Independent variables.

Ways of describing the data, often discrete.

E.g., categories, dates, binned quantities.

Can include numerical data, but doesn't make sense to aggregate.

Measures

~ Dependent variables (i.e., their value is a function of one or more dimensions).

Numerical data that can be analyzed and aggregated.

Aggregations including sum, count, avg, std. dev, etc.

Tableau - World Indicators [Read-Only] - Tableau license expires in 14 days

Fit Width | Show Me

Data | Analytics

World Indicators

Dimensions

- Above Threshold?
- Birth Rate Bin
- Country
- Ease of Business (clusters)
- GDP per Capita (bin)
- Region

Measures

- Business
  - Business Tax Rate
  - Days to Start Business
  - Ease of Business
  - Hours to do Tax
  - Lending Interest
- Development
  - CO2 Emissions
  - Energy Usage
  - GDP
  - Internet Usage
  - Mobile Phone Usage
  - Tourism Inbound
  - Tourism Outbound
- Health
  - Health Exp % GDP
  - Health Exp/Capita
  - Infant Mortality Rate
  - Life Expectancy
  - Life Expectancy Female
  - Life Expectancy Male
- Population
  - Birth Rate

Parameters

- Health Exp Threshold

Pages

Filters: Measure Names, Country

Marks: Square; Color, Size, Label, Detail, Tooltip

Measure Values, AVG(Birth Rate), AVG(Infant Mortal..), AVG(Health Exp ..), AVG(Life Expecta..), Region, Measure Values

Measure Values: AVG(Birth Rate), AVG(Infant Mortality Rat..), AVG(Health Exp % GDP), AVG(Life Expectancy)

Columns: Measure Names

Rows: Country

Health Indicators

	Birth Rate	Infant Mortality	Health Exp % GDP	Life Expectancy
Ethiopia	3.8%	0.07	4.4%	58
Malawi	4.2%	0.07	7.4%	50
Eritrea	3.9%	0.05	3.3%	59
Congo, Dem. Rep.	4.6%	0.10	5.8%	48
Niger	5.1%	0.08	7.2%	55
Madagascar	3.7%	0.05	4.7%	62
Mozambique	4.3%	0.09	6.1%	48
Rwanda	3.8%	0.07	8.0%	56
Uganda	4.6%	0.07	8.4%	54
Afghanistan	4.3%	0.08	9.2%	58
Sierra Leone	4.1%	0.13	15.6%	42
Central African Republic	3.7%	0.11	4.1%	46
Guinea	4.0%	0.08	5.8%	53
Tanzania	4.1%	0.06	5.1%	55
Nepal	2.7%	0.05	5.7%	65
Togo	3.8%	0.07	6.5%	55
Guinea-Bissau	4.0%	0.09	5.9%	53
Burkina Faso	4.4%	0.08	6.5%	53
Tajikistan	3.1%	0.05	5.1%	66
Bangladesh	2.3%	0.05	3.3%	68
Mali	4.8%	0.10	6.5%	52
Gambia, The	4.4%	0.06	4.4%	57
Haiti	2.8%	0.07	5.9%	60
Zimbabwe	3.2%	0.06		48
Benin	4.0%	0.07	4.5%	57
Cambodia	2.6%	0.05	6.1%	68
Kenya	3.8%	0.06	4.5%	56
Chad	4.9%	0.10	4.8%	48
Timor-Leste	3.8%	0.06	6.9%	64
Kyrgyz Republic	2.3%	0.03	6.0%	69
Comoros	3.8%	0.07	4.0%	59

Birth Rate: 0.8% – 5.1%

Infant Mortality Rate: 0.00 – 0.13

Health Exp % GDP: 2.2% – 18.0%

Life Expectancy: 42 – 82

Data Source | Population | Health Indicators | Care Spend | Technology | Economy | Tourism | Business | Global Indicators

788 marks | 197 rows by 4 columns | SUM of Measure Values: 13,448.53

Attribute Types

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Nominal Labels or categories.

E.g., Fruits: apples, bananas, cantaloupes, ...

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Ordinal Ordered.

E.g., Quality of meat: Grade A, AA, AAA

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Labels or categories.

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Ordinal

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E.g., Quality of meat: Grade A, AA, AAA

Quantitative (Interval)

Interval (zero can be arbitrarily located).

E.g., Dates: Jan 19, 2018; Location: (Lat 42.36, -71.09)

Only differences can be calculated (e.g., distances or spans).

Quantitative (Ratio)

Attribute Types

Nominal

Labels or categories.

E.g., Fruits: apples, bananas, cantaloupes, ...

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Only differences can be calculated (e.g., distances or spans).

Quantitative (Ratio)

Ratio (fixed zero).

E.g., Physical measurement: length, mass, temperature

Counts and amounts. Can measure ratios or proportions.

Attribute Types

Nominal
=, ≠

Labels or categories.
E.g., Fruits: apples, bananas, cantaloupes, ...

Ordinal
=, ≠, <, >

Ordered.
E.g., Quality of meat: Grade A, AA, AAA

Quantitative (Interval)
=, ≠, <, >, −

Interval (zero can be arbitrarily located).
E.g., Dates: Jan 19, 2018; Location: (Lat 42.36, -71.09)
Only differences can be calculated (e.g., distances or spans).

Quantitative (Ratio)
=, ≠, <, >, −, %

Ratio (fixed zero).
E.g., Physical measurement: length, mass, temperature
Counts and amounts. Can measure ratios or proportions.

Data Models

Physical Model

`32.5, 54.0, –17.3, ...`

Floating point numbers

Conceptual Model

Temperature (°C)

Attribute Type

Burned vs. Not-Burned (N)

Hot, Warm, Cold (O)

Temperature Value (Q)

Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: # of people in group

Year: 1850 – 2000 (every decade)

Age: 0 – 90+

Sex: Male, Female

Marital Status: Single, Married, Divorced, ...

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
6	1850	10	0	1	1260099
7	1850	10	0	2	1216114
8	1850	15	0	1	1077133
9	1850	15	0	2	1110619
10	1850	20	0	1	1017281
11	1850	20	0	2	1003841
12	1850	25	0	1	862547
13	1850	25	0	2	799482
14	1850	30	0	1	730638
15	1850	30	0	2	639636
16	1850	35	0	1	588487
17	1850	35	0	2	505012
18	1850	40	0	1	475911
19	1850	40	0	2	428185
20	1850	45	0	1	384211
21	1850	45	0	2	341254

Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count:

Year:

Age:

Sex:

Marital Status:

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
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20	1850	45	0	1	384211
21	1850	45	0	2	341254

Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Q-Ratio

Year:

Age:

Sex:

Marital Status:

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Q-Ratio

Year:

Age:

Sex: Nominal

Marital Status:

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
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What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Q-Ratio

Year:

Age:

Sex: Nominal

Marital Status: Nominal

	A	B	C	D	E
1	year	age	marst	sex	people
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Q-Ratio

Year: Ordinal or Q-Interval

Age:

Sex: Nominal

Marital Status: Nominal

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Q-Ratio

Year: Ordinal or Q-Interval

Age: Ordinal or Q-Interval

Sex: Nominal

Marital Status: Nominal

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Measure

Year:

Age:

Sex:

Marital Status:

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Measure

Year: Dimension

Age:

Sex:

Marital Status:

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Measure

Year: Dimension

Age:

Sex: Dimension

Marital Status:

	A	B	C	D	E
1	year	age	marst	sex	people
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Measure

Year: Dimension

Age:

Sex: Dimension

Marital Status: Dimension

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
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Activity: U.S. Census

What are the types of these attributes (N/O/Q and dimension/measure)?

People Count: Measure

Year: Dimension

Age: Depends!

Sex: Dimension

Marital Status: Dimension

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
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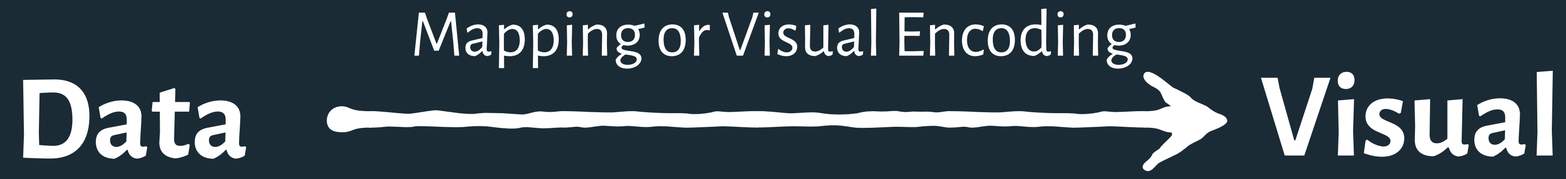

Expressiveness

A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express *all the facts in the set of data, and only the facts in the data*.

Data models give us a way of talking about this.

[Mackinlay 1986]

Mapping or Visual Encoding

Data → **Visual**

Expressiveness

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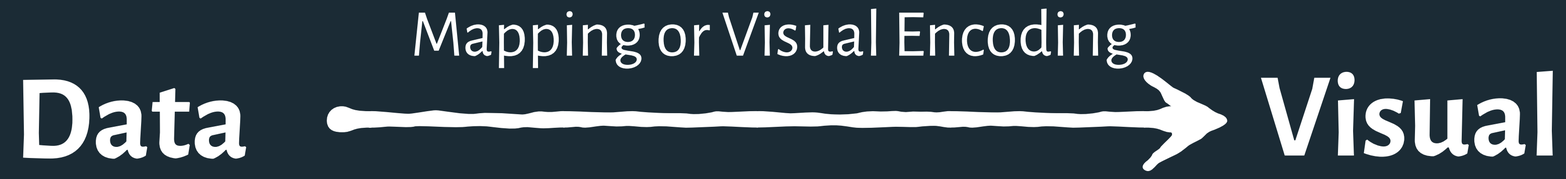
[Mackinlay 1986]

Questions?

Data models give us a way of talking about this.



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[Mackinlay 1986]

Effectiveness

A visualization is more *effective* than another if the information it conveys is more readily perceived than the information in the other visualization

Mapping or Visual Encoding

Data → **Visual**

Expressiveness

A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express *all the facts in the set of data, and only the facts in the data*.

Data models give us a way of talking about this.

[Mackinlay 1986]

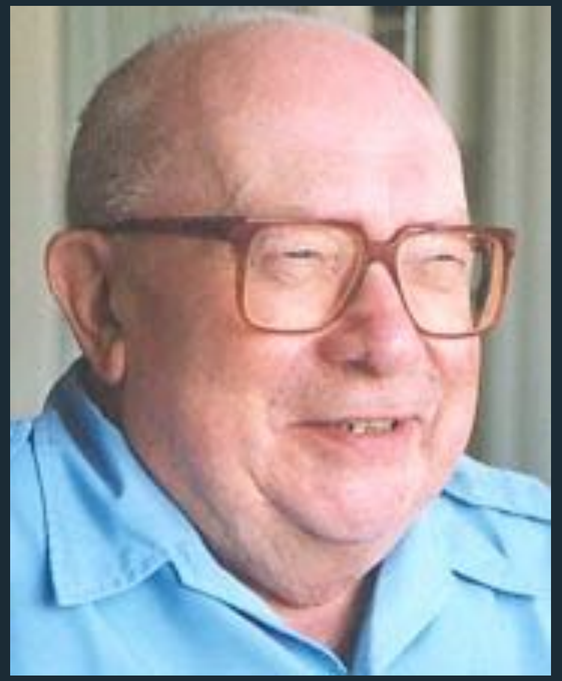
Effectiveness

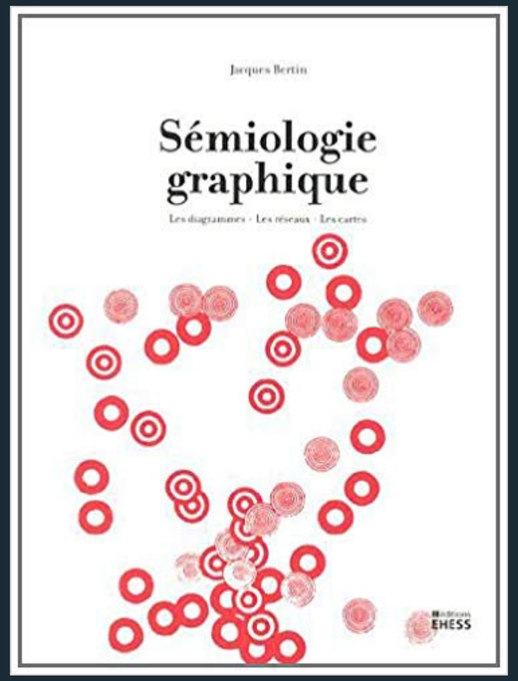
A visualization is more *effective* than another if the information it conveys *is more readily perceived* than the information in the other visualization

Image models give us a way of talking about this.

Image Models

The Semiology of Graphics (1967)

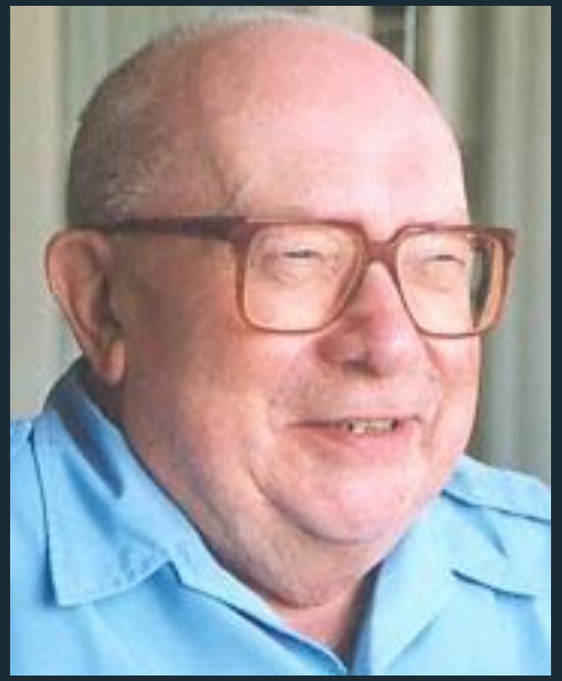


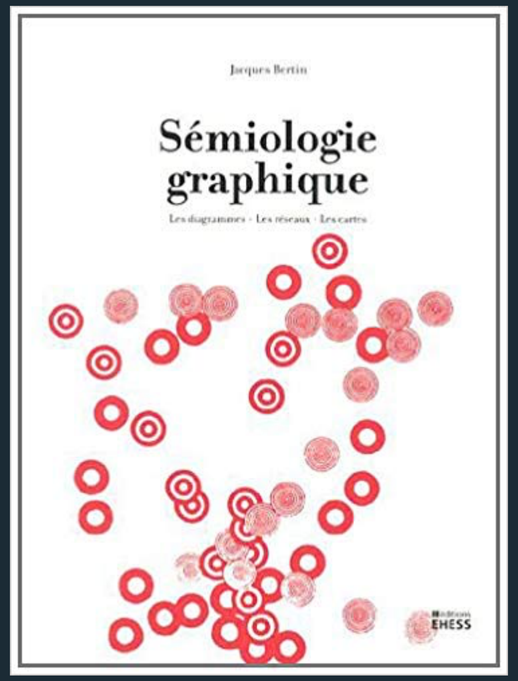


Jacques Bertin (1918 – 2010)
French cartographer

The Semiology of Graphics (1967)

Study of signs and how cultures use them.



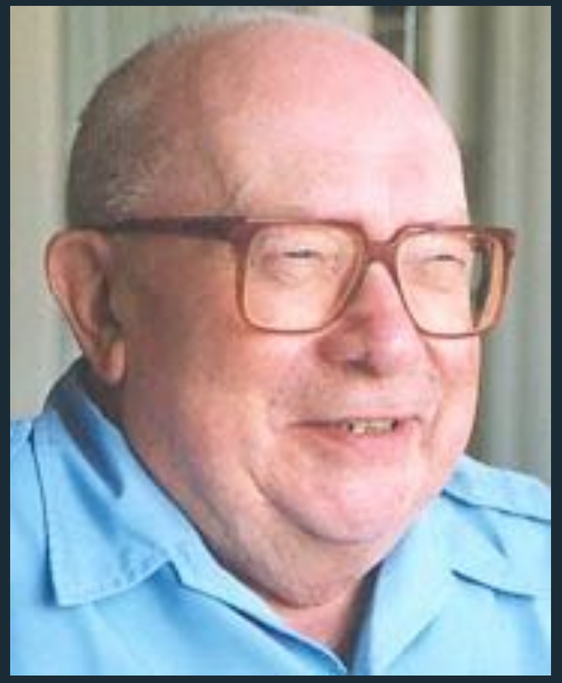


Jacques Bertin (1918 – 2010)
French cartographer

The Semiology of Graphics (1967)

*Study of **signs** and how cultures use them.*

Anything that stands for something other than itself.



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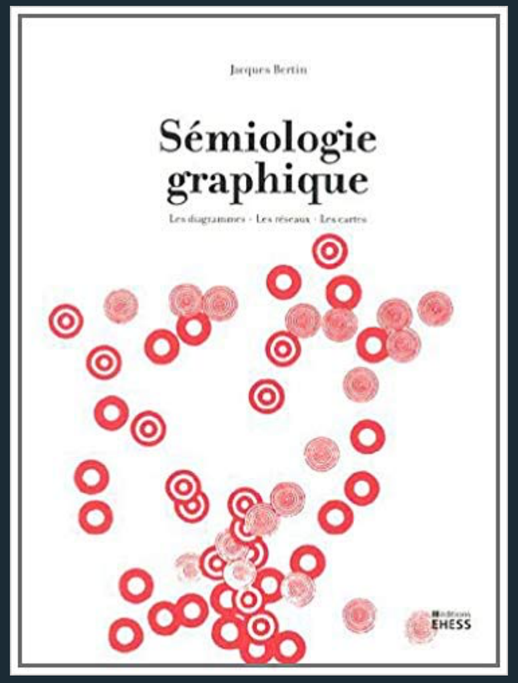
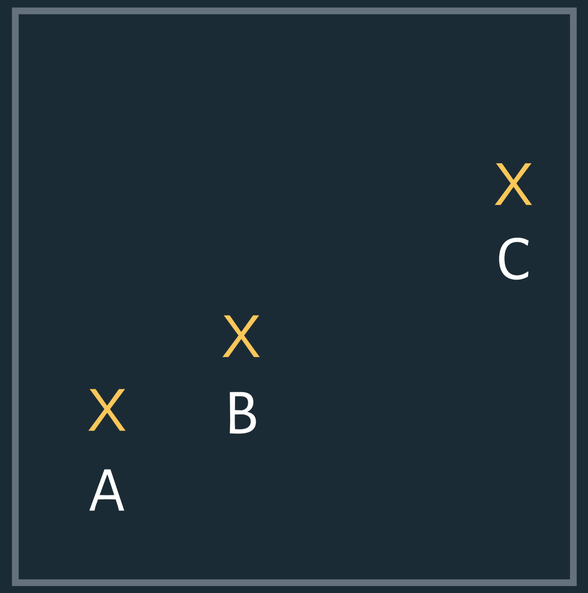


Images are perceived as a set of signs.

Sender encodes information in signs.

Through visual perception, the receiver decodes the signs for information:

1. What are the elements in question?
2. What are the relationships between them?



What do these signs signify?

1. A, B, C are distinguishable.
2. B is between A and C.
3. BC is twice as long as AB.

Sender encodes information in signs.

Through visual perception, the receiver decodes the signs for information:

1. What are the elements in question?
2. What are the relationships between them?

"Resemblance, order, and proportional are the three signfields in graphics."

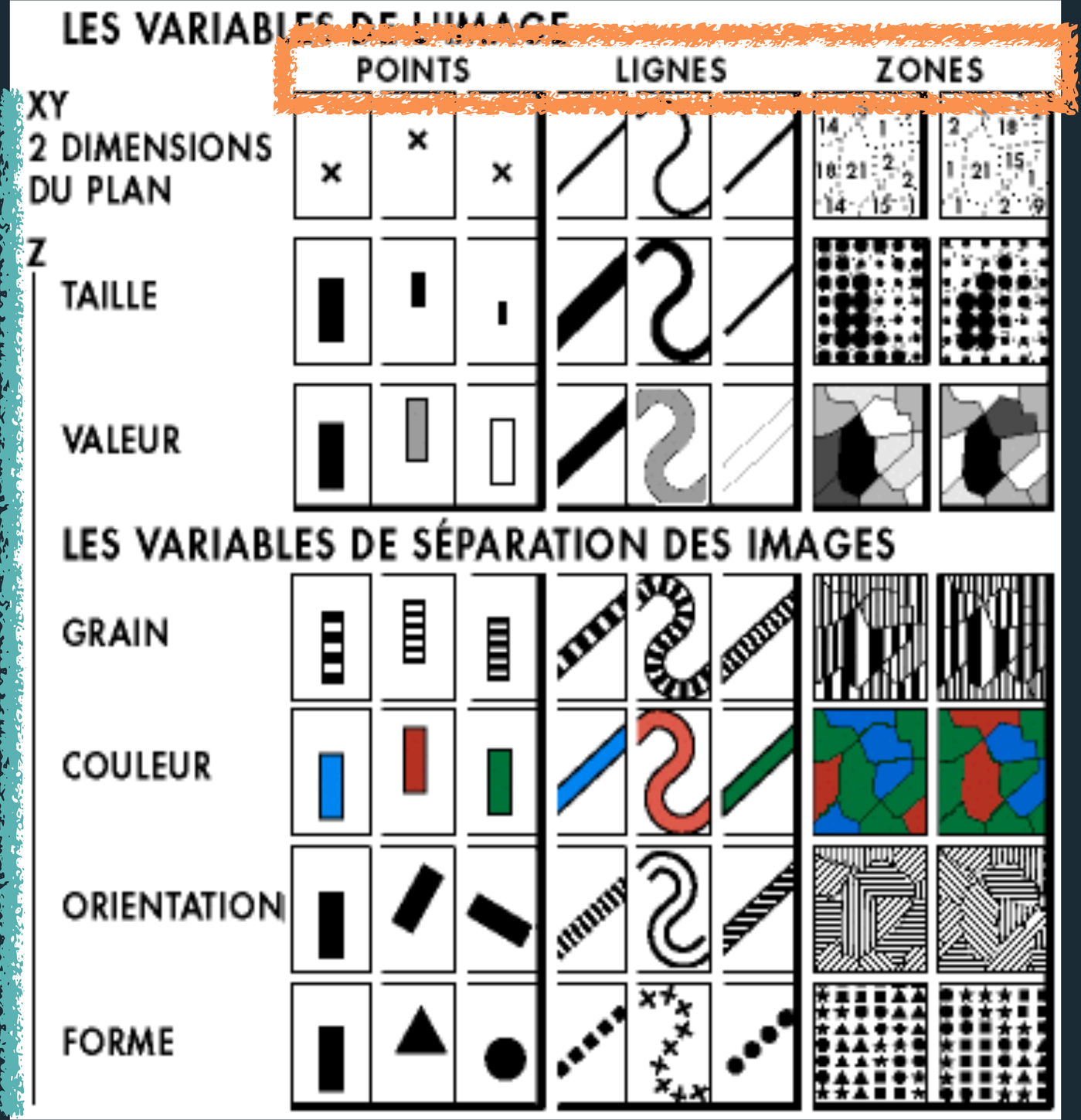
—Bertin

Visual Variables

Also called visual *channels*.

Used to encode data values as characteristics of marks.

** From 1967, so Bertin only accounted for visualizations that were printable, white paper.*



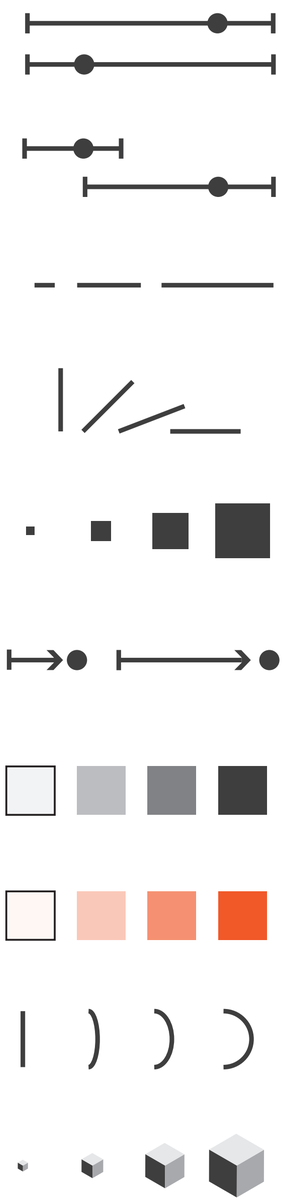
Marks

Basic graphical elements that represent data items.

Channels: Expressiveness Types and Effectiveness Ranks

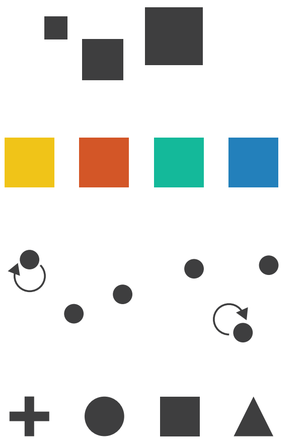
Magnitude Channels

- 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

- Spatial region
- Color hue
- Motion
- Shape

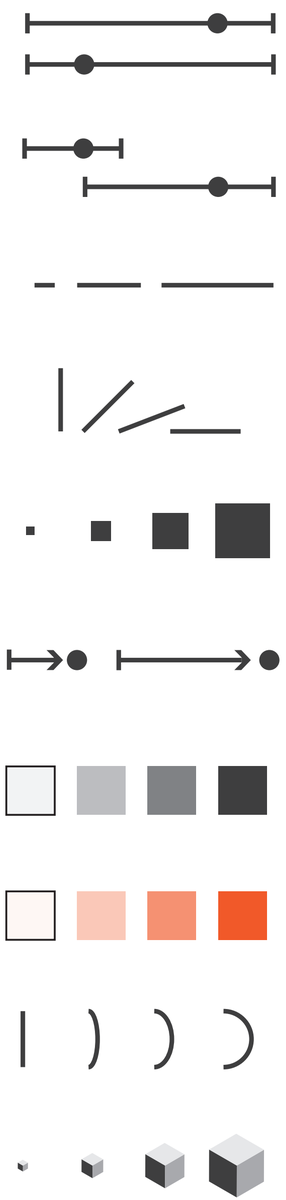


Tamara Munzner, *Visualization Analysis and Design* (2014).

Channels: Expressiveness Types and Effectiveness Ranks

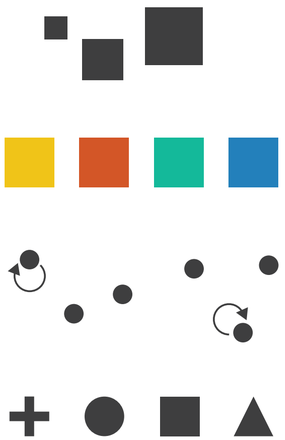
Magnitude Channels: O or Q attributes

- 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: N attributes

- Spatial region
- Color hue
- Motion
- Shape



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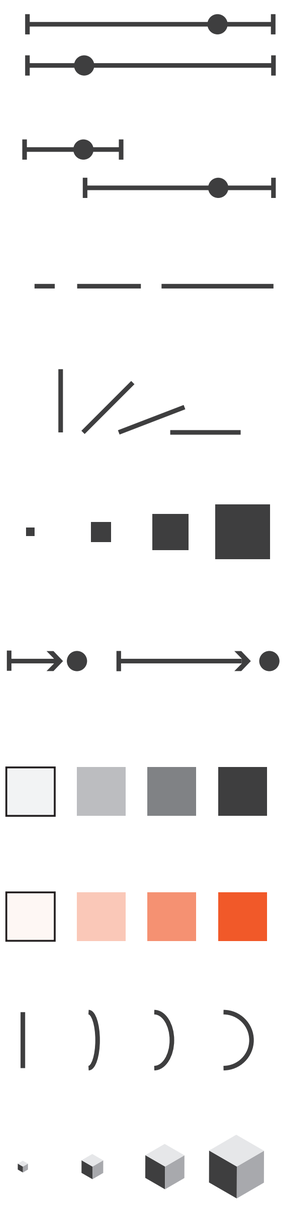


Most

Effectiveness

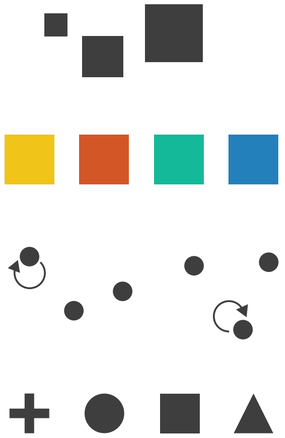
Least

Same

Same

Identity Channels: N attributes

- Spatial region
- Color hue
- Motion
- Shape



Tamara Munzner, *Visualization Analysis and Design* (2014).

Mapping or Visual Encoding

Data → **Visual**

Expressiveness

A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express *all the facts in the set of data, and only the facts in the data*.

Data models give us a way of talking about this.

[Mackinlay 1986]

Effectiveness

A visualization is more *effective* than another if the information it conveys *is more readily perceived* than the information in the other visualization

Image models give us a way of talking about this.