Data Visualization and Data Processing

SciML 2023

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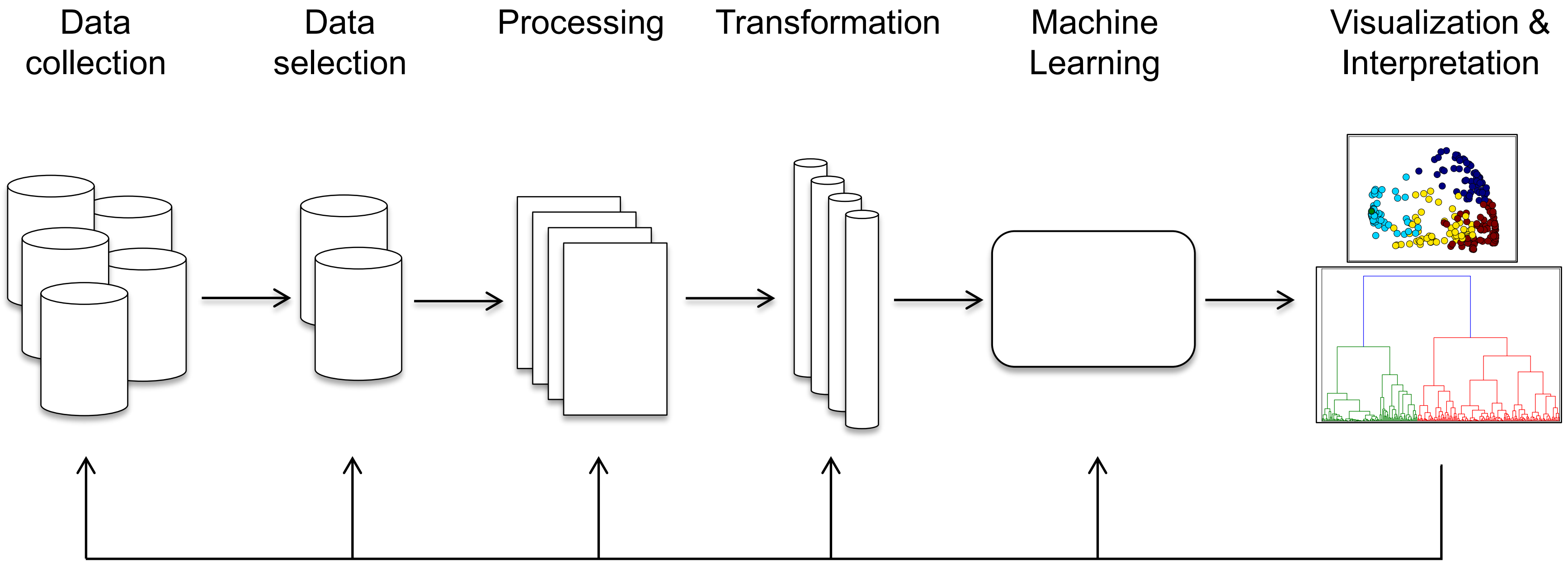
2.10.2023

Lecture overview

- Data Processing and Visualization Lecture
  - Knowledge discovery process
  - Data selection
  - Data processing
  - Data visualization

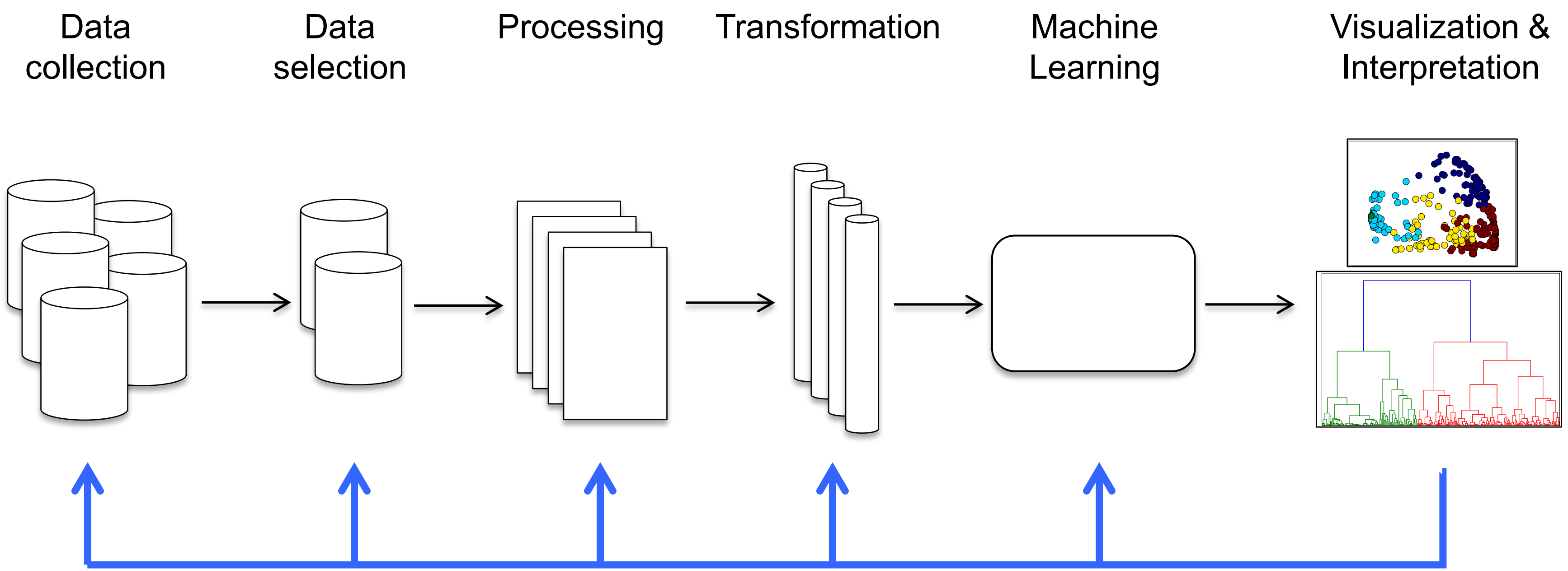
Knowledge discovery process



Typical Knowledge Discovery Diagram (KDD)

Knowledge discovery process

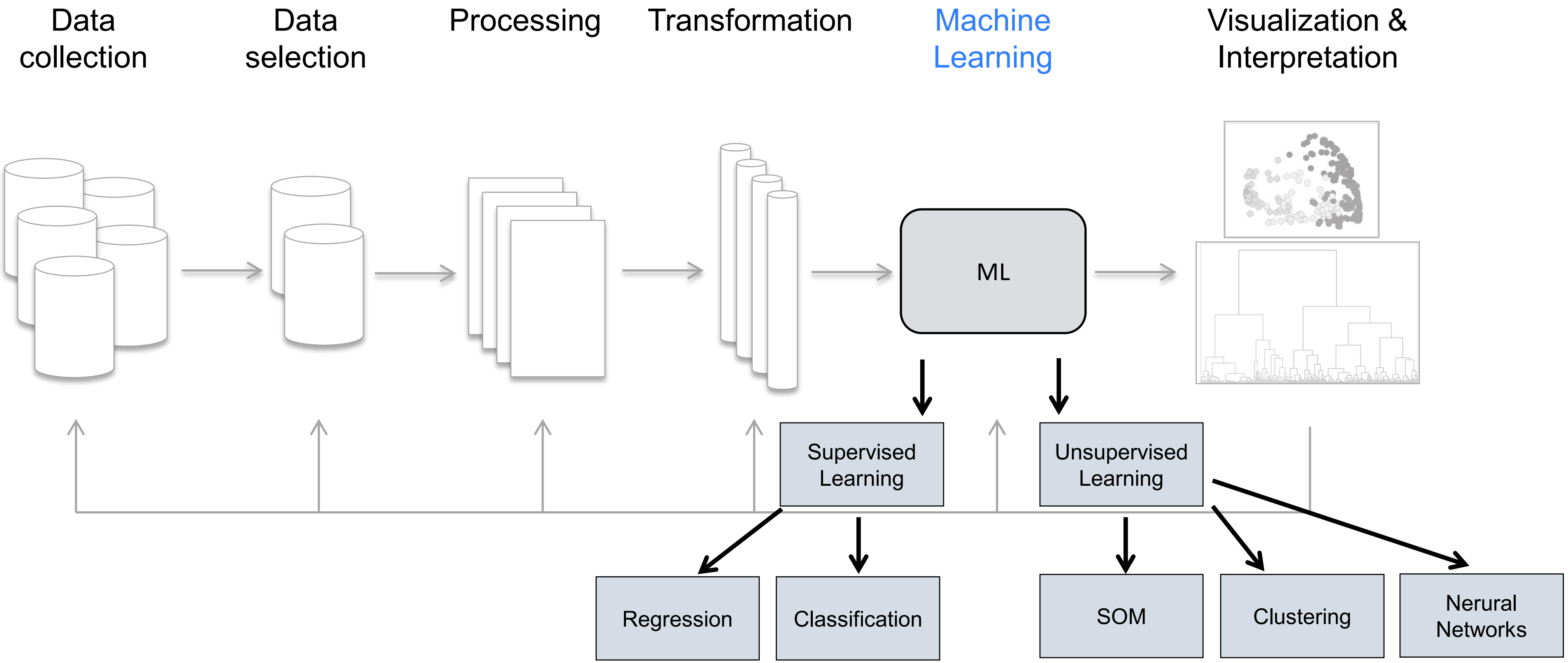
It is an exploratory and iterative process



Typical Knowledge Discovery Diagram (KDD)

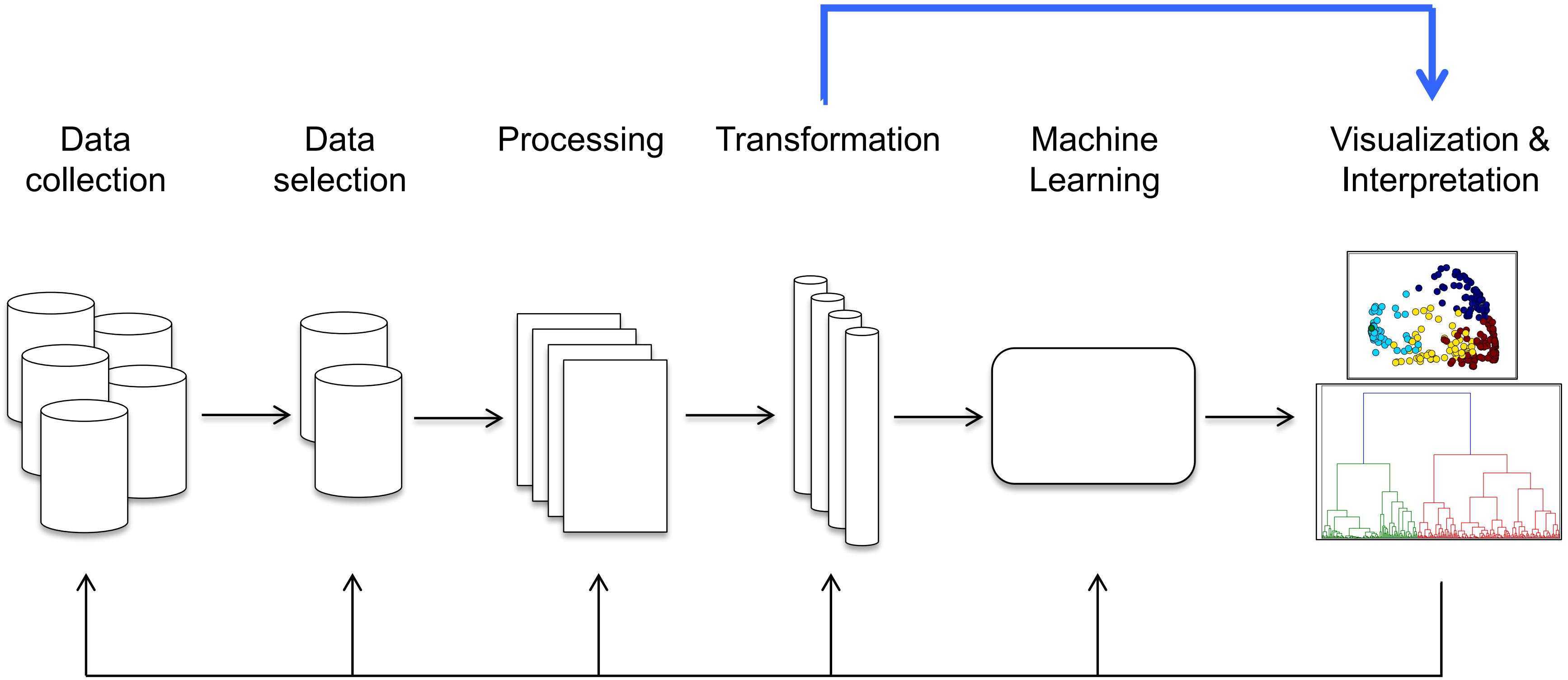
Knowledge discovery process

Where does machine learning fit into the process?



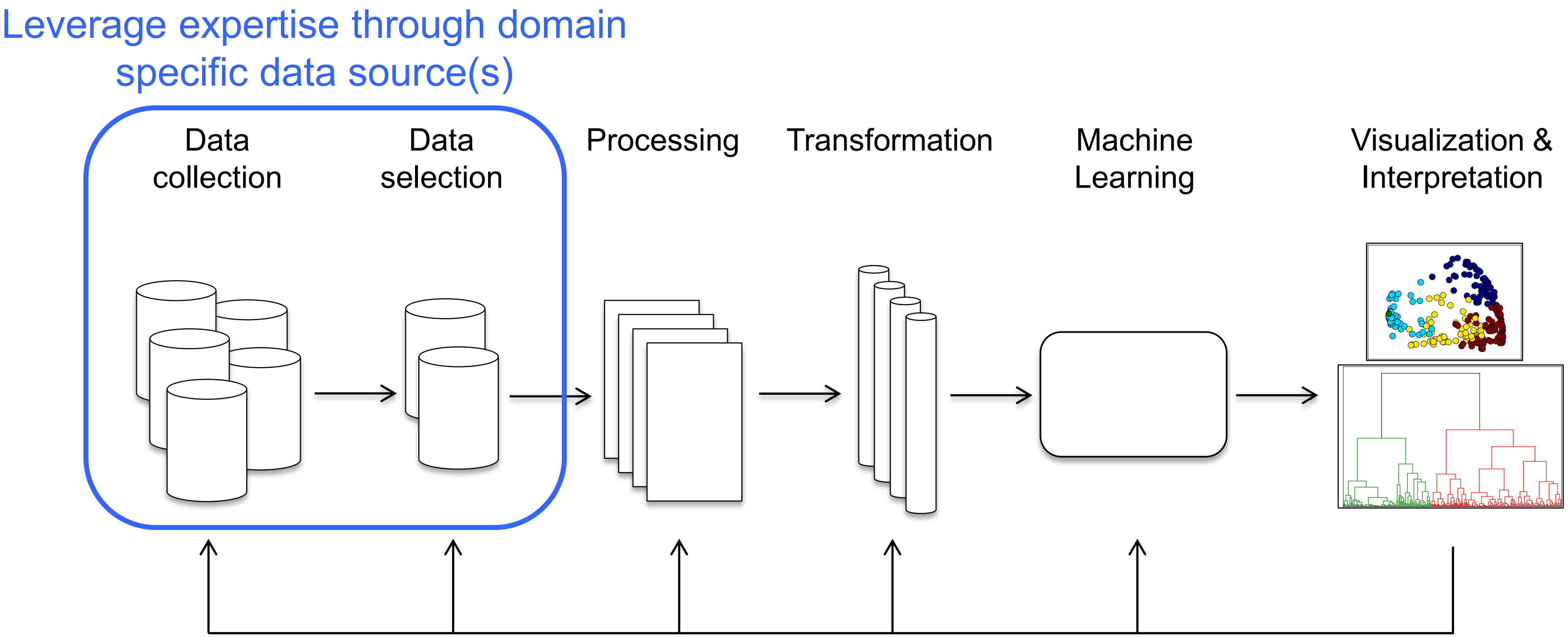
Knowledge discovery process

Data analysis does not always include machine learning, for example time-series analysis and geo-referenced data visualization



Typical Knowledge Discovery Diagram (KDD)

Knowledge discovery process



Typical Knowledge Discovery Diagram (KDD)

Data Structures

What is data in machine learning context?

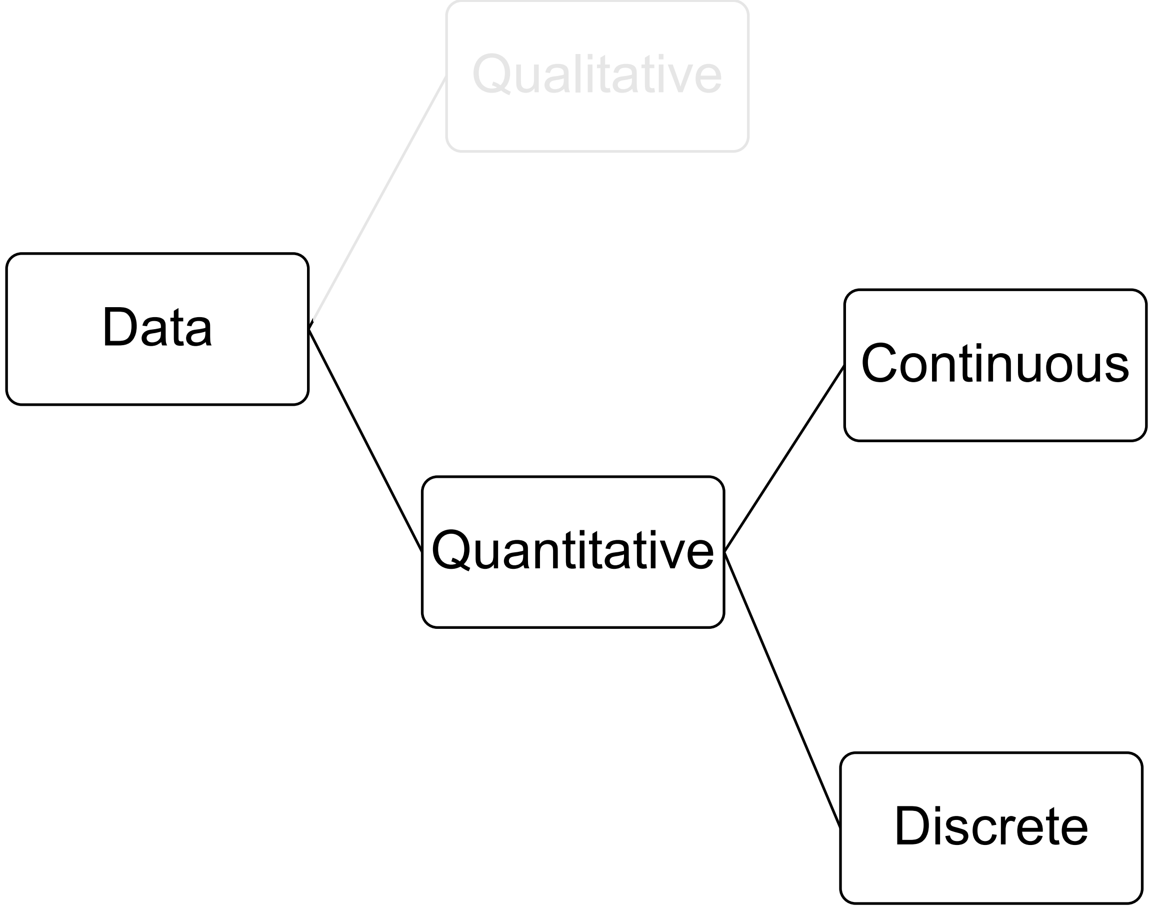
- ML can process data in all imaginable ways like
  - Pictures, videos, Excel spreadsheets, SQL databases, …
- As a machine learning engineer, you will need to understand the basic data types to build your ML pipeline
  - Numerical data
  - Categorical data
  - Time series data
  - Text data

Data Structures

Defining basic types of data

- **Numerical data**: This can be discrete or continuous data, but it always uses exact numbers that are not ordered in time. It's also called quantitative data
- **Categorical data**: This is data that expresses characteristics, so it is also called the "class label" in a super classification context. Although categorical data can be represented using numbers, the numbers do not have a mathematical meaning
- **Time series data**: This data consists of numbers that were collected across a period of time
- **Text data**: This is essentially words, which you might want to turn into numbers as soon as possible

Numerical Data



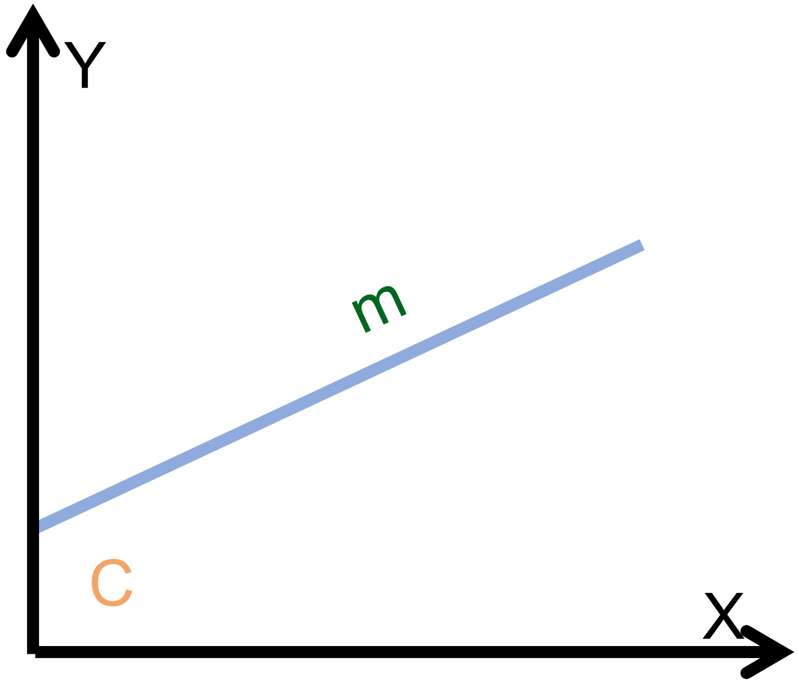
Continuous

- Always numeric
- Can be any number, positive or negative
- Something that can be measured, e.g., temperature

Discrete

- Ordinal variable – Survey ratings (0 – 5)
- Binary variables – (0 /1)
- Something that can be counted, e.g., number of students

Numerical Data

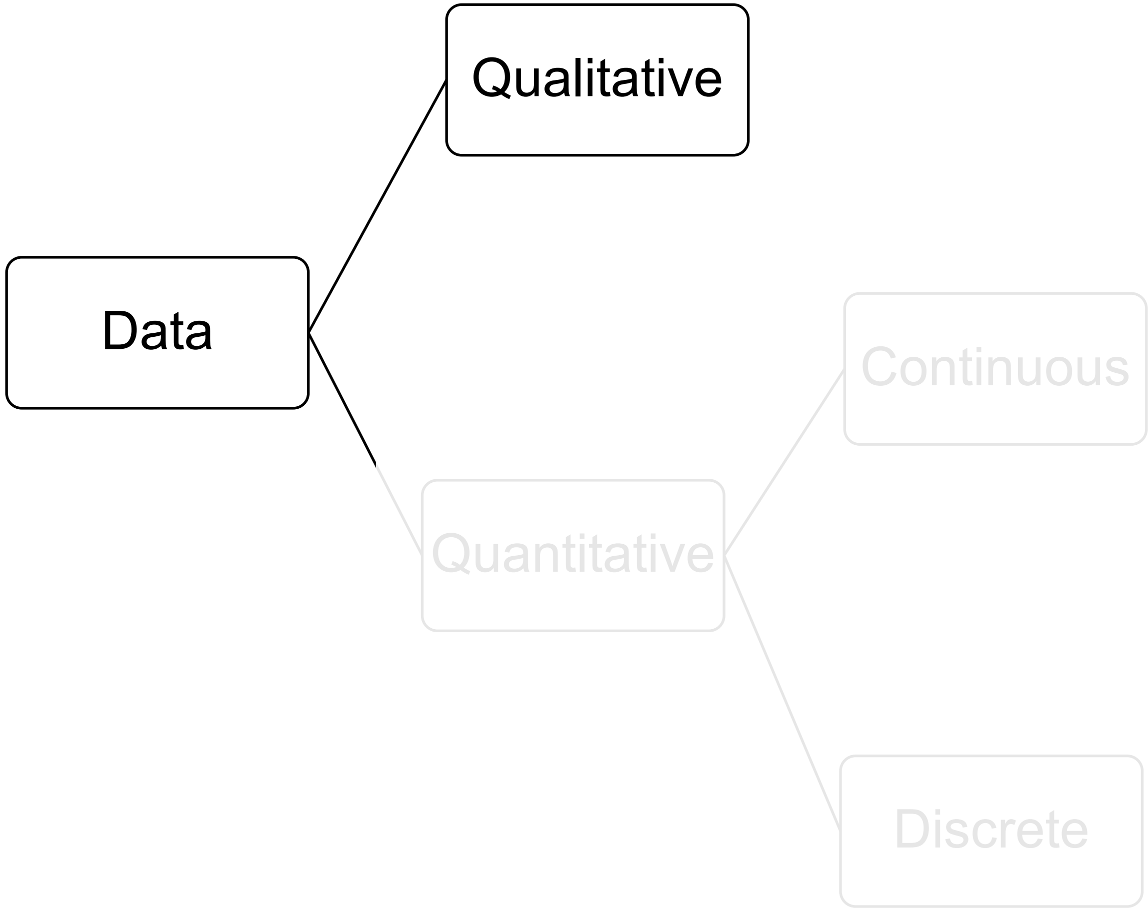


Independent / Dependent

e.g., $Y = mX + C$

Value of Y depended on m, X, and C

Categorical Data



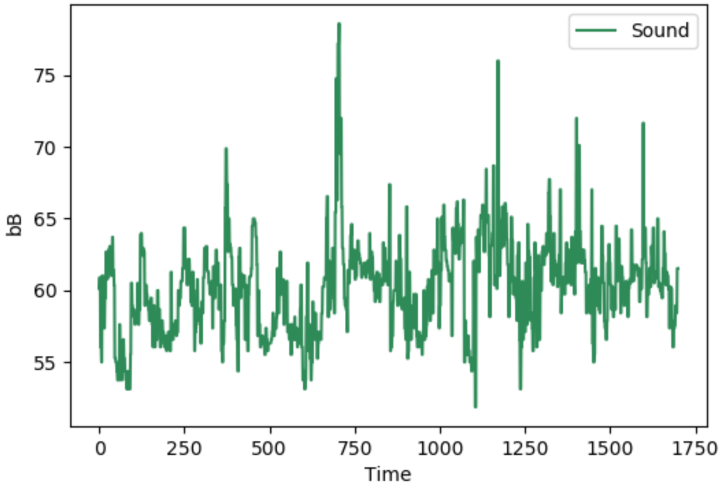
Qualitative data

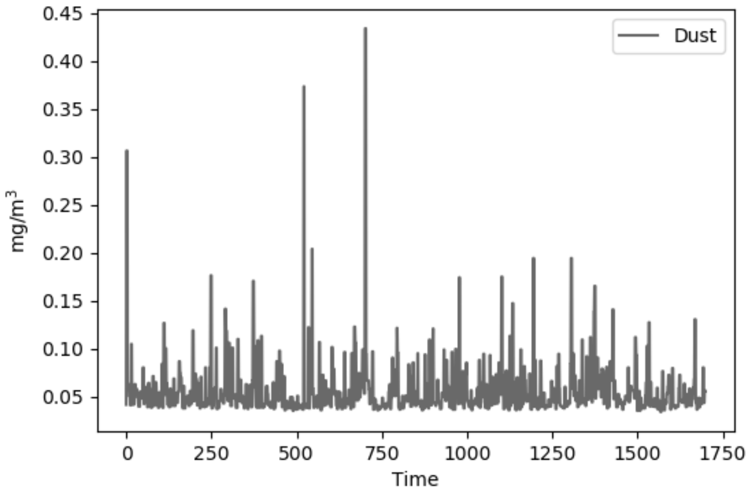
- Subjective ratings - excellent, good, fair, poor
- Meta data – gender (male, female)
- Categorical data may derive from observations made of qualitative data
- Observations of quantitative data grouped within given intervals

https://image.freepik.com/free-vector/temperature-measurement-from-cold-hot_53562-2741.jpg

Time Series Data

- Time series data is a sequence of numbers collected at regular intervals over some period of time
- Is a sequence taken at successive equally spaced points in time, thus it is a sequence of discrete-time data
- Can be applied to real-valued, continuous data, discrete numeric data, or discrete symbolic data



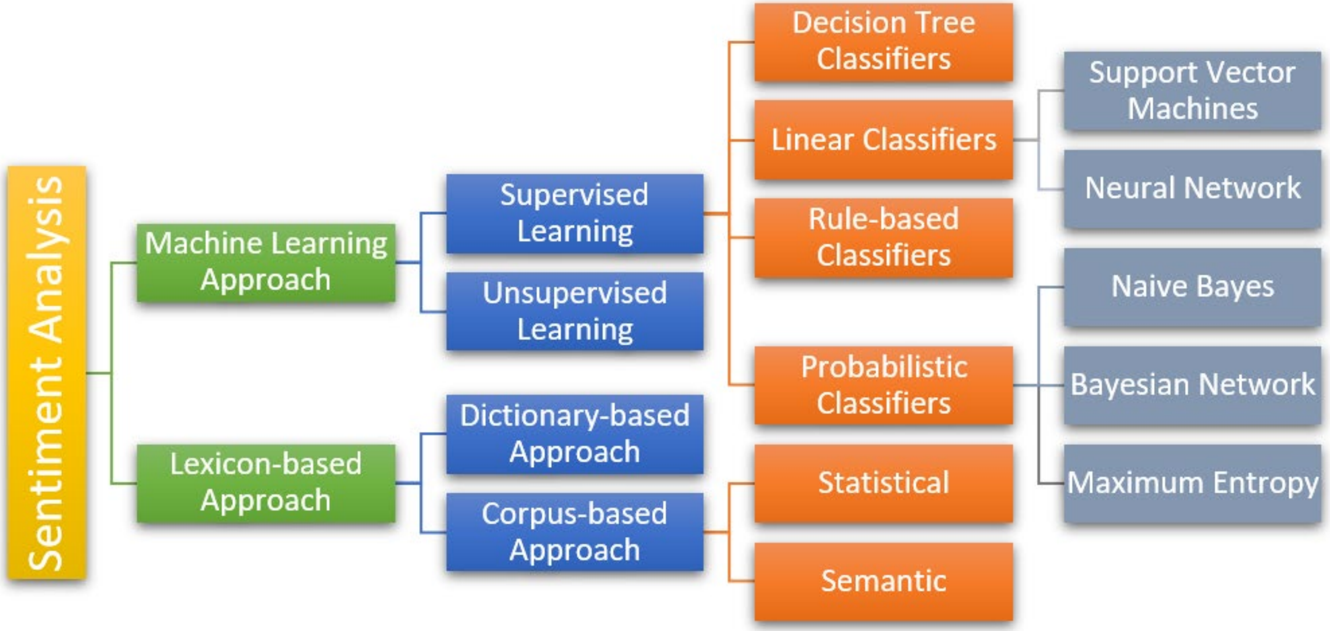


Ojha VK, Griego D, Kuliga S, Bielik M, Buš P, Schaeben C, Treyer L, Standfest M, Schneider S, König R, Donath D, Schmitt G (2018) Machine learning approaches to understand the influence of urban environments on human's physiological response, *Information Sciences*, Elsevier (pdf).https://archive.arch.ethz.ch/esum/data.html

Text Data

Text Mining:

- Process of deriving high-quality information from text
- Automation of extracting information of unknown text: websites, books, emails…
- Text analysis processes are
  - dimensionality reduction
  - Information retrieval
  - Sentiment analysis

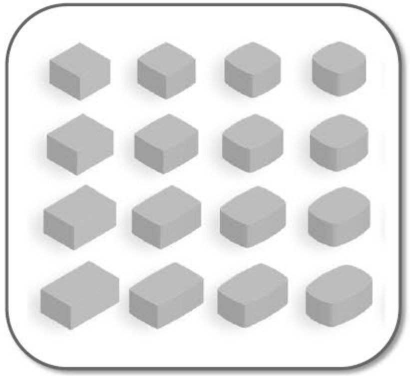


https://devopedia.org/images/article/105/8215.1532752754.png

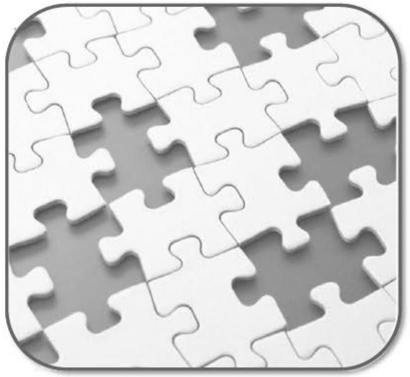
Acquiring data

Limitations of collected data in AEC

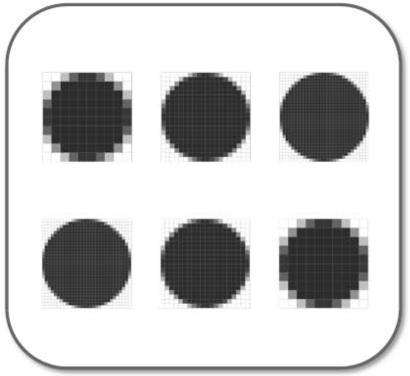
NOT ENOUGH



NOT DIVERSE



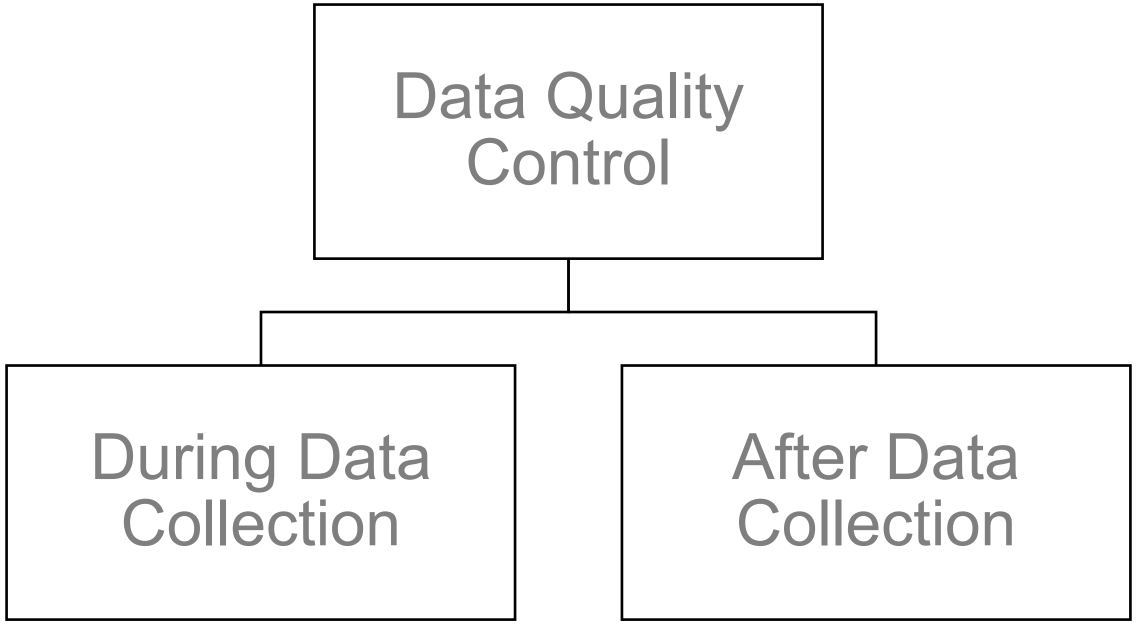
INCOMPLETE



INCOSISTENT
QUALITY & FORMAT

Data Quality Control

Improving data quality



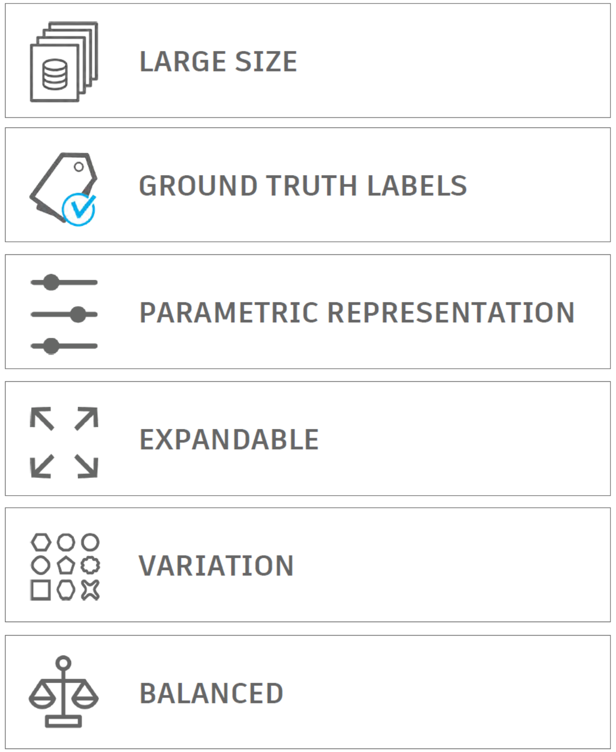
Data Collection

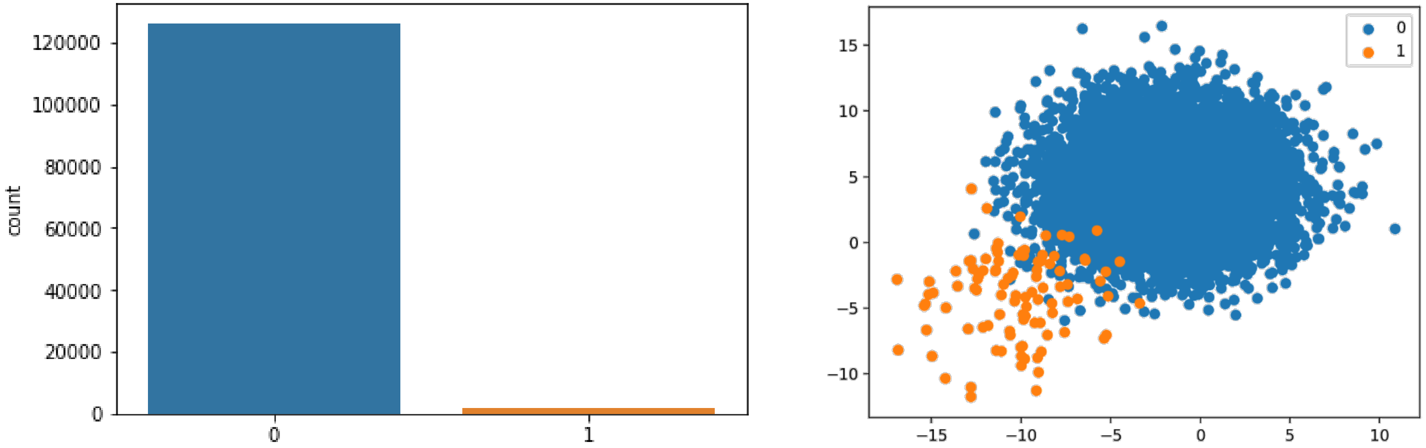
Improving data quality

Reference: Mónica Bobrowski, Martina Marré, Daniel Yankelevich, Measuring Data Quality, Report no.: 99-002, Pabellón 1 - Planta Baja - Ciudad Universitaria

Properties of a good dataset

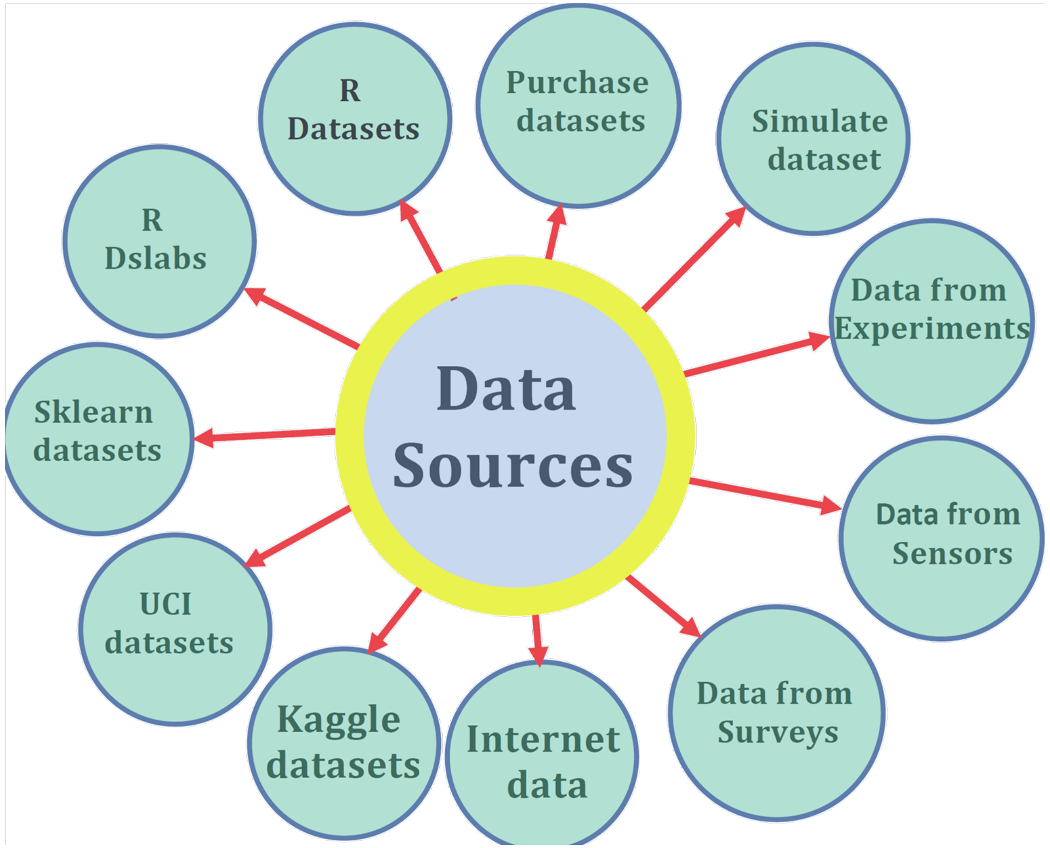
Koch et al. (2019), ABC: A Big CAD Model Dataset For Geometric Deep Learning





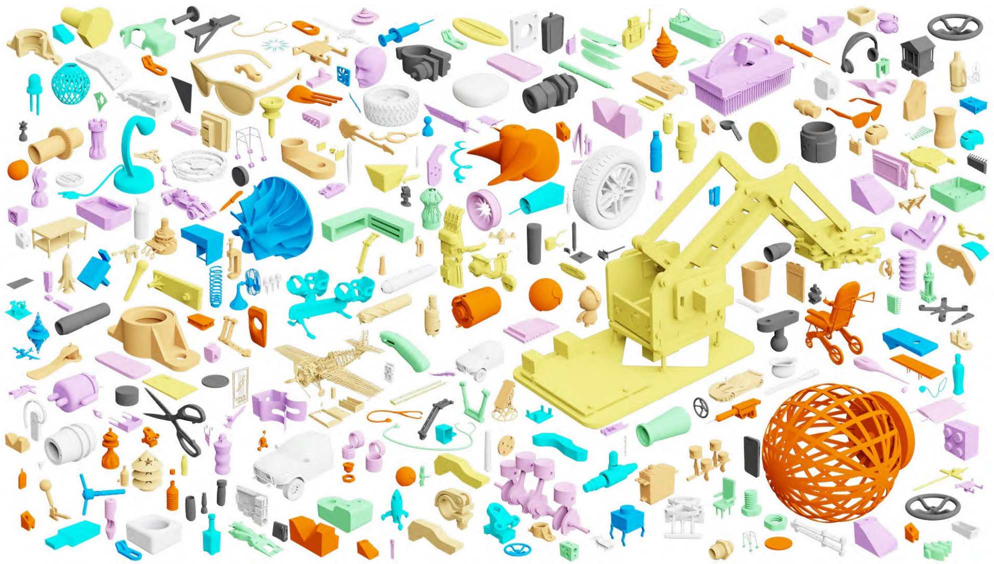
https://3qeqpr26caki16dnhd19sv6by6v-wpengine.netdna-ssl.com/wp-content/uploads/2019/10/Scatter-Plot-of-Binary-Classification-Dataset-With-1-to-100-Class-Distribution.png

Data Sources



https://miro.medium.com/max/3978/1*yPcYNnAVxcRWSDQIgKDUxg.png

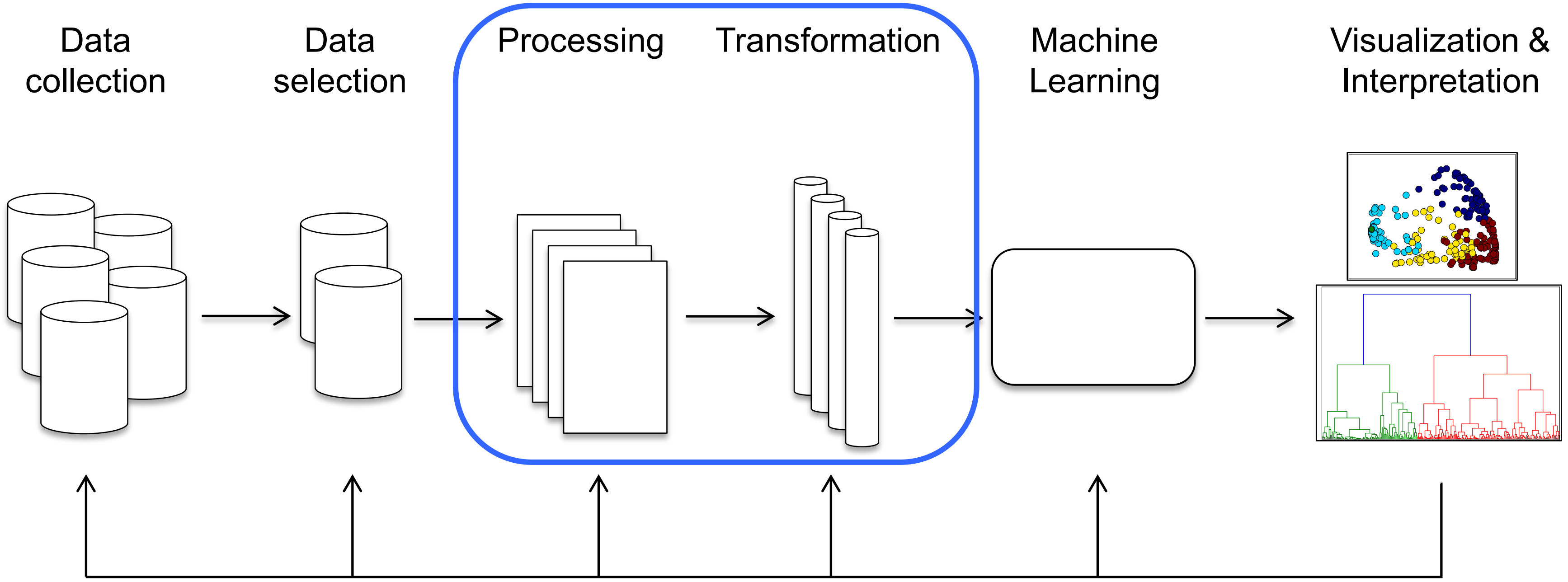
Floor plans from the CVC-FP dataset http://dag.cvc.uab.es/resources/floorplans/



Fusion 360 Gallery Dataset - https://github.com/AutodeskAILab/Fusion360GalleryDataset

Knowledge discovery process

Is the data usable? The not-so fun, but essential part of the process.

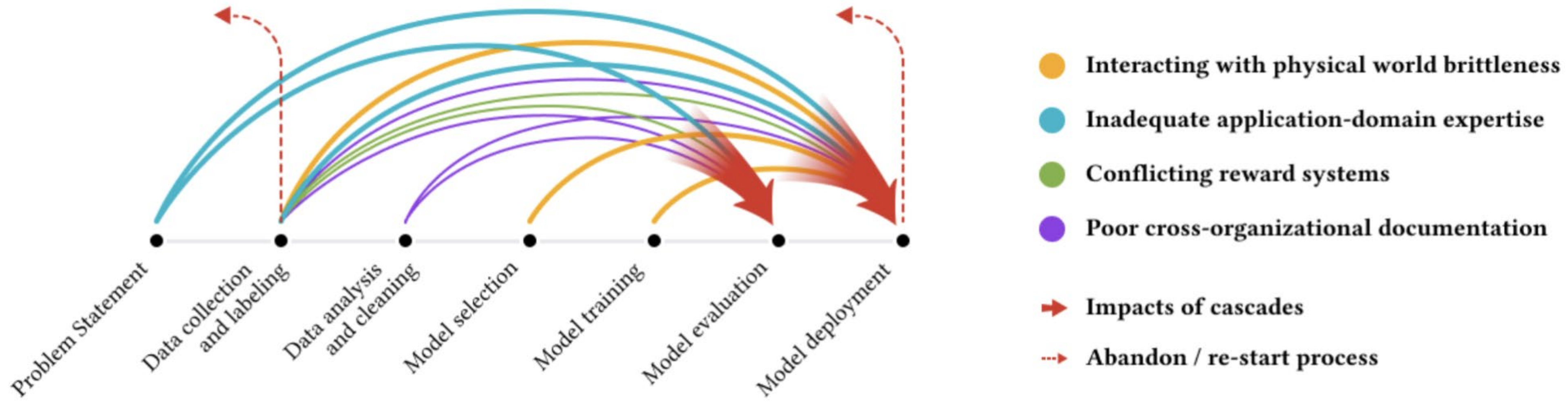


Typical Knowledge Discovery Diagram (KDD)

The not-so fun, but essential part of the process

"Everyone wants to do the model work, not the data work": Data Cascades in High-Stakes AI

Nithya Sambasivan, Shivani Kapania, Hannah Highfill, Diana Akrong, Praveen Paritosh, Lora Aroyo
[nithyasamba,kapania,hhighfill,dakrong,pkp,loraa]@google.com
Google Research
Mountain View, CA



https://ai.googleblog.com/2021/06/data-cascades-in-machine-learning.html

Data Processing

"the collection and manipulation of items of data to produce **meaningful information**." (Carl French, 1996)

Image source: http://www.marksgroup.net/blog/zoho-crm-garbage-in-garbage-out-its/

Data Processing

Improving Data Quality

Data cleaning

Fill in missing values, smooth noisy data, identify or remove outliers, and resolve inconsistencies

Data integration

Integration of multiple databases, data cubes, or files

Data transformation

Normalization and aggregation

Data reduction

Obtains reduced representation in volume but produces the same or similar analytical results

Data discretization

Part of data reduction but with particular importance, especially for numerical data

Reference: http://www.mimuw.edu.pl/~son/datamining/DM/4-preprocess.pdf

Data Processing

Data Cleaning

	Features (Variables)				
	Input features (Independent Variables)				Output feature (dependent variable)
Samples	Input V1	Input V2	Input V3	Input V4	Output V1
Sample 1	2.3	0.25	Good	1.5	y_1
Sample 2	4.5	43598.21	Good	1.8	y_2
Sample 3	4.7	0.33	Excellent	1.9	y_3
Sample 4	?	0.22	Good	3.9	y_4
Sample 5	?	0.19	Average	1.2	y_5
:	6.7	0.88	Good	1.8	:
Sample N	5.5	0.36	Bad	1.6	y_N

Missing Value

Outlier

Noise (required smoothing)

y_i Output variable can be continuous/discrete

Data Processing

Data Cleaning

Considered physiological signals

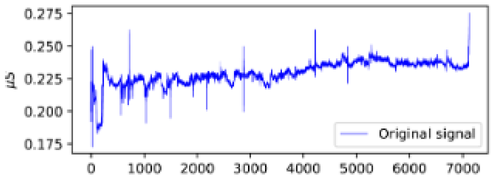


Fig Type 1

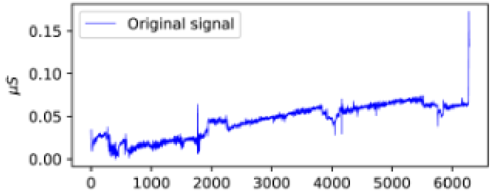


Fig Type 2

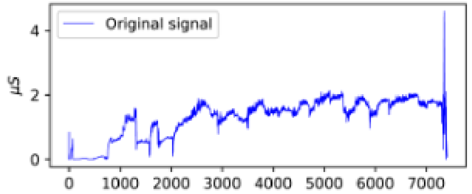


Fig Type 3

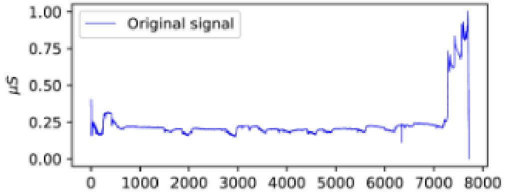


Fig Type 4

Discarded physiological signals

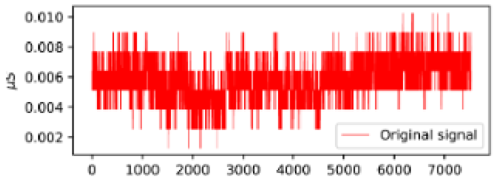


Fig Type 1: step function like signal

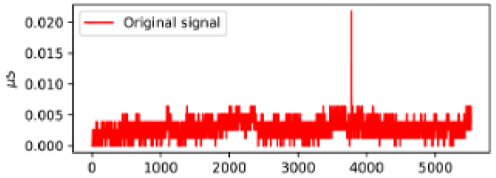


Fig Type 2: step function with major sensor loss

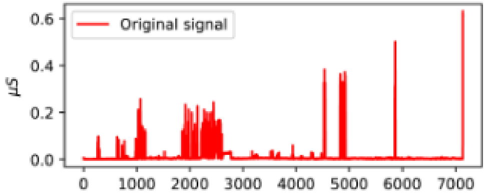


Fig Type 3: major sensor loss

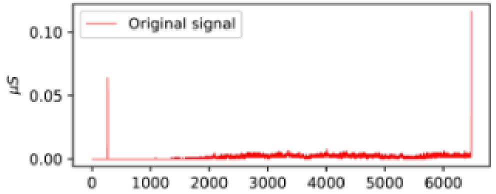
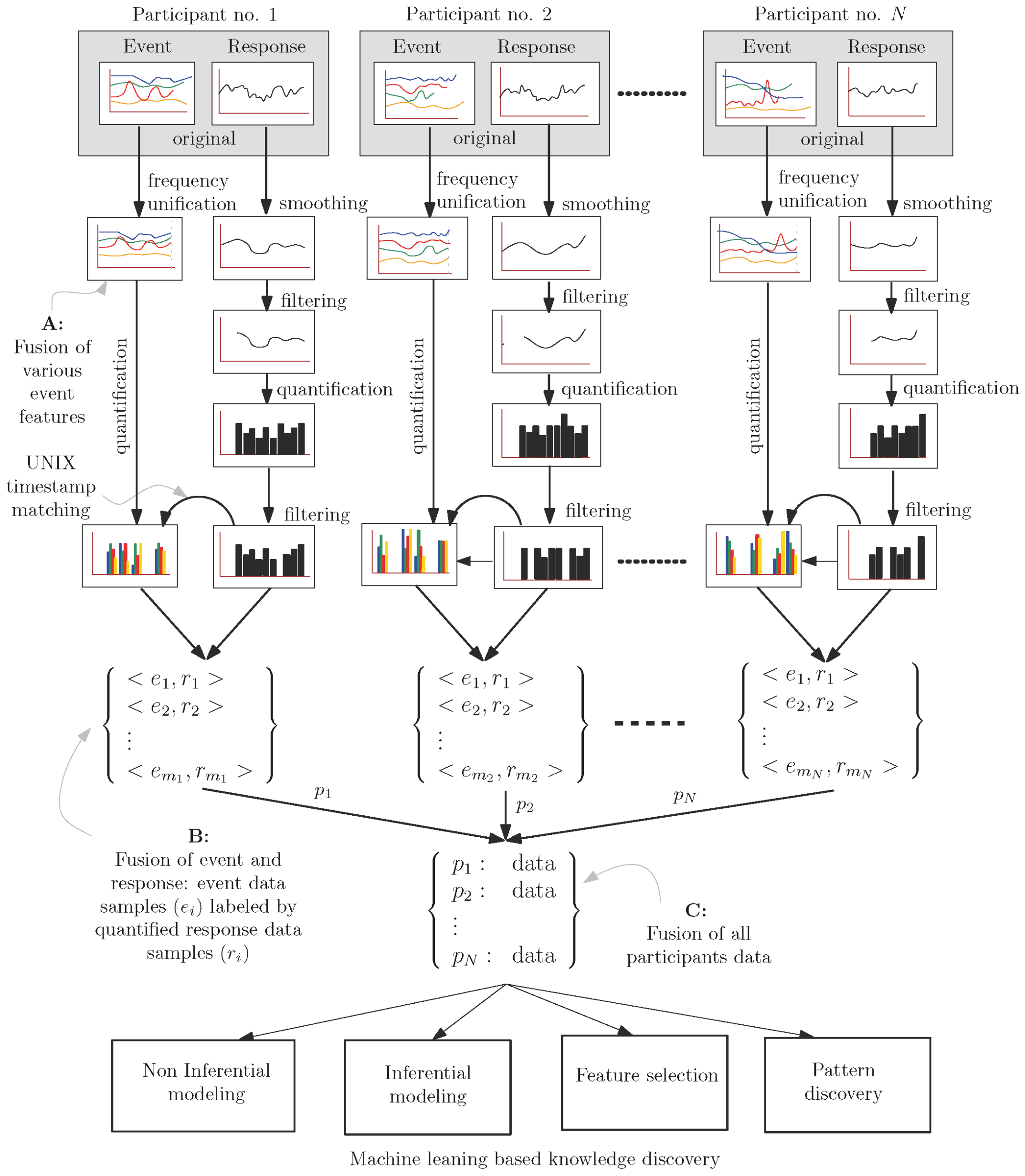


Fig Type 4: insignificant observations

Ojha VK, Griego D, Kuliga S, Bielik M, Buš P, Schaeben C, Treyer L, Standfest M, Schneider S, König R, Donath D, Schmitt G (2018) Machine learning approaches to understand the influence of urban environments on human's physiological response, *Information Sciences*, Elsevier (pdf).https://archive.arch.ethz.ch/esum/data.html

Data Processing

Data Integration



Ojha VK, Griego D, Kuliga S, Bielik M, Buš P, Schaeben C, Treyer L, Standfest M, Schneider S, König R, Donath D, Schmitt G (2018) Machine learning approaches to understand the influence of urban environments on human's physiological response, *Information Sciences*, Elsevier (pdf).https://archive.arch.ethz.ch/esum/data.html

Data Processing

Data Transformation

	Features (Variables)		
	Input features (Independent Variables)		Output feature (dependent variable)
Samples	Input V1	Input V2	Output V1
Sample 1	2.3	0.25	y_1
Sample 2	4.5	0.39	y_2
Sample 3	4.7	0.33	y_3
Sample 4	2.99	0.22	y_4
Sample 5	3.18	0.19	y_5
:	6.7	0.36	:
Sample N	5.5	0.88	y_N

	Features (Variables)		
	Input features (Independent Variables)		Output feature (dependent variable)
Samples	Input V1	Input V2	Output V1
Sample 1	0.00	0.09	y_1
Sample 2	0.50	0.29	y_2
Sample 3	0.55	0.20	y_3
Sample 4	0.16	0.04	y_4
Sample 5	0.20	0.00	y_5
:	1.00	0.25	:
Sample N	0.73	1.00	y_N

Max value

Min value

Transformed Variable

Data Processing

Data Reduction

Samples	Features (Variables)			
	Input features			Output feature
	Input V1	Input V2	Input V4	Output V1
Sample 1	2.3	0.25	1.5	y_1
Sample 2	4.5	0.39	1.8	y_2
Sample 3	4.7	0.33	1.9	y_3
Sample 4	2.99	0.22	1.6	y_4
Sample 5	3.18	0.19	1.2	y_5
:	6.7	0.88	1.8	:
Sample N	5.5	0.36	1.6	y_N

Feature Extraction

Samples	Features (Variables)			
	Input features			Output feature
	PCA 1	PCA 2		Output V1
Sample 1	-1.97	0.06		y_1
Sample 2	0.25	0.15		y_2
Sample 3	0.45	0.22		y_3
Sample 4	-1.28	0.09		y_4
Sample 5	-1.14	-0.33		y_5
:	2.48	-0.04		:
Sample N	1.21	-0.15		y_N

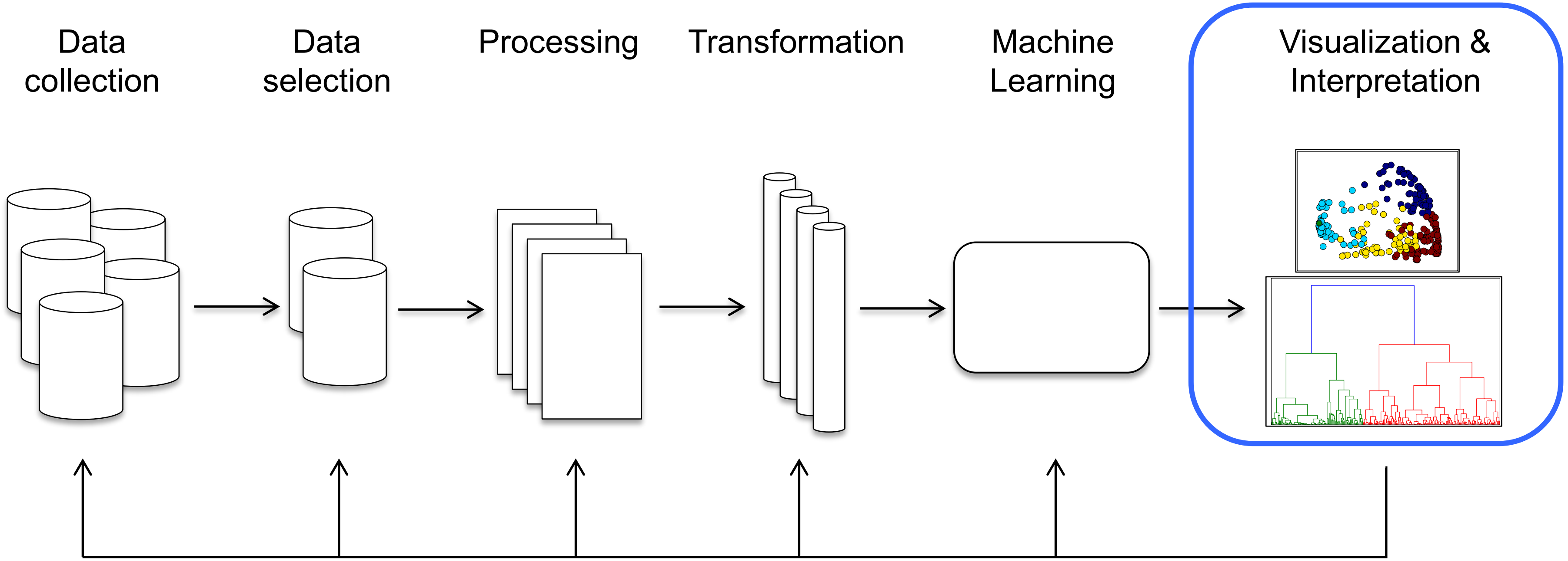
Feature Selection

Samples	Features (Variables)			
	Input features			Output feature
	Input V1		Input V4	Output V1
Sample 1	2.3		1.5	y_1
Sample 2	4.5		1.8	y_2
Sample 3	4.7		1.9	y_3
Sample 4	2.99		1.6	y_4
Sample 5	3.18		1.2	y_5
:	6.7		1.8	:
Sample N	5.5		1.6	y_N

Extracted Features

Knowledge discovery process

The visualizations tell the final story.
What do we want to know?



Typical Knowledge Discovery Diagram (KDD)

Data Visualization

Good data visualization helps to:

- make information easy to read and retain
- identify trends and patterns
- prove theories and answer questions
- control the focus and capture the audience's attention
- improves the impact of your message

Definitions- What is data visualization?

Data visualization helps researchers find patterns and relationships from data by presenting information in a **clear, efficient and meaningful way**

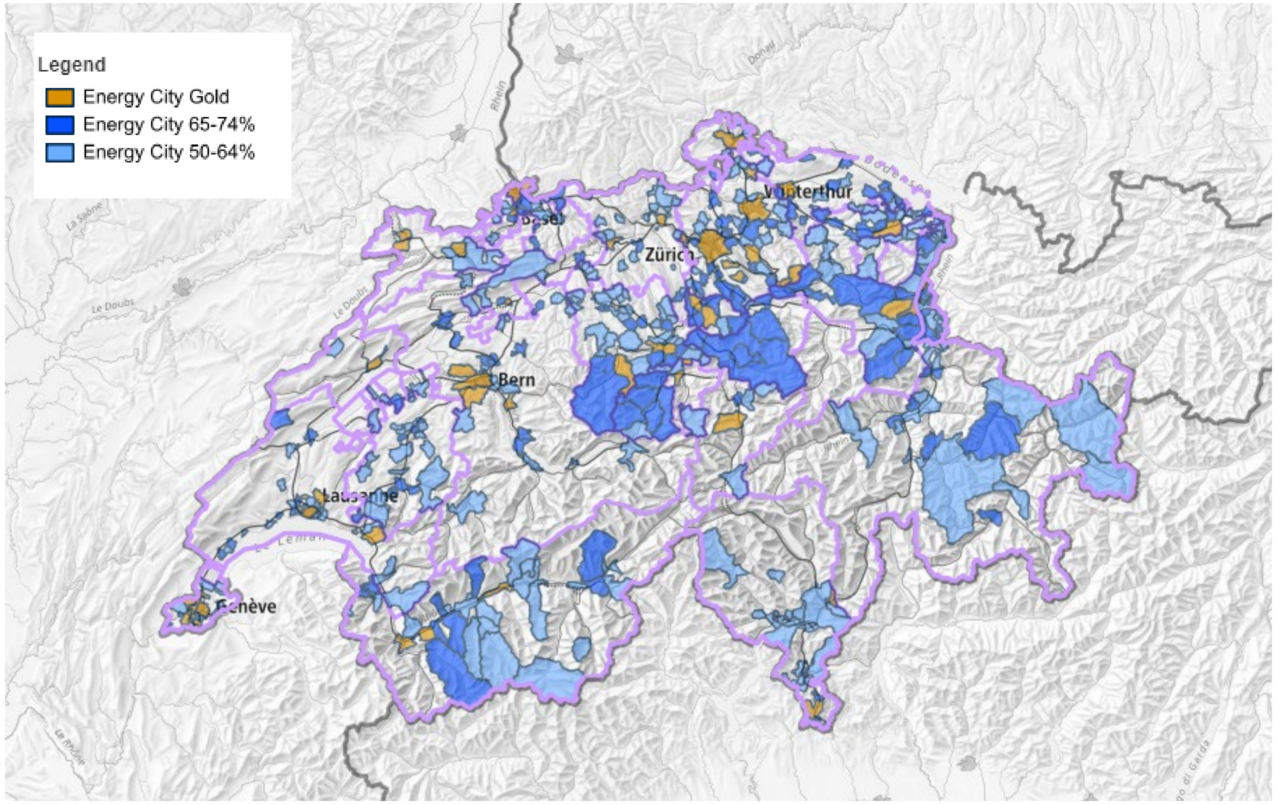
It involves an **abstracted representation** of raw data, in form of graphs, charts and drawings, in order to **enhance comprehension** and **direct the focus**

Source: https://www.theguardian.com/guardian-masterclasses/2015/aug/07/data-visualisation-a-one-day-workshop-tobias-sturt-adam-frost-digital-course

Definitions- What is information visualization?

Information visualization represents data or **information that is already somewhat understood**

Visual representations of abstract data to **reinforce human cognition**



Map of the Energy Cities in Switzerland
https://s.geo.admin.ch/8c096ea987

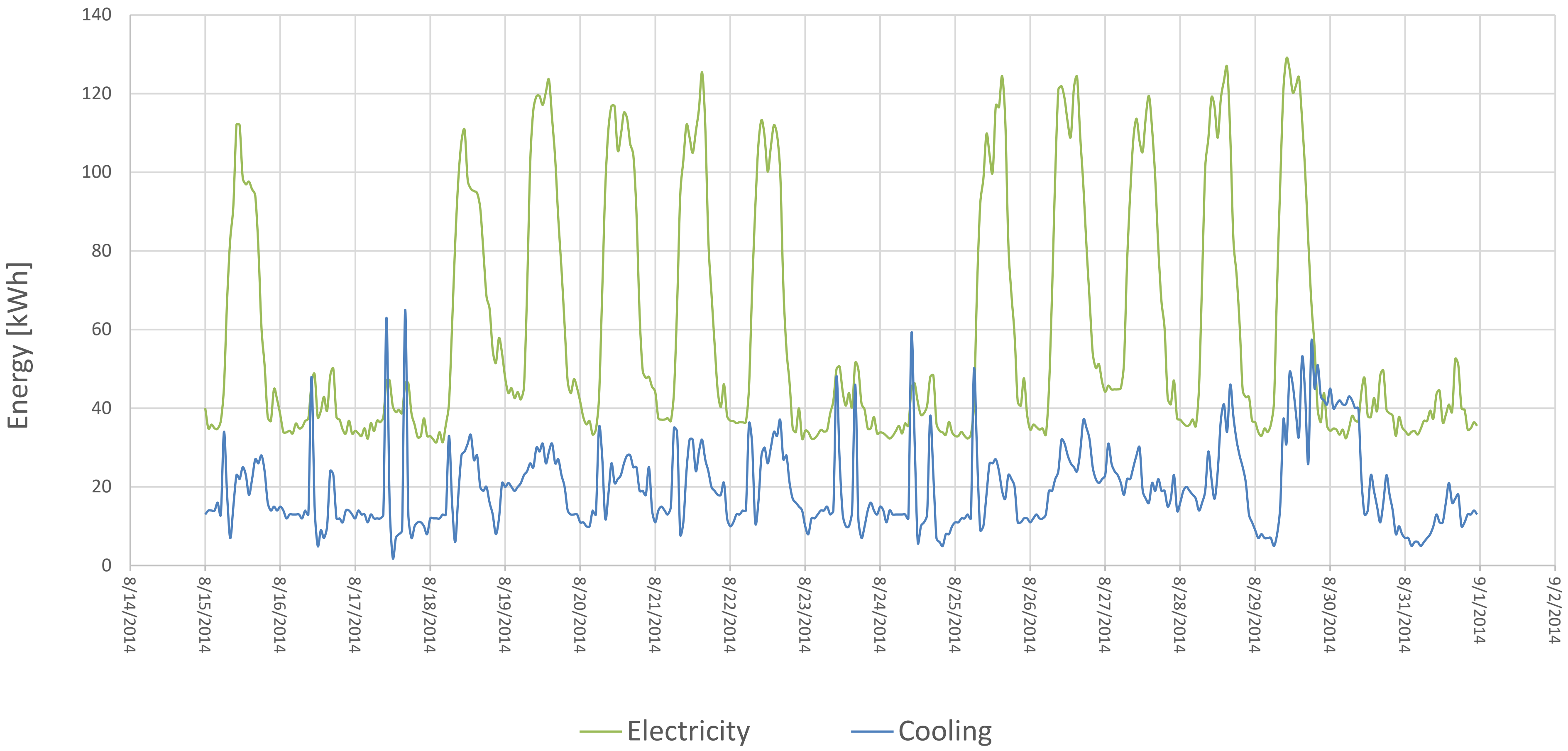
What’s the point?

Electricity and cooling demand of the ETL building, 15-21 August 2014

Elect.	Cooling	Elect.	Cooling	Elect.	Cooling	Elect.	Cooling	Elect.	Cooling	Elect.	Cooling	Elect.	Cooling
15.08.2014		16.08.2014		17.08.2014		18.08.2014		19.08.2014		20.08.2014		21.08.2014	
40.03	13.00	38.41	15.00	34.28	12.00	32.94	12.00	47.63	20.00	41.66	11.00	44.16	11.00
34.88	14.00	33.97	14.00	33.59	14.00	32.03	12.00	43.88	21.00	37.69	11.00	37.47	14.00
35.84	14.00	33.88	12.00	32.94	13.00	31.34	12.00	45.13	20.00	35.91	10.00	37.09	15.00
34.91	14.00	34.28	13.00	34.91	13.00	33.94	12.00	42.56	19.00	36.75	10.00	37.13	14.00
34.81	16.00	33.59	13.00	32.25	11.00	31.34	13.00	44.13	20.00	33.28	14.00	37.47	13.00
36.84	13.00	36.13	13.00	36.22	13.00	35.84	13.00	42.25	21.00	34.59	13.00	36.78	15.00
45.47	34.00	34.91	13.00	34.19	12.00	41.25	33.00	45.44	23.00	42.50	35.00	44.13	35.00
67.47	18.00	35.19	12.00	36.84	12.00	61.16	16.00	70.06	24.00	68.56	28.00	65.97	34.00
82.91	7.00	36.78	14.00	36.47	12.00	82.22	6.00	102.44	26.00	95.63	12.00	94.09	8.00
91.47	15.00	37.47	13.00	37.75	13.00	98.22	18.00	115.84	25.00	110.72	18.00	103.00	11.00
112.06	23.00	46.06	48.00	47.03	63.00	107.84	28.00	119.31	30.00	116.84	26.00	112.03	24.00
112.00	22.00	48.66	15.00	47.09	16.00	110.75	29.00	119.38	29.00	116.78	21.00	108.81	32.00
98.56	25.00	37.75	5.00	40.63	2.00	97.91	31.00	117.13	31.00	105.56	22.00	104.94	32.00
96.94	23.00	39.34	9.00	39.03	7.00	95.82	33.20	120.31	26.00	109.44	23.00	110.41	24.00
97.63	18.00	42.91	7.00	39.63	8.00	95.21	26.80	123.50	29.00	115.19	26.00	116.16	29.00
95.63	22.00	39.38	10.00	38.78	9.00	94.72	28.00	113.66	31.00	113.66	28.00	125.41	32.00
94.09	27.00	48.28	24.00	46.41	65.00	90.91	20.00	103.34	26.00	107.19	28.00	112.03	27.00
80.97	26.00	49.97	23.00	46.38	13.00	79.97	19.00	88.00	27.00	104.31	25.00	82.84	24.00
60.47	28.00	37.75	12.00	38.72	7.00	68.53	20.00	75.47	23.00	89.63	25.00	69.16	20.00
50.91	24.00	37.09	12.00	35.84	10.00	65.25	16.00	61.16	20.00	64.00	19.00	56.34	19.00
37.78	16.00	34.56	11.00	32.63	11.00	54.75	13.00	46.72	14.00	49.56	19.00	44.47	18.00
36.75	14.00	33.59	14.00	32.97	11.00	51.50	8.00	43.84	13.00	47.72	18.00	40.31	18.00
44.84	15.00	36.84	14.00	37.44	10.00	57.88	12.00	47.38	13.00	47.97	25.00	46.09	21.00
42.19	14.00	33.56	13.00	32.97	8.00	53.84	21.00	45.09	13.00	45.44	14.00	38.03	12.00

What’s the point?

Electricity and cooling demand of the ETL building, 15-21 August 2014



The point is …

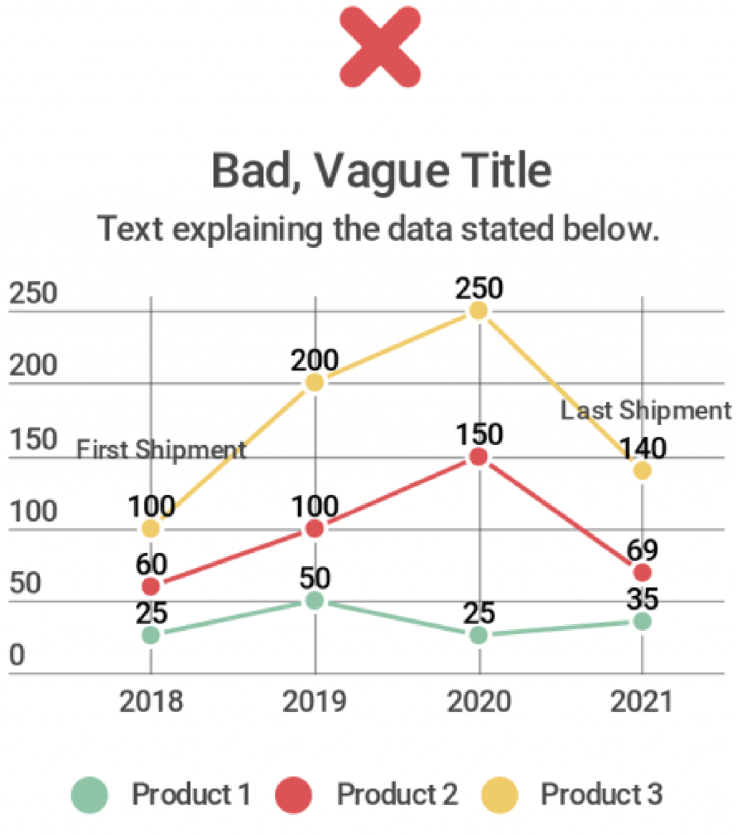
The human brain can capture an image in as little as 13 milliseconds!

Can you say the same about text or numbers?

"while the images are seen for only 13 milliseconds before the next image appears, part of the brain continues to process those images for longer than that"

Source: http://news.mit.edu/2014/in-the-blink-of-an-eye-0116

All data visualisation is not the same



Source: https://infogram.com/blog/do-this-not-that-data-visualization-before-and-after-examples/

Selecting the right visualization

- Define **a focus sentence** that summarizes what you want to show
- Decide how many **variables** you want to show in a single chart
- Decide how many **items** you want to display for every variable
- Decide if values are **spread** or **grouped**
- Identify **data types** and choose **representation styles**
- Choose the appropriate chart type
- Check if the chart fulfils the requirements of the focus sentence.

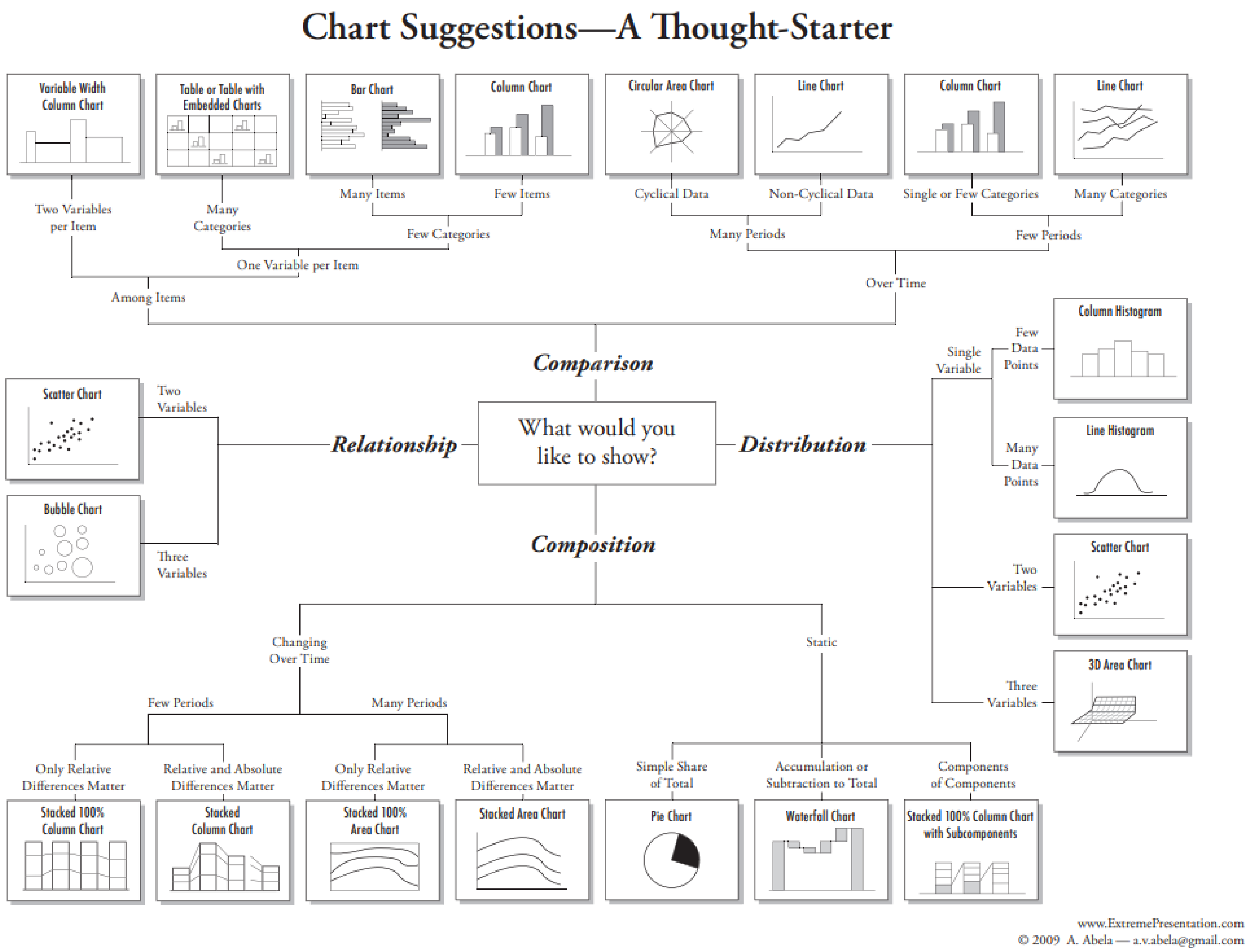
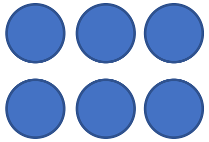
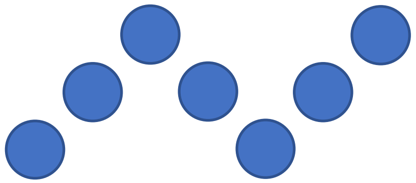


Chart Suggestions—A Thought-Starter
Variable Width Column Chart
Table or Table with Embedded Charts
Bar Chart
Column Chart
Circular Area Chart
Line Chart
Column Chart
Line Chart
Two Variables per Item
Many Categories
Many Items
Few Items
Cyclical Data
Non-Cyclical Data
Single or Few Categories
Many Categories
Few Categories
Many Periods
Few Periods
One Variable per Item
Over Time
Among Items
Comparison
Scatter Chart
Two Variables
Bubble Chart
Three Variables
Relationship
What would you like to show?
Distribution
Single Variable
Few Data Points
Column Histogram
Many Data Points
Line Histogram
Two Variables
Scatter Chart
Three Variables
3D Area Chart
Composition
Changing Over Time
Static
Few Periods
Many Periods
Only Relative Differences Matter
Relative and Absolute Differences Matter
Only Relative Differences Matter
Relative and Absolute Differences Matter
Simple Share of Total
Accumulation or Subtraction to Total
Components of Components
Stacked 100% Column Chart
Stacked Column Chart
Stacked 100% Area Chart
Stacked Area Chart
Pie Chart
Waterfall Chart
Stacked 100% Column Chart with Subcomponents
www.ExtremePresentation.com
© 2009 A. Abela — a.v.abela@gmail.com

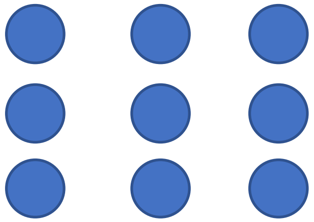
Data types



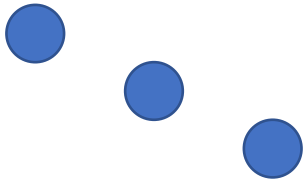
Quantitative
Data that can be counted or measured; has numerical values



Continuous
Data that can take any value within a certain range, even if data points are missing

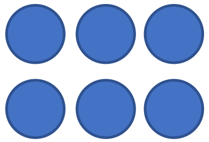


Qualitative / Categorical
Data that can be sorted in groups or categories

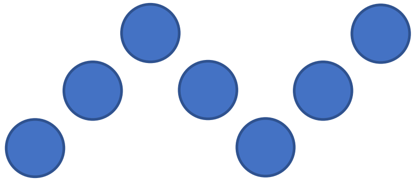


Discrete
Data with a finite number of possible values; countable

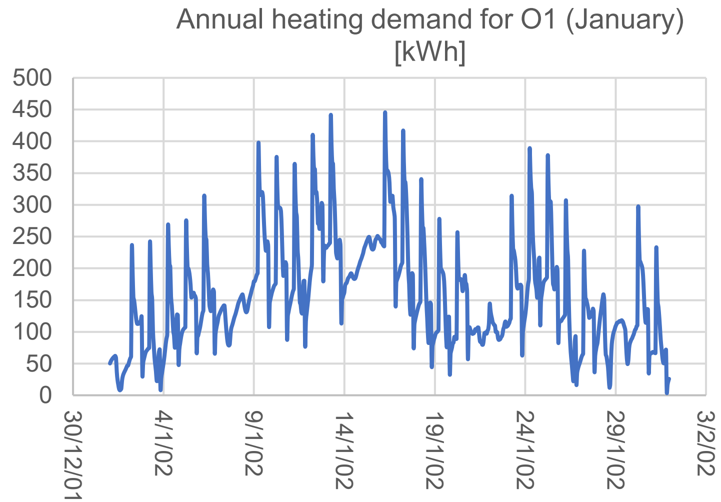
Data types



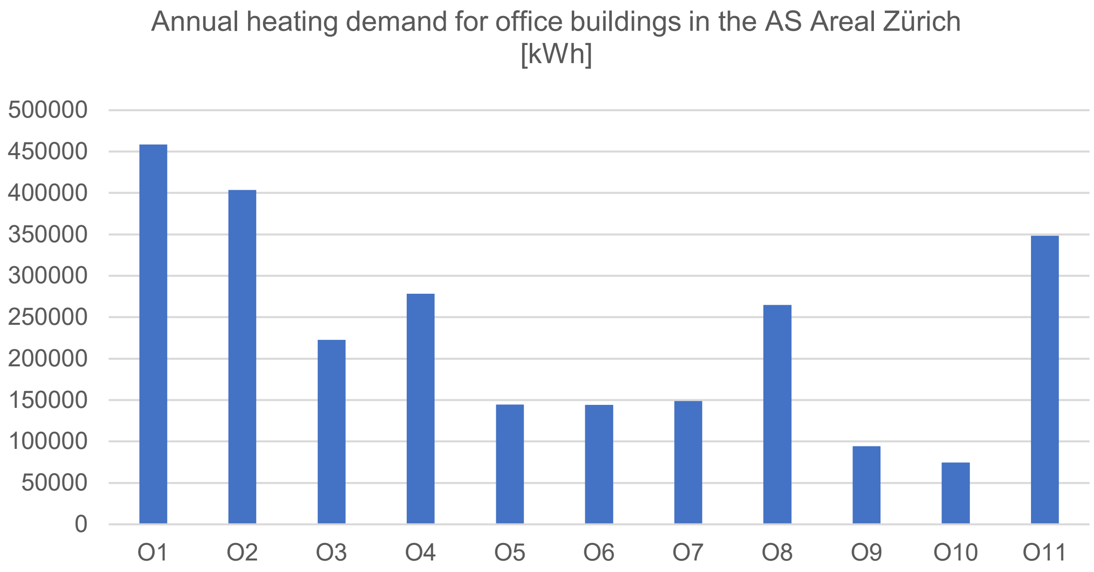
Quantitative
Data that can be counted or measured; has numerical values

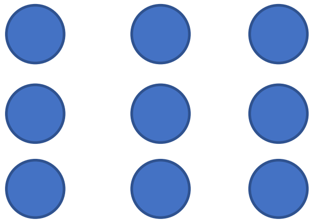


Continuous
Data that can take any value within a certain range, even if data points are missing (interpolation)

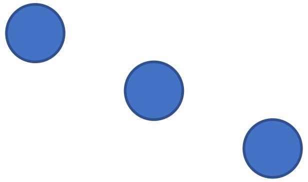


Data types



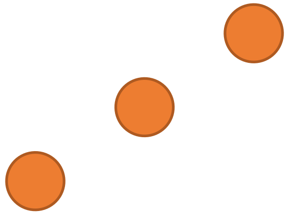


Qualitative / Categorical
Data that can be sorted in groups or categories

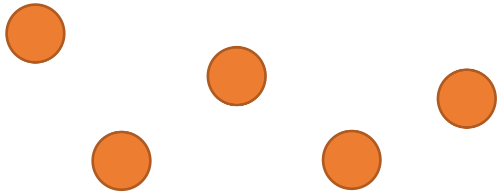


Discrete
Data with a finite number of possible values; directly countable

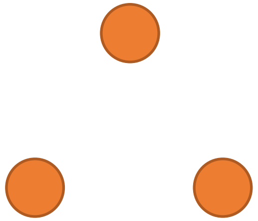
Representation types



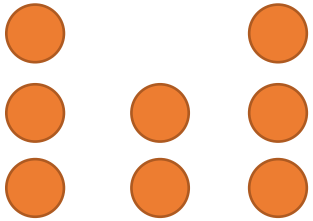
Comparison
Between two or multiple items, with emphasis on the difference or ranking



Distribution
Of one or more parameters over a series of categories, without emphasis on difference or ranking

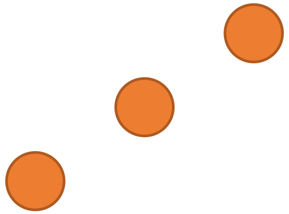


Relationship
Between two or more parameters of a series of items

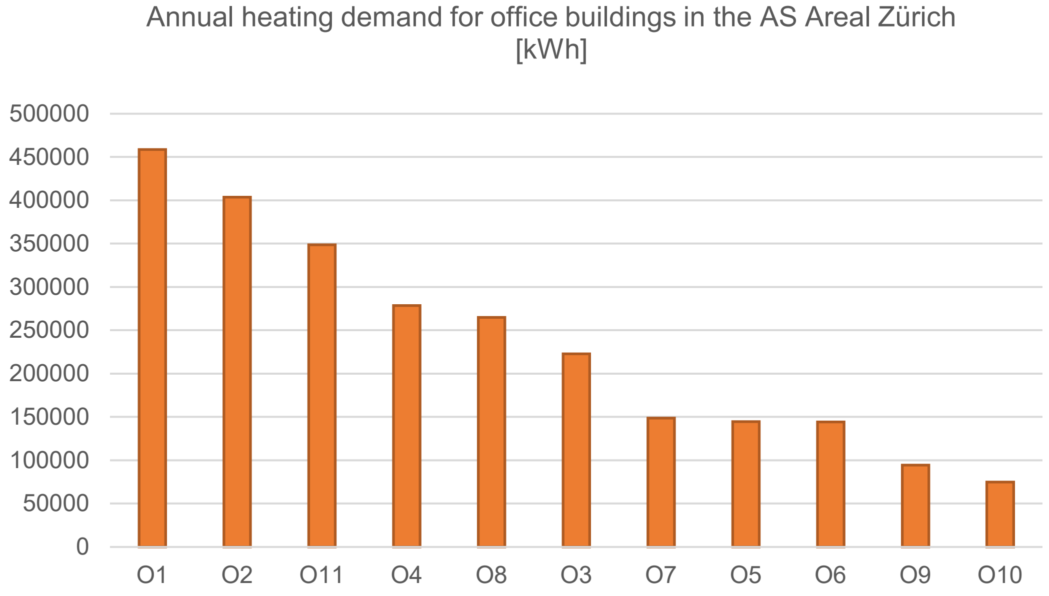


Composition
Shows subsets of data as part of the “whole” for a series of items

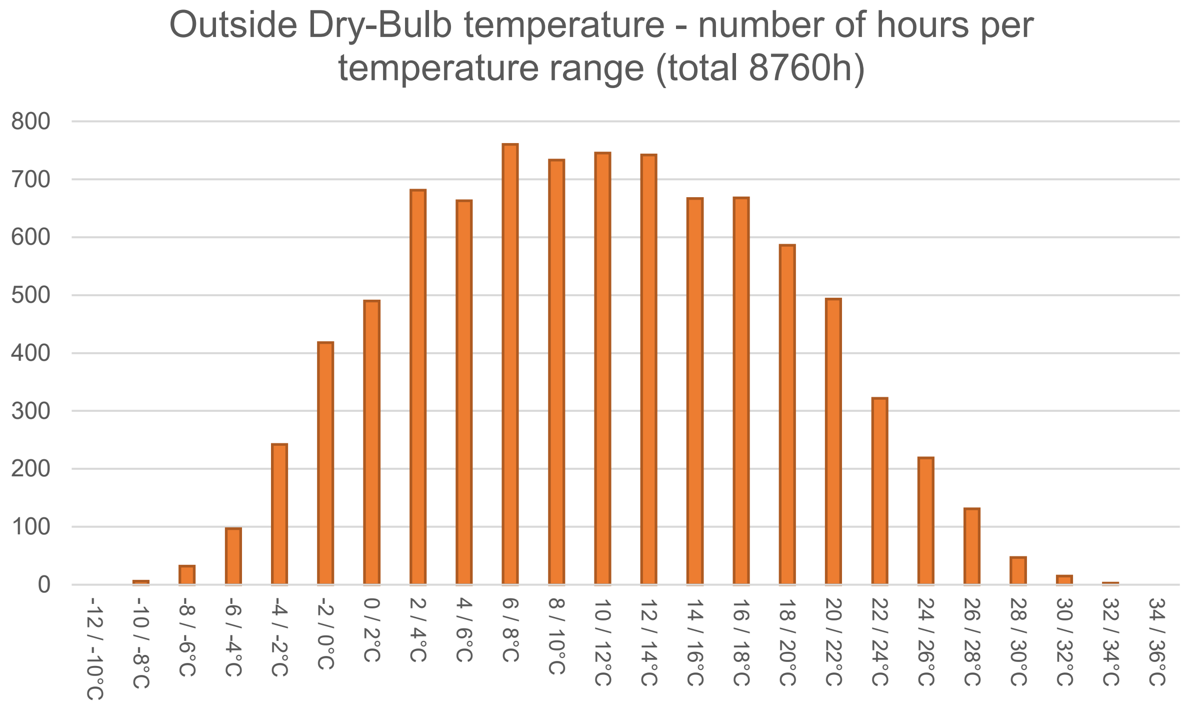
Representation types

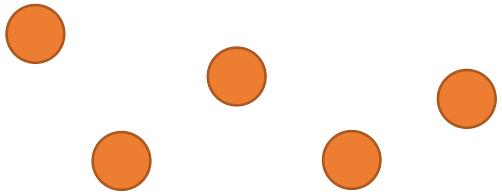


Comparison
Between two or multiple items, with emphasis on the difference or ranking



Representation types



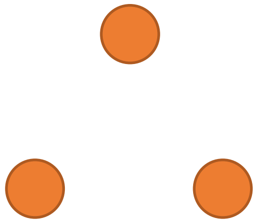


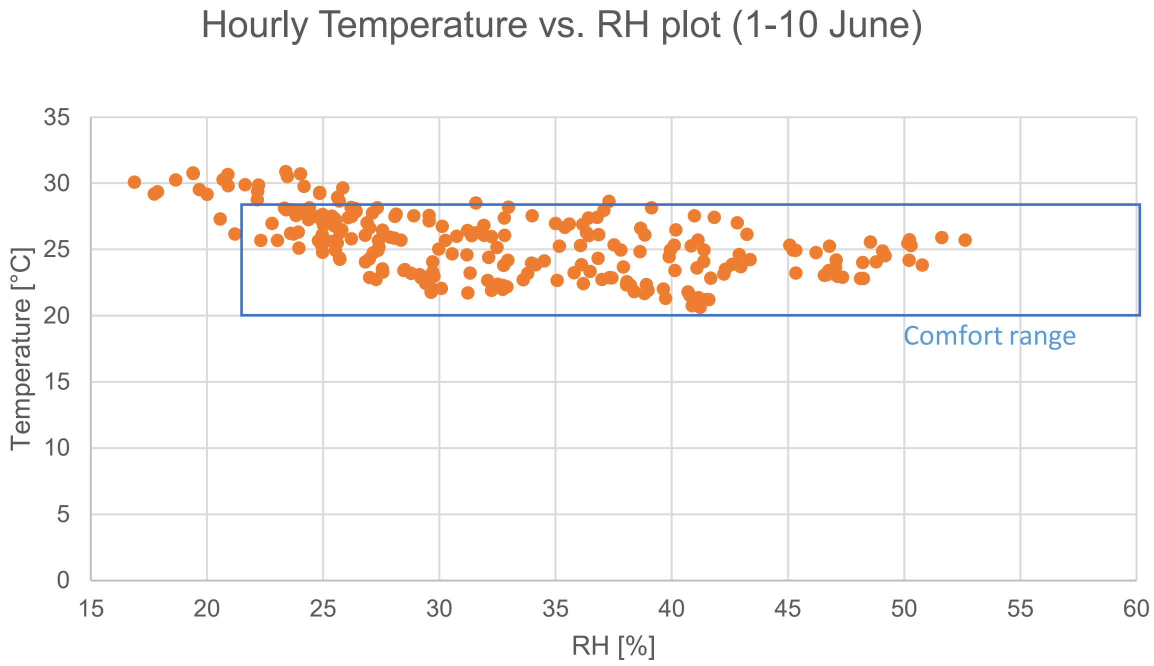
Distribution

No emphasis on difference or ranking.

Order of horizontal categories has priority

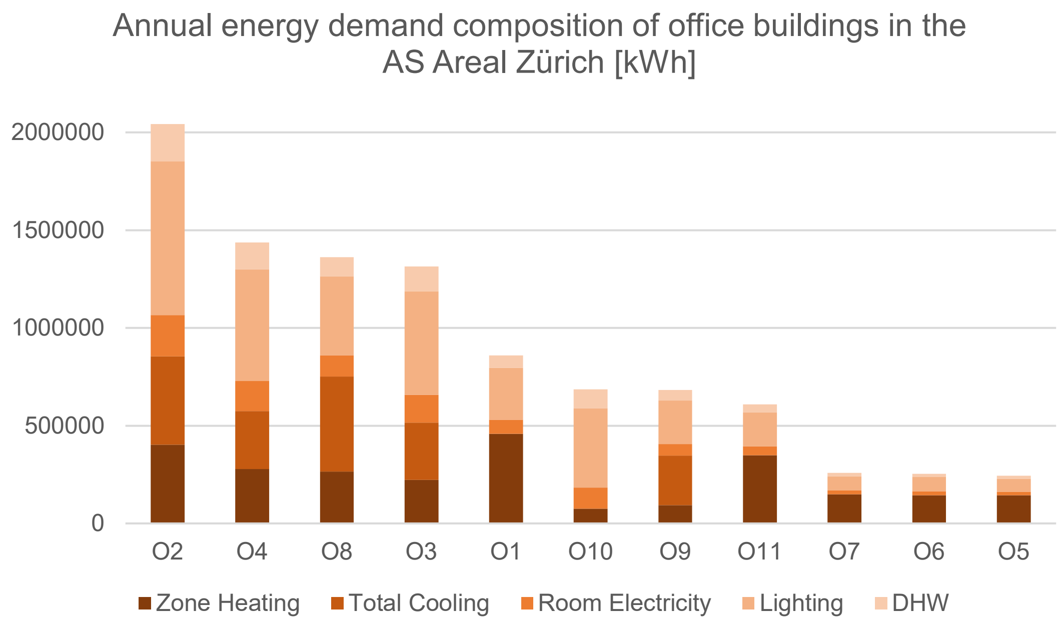
Representation types

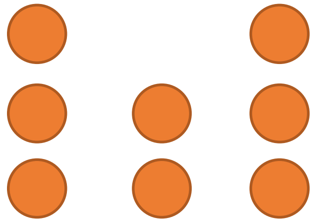




Relationship
Between two or more parameters of a series of items

Representation types





Composition

Shows subsets of data as part of the "whole" for a series of items

Select the right visualization – iterative process

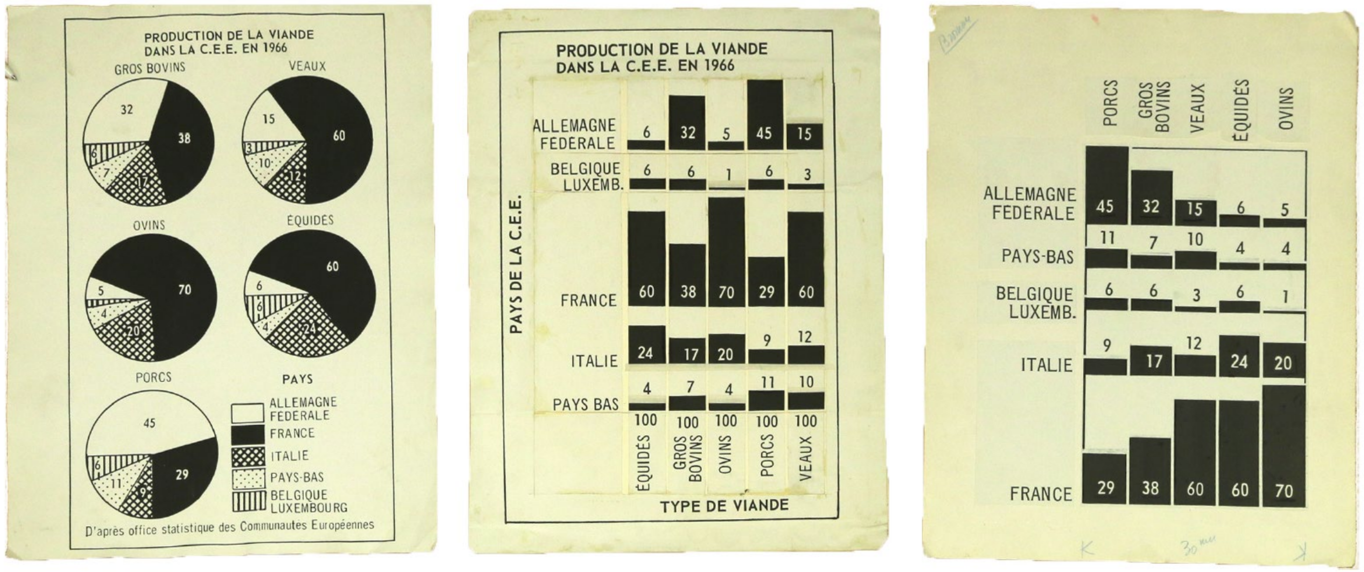
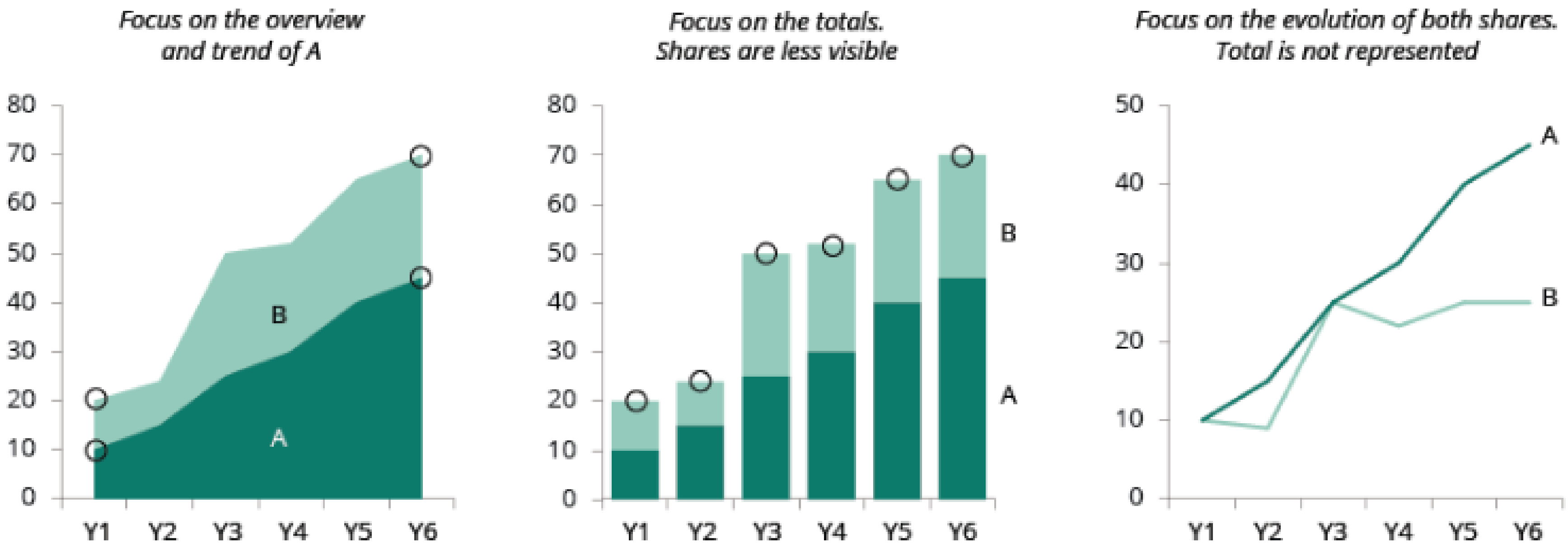


Figure 2. *Left:* Pie charts showing the contribution of different countries in the production of different types of meat, which Bertin qualified as "useless". *Middle*: With a matrix visualization, high-level patterns become immediately visible. *Right*: Since countries and meats do not have a natural order, many other matrices can be produced, including this one, which is more effective. Thus, being able to try different orderings was essential. Drafts for the book *La Graphique* (Bertin, 1977) Courtesy of EHESS/AN ref. 20010291/36.

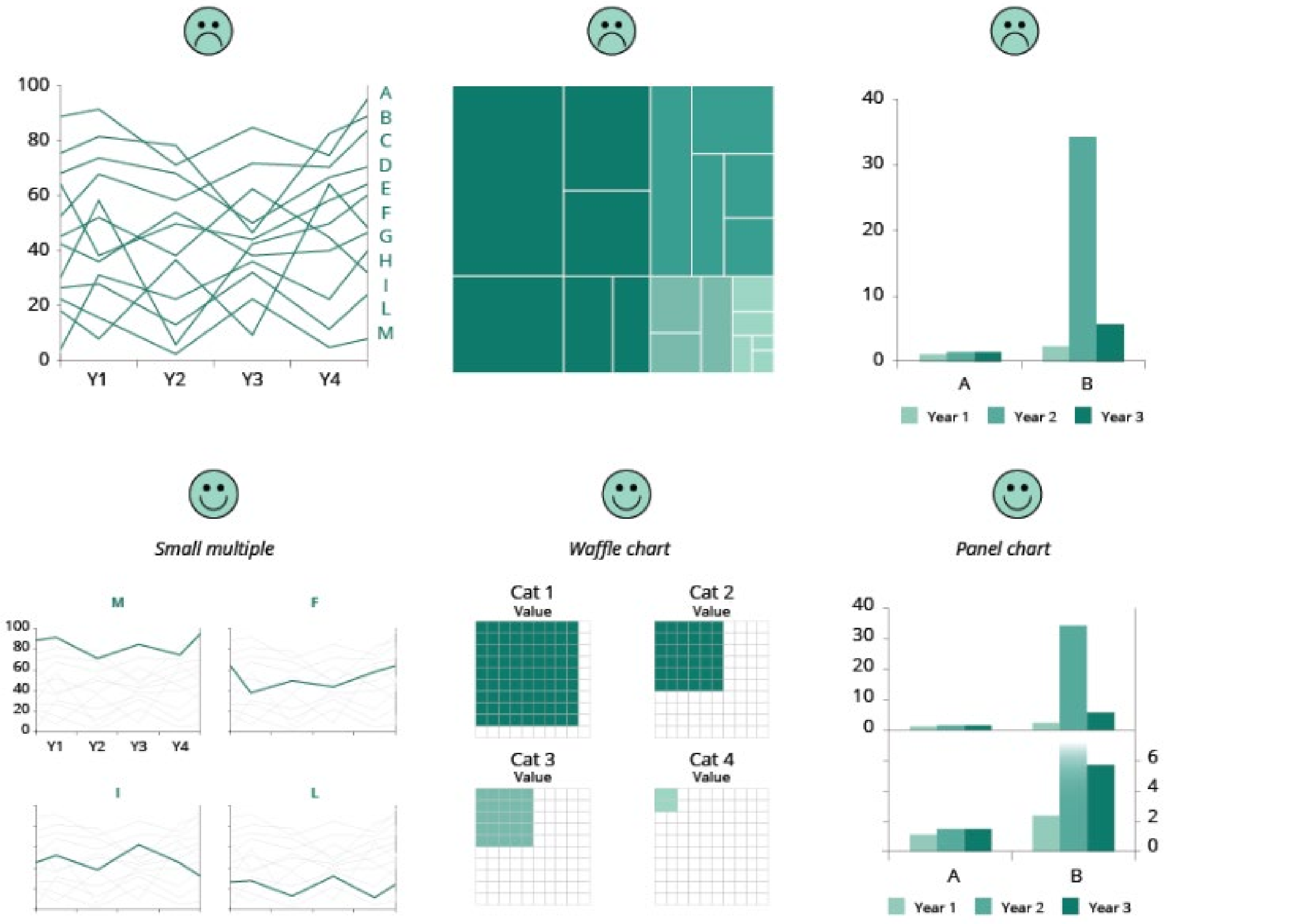
Source: Charles Perin,"Jacques Bertin's Legacy in Information Visualization and the Reorderable Matrix"

Select the right visualization



Source: [European Environment Agency-Chart dos and don’ts]

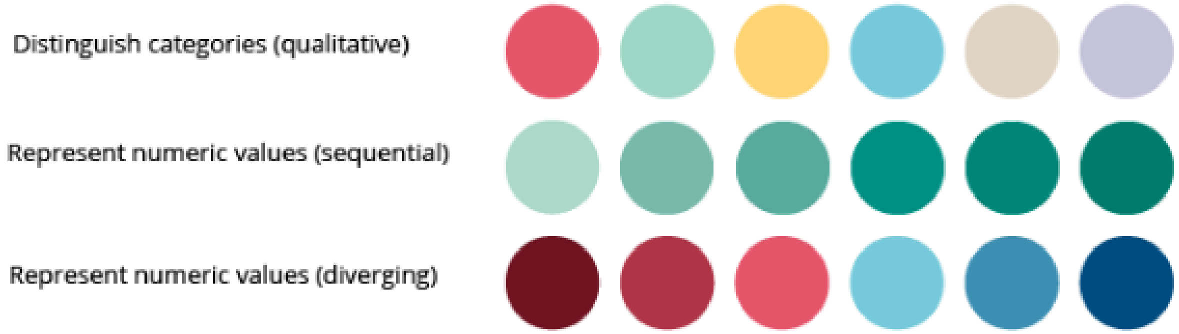
Select the right visualization



Source: [European Environment Agency-Chart dos and don’ts]()

Chart design

- Keep the design simple and elegant
- Limit the number of colours you use (use tones)
- Do not use the same colour palette for different categories
- Keep the colour scheme coherent in all your charts
- Consider a colour-blind colour scheme
- Use a legend only if necessary

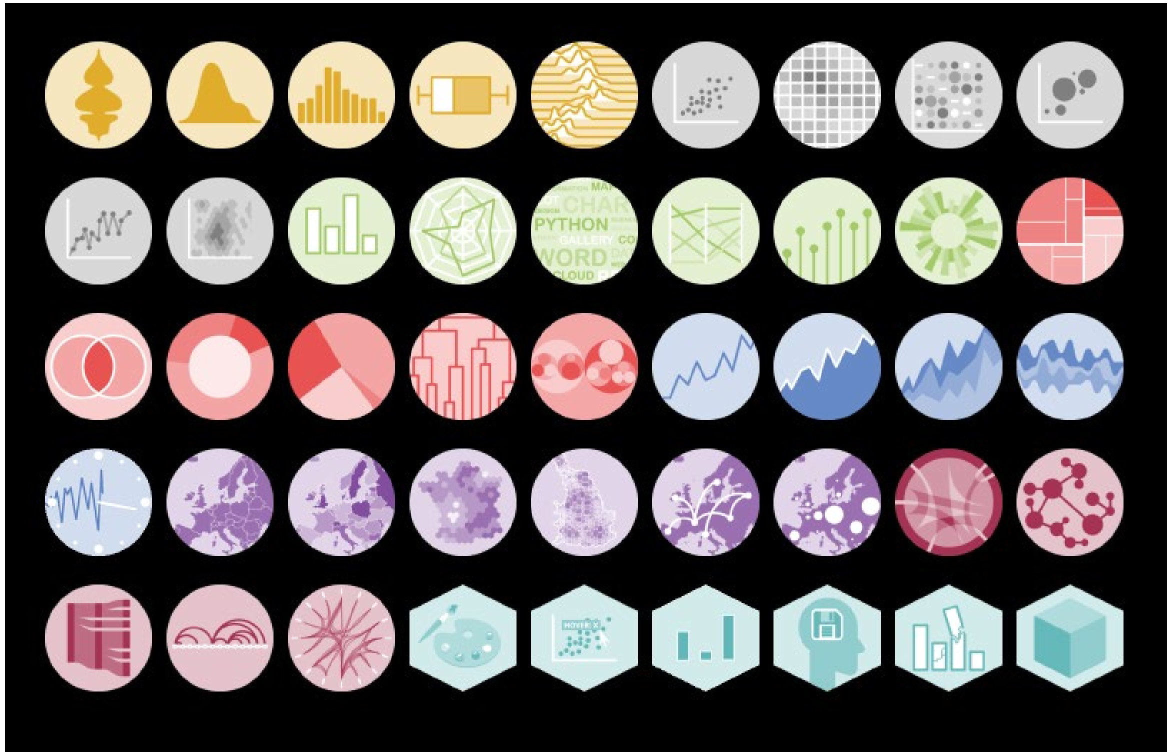


Visualization Resources

For inspiration

https://datavizcatalogue.com/index.html

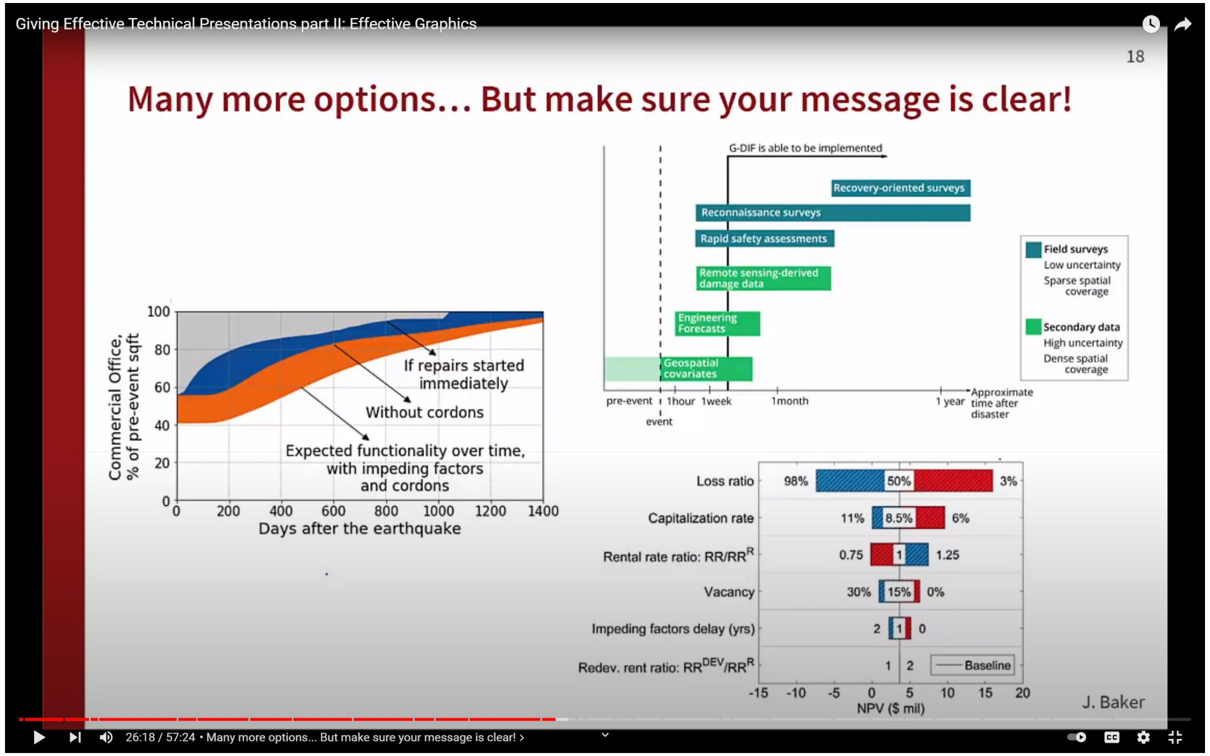
For implementation



https://www.python-graph-gallery.com/

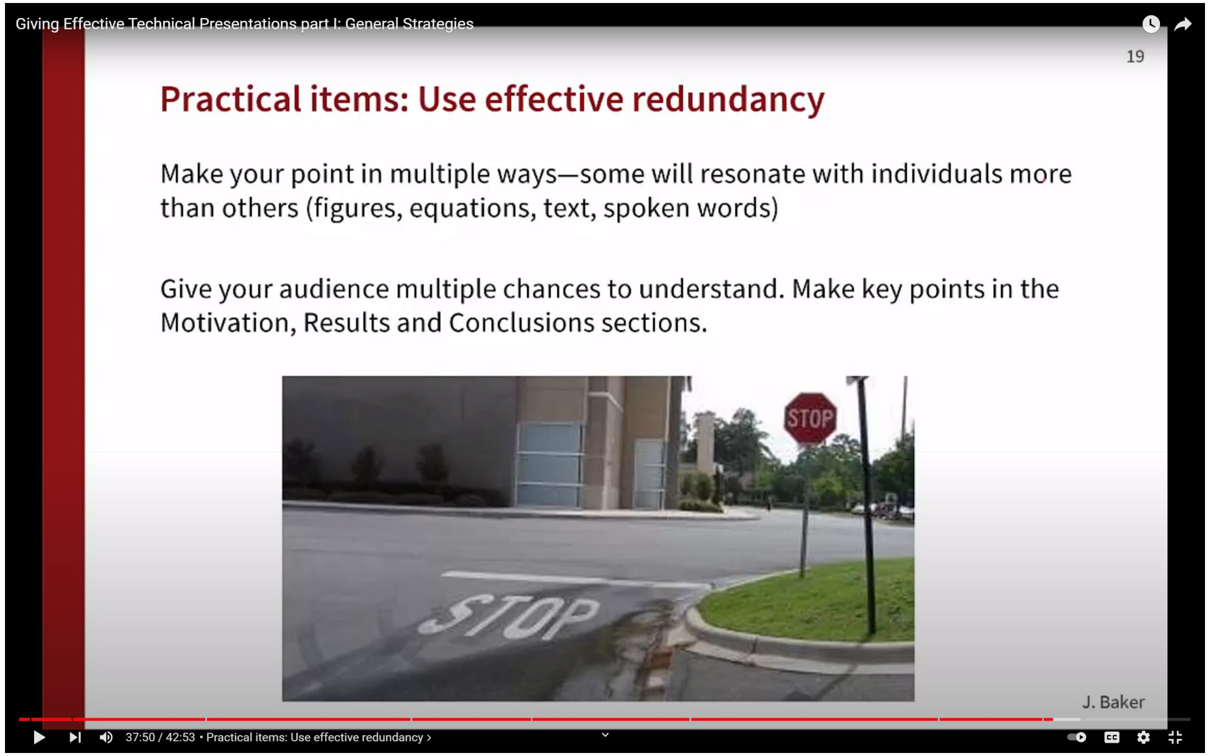
Further Resources

Effective Graphics



https://youtu.be/Z0BCD6f9b4I

Technical Presentations



https://youtu.be/wexYJHkDXiA