# Data Visualization (CSCI 490/680)

## Sets

Dr. Maoyuan Sun
(slides prepared by Dr. Koop)

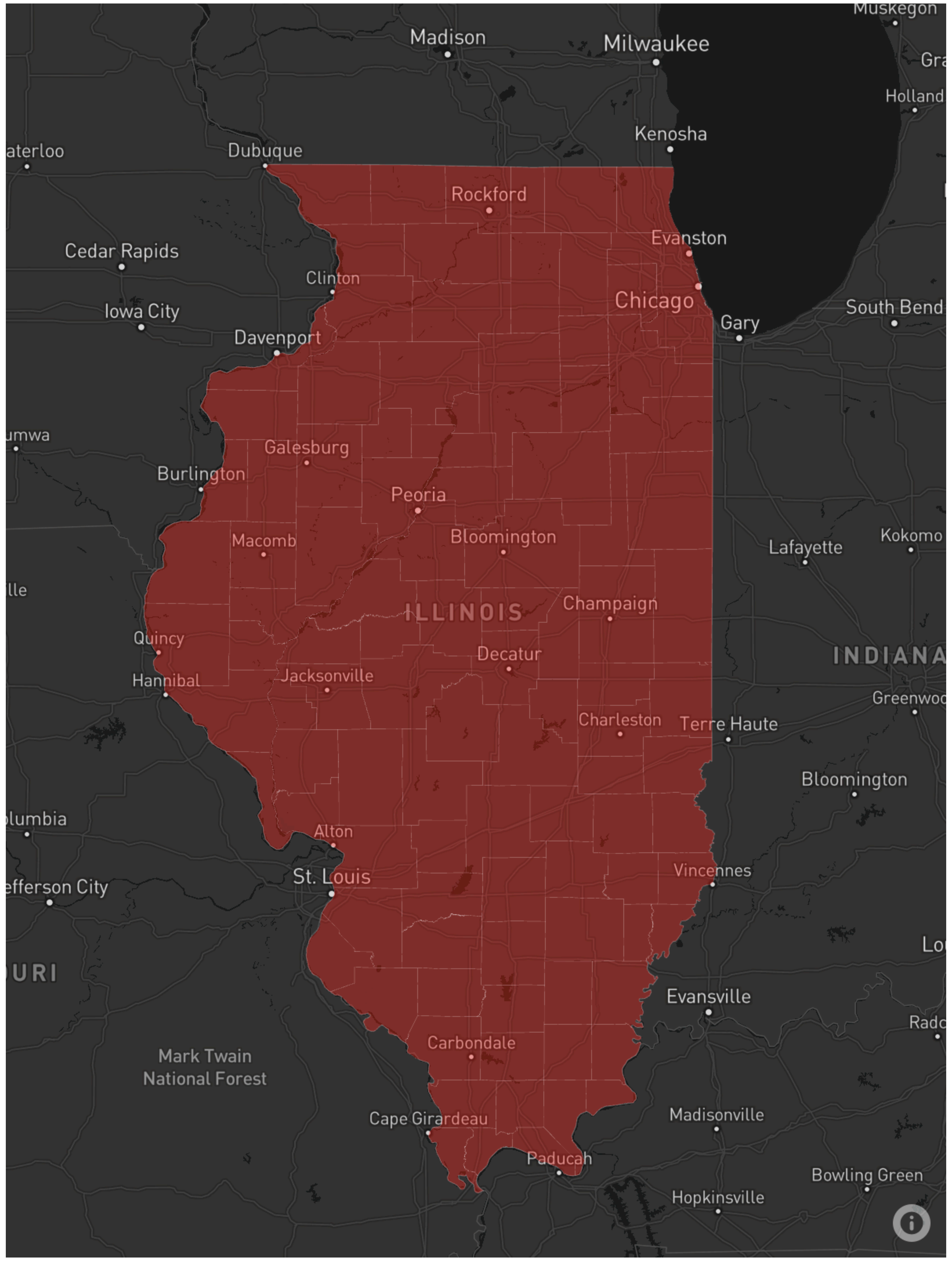
# Announcements

# Project Design

- Start working on turning your visualization ideas into designs
- Sketch
- Options:
  - Try vastly different options
  - Refine an initial idea

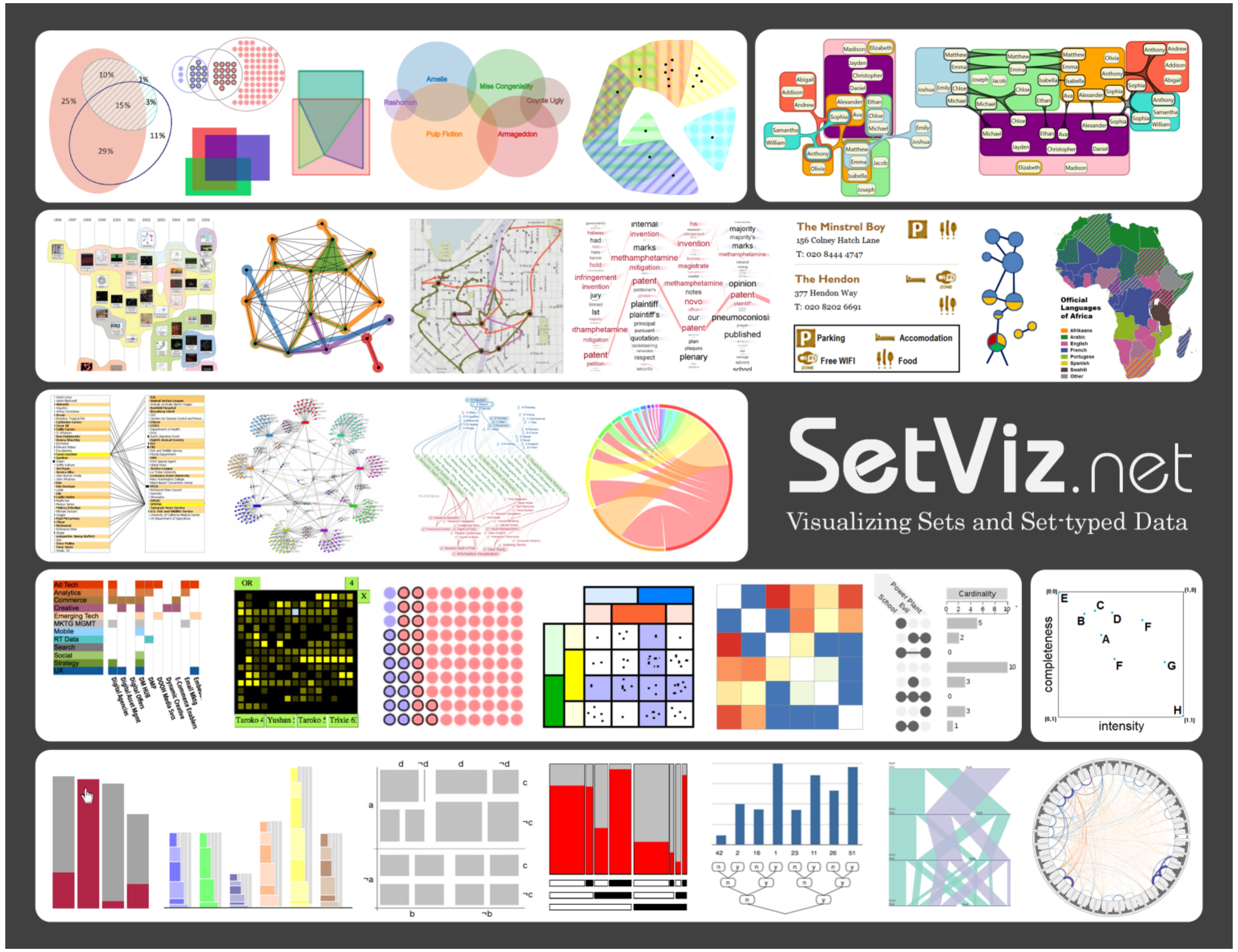
# Assignment 4

- Create Choropleth Maps
  - Deal with projections and GeoJSON Data
  - Select appropriate colormaps
- [CS 680 Only] Part 3 is using other libraries, you only need to do **one** option
- Example image at the right is **not** a solution to Part 3, needs proper colormapping!



# Set and Cluster Visualization

- Set and cluster visualization not covered in depth in the textbook
- Nice summary of set visualization in the following paper:
  - [Visualizing Sets and Set-typed Data](), B. Alsallakh et al., 2014
  - Also: [http://www.setviz.net]()

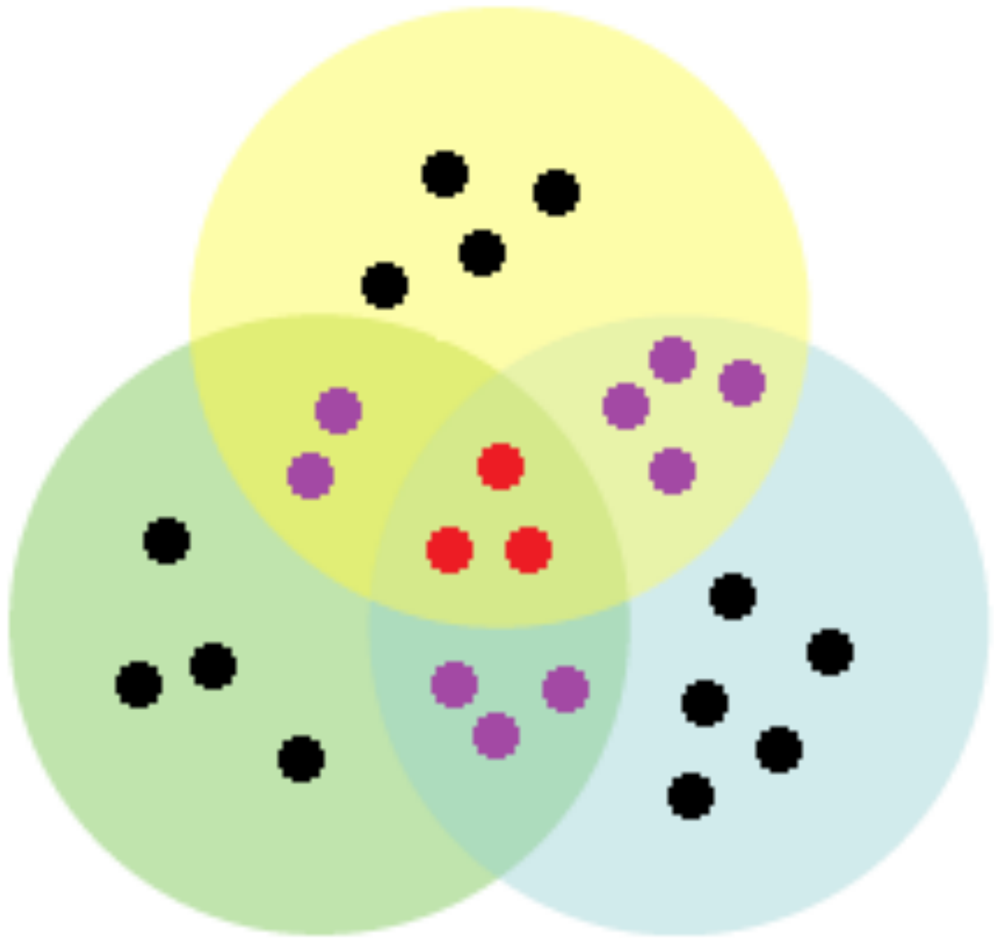


# Sets

- A set is a collection of **unique** objects
  - Generally **unordered**
  - Example: `s = {"apple", "pear", "orange"})`
- What questions can we ask about sets?
  - Containment: Is some item `x` in `s`?
  - Intersection: what items are in both `s` and `t`?
  - Union: what items are in either `s` or `t`?
  - Difference: what items are in `s` but not `t`?
  - …

# Set-typed Data - Characteristics

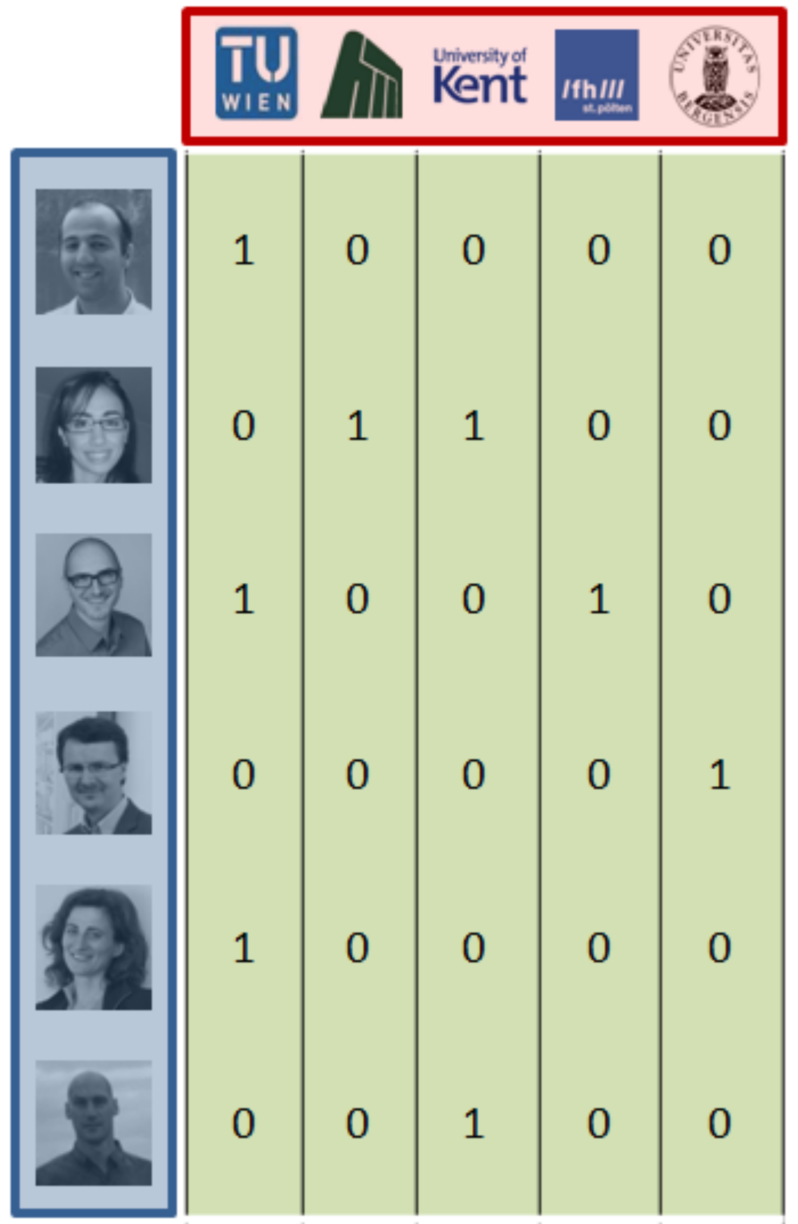
- **Set Algebra**
  - Set operations, Cartesian product, power set, ...
- **Set similarities**
  - Similarity measures (Jaccard, Tversky, etc.)
- **Element degree**
  - exclusive set membership
- **Dimensionality**
  - 2^n possible combinations
  - 2^(2^n) possible queries



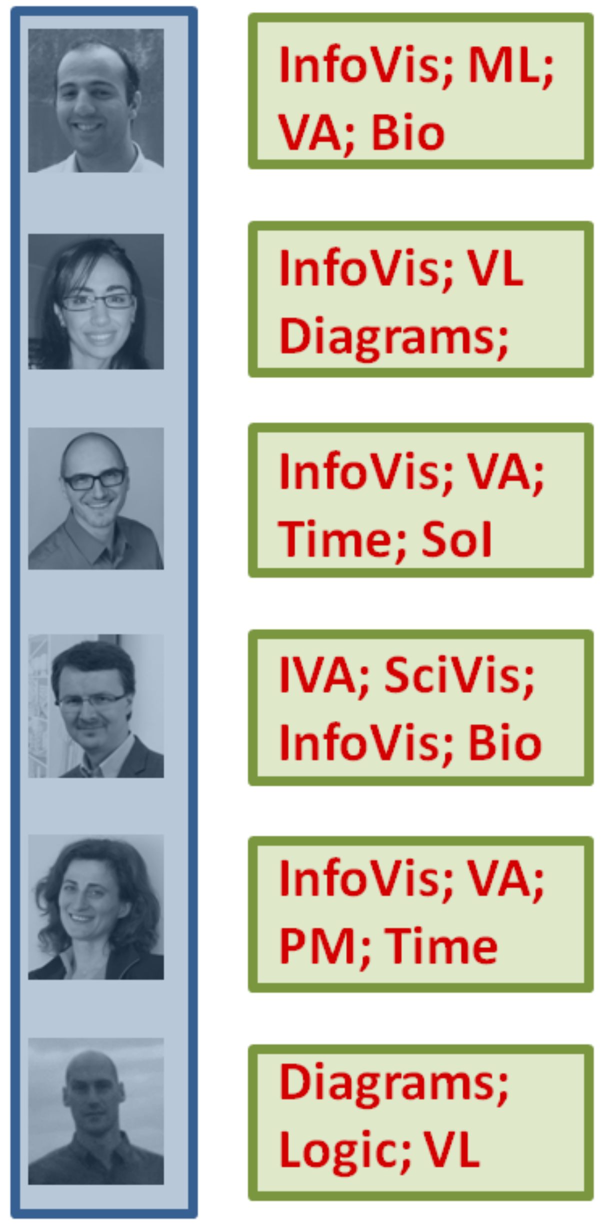
[B. Alsallakh et al., 2014]

# Set-typed Data - Representations

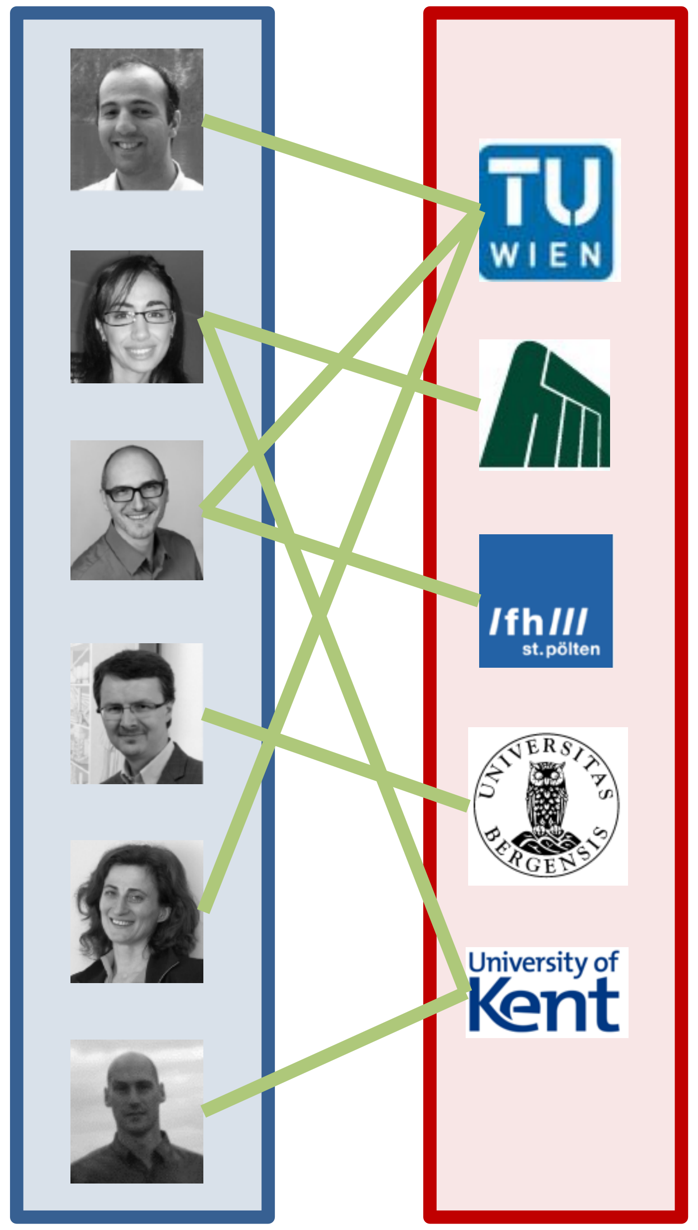
Boolean Attributes




Multi-valued Attribute



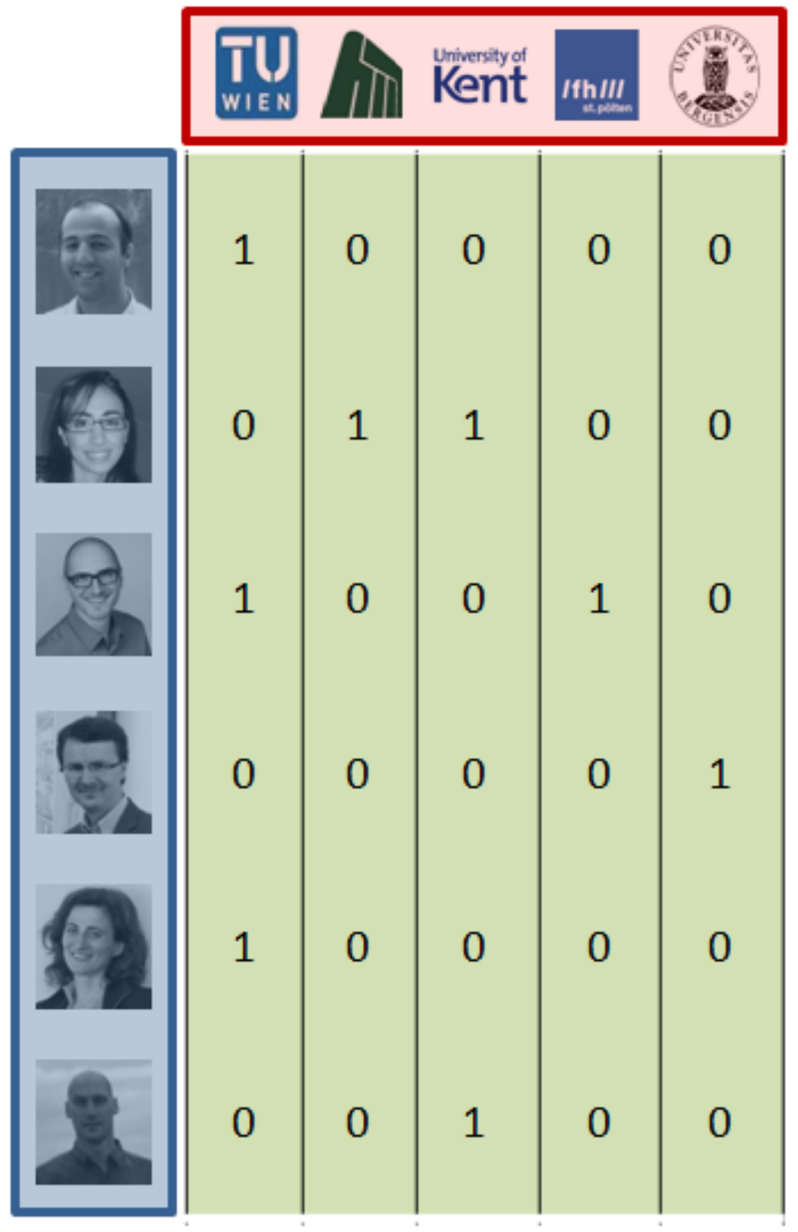

Element-Set Tuples



[B. Alsallakh et al., 2014]

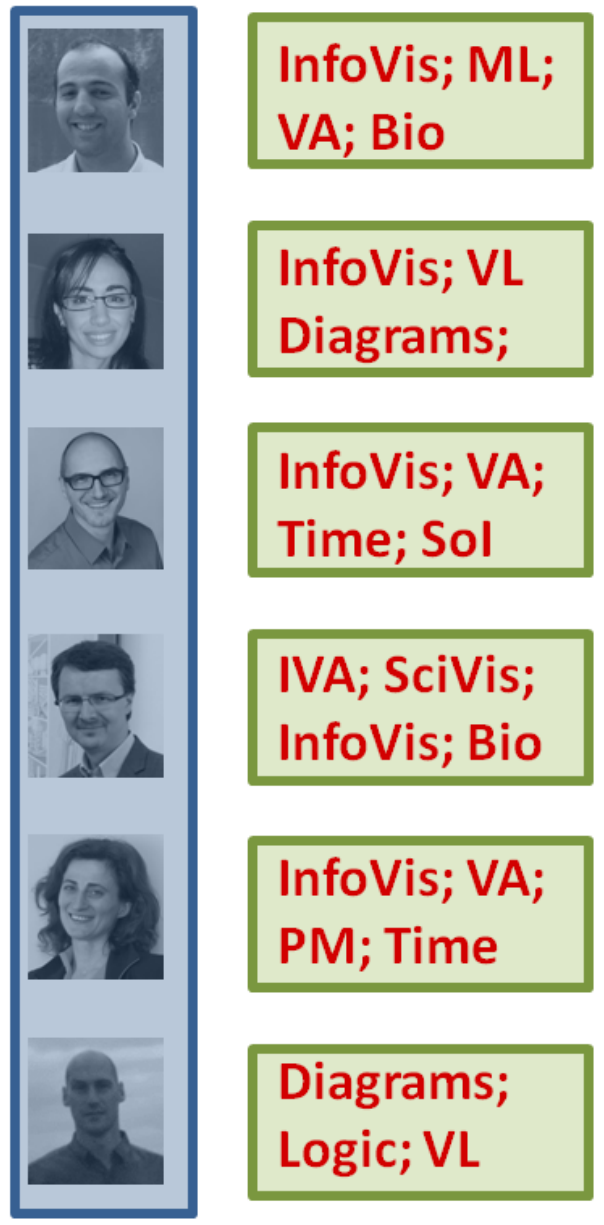
# Set-typed Data - Representations

Boolean Attributes



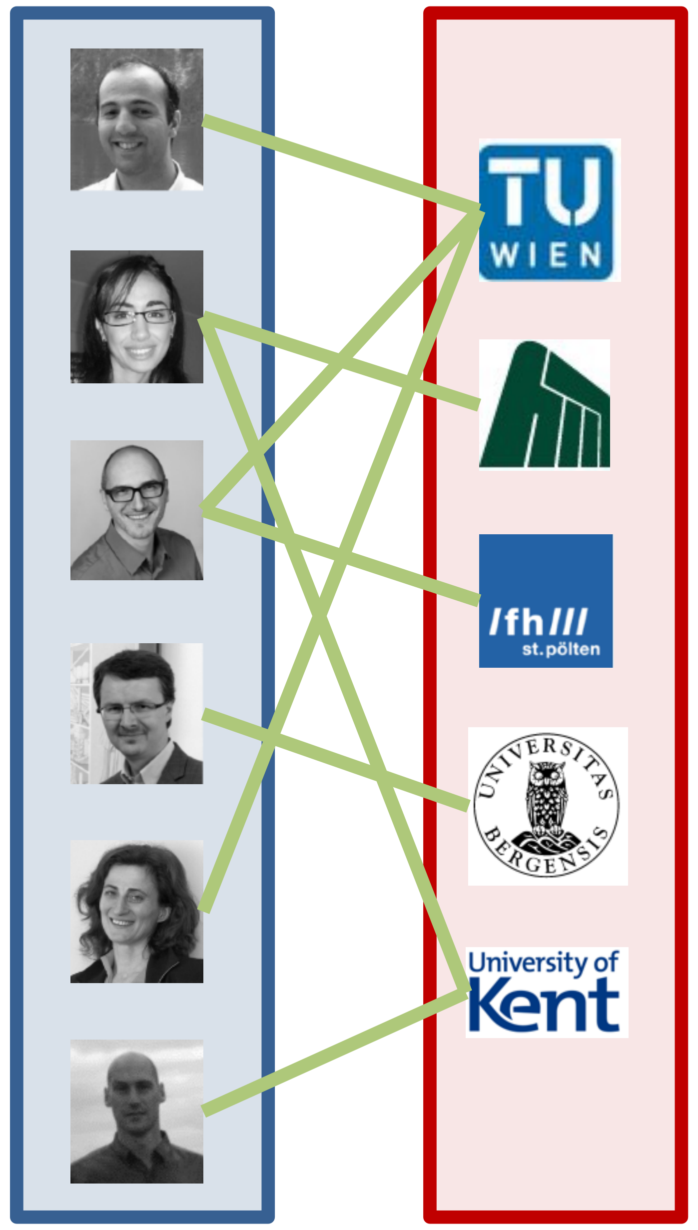

Adjacency Matrix

Multi-valued Attribute




Adjacency List

Element-Set Tuples

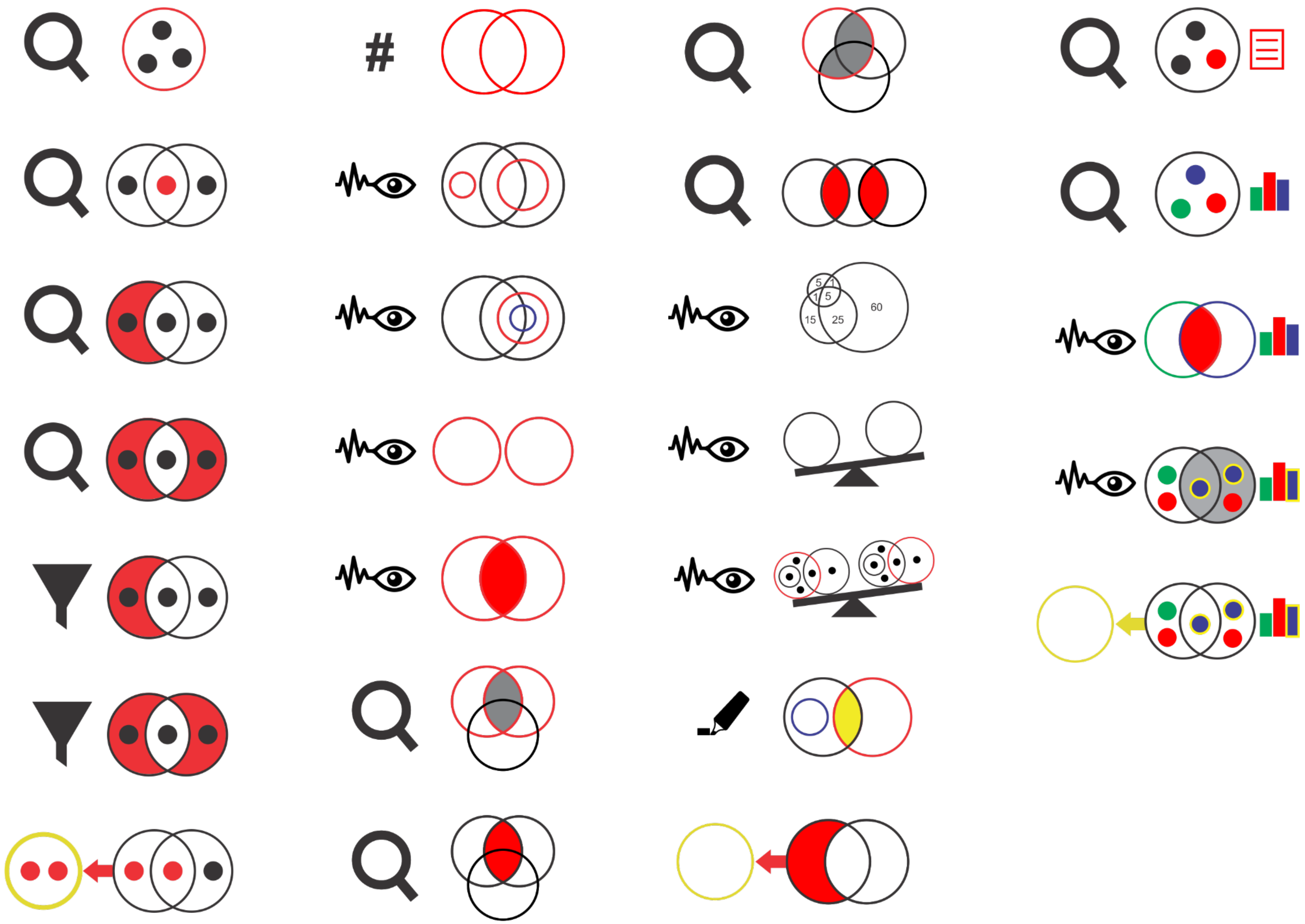


Edge List

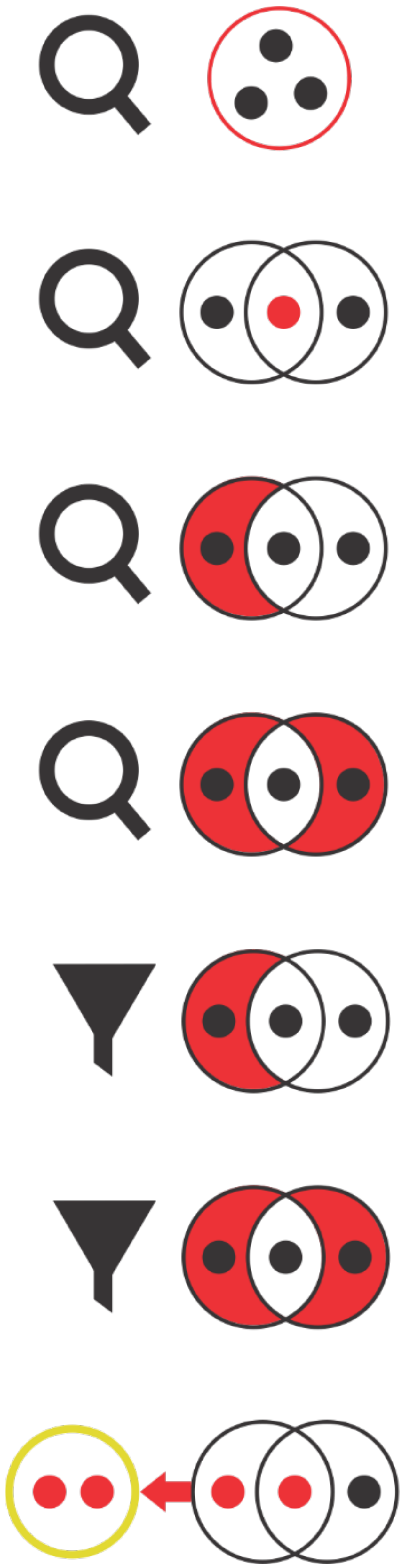
[B. Alsallakh et al., 2014]

# What are tasks with set data?

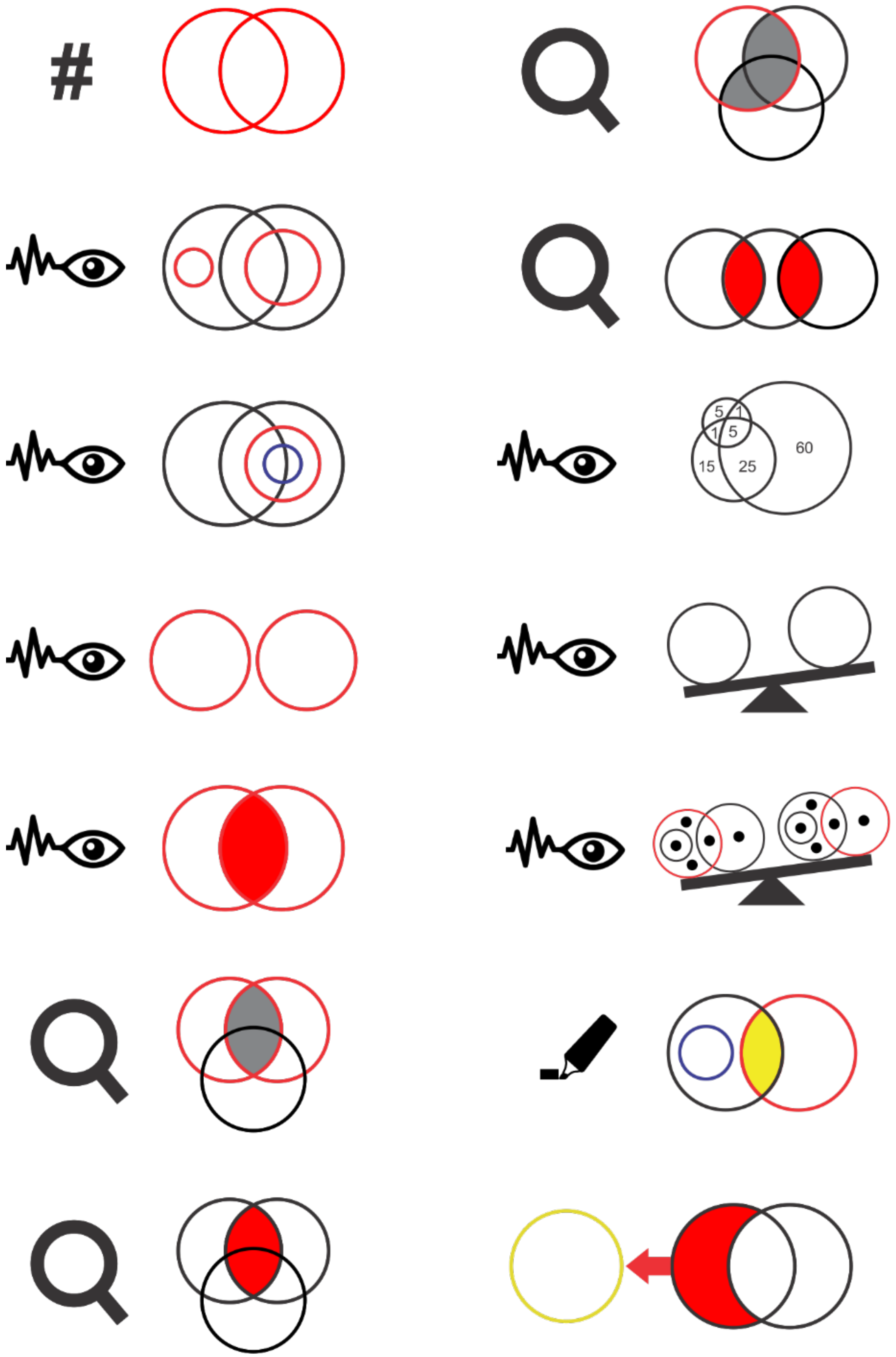
[All of the following Slides from B. Alsallakh et al., 2014]


#
5
1
1
5
15
25
60

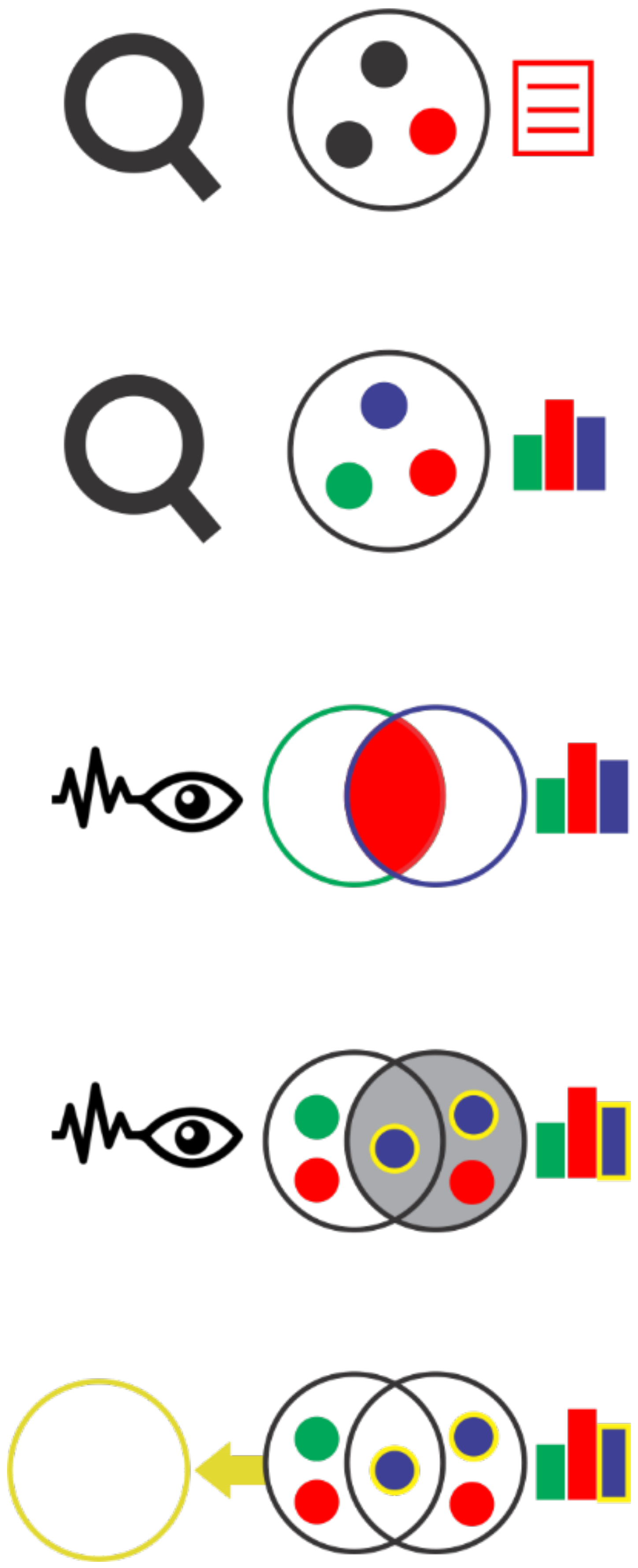
## Elements



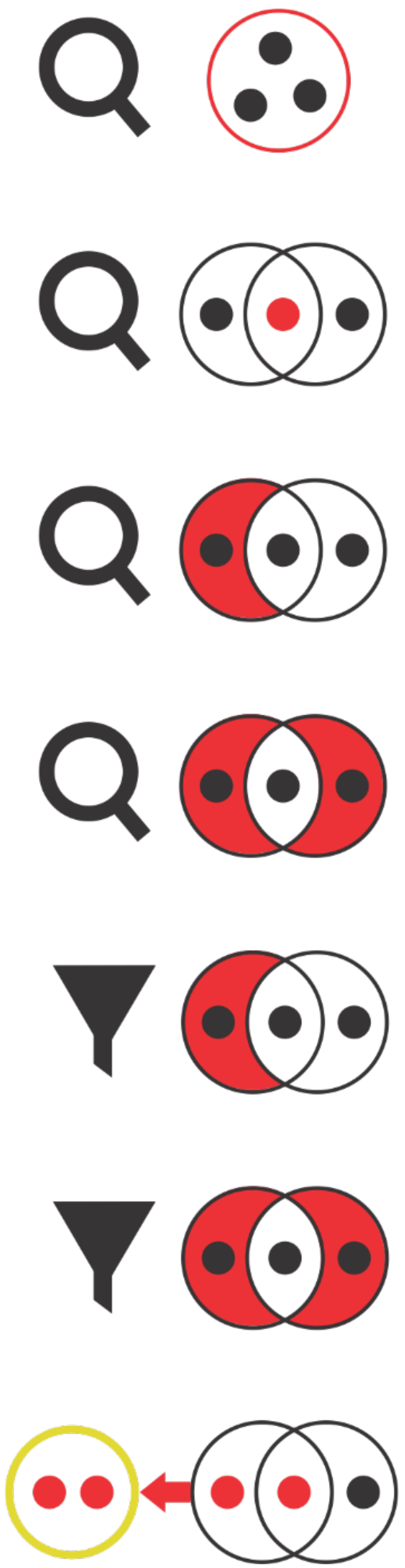
## Sets and Set Relations



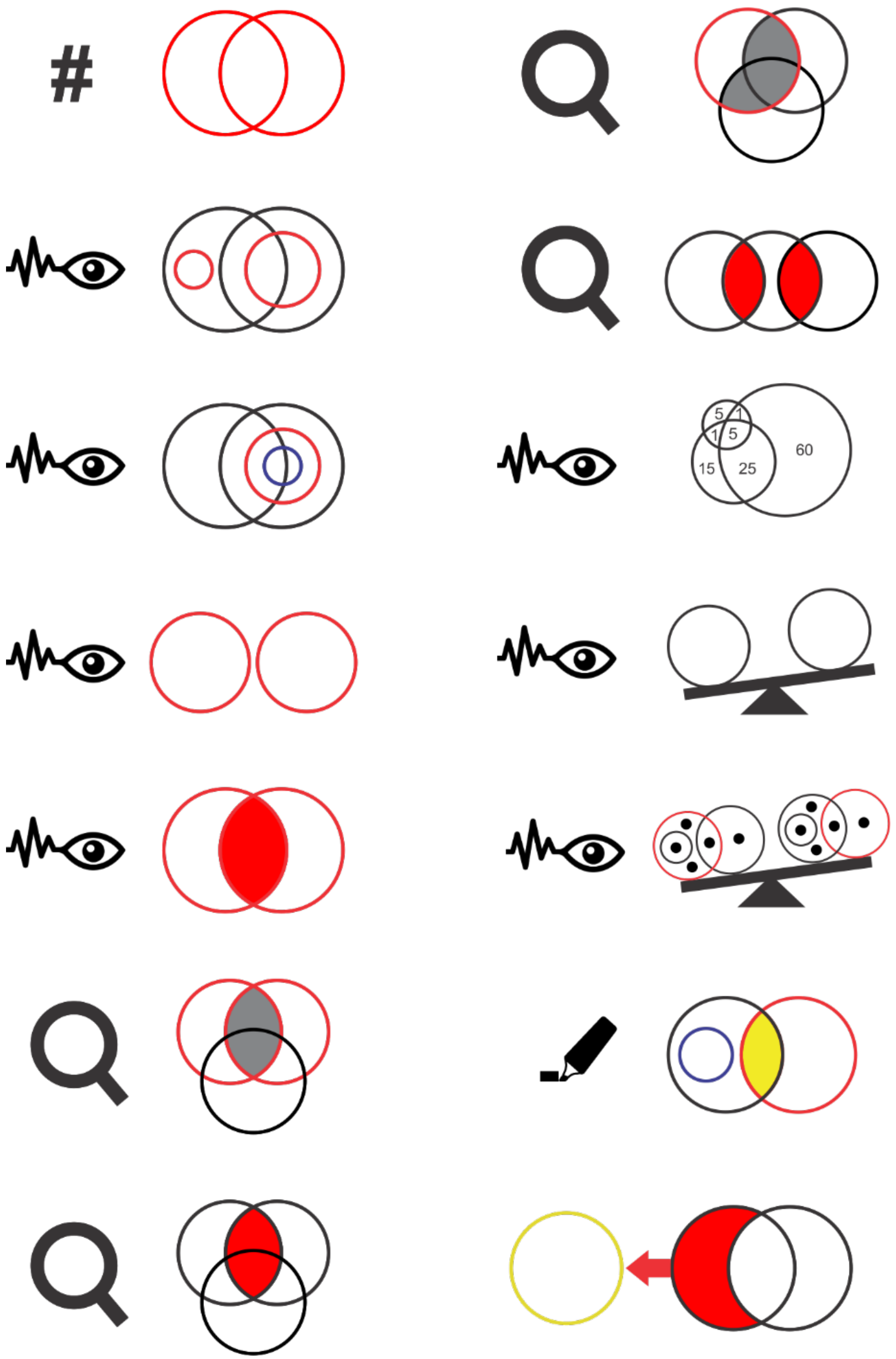

## Element Attributes



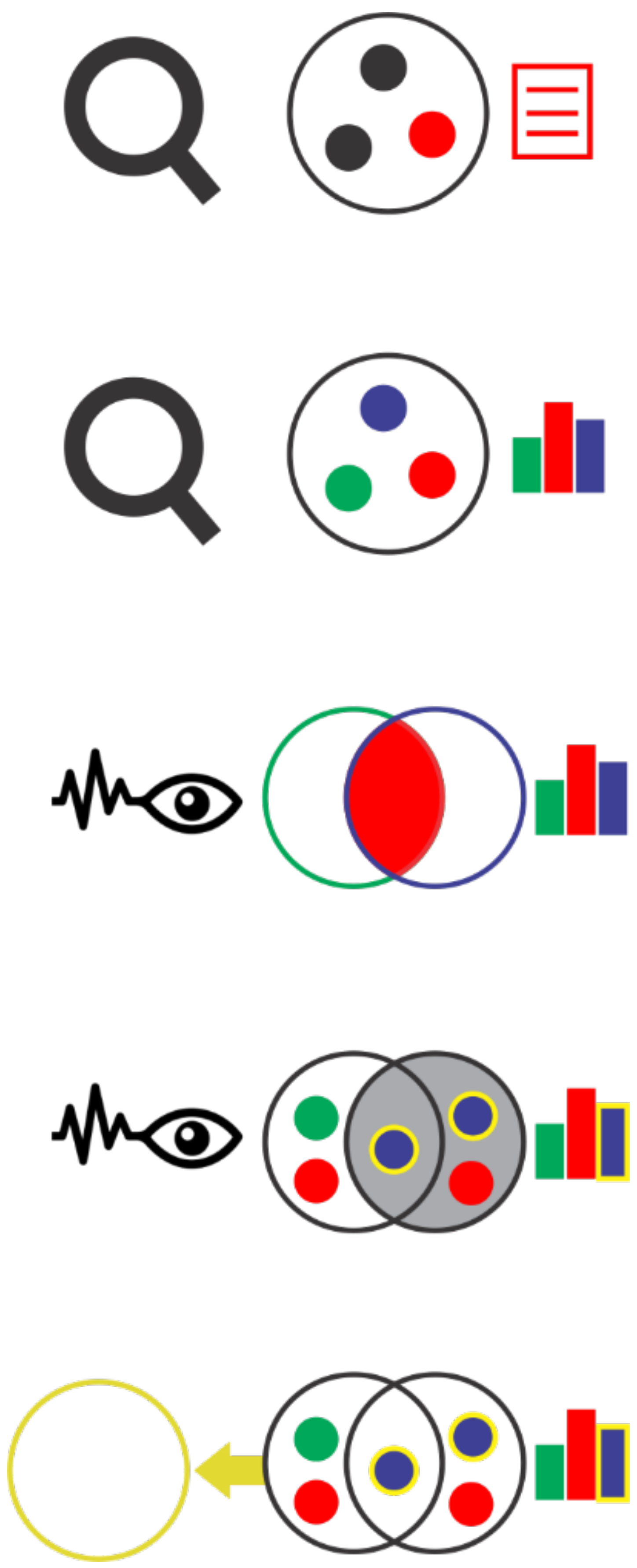
## Elements



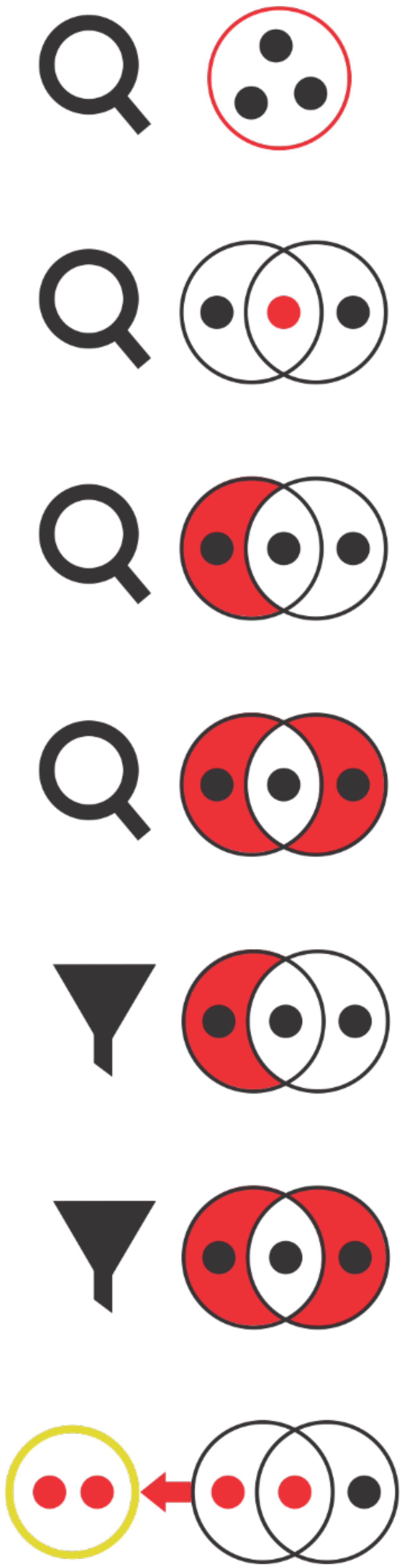
## Sets and Set Relations



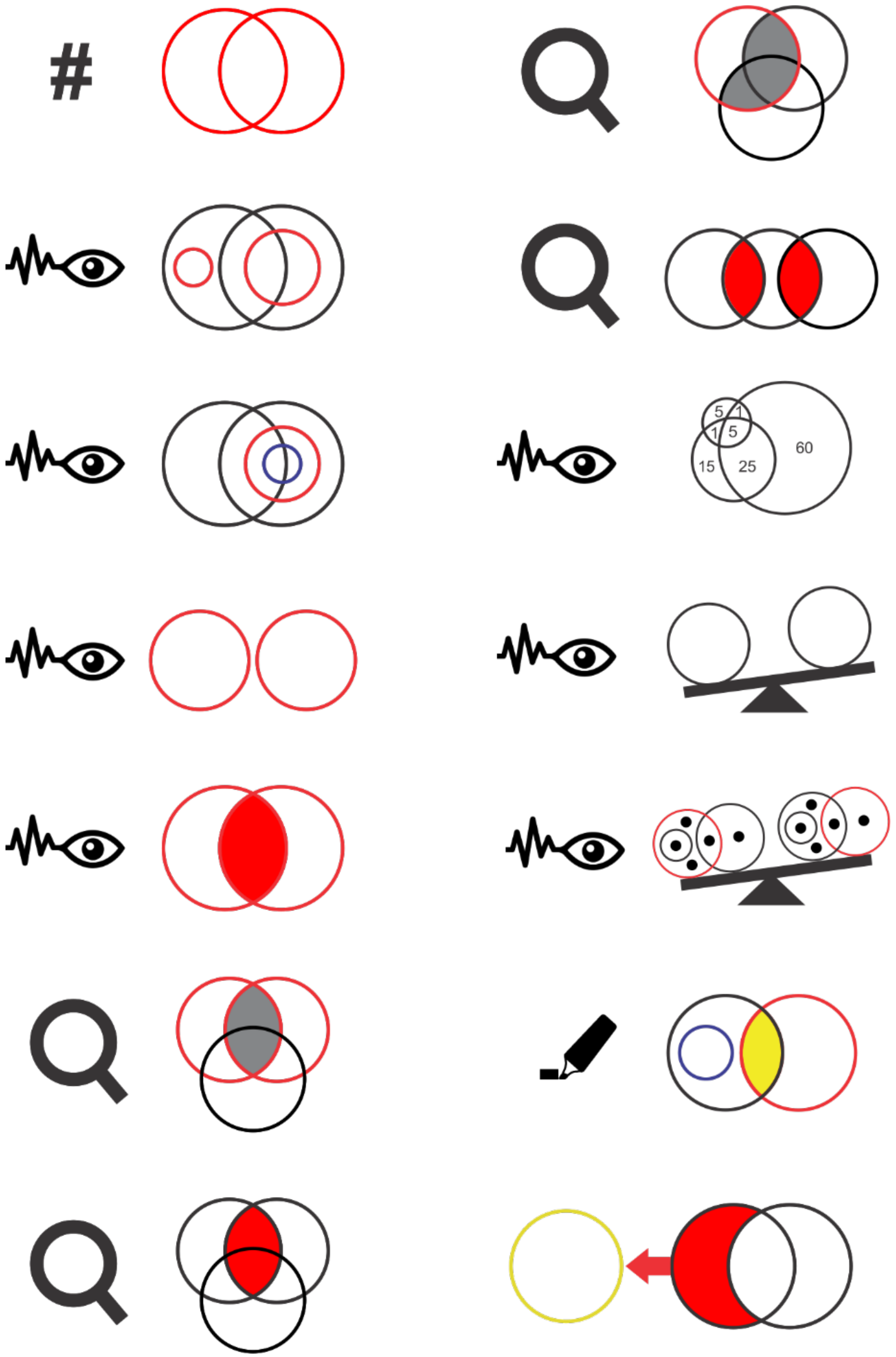
## Element Attributes



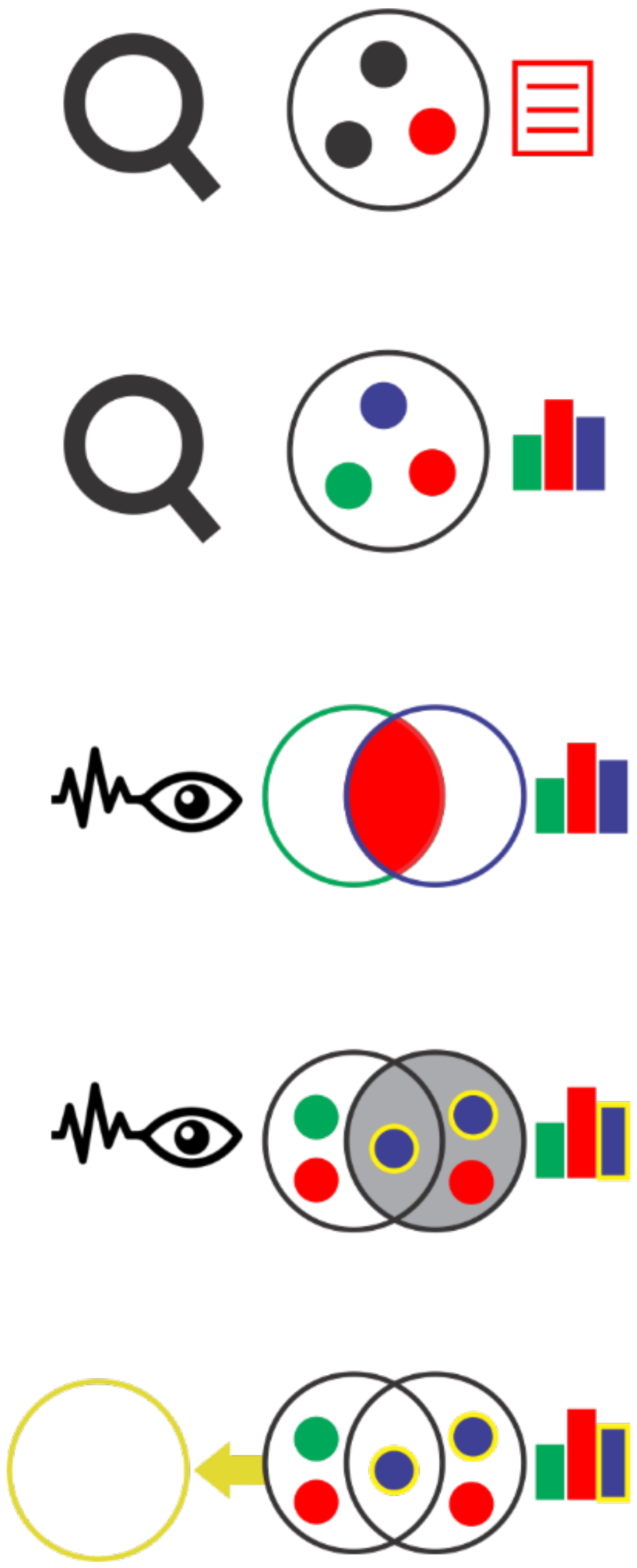
## Elements



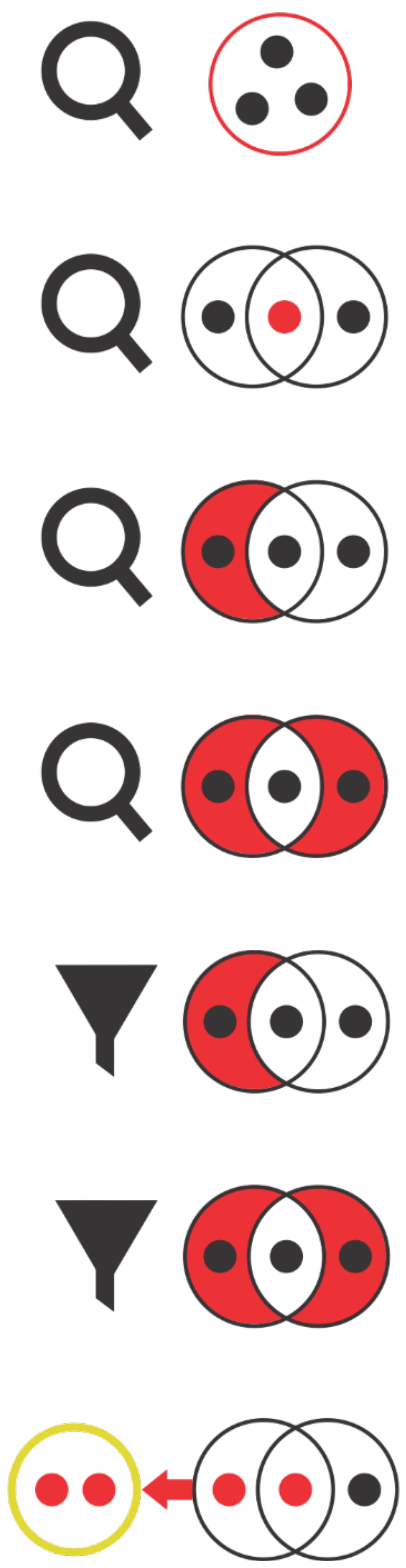
## Sets and Set Relations



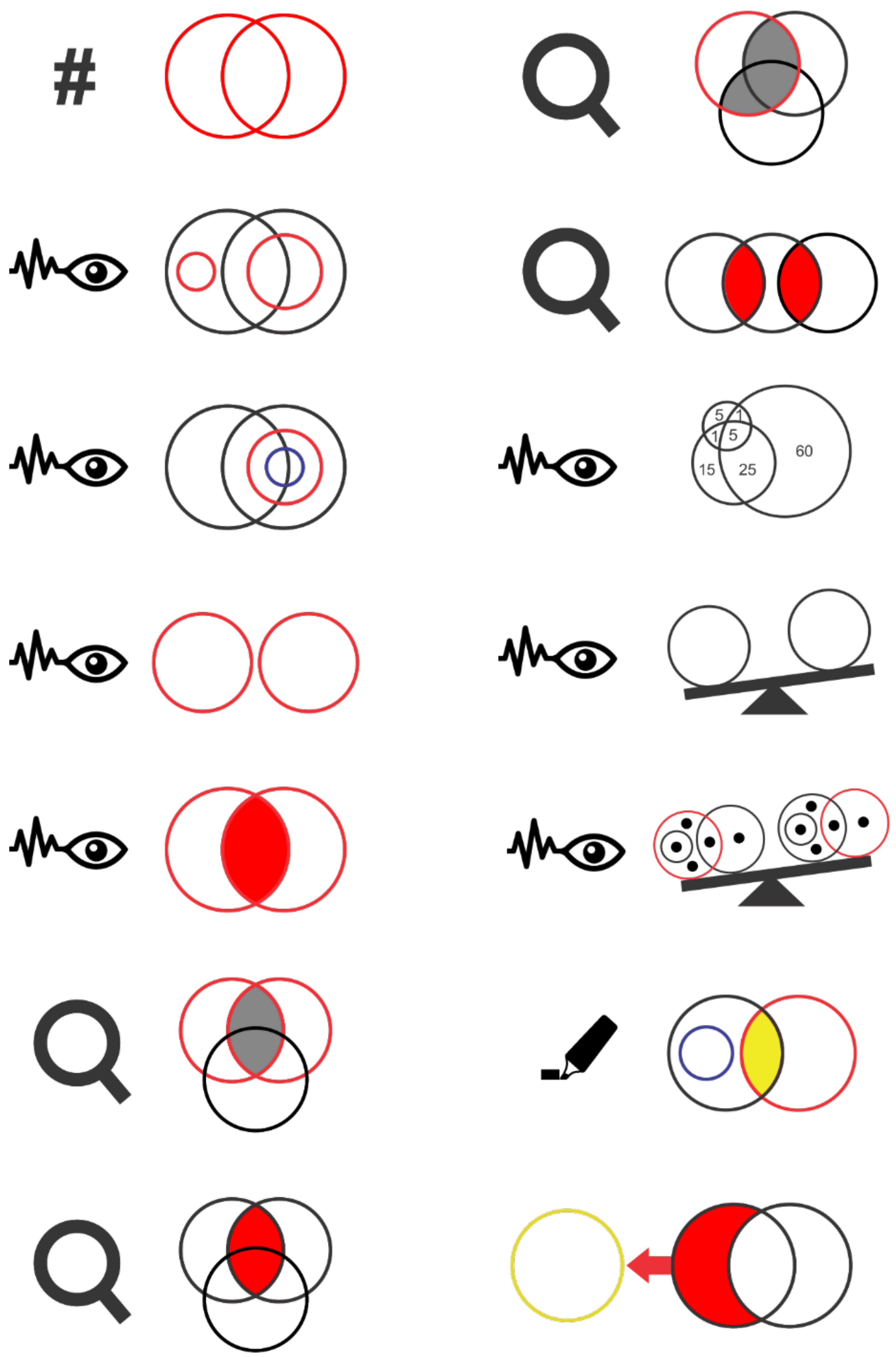

## Element Attributes



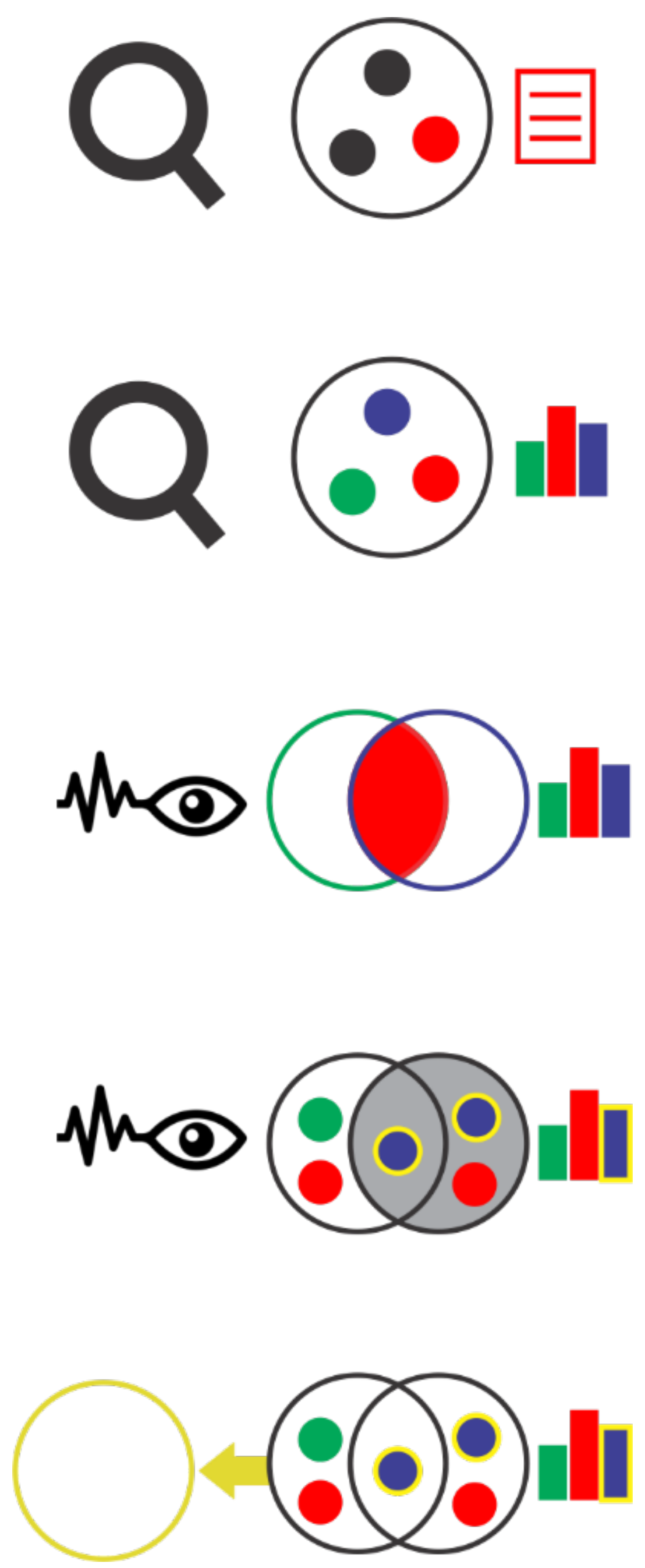
## Elements



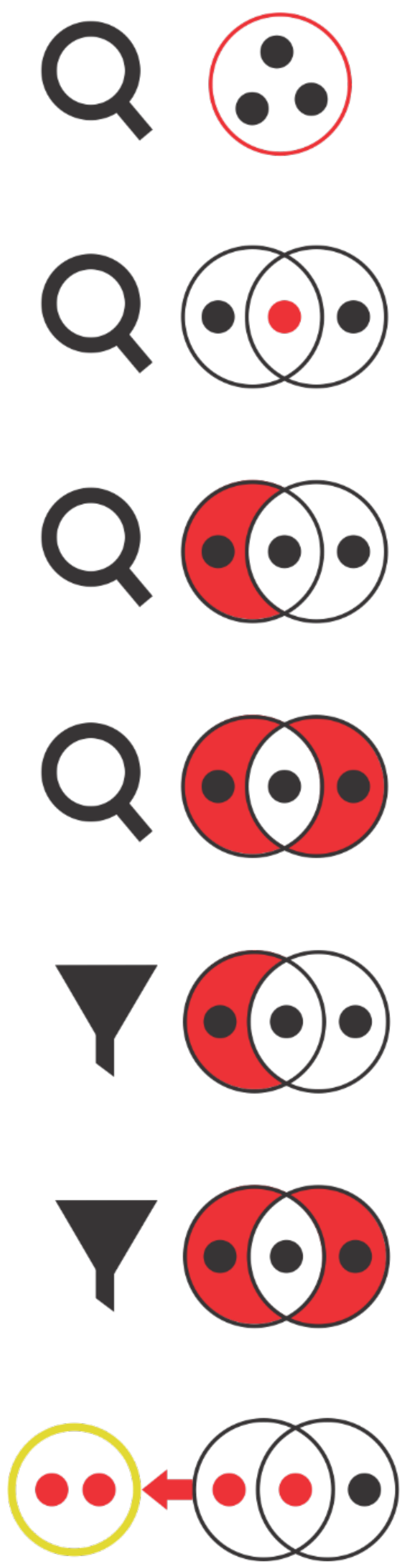
## Sets and Set Relations



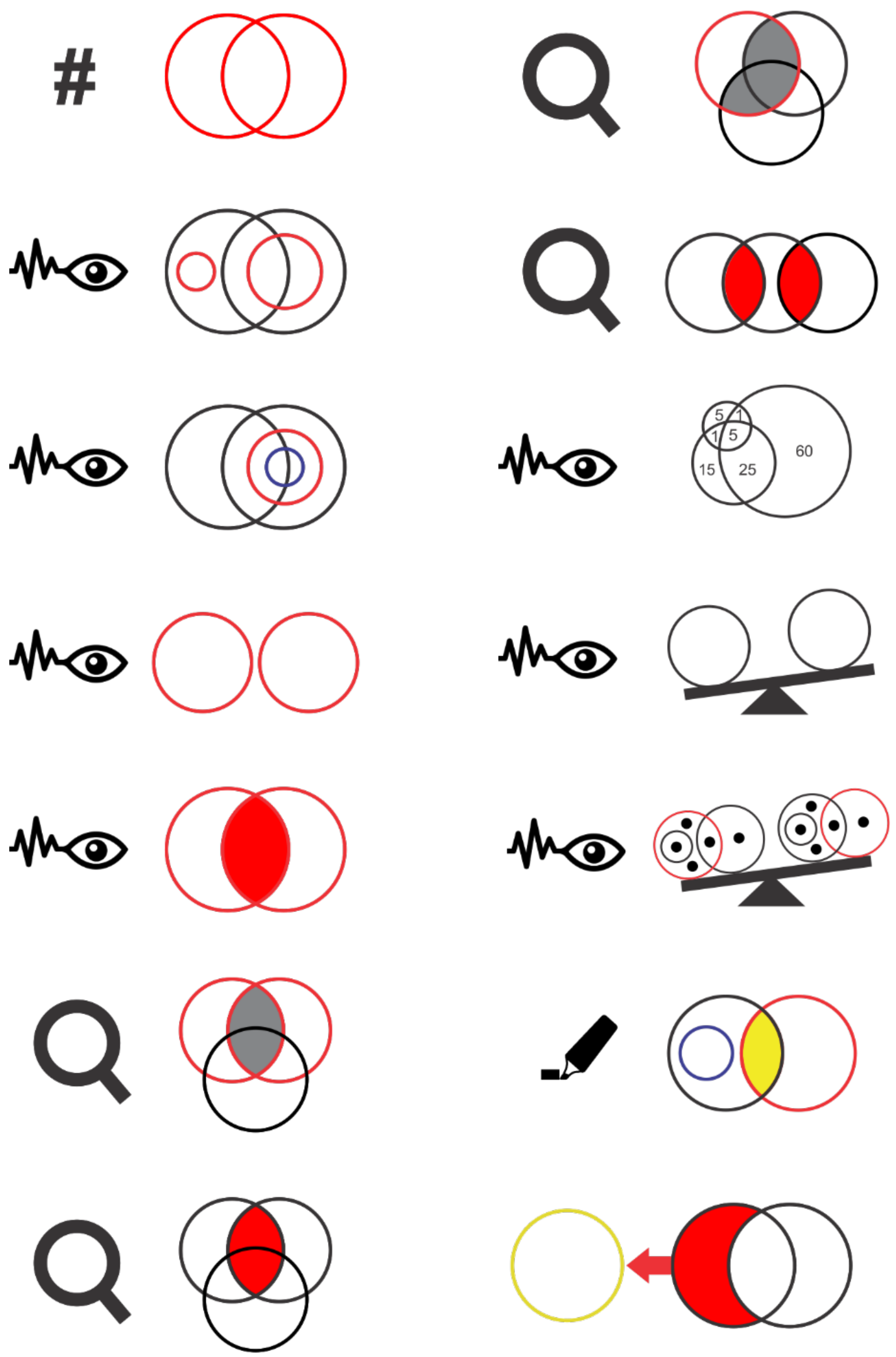
## Element Attributes



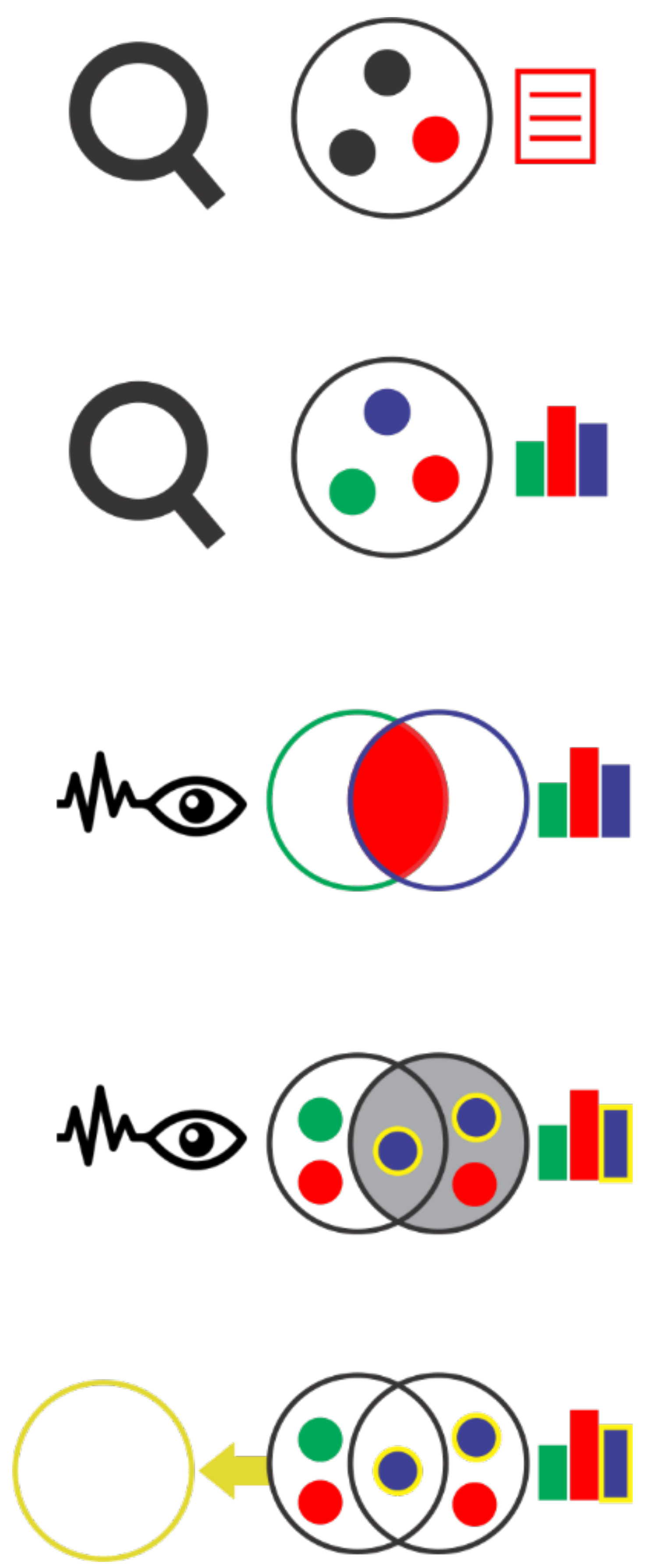
## Elements



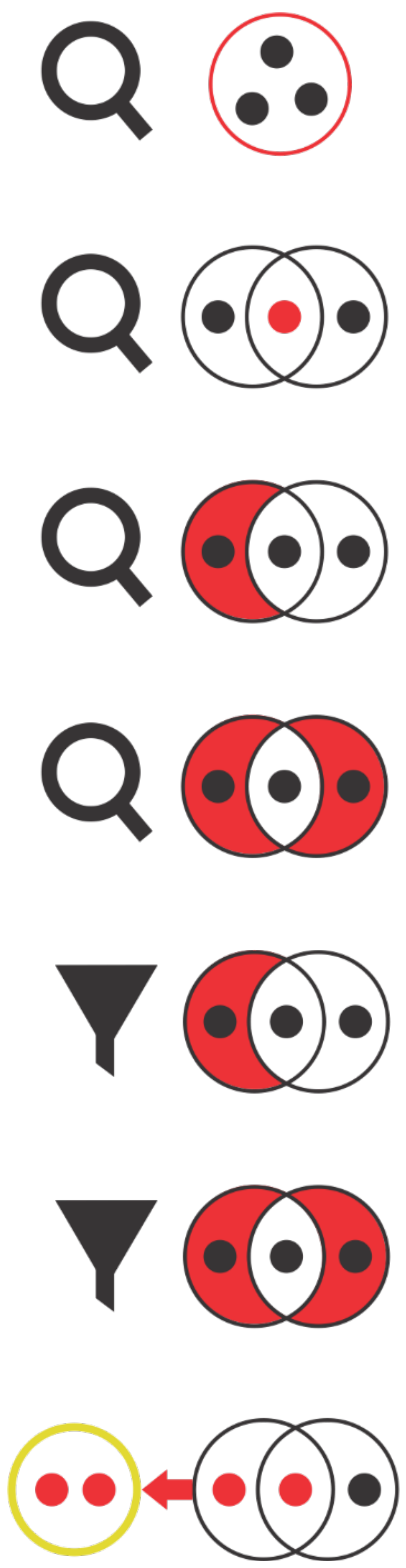
## Sets and Set Relations



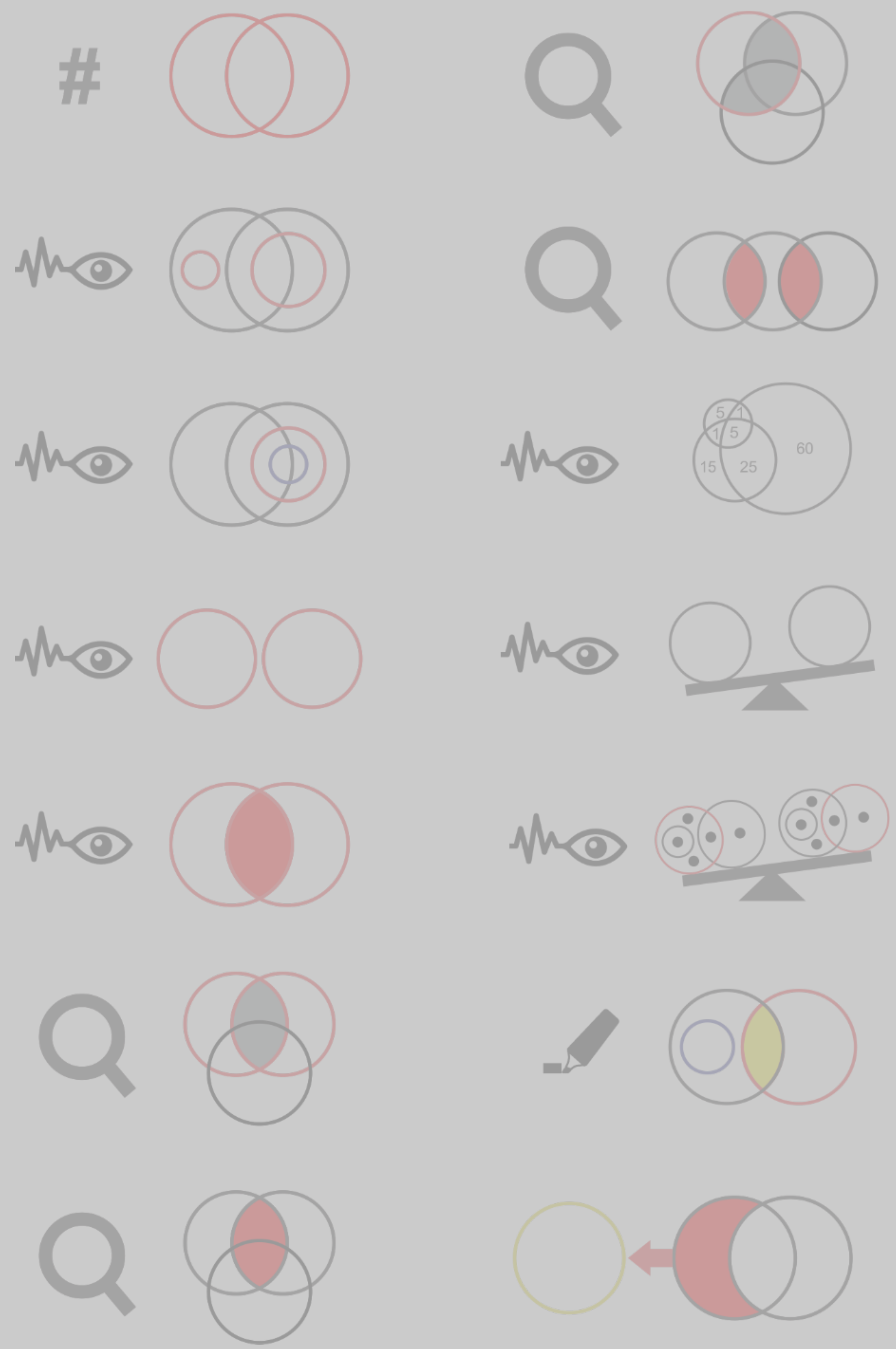

## Element Attributes



## Elements

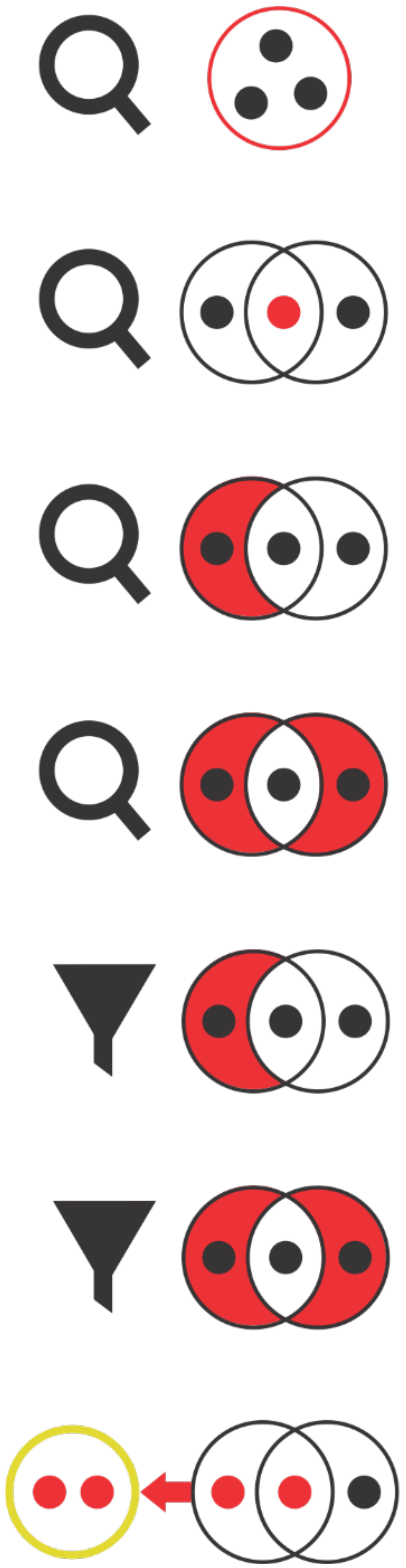


## Sets and Set Relations



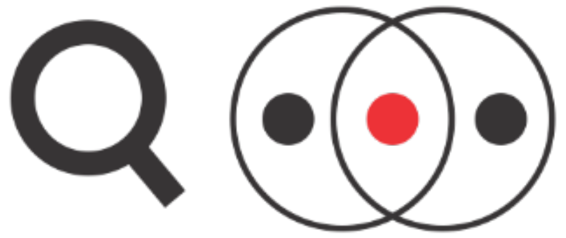
## Element Attributes

## Elements



## Elements


Find elements belonging to a specific set

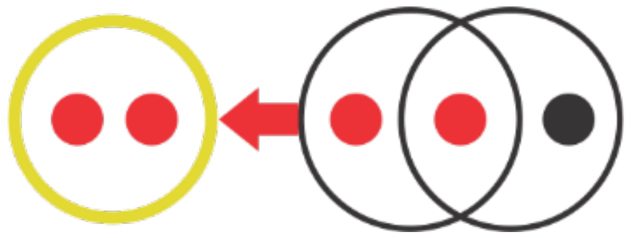

Find sets containing a specific element


Find elements based on their set memberships


Find elements with a specific set membership degree

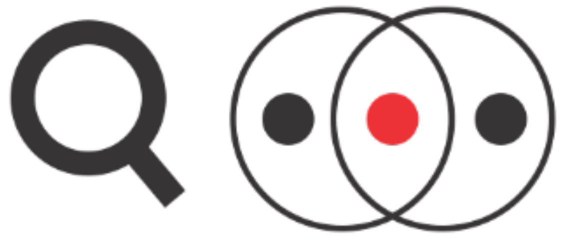

Filter out elements based on their set memberships


Filter out elements based on their set membership degrees


Create **a new set** that contains certain elements

## Elements


Find elements belonging to a specific set

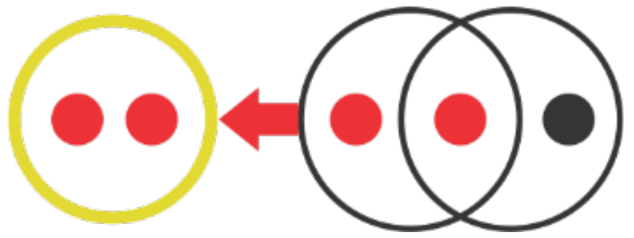

Find sets containing a specific element


Find elements based on their set memberships

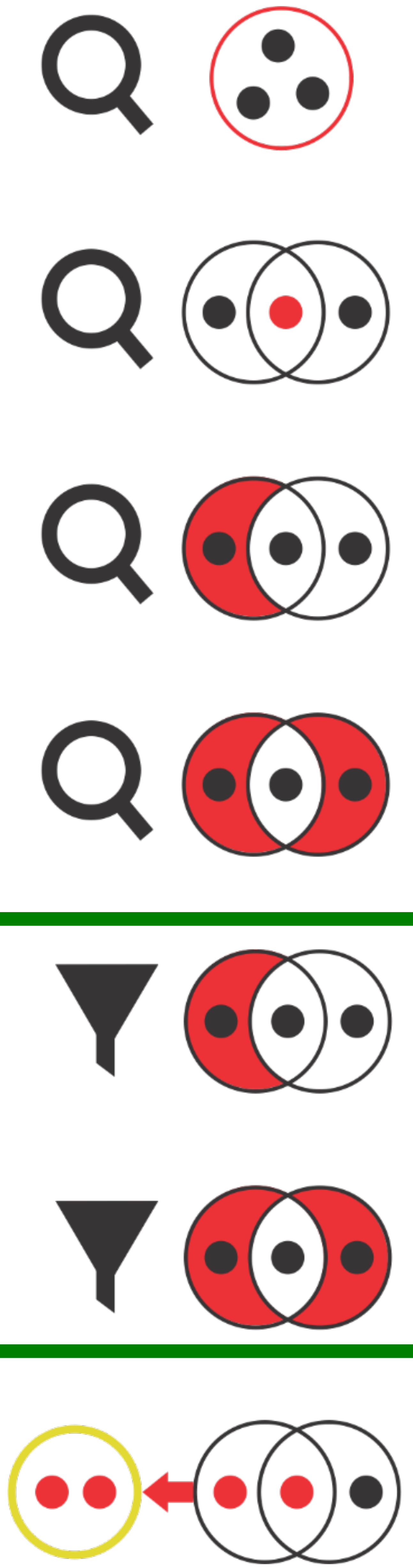

Find elements with a specific set membership degree


Filter out elements based on their set memberships


Filter out elements based on their set membership degrees


Create **a new set** that contains certain elements

# Elements



Find elements belonging to a specific set

Find sets containing a specific element

Find elements based on their set memberships

Find elements with a specific set membership degree

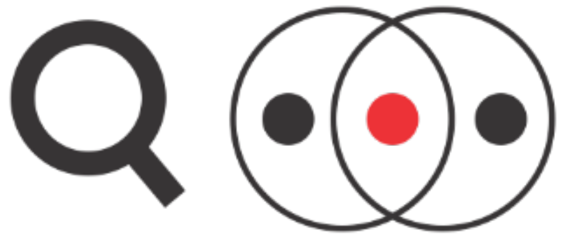
Filter out elements based on their set memberships

Filter out elements based on their set membership degrees

Create a new set that contains certain elements

## Elements

Find elements belonging to a specific set



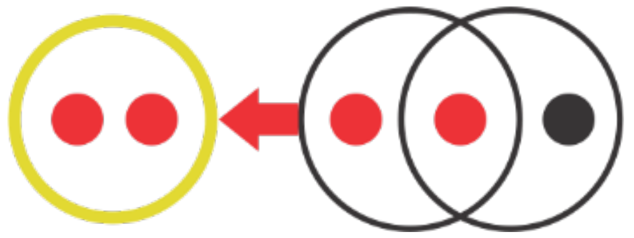
Find sets containing a specific element

Find elements based on their set memberships

Find elements with a specific set membership degree

Filter out elements based on their set memberships

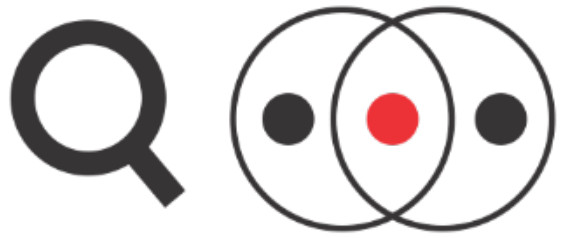
Filter out elements based on their set membership degrees



Create **a new set** that contains certain elements

## Elements

Find elements belonging to a specific set



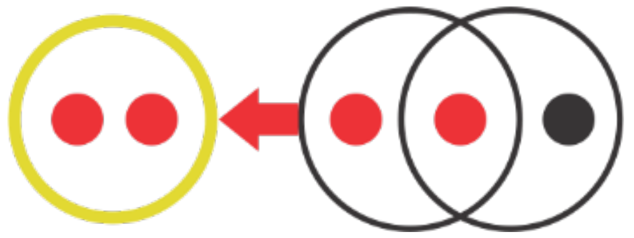
Find sets containing a specific element

Find elements based on their set memberships

Find elements with a specific set membership degree

Filter out elements based on their set memberships

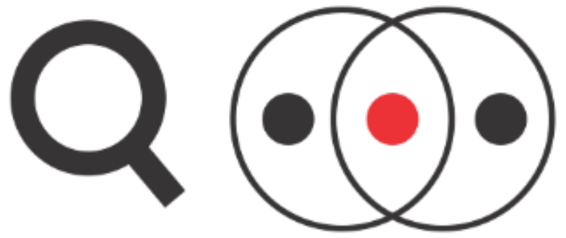
Filter out elements based on their set membership degrees



Create **a new set** that contains certain elements

## Elements

 Find elements belonging to a specific set

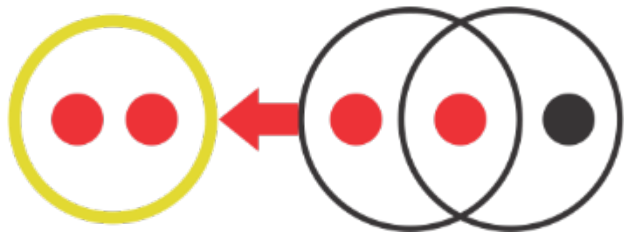
 Find sets containing a specific element

 Find elements based on their set memberships

 Find elements with a specific set membership degree

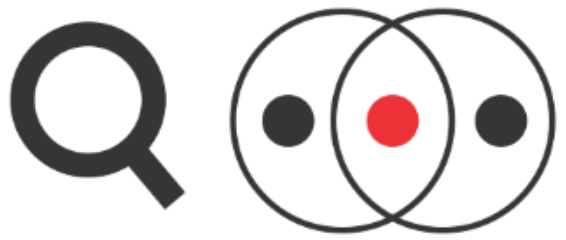
 Filter out elements based on their set memberships

 Filter out elements based on their set membership degrees

 Create **a new set** that contains certain elements

## Elements

Find elements belonging to a specific set

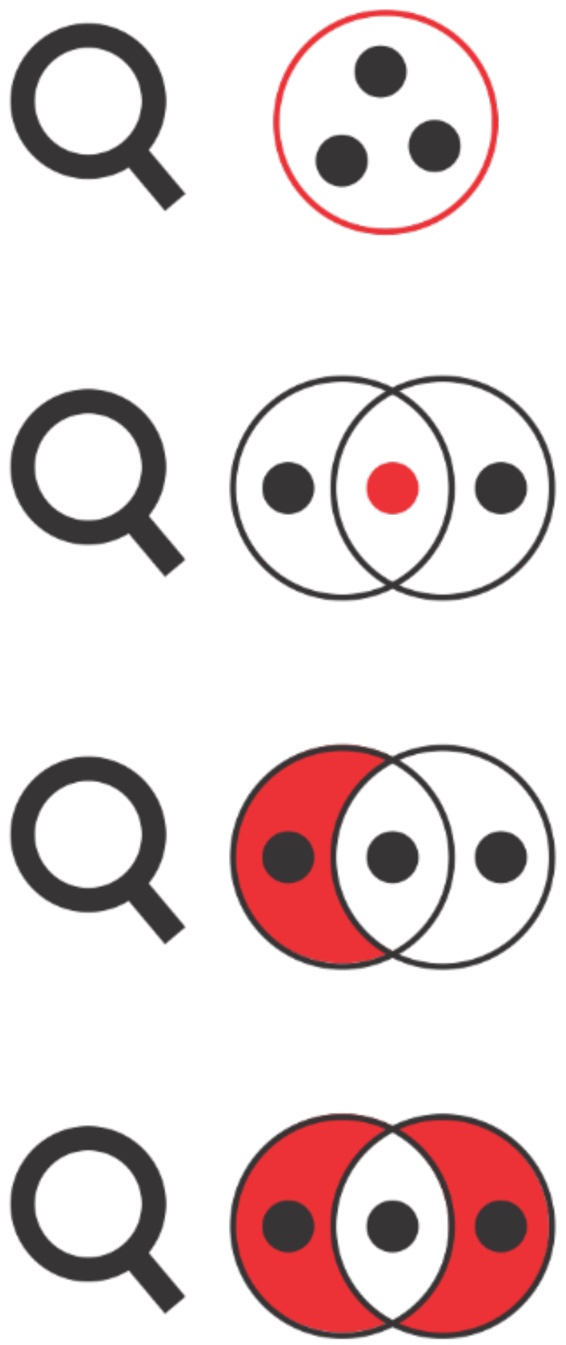


Find sets containing a specific element

Find elements based on their set memberships

Find elements with a specific set membership degree

## Elements



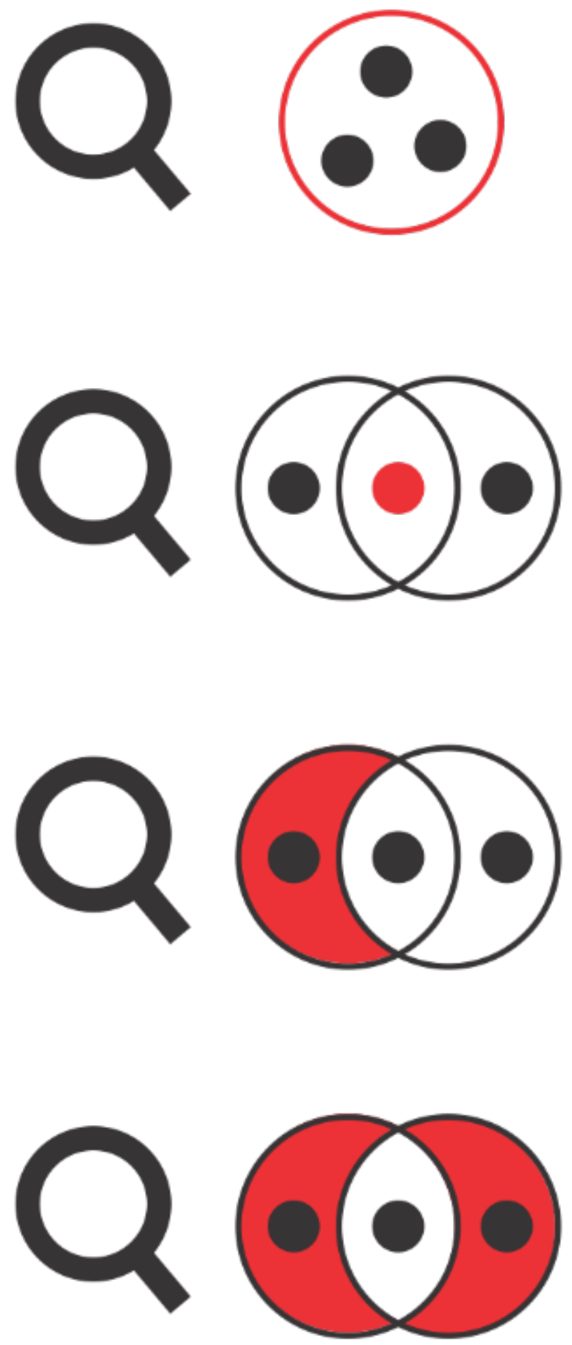
Find elements belonging to a specific set

Find sets containing a specific element

Find elements based on their set memberships

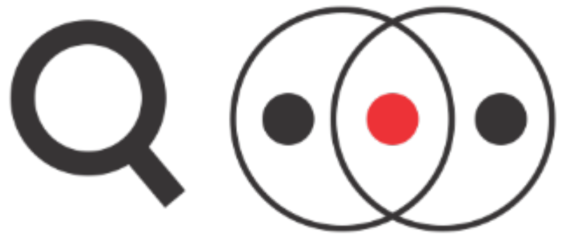
Find elements with a specific set membership degree

## Elements

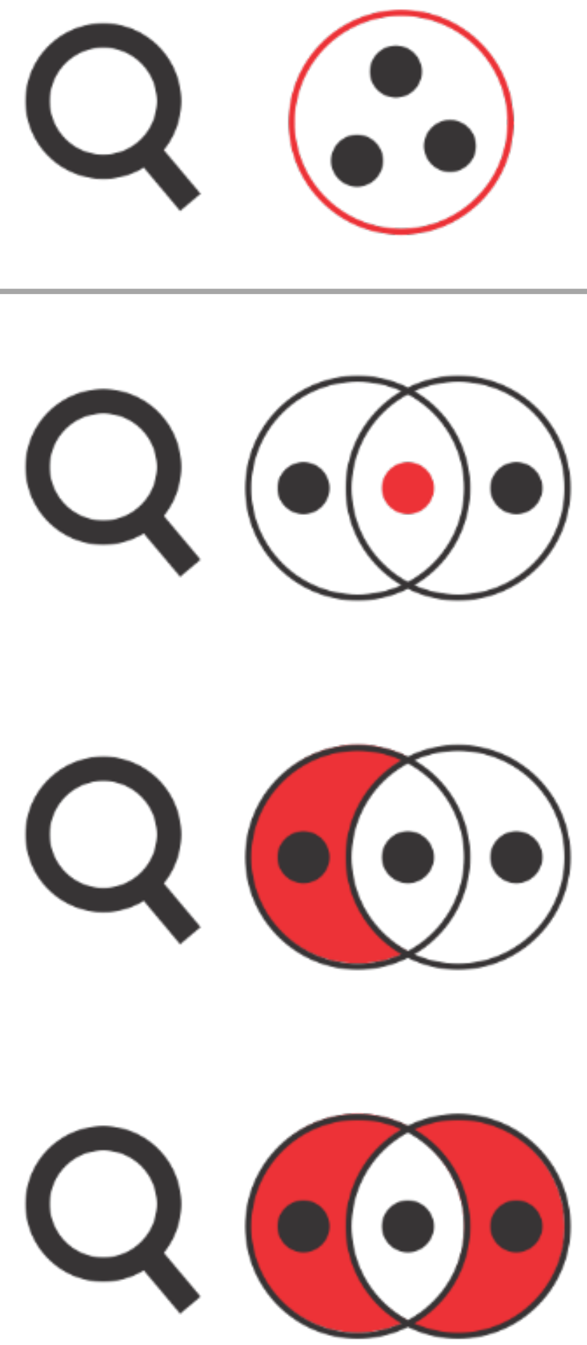


# Elements

Find elements belonging to a specific set

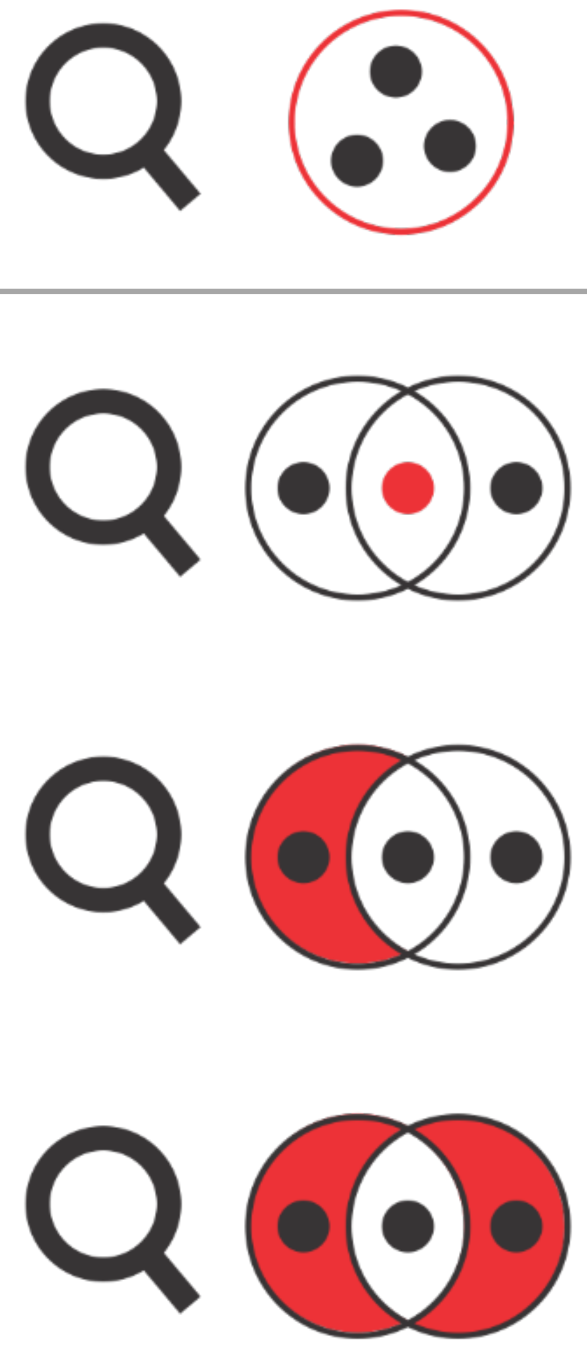


# Elements



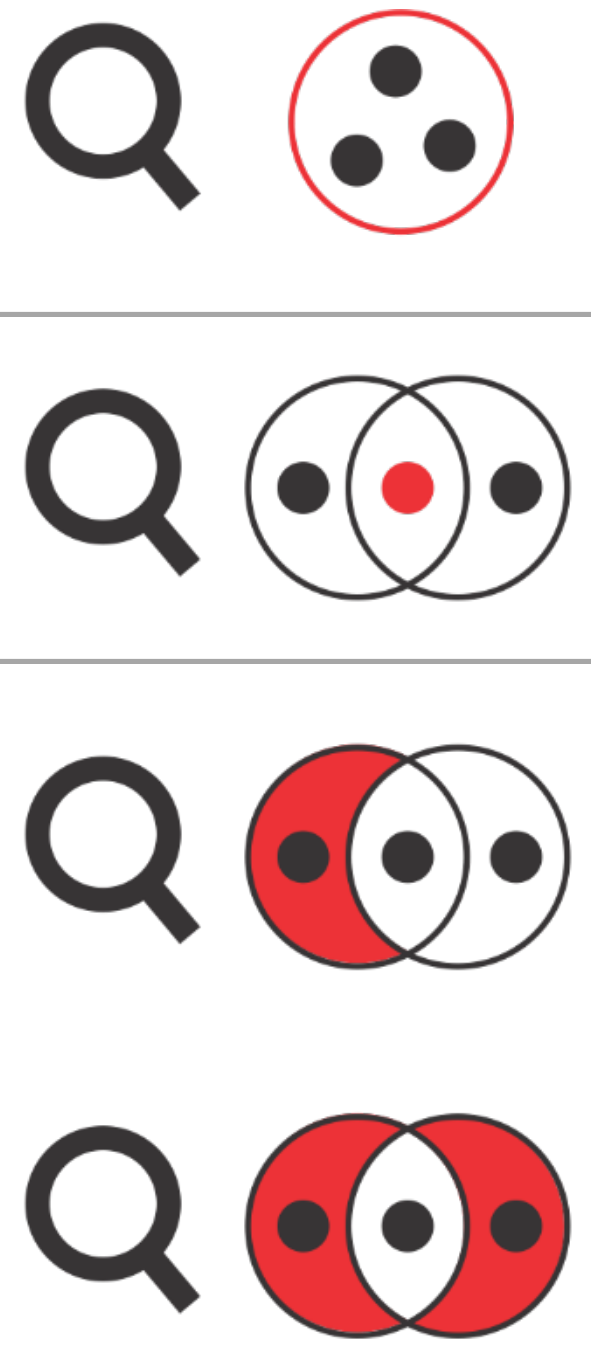
Find elements belonging to a specific set

# Elements

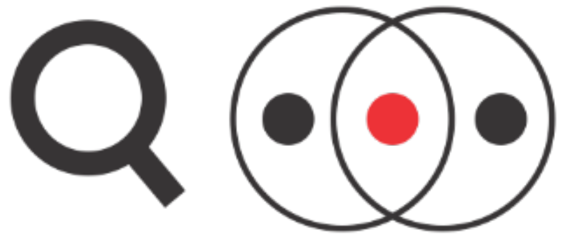


Find elements belonging to a specific set

# Elements

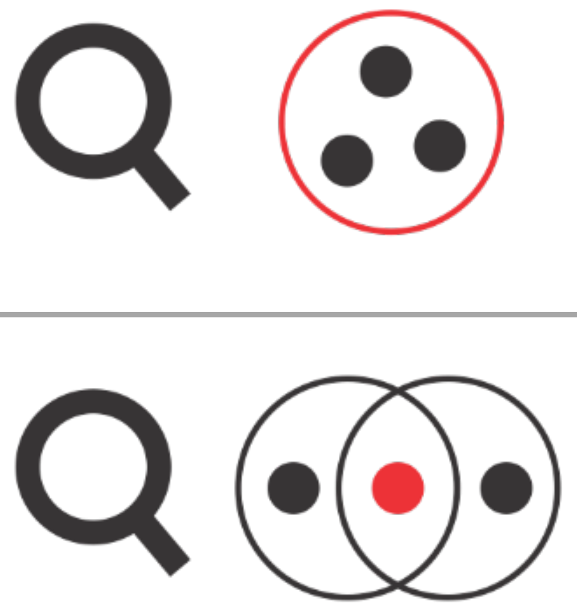


## Elements

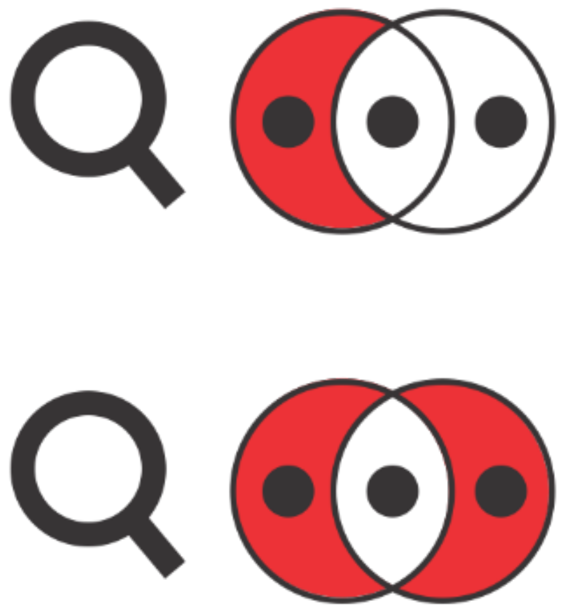


Find sets containing a specific element

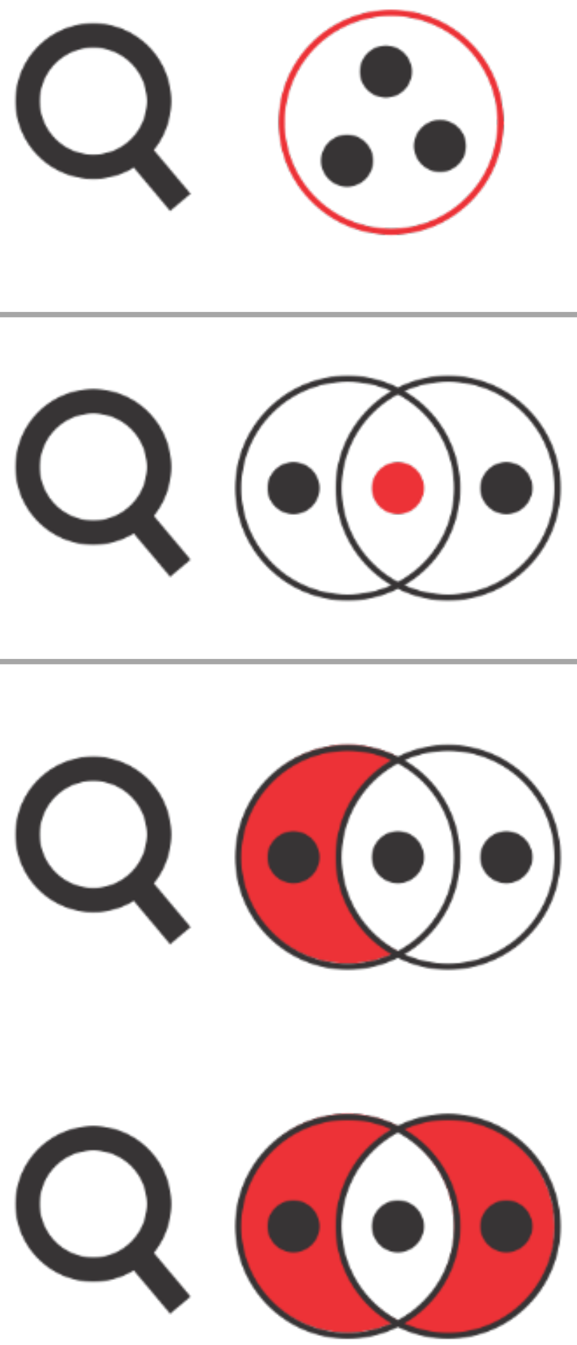
## Elements



Find sets containing a specific element



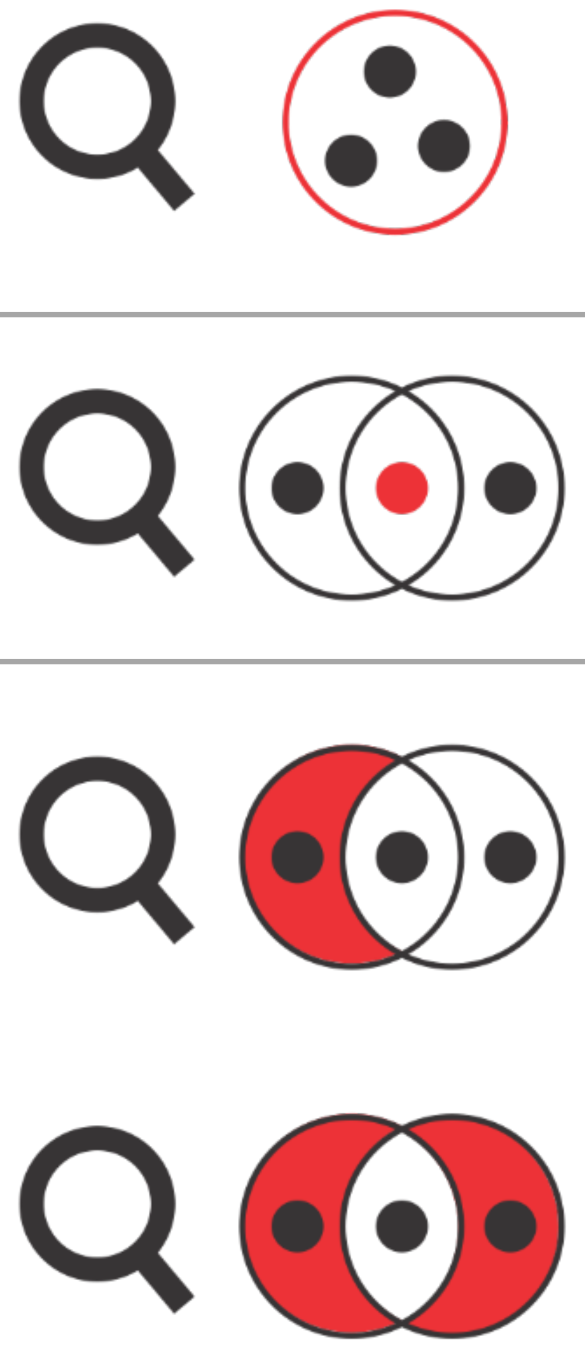
# Elements



Find sets containing a specific element

affiliations

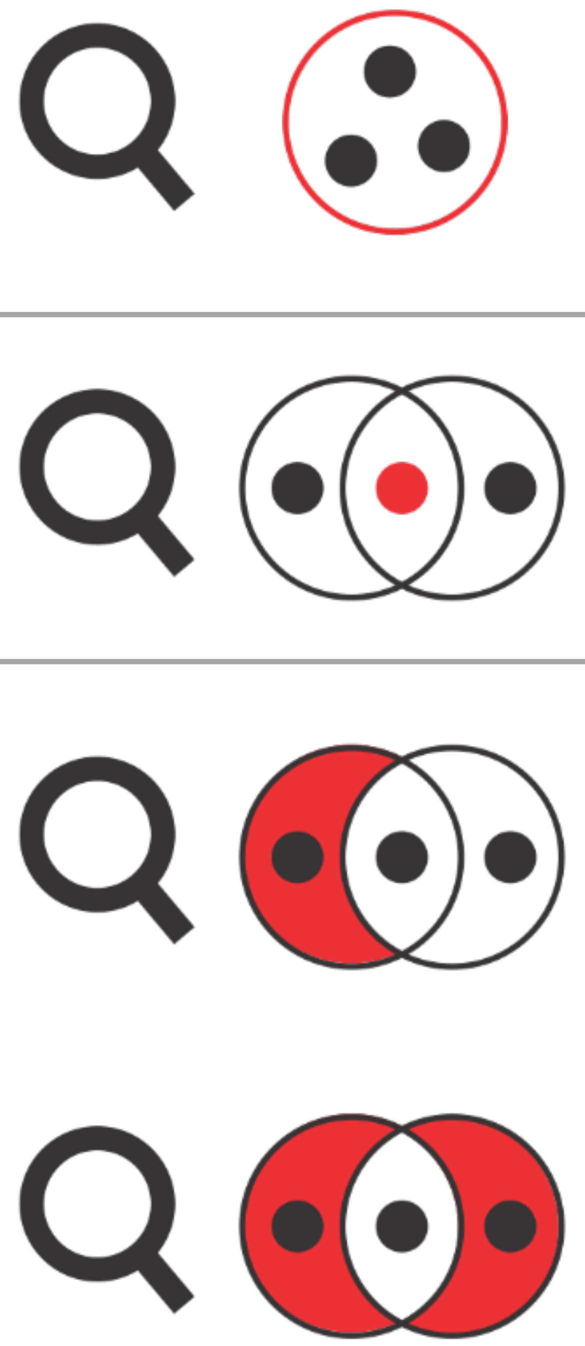
# Elements



Find sets containing a specific element

affiliations

# Elements



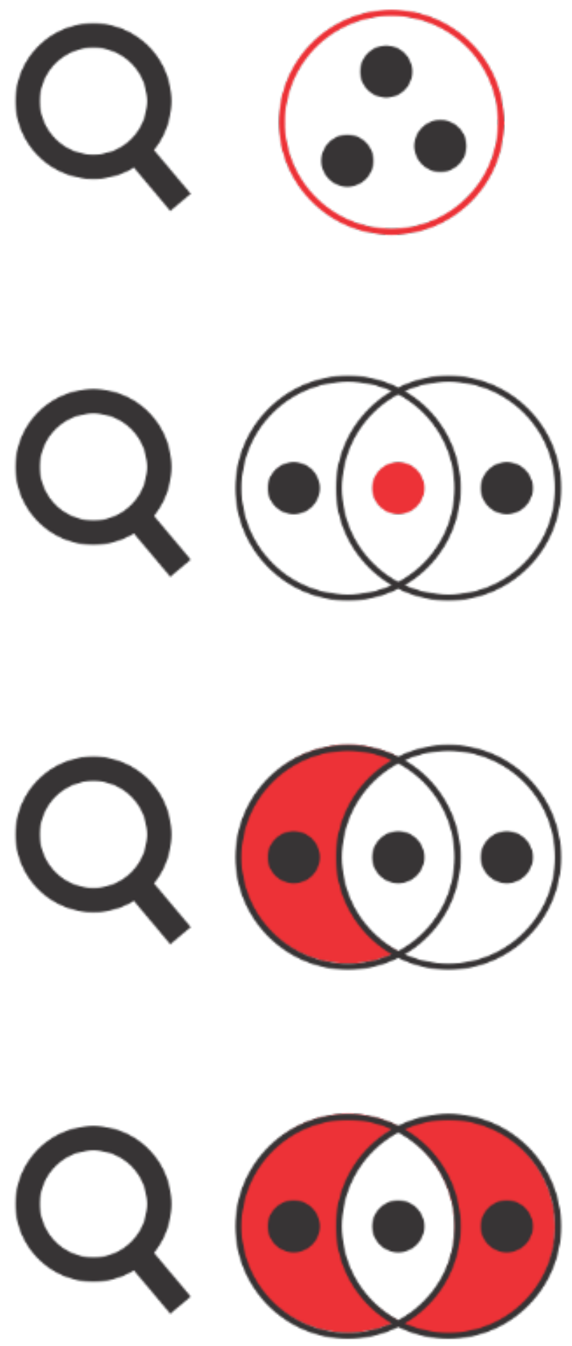
Find sets containing a specific element

affiliations

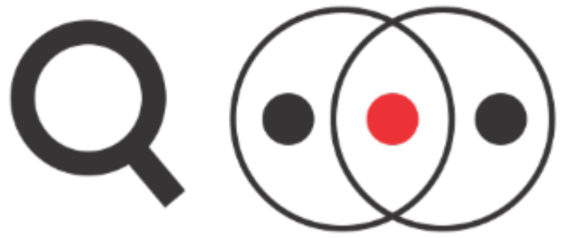
TU WIEN

/fh/// st.pölten

# Elements

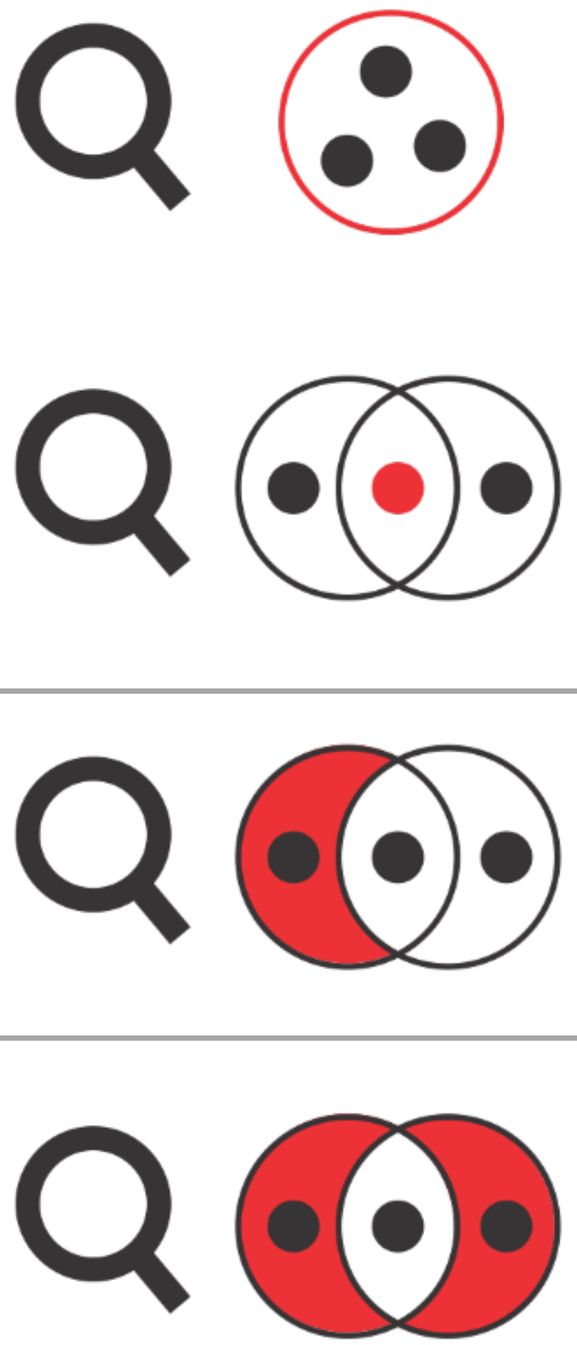


## Elements



Find elements based on their set memberships

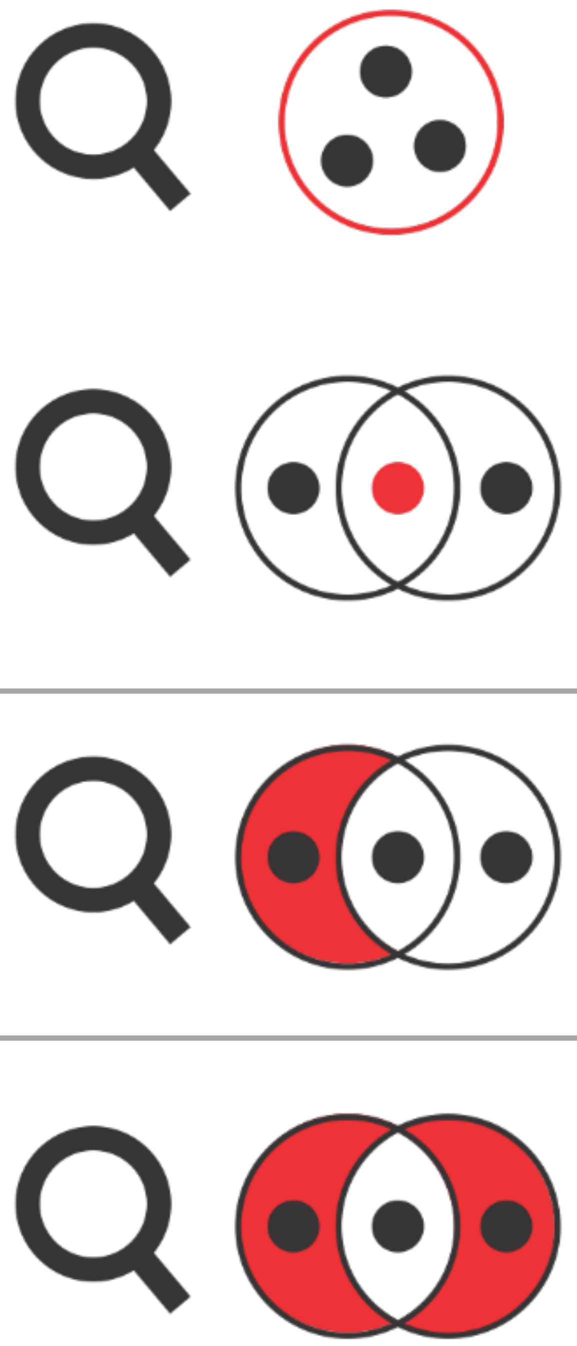
# Elements



Find elements based on their set memberships

HELSINKI INSTITUTE FOR INFORMATION TECHNOLOGY $\cap$ University of Kent $\cap \neg$ TU WIEN

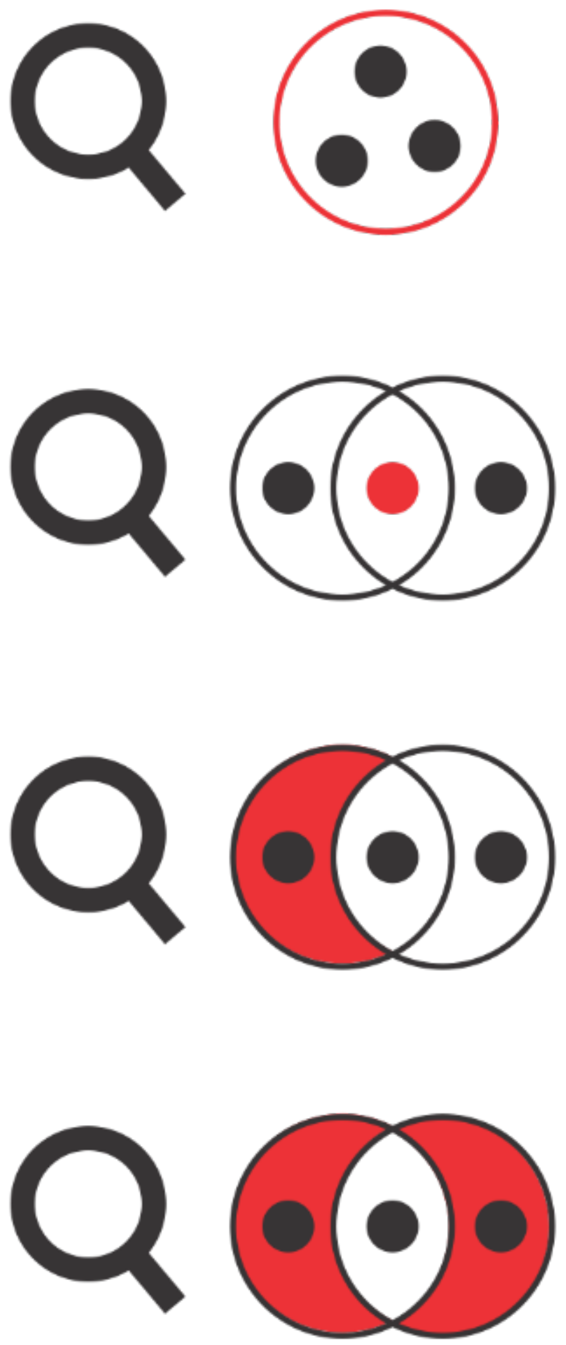
# Elements



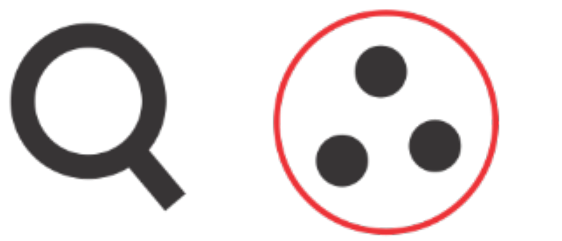
Find elements based on their set memberships

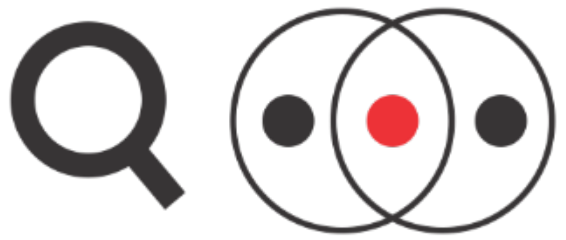
HELSINKI INSTITUTE FOR INFORMATION TECHNOLOGY ∩ University of Kent ∩ ¬ TU WIEN

## Elements



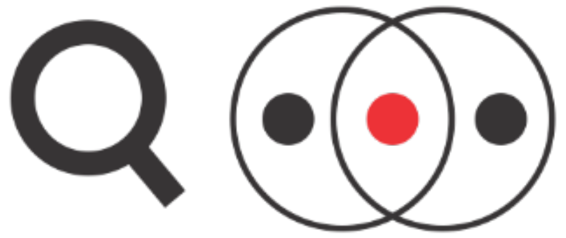
# Elements





Find elements with a specific set membership degree

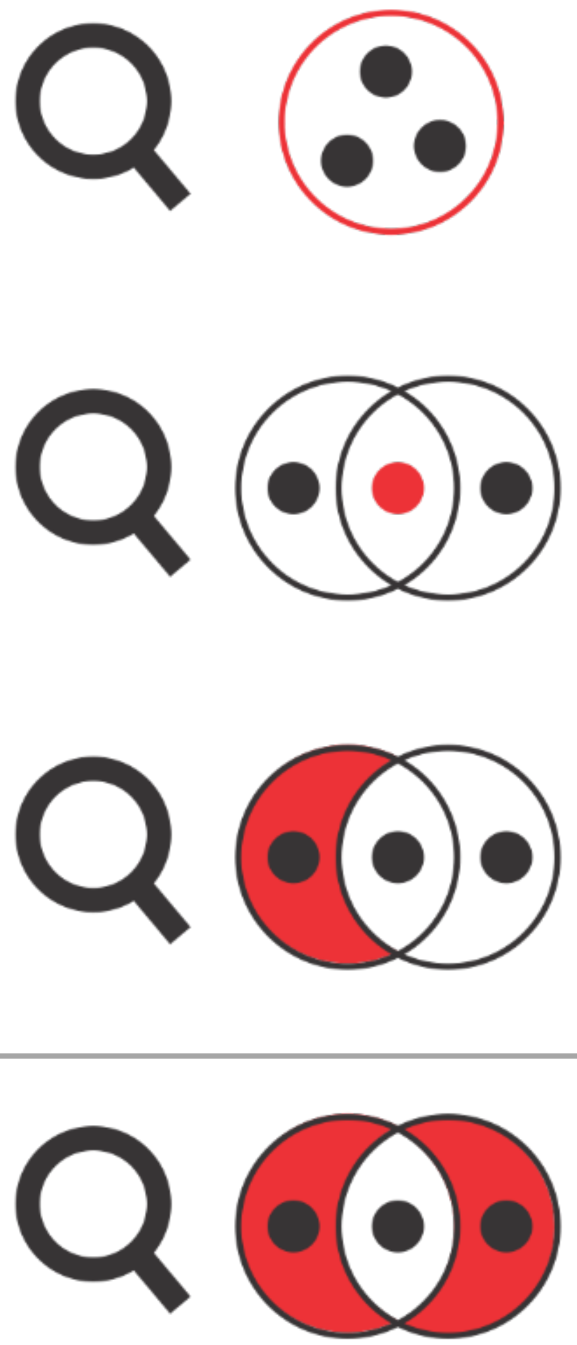
## Elements



Find elements with a specific set membership degree

2 affiliations

# Elements

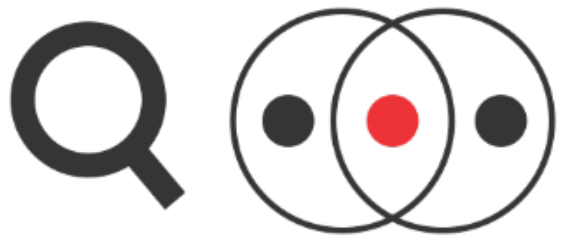


Find elements with a specific set membership degree

2 affiliations

## Elements

Find elements belonging to a specific set



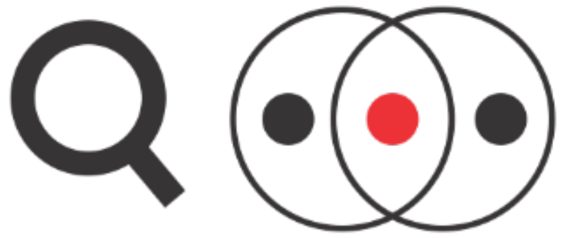
Find sets containing a specific element

Find elements based on their set memberships

Find elements with a specific set membership degree

## Elements


Find elements belonging to a specific set

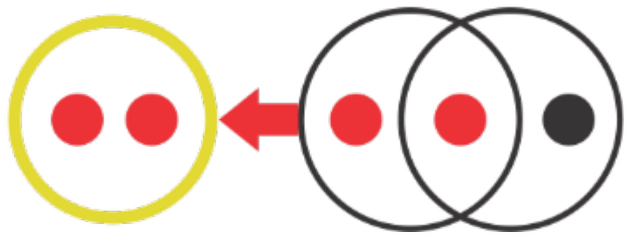

Find sets containing a specific element


Find elements based on their set memberships

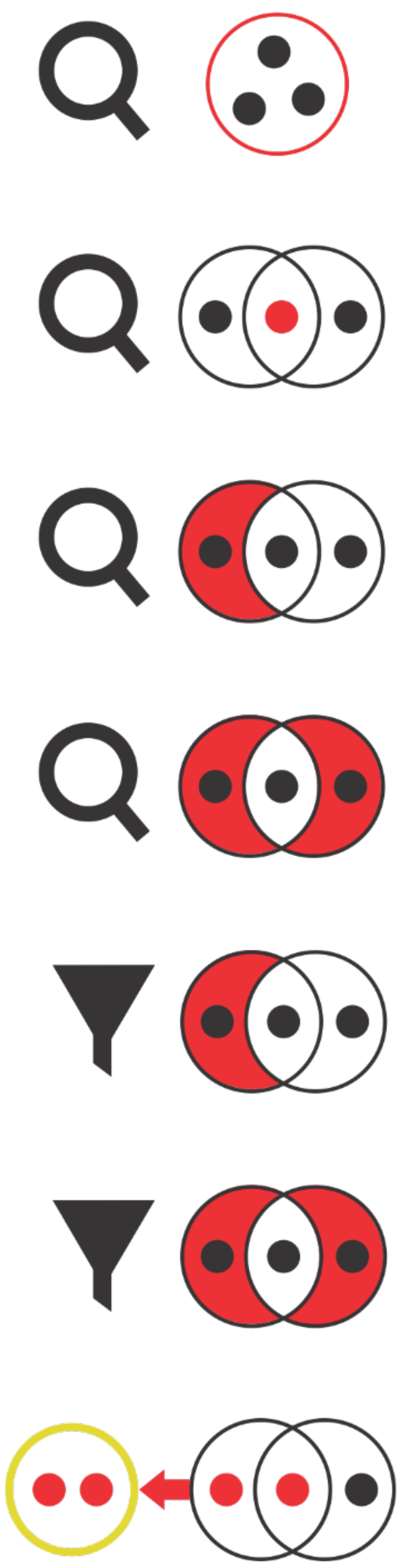

Find elements with a specific set membership degree


Filter out elements based on their set memberships

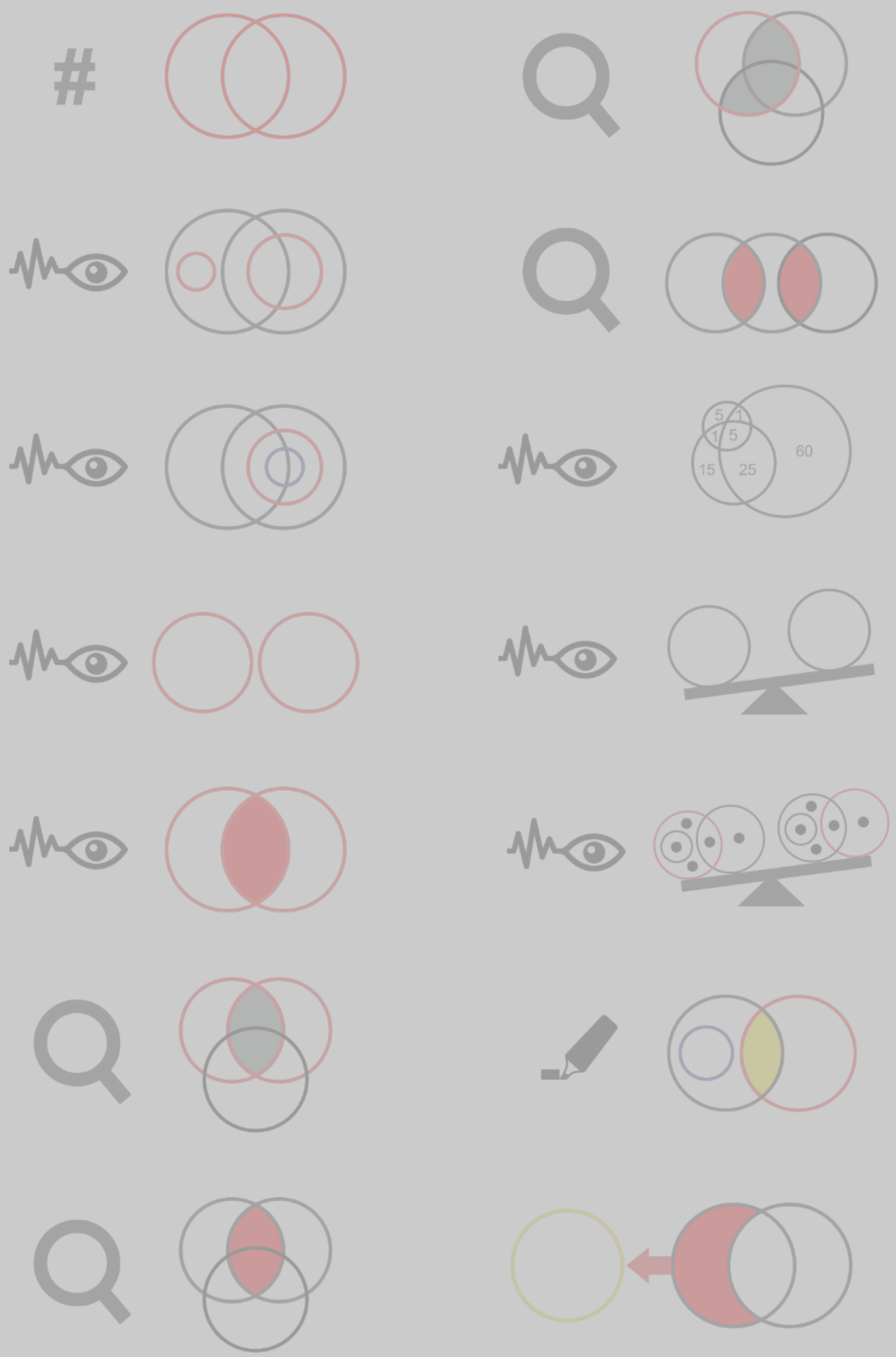

Filter out elements based on their set membership degrees


Create **a new set** that contains certain elements

## Elements



## Sets and Set Relations

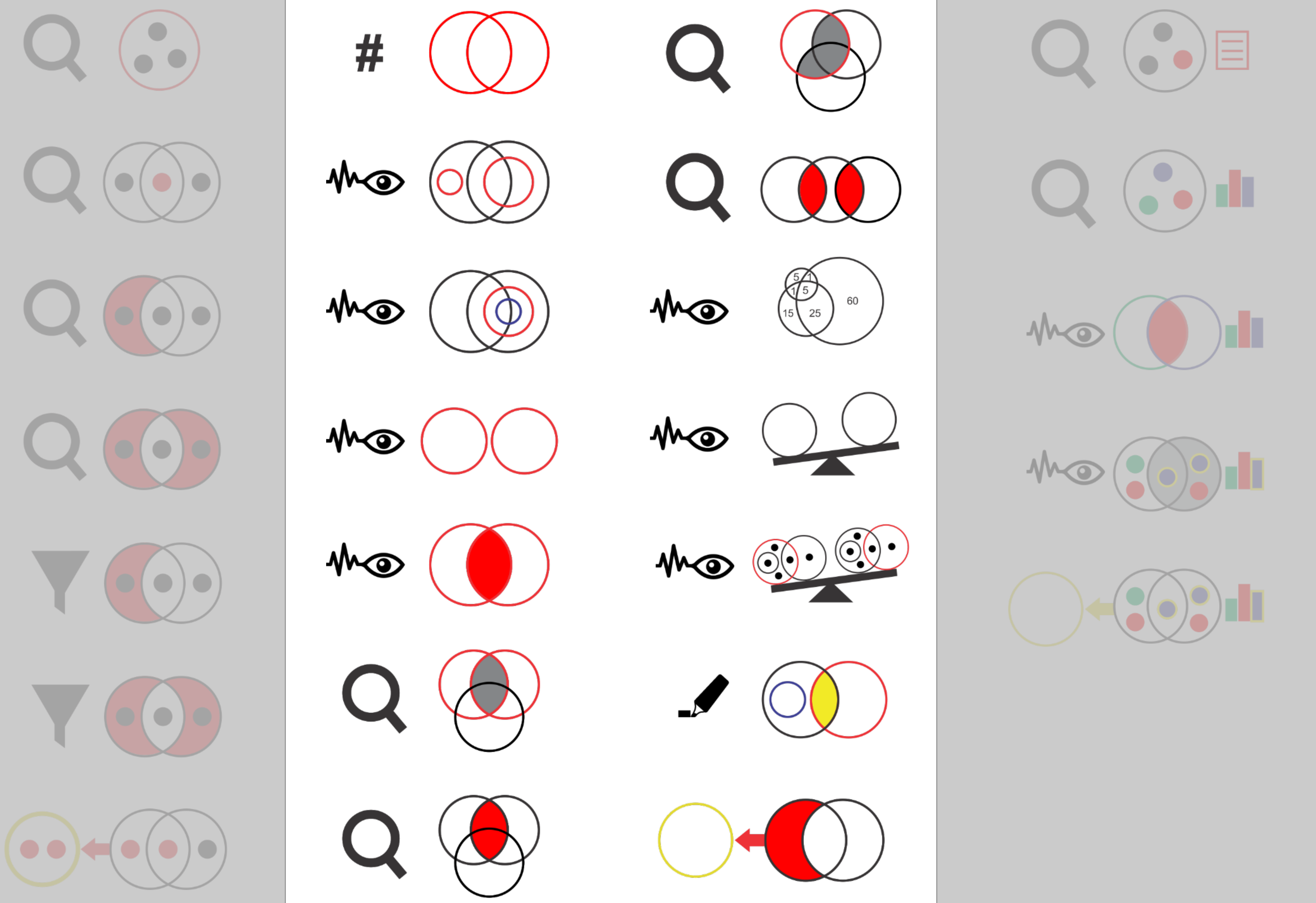



## Element Attributes

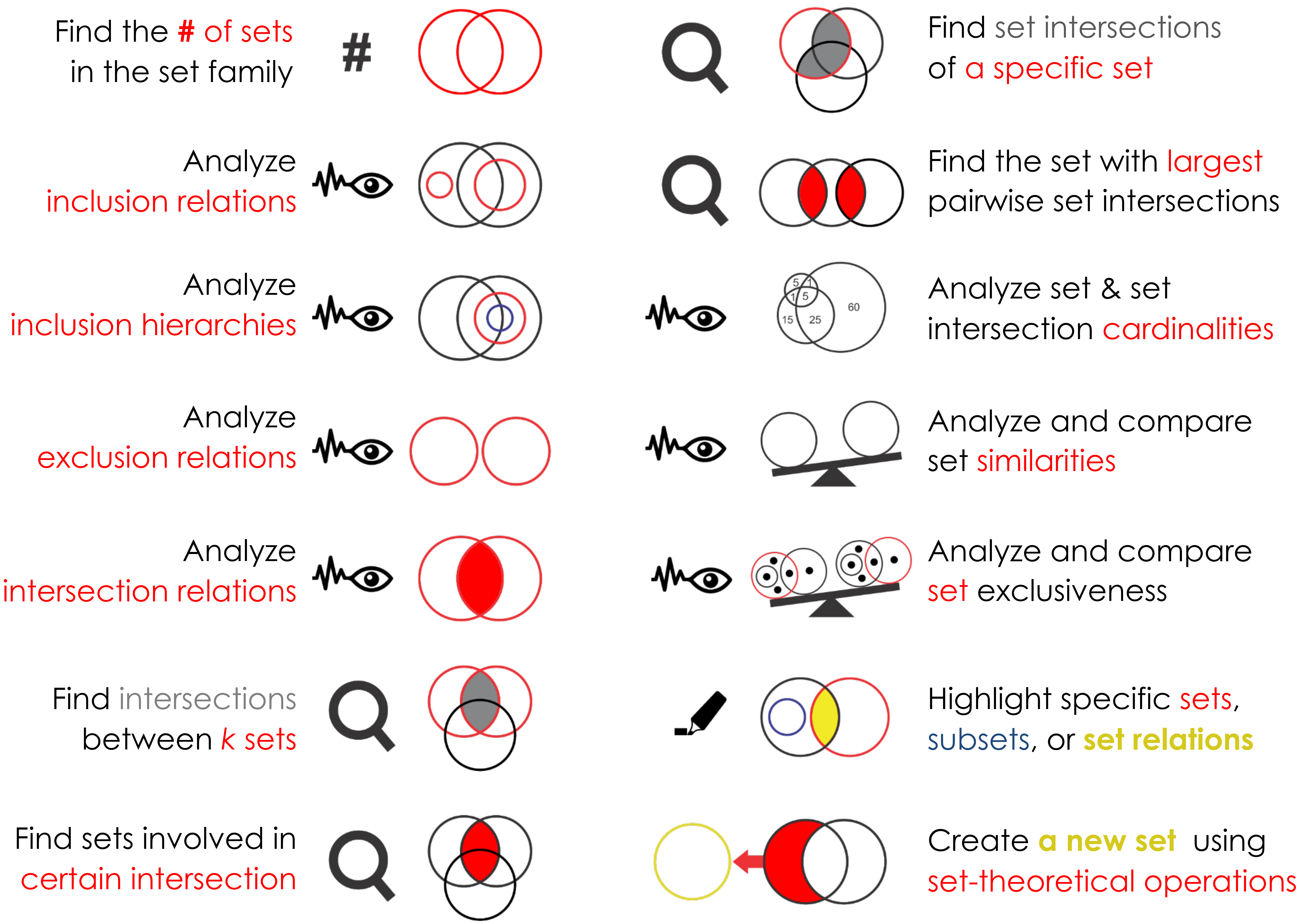
## Elements

## Sets and Set Relations

## Element Attributes



# Sets and Set Relations



# Sets and Set Relations

Find the # of sets in the set family

Analyze inclusion relations

Analyze inclusion hierarchies

Analyze exclusion relations

Analyze intersection relations

Find intersections between *k* sets

Find sets involved in certain intersection

Find set intersections of a specific set

Find the set with largest pairwise set intersections

Analyze set & set intersection cardinalities

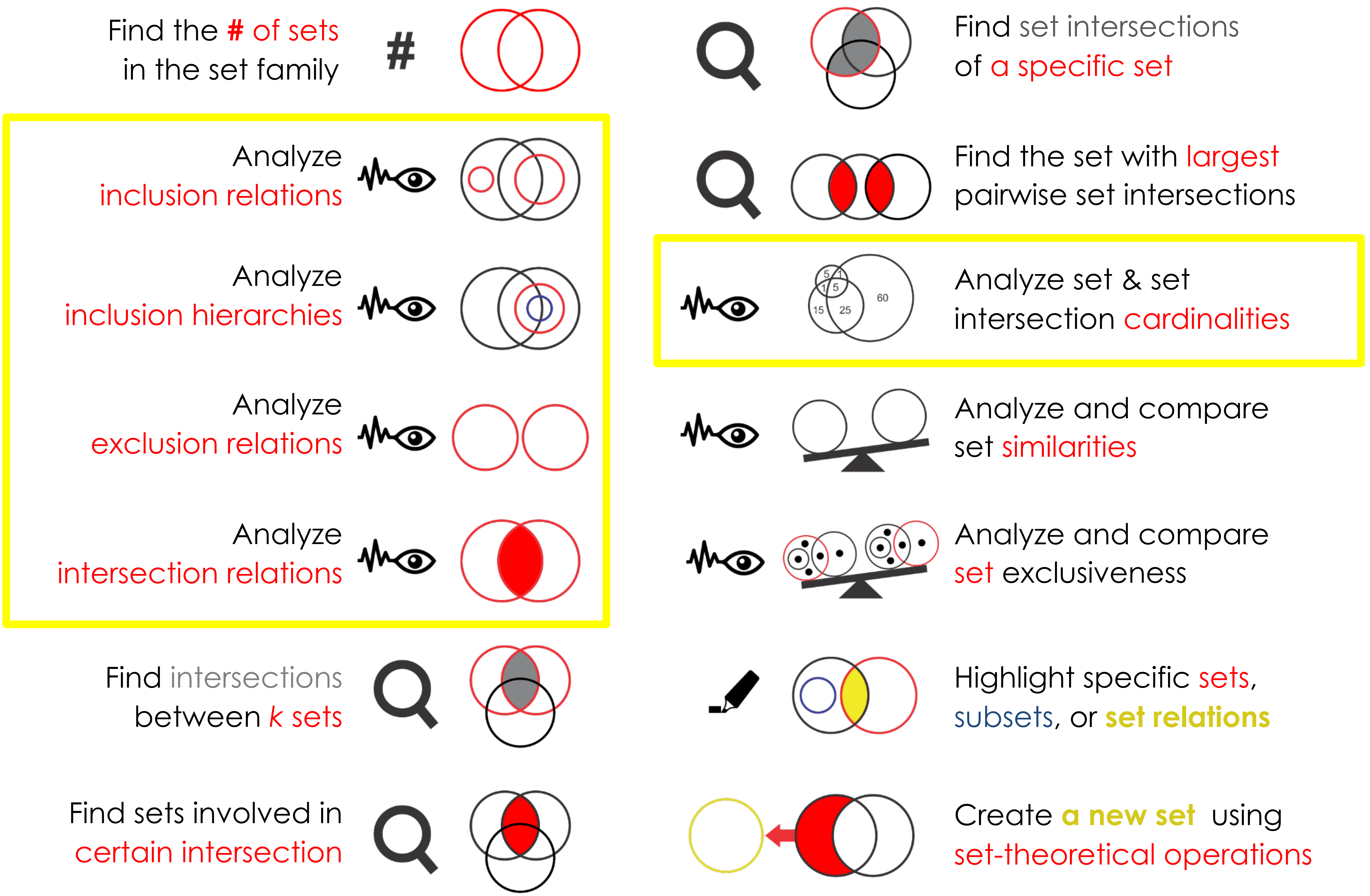
Analyze and compare set similarities

Analyze and compare set exclusiveness

Highlight specific sets, subsets, or **set relations**

Create **a new set** using set-theoretical operations

# Sets and Set Relations



# Sets and Set Relations

Find the # of sets in the set family

Analyze inclusion relations

Analyze inclusion hierarchies

Analyze exclusion relations

Analyze intersection relations

Find intersections between *k* sets

Find sets involved in certain intersection

Find set intersections of a specific set

Find the set with largest pairwise set intersections

Analyze set & set intersection cardinalities

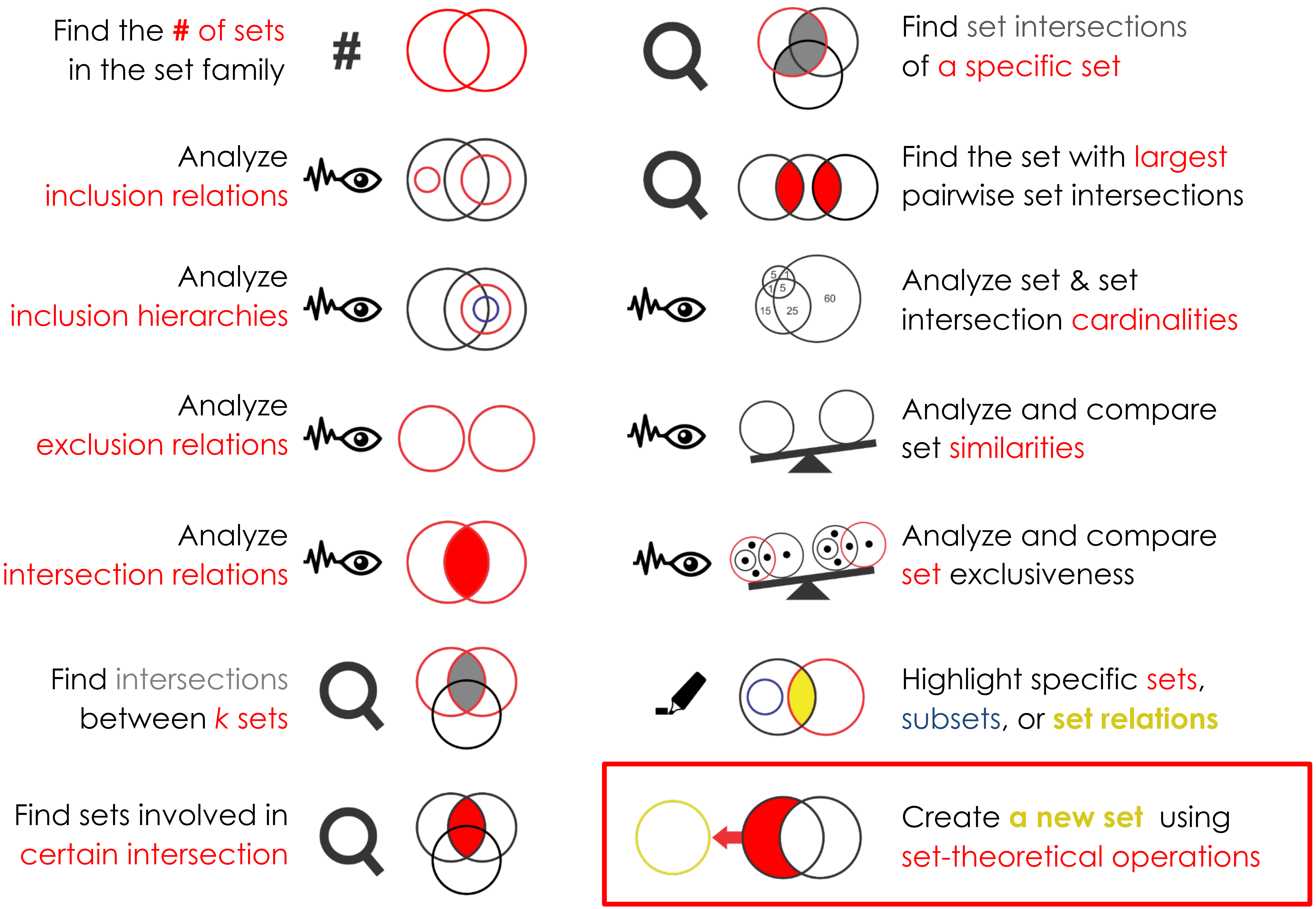
Analyze and compare set similarities

Analyze and compare set exclusiveness

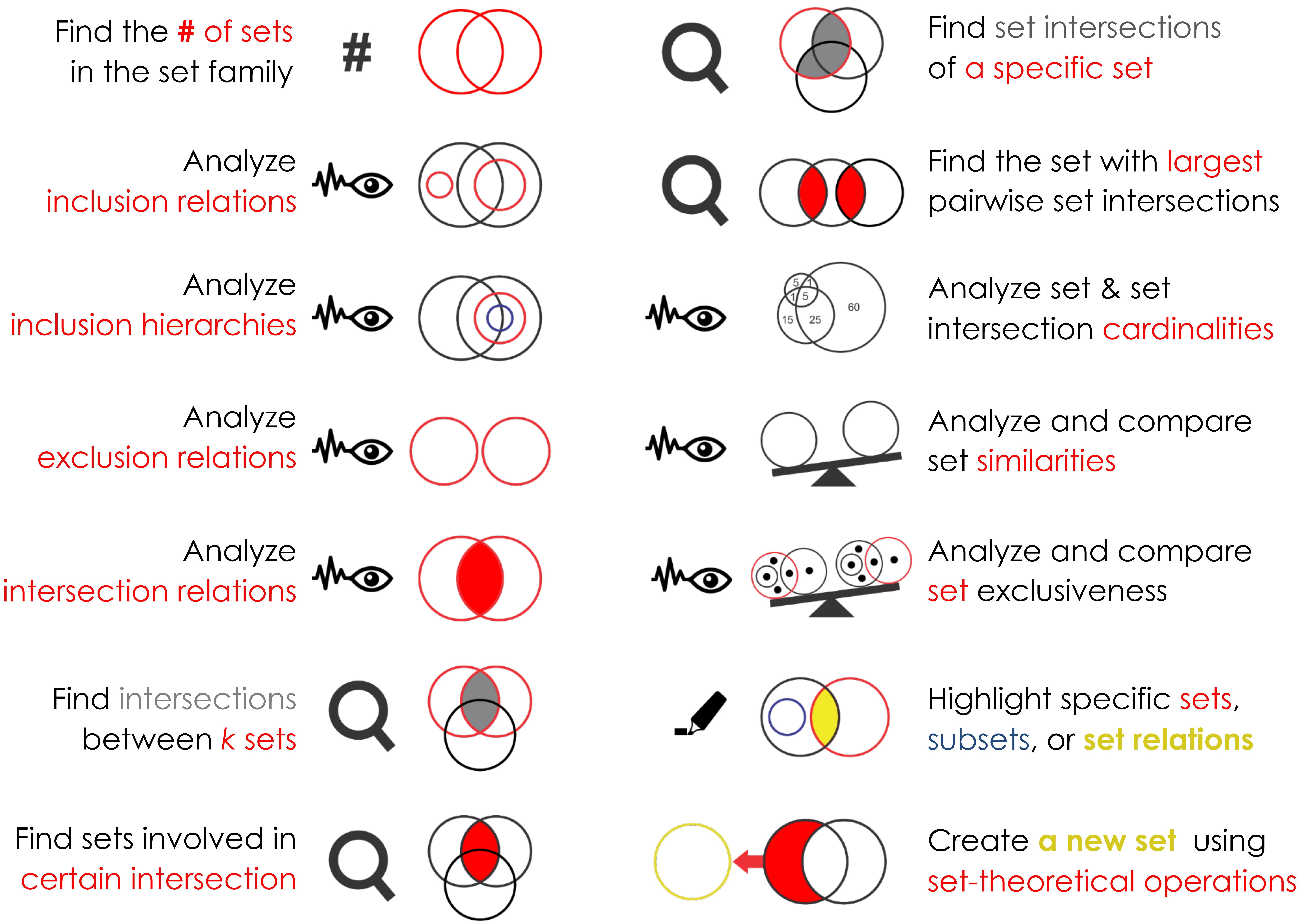
Highlight specific sets, subsets, or **set relations**

Create **a new set** using set-theoretical operations

# Sets and Set Relations



# Sets and Set Relations



# Sets and Set Relations

Find the # of sets in the set family

Analyze inclusion relations

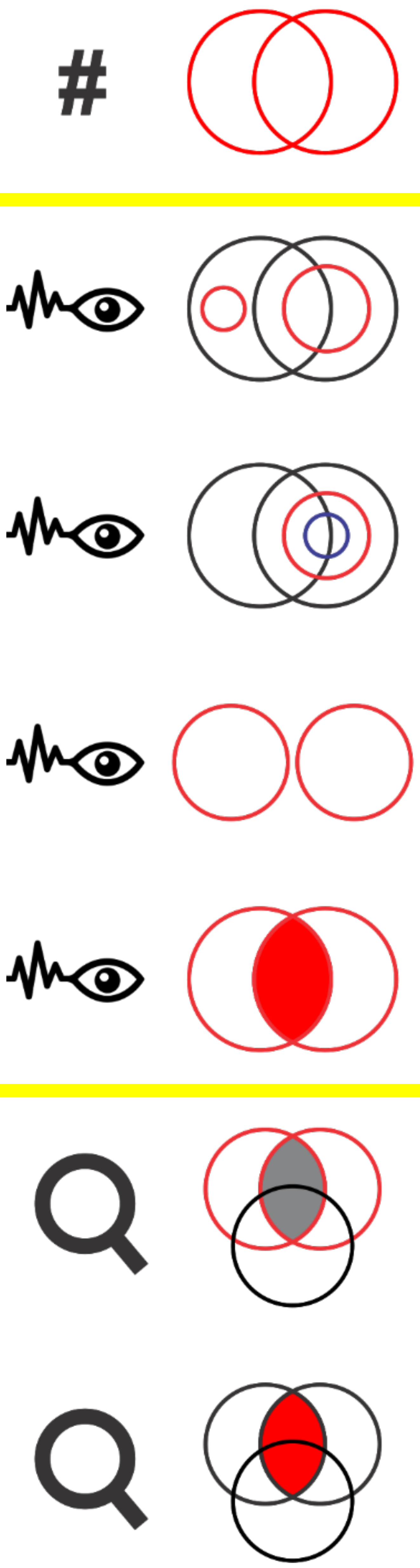
Analyze inclusion hierarchies

Analyze exclusion relations

Analyze intersection relations

Find intersections between *k* sets

Find sets involved in certain intersection




Find set intersections of a specific set

Find the set with largest pairwise set intersections

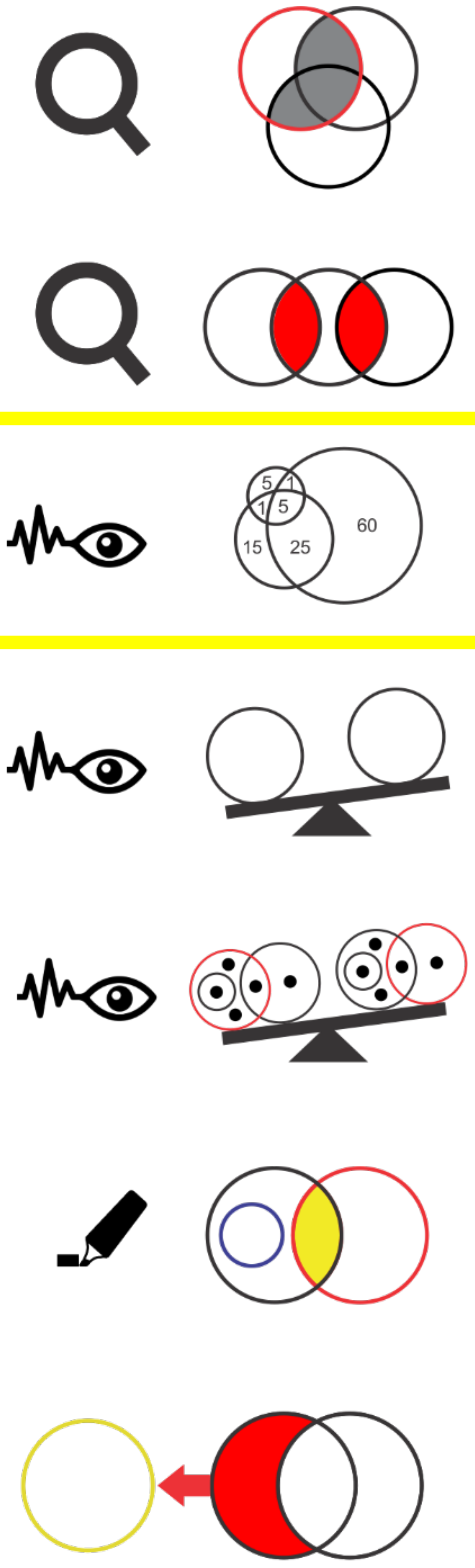
Analyze set & set intersection cardinalities

Analyze and compare set similarities

Analyze and compare set exclusiveness

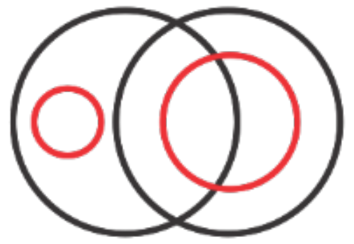
Highlight specific sets, subsets, or **set relations**

Create **a new set** using set-theoretical operations

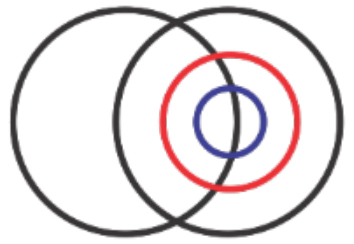


# Sets and Set Relations

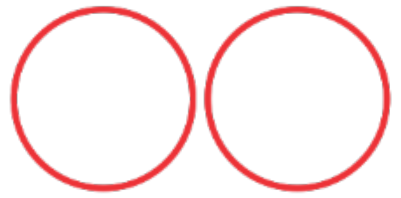
Analyze
inclusion relations



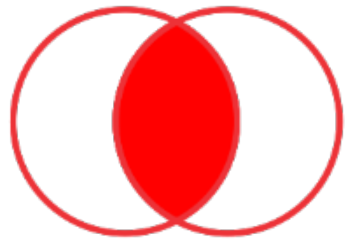
Analyze
inclusion hierarchies

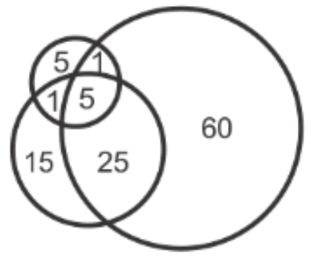


Analyze
exclusion relations



Analyze
intersection relations

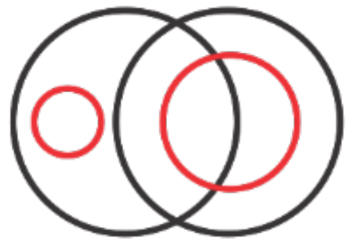




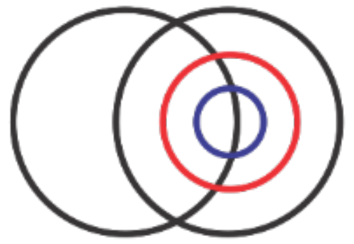

Analyze set & set
intersection cardinalities

# Sets and Set Relations

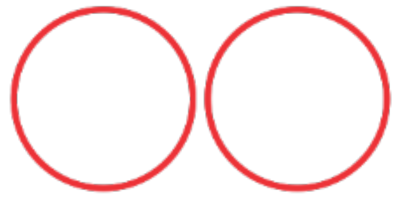
Analyze
inclusion relations



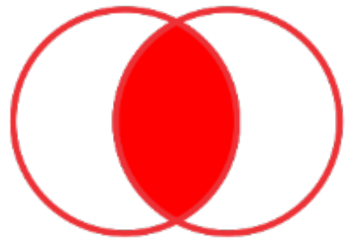
Analyze
inclusion hierarchies

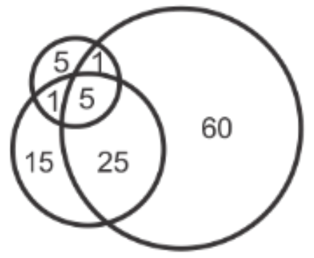


Analyze
exclusion relations



Analyze
intersection relations



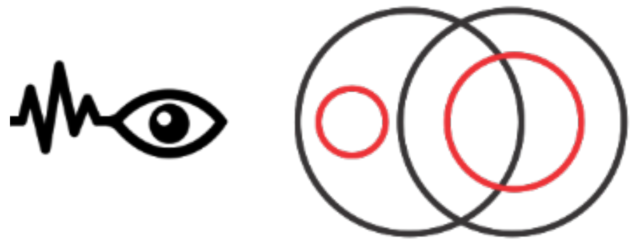


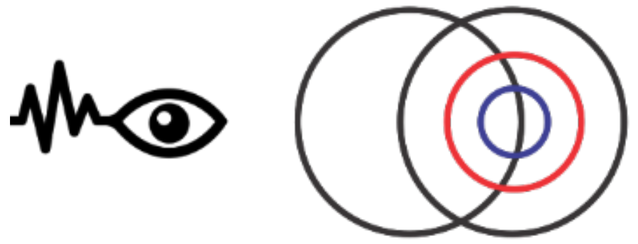

Analyze set & set
intersection cardinalities



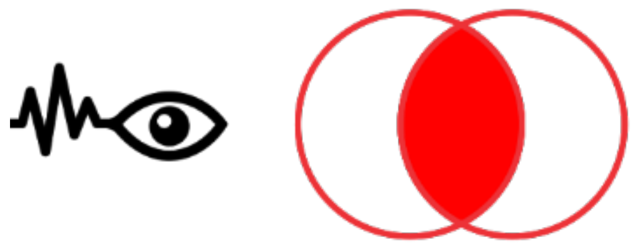


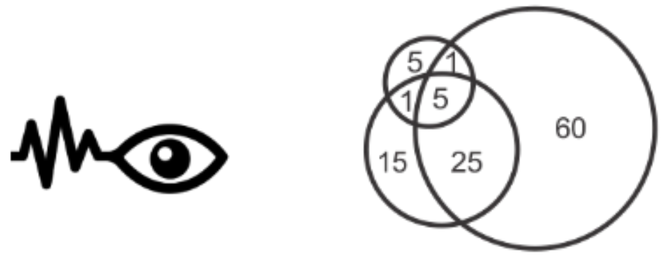

# Sets and Set Relations

Analyze
inclusion relations


Analyze
inclusion hierarchies


Analyze
exclusion relations


Analyze
intersection relations


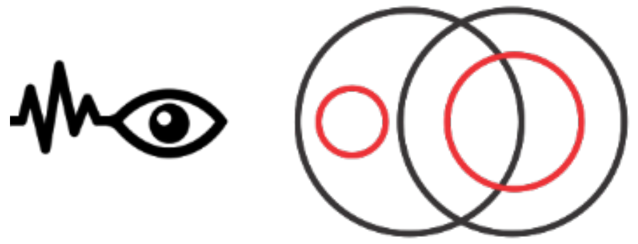



Analyze set & set
intersection cardinalities

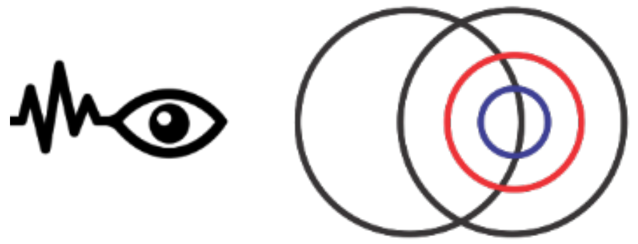
InfoVis
Visual Analytics
Time-oriented Data
Diagrams

# Sets and Set Relations

Analyze
inclusion relations

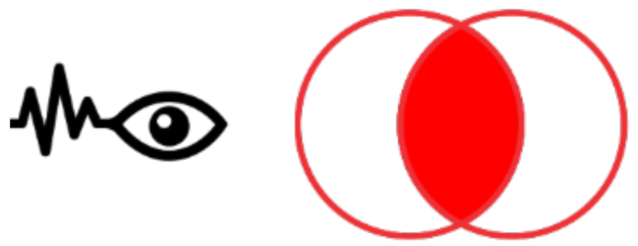


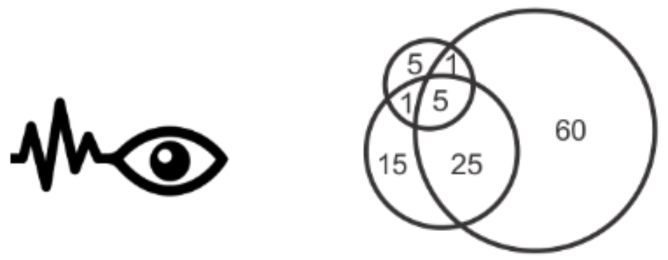
Analyze
inclusion hierarchies



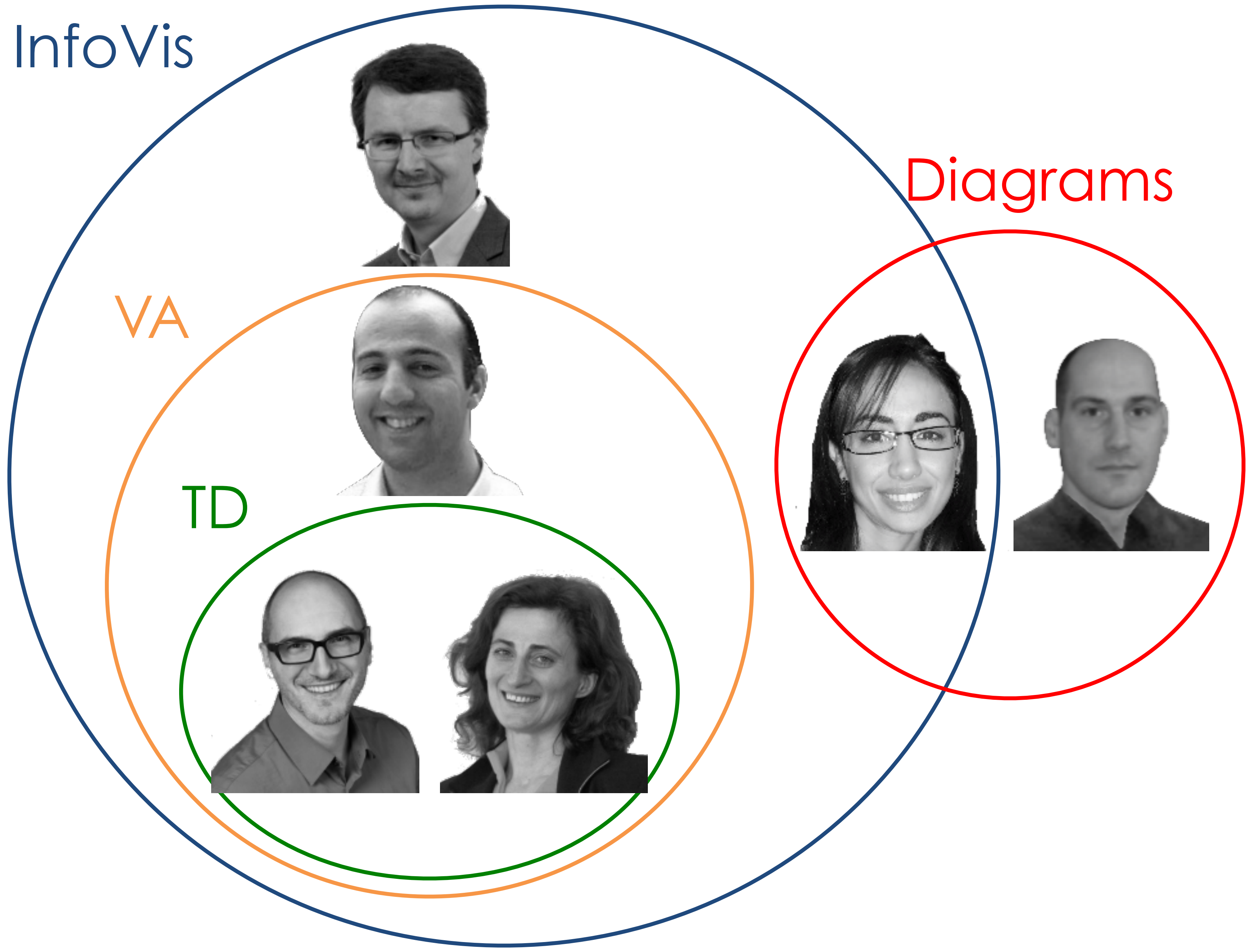
Analyze
exclusion relations

Analyze
intersection relations



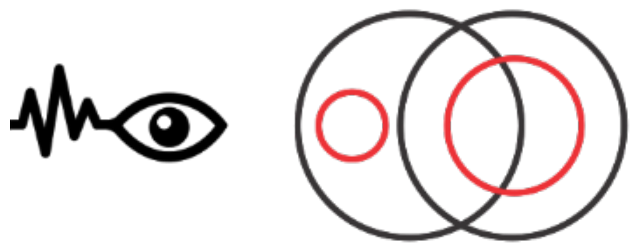


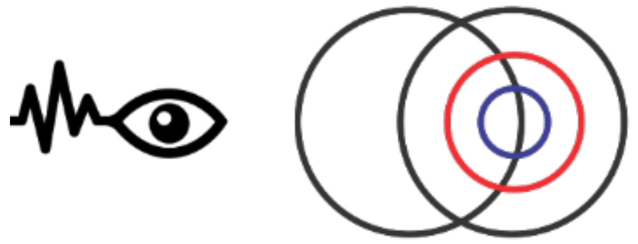
Analyze set & set
intersection cardinalities

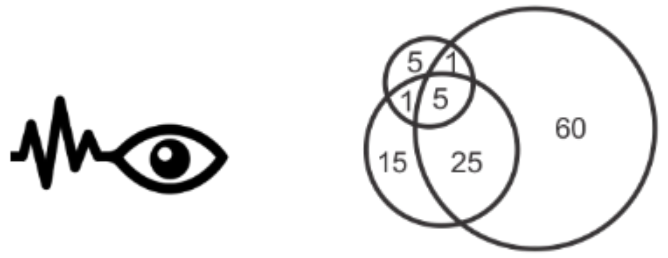


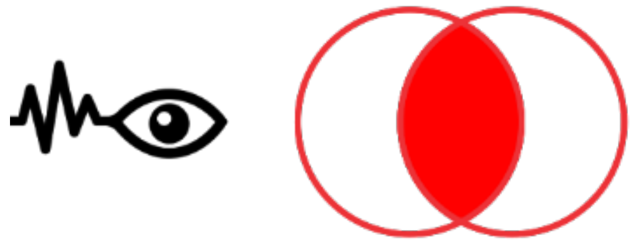

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

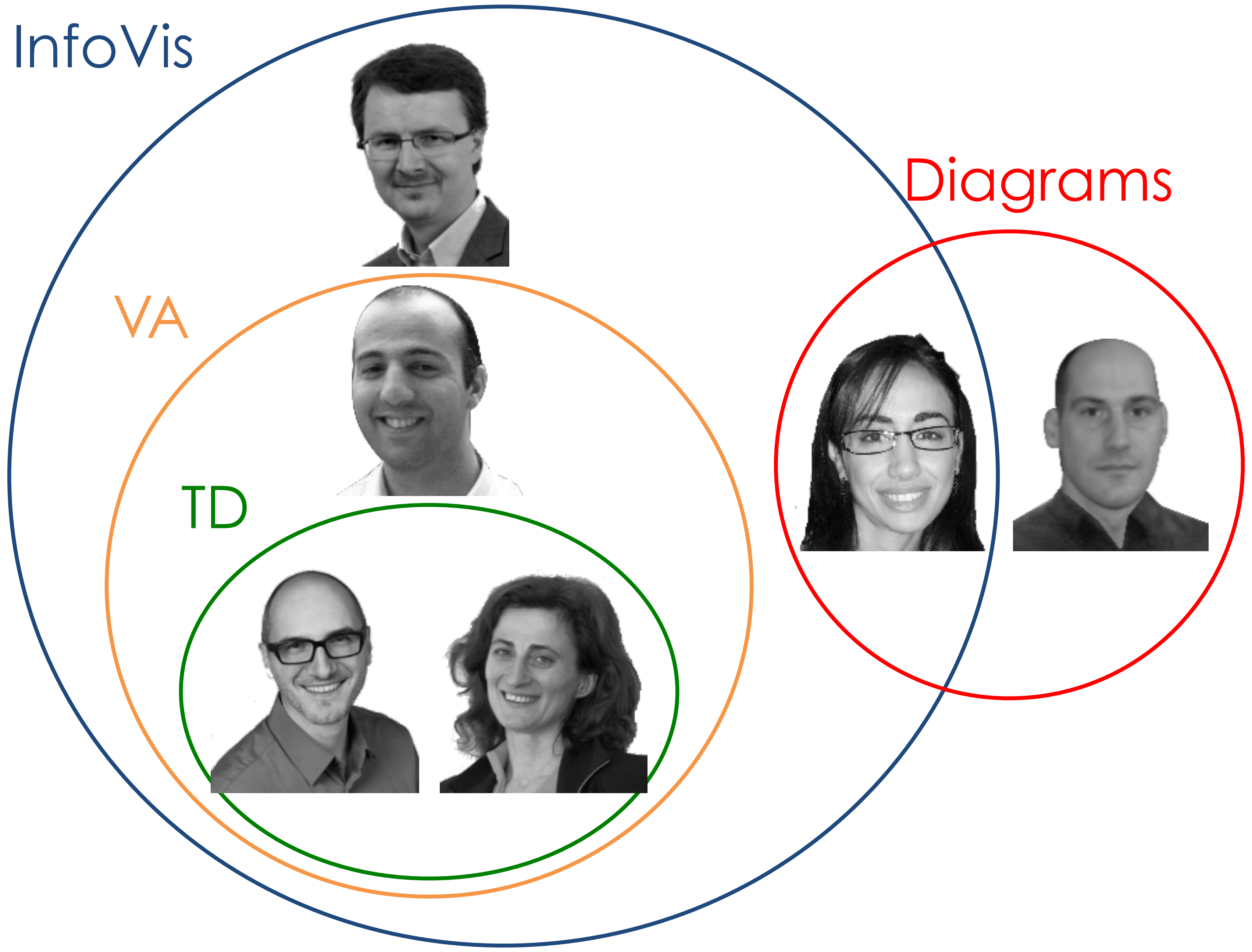
# Sets and Set Relations







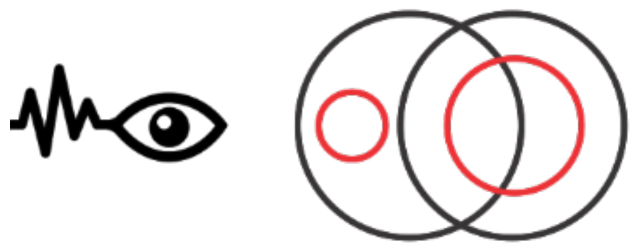



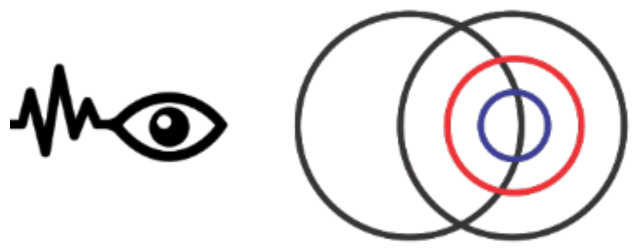


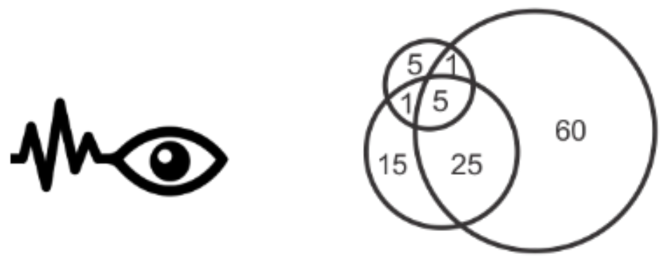

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

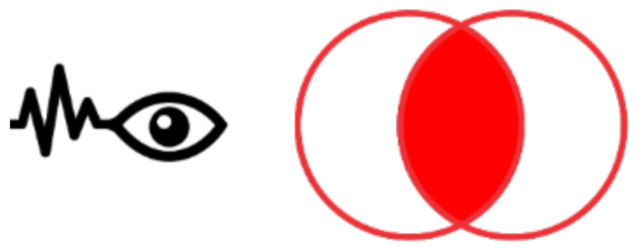
# Sets and Set Relations

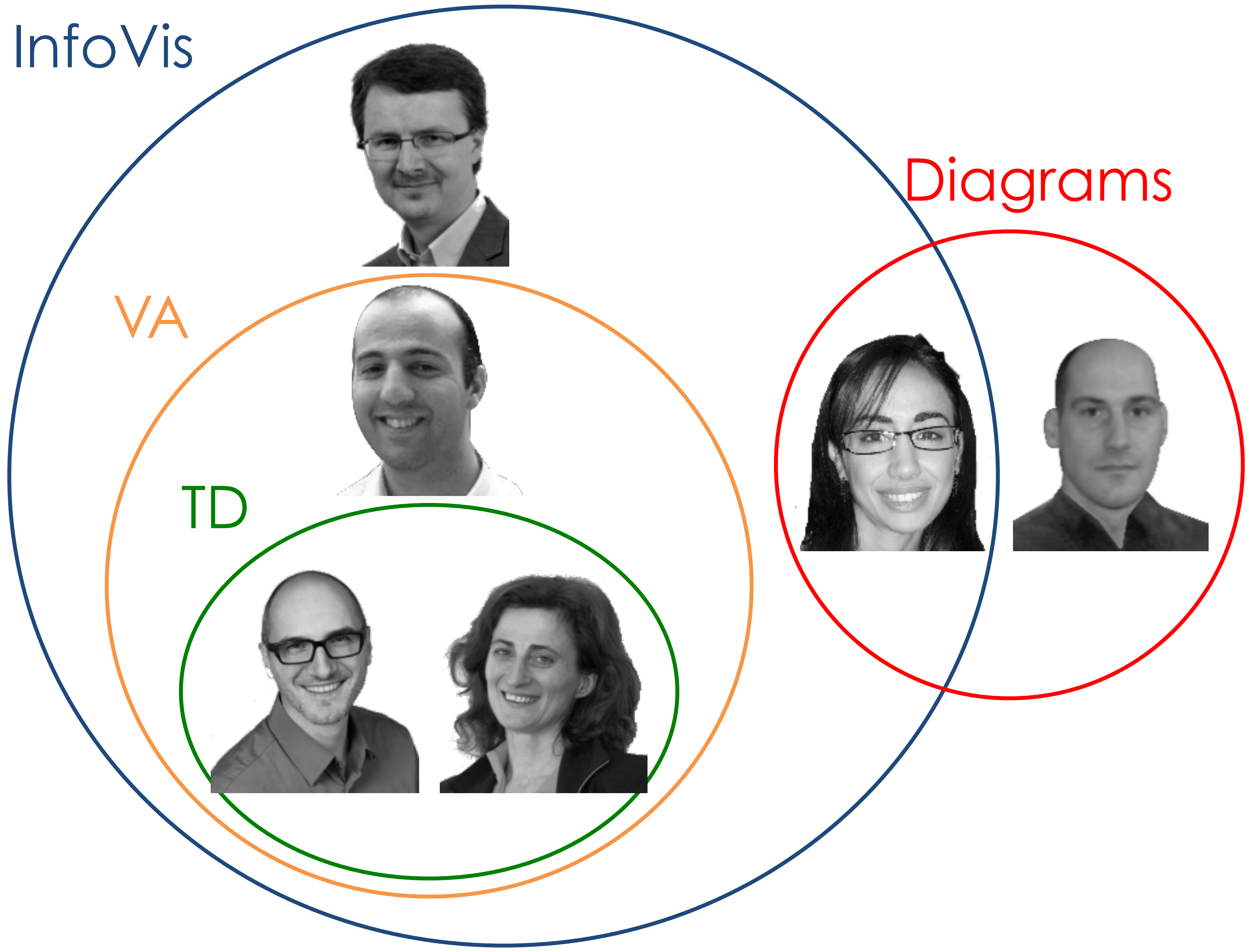
Analyze
inclusion relations







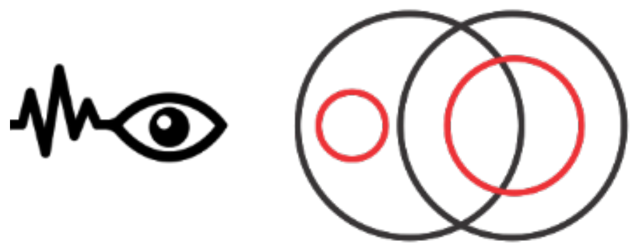



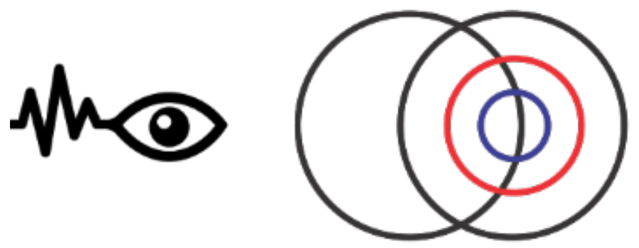


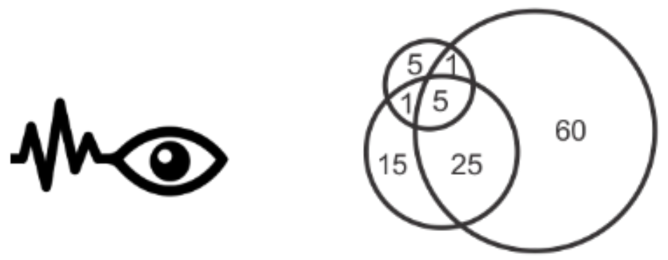

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

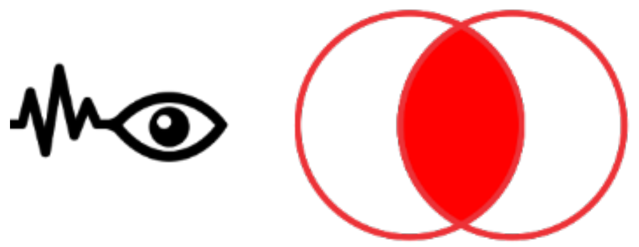
# Sets and Set Relations

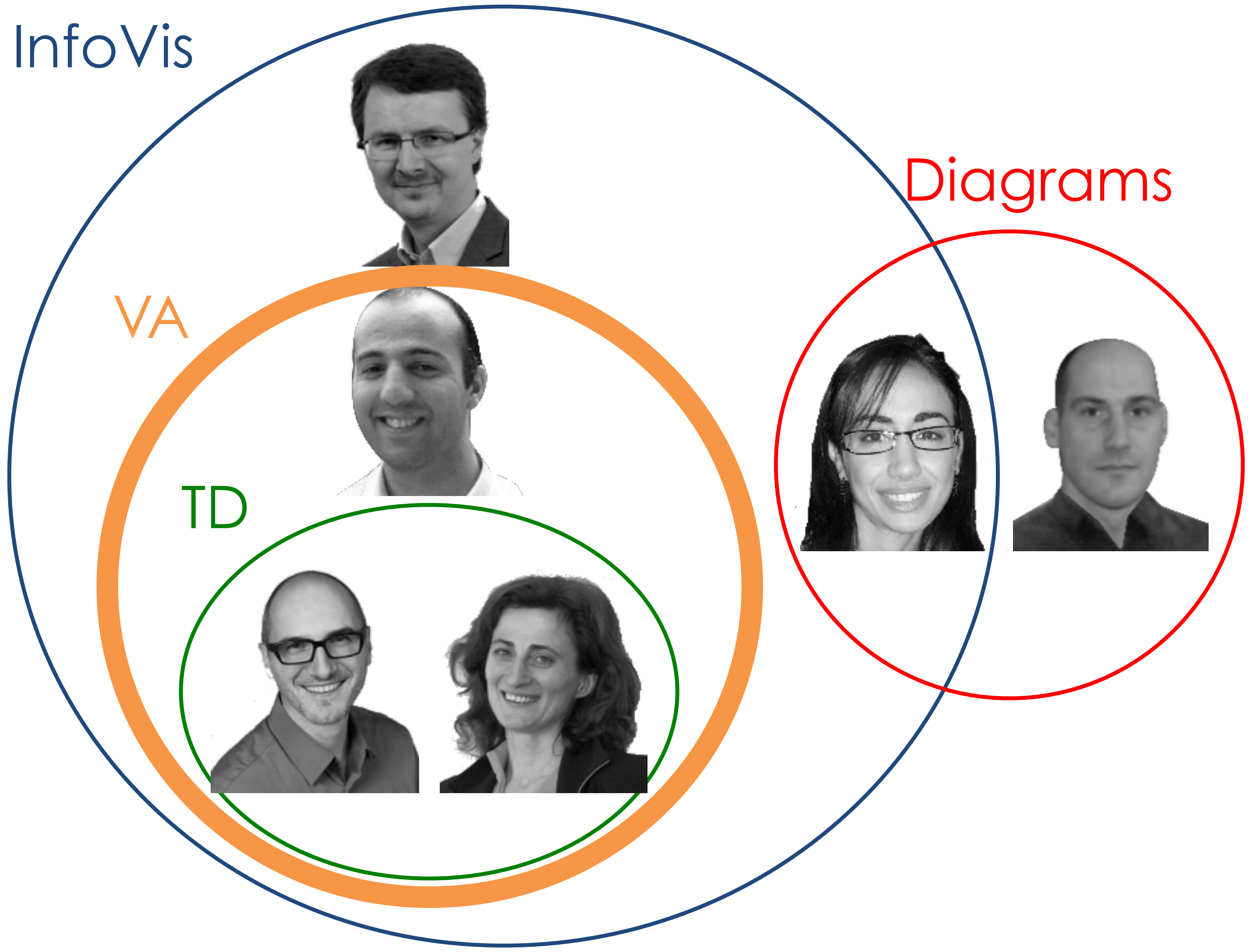
Analyze
inclusion relations







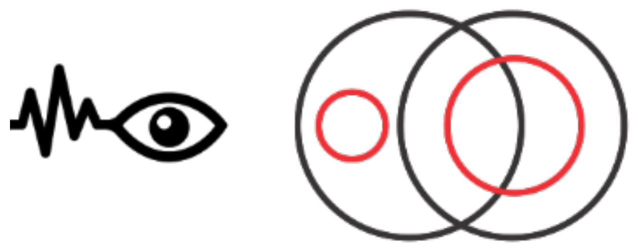



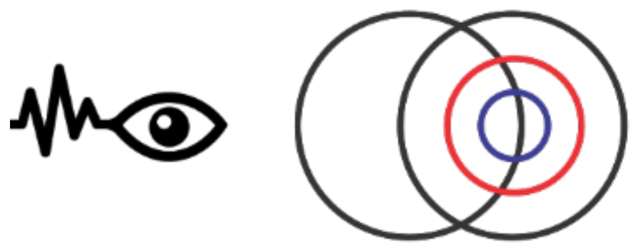


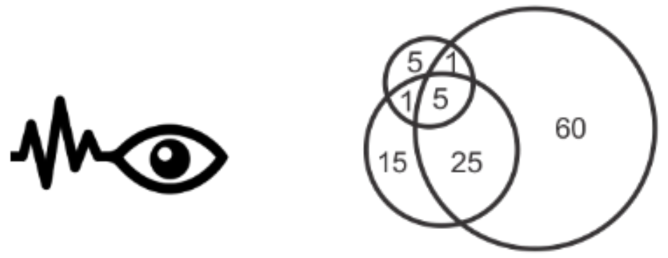

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

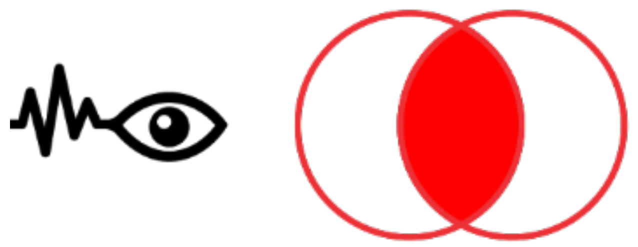
# Sets and Set Relations

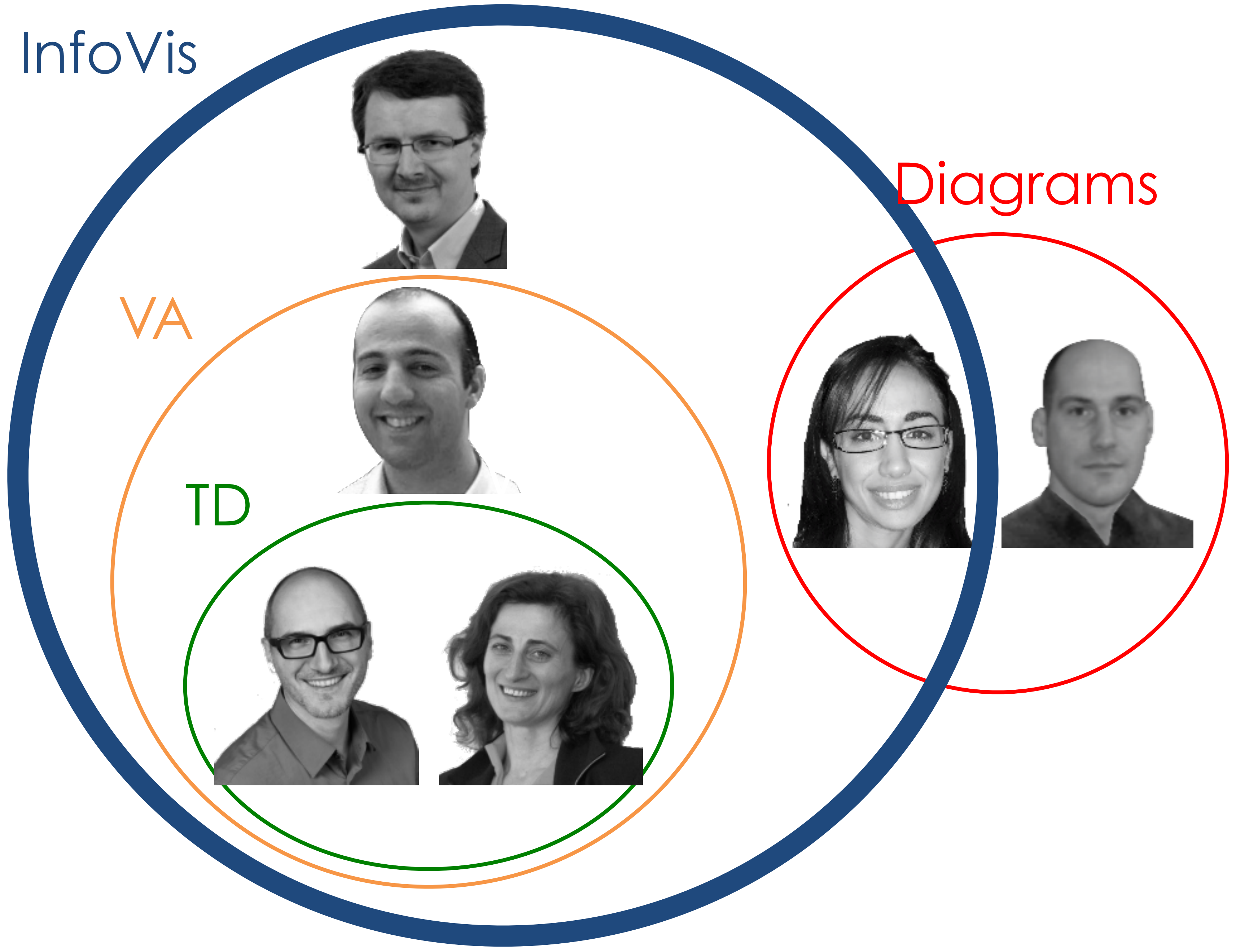
Analyze
inclusion relations







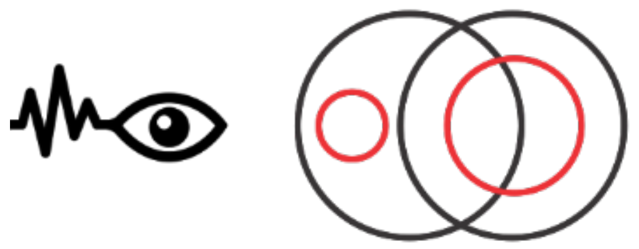



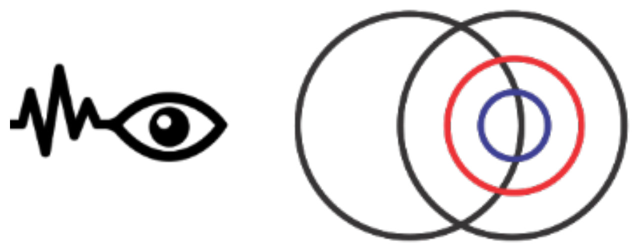


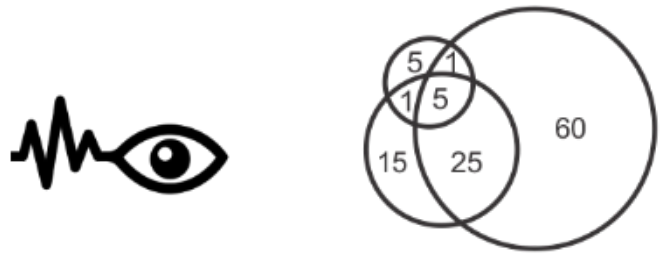

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

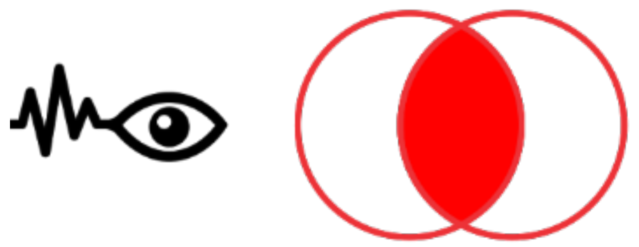
# Sets and Set Relations

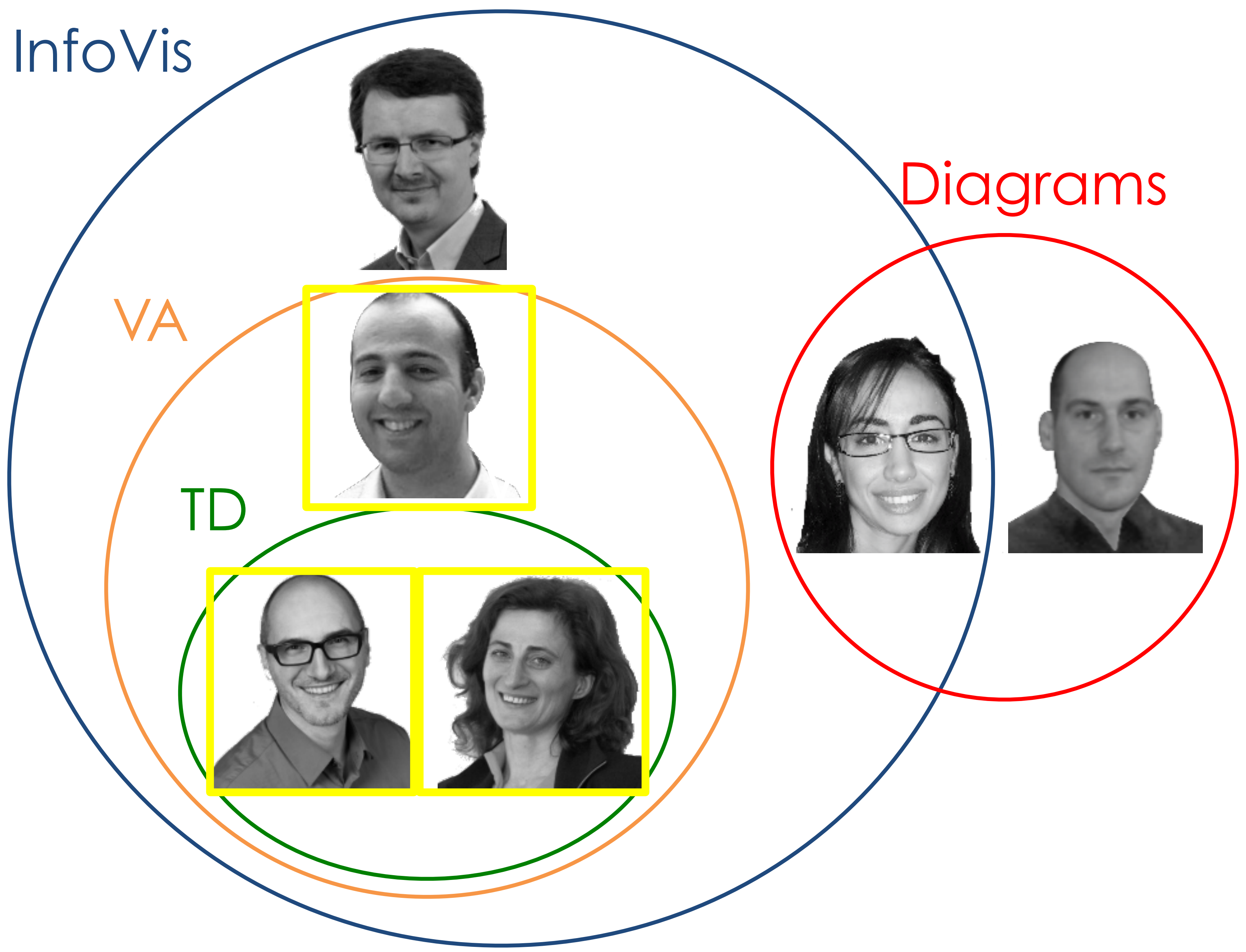
Analyze
inclusion relations





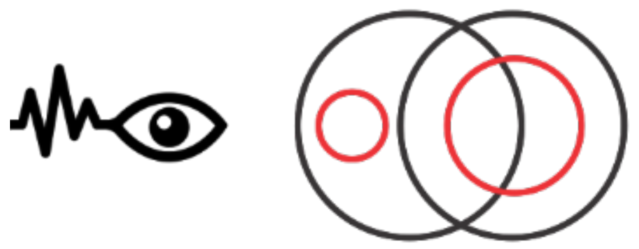


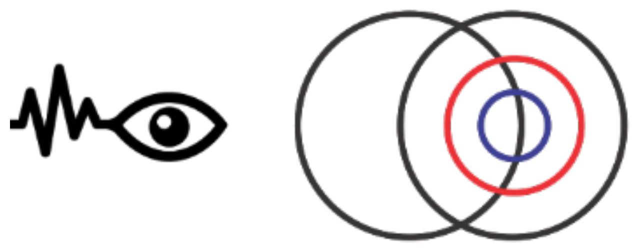



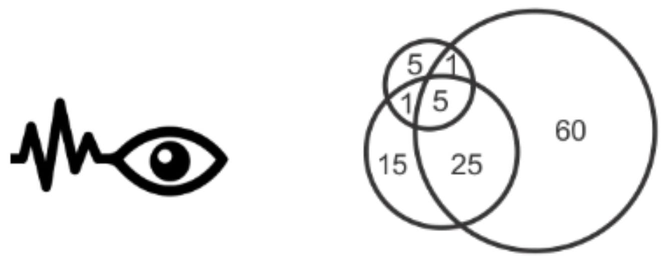


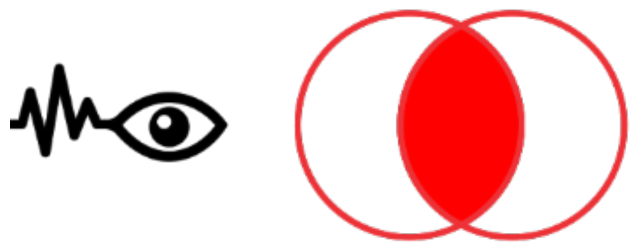

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations

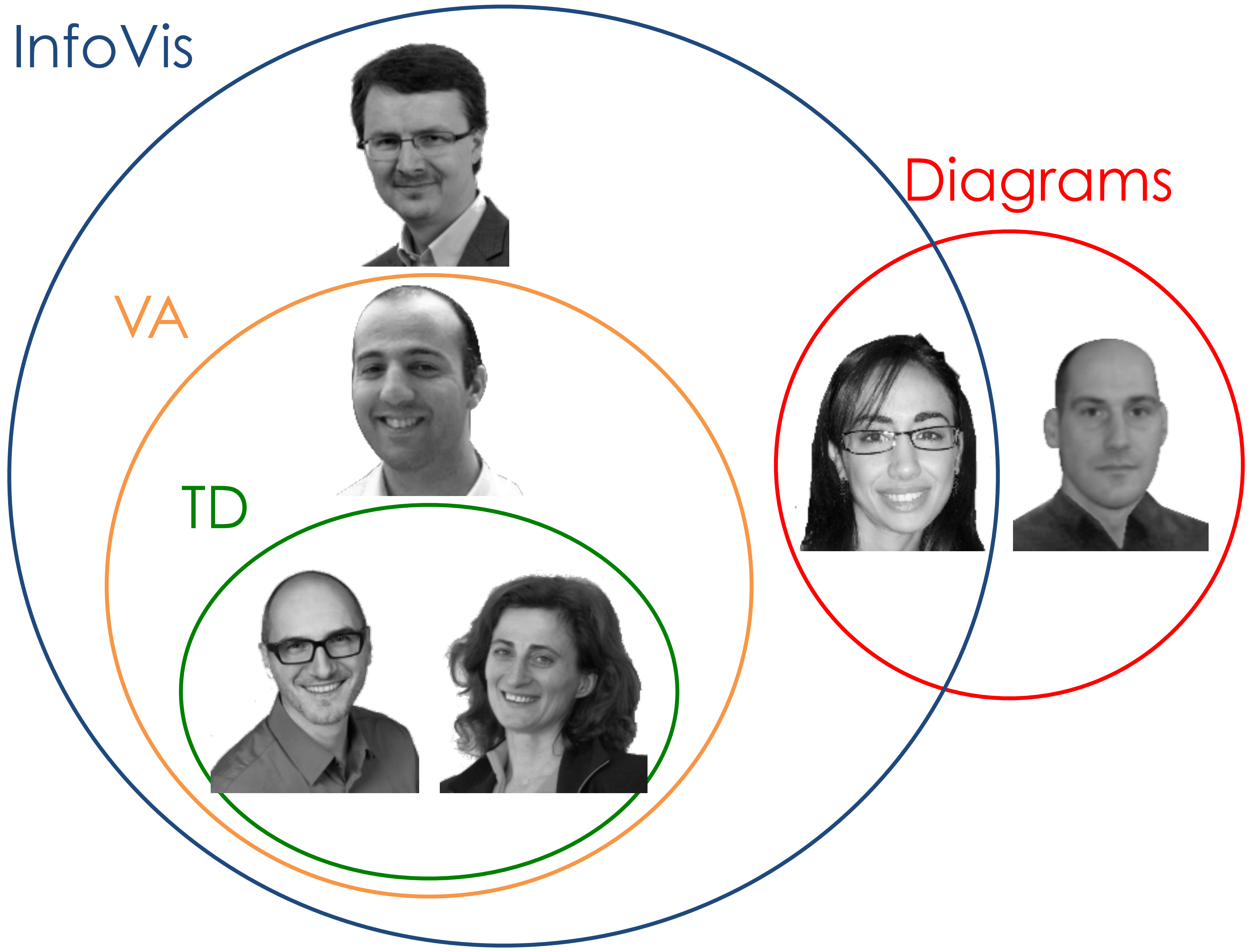




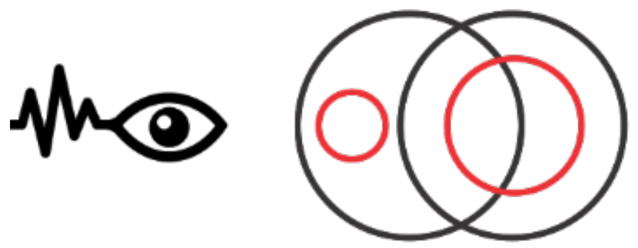


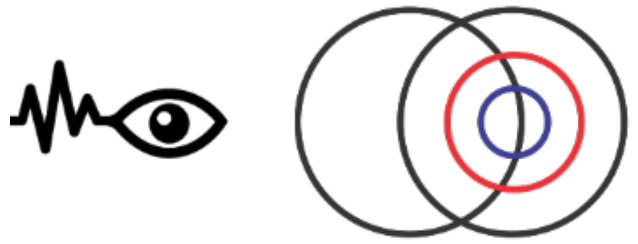
InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

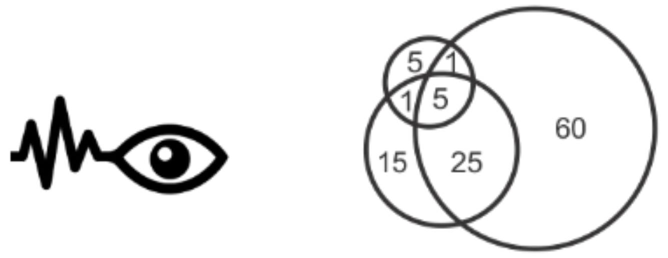


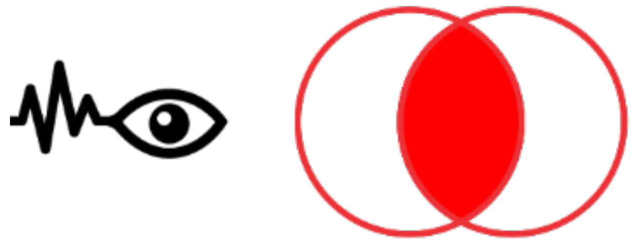
# Sets and Set Relations



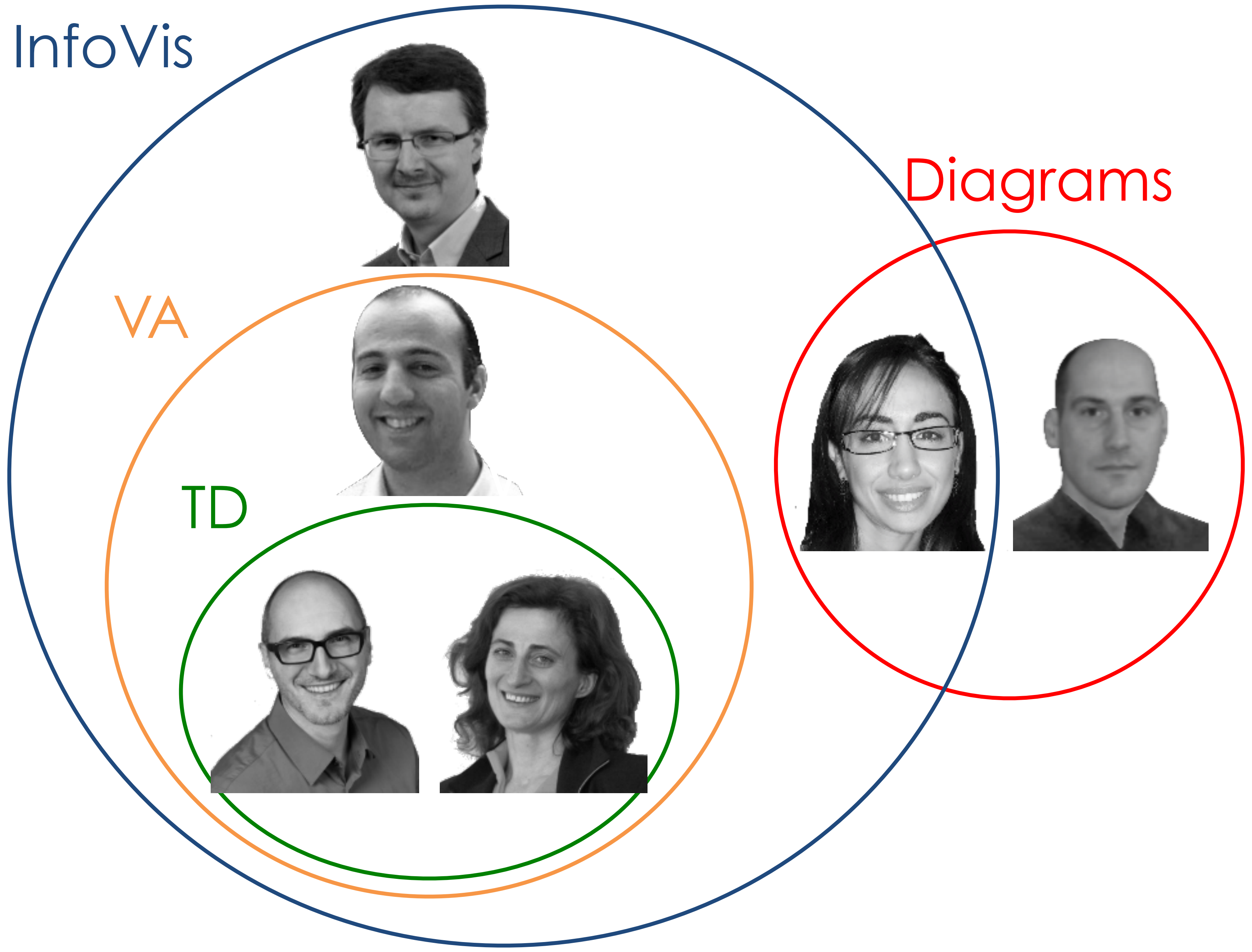
Analyze
inclusion hierarchies



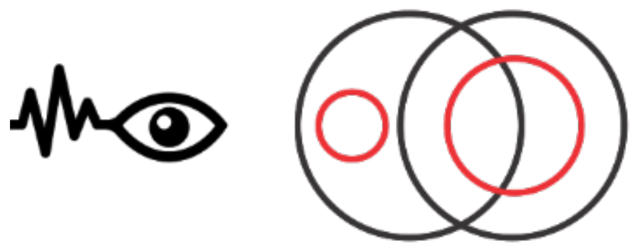




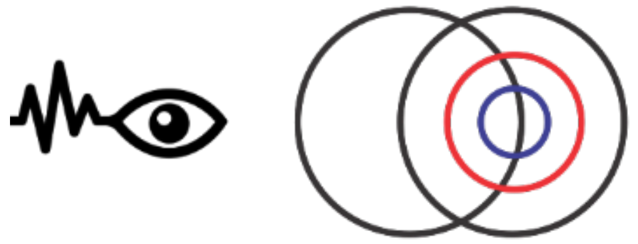
InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

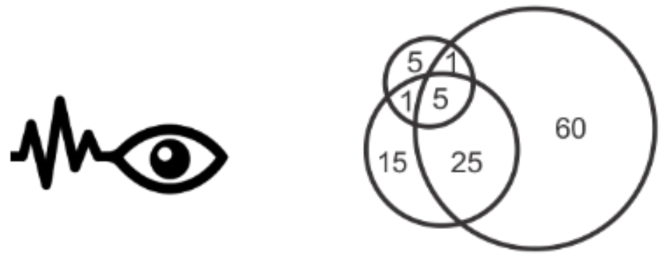


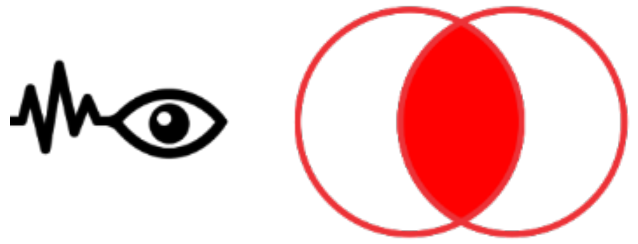
# Sets and Set Relations

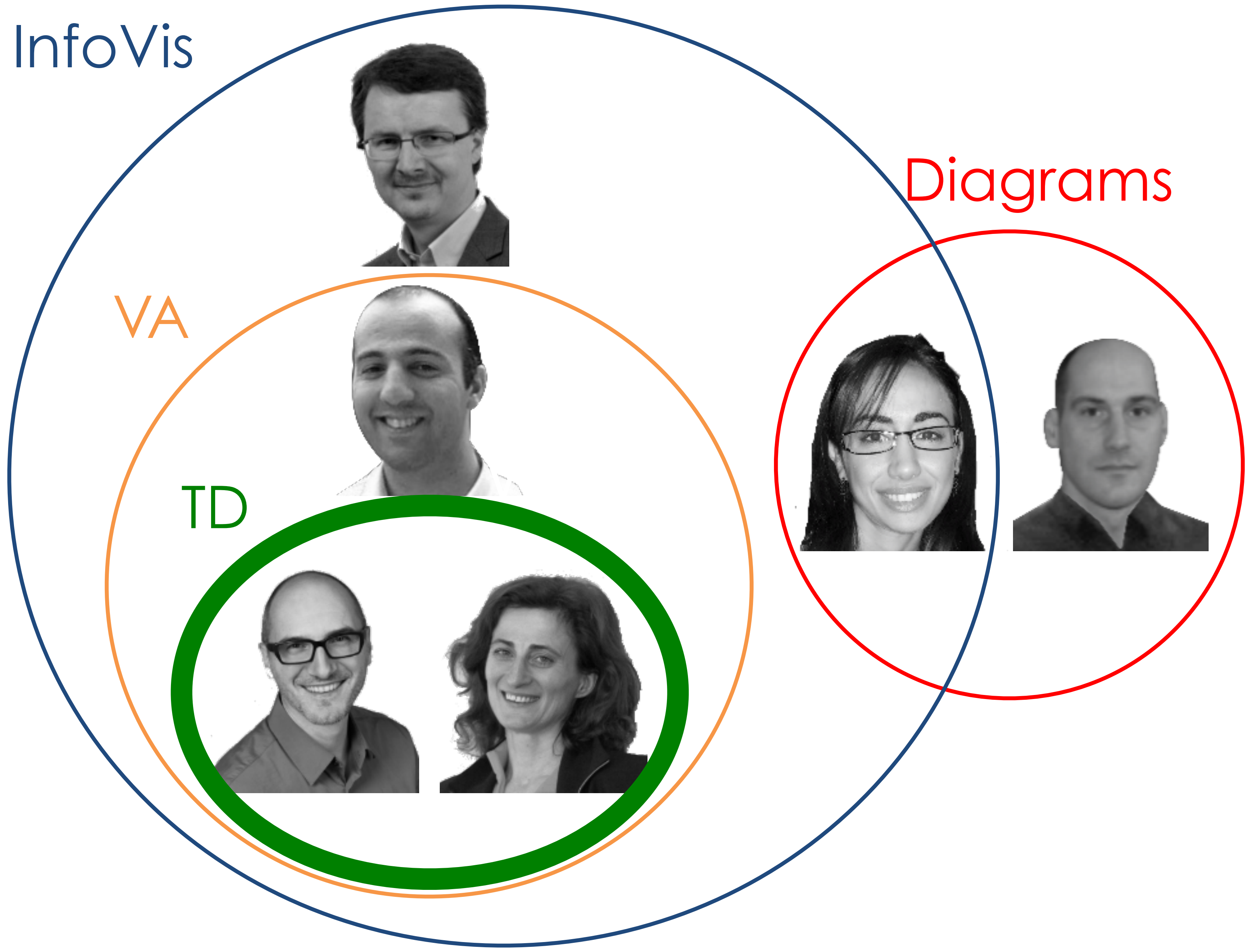


Analyze
inclusion hierarchies



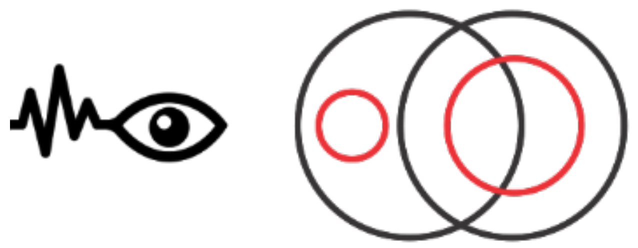


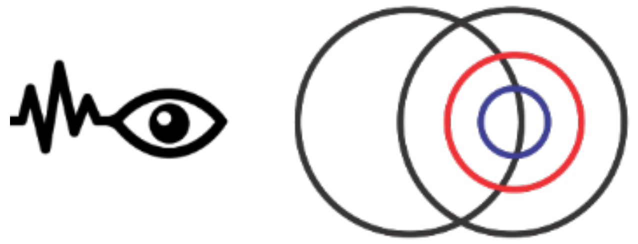


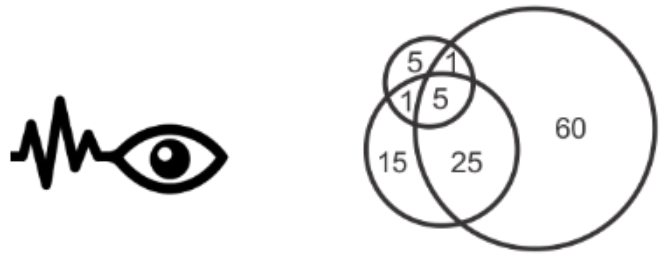

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

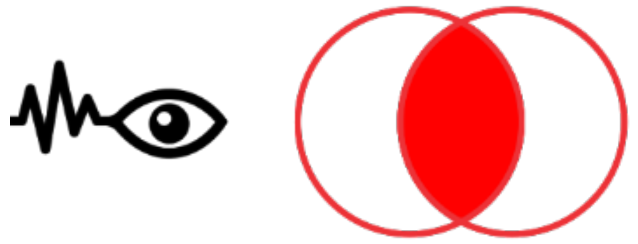
# Sets and Set Relations

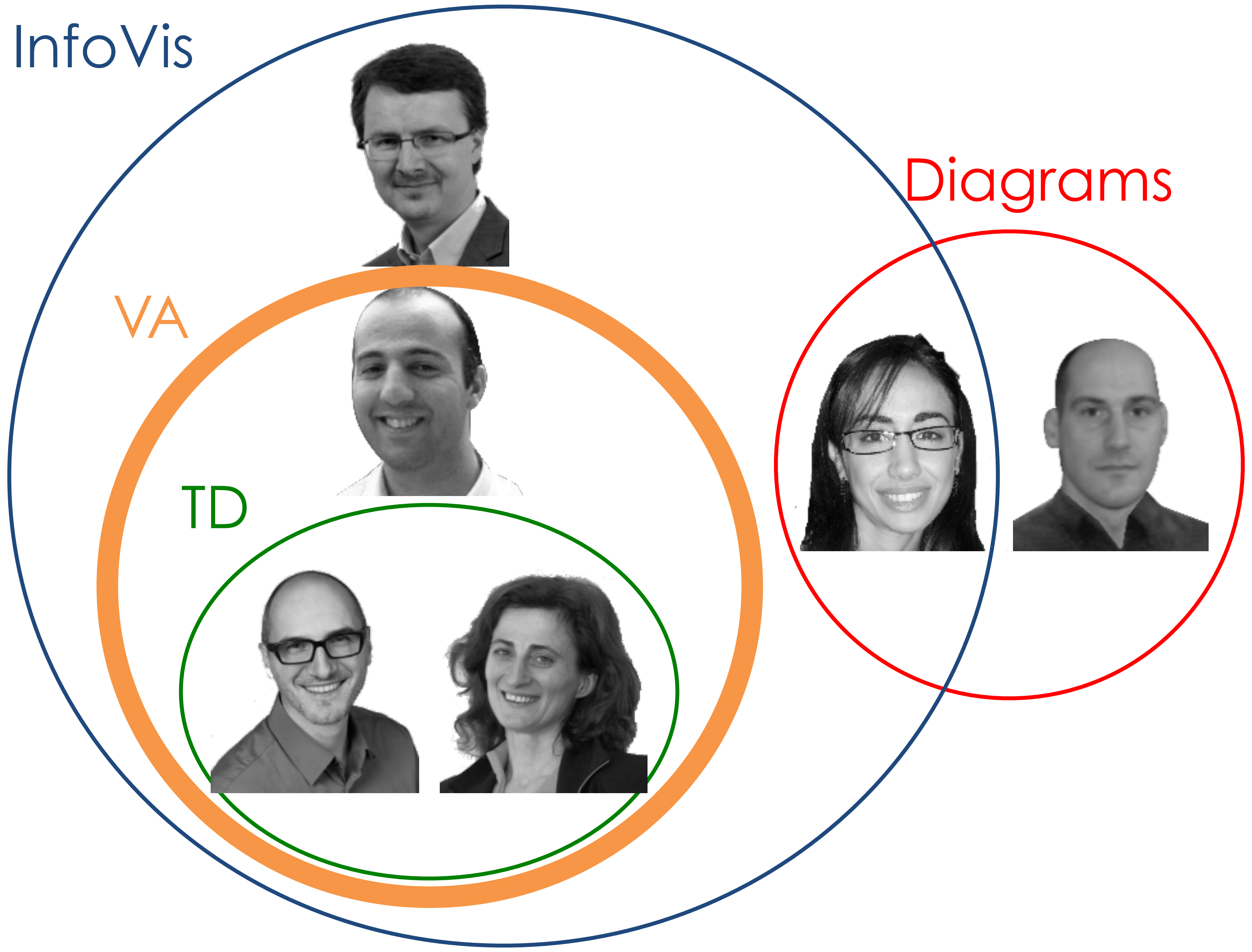


Analyze
inclusion hierarchies



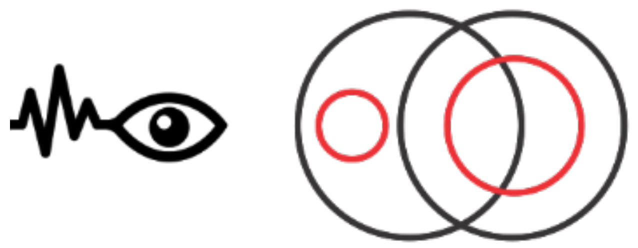


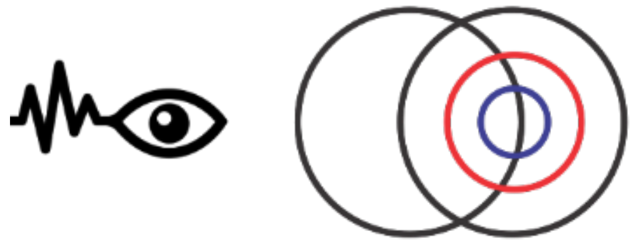


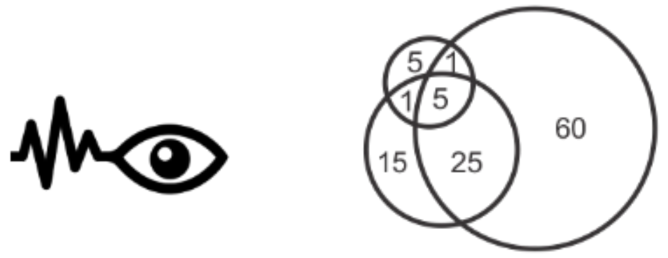

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

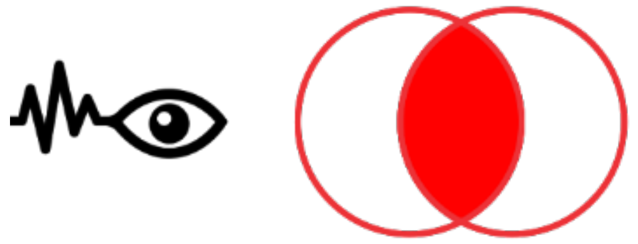
# Sets and Set Relations

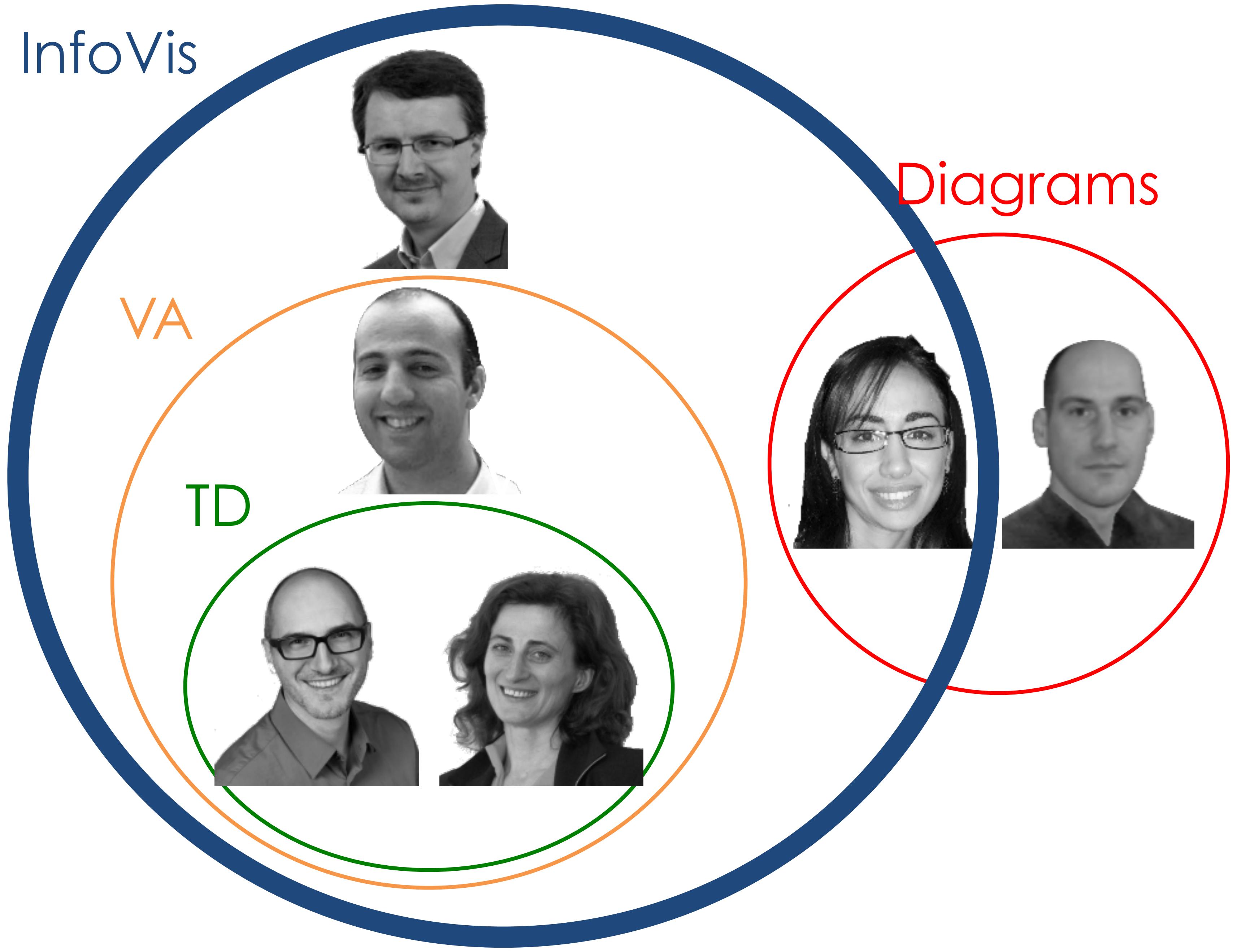


Analyze
inclusion hierarchies



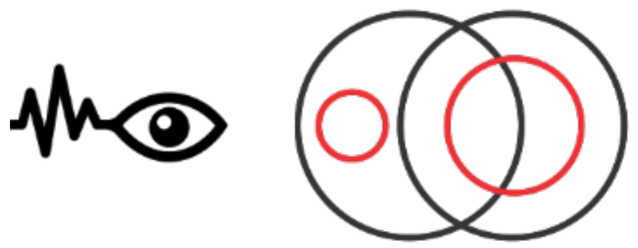


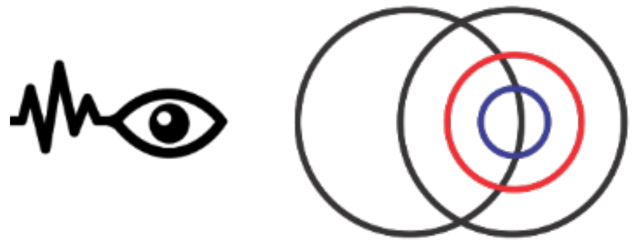


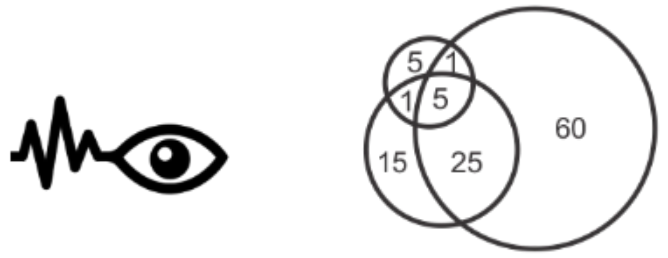

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

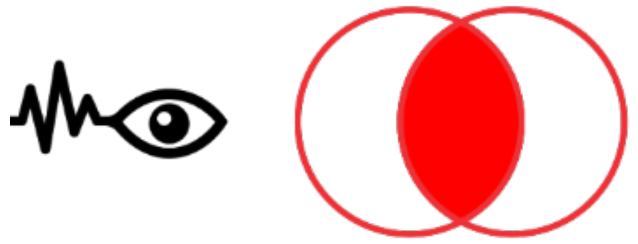
# Sets and Set Relations

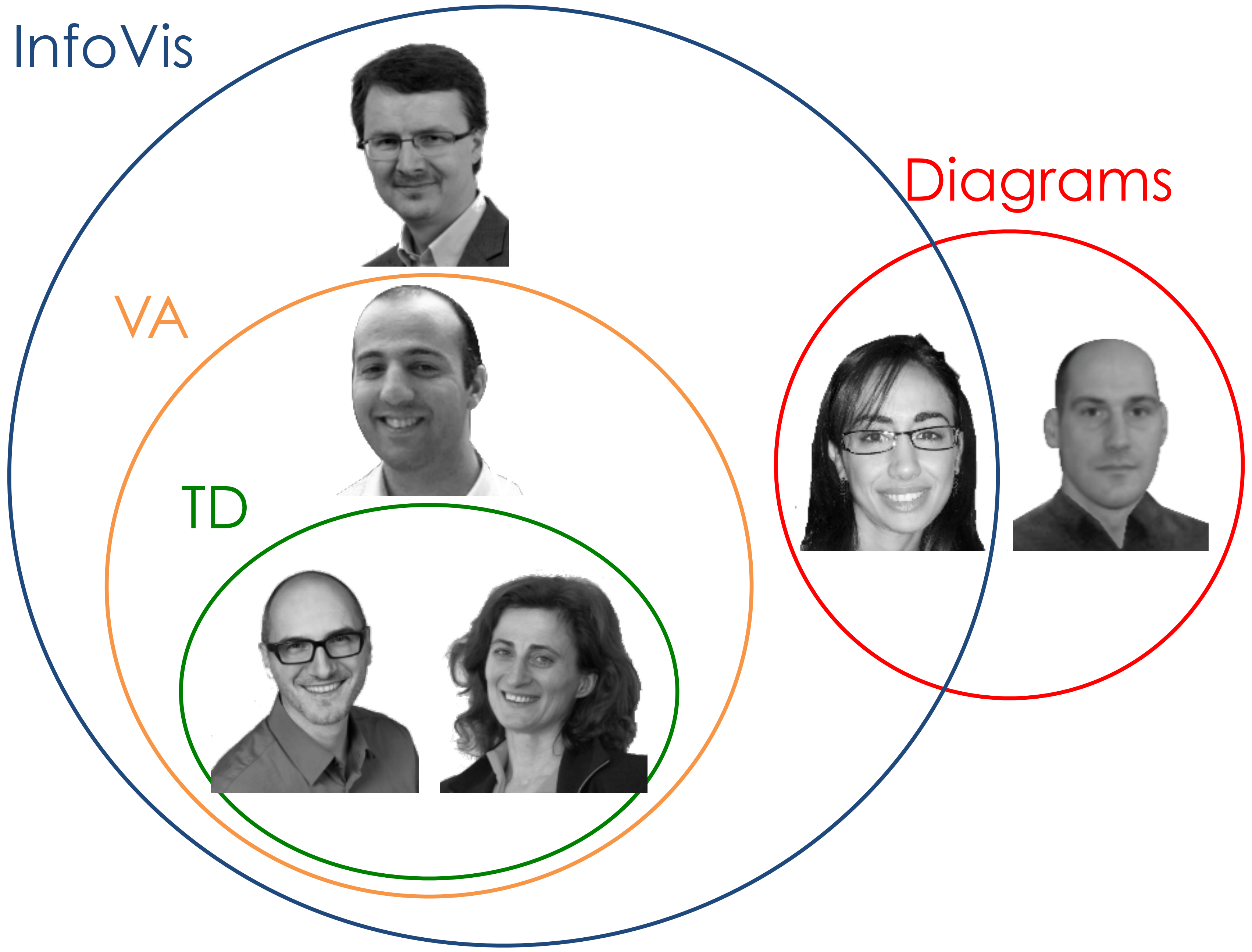


Analyze
inclusion hierarchies



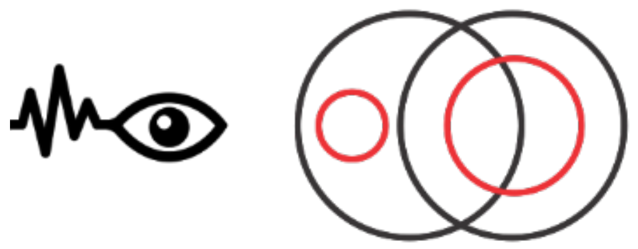


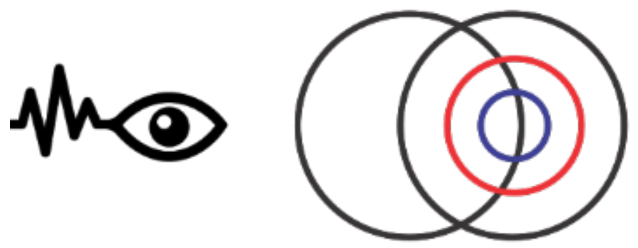



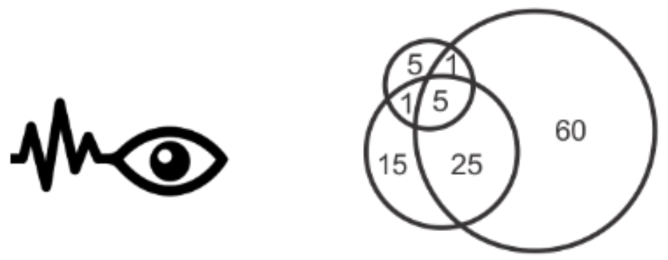


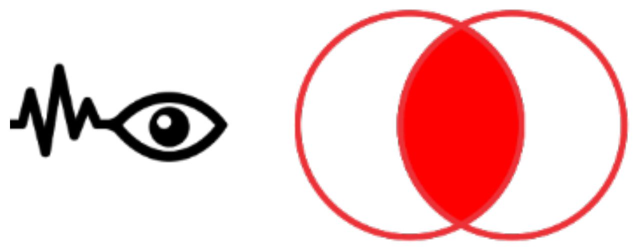

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

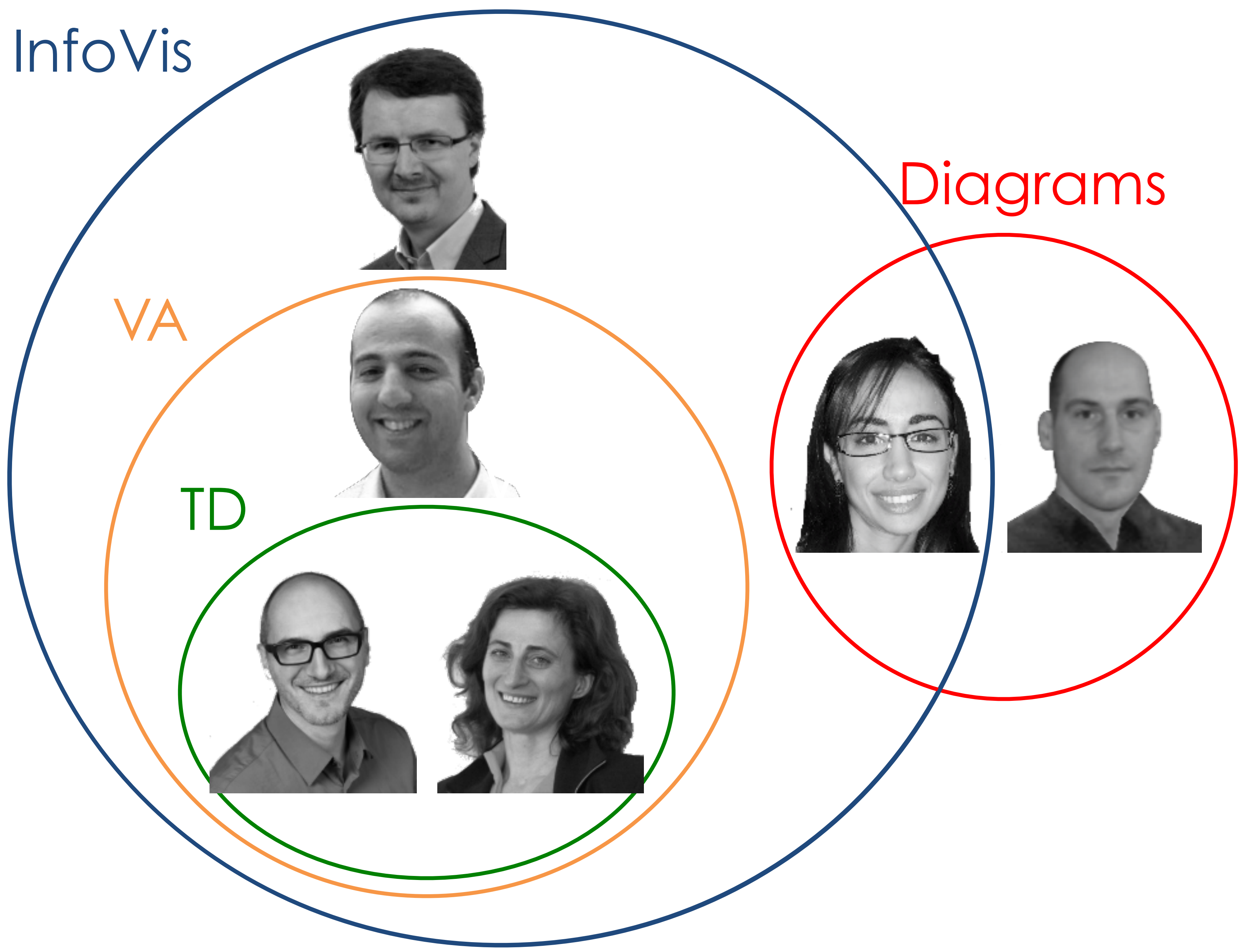
# Sets and Set Relations





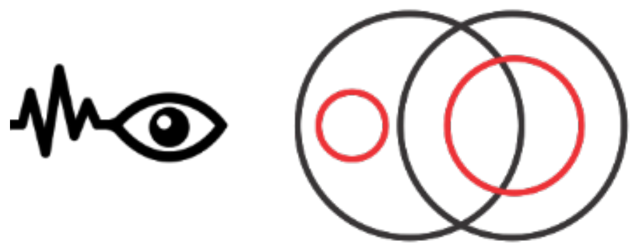


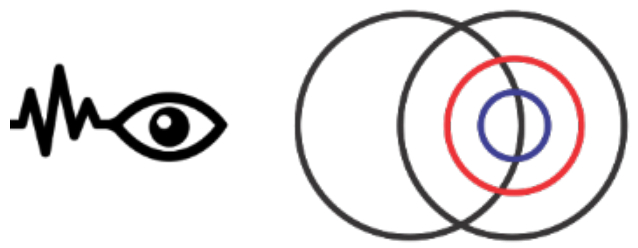



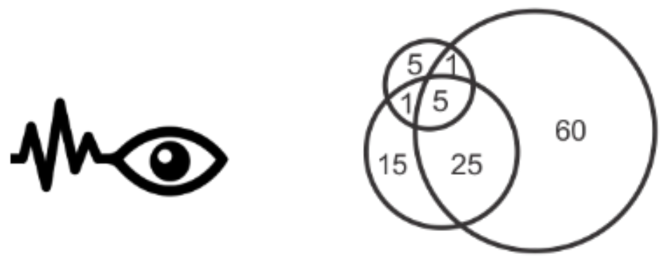



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

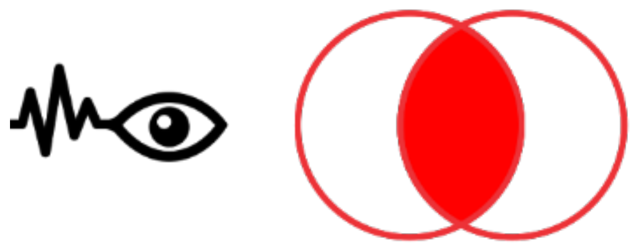
# Sets and Set Relations

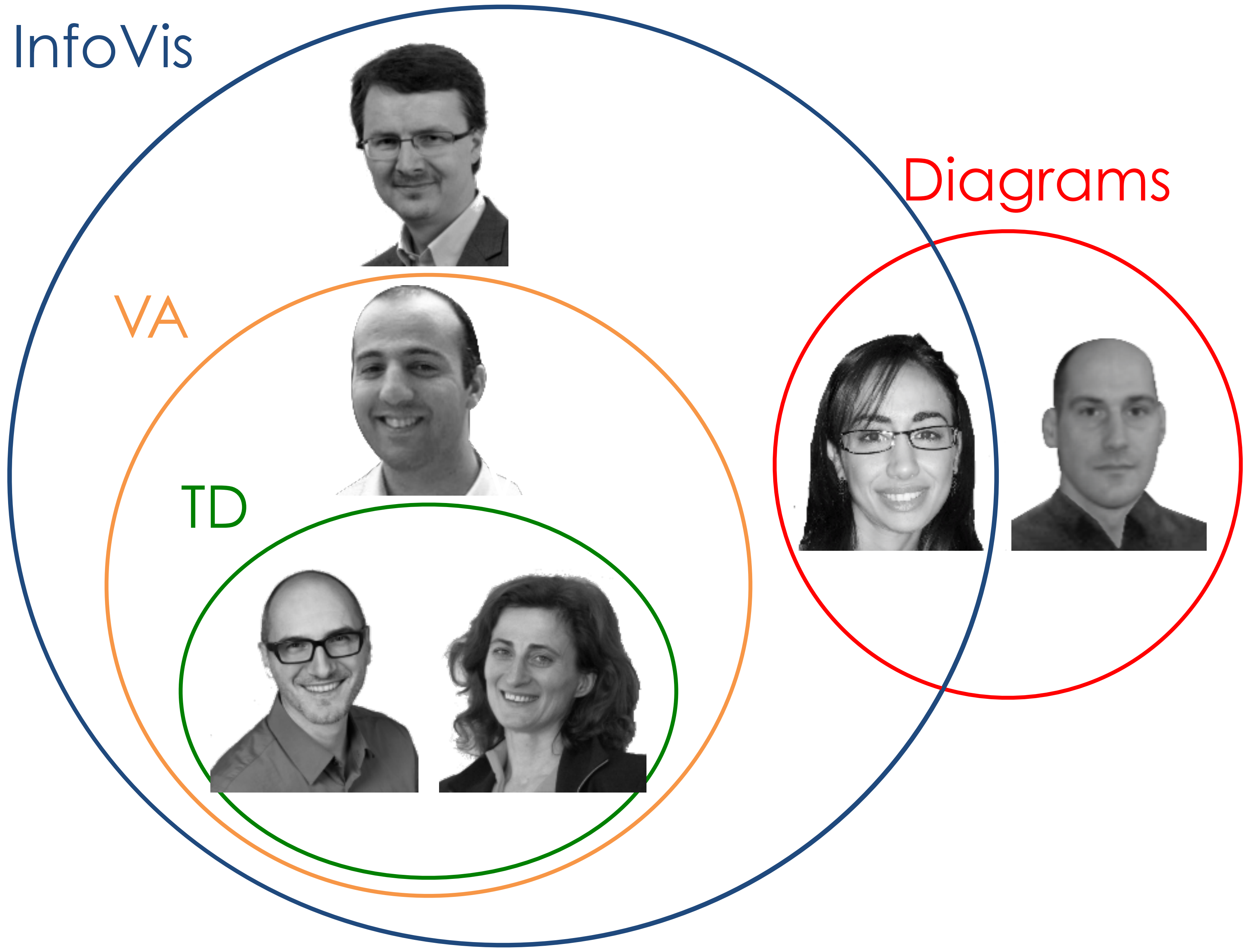






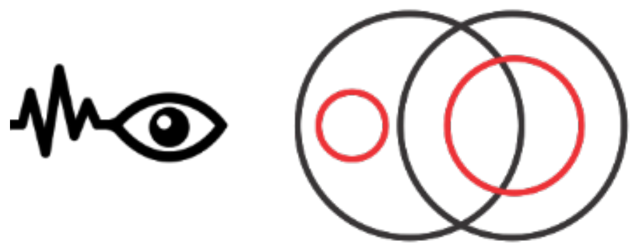

Analyze
exclusion relations

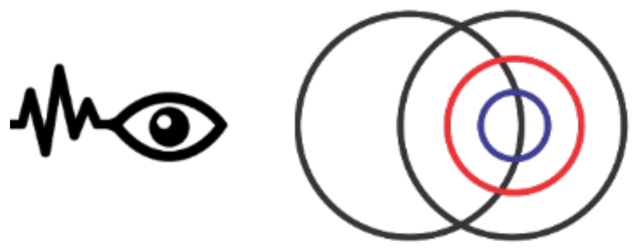


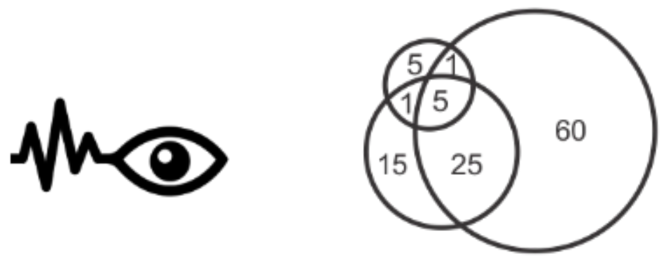



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

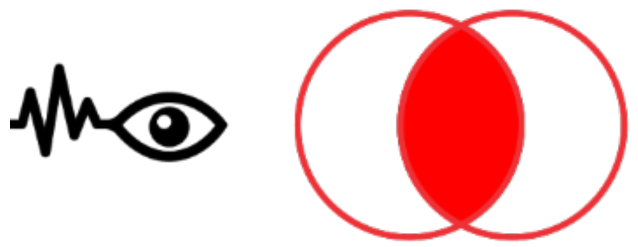
# Sets and Set Relations

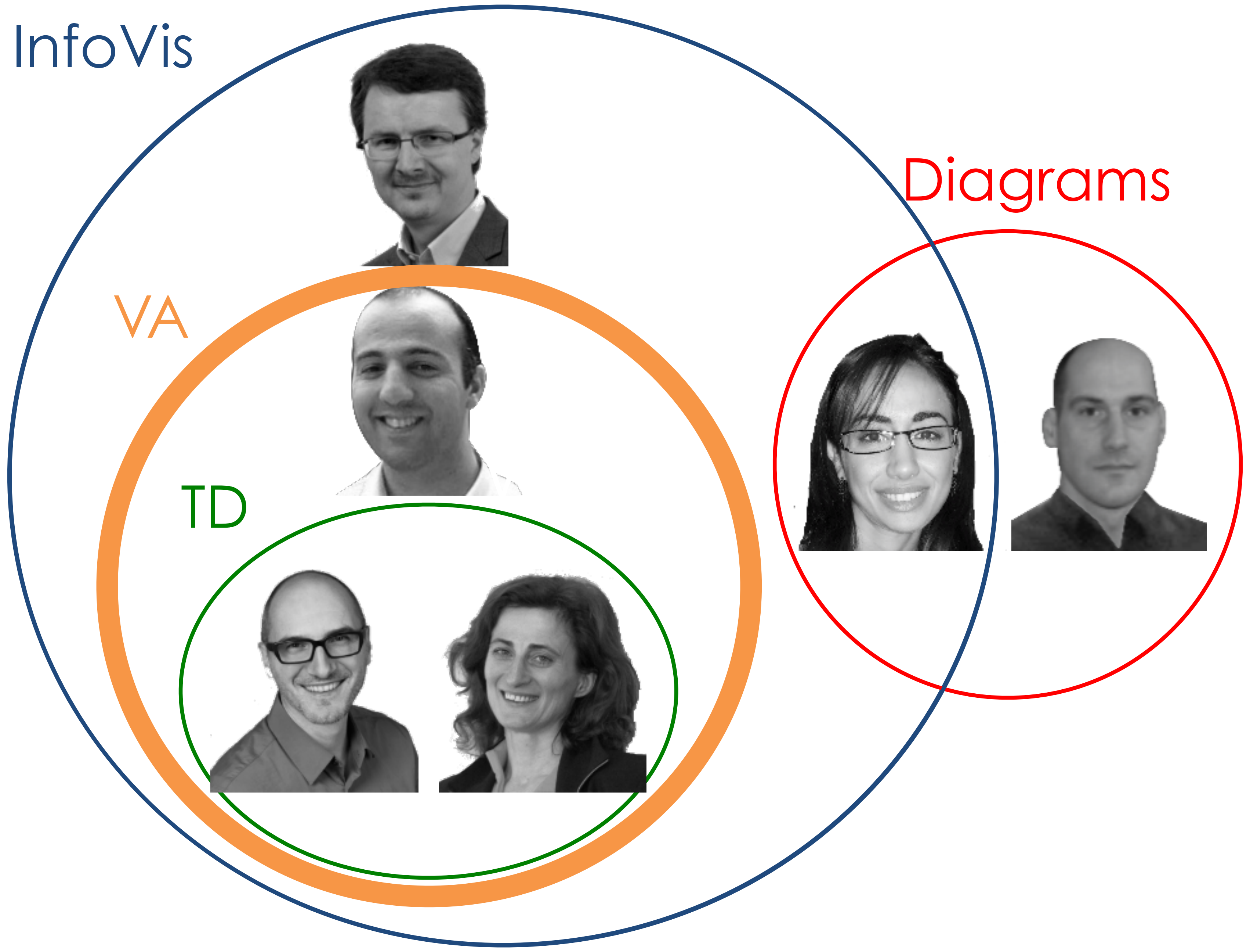






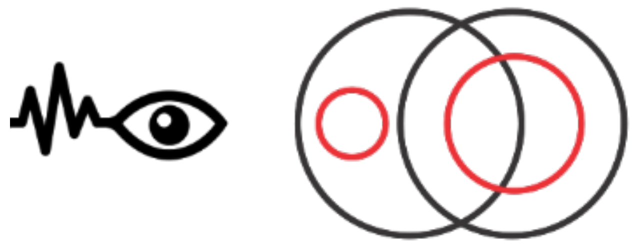

Analyze
exclusion relations

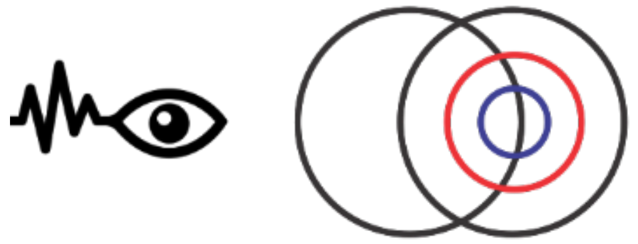


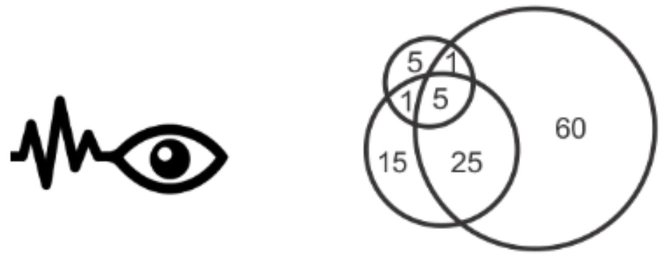



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

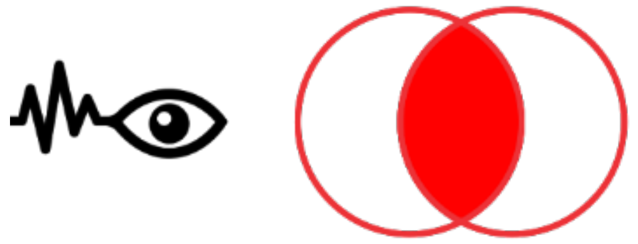
# Sets and Set Relations

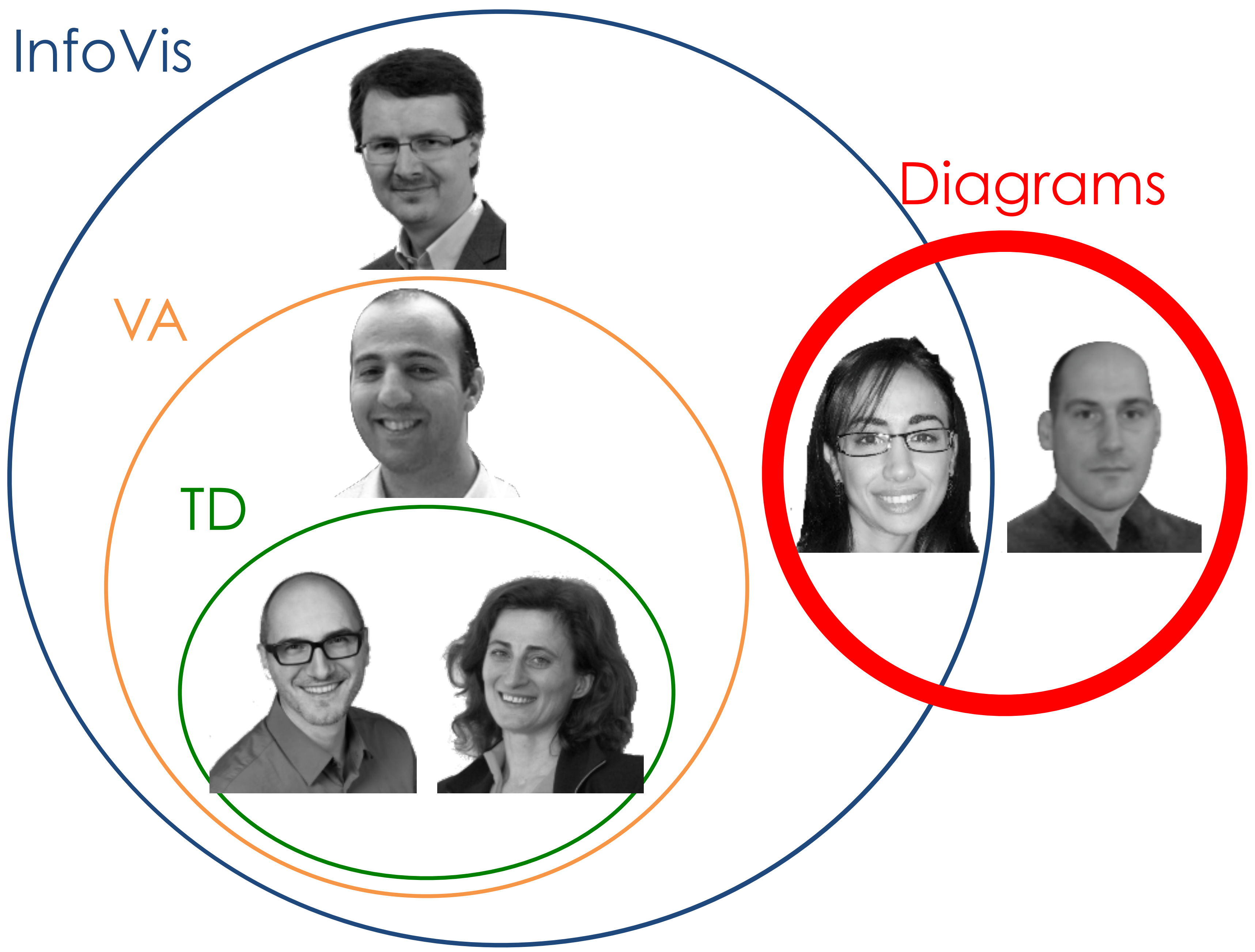






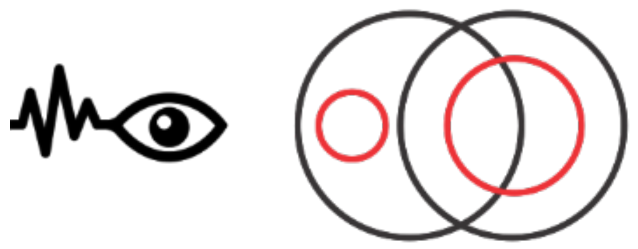

Analyze
exclusion relations

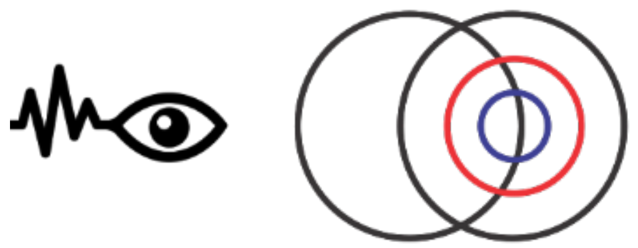


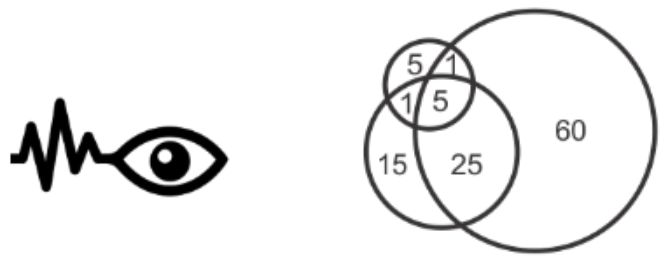



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

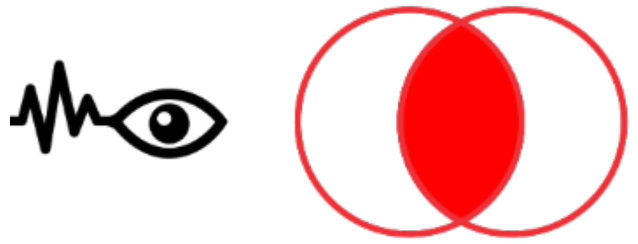
# Sets and Set Relations

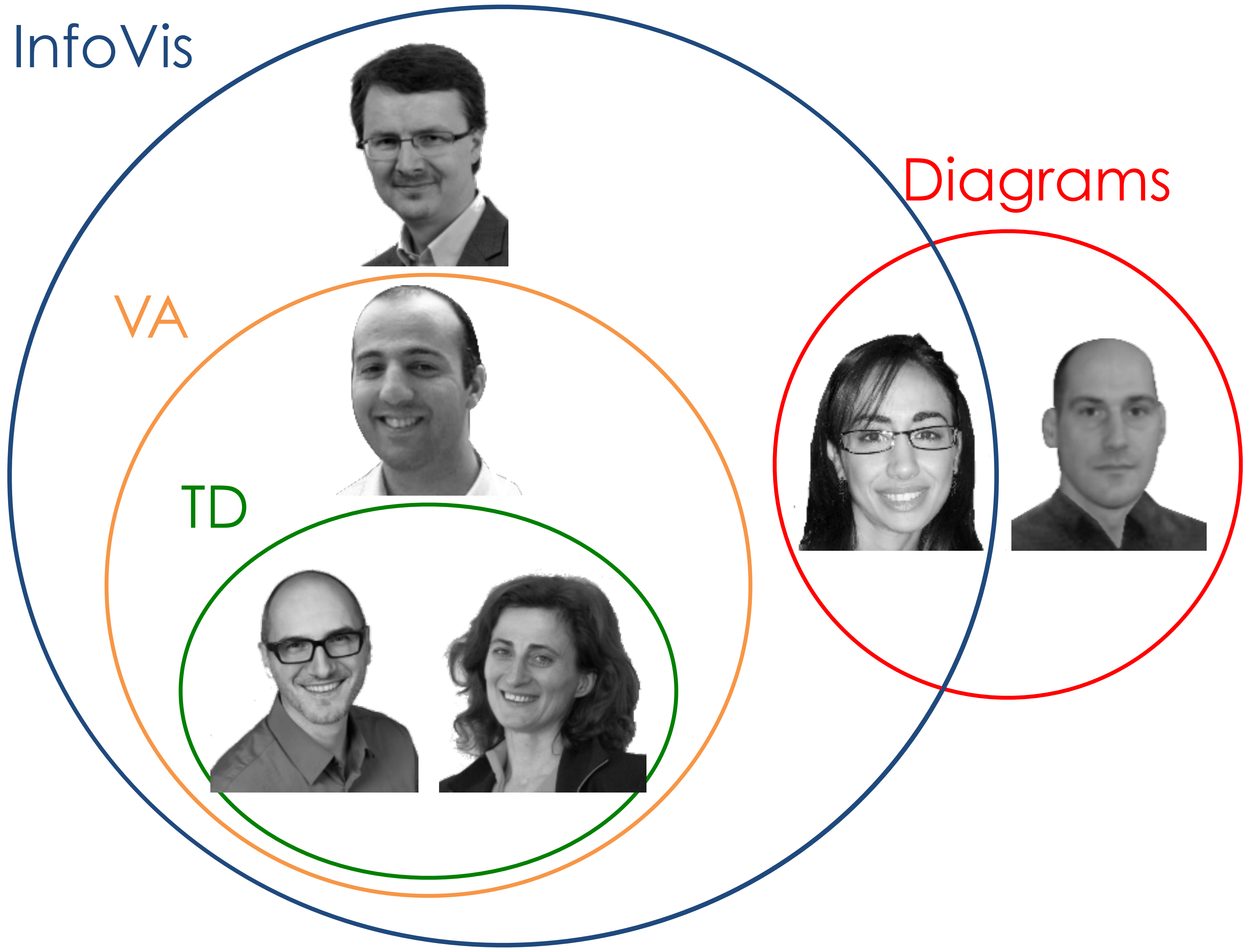






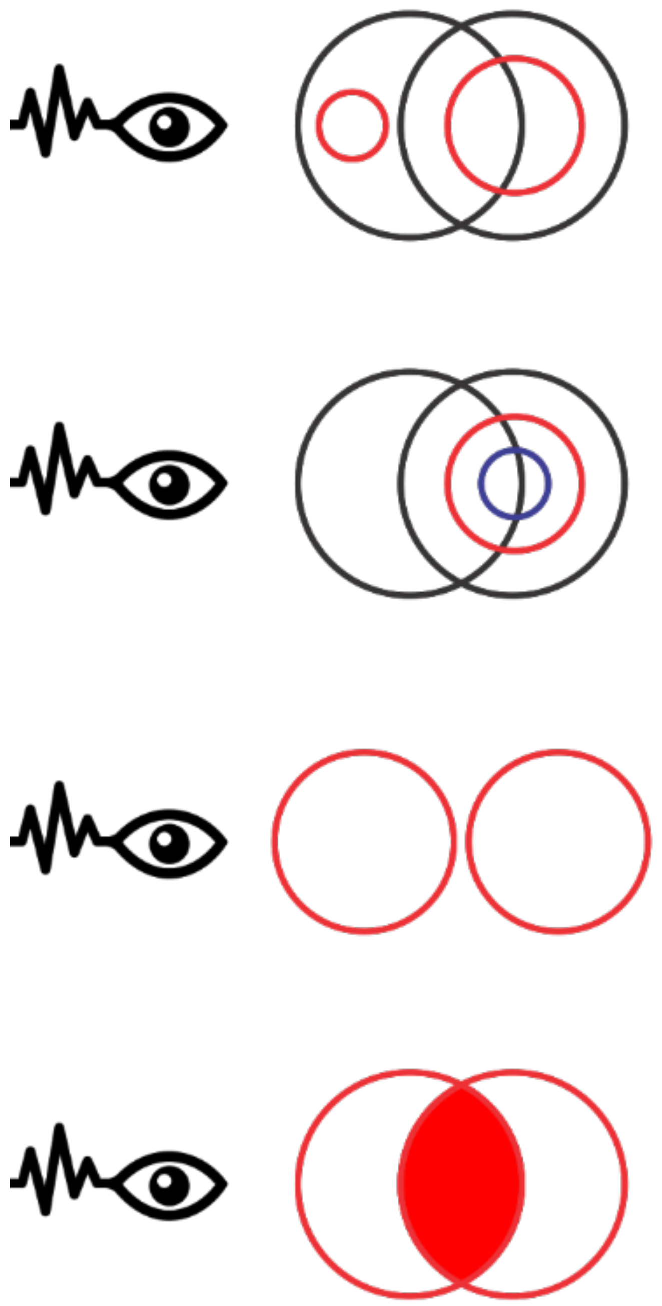

Analyze
exclusion relations

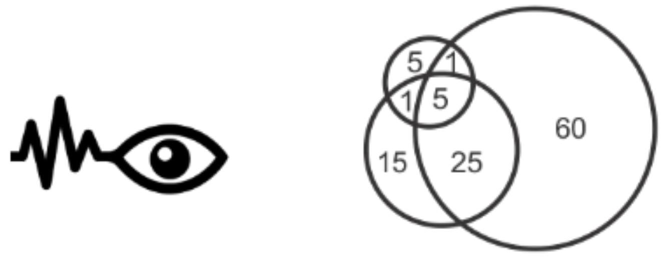


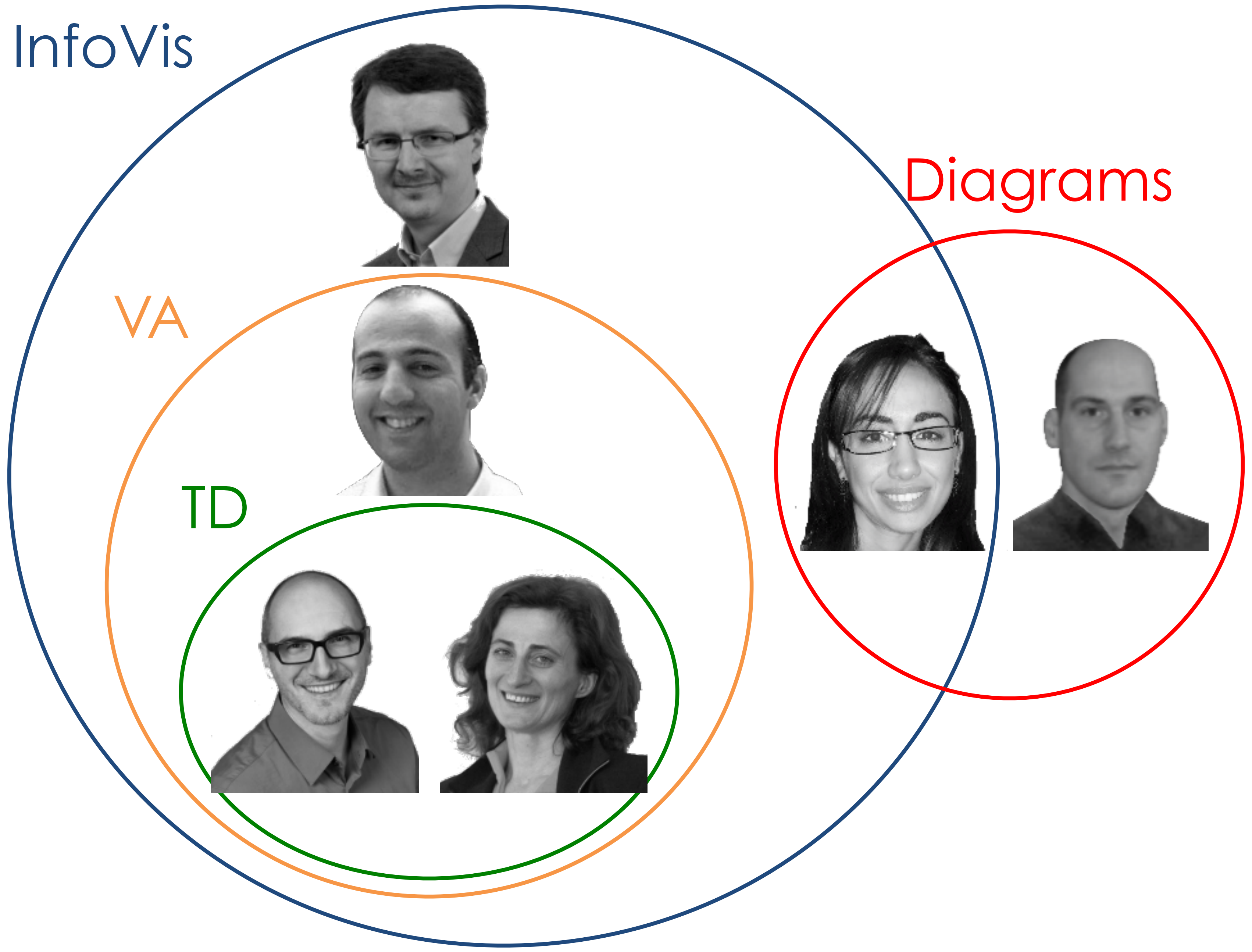



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations

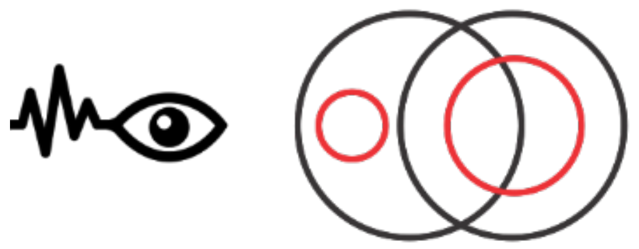


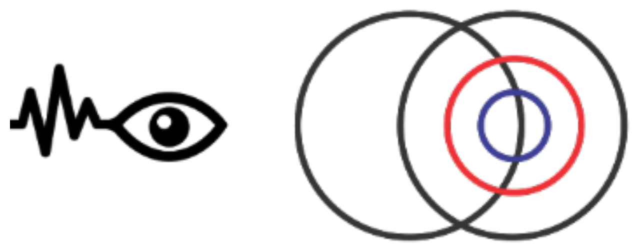


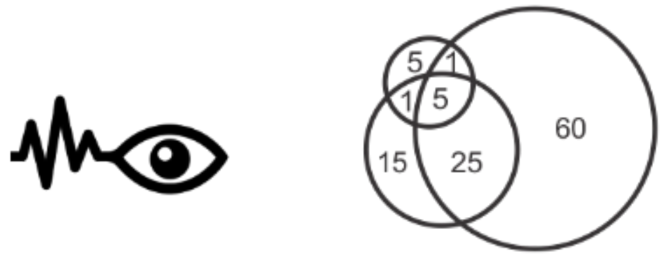




InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations

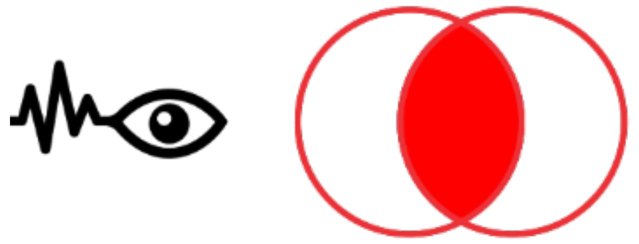


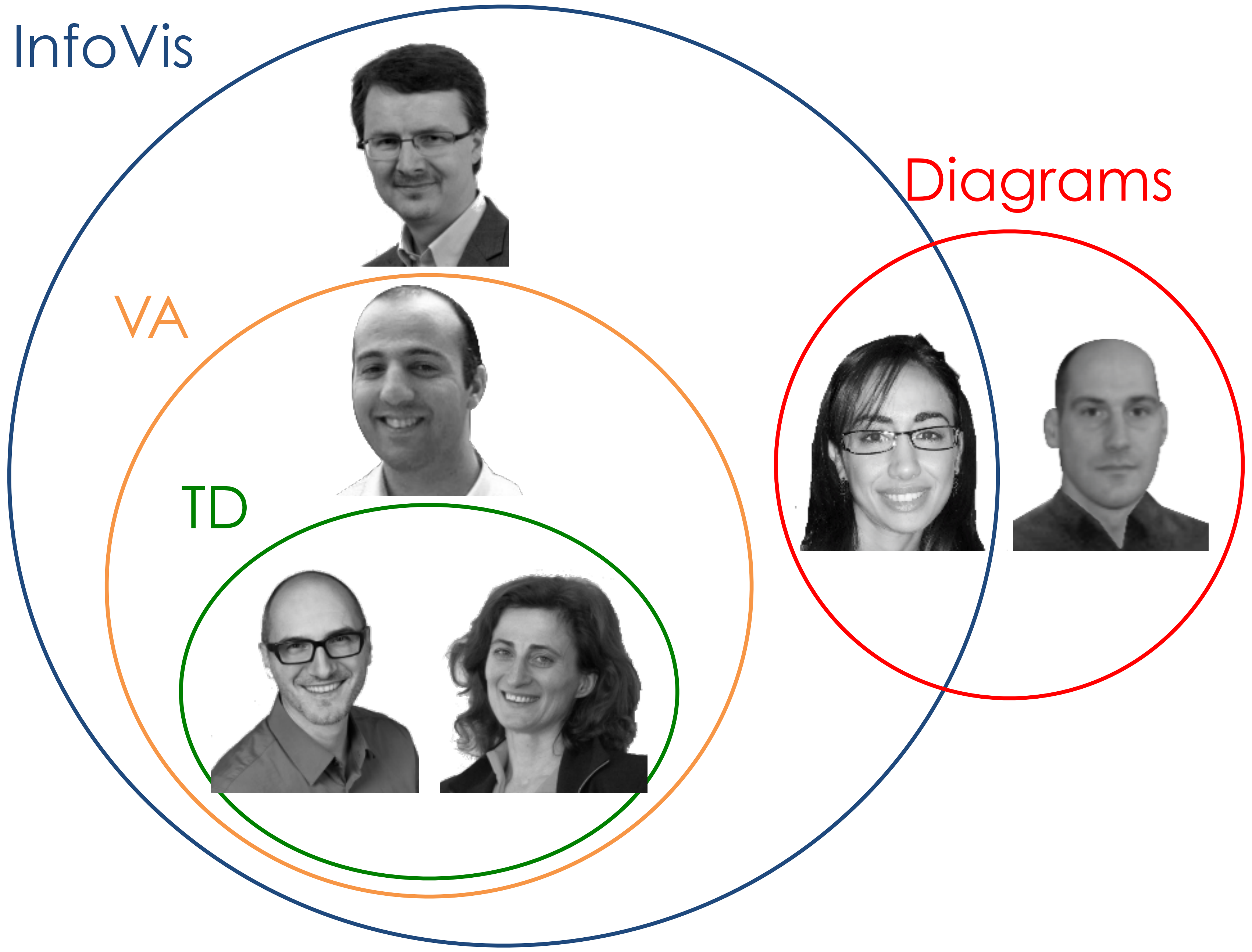






Analyze
intersection relations

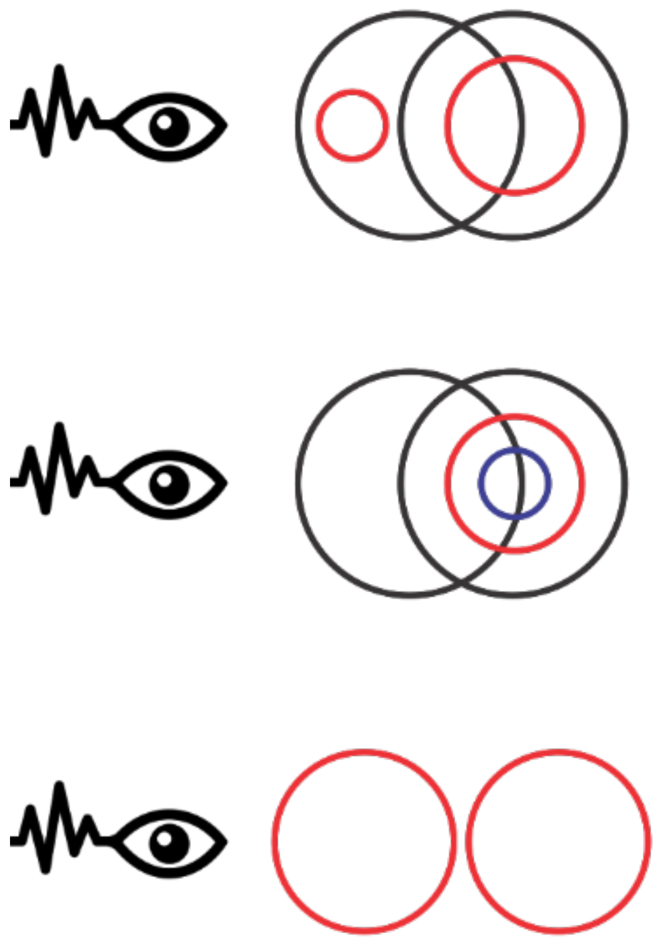


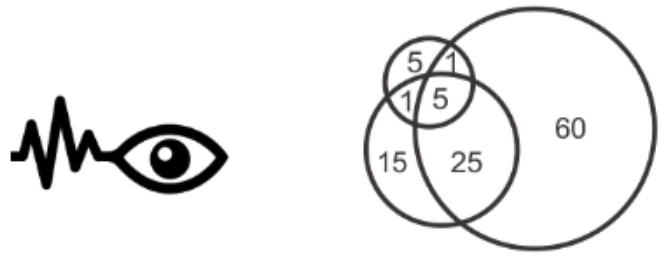




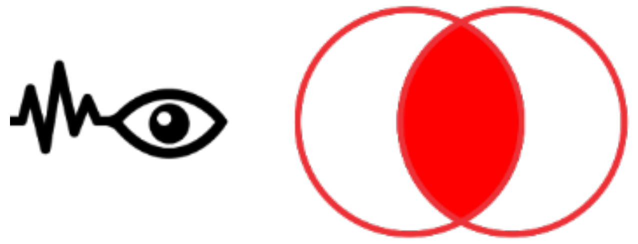
InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

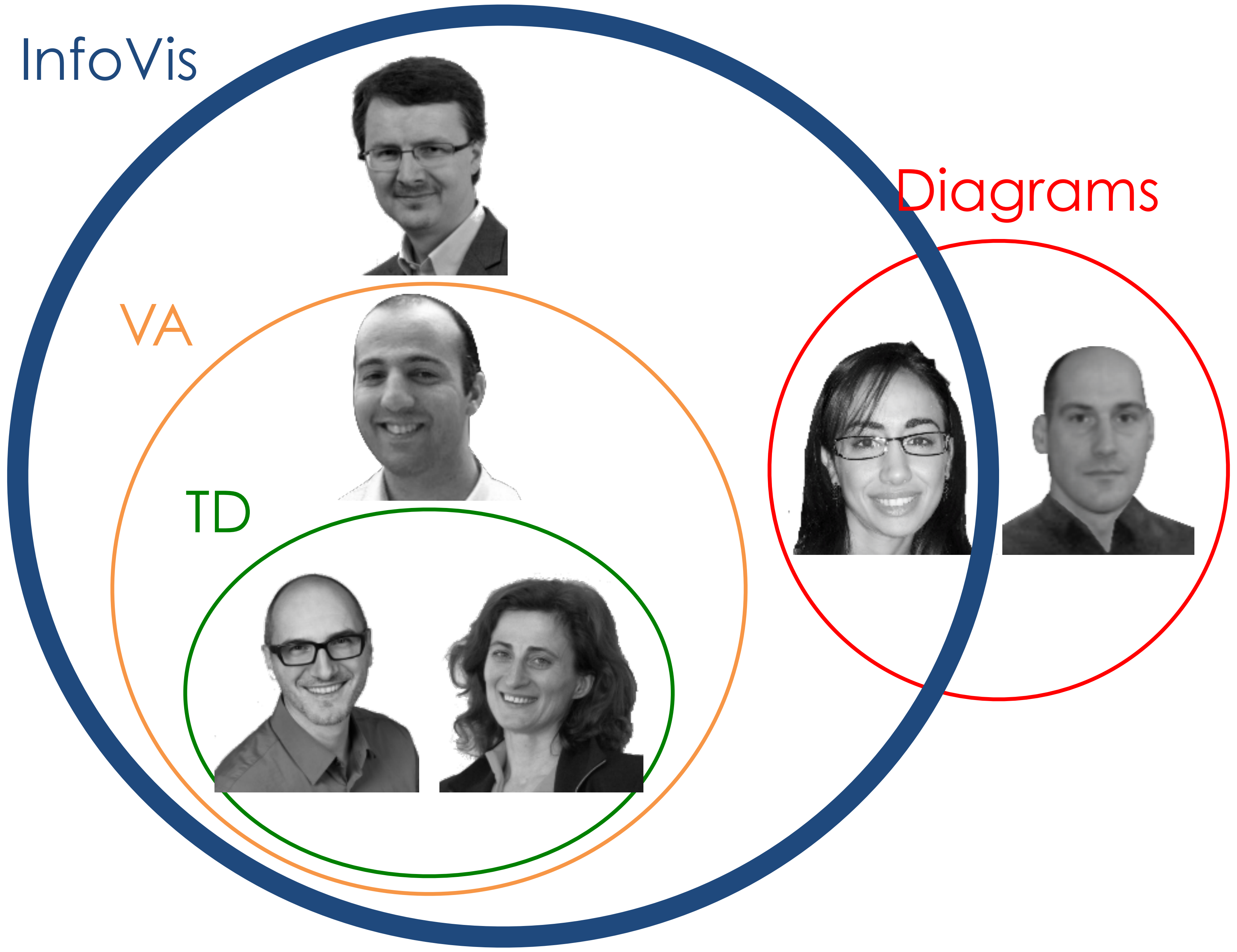
# Sets and Set Relations





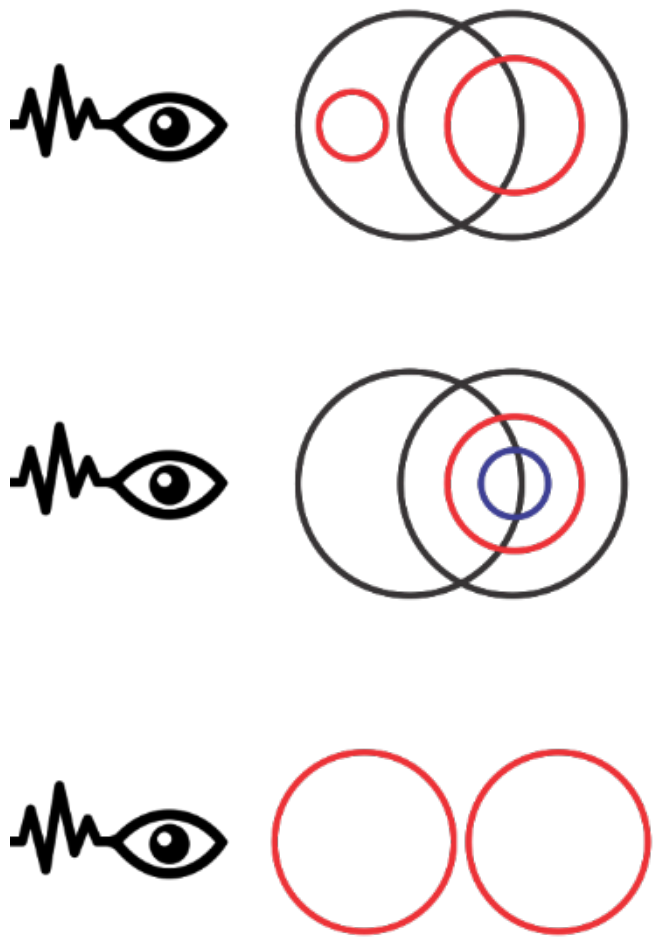

Analyze
intersection relations

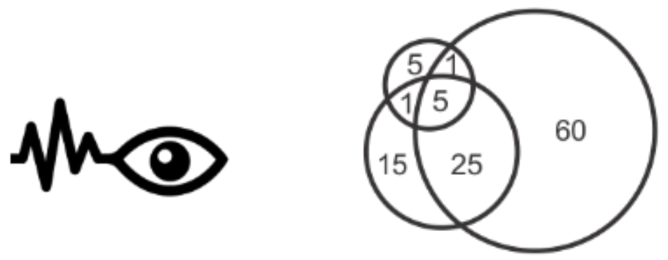




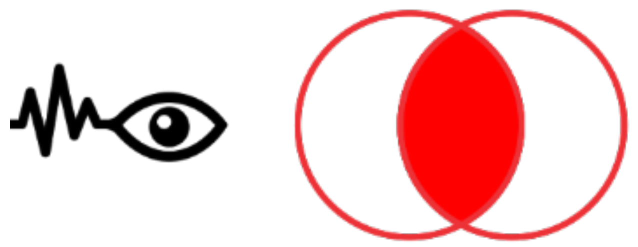

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

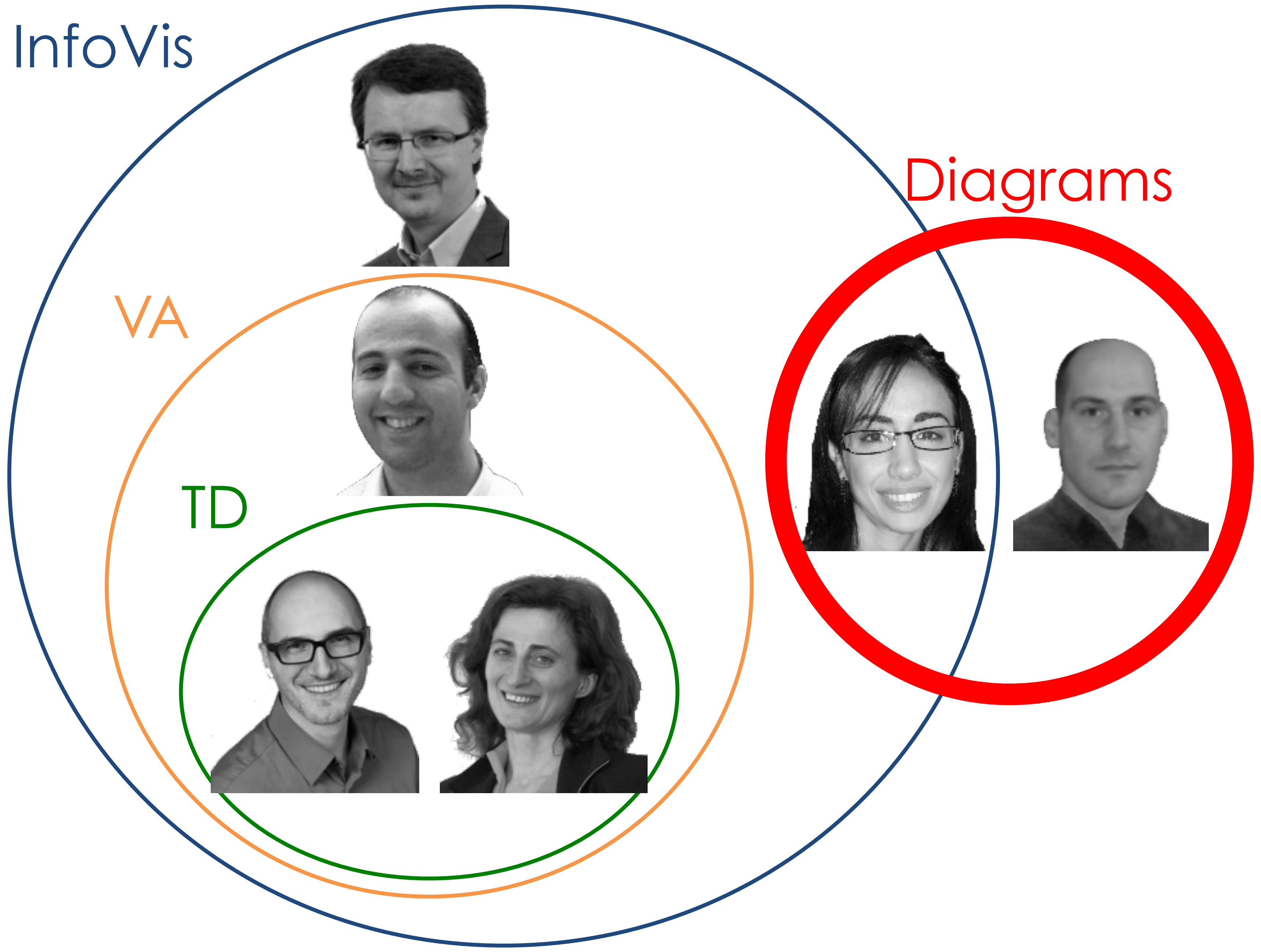
# Sets and Set Relations





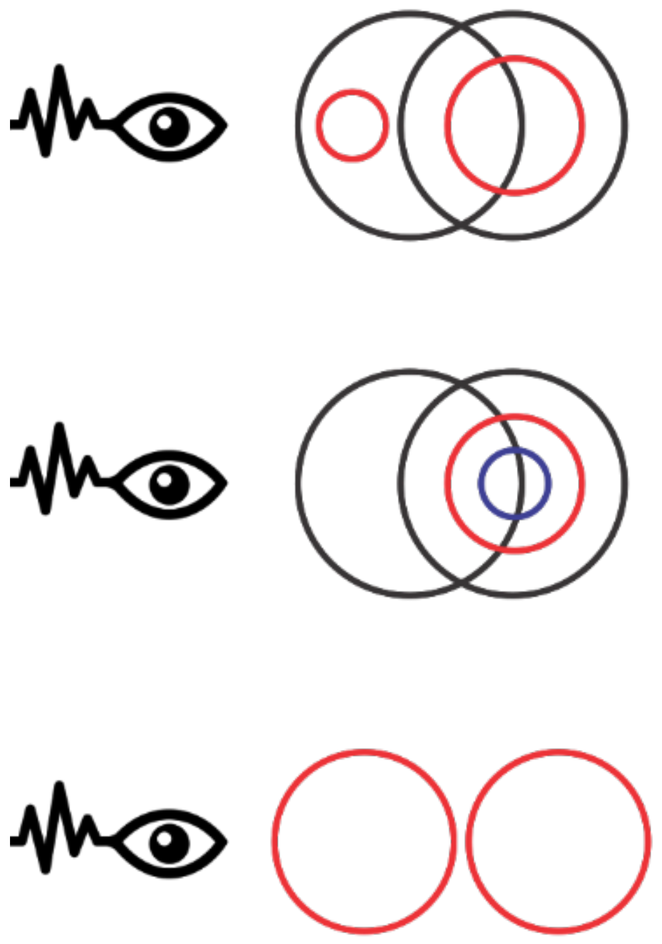

Analyze
intersection relations

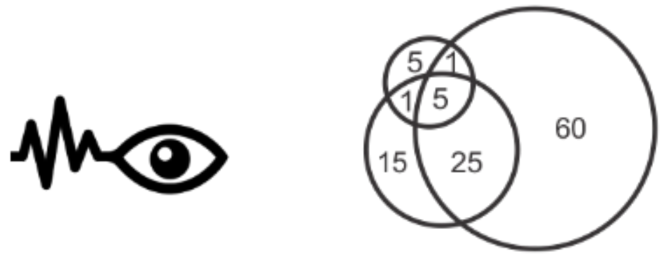




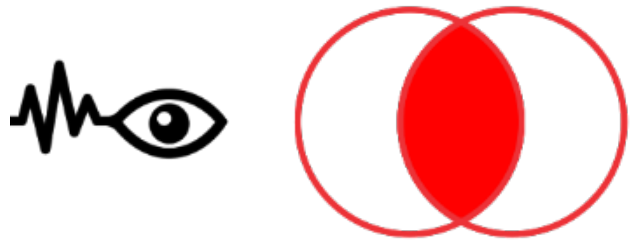

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

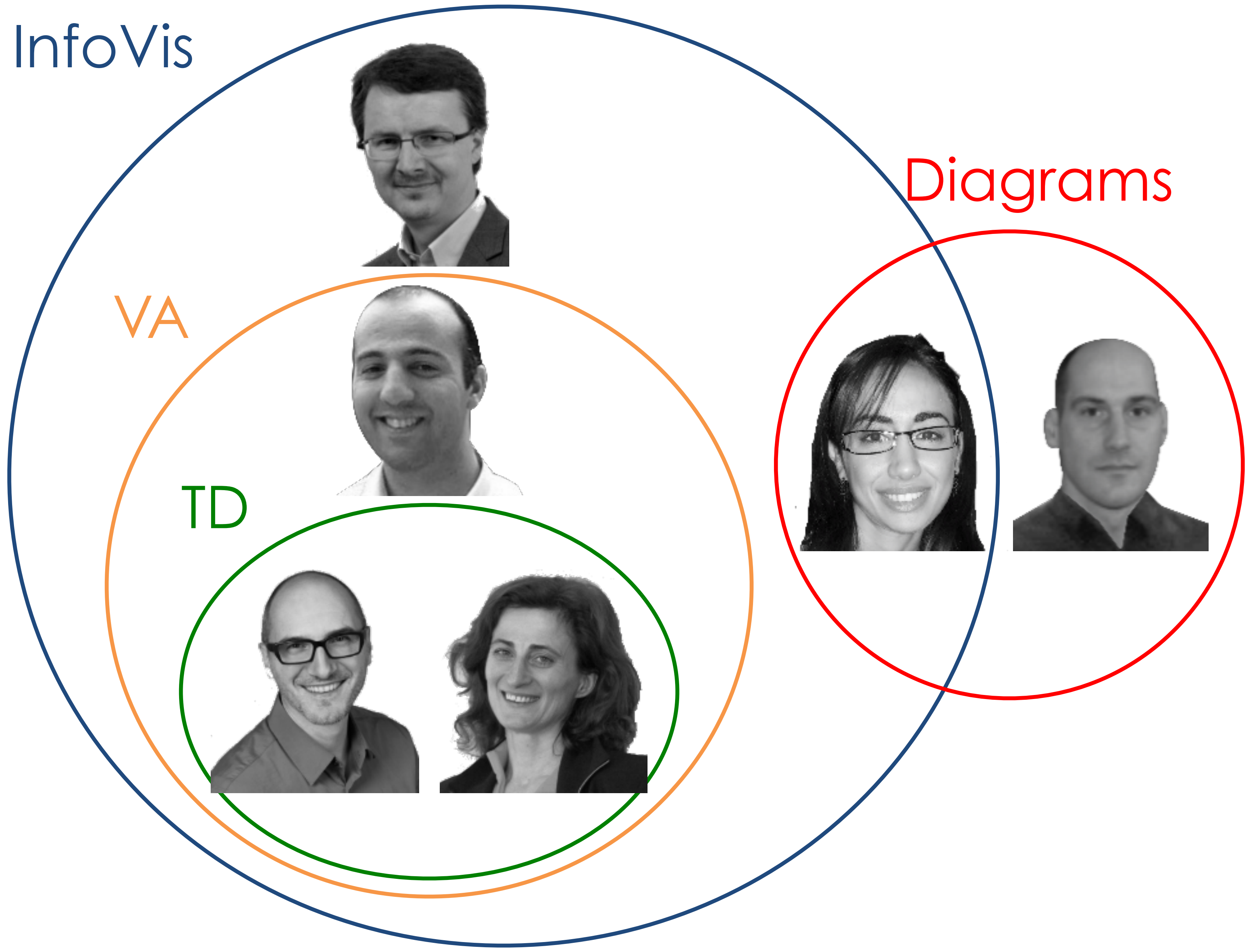
# Sets and Set Relations





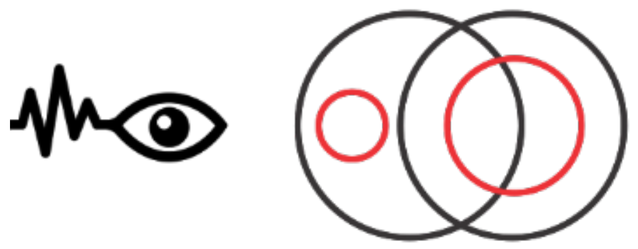

Analyze
intersection relations

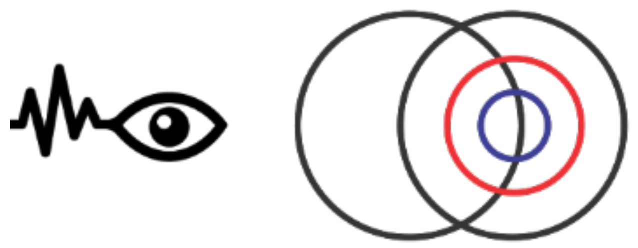


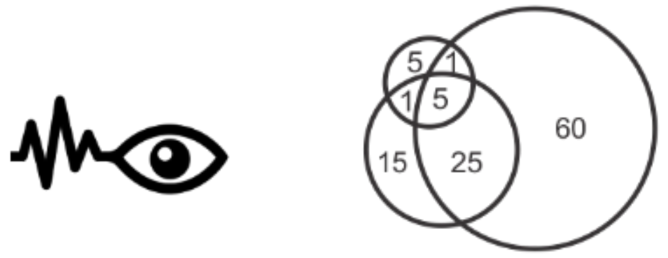



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

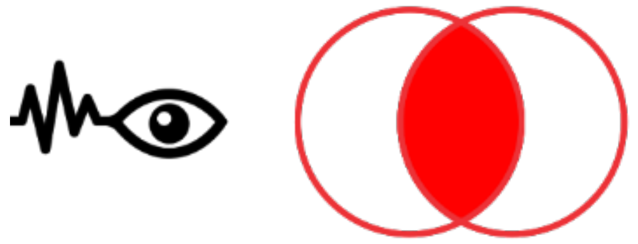
# Sets and Set Relations

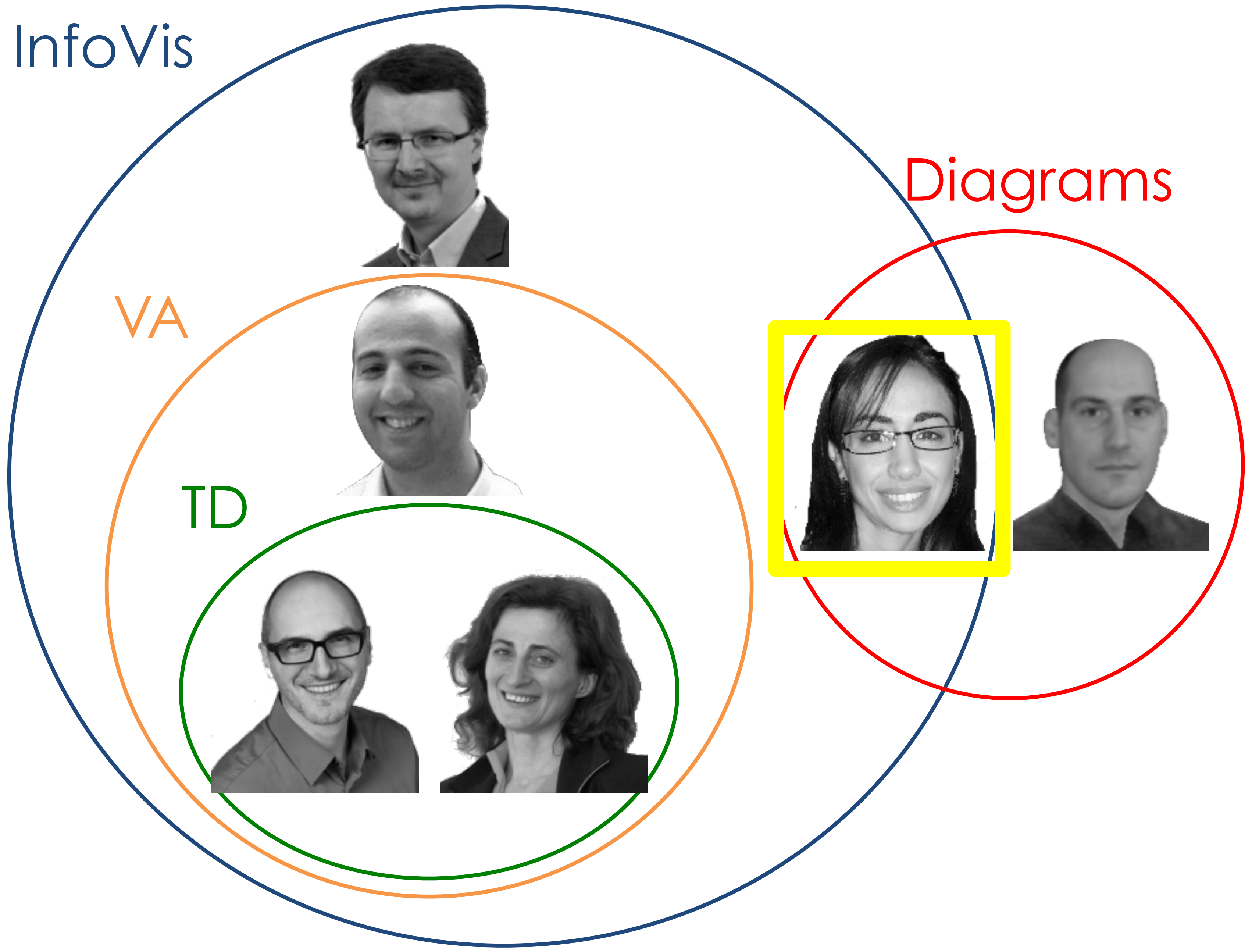






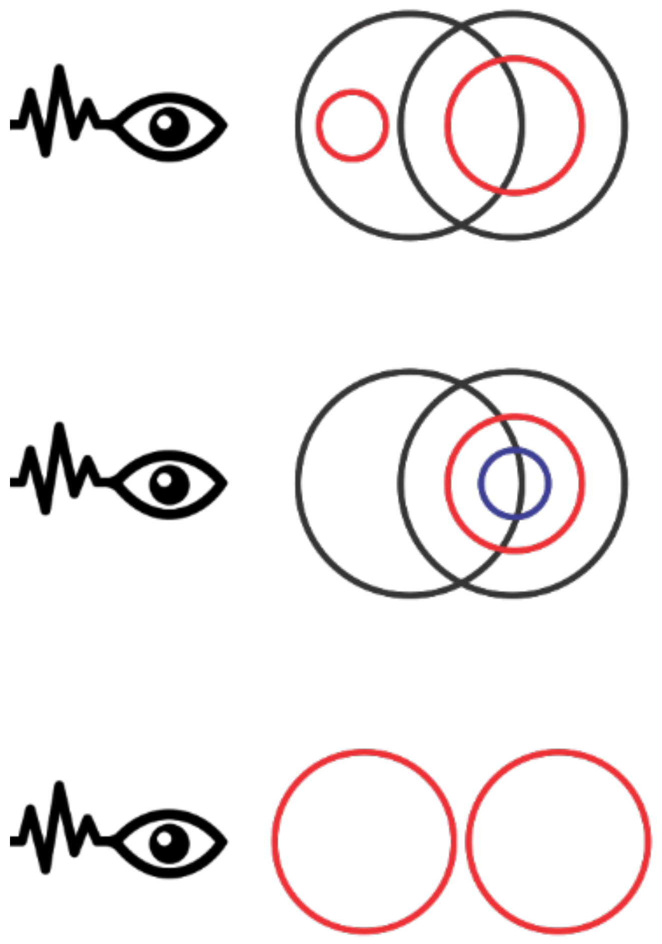

Analyze
intersection relations

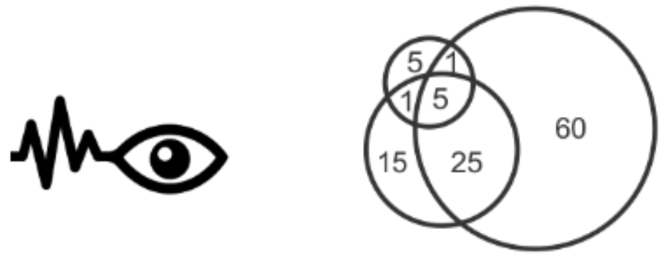




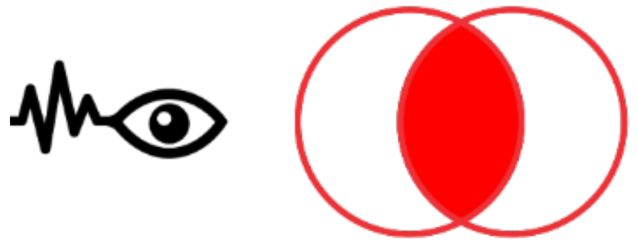

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

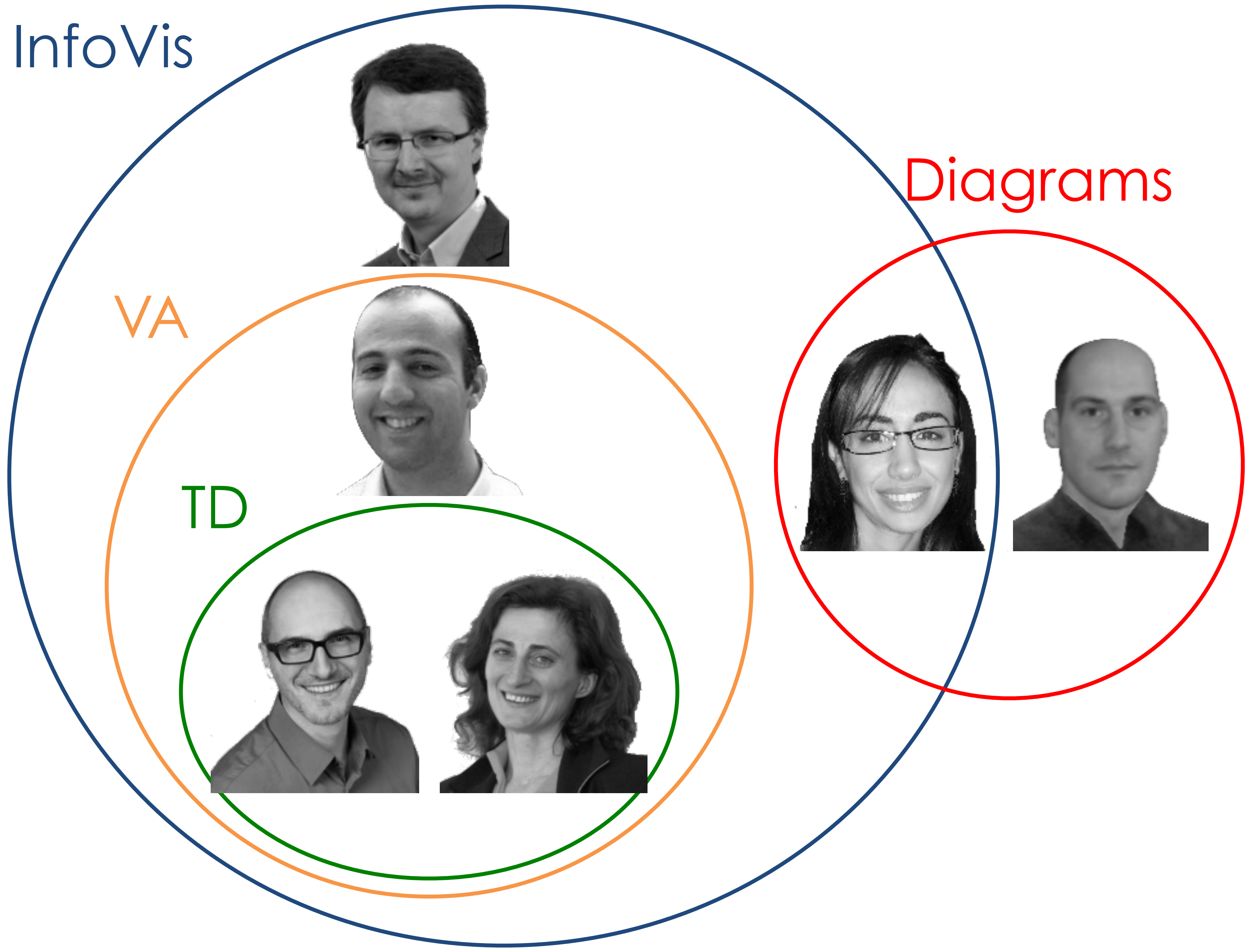
# Sets and Set Relations





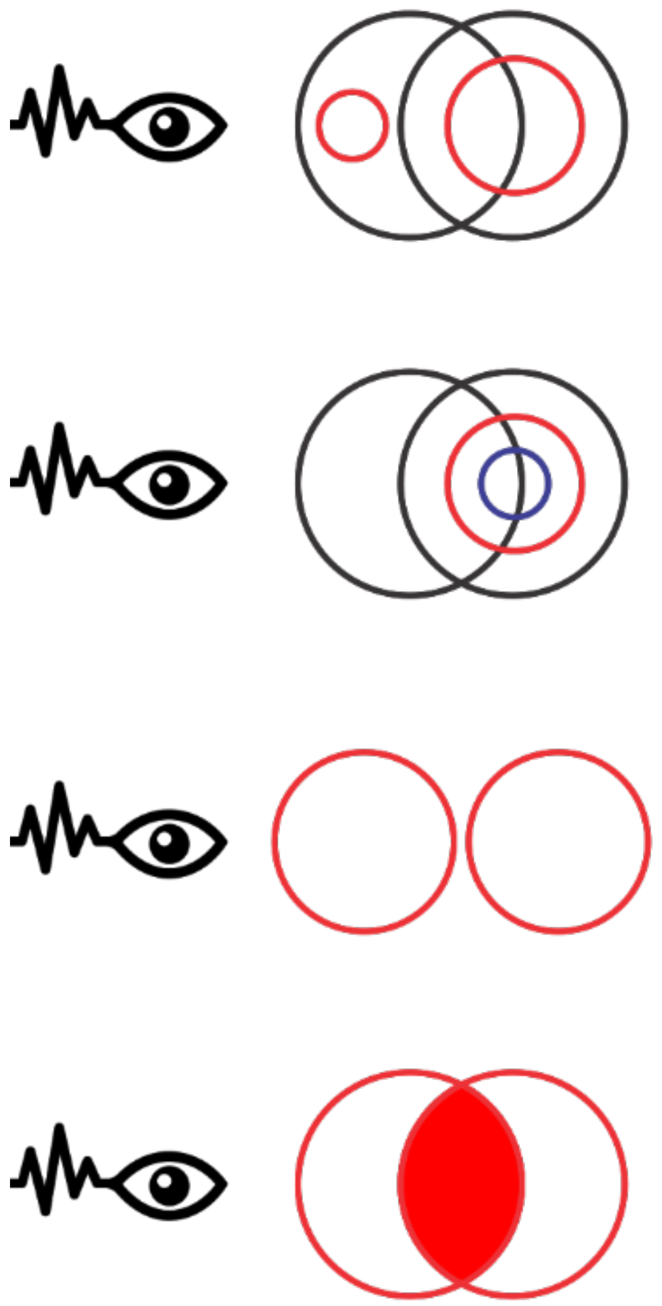

Analyze
intersection relations

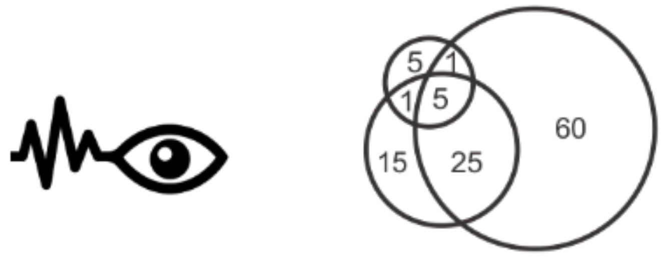


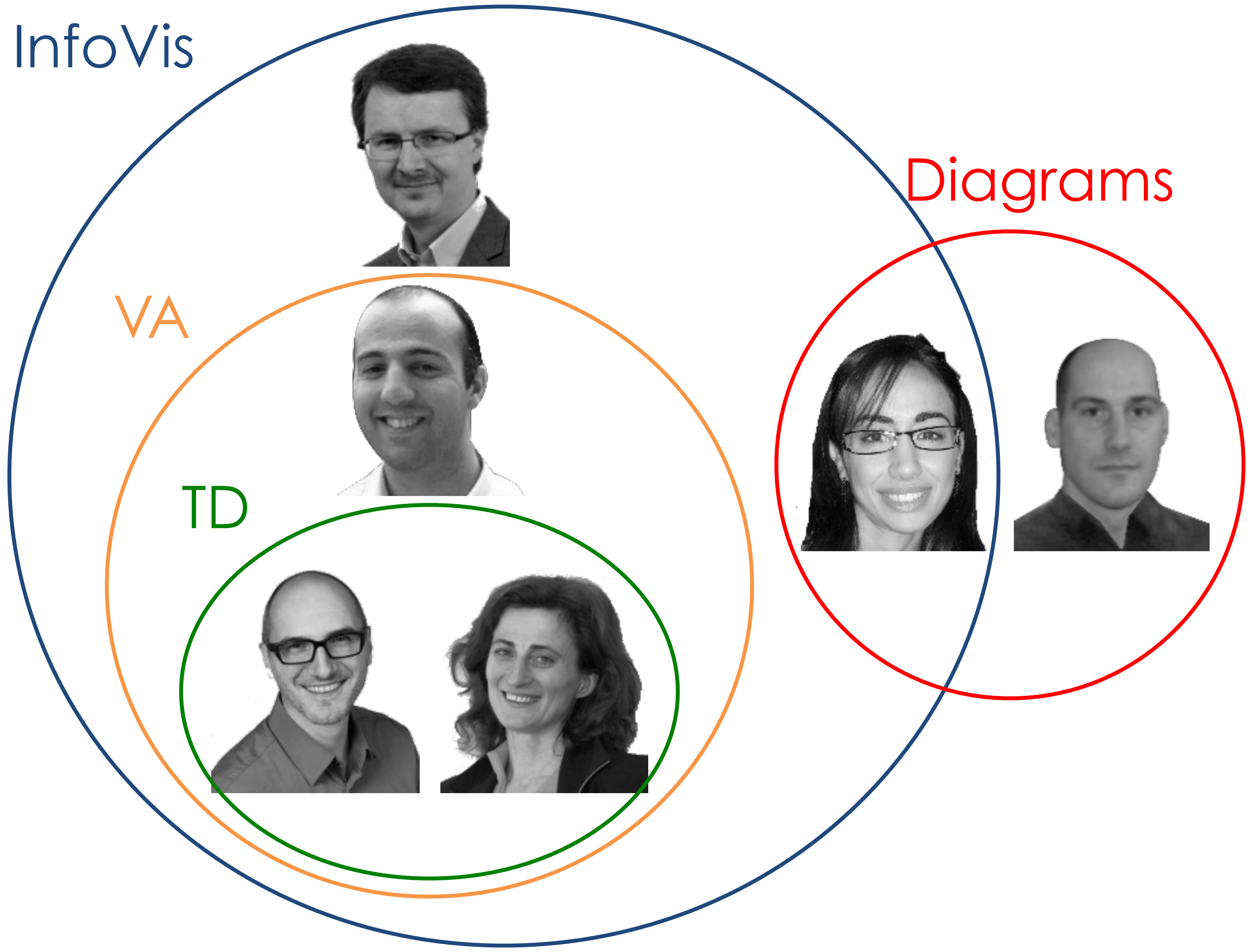



InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations

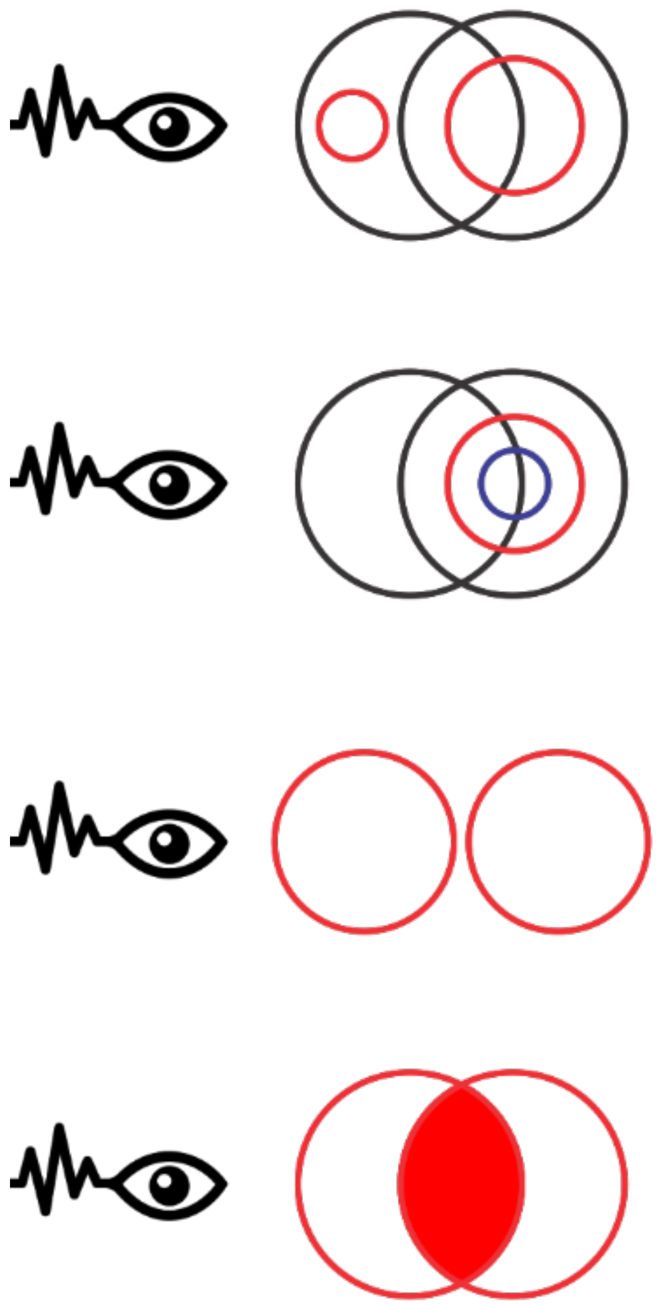


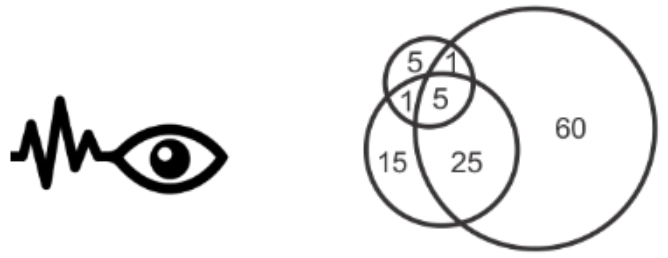


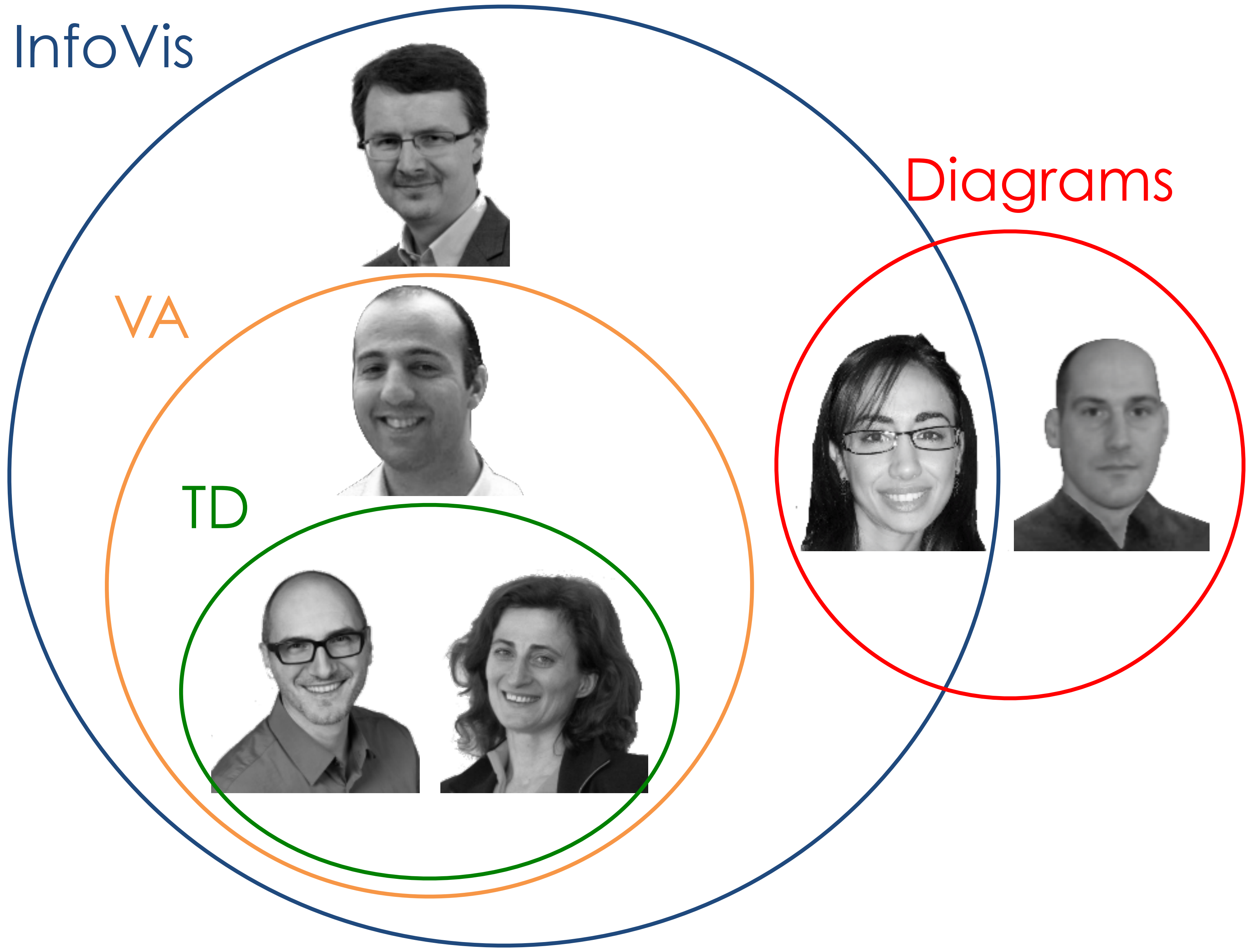

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations



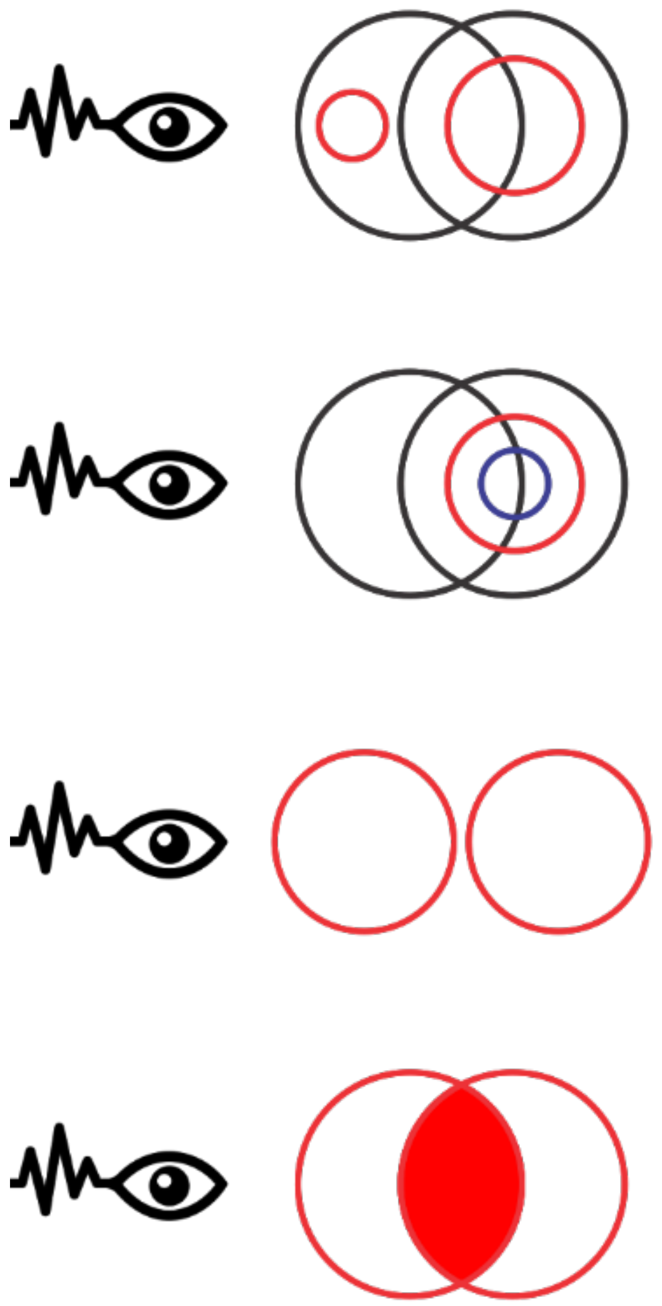


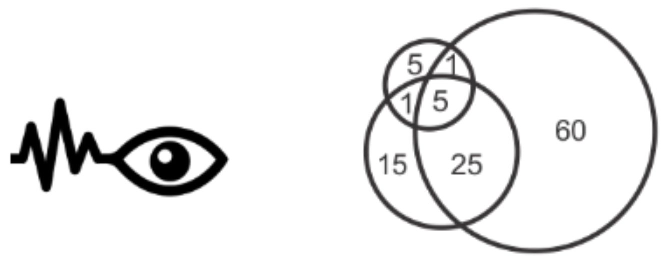

Analyze set & set intersection cardinalities



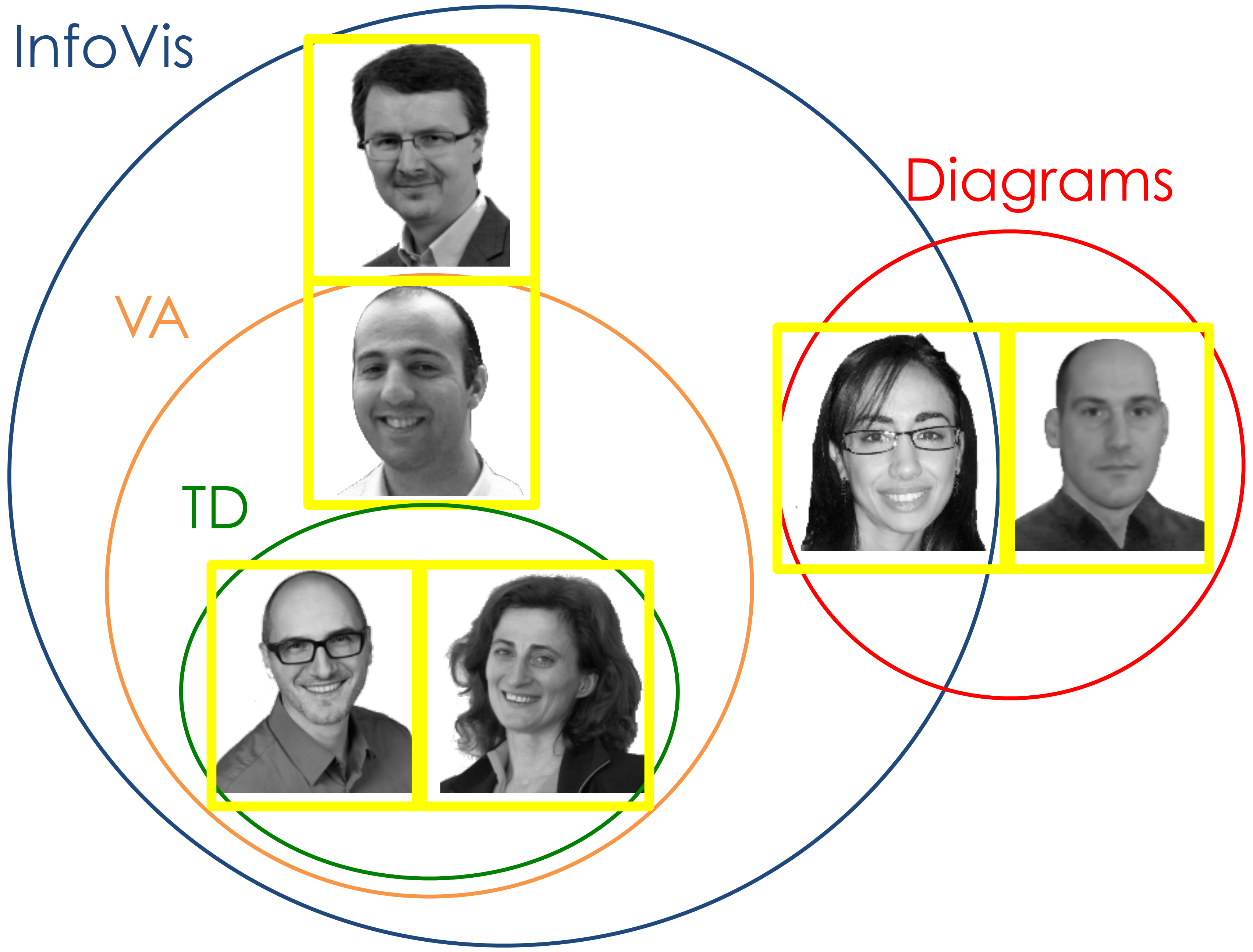

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations



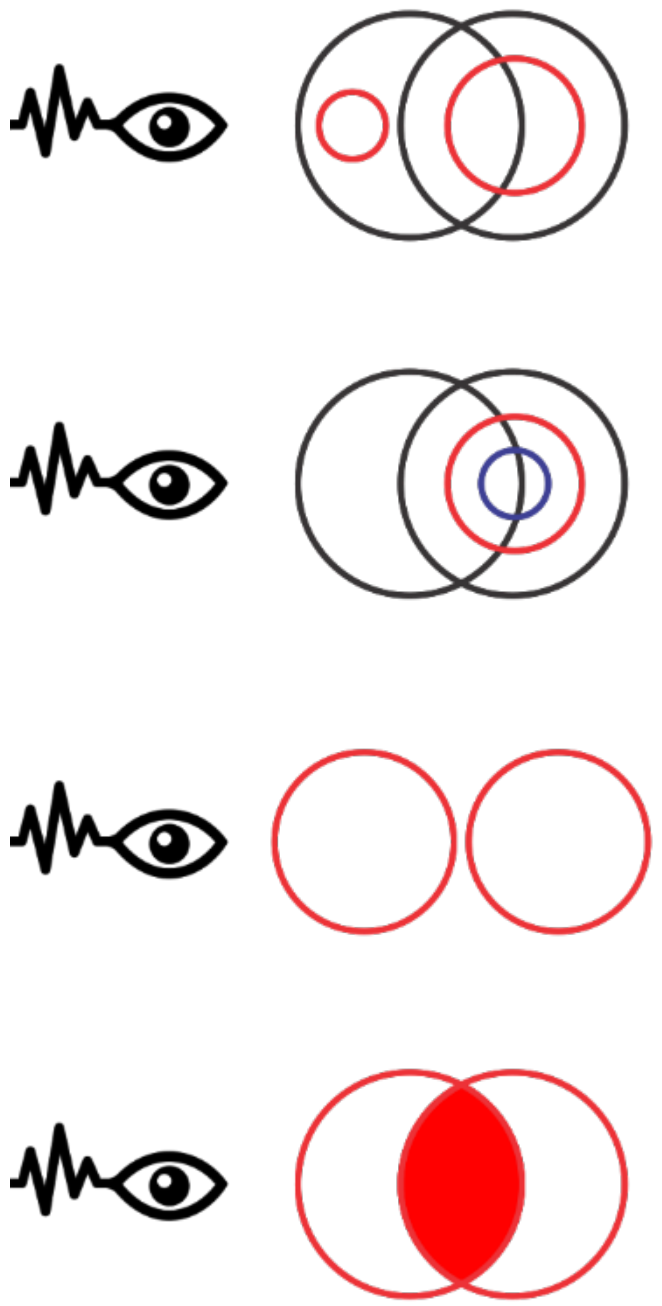


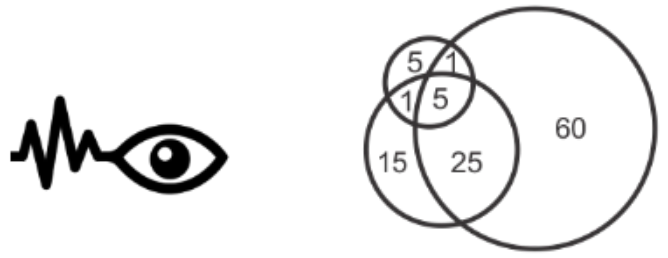

Analyze set & set intersection cardinalities



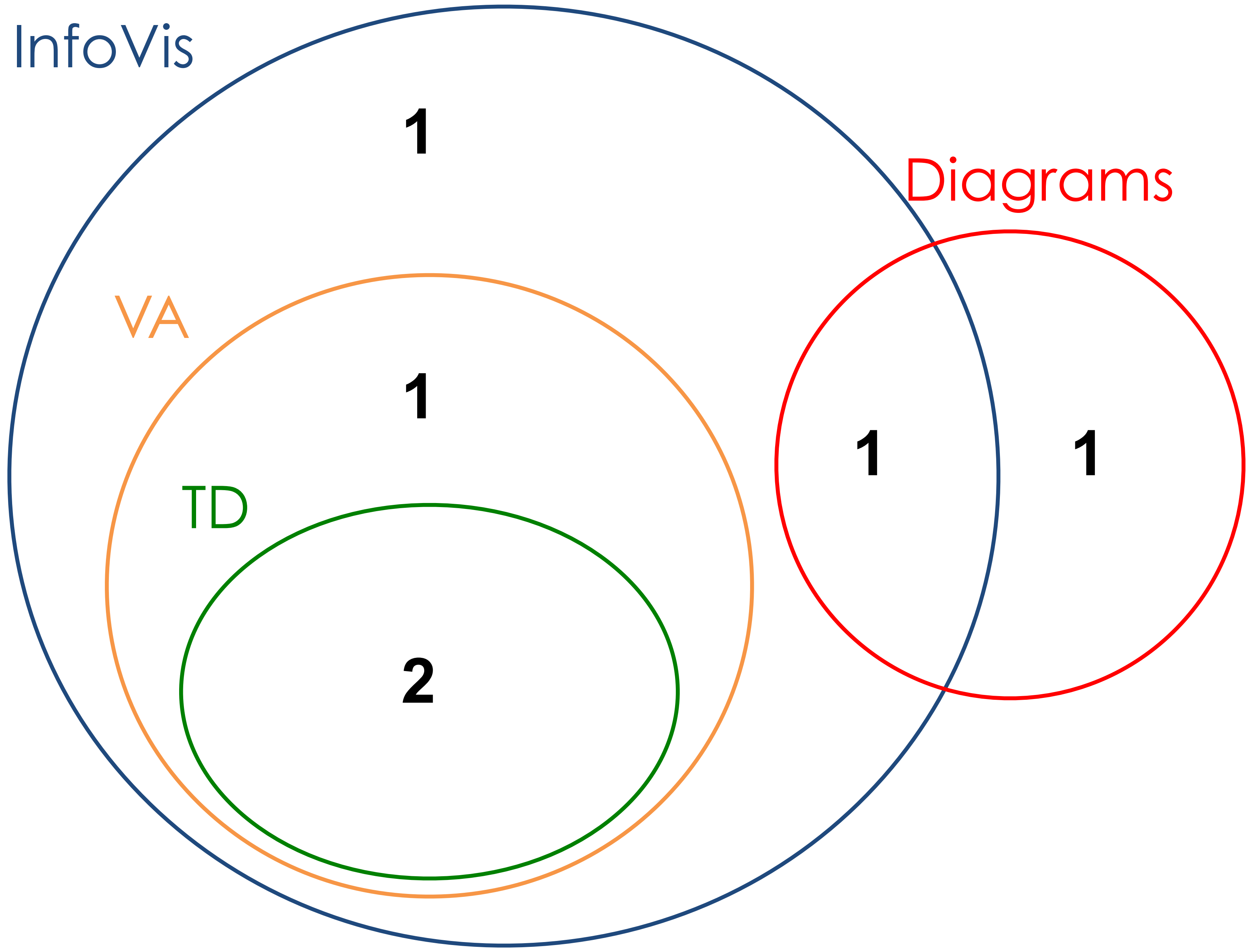

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations





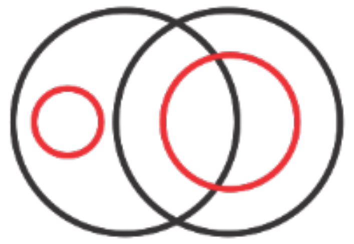

Analyze set & set intersection cardinalities



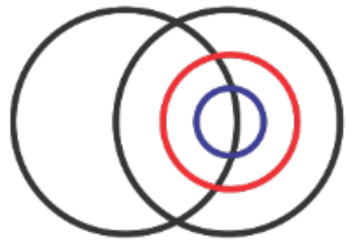

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Sets and Set Relations

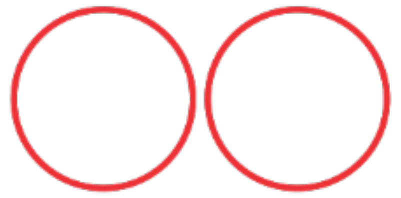
Analyze
inclusion relations



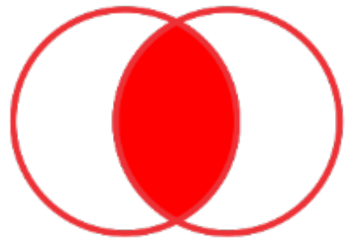
Analyze
inclusion hierarchies

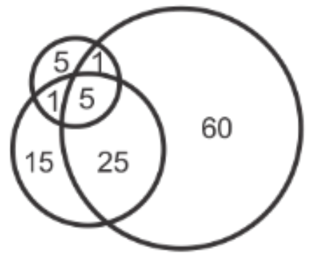


Analyze
exclusion relations



Analyze
intersection relations

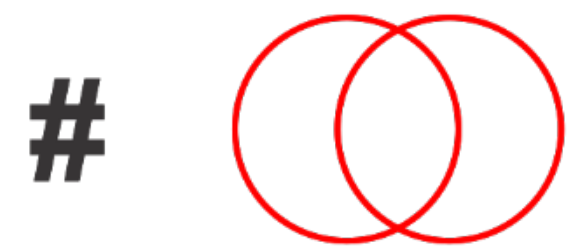





Analyze set & set
intersection cardinalities

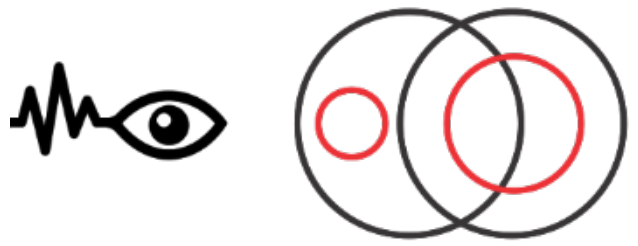
# Sets and Set Relations

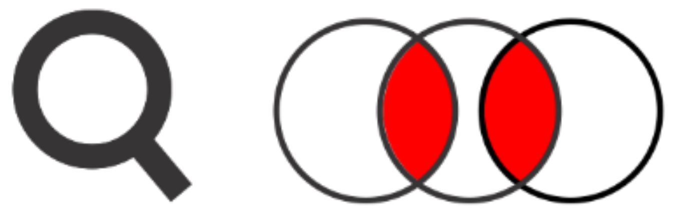
Find the # of sets in the set family



Find set intersections of a specific set

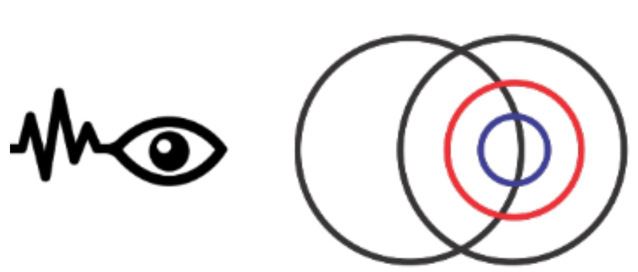
Analyze inclusion relations

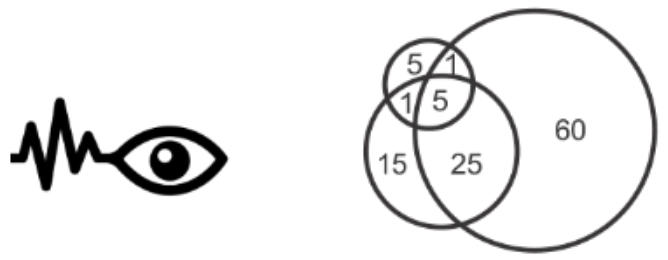




Find the set with largest pairwise set intersections

Analyze inclusion hierarchies



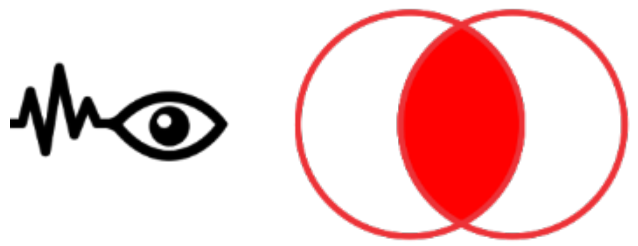


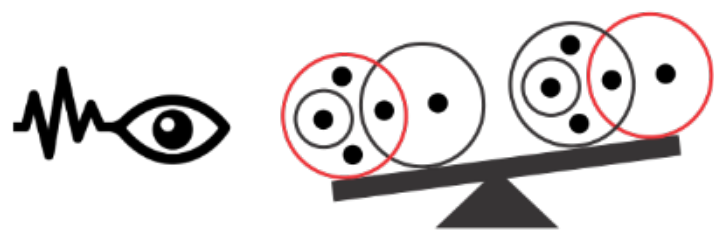

Analyze set & set intersection cardinalities

Analyze exclusion relations

Analyze and compare set similarities

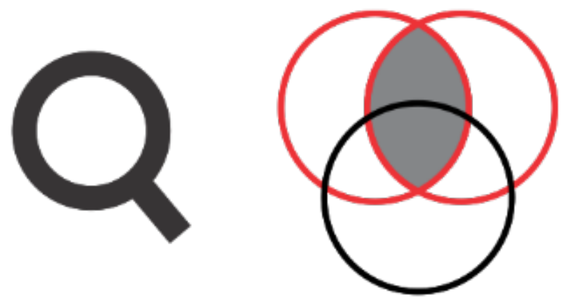
Analyze intersection relations

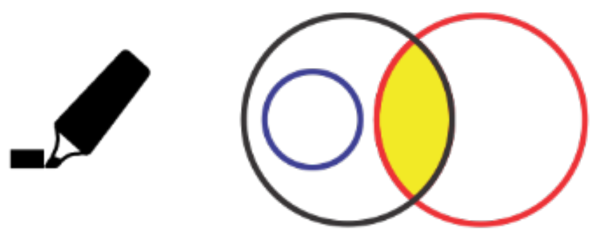




Analyze and compare set exclusiveness

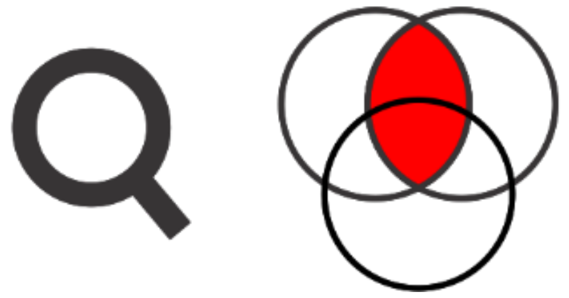
Find intersections between *k* sets

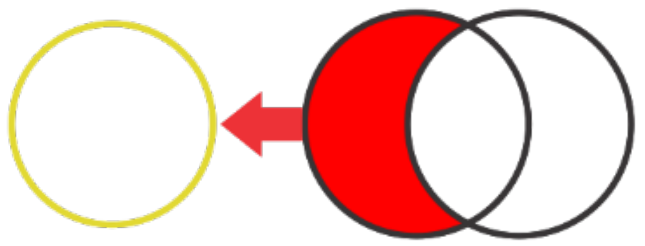




Highlight specific sets, subsets, or **set relations**

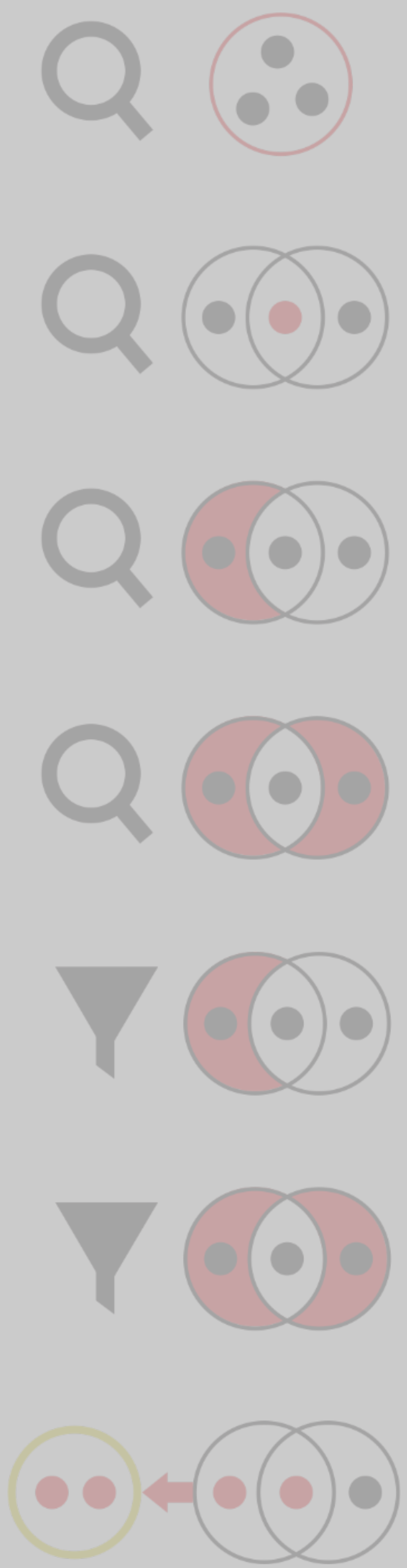
Find sets involved in certain intersection



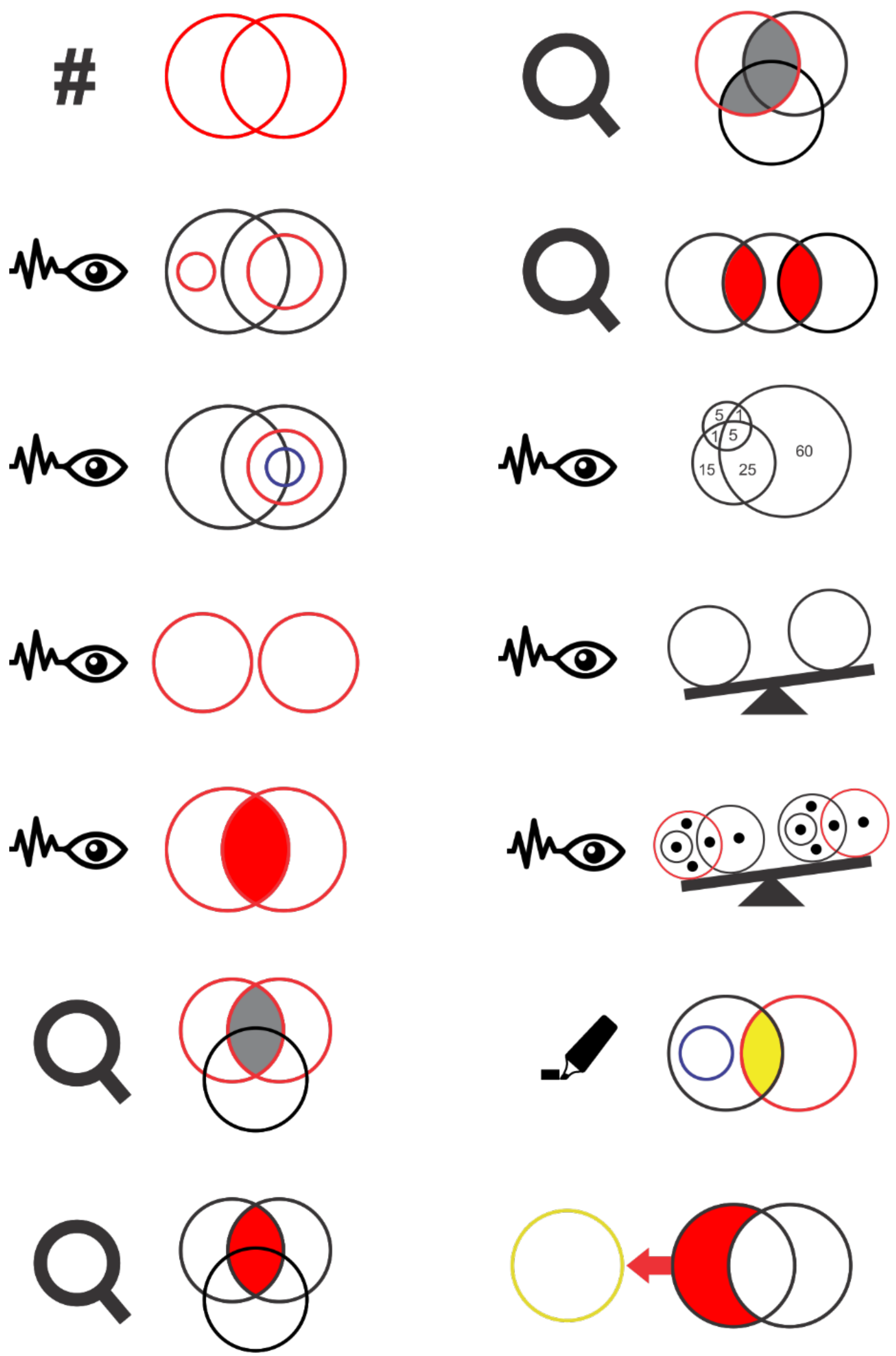


Create **a new set** using set-theoretical operations

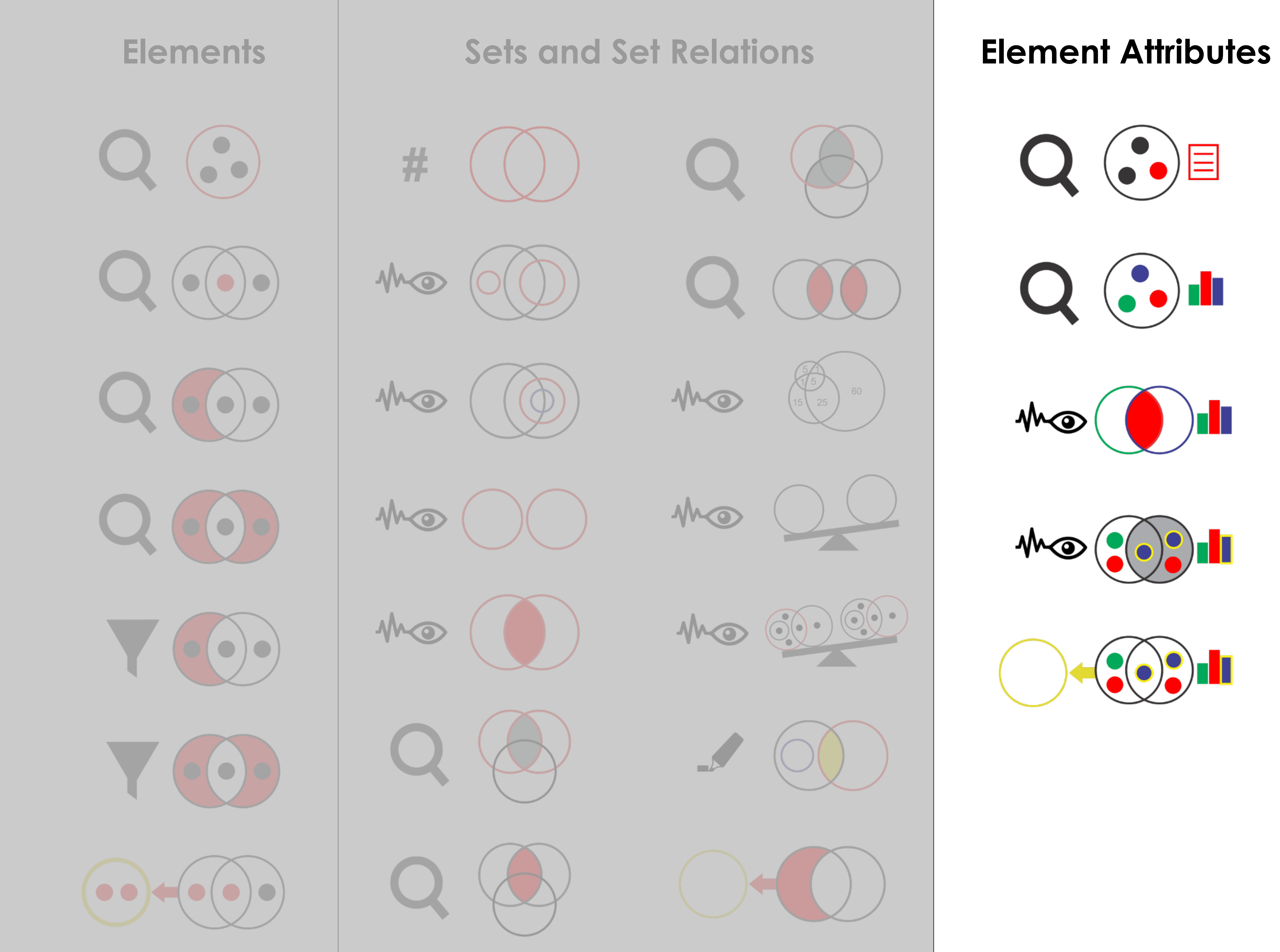
## Elements



## Sets and Set Relations




## Element Attributes


Elements
Sets and Set Relations
Element Attributes
#
5
15
25
60

# Element Attributes

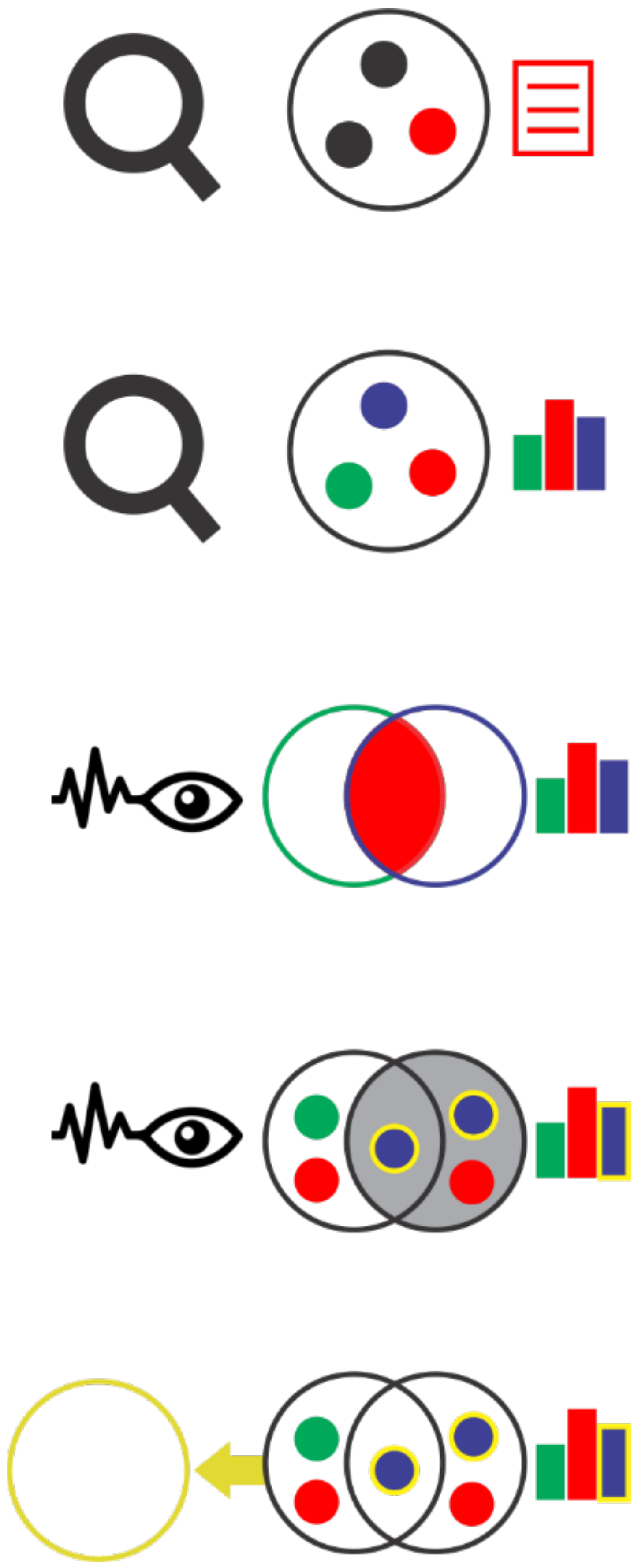
Find the attribute value of a certain element

Find the distribution of an attribute in a certain set or subset

Compare the attribute values of sets or set intersections

Analyze the set memberships for elements having
**certain attribute values**

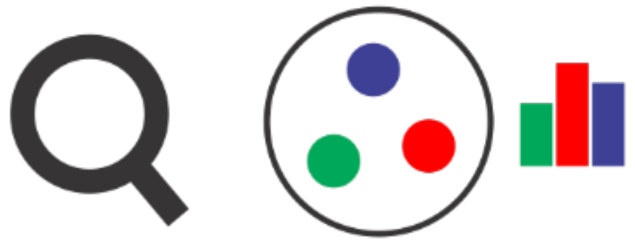
Create **a new set** out of elements having
**certain attribute values**



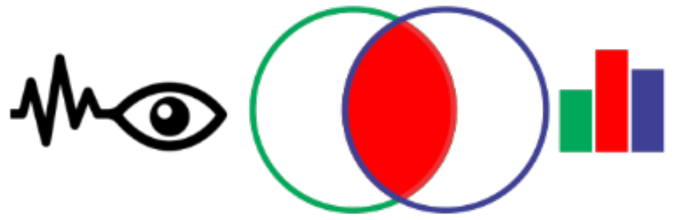
## Element Attributes

Find the attribute value of a certain element

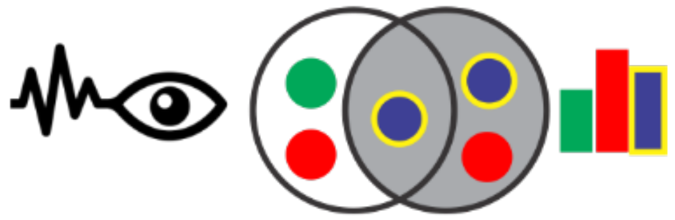
Find the distribution of an attribute in a certain set or subset



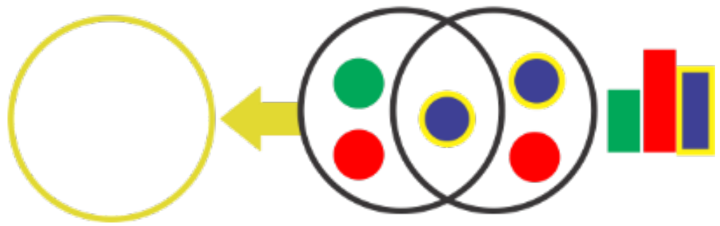
Compare the attribute values of sets or set intersections



Analyze the set memberships for elements having **certain attribute values**



Create **a new set** out of elements having **certain attribute values**



## Element Attributes

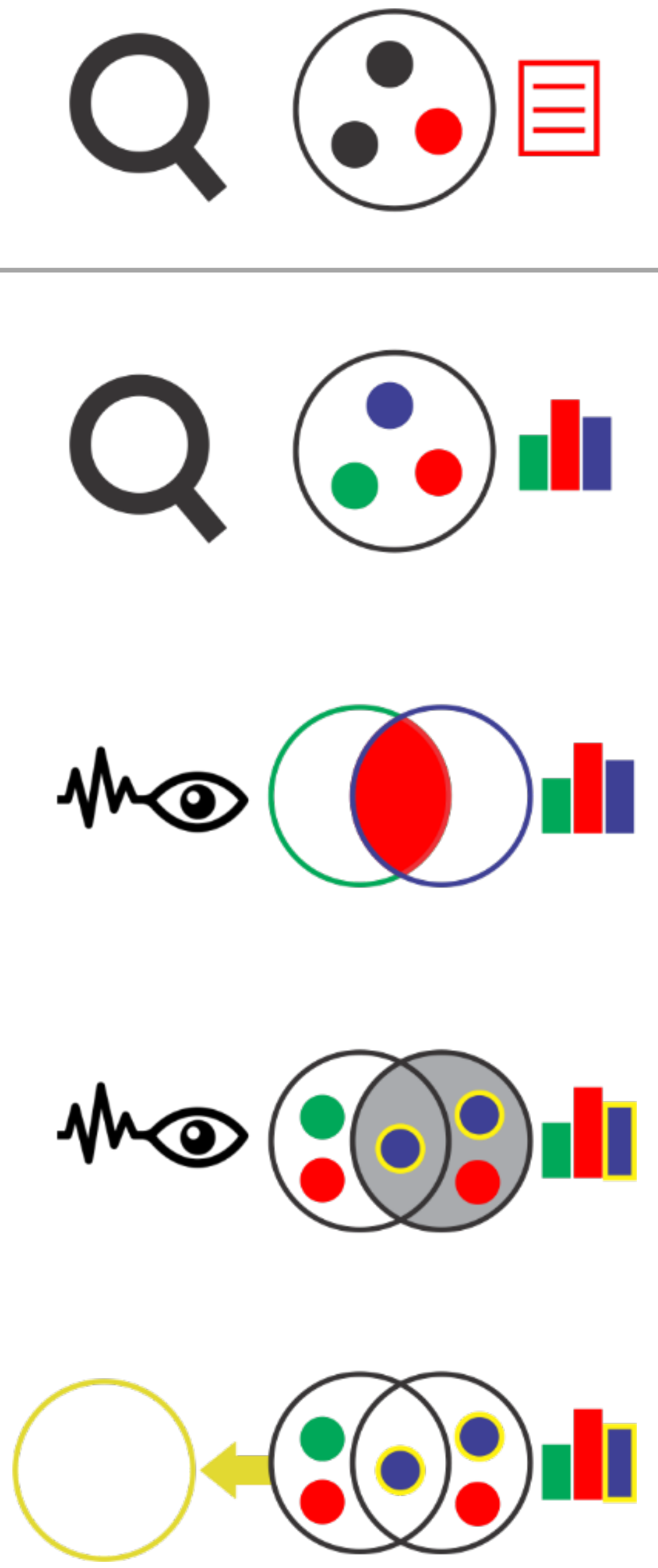
Find the attribute value of a certain element

Find the distribution of an attribute in a certain set or subset

Compare the attribute values of sets or set intersections

Analyze the set memberships for elements having
**certain attribute values**

Create **a new set** out of elements having
**certain attribute values**



age

## Element Attributes

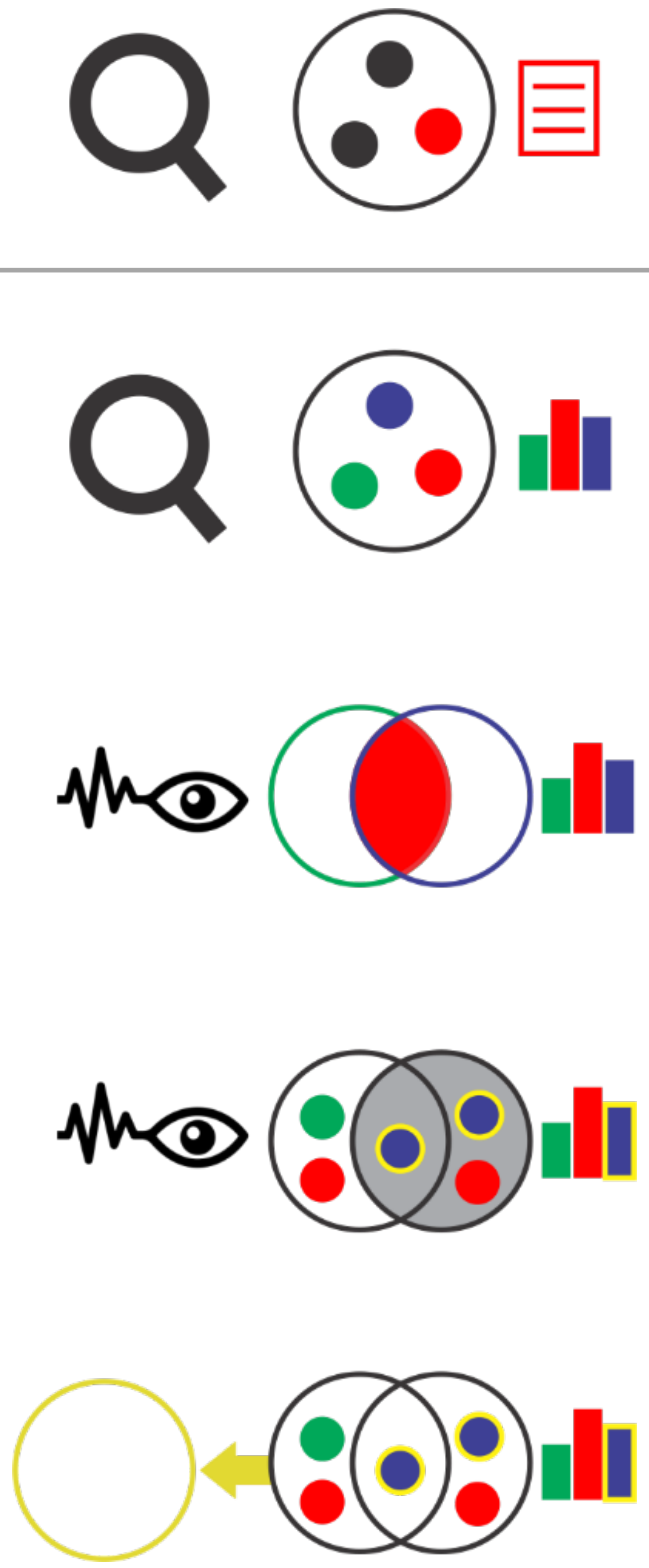
Find the attribute value of a certain element

Find the distribution of an attribute in a certain set or subset

Compare the attribute values of sets or set intersections

Analyze the set memberships for elements having
**certain attribute values**

Create **a new set** out of elements having
**certain attribute values**

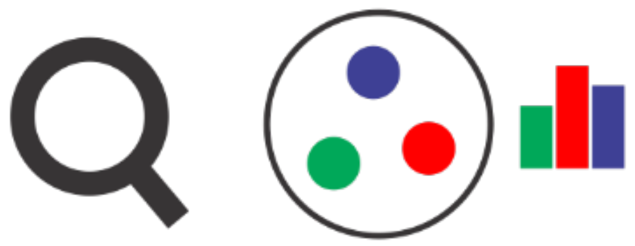


age

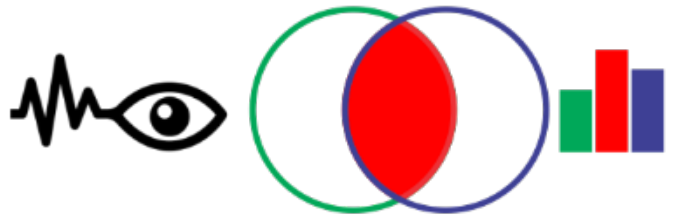
# Element Attributes

Find the attribute value of a certain element

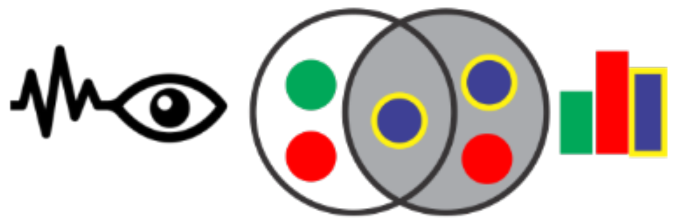
Find the distribution of an attribute in a certain set or subset



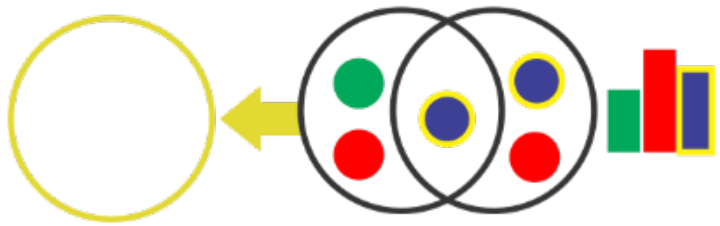
Compare the attribute values of sets or set intersections



Analyze the set memberships for elements having **certain attribute values**



Create **a new set** out of elements having **certain attribute values**



age

# Element Attributes

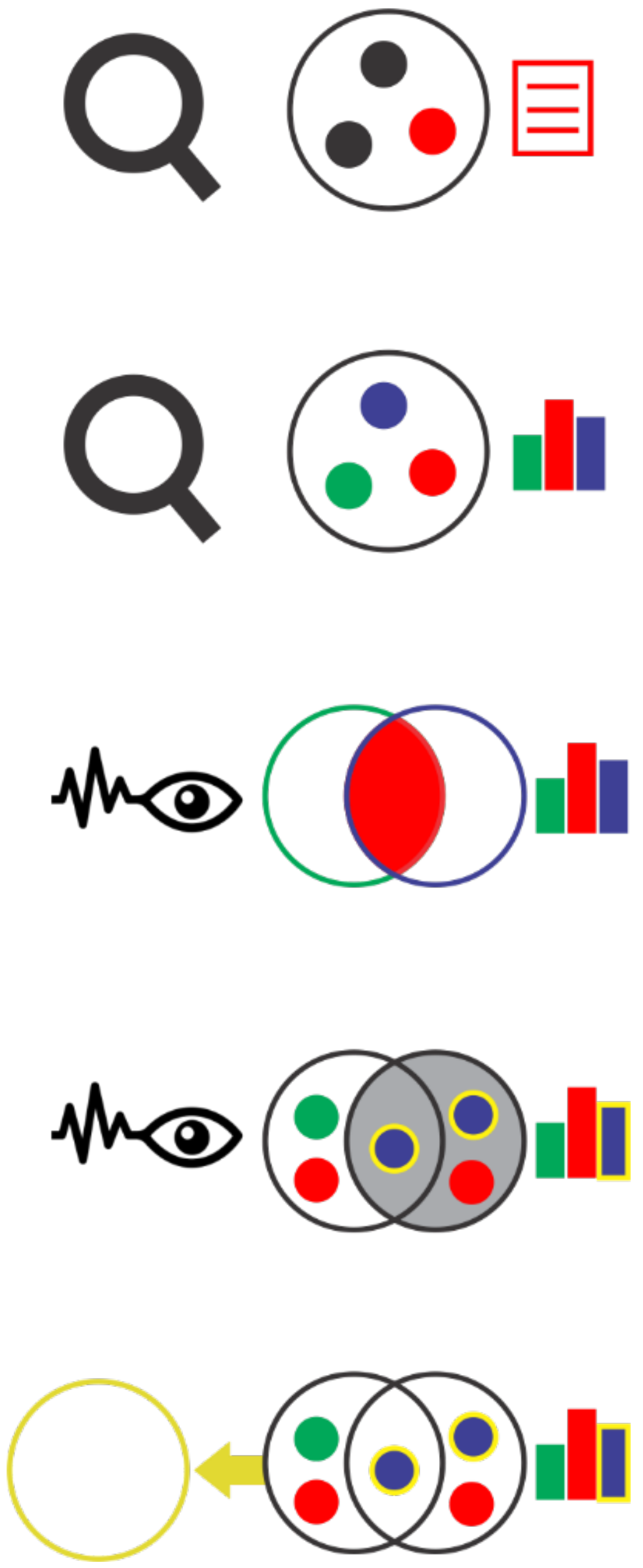
Find the attribute value of a certain element

Find the distribution of an attribute in a certain set or subset

Compare the attribute values of sets or set intersections

Analyze the set memberships for elements having
**certain attribute values**

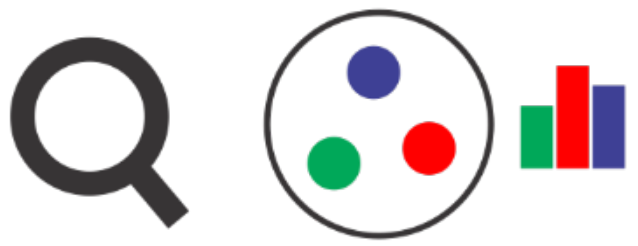
Create **a new set** out of elements having
**certain attribute values**



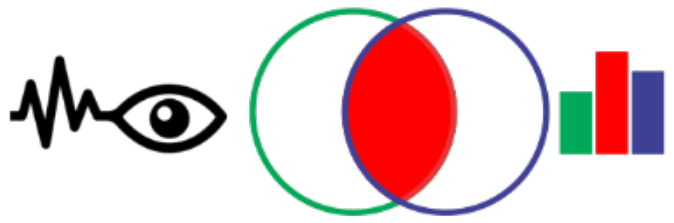
## Element Attributes

Find the attribute value of a certain element

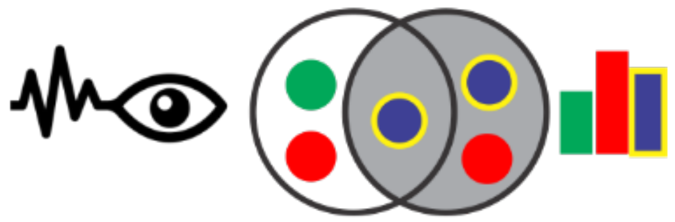
Find the distribution of an attribute in a certain set or subset



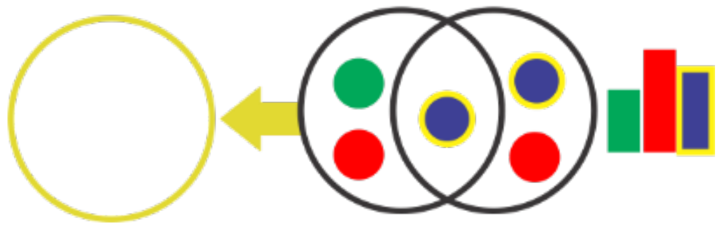
Compare the attribute values of sets or set intersections



Analyze the set memberships for elements having
**certain attribute values**



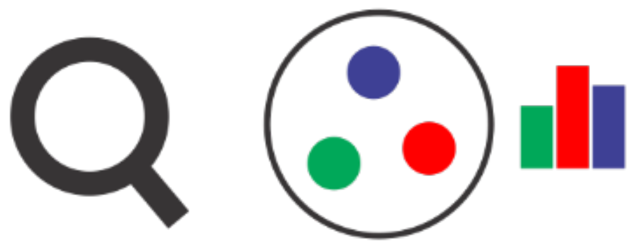
Create **a new set** out of elements having
**certain attribute values**



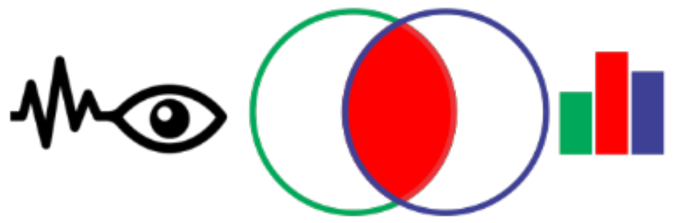
## Element Attributes

Find the attribute value of a certain element

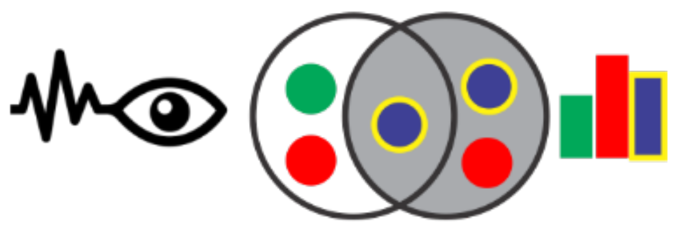
Find the distribution of an attribute in a certain set or subset



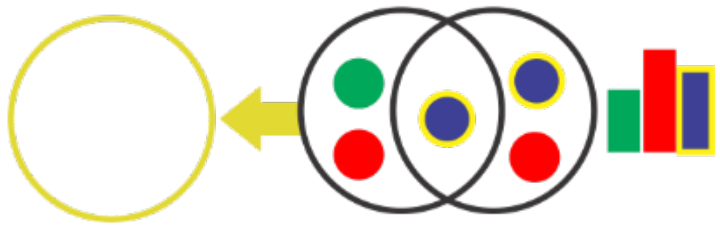
Compare the attribute values of sets or set intersections



Analyze the set memberships for elements having
**certain attribute values**

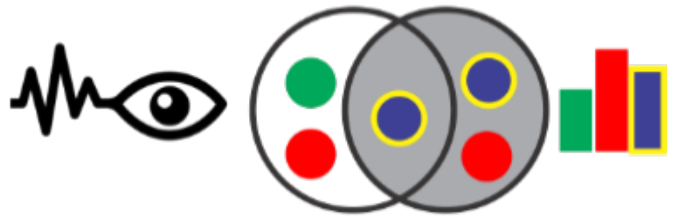


Create **a new set** out of elements having
**certain attribute values**

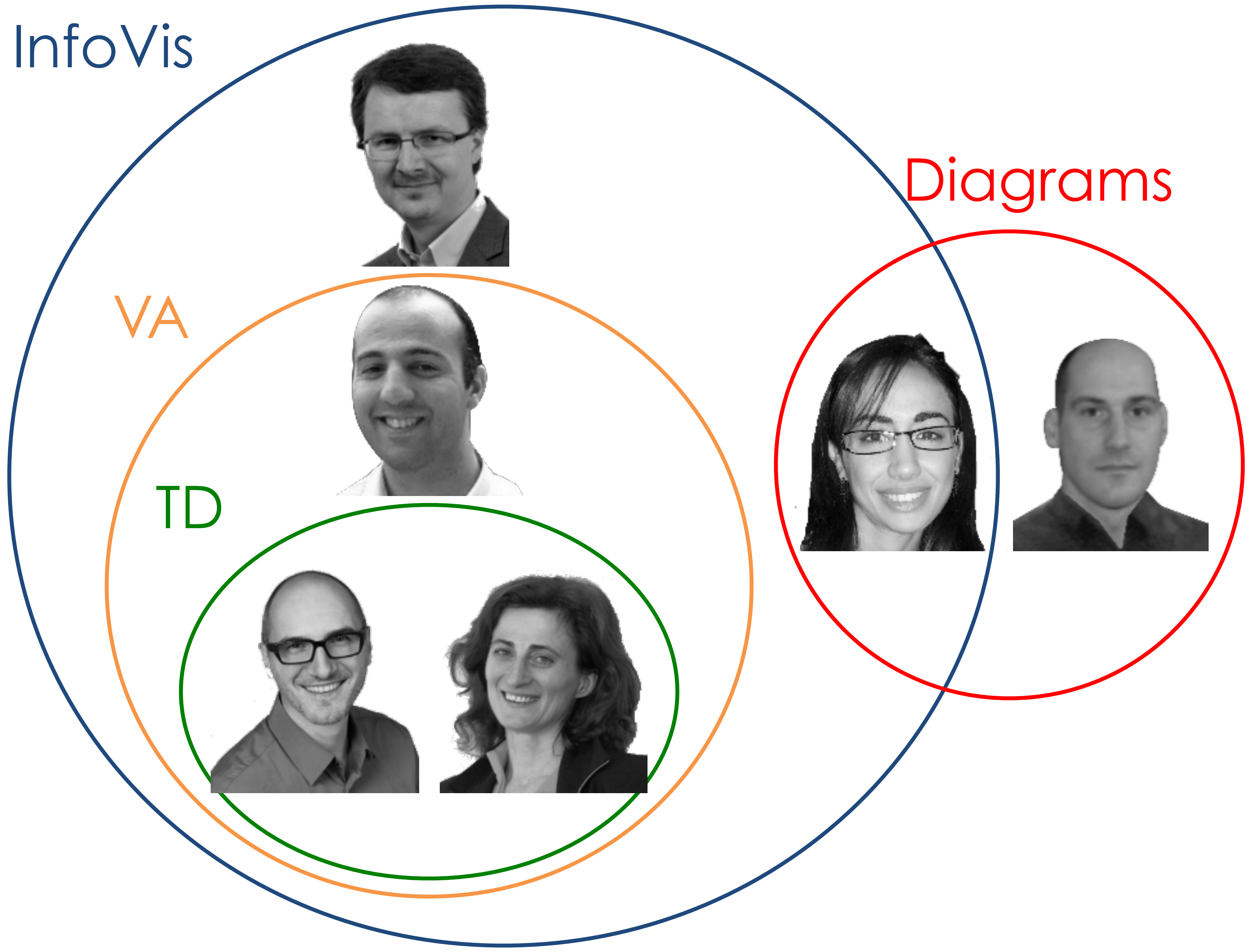


# Element Attributes

Analyze the set memberships for elements having
certain attribute values

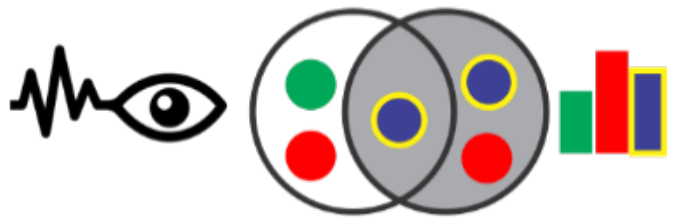


InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams



# Element Attributes

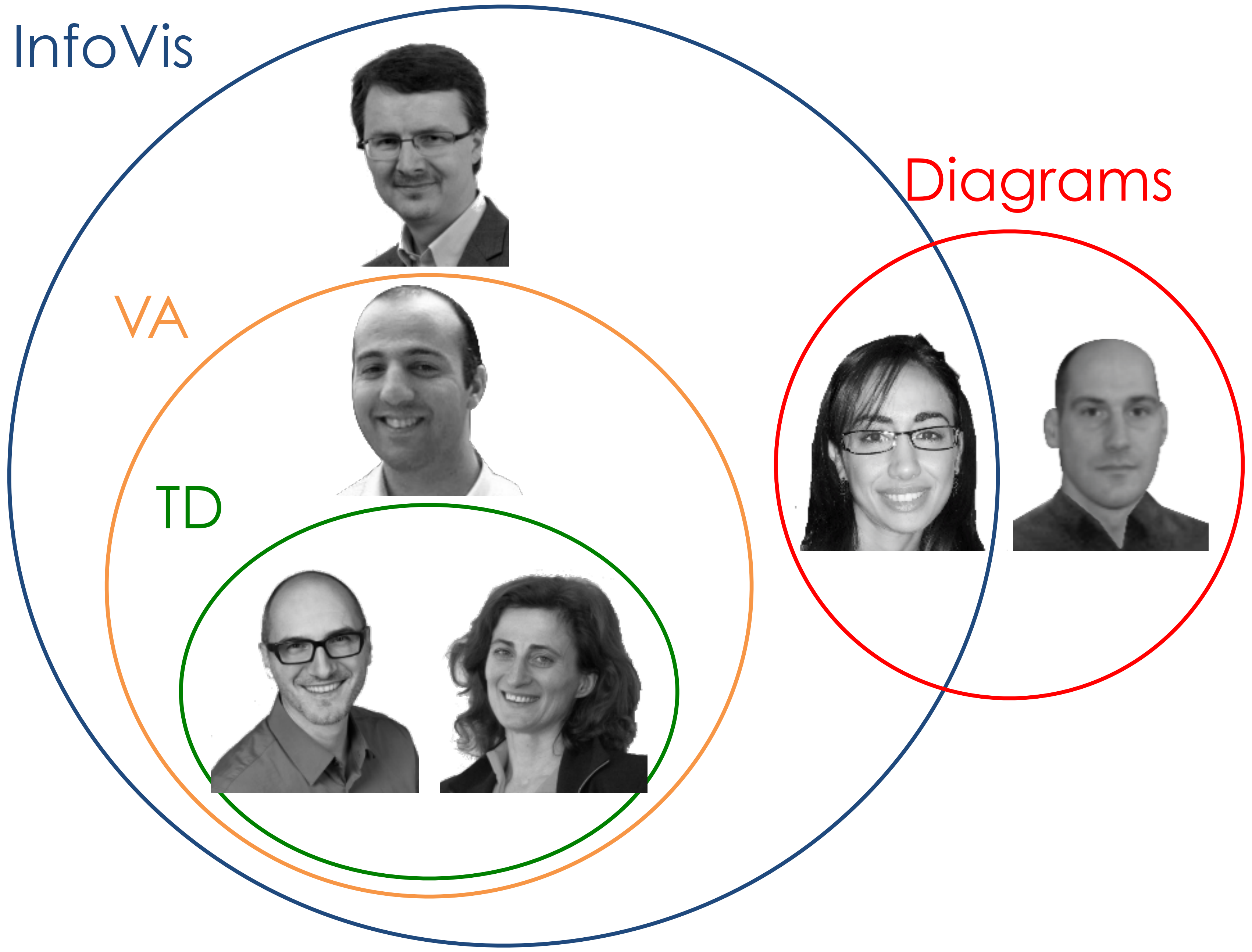
Analyze the set memberships for elements having
**certain attribute values**



set memberships = research areas

elements = authors

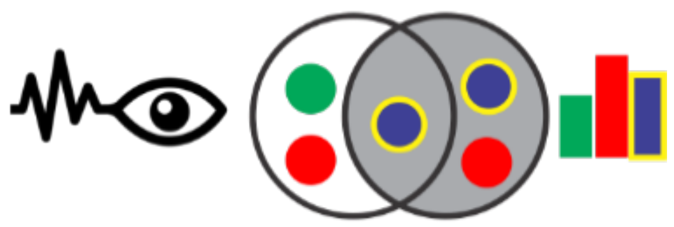
**attribute value** = female




InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Element Attributes

Analyze the set memberships for elements having **certain attribute values**

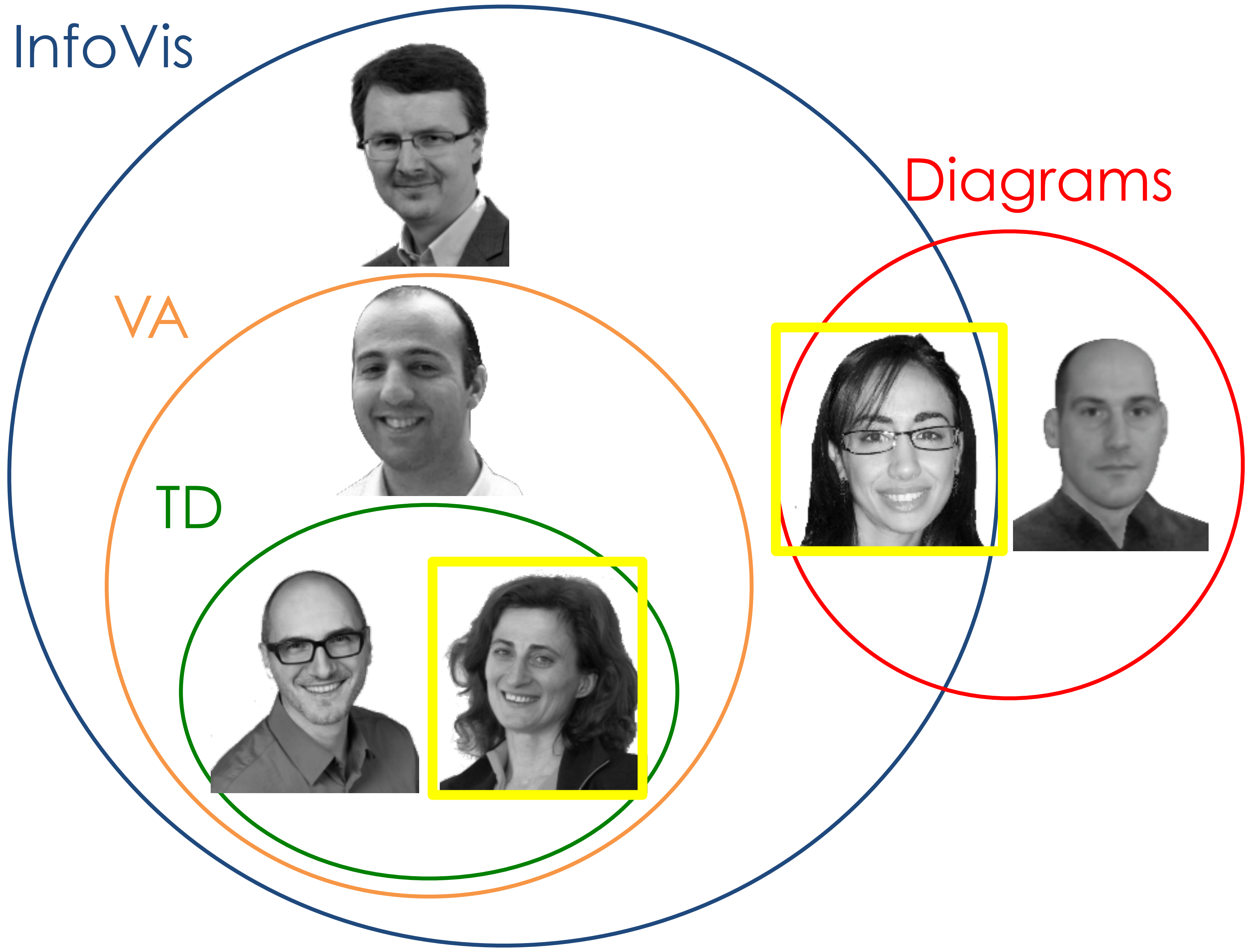


set memberships = research areas

elements = authors

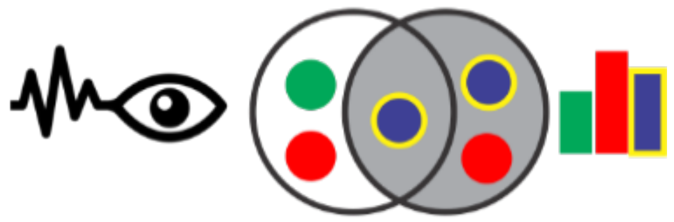
**attribute value** = female

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams



# Element Attributes

Analyze the set memberships for elements having
**certain attribute values**

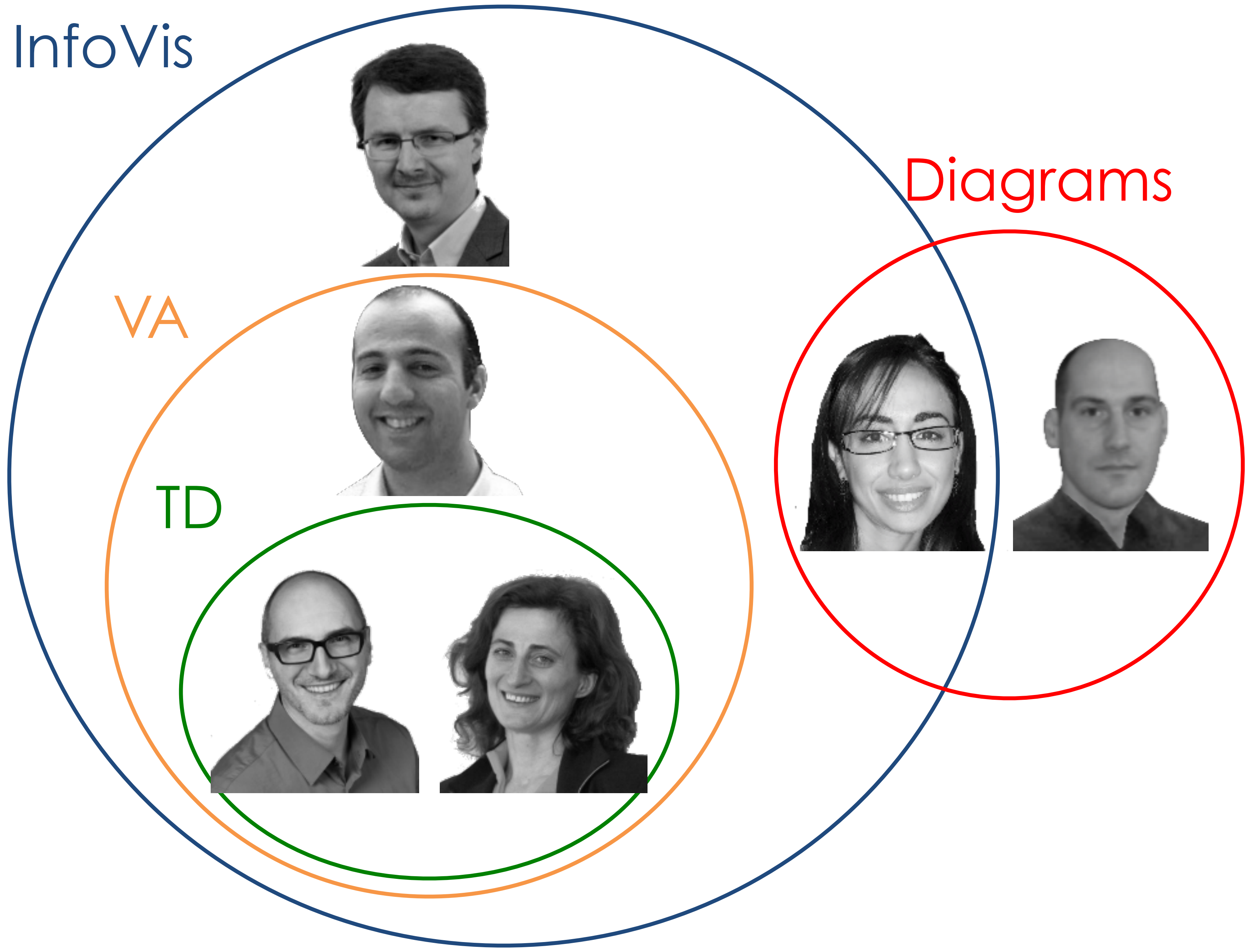


set memberships = research areas

elements = authors

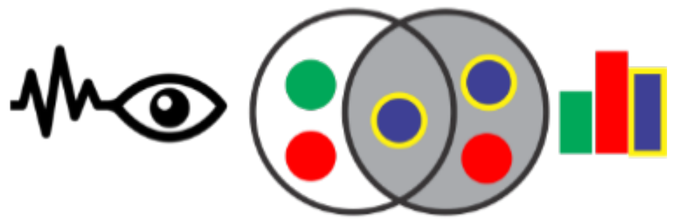
**attribute value** = female

InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams



# Element Attributes

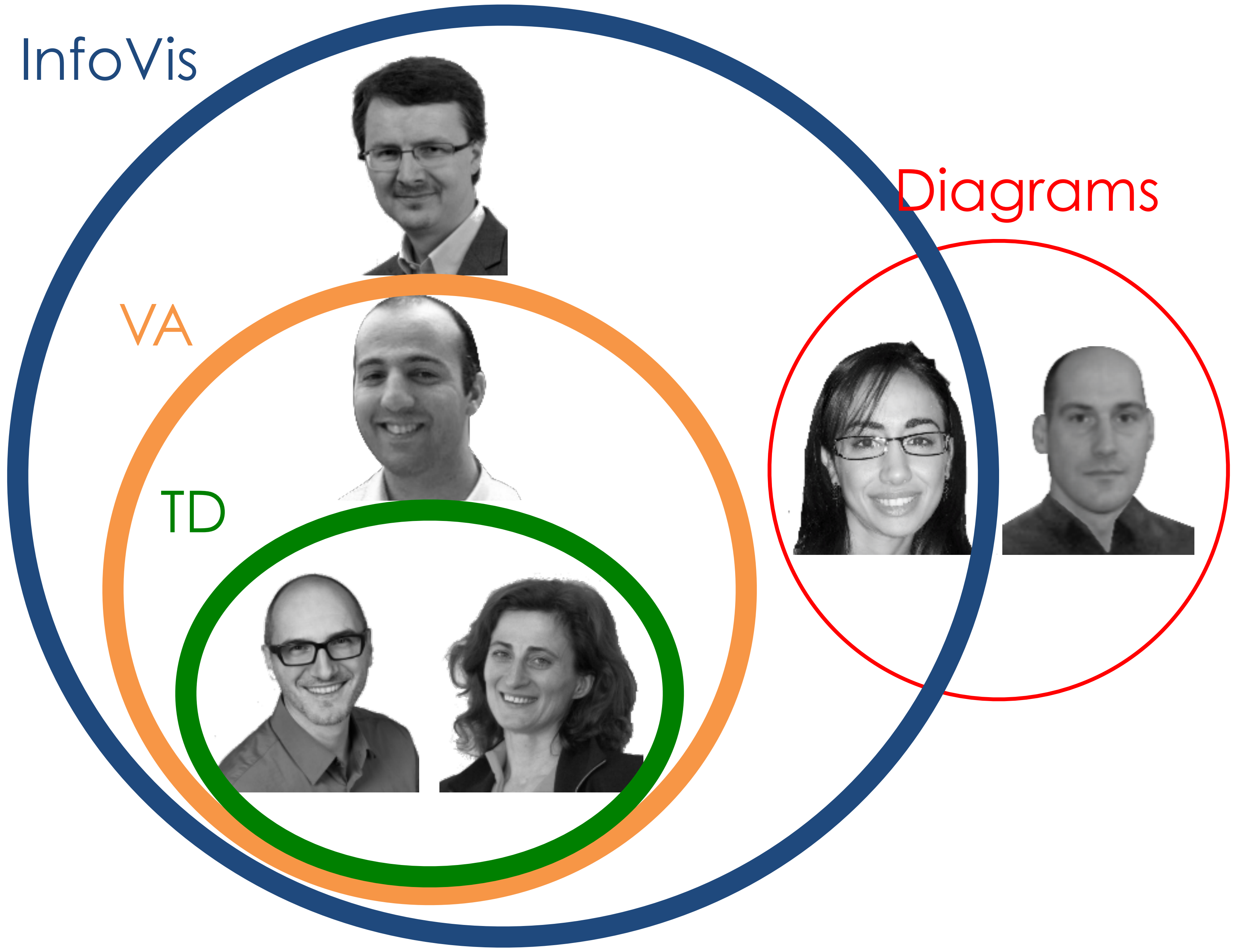
Analyze the set memberships for elements having **certain attribute values**



set memberships = research areas

elements = authors

**attribute value** = female




InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams

# Element Attributes

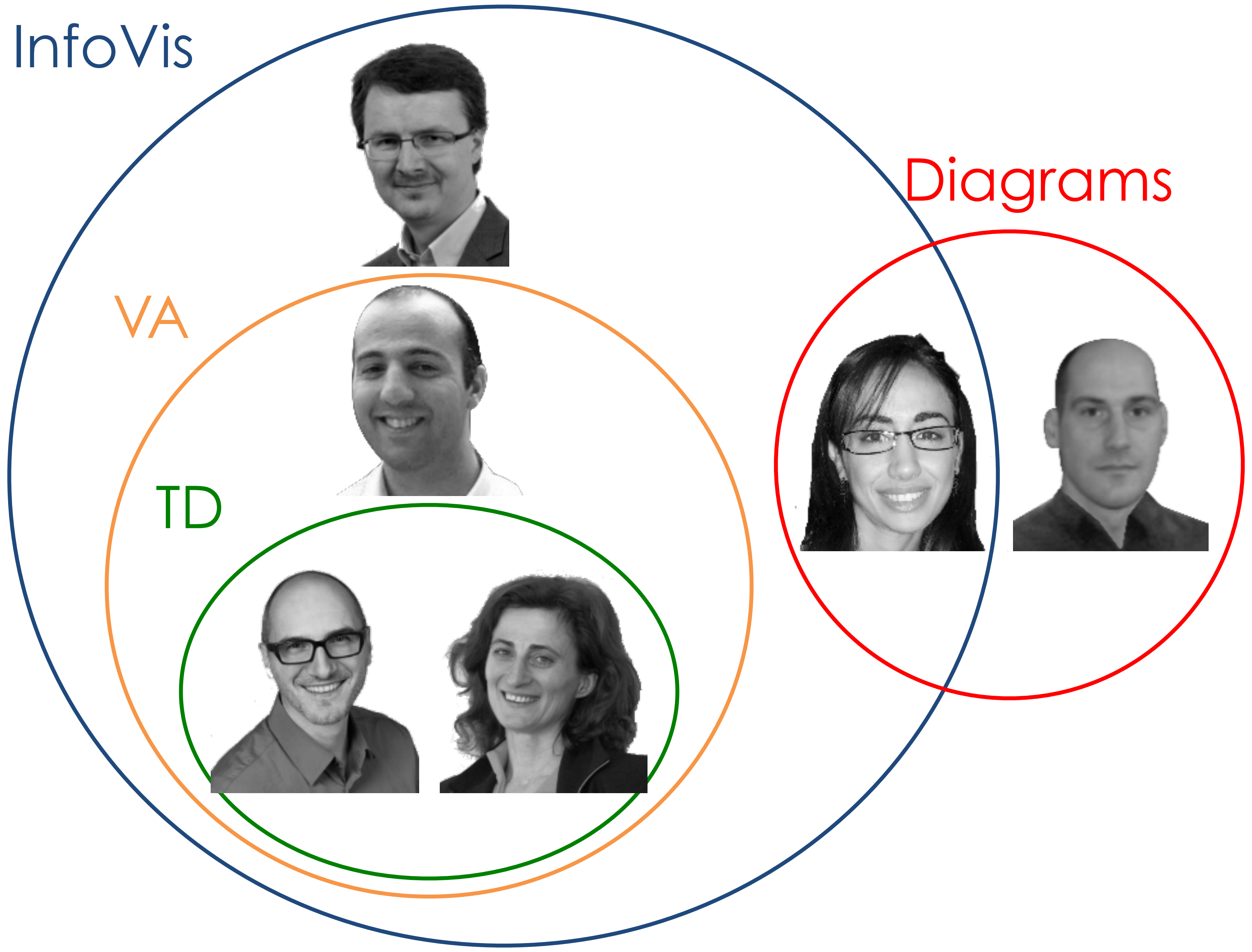
Analyze the set memberships for elements having
**certain attribute values**

set memberships = research areas

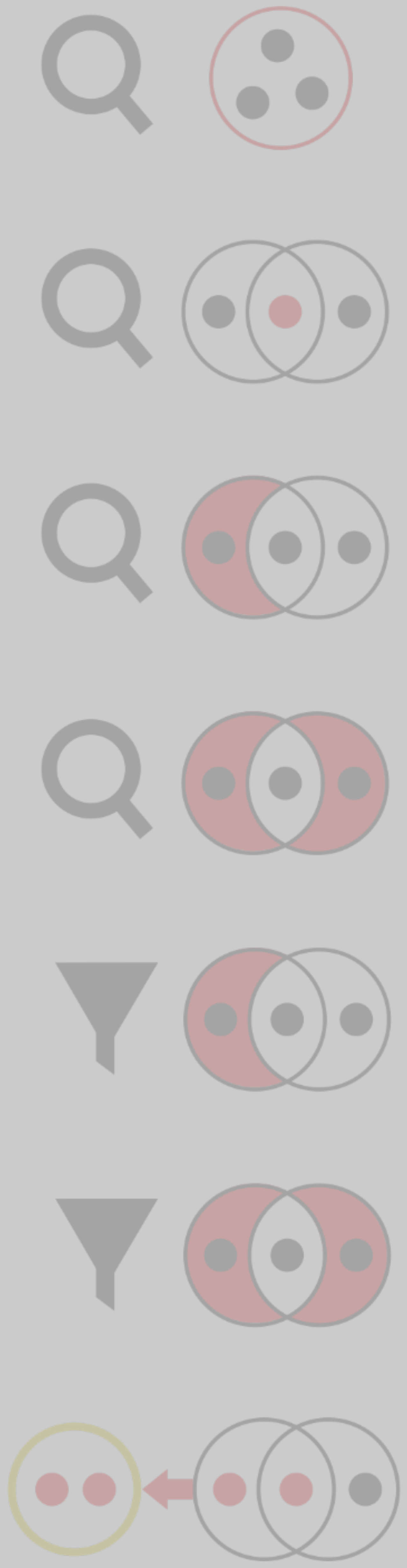
elements = authors

**attribute value** = female

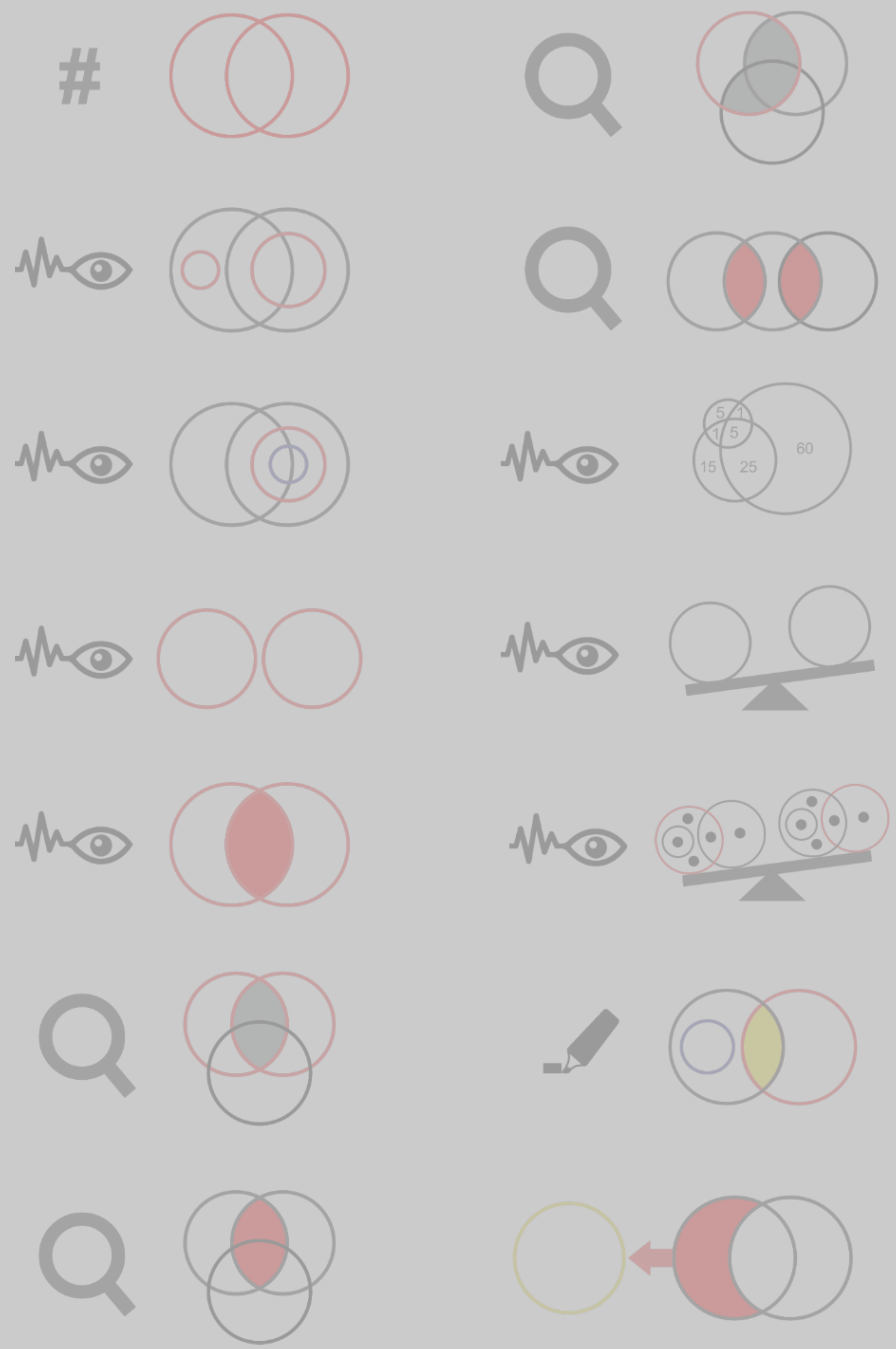
InfoVis
Visual Analytics (VA)
Time-oriented Data (TD)
Diagrams



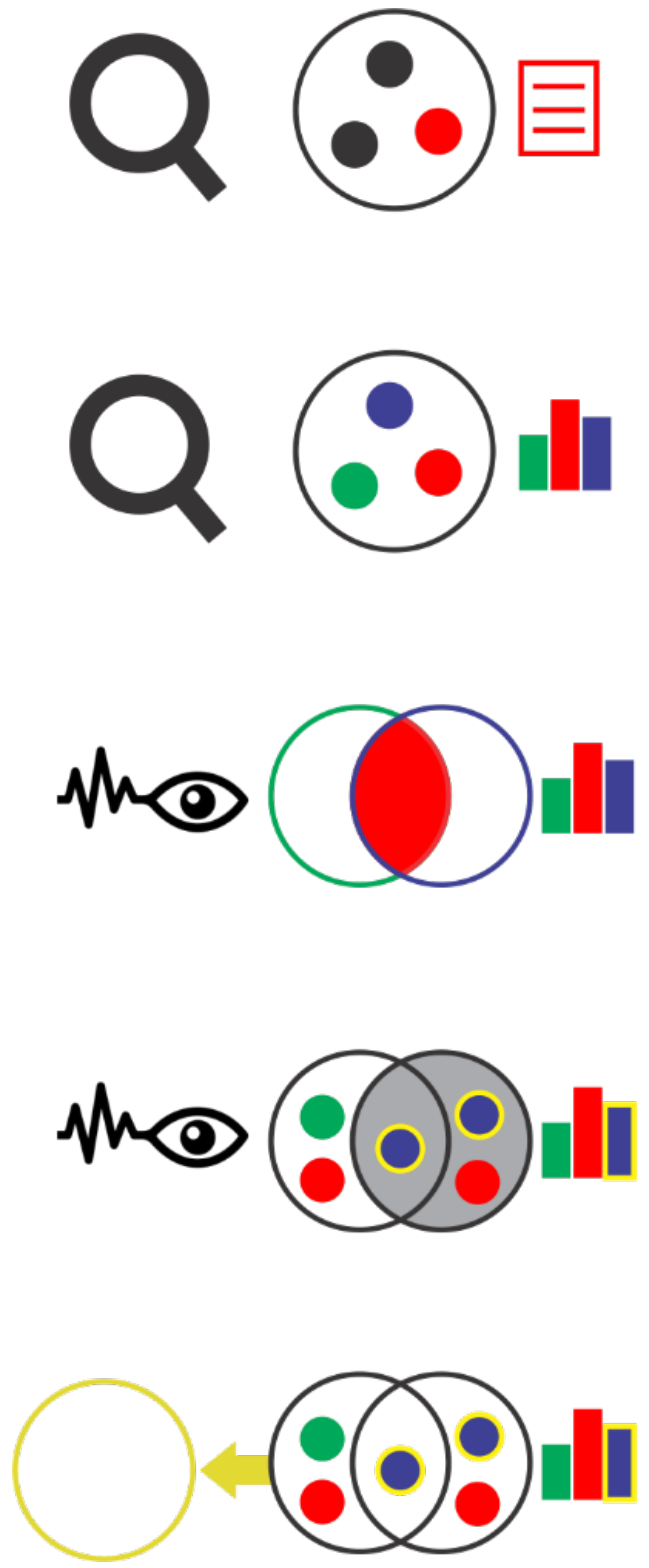
## Elements



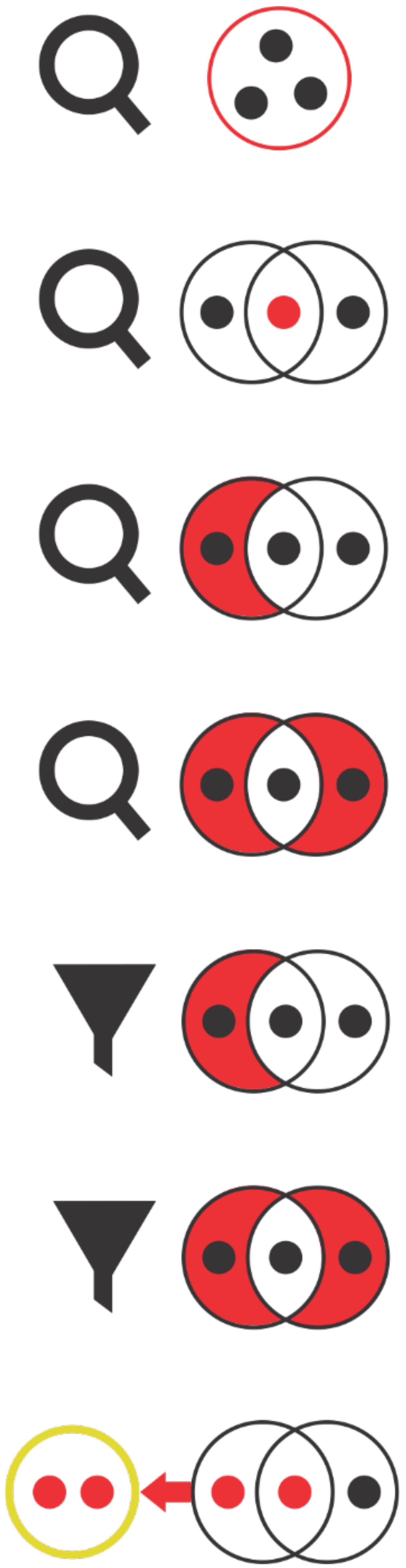
## Sets and Set Relations



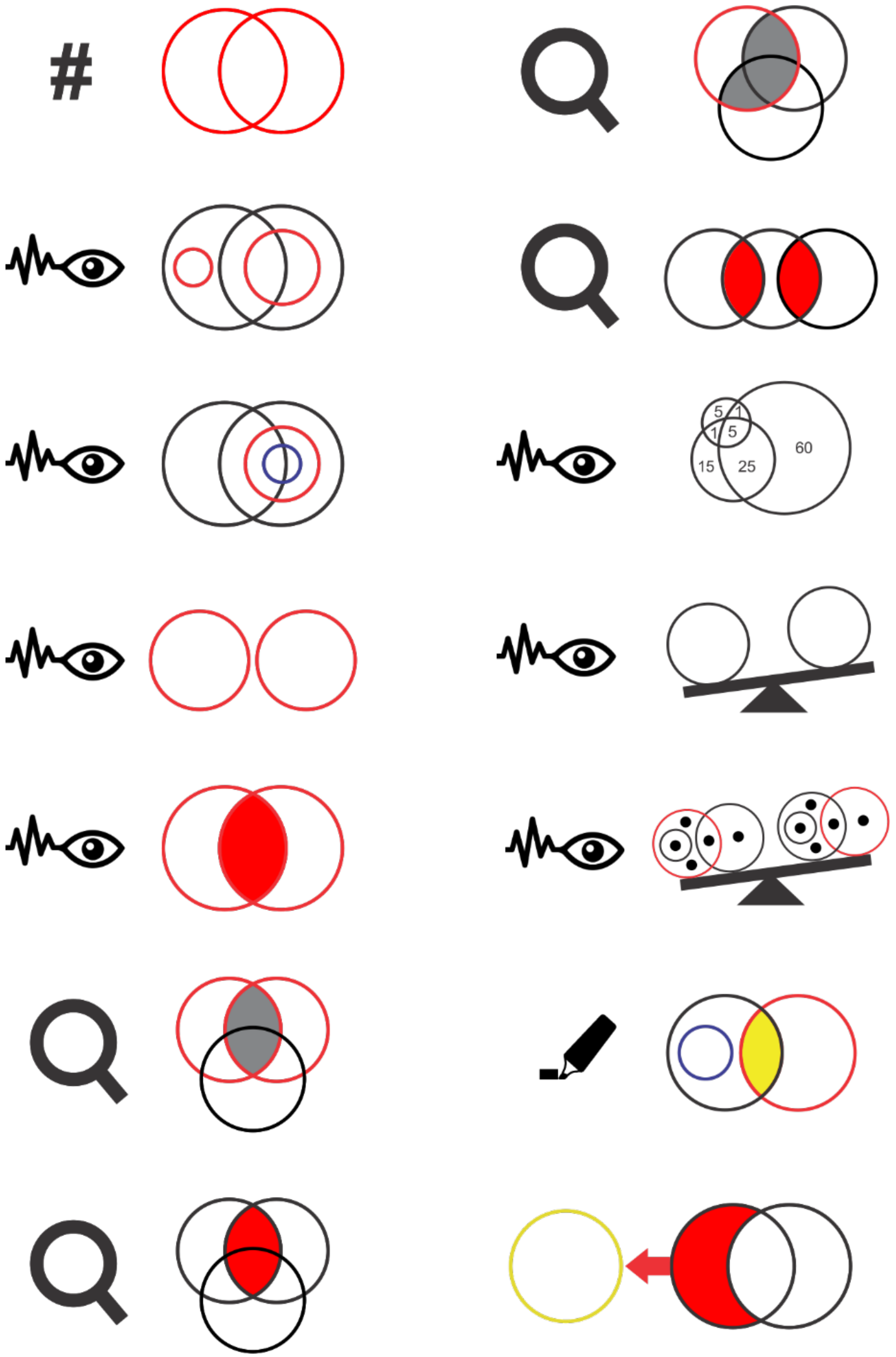
## Element Attributes



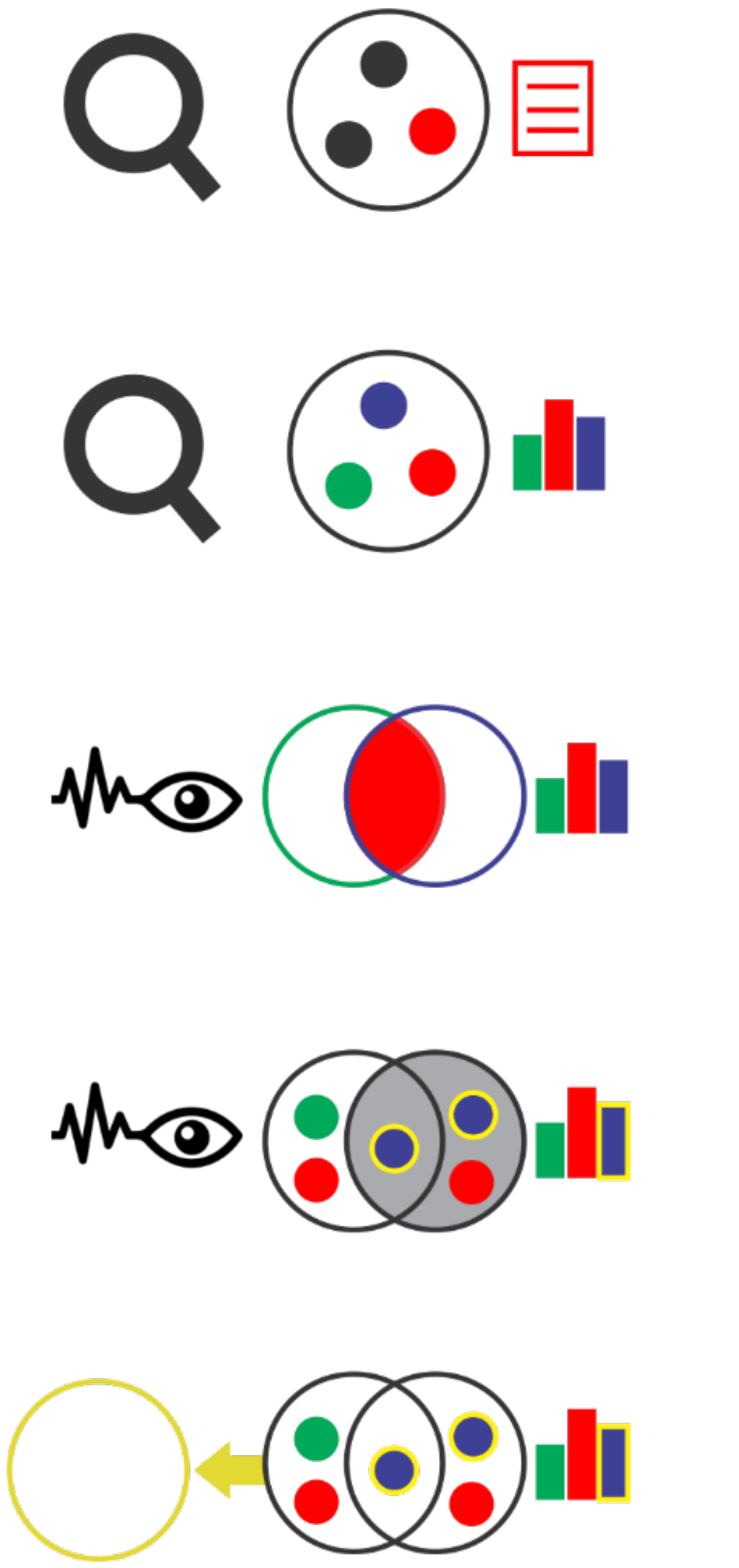
## Elements



## Sets and Set Relations

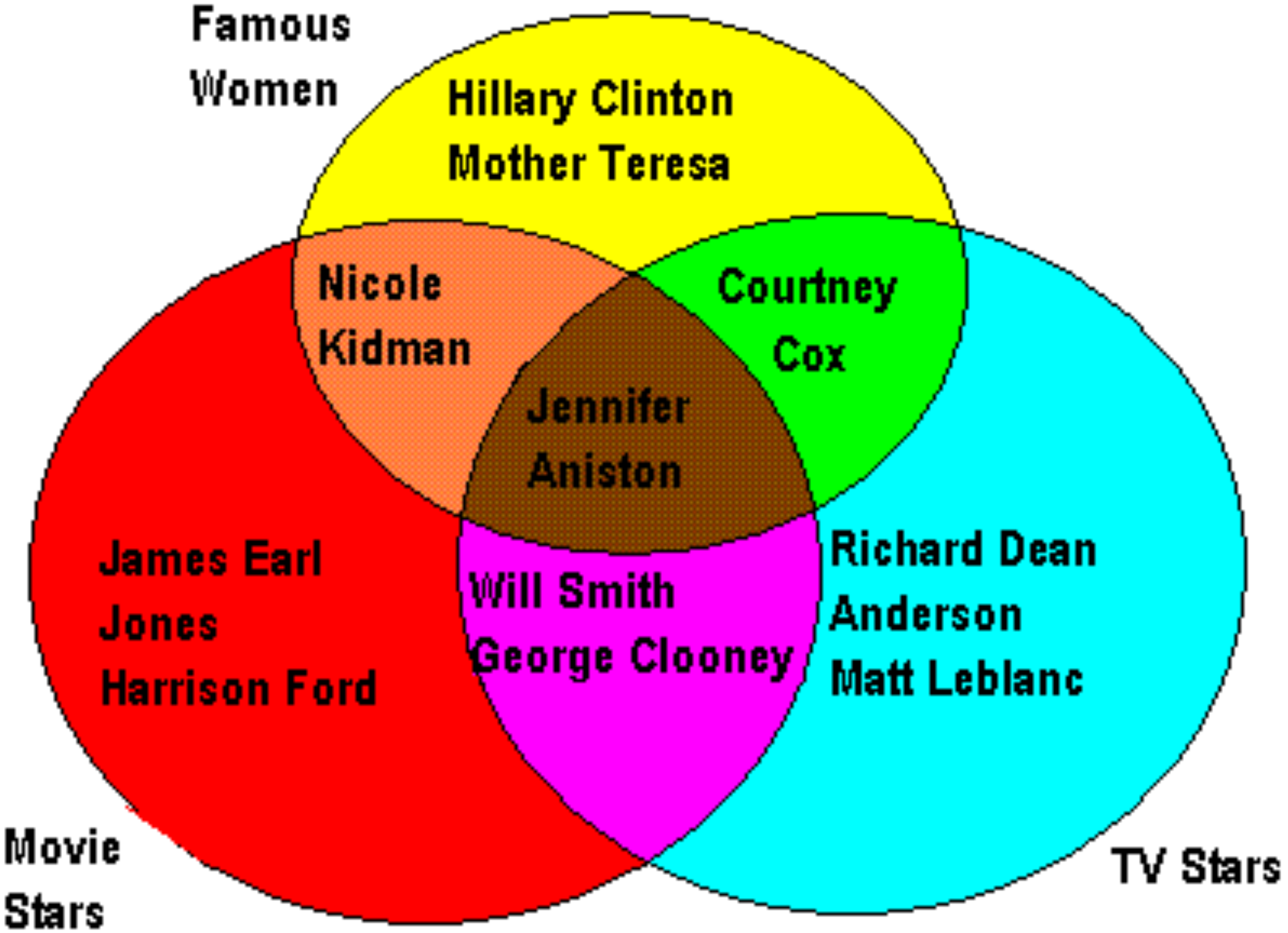



## Element Attributes



# Techniques

# Venn Diagram



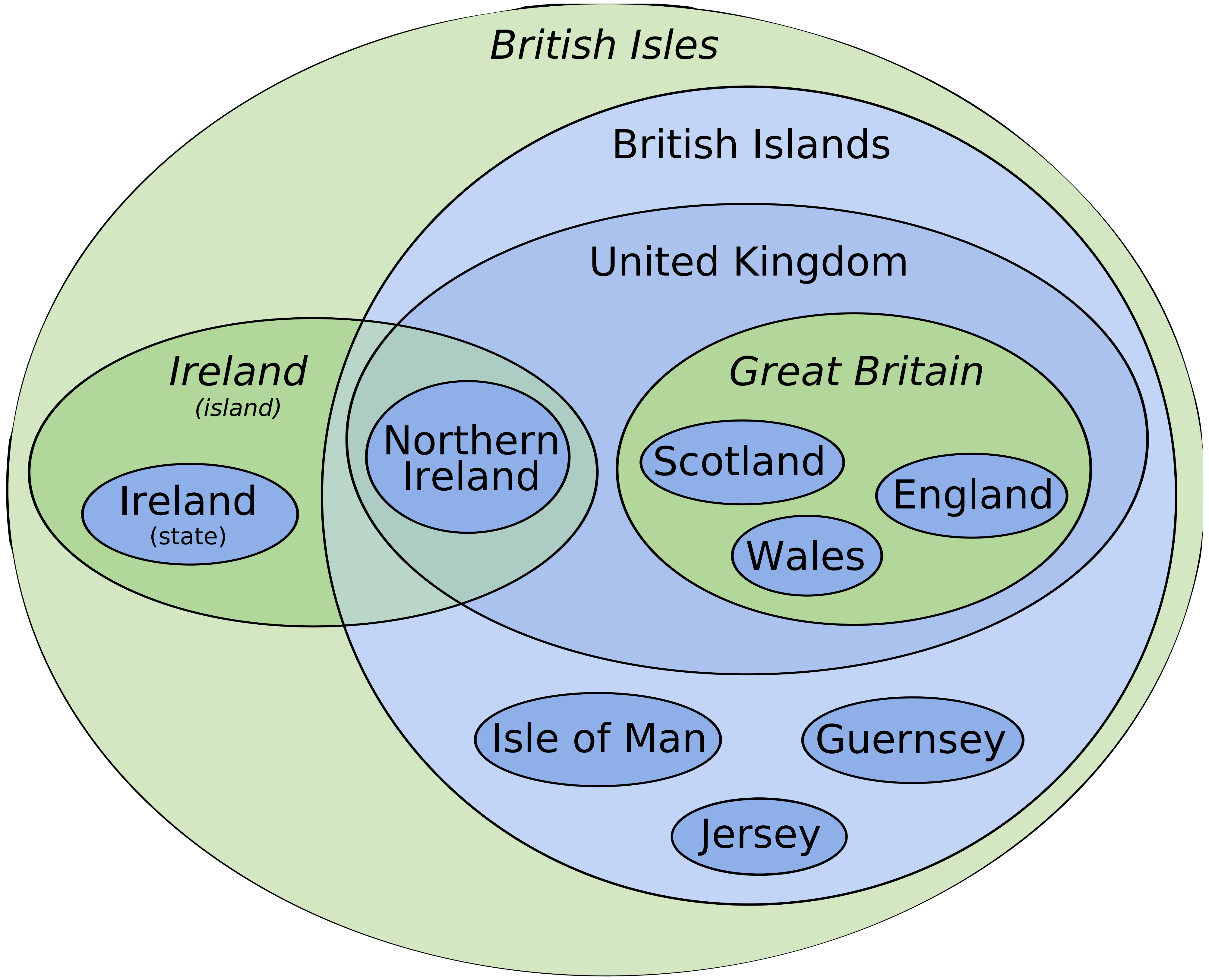

[http://askville.amazon.com/idea-Venn-diagram/AnswerViewer.do?requestId=8420613]

# Venn Diagram?


[viz.wtf]

# Scalability

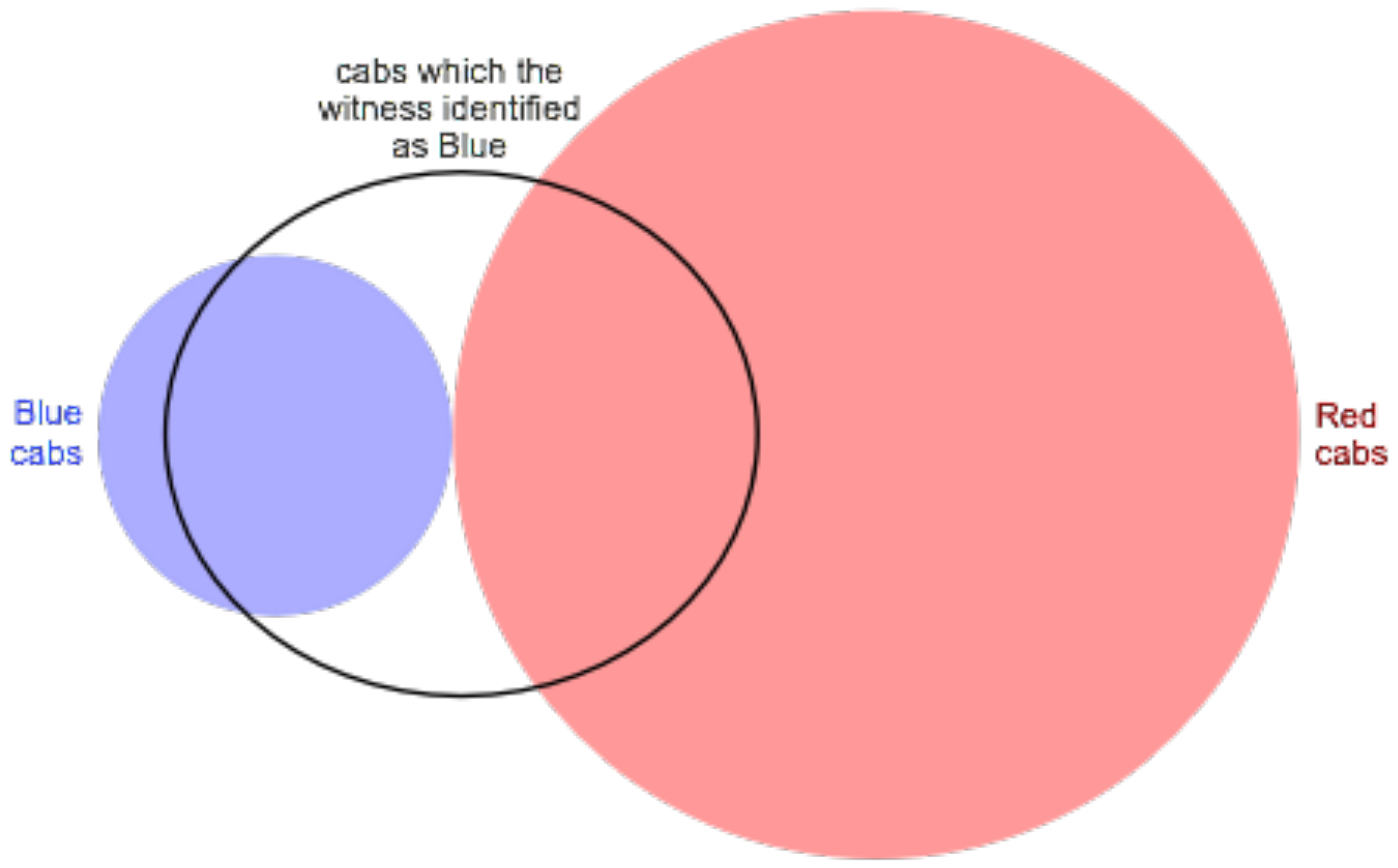
- How to show the intersection of four sets? 8?
- Euler Diagrams: only show intersections/containments that exist
- Still run into scalability issues



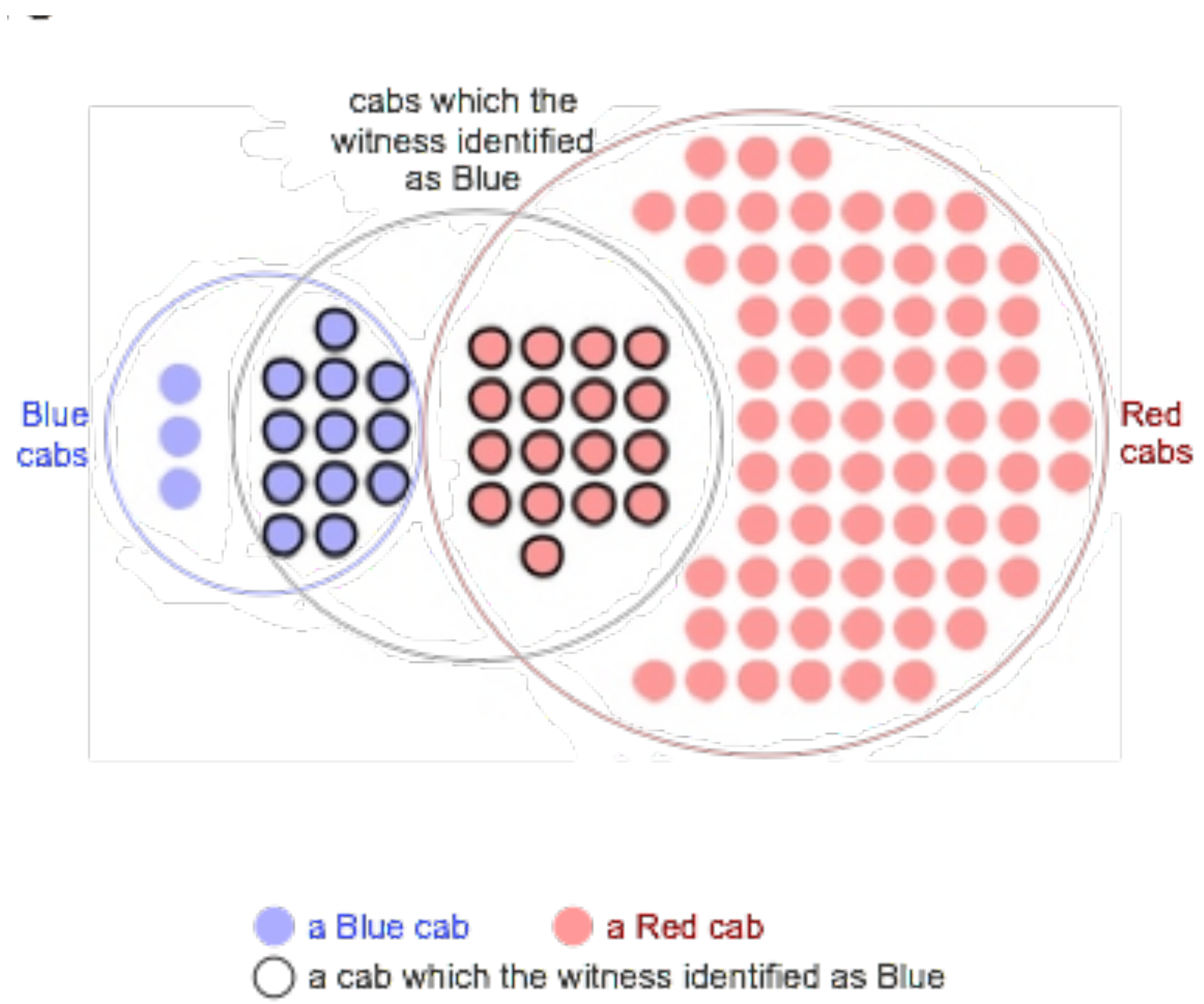

[Wikipedia]

# What about cardinality?

Area encoding

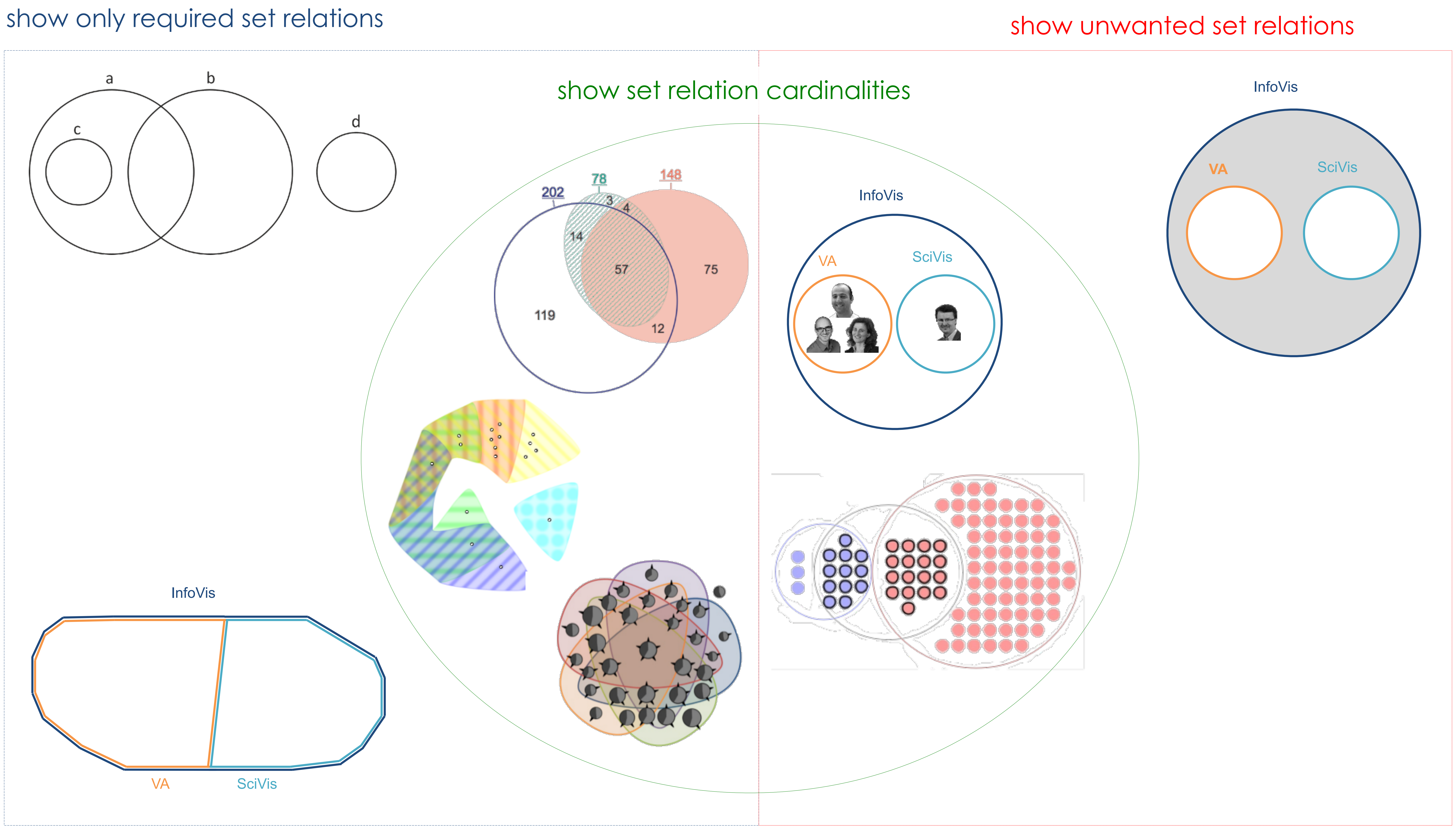



Using glyphs




[B. Alsallakh et al., 2014]

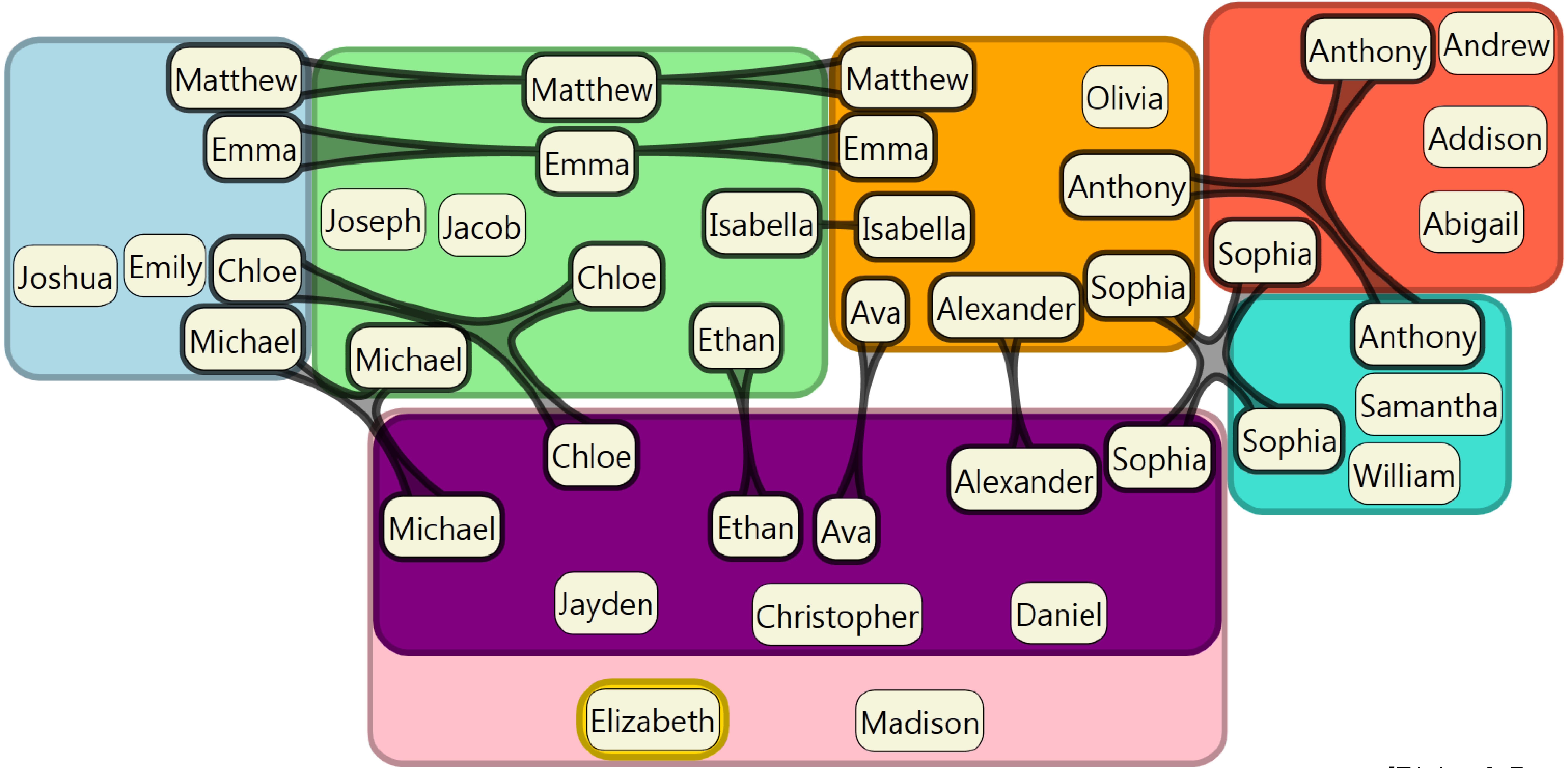
# Venn Diagram Visualizations




[B. Alsallakh et al., 2014]

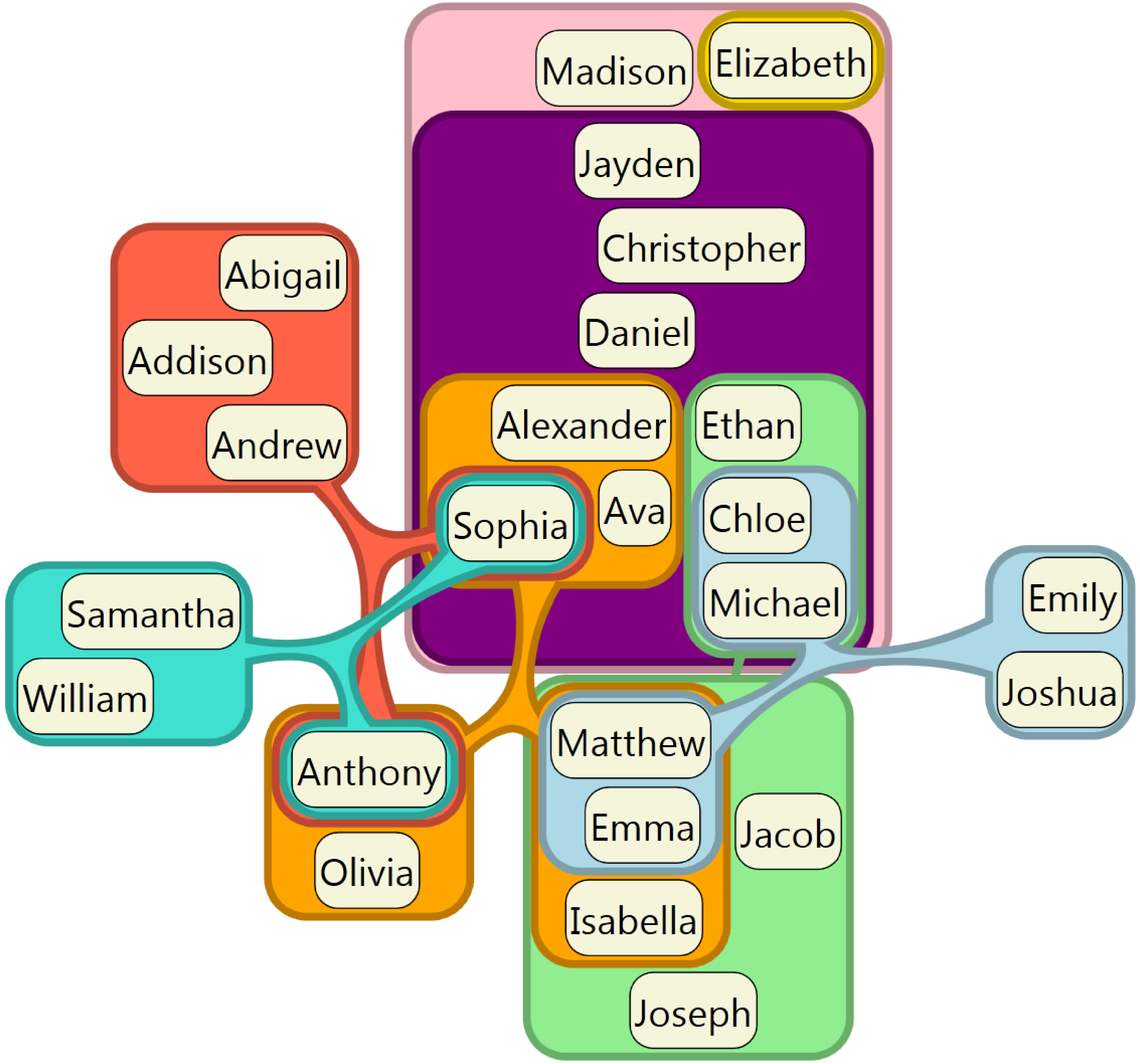
What if we don't worry so much about nice circles/ ellipses?

# Compact Euler Diagrams: Use edges




[Riche & Dwyer, 2010]

# Compact Euler Diagrams: Use nesting

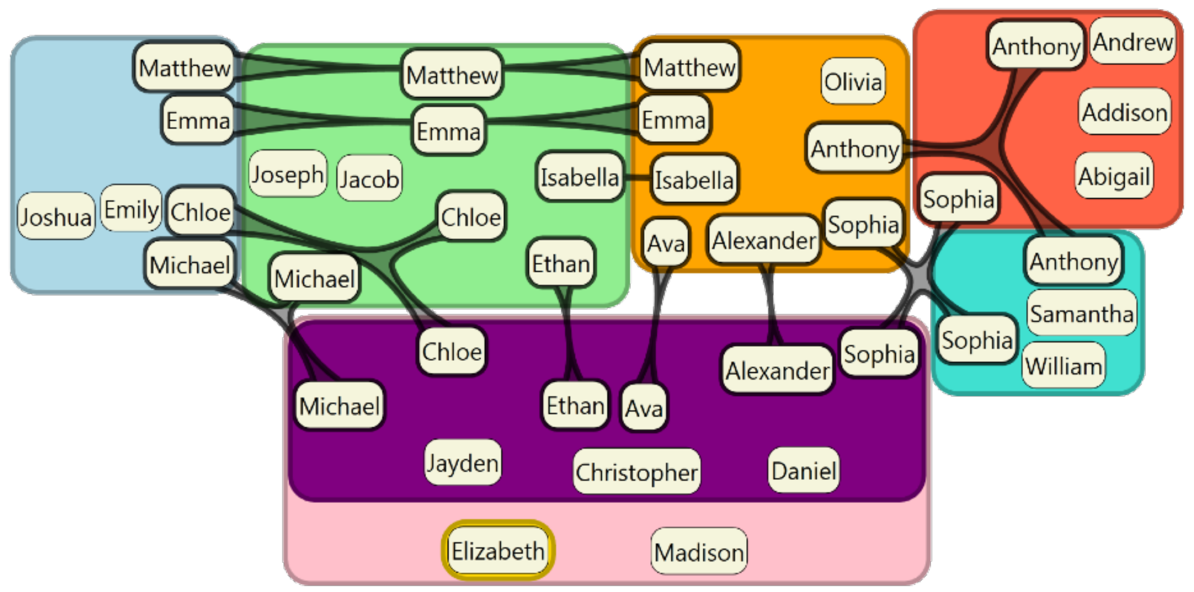


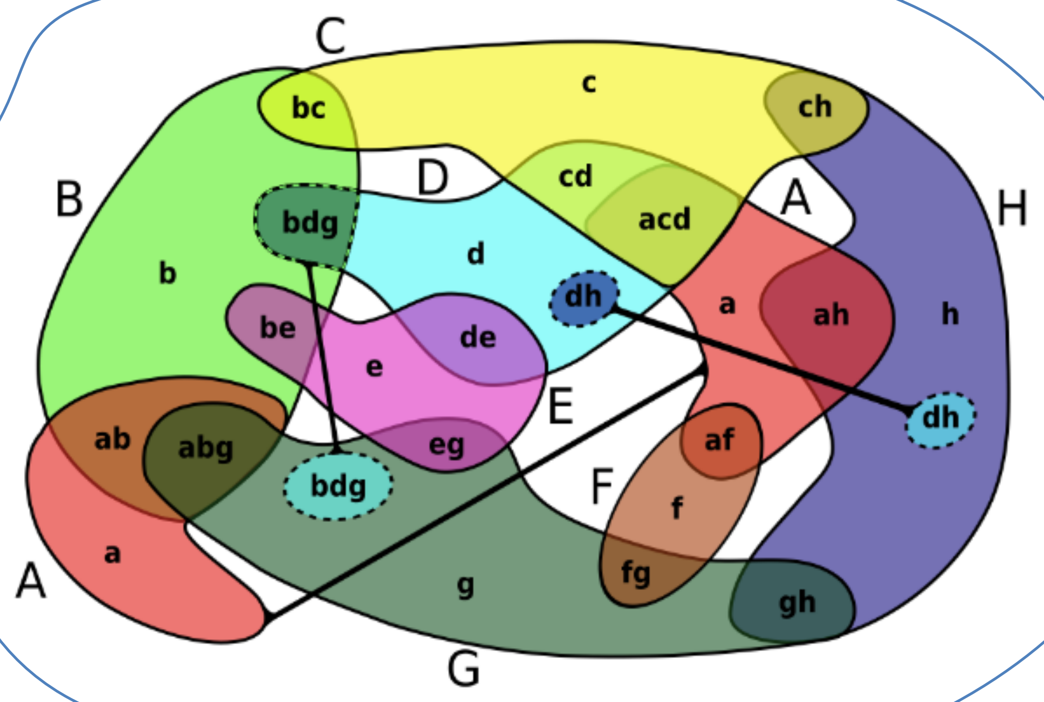

[Riche & Dwyer, 2010]

# Euler Diagram Variants

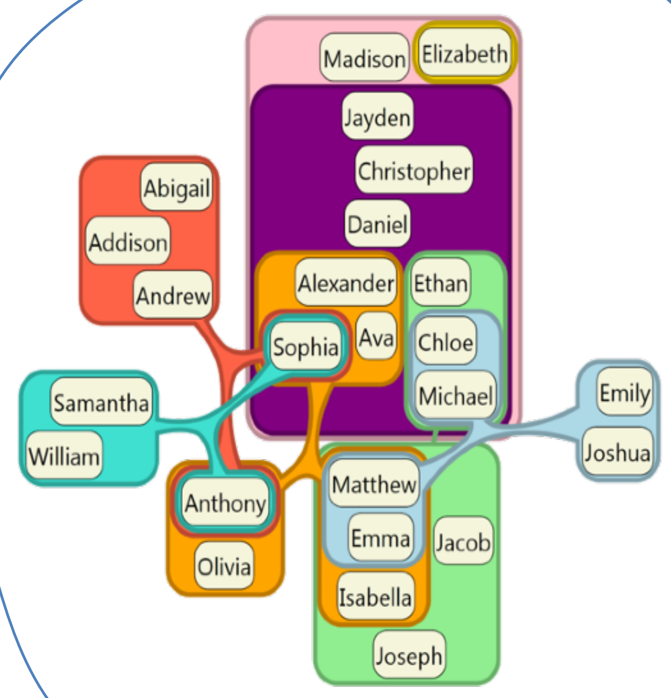
use edges

split set into components

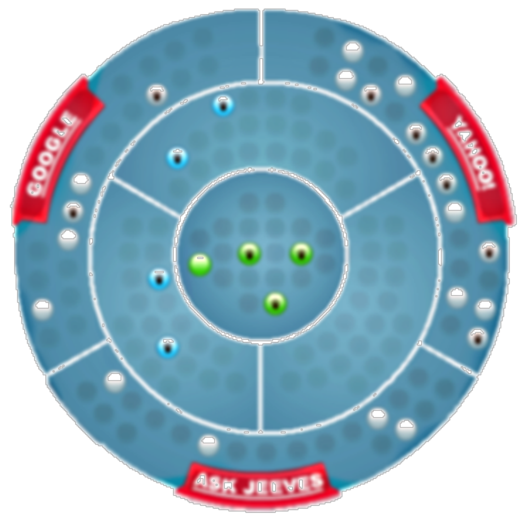


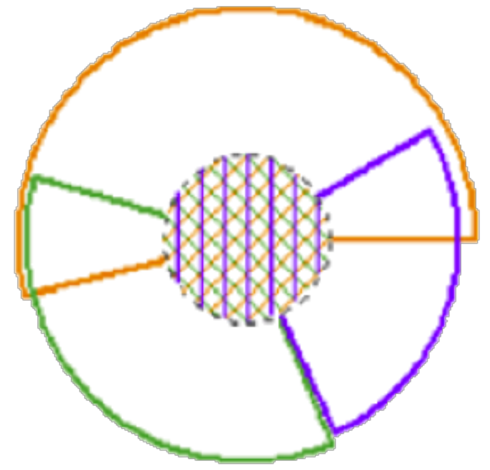




split set into components



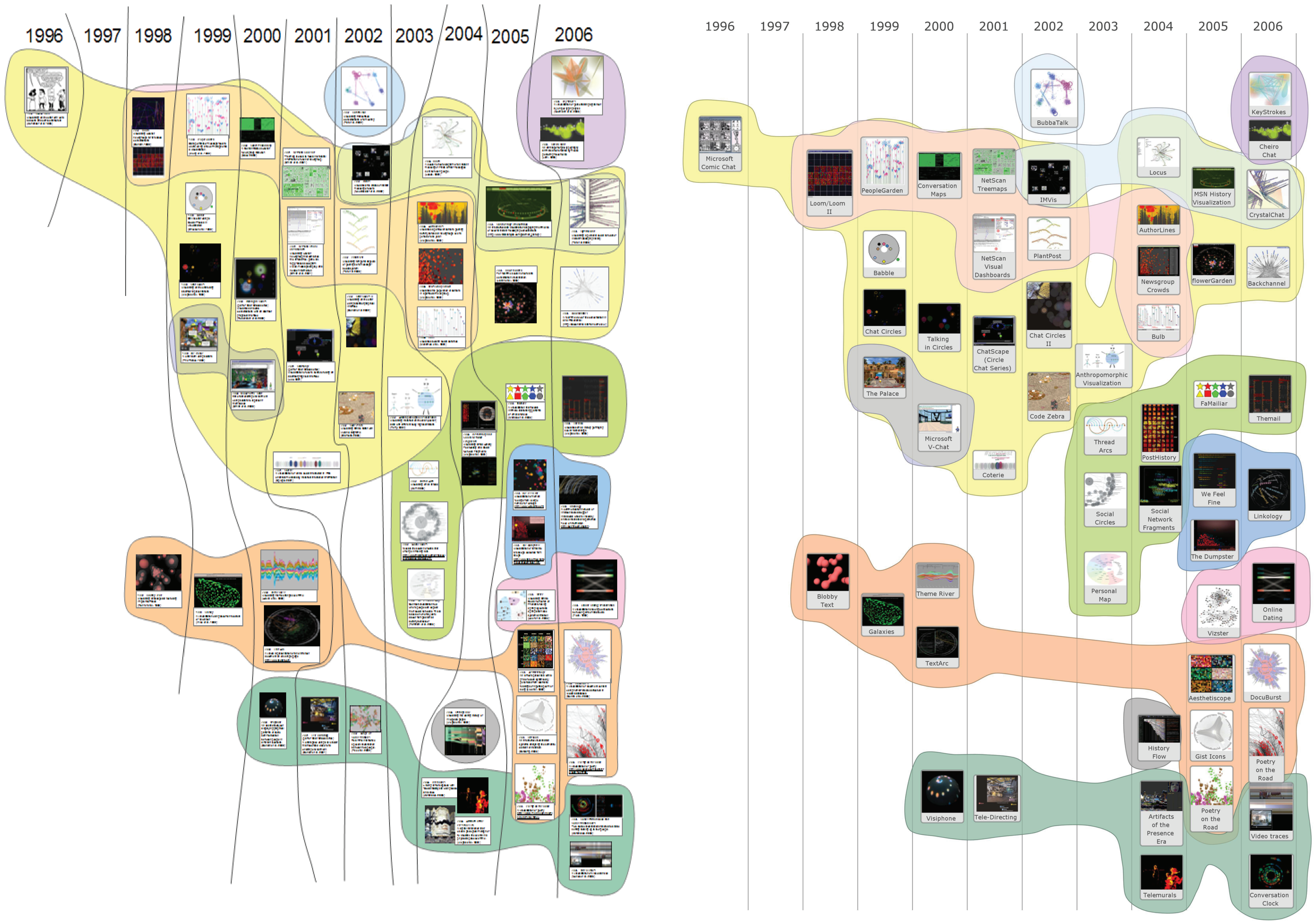

use a concentric layout



[B. Alsallakh et al., 2014]

# Bubble Sets: Overlay set membership




a

b

[Collins et al., 2009]

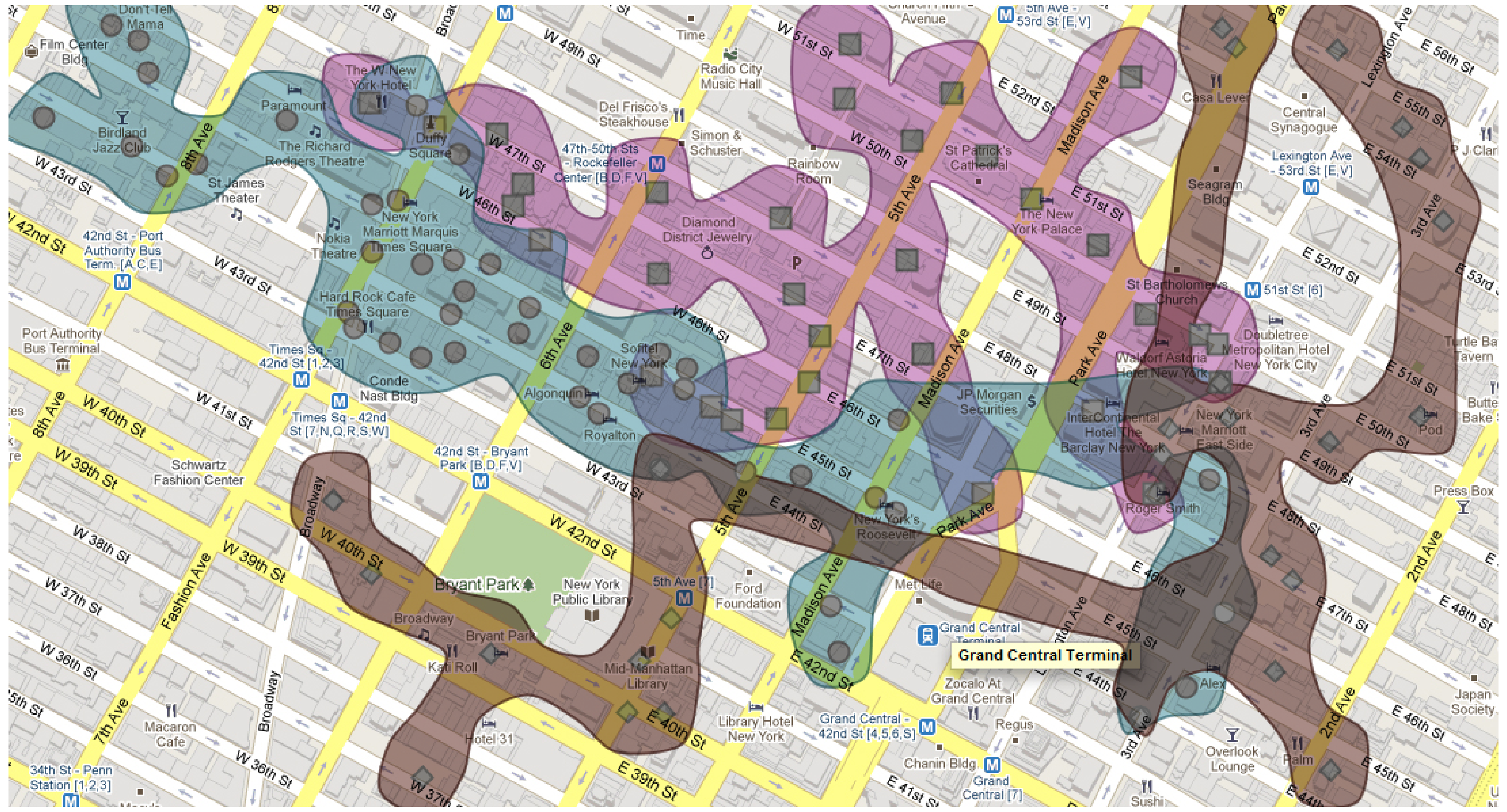
# Bubble Sets & Overlay Techniques

- Given spatial layout is determined by other attributes, want to show set containment without modifying spatial layout
- Idea of "spatial rights"
- Construct regions based on a potential **field**
- Draw using containment marks
- How do we compute these?

# Bubble Sets & Overlay Techniques

- Given spatial layout is determined by other attributes, want to show set containment without modifying spatial layout
- Idea of "spatial rights"
- Construct regions based on a potential **field**
- Draw using containment marks
- How do we compute these?
  - Marching Squares!

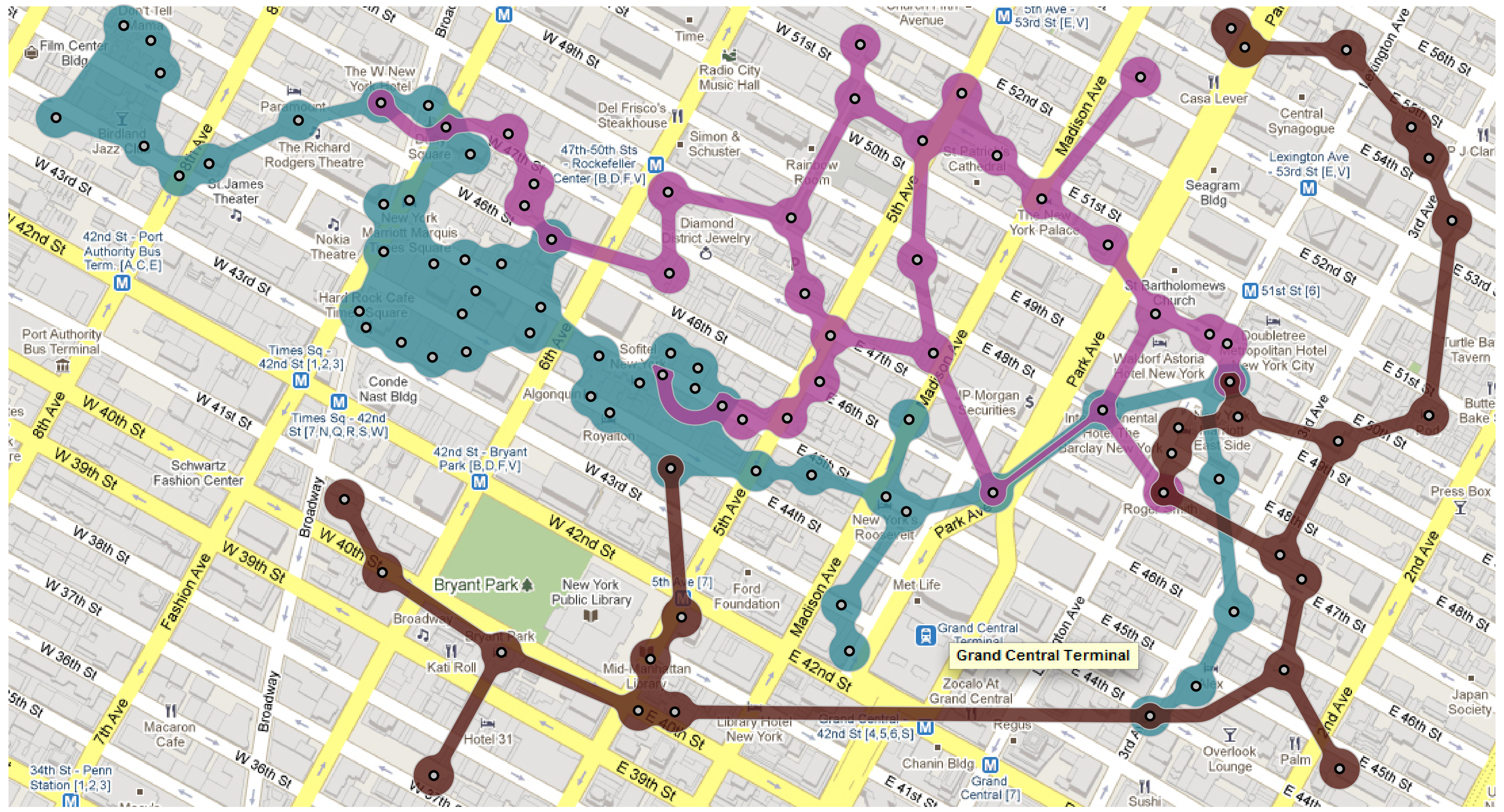
# KelpFusion



(a) Bubble Sets

(c) LineSets

(b) Kelp Diagrams

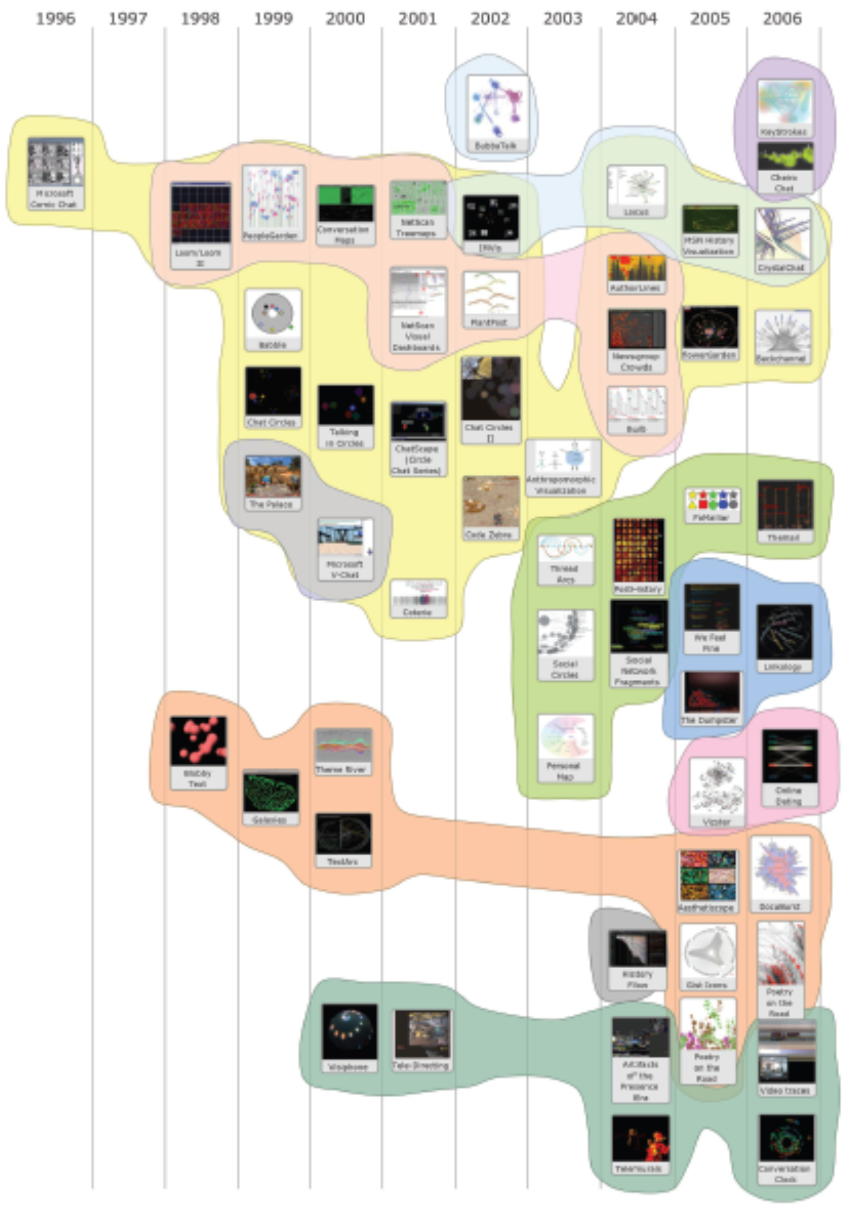


(e) KelpFusion (medium)

[Meulemans et al., 2013]

# Overlays

Region-based

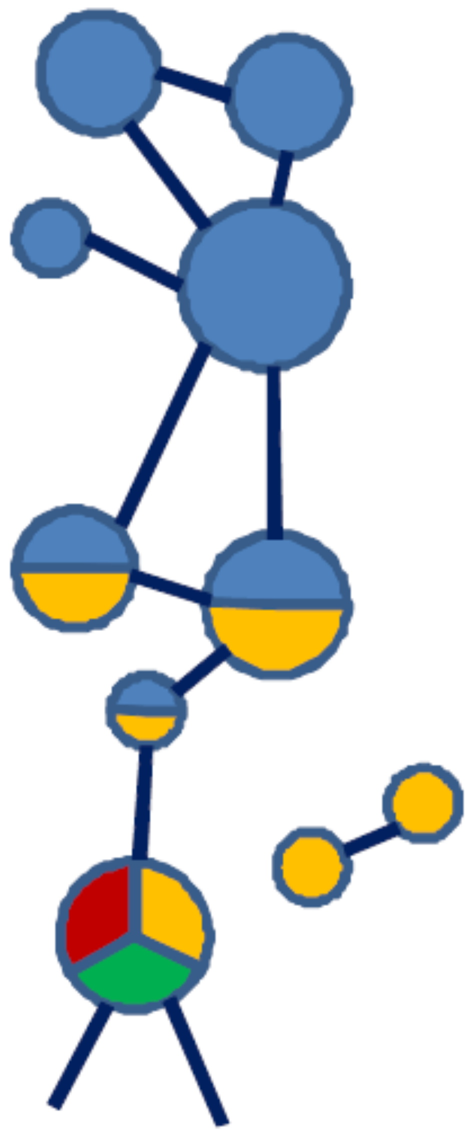


[Collins et al., 2009]

Line-based

[Dinkla et al., 2012]

Glyph-based

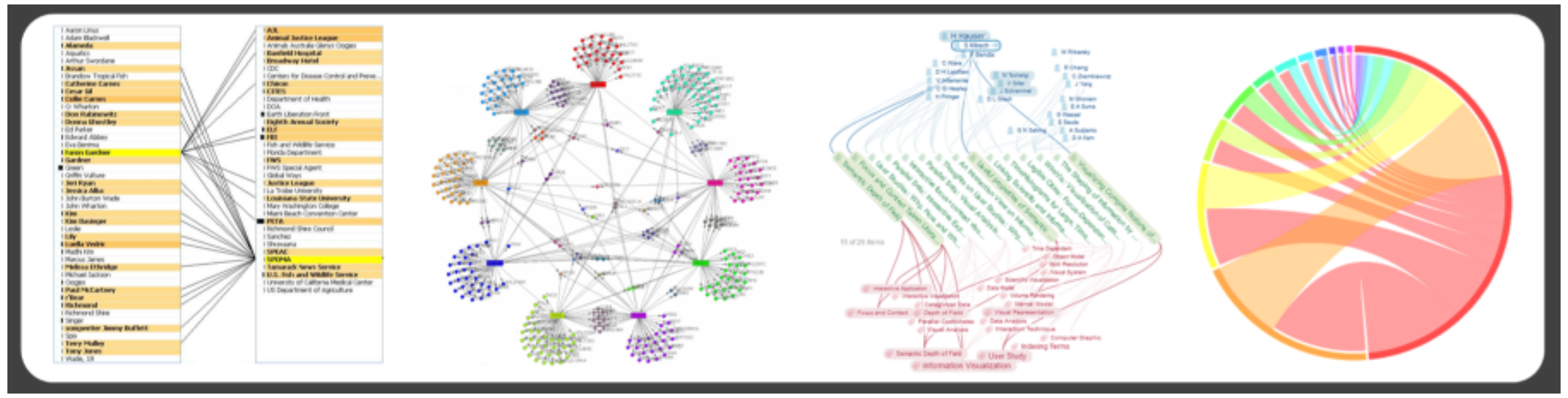


[Itoh et al., 2009]

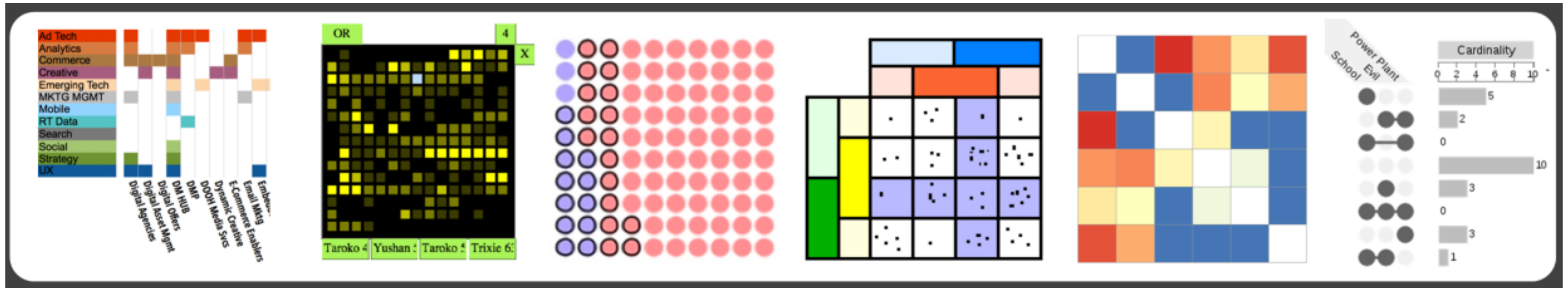
[via B. Alsallakh et al., 2014]

# More…

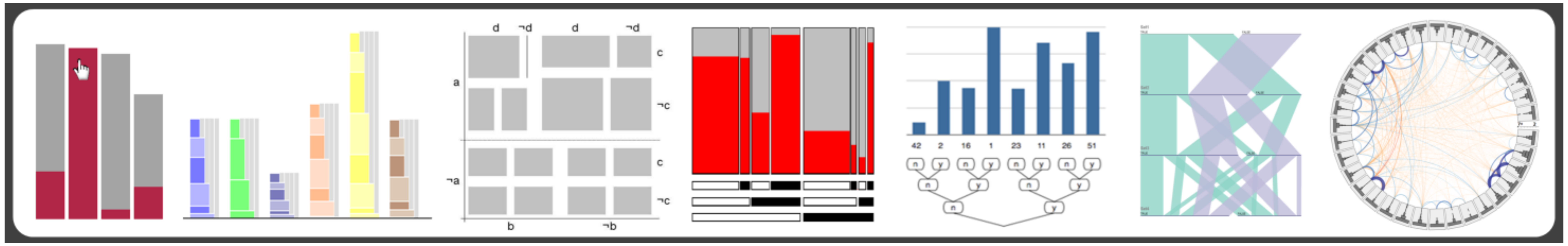
- Node-Link Visualizations



- Matrix-based techniques

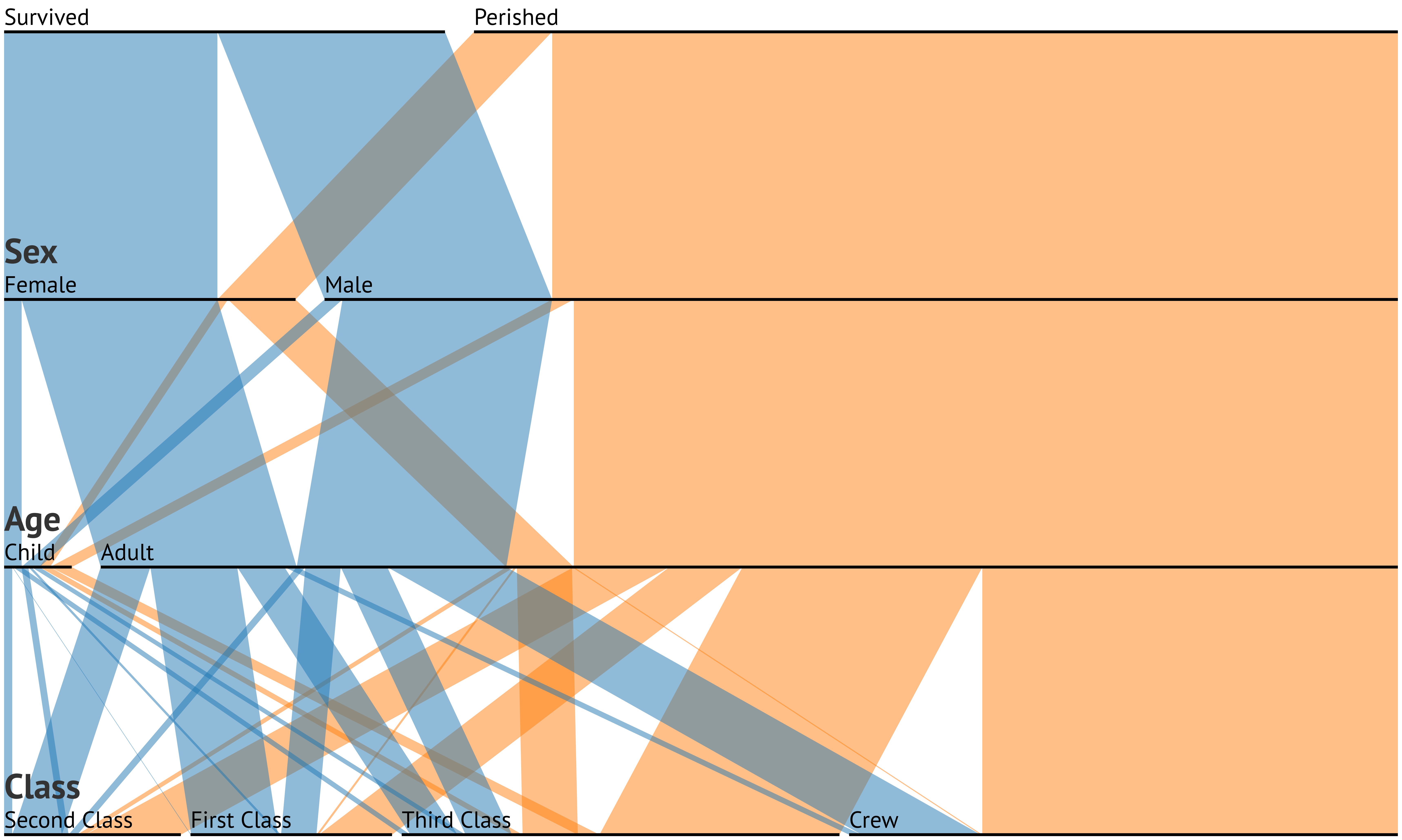


- Aggregation-based techniques



[via B. Alsallakh et al., 2014]

# More… Parallel Sets




[Kosara et al., 2006, Example: J. Davies]

# Clusters

- What is a cluster?
  - A **grouping** of objects (sets of objects)
  - Why is this not more precise?
- How do we determine if two items should be in the same cluster?

# Clusters

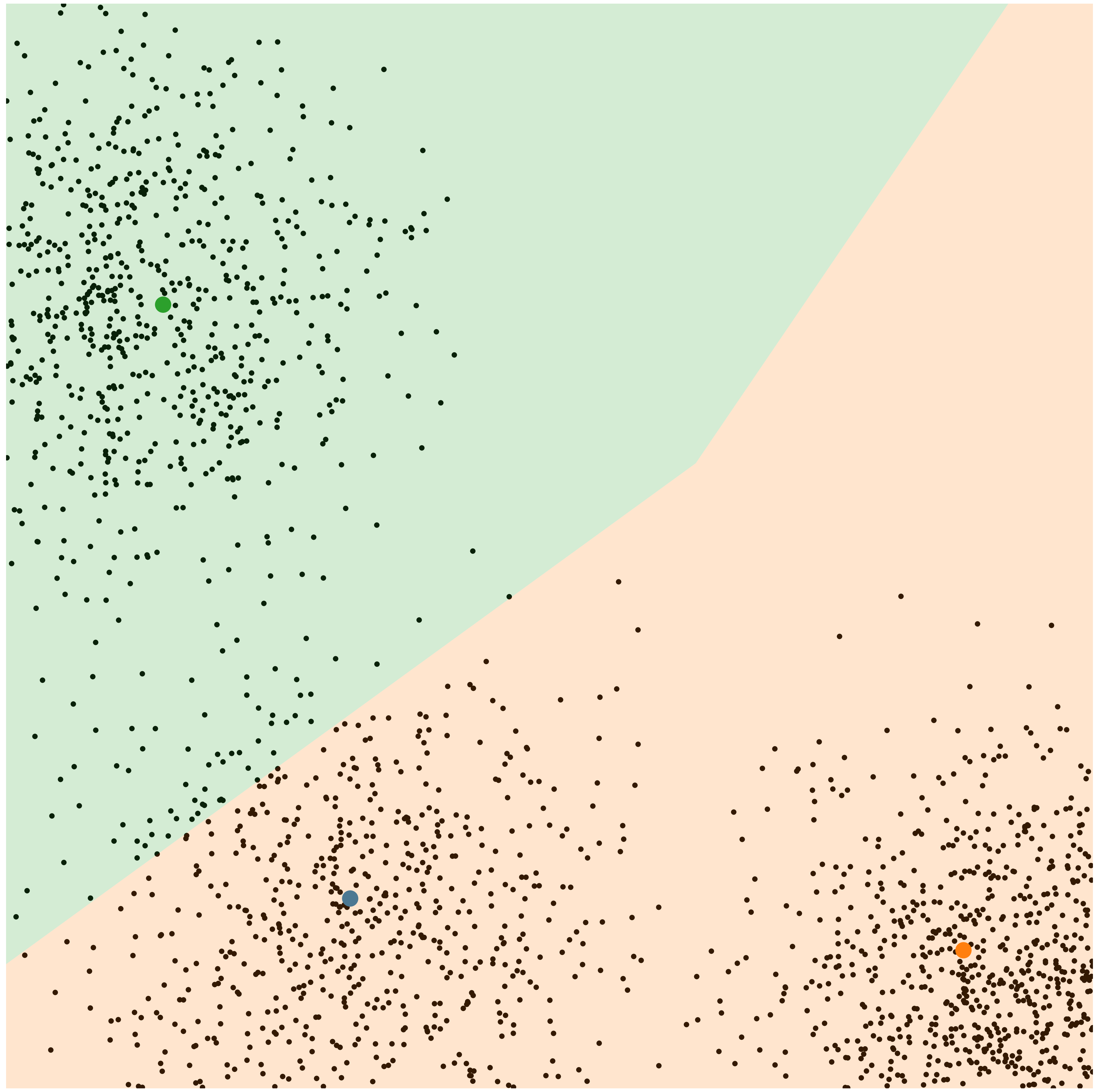
- What is a cluster?
  - A **grouping** of objects (sets of objects)
  - Why is this not more precise?
- How do we determine if two items should be in the same cluster?
  - Distance
  - Relationships: Connectivity and Containment (Hierarchies)
  - Distributions

# Clusters

- What is a cluster?
  - A **grouping** of objects (sets of objects)
  - Why is this not more precise?
- How do we determine if two items should be in the same cluster?
  - Distance
  - Relationships: Connectivity and Containment (Hierarchies)
  - Distributions
- Can an item be in more than one cluster?
  - Hard clustering: no
  - Soft (fuzzy) clustering: yes, for example, with likelihood of being in a cluster

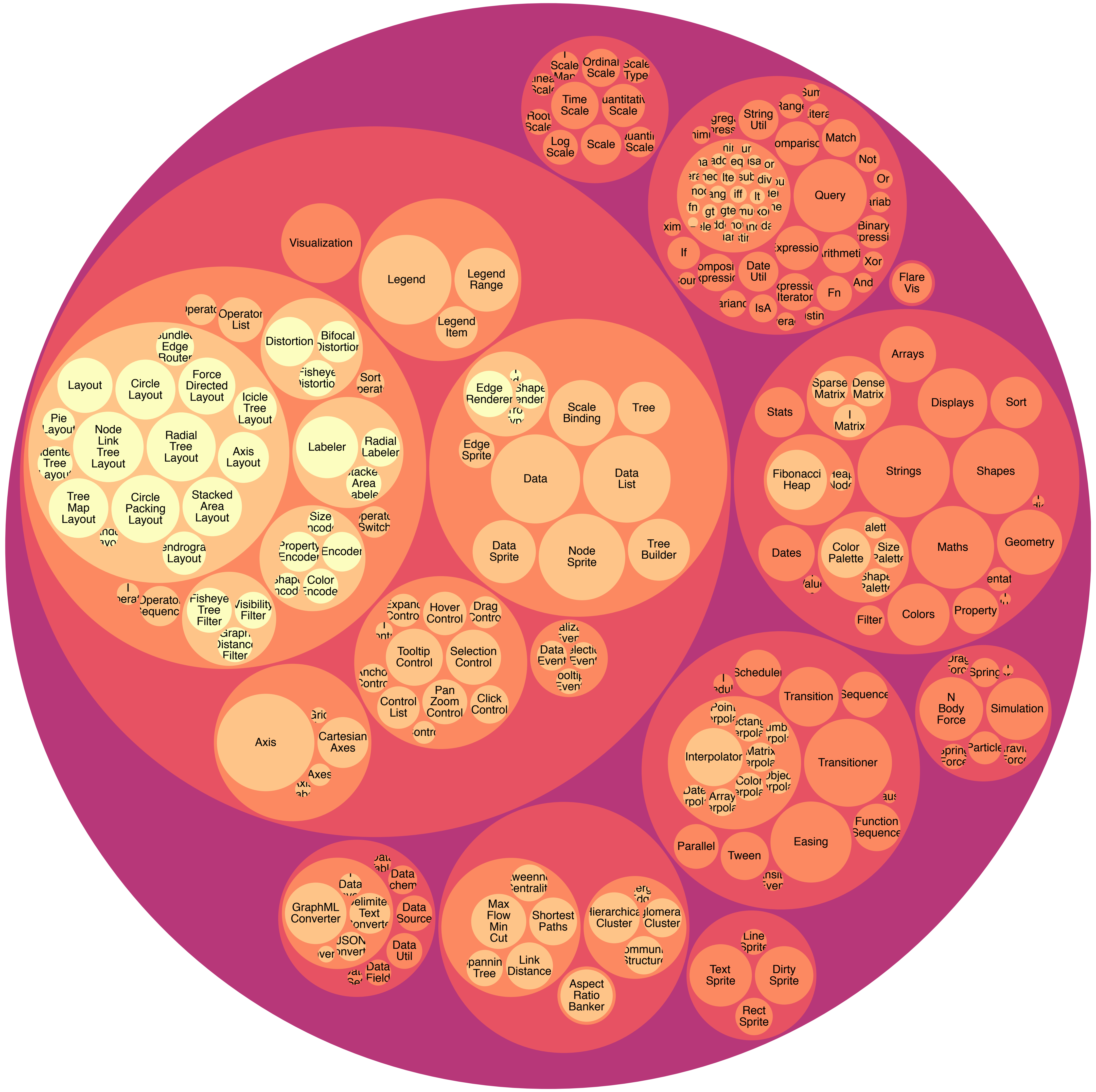
# Visualizing Clusters

- If a clustering algorithm assigns each data item to a cluster, we can treat this like set visualization
- If a spatial distance is used, this often means there is a no overlap (e.g. in 2D)
- What visual encodings could work?



[C. Polis, 2014]

# Hierarchical Clustering

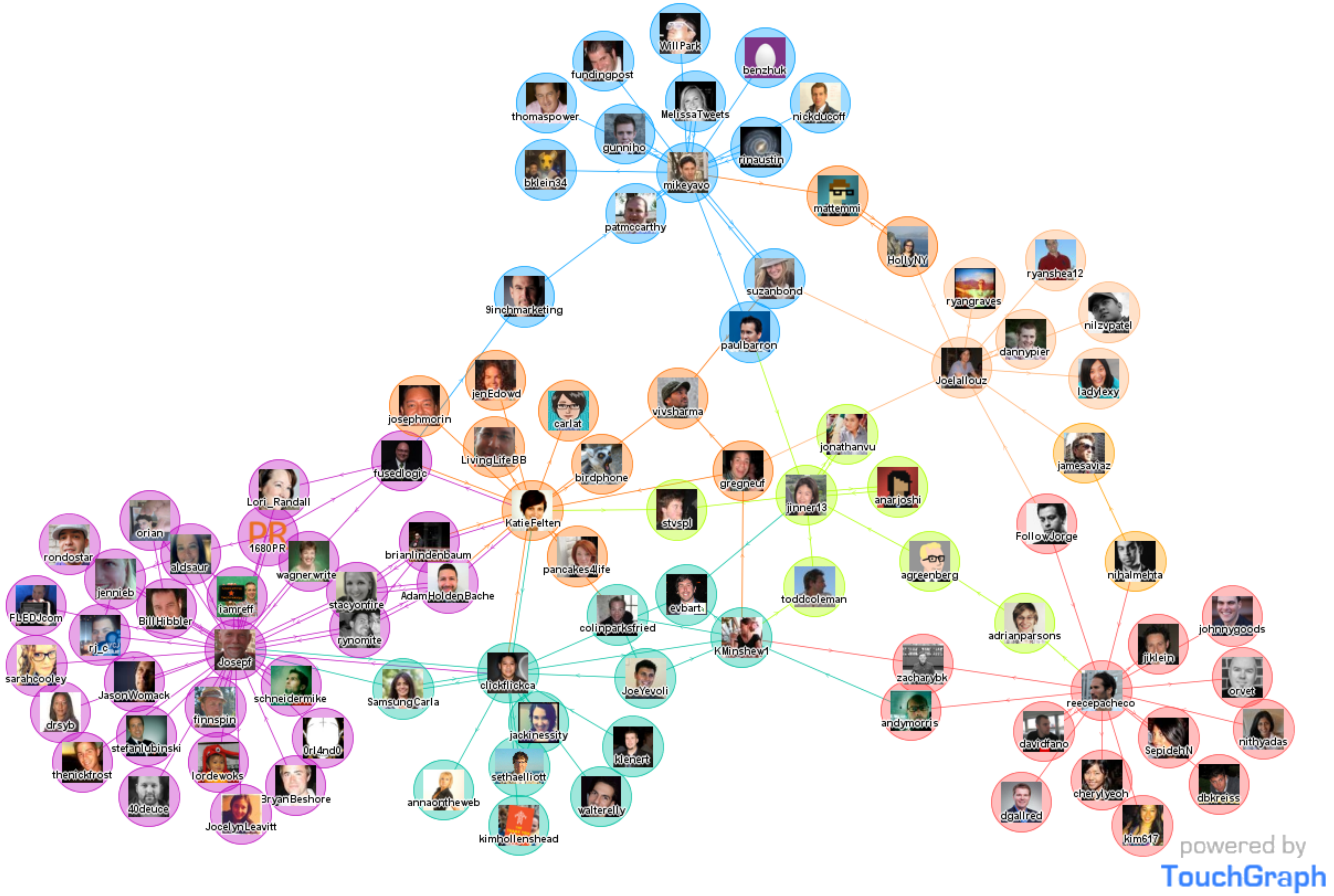



[M. Bostock, 2016]

# Hierarchical Clustering

- Each item may belong to multiple groups, but groups are nested
- Data items are organized in a **tree**
- Creating hierarchical clusters:
  - Agglomerative: start with individuals and group
  - Divisive: start with one group and divide
- Any tree visualization method will work, but…
- …generally containment marks used for clusters

# Network Clusters

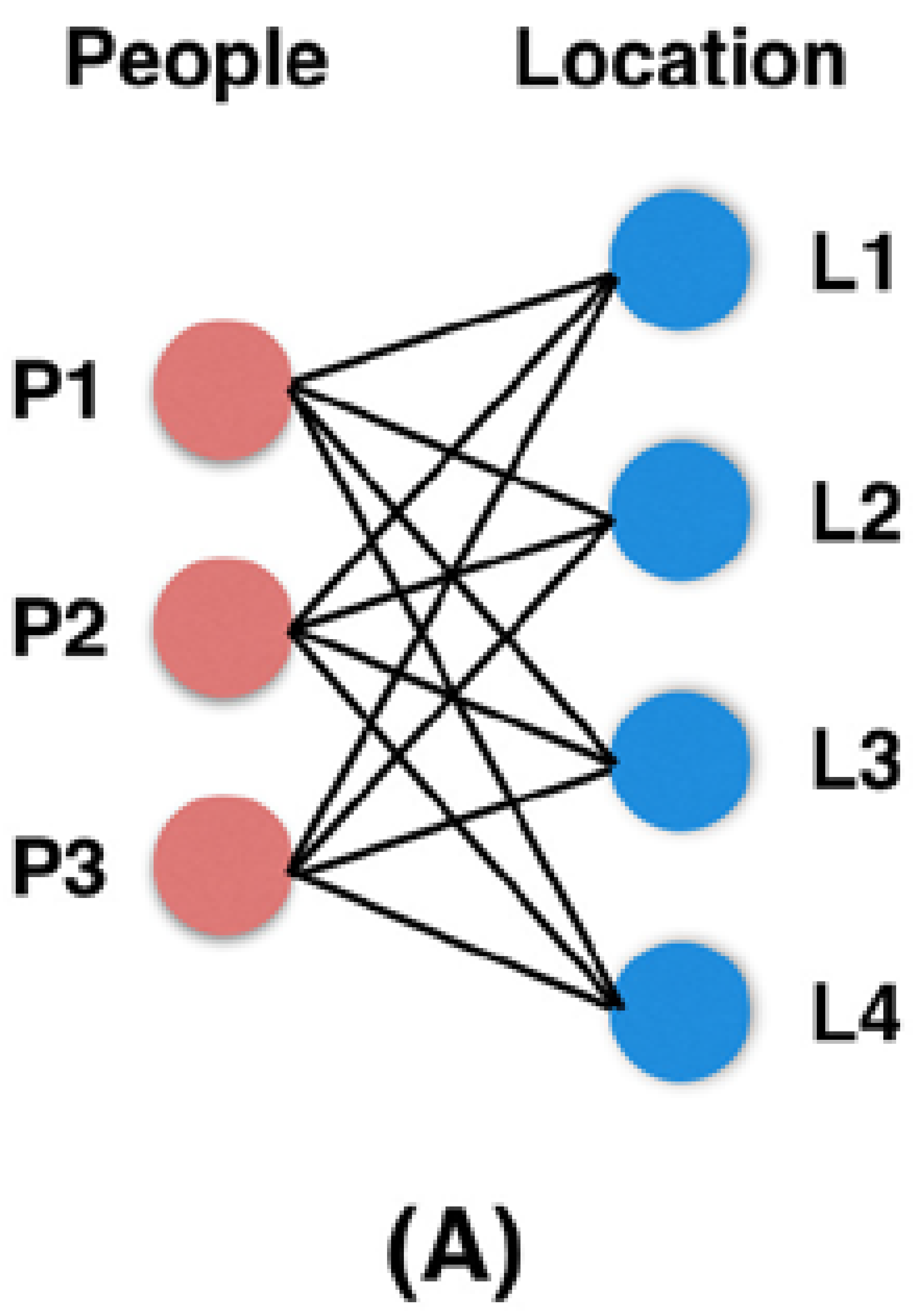



[touchgraph.com]

# Network Clusters

- Create groups based on connectivity
- Layout may be important (or could be used to create clusters)
- How to create network clusters:
  - Idea: Low connectivity between groups induces cuts
  - Example: group of friends from home and group of friends at college (and potential intersection)
  - Can also use attribute information

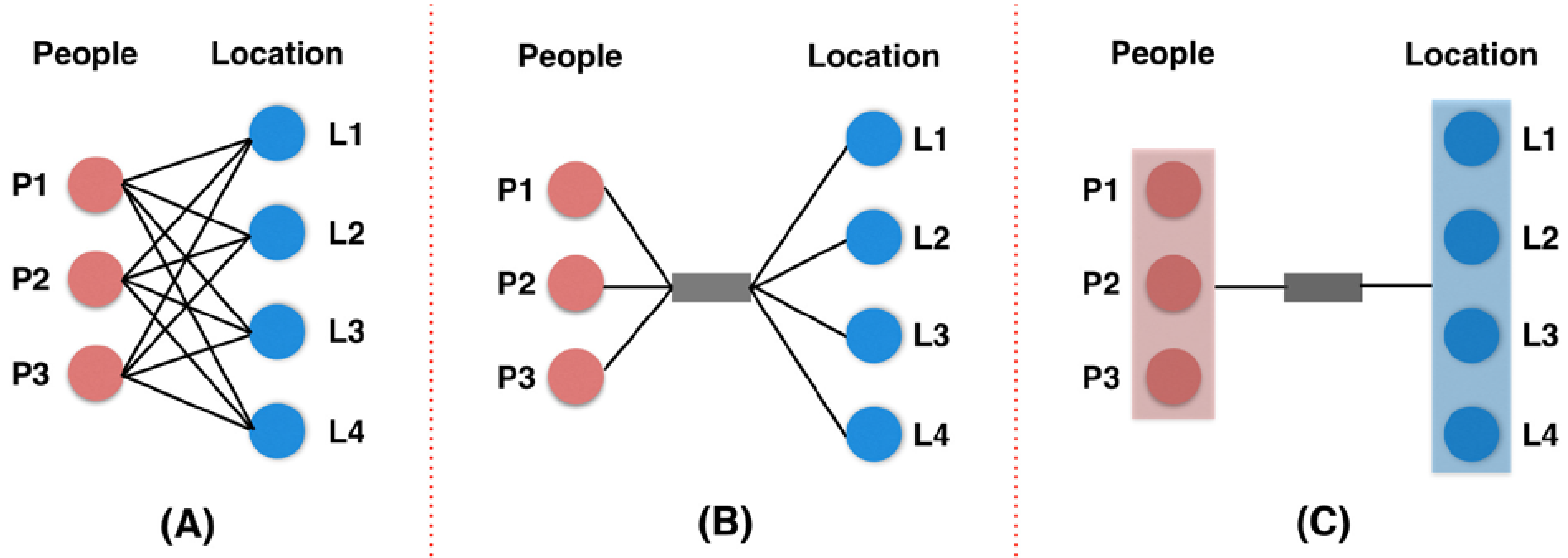
# Biclustering




- Bicluster: network concept
- Given two groups, each node in one group is connected to every node in the other group (goes both directions)

[M. Sun et al., 2016]

# Biset edge bundling (and grouping)

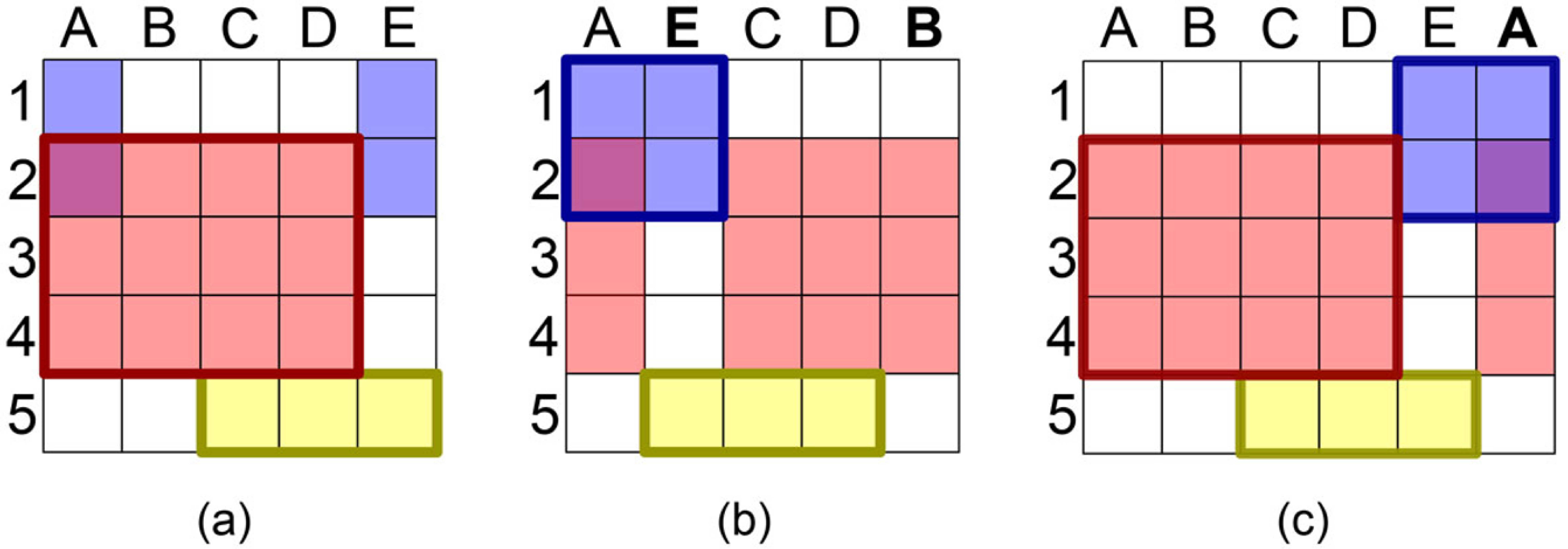



[M. Sun et al., 2016]

# Biset Edge Bundling

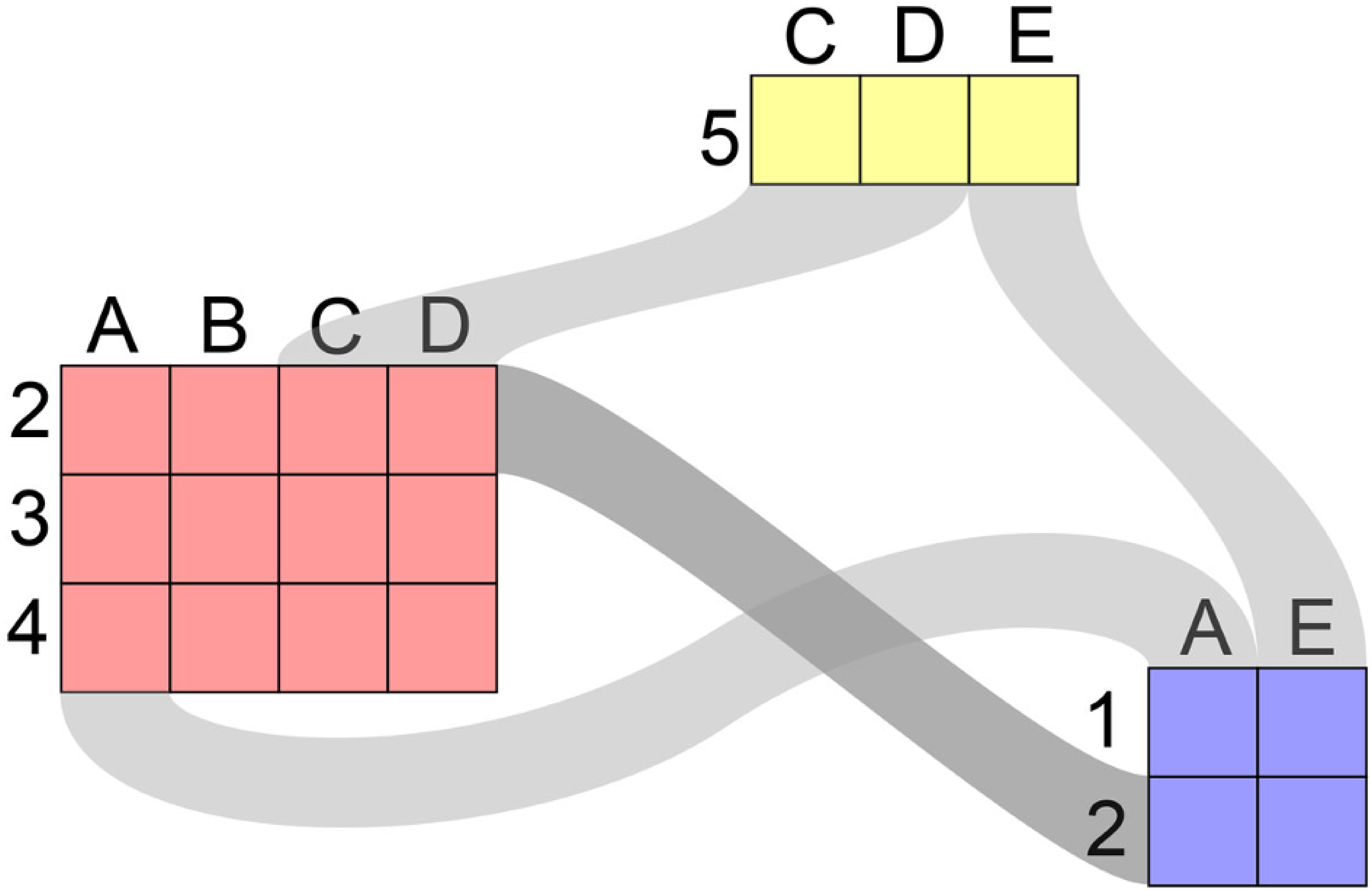

[M. Sun et al., 2016]

# Bicluster Reordering Problem




[Streit et al., 2014]

# Bicluster relationships as a graph




[Streit et al., 2014]