SOFTWARE QUALITY

CPTS 583

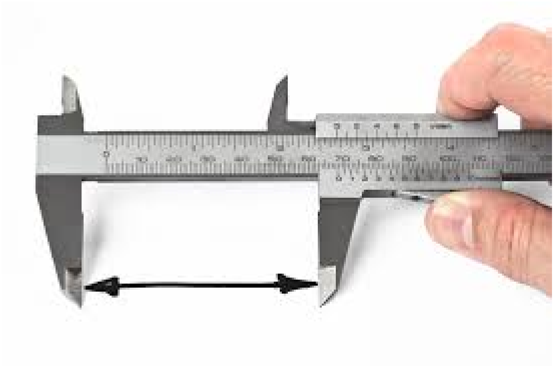
Quality Metrics and Measurement (I)

-- *overview, measurement theory, fundamentals*

Outline

- Definitions
  - Abstraction hierarchy
- Measurement Levels
  - Nominal, ordinal, interval, ratio
- Basic Measures
  - Ratio, proportion, percentage, rate

What is measurement?



- Measurement is the process by which numbers or symbols are assigned to attributes of entities in the world *according to clearly defined rules*.

- Measurement is the acquisition of information about a state or phenomenon (object of measurement) in the world around us.

Definitions

- ***Entities*** – Objects in the real world. May be animate, inanimate or even events.
- ***Attributes*** – Characteristics / features / properties of an entity

<u>Example</u>

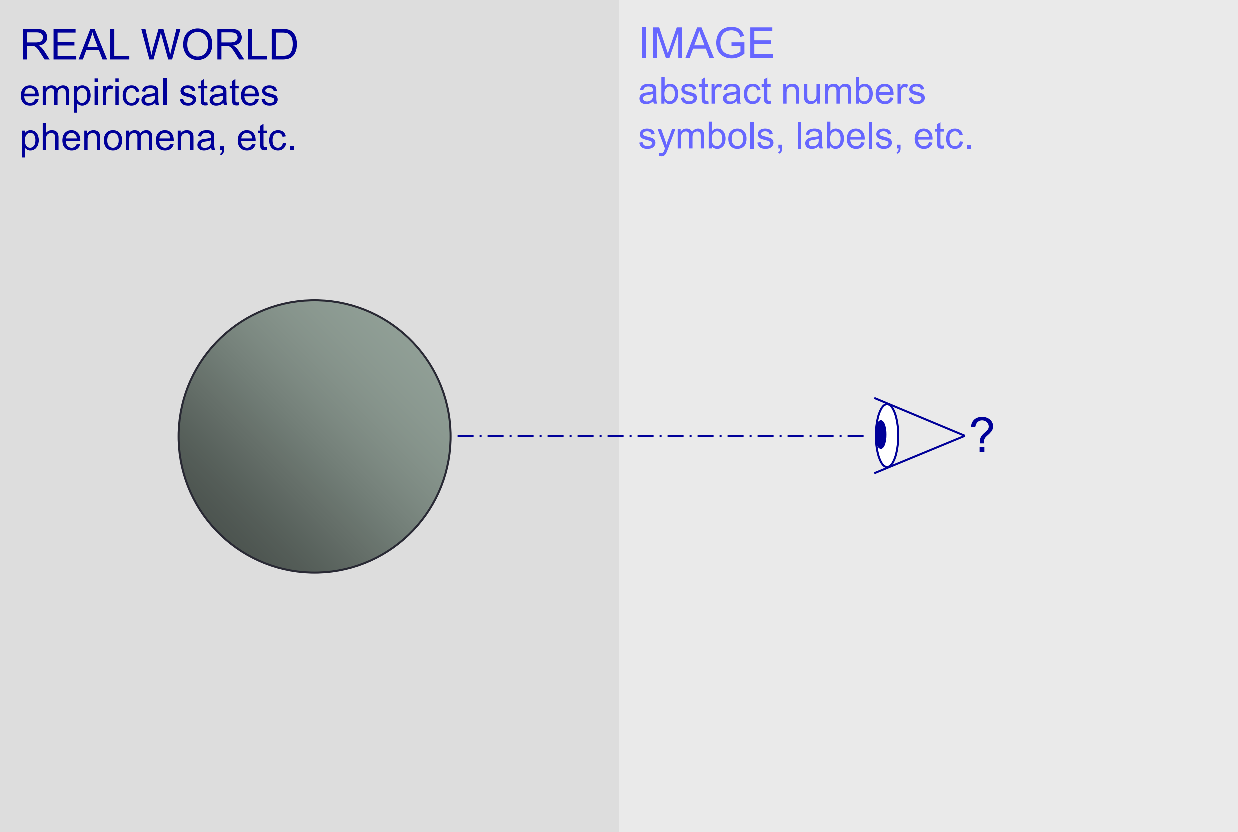
Entity: Program

Attributes

- Time to Develop
- Lines of code
- Number of Defects

Three aspects of measurement

- A measurement must be descriptive (observable)
  - a relationship between the *object of measurement* and the *measurement result* must exist



Three aspects of measurement

- A measurement must be selective
  - It only provide information about the attribute the measurement focuses on: measurand
- A measurement must be objective
  - Measurement result is independent of observer

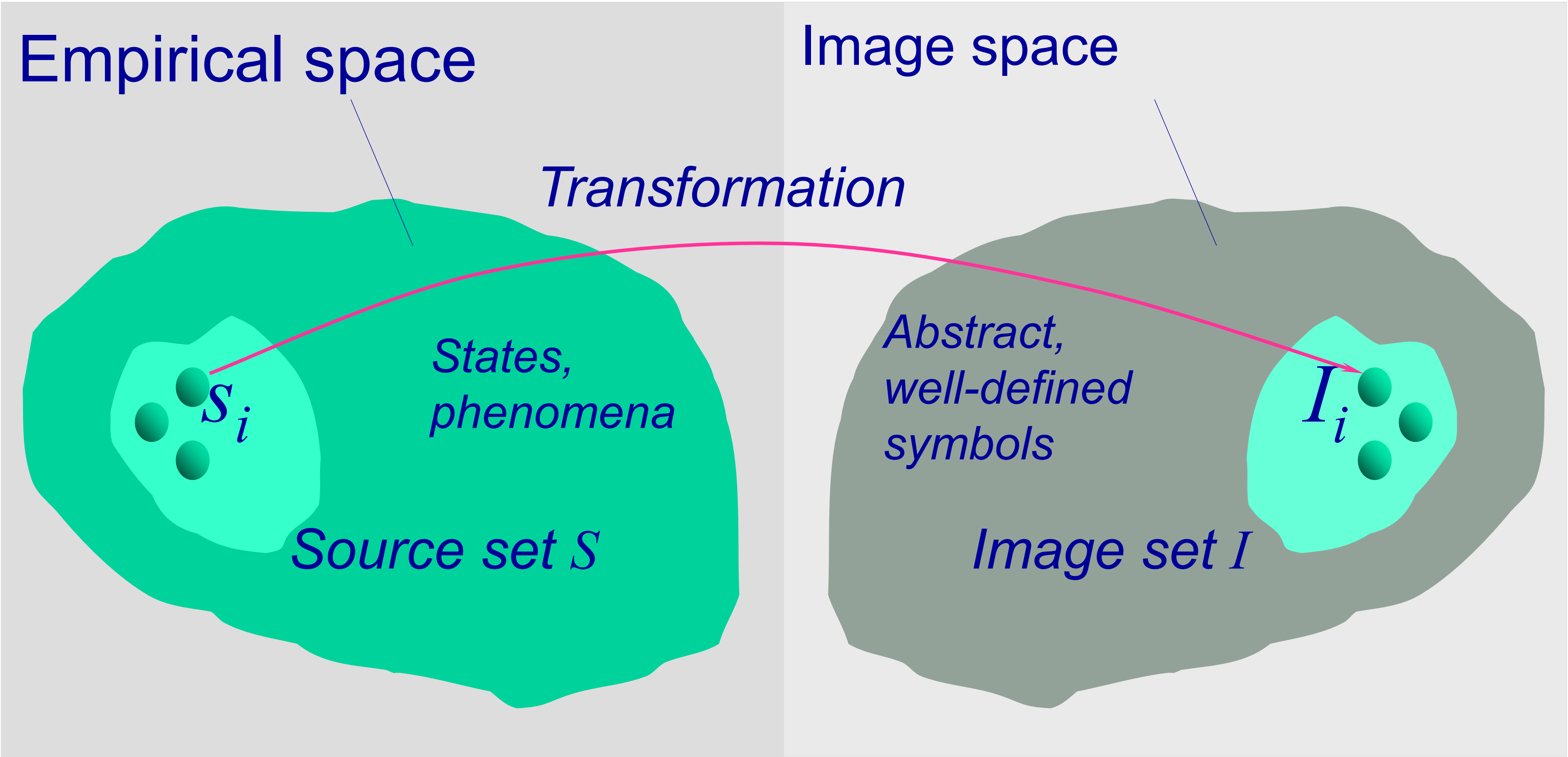
Objective= can be proven to be true

should not have any bias

Just the Facts

Measurement as a mapping

- Elements from an empirical source set -> elements of an abstract image set



Measurement as a mapping

- Example

Empirical space

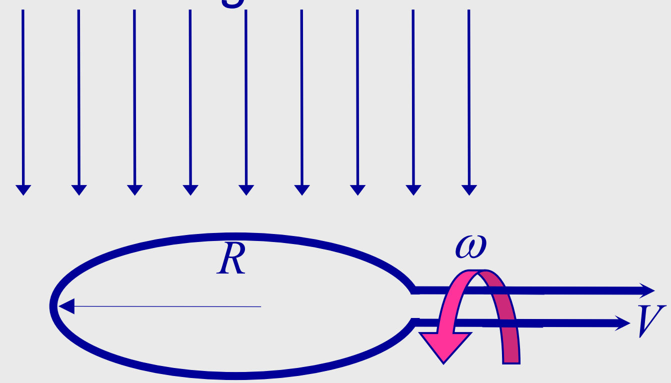
Image space

State (phenomenon):

Transformation

Abstract symbol, B

Static magnetic field



Instrumentation

$$B = f(R, \omega, V)$$

The importance of Measurement

- Measurement is ***crucial*** to the progress of all sciences, *including computer science*
- Scientific progress is made through
  - Observations and generalisations…
  - …based on data and measurements
  - Derivation of theories and…
  - …confirmation or refutation of these theories
- Measurement turns an art into a science

The importance of Measurement

- "When you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginnings of knowledge but you have scarcely in your thoughts advanced to the stage of Science."

  – Lord Kelvin (Physicist)
- "You cannot control what you cannot measure." "If you cannot measure it, you cannot manage it"

  – Tom DeMarco (Software Engineer)

Uses of Measurement

- Measurement helps us to understand
  - Makes the current activity visible
  - Measures establish guidelines
- Measurement allows us to control
  - Predict outcomes and change processes
- Measurement encourages us to improve
  - When we hold our product up to a measuring stick, we can establish quality targets and aim to improve

Abstraction Hierarchy

Theory

↓

Abstract World

Proposition — An assumption or set of assumptions which are taken to be true.

↓

Empirical World

Hypothesis — An proposed explanation of a phenomenon.

↓

Data Analysis

- Take measurements, carry out studies, look at past data, etc.
- Proof or refute the hypothesis.

Definitions

- ***Theory*** - *A* supposition which is supported by experience, observations and empirical data.
- ***Proposition*** – *A* claim or series of claims which are <u>assumed</u> to be true.
- ***Hypothesis*** – *A* proposed explanation for a phenomenon. Must be ***testable*** and based on previous observations or scientific principles.

Example propositions

- Developers who drink coffee in the morning produce better code than those who do drink orange juice
- The more you test the system, the more reliable it will be in the field
- If you add more people to a project, it will be completed faster

Example hypotheses

- For software projects, the higher the percentage of the designs and code that are inspected, the lower the defect rate at the later phase of formal machine testing.
- The more effective the design reviews and the code inspections as scored by the inspection team, the lower the defect rate at the later phase of formal machine testing.

Example: Proving a theory

Abstract World

Theory: Adding more developers to a late project will only make it later.

Proposition:
- If a project misses one or more milestone deadlines, it is considered to be late.
- The greater the difference between the current time and the missed milestone, the later the project is said to be.

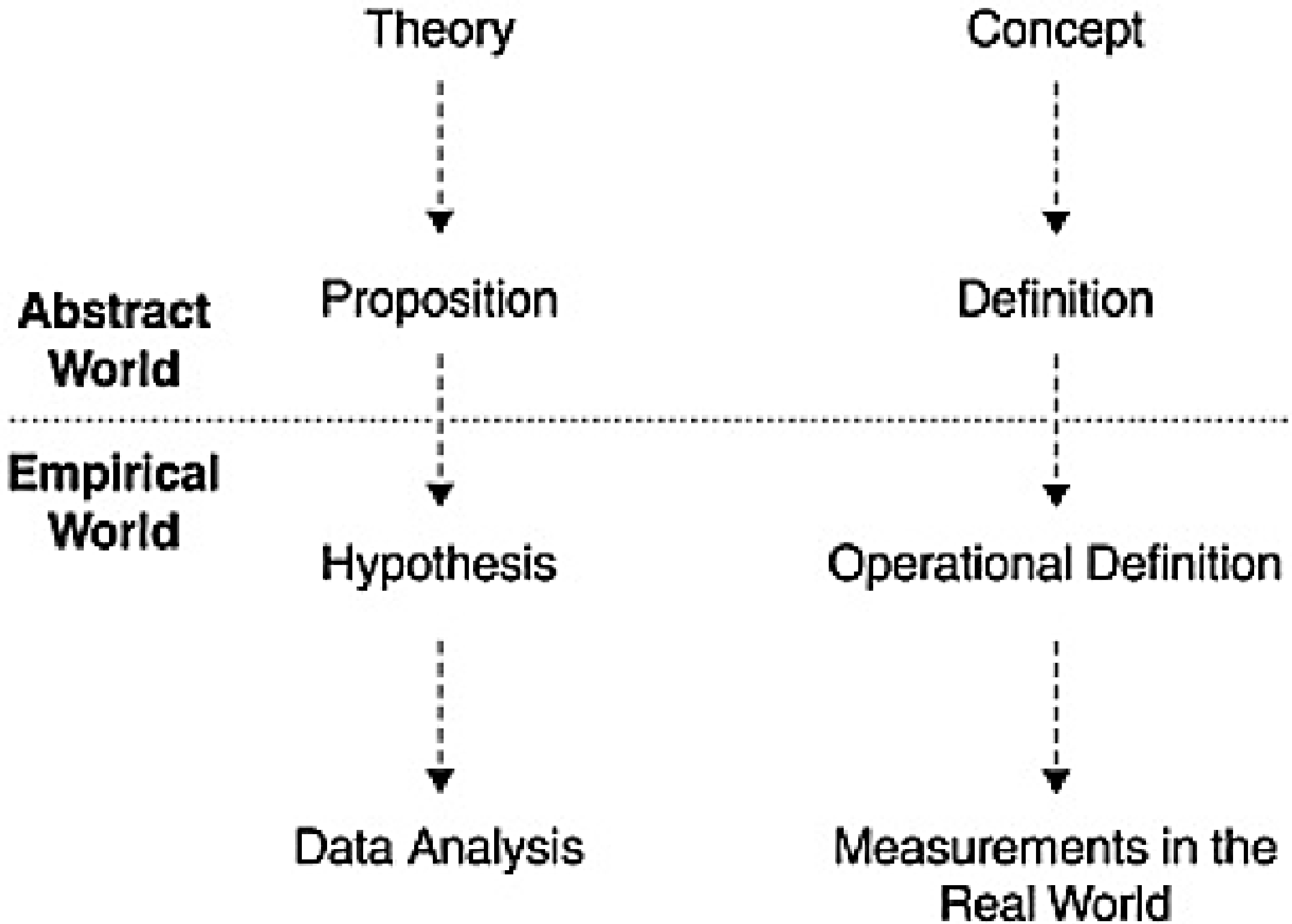
Empirical World

Hypothesis:
Project p has n developers working on it
Project p missed a deadline by x days ($x > 0$)
If we add m developers ($m > 0$), then when the milestone is reached, the project would be y days late ($y > x$)

Data Analysis: Carry out studies, analyse data from past projects,…
Verify or disprove the theory

Abstraction Hierarchy

- From concept to measurements

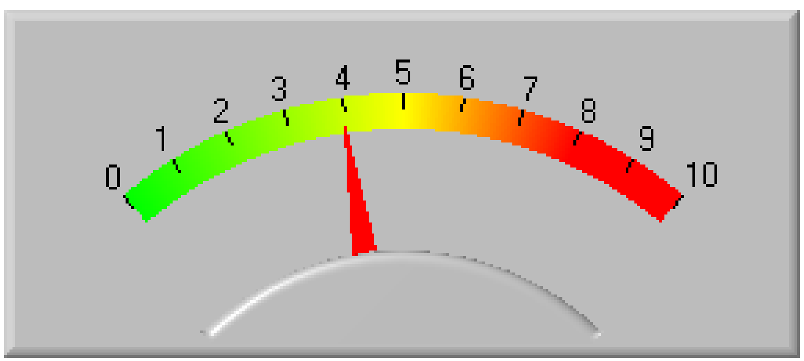


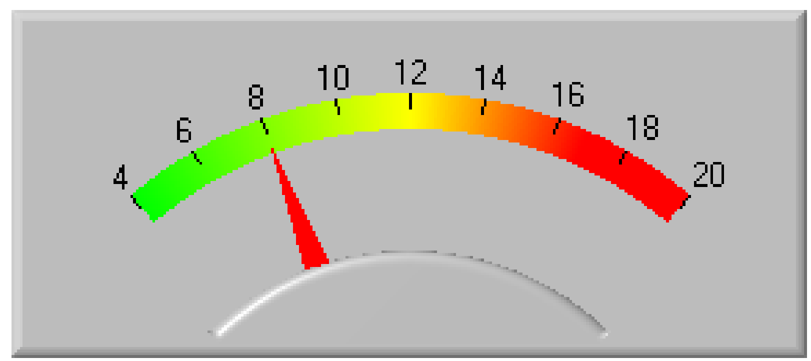
Levels of Measurement

Measurement scale

A scale is an organized set of measurements, all of which measure one property.

A scale is not always unique; it can be changed without loss of isomorphism.

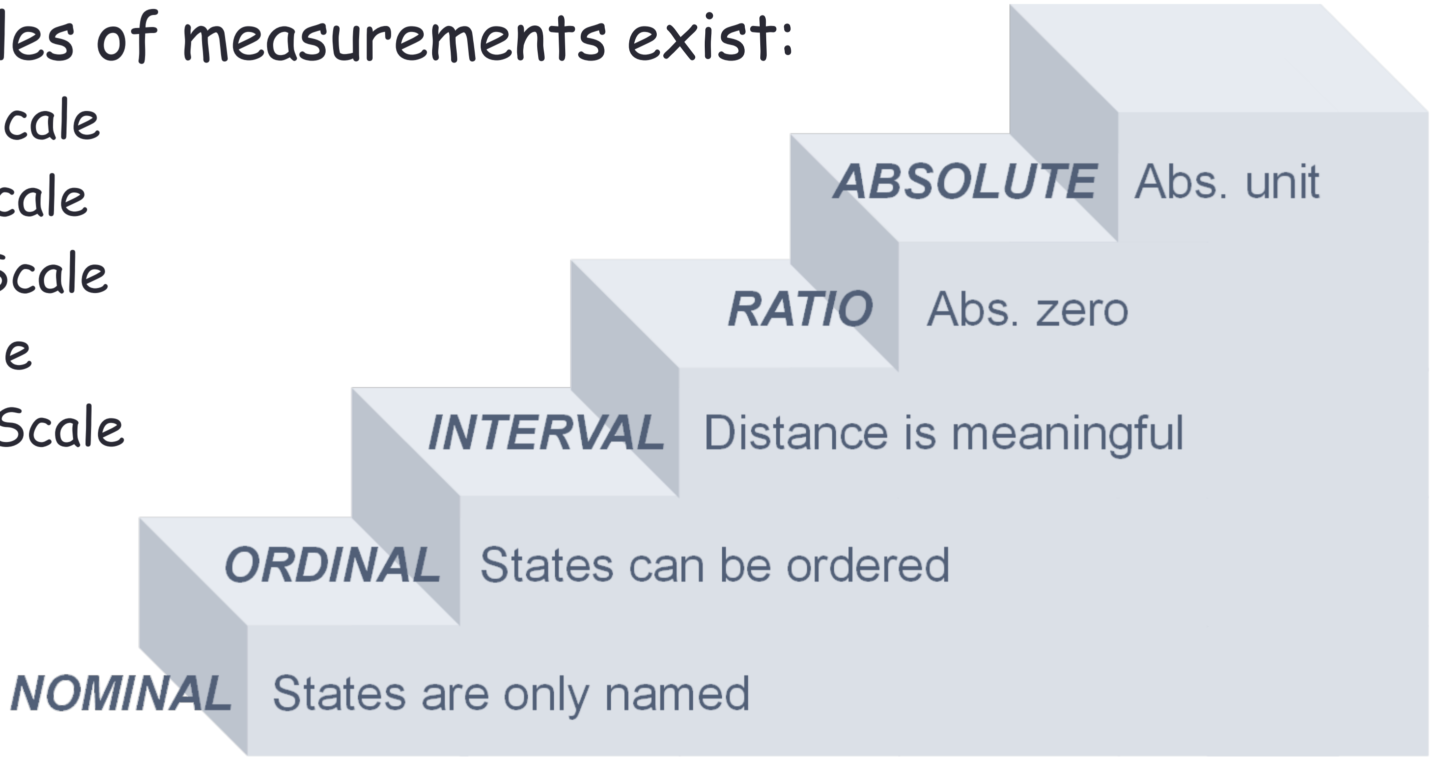




Levels of Measurement

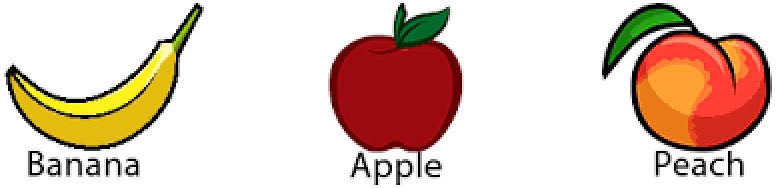
Various scales of measurements exist:

- Nominal Scale
- Ordinal Scale
- Interval Scale
- Ratio Scale
- Absolute Scale



A scale is an organized set of measurements, all of which measure one property.

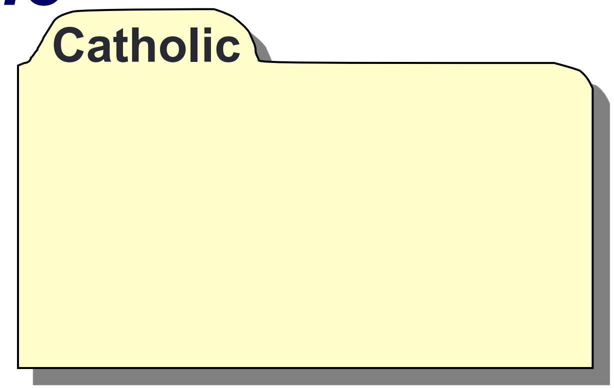
The Nominal Scale



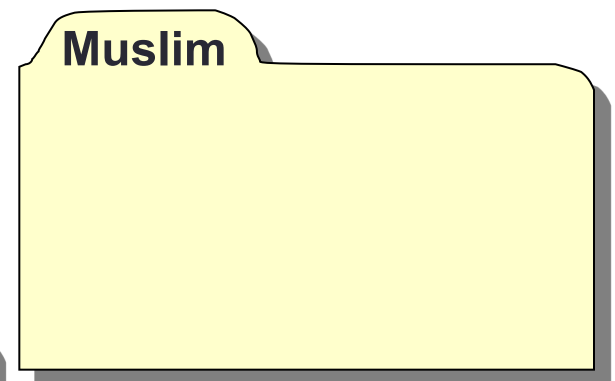
- Simplest
- Classification
- Involves sorting elements into categories with regards to a certain attribute
- There is no form of ranking
- Categories must be:
  - Jointly exhaustive
  - Mutually exclusive

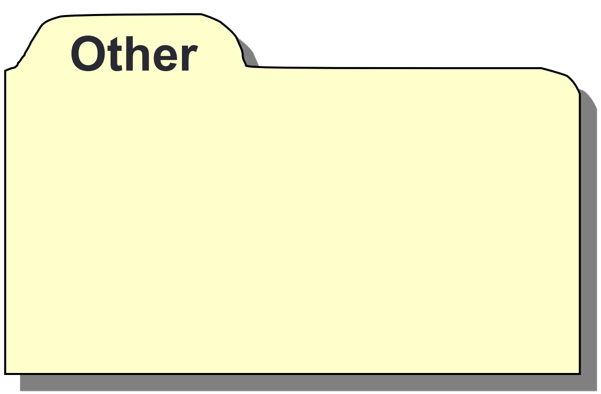
The Nominal Scale

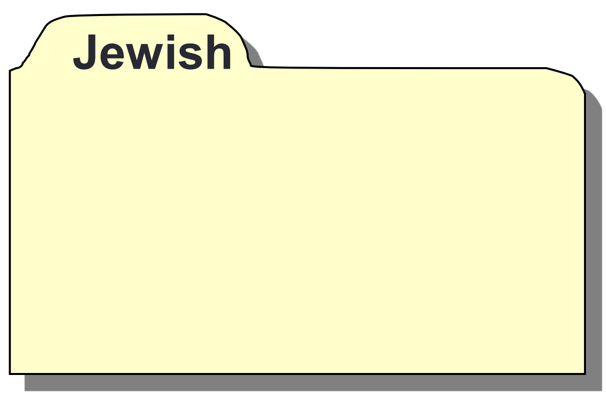
Example: ***A <u>religion</u> nominal scale***



Joe	Michelle
Rachel	Christine
Michael	James
Clyde	Wendy

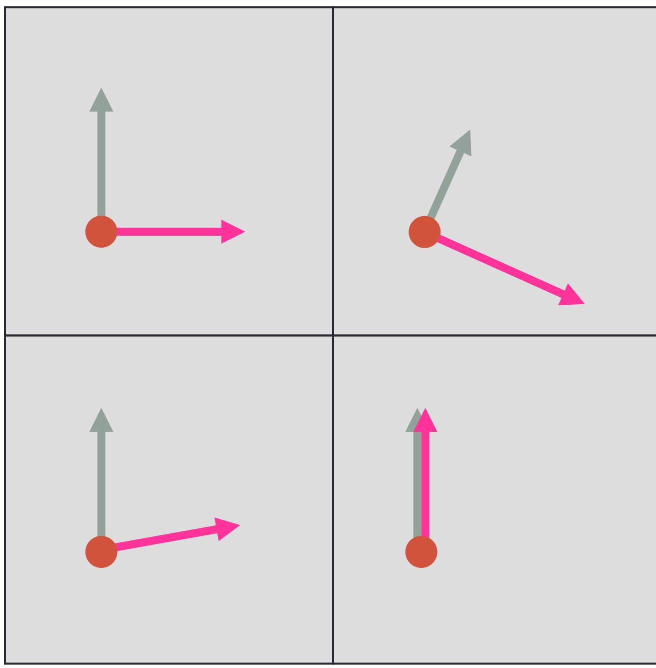






The Nominal Scale

State $\equiv$ orthogonality



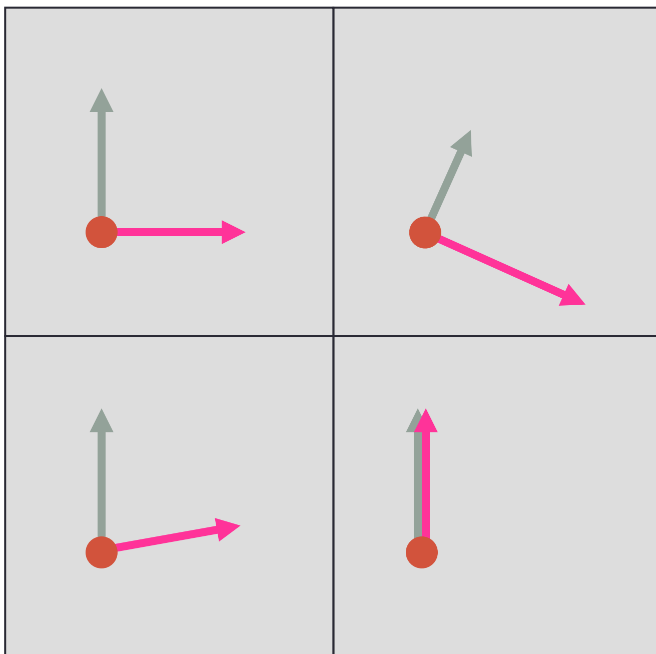
$Image_1$

1	1
0	0

The Nominal Scale

- Any one-to-one transformation can be used to change the scale.

State ≡ orthogonality

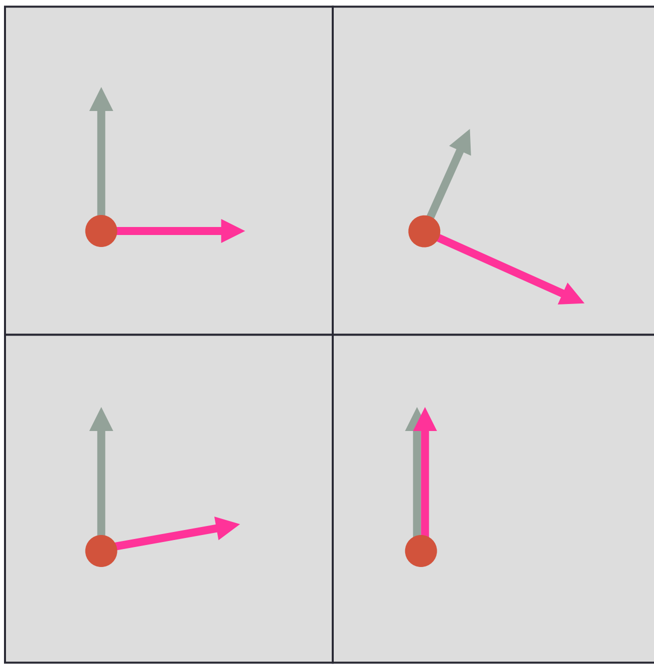


$$Image_2 = (Image_1 + 1) \times \pi$$

2π	2π
π	π

The Nominal Scale

State ≡ orthogonality

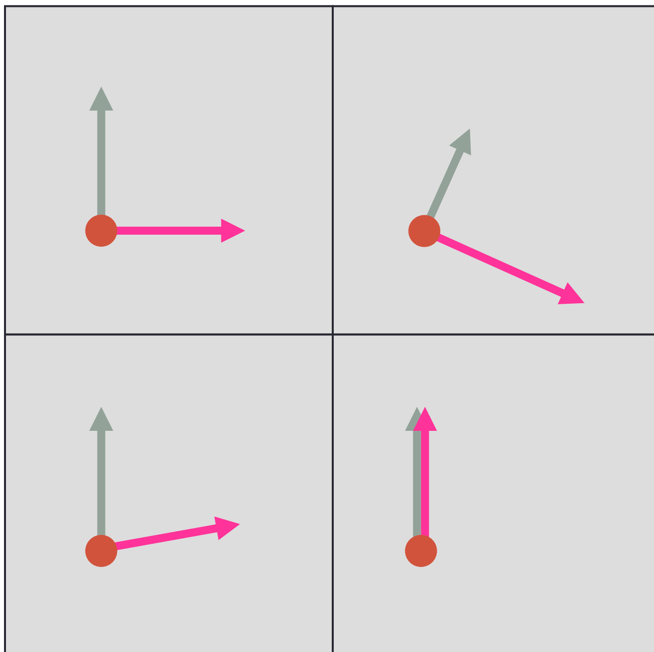


$Image_3 = \mathrm{Cos}(Image_2)$

1	1
-1	-1

The Nominal Scale

State ≡ orthogonality

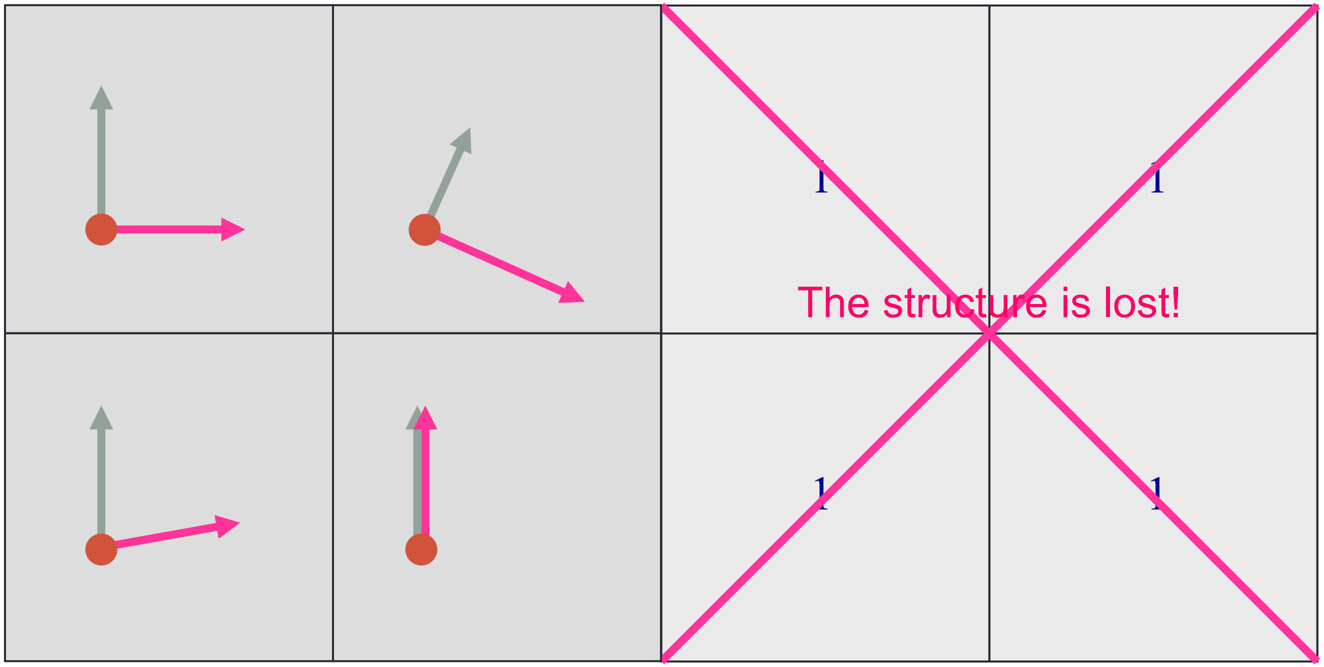


$Image_4 = Image_3 \times 2\pi$

2π	2π
-2π	-2π

The Nominal Scale

State ≡ orthogonality $\quad$ $Image_5 = \mathrm{Cos}(Image_4)$



The Ordinal Scale

- Elements classified into categories
- Categories are ranked
- Categories are transitive $A > B$ & $B > C \rightarrow A > C$
- Elements in one category can be said to be better (or worse) than elements in another category
- Elements in the same category are not rankable in any way
- As with nominal scale, categories must be:
  - Jointly exhaustive
  - Mutually exclusive

The Ordinal Scale

Example: ***A flight seat class ordinal scale***

Joe Michelle

Rachel Christine

Michael James

Clyde Wendy

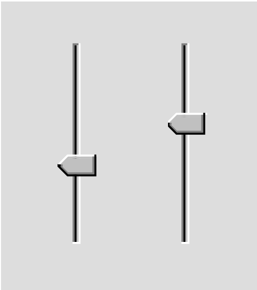
1st Class

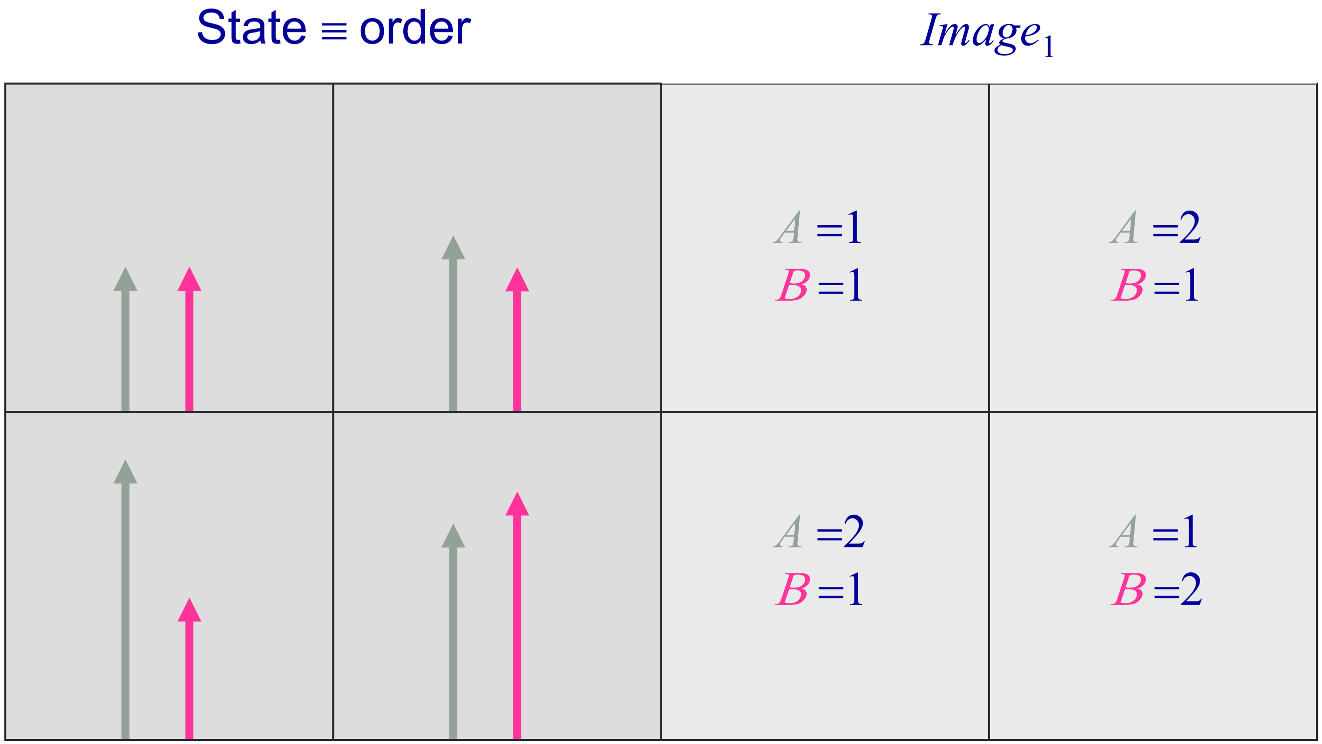
2nd Class

none

3rd Class

The Ordinal Scale

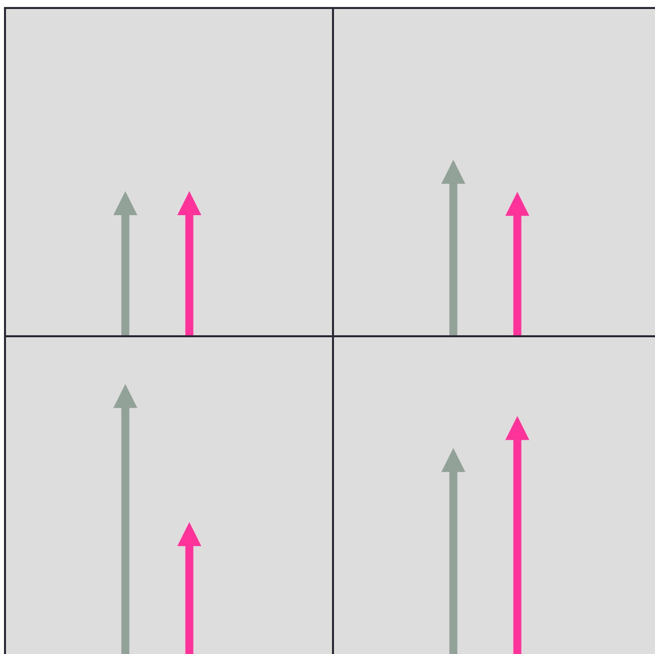




The Ordinal Scale

- A one-to-one transformation can be used to change the scale.

State ≡ order



$$Image_2 = Image_1^{\,2}$$

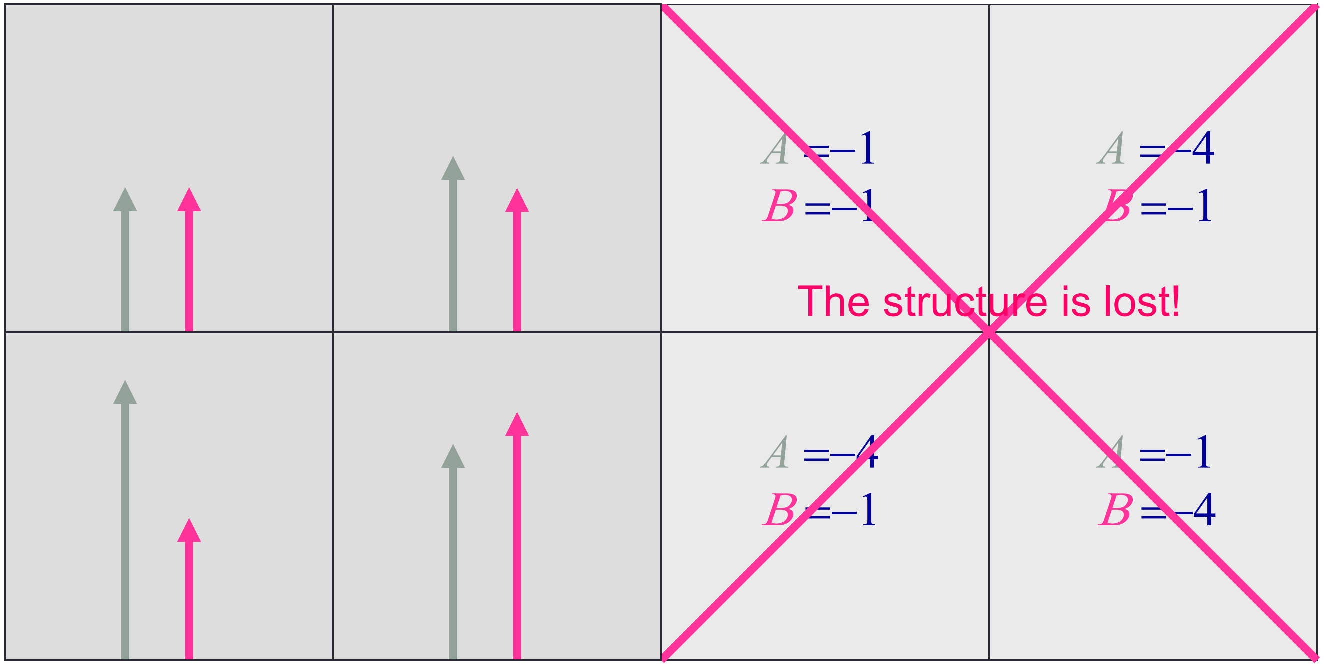
$A=1$ $B=1$	$A=4$ $B=1$
$A=4$ $B=1$	$A=1$ $B=4$

The Ordinal Scale

- The transformation needs to be monotonically increasing

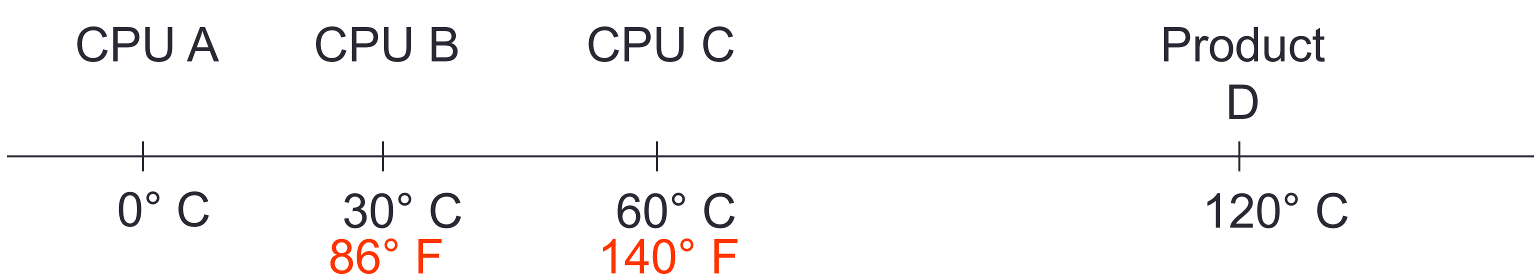
State ≡ order

$$Image_3 = -Image_2$$



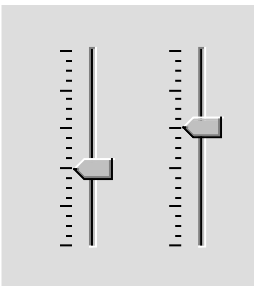
The Interval Scale

- Indicates exact differences between measurement points
- Addition and subtraction can be applied
- Multiplication and Division **CANNOT** be applied
- We can say that product D has 8 more crashes per month but we cannot say that it has 3 times as more crashes

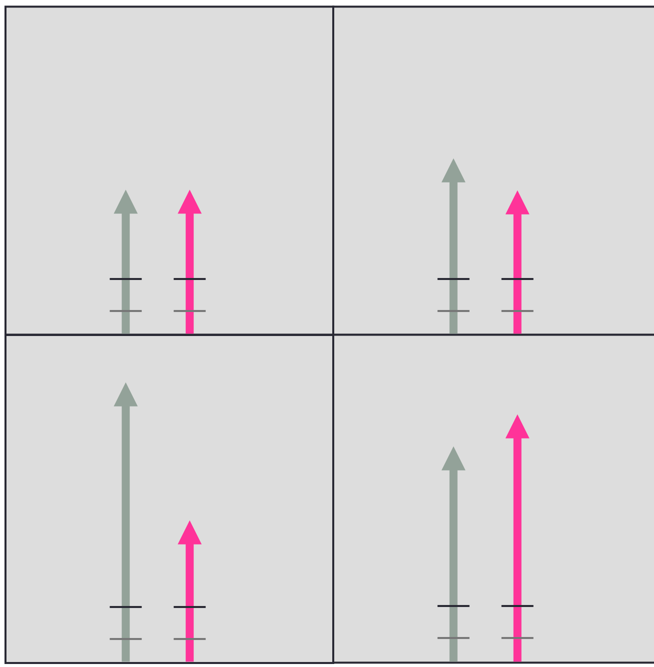


Temperature of Different CPUs

The Interval Scale



State ≡ interval



$Image_1$

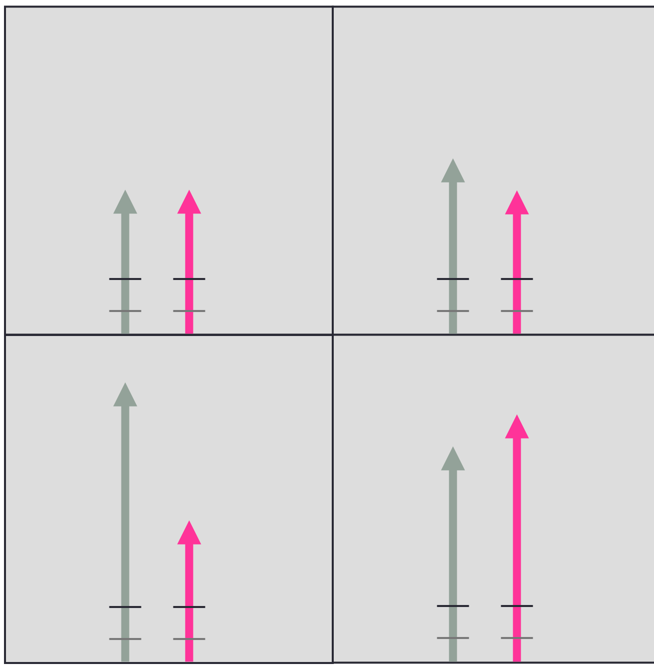
$A = 4$ $B = 4$ $\lvert A - B \rvert = 0$	$A = 5$ $B = 4$ $\lvert A - B \rvert = 1$
$A = 8$ $B = 4$ $\lvert A - B \rvert = 4$	$A = 6$ $B = 7$ $\lvert A - B \rvert = 1$

The Interval Scale

- Any increasing linear transformation can be used to change the scale.

State $\equiv$ interval

$$Image_2 = 10 \times Image_1 + 2$$



$A = 42$ $B = 42$ $\lvert A - B \rvert = 0$	$A = 52$ $B = 42$ $\lvert A - B \rvert = 10$
$A = 82$ $B = 42$ $\lvert A - B \rvert = 40$	$A = 62$ $B = 72$ $\lvert A - B \rvert = 10$

The Ratio Scale

- When an absolute zero point can be located on an interval scale, it becomes a ratio scale
  - Zero means none /not-existent
- Multiplication and division can be applied (product D crashes 4 times as much per month than product B)
- For all practical purposes almost all interval measurement scales are also ratio scales

The Ratio Scale

- Age. Zero means no age.
- Weight. Zero means no weight.
- Height. Zero no height.
- Sales figures. Zero sale-> nothing sold
- Quantity purchased. Zero items bought->nothing bought.
- ……

Zero/absolute point that means nothing/non-existent

The Ratio Scale

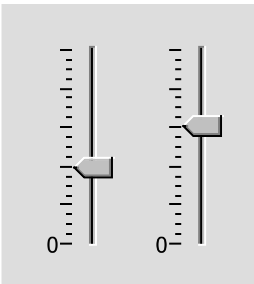
- Temperature in F or C, 0.0 does not mean 'no heat'.
  - What if temperature in Kelvin ?
- pH. pH=0 does not mean 'no acidity'
- ……

These are NOT in ratio scale!
(although they are in interval scale)

The Ratio Scale

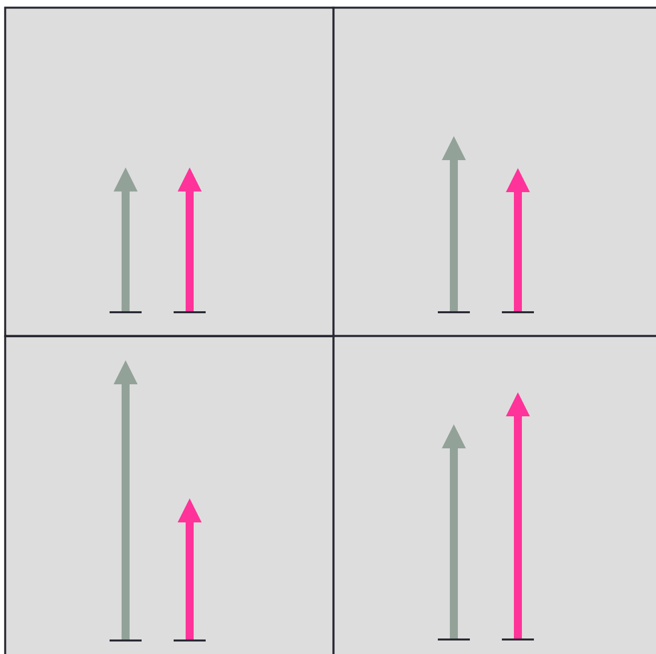
- Compute ratio in ratio scale
  - Age 10 is twice as old as age 5: 10/5=2
- Ratio cannot be computed in interval scale
  - pH=10 is NOT twice as acidic as pH=20

The Ratio Scale



State $\equiv$ ratio

$Image_1$



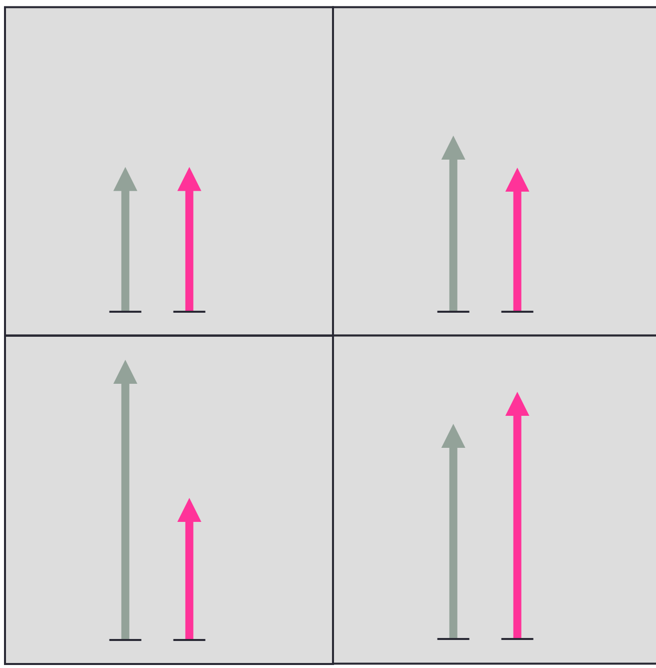
$A = 4$ $B = 4$ $A/B = 1$	$A = 5$ $B = 4$ $A/B = 5/4$
$A = 8$ $B = 4$ $A/B = 2$	$A = 6$ $B = 7$ $A/B = 6/7$

The Ratio Scale

- The only transformation that can be used to change the scale is the multiplication by any positive real number.

State ≡ ratio

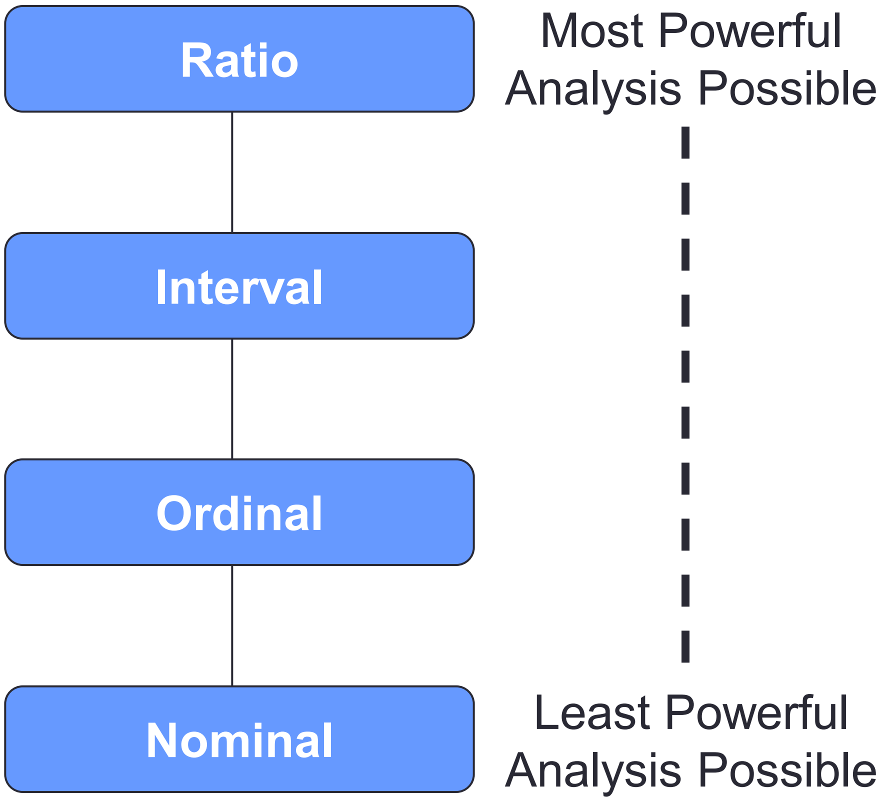
$$Image_2 = 10 \times Image_1$$



$A = 40$ $B = 40$ $A/B = 1$	$A = 50$ $B = 40$ $A/B = 5/4$
$A = 80$ $B = 40$ $A/B = 2$	$A = 60$ $B = 70$ $A/B = 6/7$

Measurement Scales Hierarchy

- Scales are hierarchical
- Each higher-level scale possesses all the properties of the lower ones
- A higher-level of measurement can be reduced to a lower one but not vice-versa

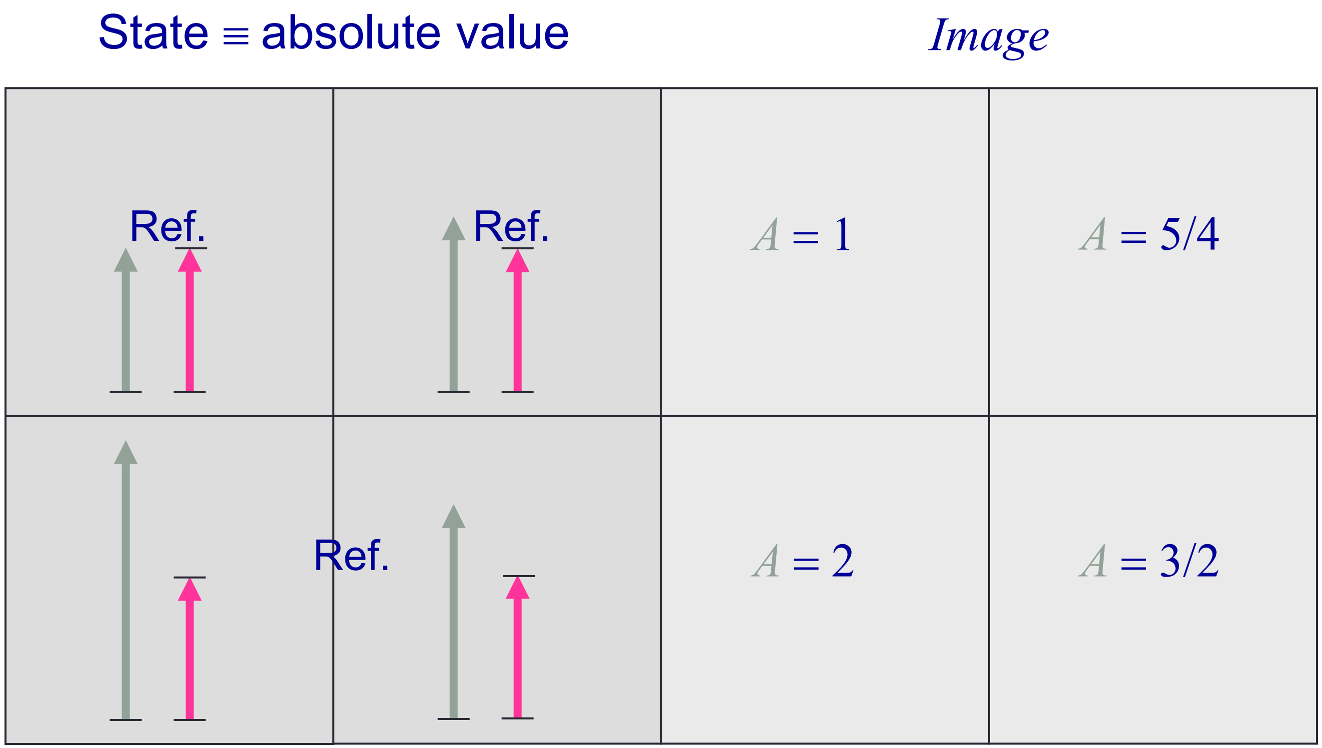


Measurement Scales Hierarchy

Things you can compute	Nominal	Ordinal	Interval	Ratio
frequency distribution.	Yes	Yes	Yes	Yes
median and percentiles.	No	Yes	Yes	Yes
add or subtract.	No	No	Yes	Yes
mean, standard deviation, standard error of the mean.	No	No	Yes	Yes
ratio, or coefficient of variation.	No	No	No	Yes

The Absolute Scale

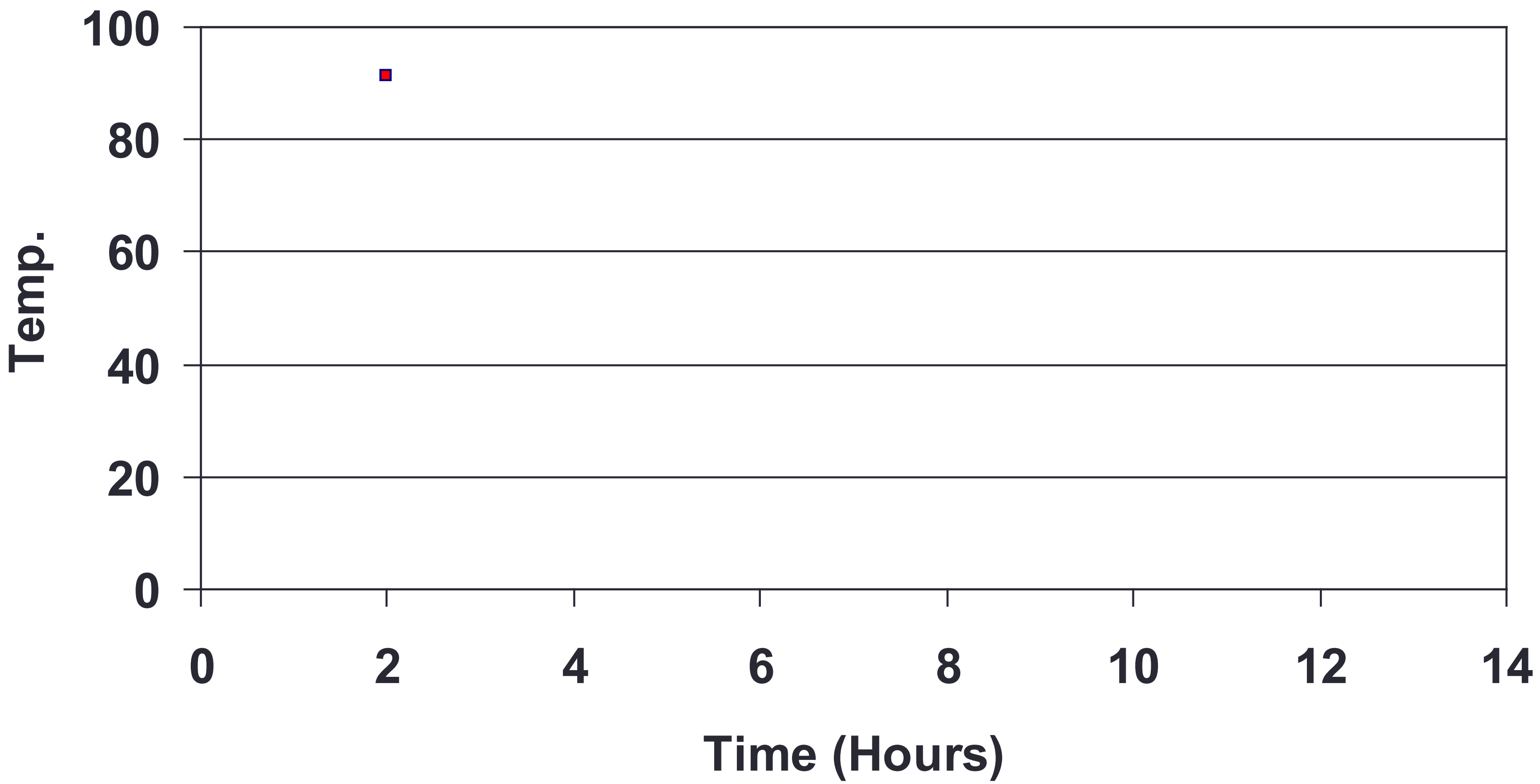
- No transformation can be used to change the scale.



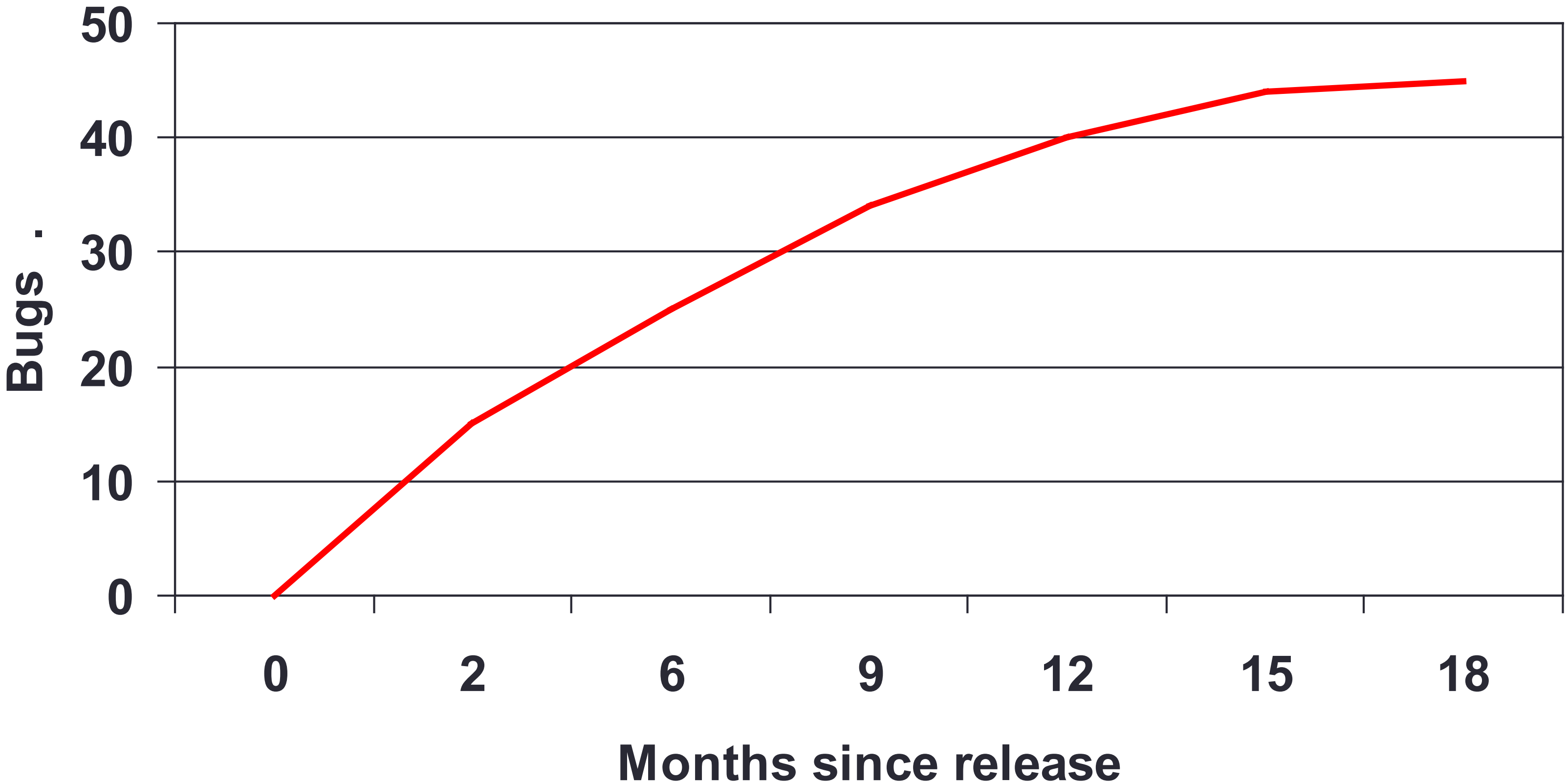
Measures, Metrics and Indicators

- ***Measure*** – An appraisal or ascertainment by comparing to a standard. E.g. Joe's body temperature is 99° fahrenheit
- ***Metric*** – A quantitative measure of the degree to which an element (e.g. software system) given attribute.
  - E.g. 2 errors were discovered by customers in 18 months (more meaningful than saying that 2 errors were found)
- ***Indicator*** – A device, variable or metric can indicate whether a particular state or goal has been achieved. Usually used to draw someone's attention to something.
  - E.g. A half-mast flag indicates that someone has died

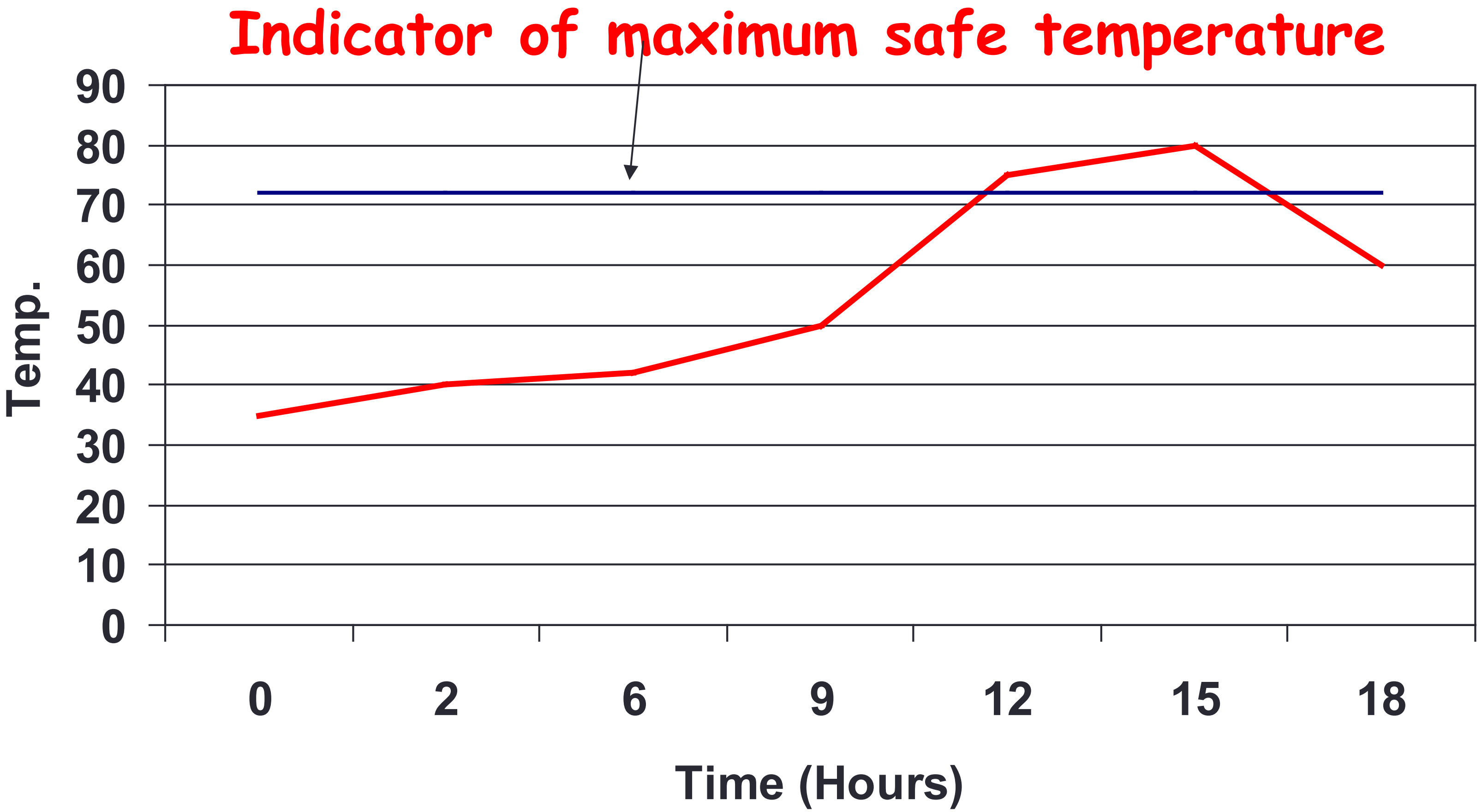
Example of a Measure



Example of a Metric



Example of a Indicator



Some basic measures

- Ratio
  - Result of dividing one quantity by another.
  - E.g. The ratio of testers to developers in our company is 1:5
  - The numerator and denominator are from two distinct populations and are mutually exclusive
- Proportion
  - Similar to ratio but the numerator is part of the denominator as well
  - E.g.

$$\frac{\text{Number of satisfied customers}}{\text{Total number of customers}}$$

Some basic measures

- Percentage
  - A proportion or ration express in terms of per hundred units
  - E.g. 75% of our customers are satisfied with our product

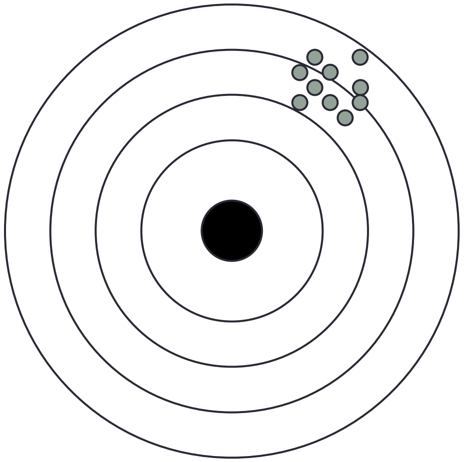
- Rate
  - Ratios, proportions and percentages are static measures
  - Rate provides a dynamic view of a system
  - Rate shows how one variable changes in relation to another (one of the variables is usually time)
  - E.g. Lines of Code per day, Bugs per Month, etc

Reliability and Validity of Measurements

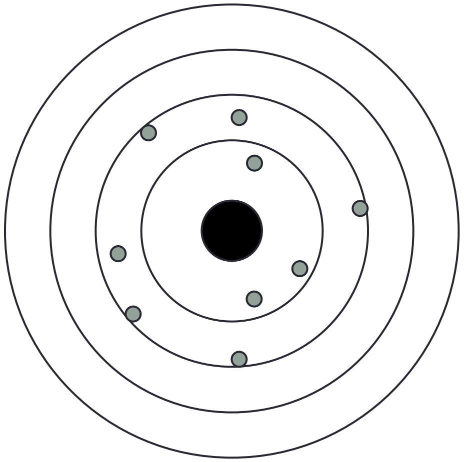
- Reliability – Refers to the consistency of a number of measurements taken using the same measurement method

- Validity – Refers to whether the measurement or metric really measures what we intend it to measure.

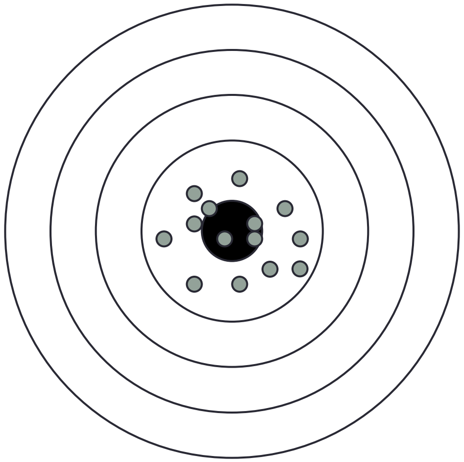
Reliability and Validity of Measurements



Reliable but not valid



Valid but not reliable



Reliable and Valid

Summary

- Measurement: concept, abstraction hierarchy, as a mapping from empirical to abstract (image) space
- Levels/scales of measurement: nominal, ordinal, interval, and ratio
  - Requirements for the transformation for preserving scale structure
- Measure, metric, and indicator
  - Measure versus metric
- Basic measures: ratio, proportion, percentage, rate
- Validity and reliability of measurements