Measurement Across the Sciences Workshop

Luca Mari, Mark Wilson

UC Berkeley, 4 August 2024

Workshop Outline

Part I. Introduction to MATS (Each subsection to include at least one area of application as an example)

(i) The basic evaluation equation (BEE) (5' *)

(ii) What makes a measurement trustworthy? (objectivity and intersubjectivity) (10' *)

(iii) Background for the Hexagon Framework (e.g., direct and indirect measurement) (10' *)

(iv) The Hexagon Framework (25' *)

(v) General discussion (15')

Part II. MATS workshop activity

(i) Form 4 teams according to affinities (e.g., application topics, etc.) (5')

Each team:

(ii) decides on a specific target for measurement (5')

(iii) discusses how the Hexagon Framework functions in their application (15')

(iv) prepares materials to present to the rest (5')

(v) presents their account to the whole group, and responds to questions (4 X 5' **)

(vi) General discussion about the presentations and conclusions. (10')

Part III. Extension and Deepening

(i) Extension. Using the Hexagon as a basis for instrument development (MW, 20' plus 5' discussion at end)

(ii) Deepening. Return to the Fundamentals: What are quantities, units, values, etc.? (LM, 20' plus 5' discussion at end)

* Including discussion and Q&A

** If we have more than 4 teams, we will possibly need a bit of extra time for this

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Abstract

What is it that makes a given process a measurement? In particular, can psychological and social properties, such as well-being and reading comprehension ability, truly be measured, as is frequently claimed by human scientists and educational testing professionals, and if so, in what way are such processes related to the measurement of physical properties such as length or temperature? Are there shared elements of measurement processes across different domains of application? If so, why have the fields of psychometrics and metrology historically been so disconnected? And if not, are claims about the measurability of psychosocial properties well justified, or even coherent, given the way measurement is broadly understood in both scientific and lay communities?

In this workshop we present a summary of the positions we have arrived at as a result of our collaboration on these issues (see Mari et al., 2023). We propose a concept system for measurement and the “hexagon framework” as its formalization that we believe can be useful to anyone interested in measurement of physical or psychosocial properties. Our proposal, we hope, balances the need for specificity and generality, and as such is indeed a sound compromise around which progress can be made.

We hope that even if a workshop participant does not agree with everything we propose here, our work will facilitate interdisciplinary communication about measurement (and by extension, science and epistemology in general), and we look forward to the conversations on the day, and those that will follow.

Reference

Mari, L, Wilson, M. & Maul, A. (2023). Measurement across the sciences: Developing a shared concept system for measurement, Second edition. New York: Springer.

Purpose

Despite, or because of, its acknowledged societal importance and long history,
measurement is loaded with stereotypes

“After measurement, the length of this rod is 0.123 m”
and
“In my opinion, the length of this rod is 0.123 m”
convey different messages, though both with quantitative information on an empirical property

Q1: What makes measurement different from opinion?
Q2: Is this characterizing feature independent of the nature of the measured properties, so that there can be a common framework for measurement across the sciences?

(we are looking for adequacy, not truth: there is nothing like the true meaning of “measurement”)

Spoiler

Q1: What makes measurement different from opinion?
→ **Societal trustworthiness of produced information**

Q2: Is this characterizing feature independent of the nature of the measured properties,
so that there can be a common framework for measurement across the sciences?
→ **Definitely yes**

Such a common framework must provide a domain-independent, operational interpretation of what is a process aimed at producing trustworthy information on empirical properties

→ Is the concept ‘untrustworthy measurement’ contradictory? Yes
→ Are the concepts ‘useless measurement’ or ‘bad measurement’ contradictory? No

Strategy

Let’s start from **physical** quantities, and then apply what we learned to **psychosocial** ones

Let’s start from **quantitative** properties, and then apply what we learned to **non-quantitative** ones

Let’s start from **simple** cases, and then apply what we learned to **more complex** ones

Let’s assume that measurement is about **empirical** properties

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(Bonus: Return to the Fundamentals: what are quantities, units, values?)

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Reporting measurement information

A statement reporting a measurement result [*] is usually presented as [**]

measurand = measured value

(we call it "**Basic Evaluation Equation**", BEE)

for example

"the length of object a is $0.123\ \mathrm{m}$"

more formally written

(eq1) $$\ell(a) = 0.123\ \mathrm{m}$$

What kind of information does (eq1) convey?

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[*] Some information on measurement uncertainty should be also present, but is omitted here

[**] Terms from the *International Vocabulary of Metrology* (VIM)

Significance of the question

Establishing the kind of information conveyed by a relation like

(eq1) $\ell(a) = 0.123\ \mathrm{m}$

requires us to better understand:

- what are entities like $0.123\ \mathrm{m}$ (“values of quantities”)
- what are entities like $\ell(a)$ (“measurands”, “individual quantities”)
- what are entities like ℓ (“general quantities”)
- if and how (eq1) depends on models, idealizations, etc
- …

Some lexicon (*)

"**quantity**" refers to a quantitative property

"**value of a quantity**" refers to an entity like $0.123\ \mathrm{m}$,
where 0.123 is a **numerical value** and m is a **measurement unit**

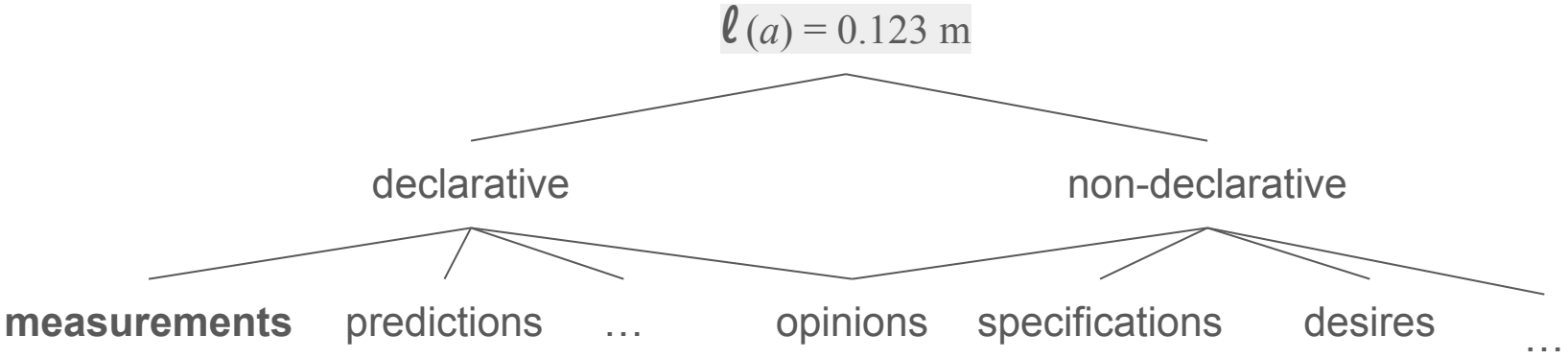
"**measurement**" refers to a process and "**measurement result**" to its result

Only in the simplest cases a measurement result is reported as a value of a quantity;
more generally it includes also some information about **measurement uncertainty**,
for example (**) as $\ell(a) = 0.123(1)\ \mathrm{m}$

(*) Terms from the *International Vocabulary of Metrology* (VIM)
(**) From the *Guide to the Expression of Uncertainty in Measurement* (GUM)

Pragmatic background

An expression like "$\ell(a) = 0.123\ \mathrm{m}$" reports the attribution of a value to a quantity, and may report information other than a measurement result



All of them are attributions of a value to a quantity – "evaluations" for short – and measurements are then evaluations; but **not all evaluations are measurements**

Fundamental hypothesis

Measurement is a **trustworthy** evaluation, because it produces information

1. about empirical properties
   → **object-relatedness (“objectivity”)**
2. socially reported
   → **subject-independence (“intersubjectivity”)**

A good measurement produces sufficiently objective and intersubjective information

But bad measurements are however measurements:

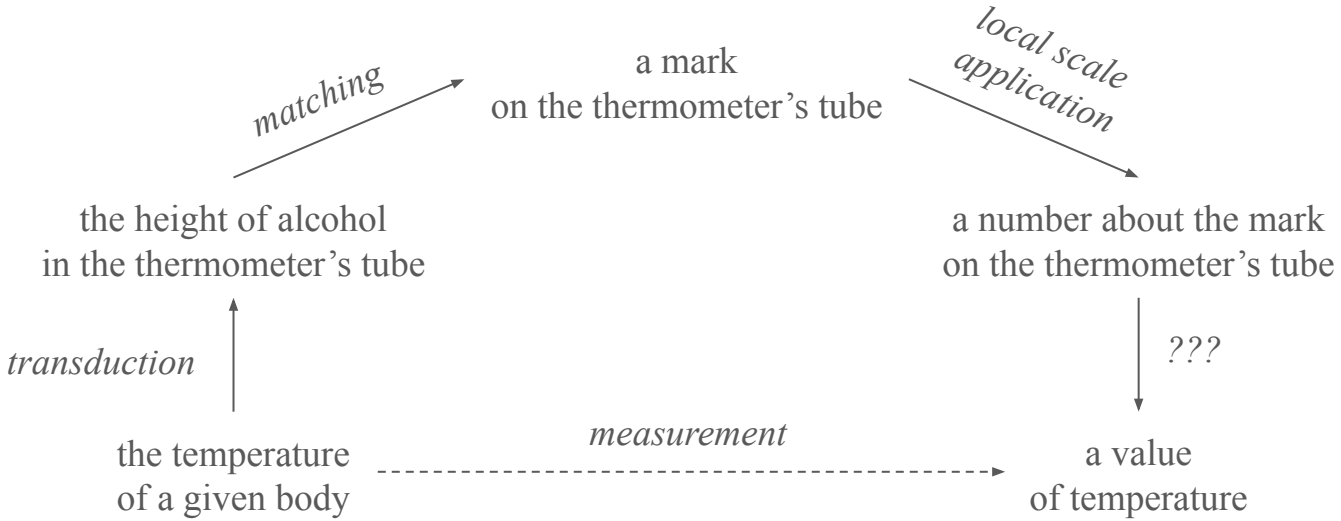
measurement is a trustworthy evaluation
because it produces explicitly justifiable information
in terms of their “degree of objectivity” and “degree of intersubjectivity”

A MATS framework

A MATS framework should provide a domain-independent, operational structure for a process that produces information that is explicitly justifiable because the objectivity and intersubjectivity of the produced information are socially agreeable

Hence, our next step is to present and discuss the structure of such a process

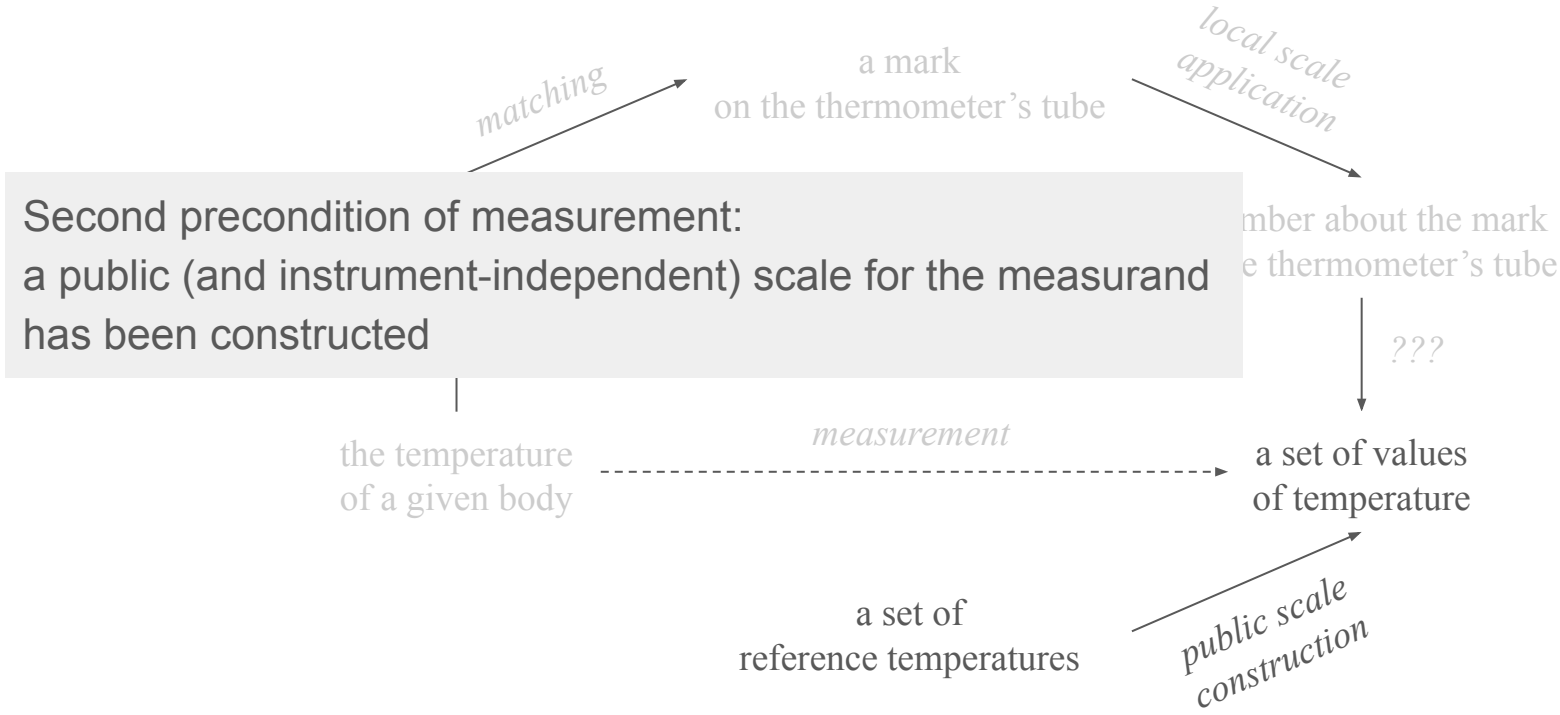
The Hexagon Framework: from a simple example



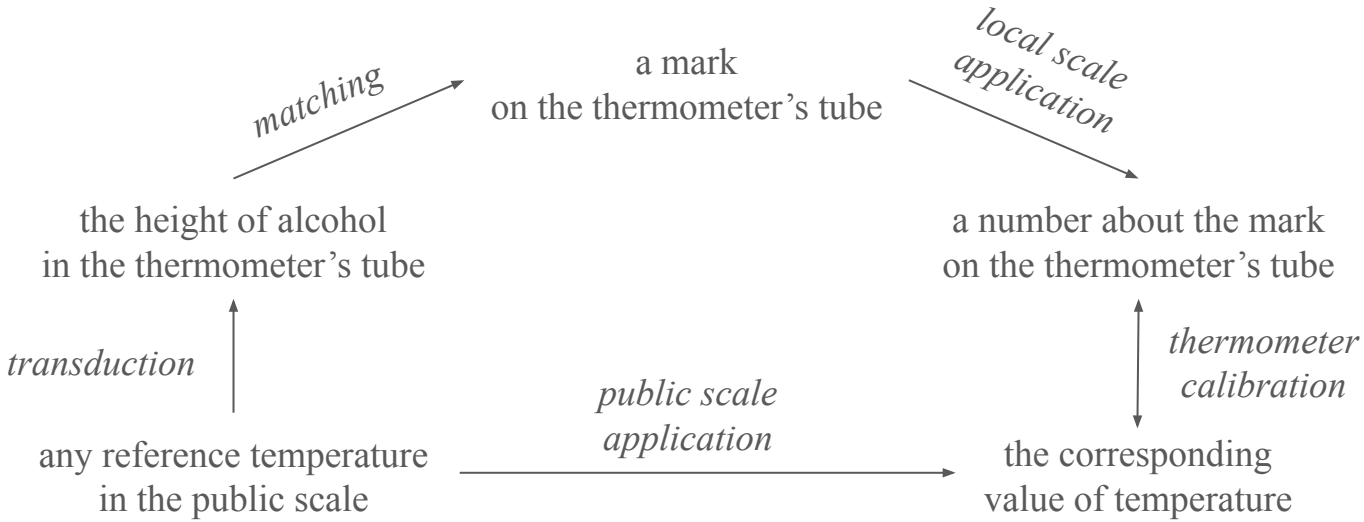
How are instrument-related values mapped to values of the measurand?

First precondition of measurement:
a measurand-sensitive instrument has been constructed

The Hexagon Framework: from a simple example /2



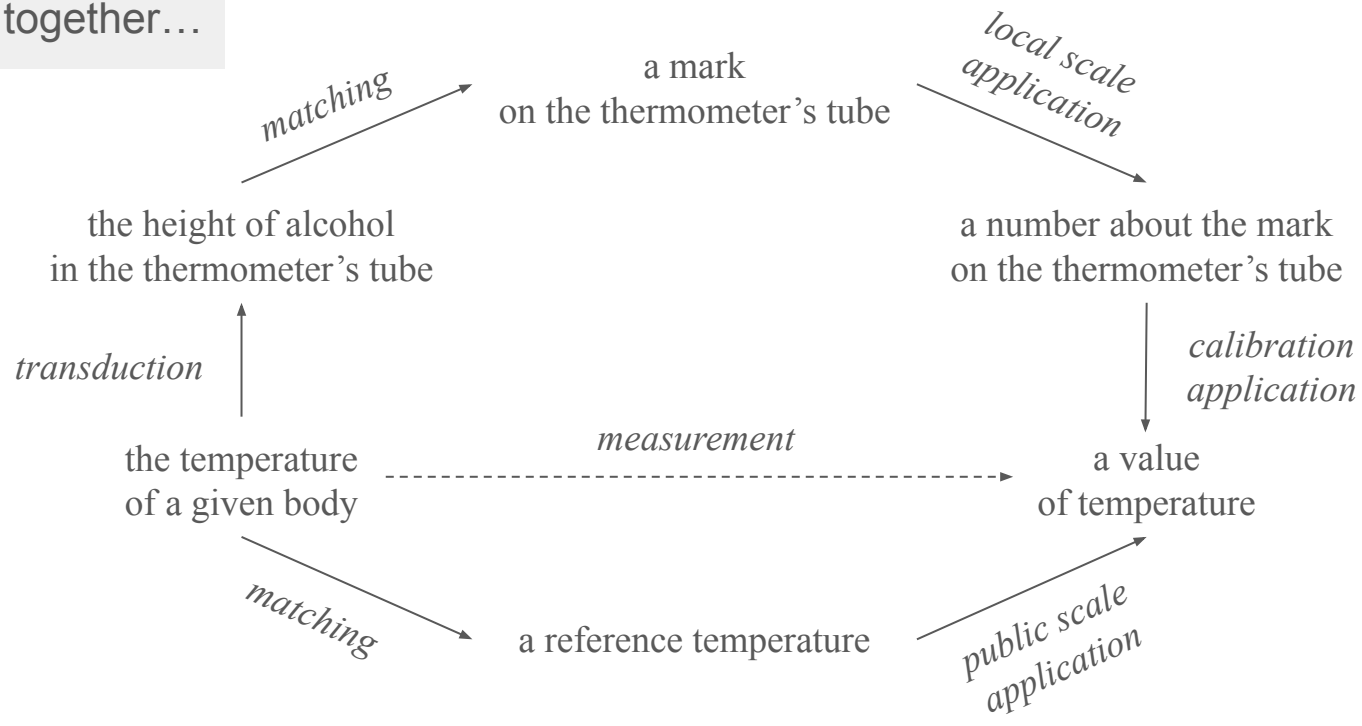
The Hexagon Framework: from a simple example /3



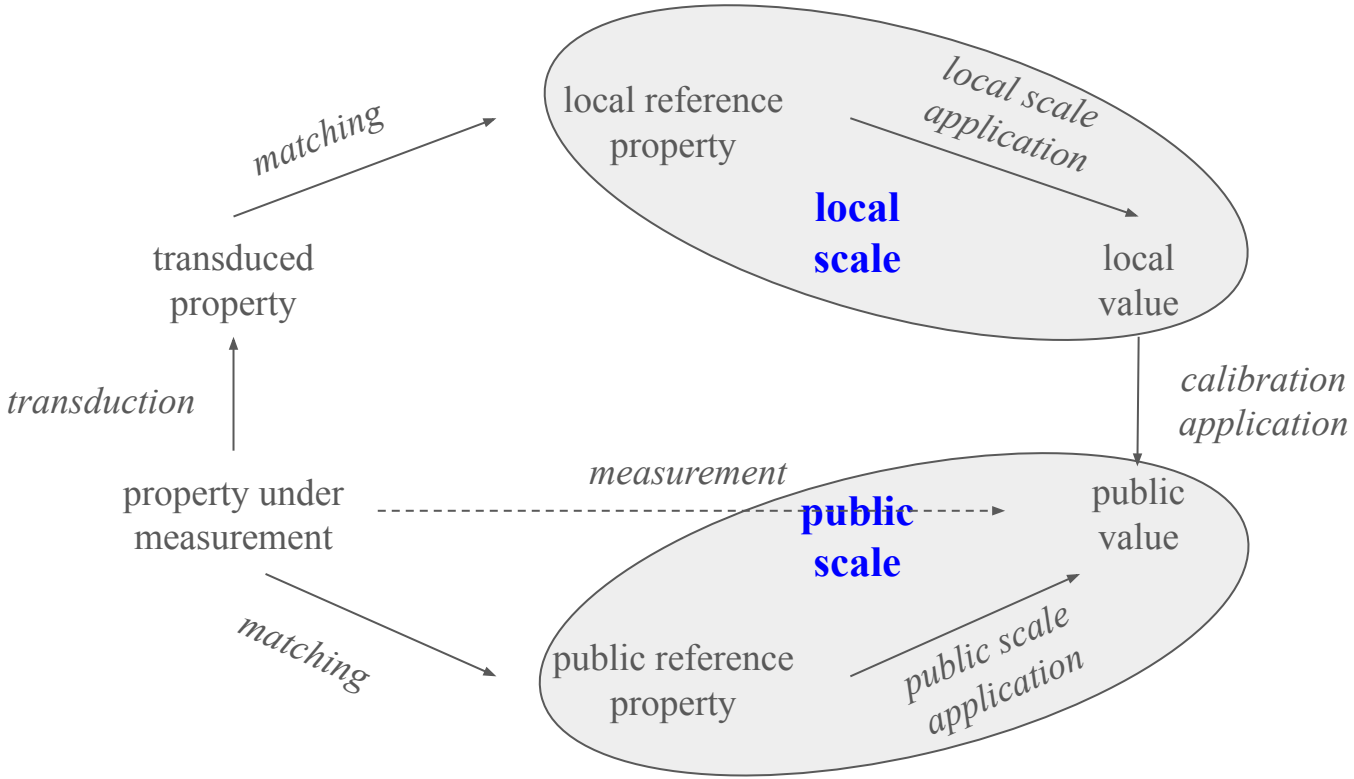
Third precondition of measurement:
the instrument has been calibrated against the public scale

The Hexagon Framework: from a simple example /4

Putting it all together…



The Hexagon Framework: underlying structures



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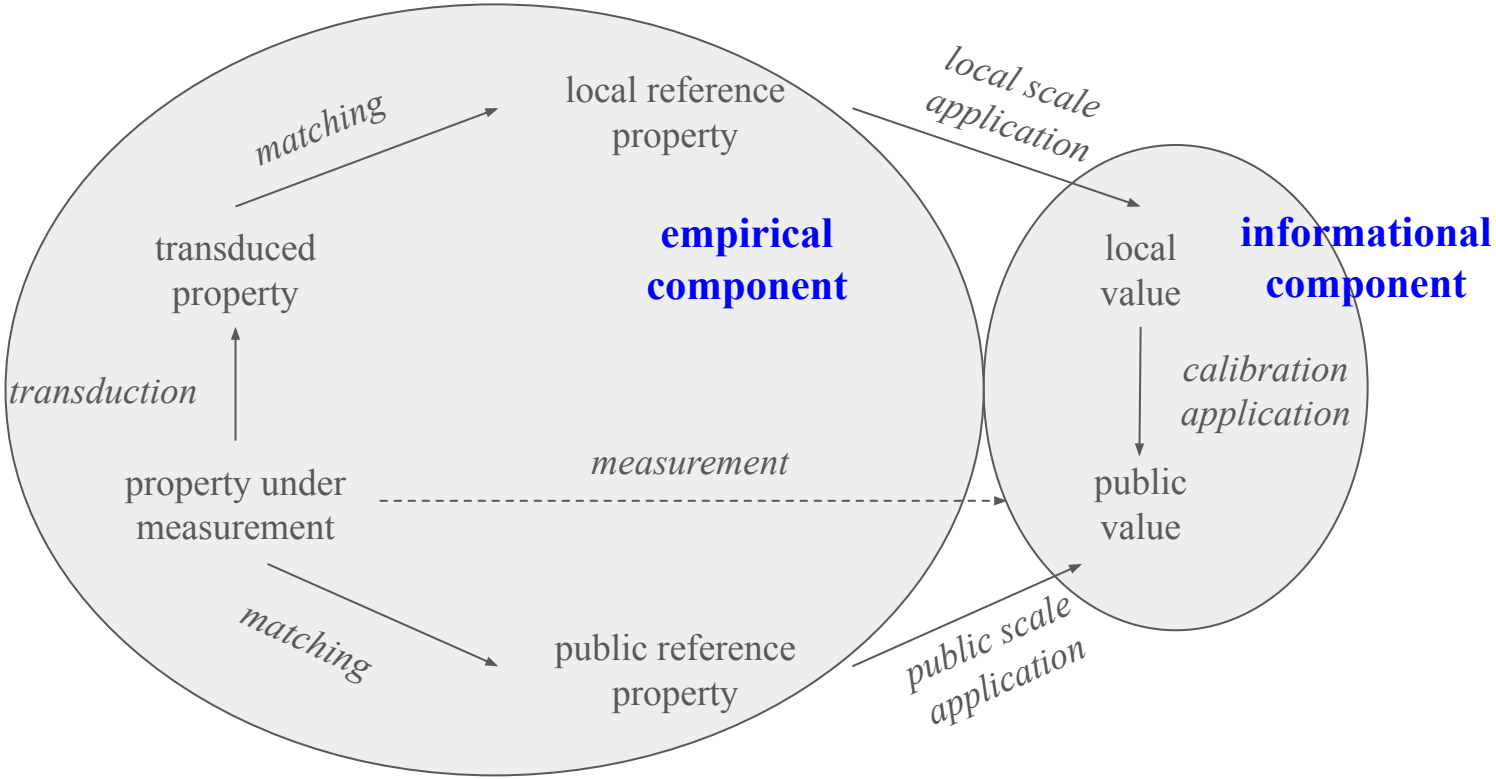

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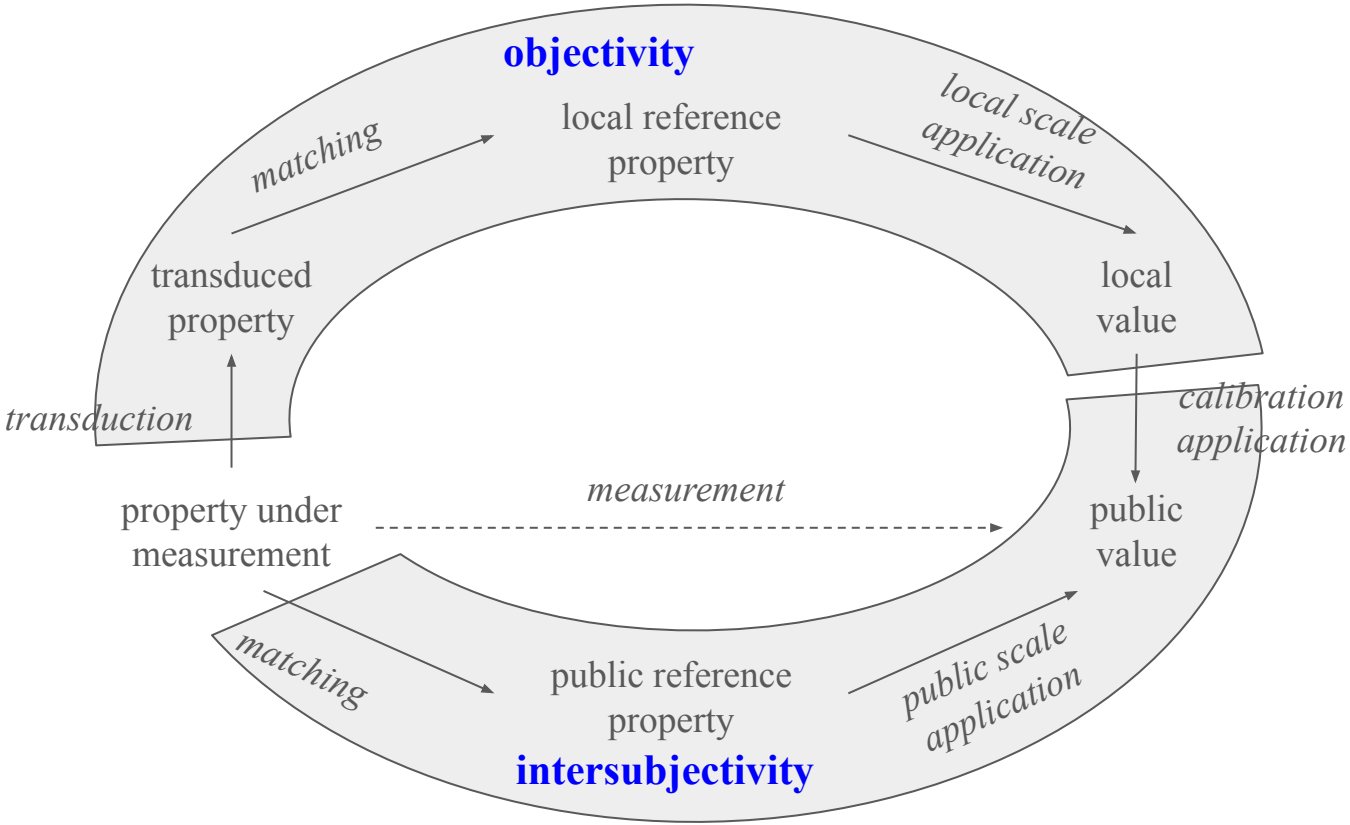

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(Bonus: Return to the Fundamentals: what are quantities, units, values?)

MATS workshop activity

Form 4 teams according to affinities (e.g., application topics, etc.)

Each team:

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- prepares materials to present to the rest (a labelled hexagon)
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General discussion about the presentations and conclusions

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An overview of two underlying ontologies

The statements reporting measurement results are sometimes presented, e.g., as

"the length in metres of object a is 0.123"

and written

(eq2) $\ell_{\mathrm{m}}(a) = 0.123$

Is there any **fundamental** difference between

(eq1) $\ell(a) = 0.123\ \mathrm{m}$ and (eq2) $\ell_{\mathrm{m}}(a) = 0.123$

?

The broader picture

With some differences, this applies also to non-quantitative or non-physical cases like

(eq1) the blood group
of person z
is A in the ABO System

$$b(z) = \text{A in ABO\_Sys}$$

(eq2) the blood group in the ABO System
of person z
is A

$$b_{\text{ABO\_Sys}}(z) = \text{A}$$

Hence, **our subject is neither type-specific nor domain-specific**

Hypothesis

While the information conveyed by

(eq1) $\ell(a) = 0.123\ \mathrm{m}$ and (eq2) $\ell_{\mathrm{m}}(a) = 0.123$

is operationally the same,

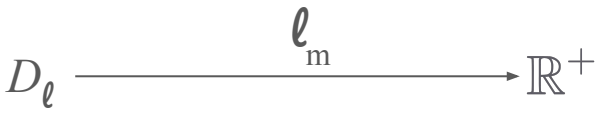
their underlying ontologies can be significantly different

(hint: while (eq2) is about numbers, (eq1) is about *something else*)

Let us explore the issue…

Exploring (the simpler) Onto2

(eq2) $\ell_{\mathrm{m}}(a) = 0.123$



The function ℓ_{m}, length-in-metres, is a **scale**,
that associates objects-having-length in D_ℓ with numbers

$\ell_{\mathrm{m}}(a)$ is the length-in-metres of a, that is a number.

Any two objects a and b in D_L are comparable by length-related indistinguishability,
and two indistinguishable objects must be mapped to the same length-in-metres:

if $a \approx_\ell b$ then $\ell_{\mathrm{m}}(a) = \ell_{\mathrm{m}}(b)$

Any given length can be extensionally identified with an $\approx_\ell$-equivalence class of objects

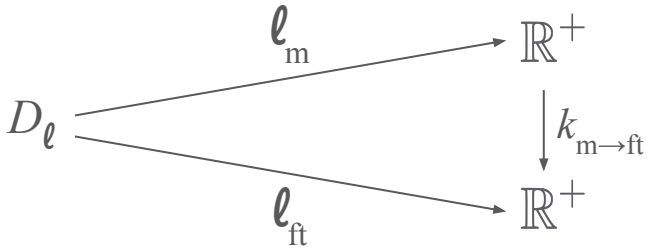
Exploring (the simpler) Onto2

Any two objects a and b in D_ℓ are comparable by ℓ-related order and ratio, where

if $a \leq_\ell b$ then $\ell_m(a) \leq \ell_m(b)$

if $a +_\ell b \approx_\ell c$ then $\ell_m(a) + \ell_m(b) = \ell_m(c)$

There can be other scales defined on the same domain D_ℓ, e.g., ℓ_{ft},
and such scales can be transformed to each other, i.e., there exists a constant $k_{m\to ft}$ such that
for any a in D_ℓ, $\ell_{ft}(a) = k_{m\to ft}\,\ell_m(a)$



Length can be extensionally identified with the set $\{\ell_x\}$, where each scale ℓ_x can be obtained from any other ℓ_y by applying a transformation $k_{y\to x}$

Exploring (the simpler) Onto2

Conditionals like

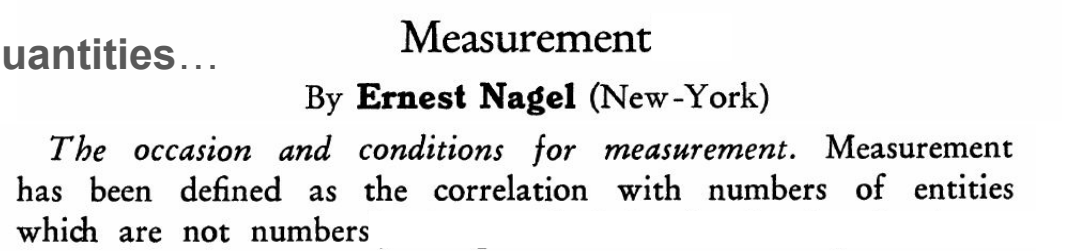
if $a \approx_{\ell} b$ then $\ell_{\mathrm{m}}(a) = \ell_{\mathrm{m}}(b)$

if $a \leq_{\ell} b$ then $\ell_{\mathrm{m}}(a) \leq \ell_{\mathrm{m}}(b)$

if $a +_{\ell} b \approx_{\ell} c$ then $\ell_{\mathrm{m}}(a) + \ell_{\mathrm{m}}(b) = \ell_{\mathrm{m}}(c)$

are **consistency**, not truth, conditions

This strategy **gets rid of properties / quantities**…



Measurement

By **Ernest Nagel** (New-York)

The occasion and conditions for measurement. Measurement has been defined as the correlation with numbers of entities which are not numbers

… and emphasizes the **representational** nature of measurement

(eq2) $\ell_{\mathrm{m}}(a) = 0.123$ can be interpreted as: the object a is ℓ_{m}-represented by the number 0.123

Are we ready to avoid properties?

Is it really the case that
– definitions like: velocity is the first derivative of position
– physical laws like Hooke's law ($F = k\,x$)
– designs and models of measuring instruments and of measurements
– …
do not involve properties / quantities, but only equivalence classes of objects or sets of transformable functions?

Observation:

(eq2) $\ell_{\mathrm{m}}(a) = 0.123$ is compatible not only with strict representationalism:

let us explore another position / ontology

Beyond representationalism: from (eq2) to (eq1)

According to a century-long tradition, relation (eq2) $\ell_{\mathrm{m}}(a) = 0.123$

may be interpreted as $\ell(a) / \mathrm{m} = 0.123$

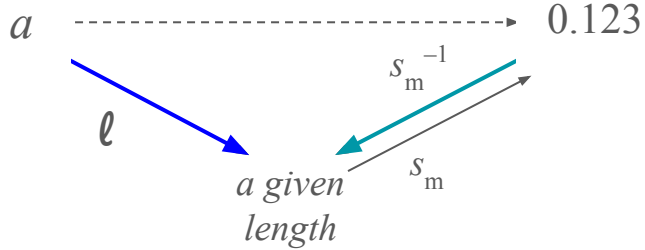
and therefore as (eq1) $\ell(a) = 0.123\ \mathrm{m}$

where for the ratio $\ell(a) / \mathrm{m}$ to be meaningful $\ell(a)$ and m must be entities of the same sort

Exploring (the more complex) Onto1

(eq1) $\ell(a) = 0.123\ \text{m}$

The function ℓ, length, associates objects having length with lengths, so that $\ell(a)$ is the length of a



The function s_{m}, in-metres, is a **scale**, that associates lengths with numbers

(eq1) means that there is a length that can be presented both as the length of a and as 0.123 times the length identified as the metre:

(eq1) is true if and only if $\ell(a)$ and $s_{\text{m}}^{-1}(0.123)$ are the same length

Some pros of Onto1

It provides

- a simple answer to the question: what is a measurement unit?
  (what is the metre? a length)
- an account of comparison of objects with respect to properties
  in terms of comparison of the properties themselves
  (b is longer than a if the length of b is greater than the length of a,
  and this is an empirical fact independent of numbers, units, scales, etc)
- a simple answer to the question: what is a value of a quantity?
  (what is $0.123\ \mathrm{m}$? a multiple of a unit, and therefore a length)

**This explanatory power is obtained thanks to a rich ontology,
that explicitly includes properties**

Summary

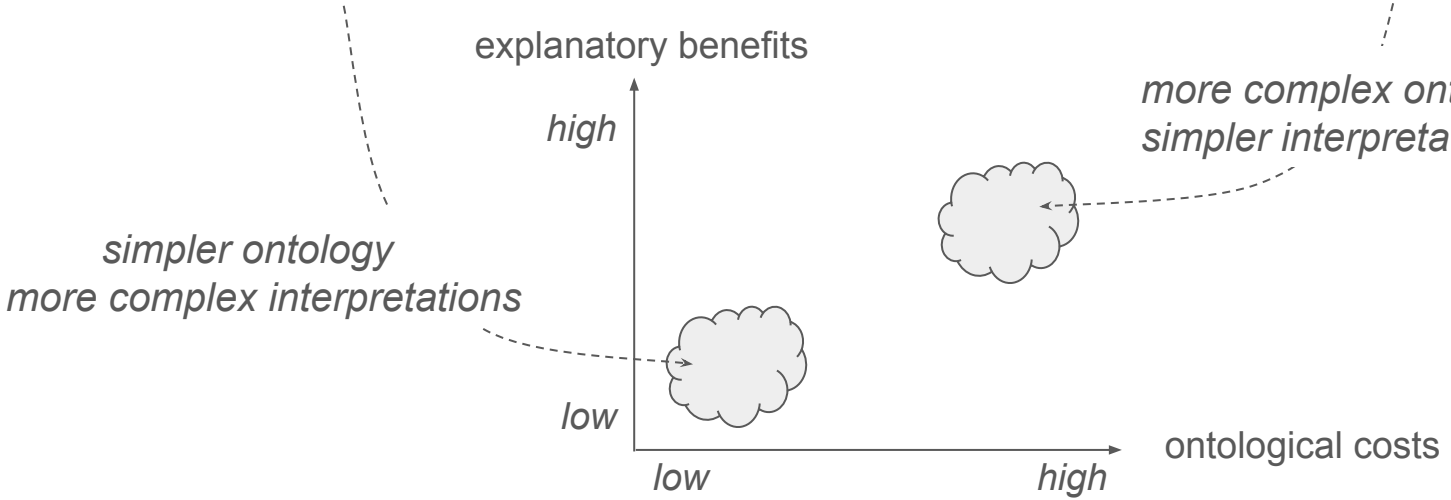
(eq2) $\ell_{\mathrm{m}}(a) = 0.123$

(strict) representationalism

“equationalism”

(eq2) interpreted as such and *nothing else*
→ emphasis on (eq2) as a **representation**

(eq2) interpreted as (eq1)
→ emphasis on (eq1) as an **equation**



Thanks for your participation!

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