Some reflections on what is measurement - and what it is not

Luca Mari
Università Cattaneo – LIUC, Italy

Warwick Business School
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Abstract

The concept of measurement is central to both physical and social sciences, as it is intimately related to the experimental acquisition and validation of knowledge. However, measurement is commonly considered a critical but only instrumental process, which provides “the correct assignment of numbers to physical variables” (Chang, Cartwright 2008) and that connects “reason to Nature” (Margenau 1958). Regrettably, despite its long history, measurement is laden with stereotypes rooted in outdated conceptions of the physical world, which hinder its theoretical advancement and practical contribution. Moreover, the adoption of measurement in very diverse fields has resulted in context-dependent, ambiguous terminology (e.g., “quantity”, “accuracy”, “scale”) that makes interdisciplinary communication and collaboration on measurement related topics difficult.

This seminar will start by presenting a brief history of measurement and will then discuss the following:

- what is measurement and why is it so important?
- how is measurement different from opinion and generic evaluation?
- how can we decide whether measurement results are acceptable?
- what are the effects of measurement on what is being measured?
- can measurement be defined and used in the same way for both physical and non-physical properties?

My profile

Luca Mari (M.Sc. in physics; Ph.D. in measurement science) is full professor of measurement science at the Cattaneo University – LIUC, Castellanza (VA), Italy, where he teaches courses on measurement science, statistical data analysis, system theory.

He is currently the chairman of the TC1 (Terminology) and the secretary of the TC25 (Quantities and Units) of the International Electrotechnical Commission (IEC), and an IEC expert in the WG2 (VIM) of the Joint Committee for Guides in Metrology (JCGM). He has been the chairman of the TC7 (Measurement Science) of the International Measurement Confederation (IMEKO). He is the author or coauthor of several scientific papers published in international journals and international conference proceedings. His research interests include measurement science and system theory.

Some of my recent publications

D.Petri, LM, P.Carbone, **A structured methodology for measurement development**, *IEEE Trans. Instr. Meas.*, 2015

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P.Micheli, LM, **The theory and practice of performance measurement**, *Manag. Accounting Research*, 2014

LM, M.Wilson, **An introduction to the Rasch measurement approach for metrologists**, *Measurement*, 2014

A.Frigerio, A.Giordani, LM, **On representing information: a characterization of the analog/digital distinction**, *Dialectica*, 2013

LM, **A quest for the definition of measurement**, *Measurement*, 2013

LM, A.Giordani, **Quantity and quantity value**, *Metrologia*, 2012

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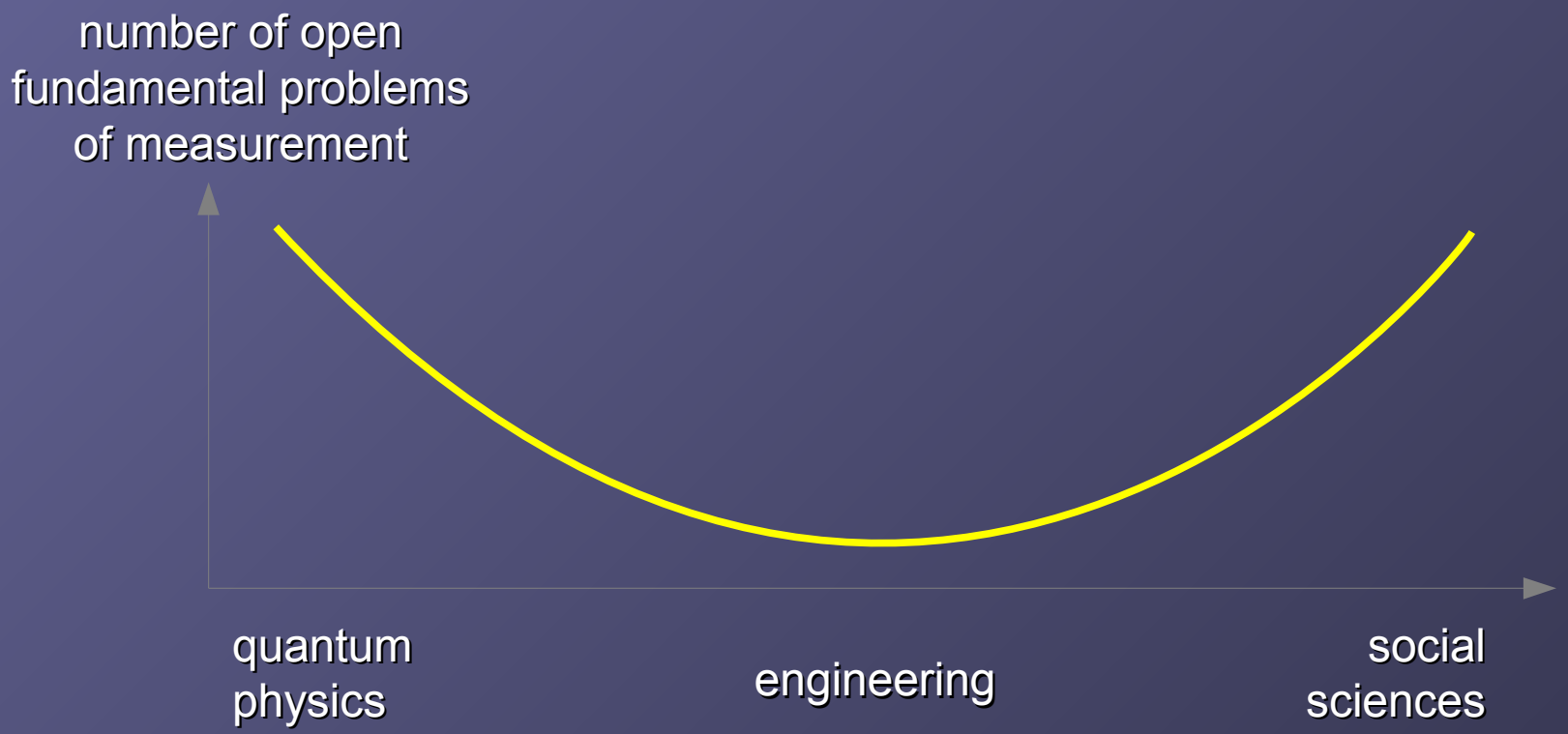
V.Lazzarotti, R.Manzini, LM, **A model for R&D performance measurement**, *Int. J. Production Economics*, 2011

A.Frigerio, A.Giordani, LM, **Outline of a general model of measurement**, *Synthese*, 2010

D.Macii, LM, D.Petri, **Comparison of measured quantity value estimators in nonlinear models**, *IEEE Trans. Instr. Meas.*, 2010

A customary opinion



Consequence:

never argue with an engineer
if you are interested in
fundamental problems of measurement

Correct?

A basic question

What is the difference between measurement and opinion?

Lexical note:

- “measurement”: the process (a *nomen actionis*)
- “measurement result”: the result (a *nomen rei actae*)

The different interpretations
on the scientific role of measurement
shed some light
on the different interpretations
of what measurement is

«Our most prevalent notions
both about the function of measurement
and about the source of its special efficacy
are derived largely from myth»

[Kuhn 1961]

The traditional interpretation of the role of measurement

According to the Euclid's Elements, Book V,

– sometimes intended as "the earliest contribution to the philosophy of measurement available in the historical record" [Michell 2005] –

«a magnitude is a part of a(nother) magnitude, the lesser of the greater, when it **measures** the greater»

Measurement is a (the?) tool to obtain quantitative information

The traditional interpretation of the scientific role of measurement

«[Newton's mechanics] was a deductive science, exactly like geometry. Yet Newton himself asserted that he had wrested its functional principles from experience by *induction*. In other words, Newton asserted that **the truth of his theory could be logically derived from the truth of certain *observation-statements***.»

[Popper 1962]

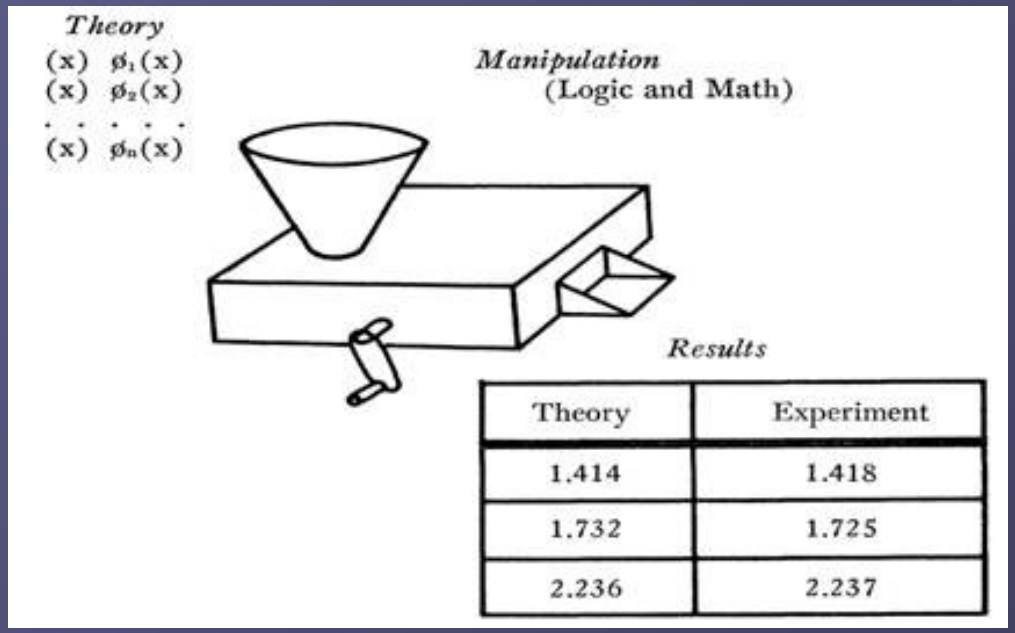
Measurement is a (the?) tool to obtain true observation-statements

true values of **quantities**

Falsificationism

«Theories cannot be logically derived from observations. They can, however, clash with observations: they can contradict observations. This fact makes it possible to infer from observations that a theory is false. **The possibility of refuting theories by observations is the basis of all empirical tests**.»

[Popper 1962]



Theory	Experiment
1.414	1.418
1.732	1.725
2.236	2.237

«The results in the table seem to function as a test of theory. If corresponding numbers in the two columns agree, the theory is acceptable; if they do not, the theory must be modified or rejected.»

[Kuhn 1961]

Falsificationism

Given the emphasis on theories and their epistemic role, falsificationism seems to be less interested in “observations”:

measurement results can be still taken for granted...

This position does not imply a re-interpretation of the scientific role of measurement

Constructivism

«Seeing is a “theory-laden” undertaking: **observation of *x* is shaped by prior knowledge of *x***»

[Hanson 1958]

... so that «pure or neutral observation-languages» do not exist

[Kuhn 1962]

«Although conception without perception is merely *empty*, perception without conception is *blind* (totally inoperative). [...]

With false hope of a firm foundation gone, with the world displaced by worlds that are but versions, with substance dissolved into function, and with **the given acknowledged as taken**, we face the questions how worlds are made, tested, and known.»

[Goodman 1978]

Constructivism

If «anything holds» (including cheating about experimental results) [Feyerabend 1975], what does it remain of the claimed “special efficacy” of measurement?

How is measurement different from opinion, judgment by experience, guess, … then?

… maybe it is because quantification,
as in Euclidean geometry?

Measurement is not quantification

Euclid's Elements:

«a magnitude
is a part of a(nother)
magnitude,
the lesser of the greater,
when it **measures** the greater»

«a number
is a part of a(nother)
number,
the lesser of the greater,
when it **measures** the greater»

and in fact, throughout the Elements, 'measurement' is never used, since «in the geometrical constructions employed in the Elements empirical proofs by means of measurement are strictly forbidden»

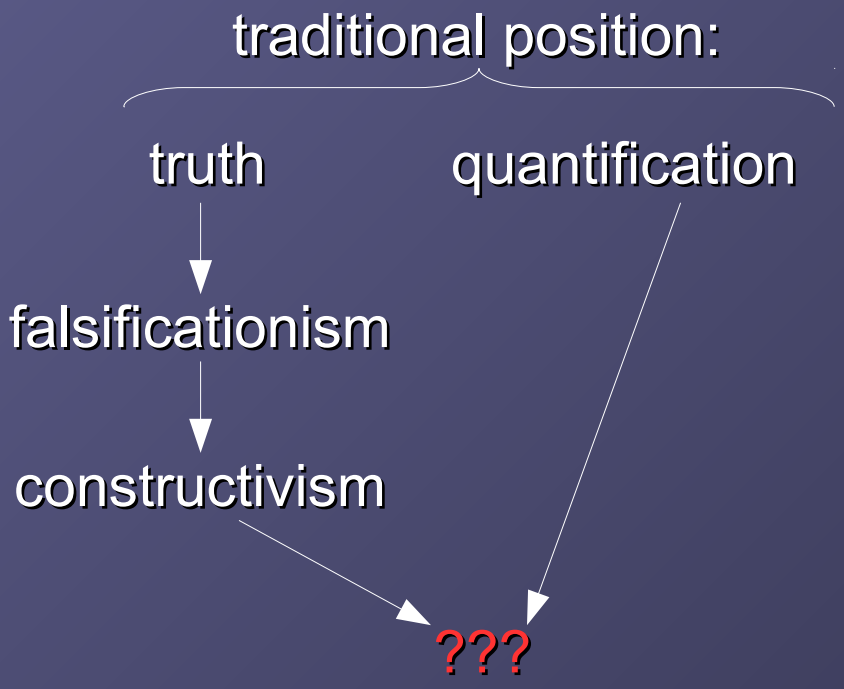
(from the introductory notes of [Euclid])

Do not consider "measure" and "measurement" as synonymous!

see also [Bunge 1973]

claim: measurement ≠ opinion

why?



Measurement DOES remain different from opinion: but how?

Trying to recover measurement...

The default position for PHYSICAL properties is, more or less:

measurement is a process performed
by a properly designed, setup, and operated measuring instrument,
based on a sensor able to interact
with the property under measurement

This is maybe ok, but does not apply for NON-PHYSICAL properties

Here appear the so-called “representational theories of measurement”

Representational theories of measurement

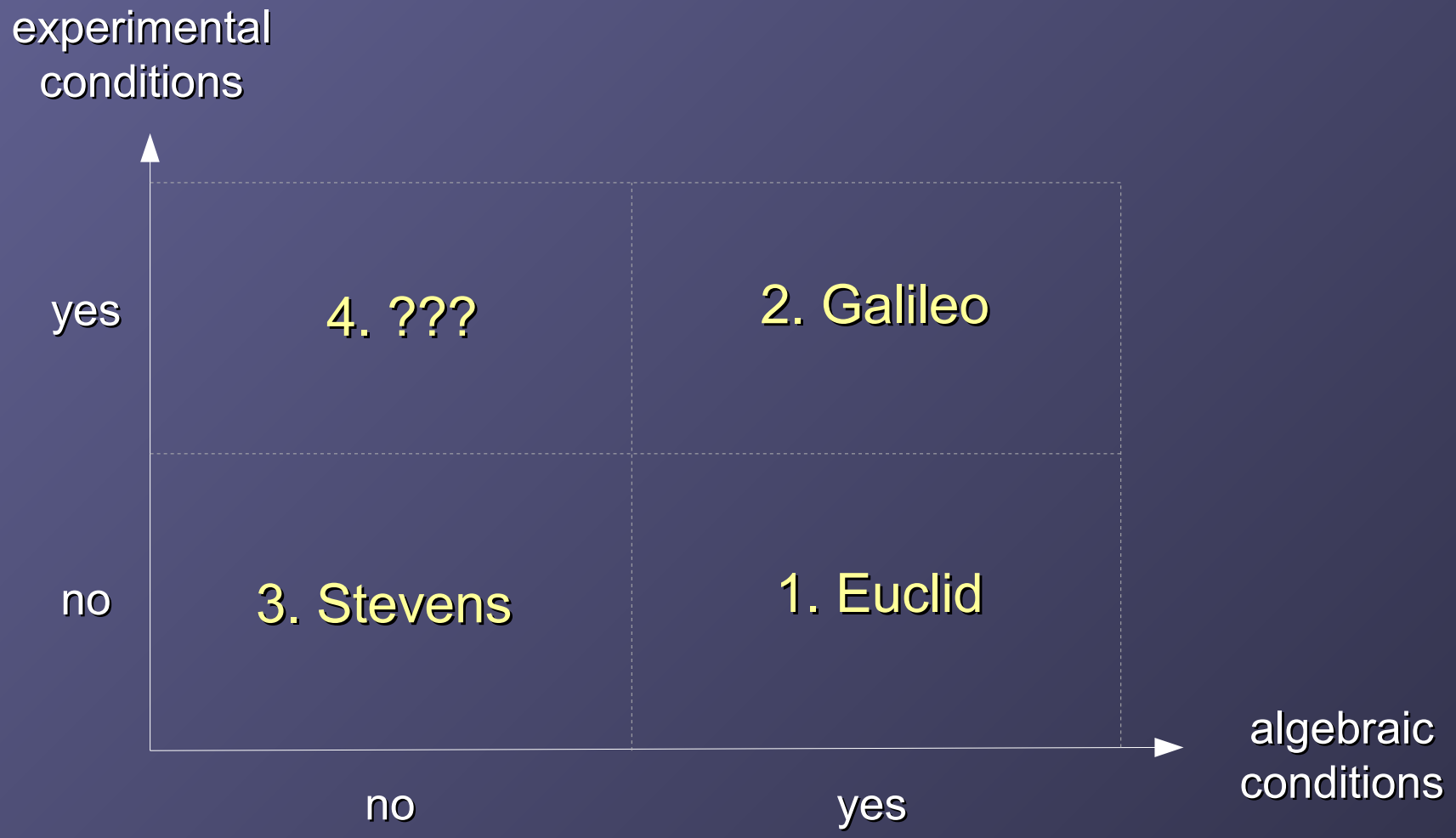
Measurement is any process producing information that preserves empirical relations (“measurement as morphic representation”)

(see, e.g., the monumental [Krantz et al 1971, 1989, 1990])

This is a reasonable necessary condition, but hardly sufficient

(it neglects things such as measurement standards, instrument calibration, metrological traceability, ...)

What is measurement then?



A proposal

Measurement is a process that delivers information, as values of properties, that is:

- specifically related to the measurand and not to some other properties of the object under measurement or the empirical environment, which includes also the subject who is measuring
  → it is a *condition of object-relatedness*,
  i.e., of **objectivity**

- univocally interpretable by different users in different places and times, thus implying that a measurement result has to be unambiguous and unambiguously expressed
  → it is a *condition of subject-transparency*,
  i.e., of **intersubjectivity**

(see, e.g., [Mari et al 2012])

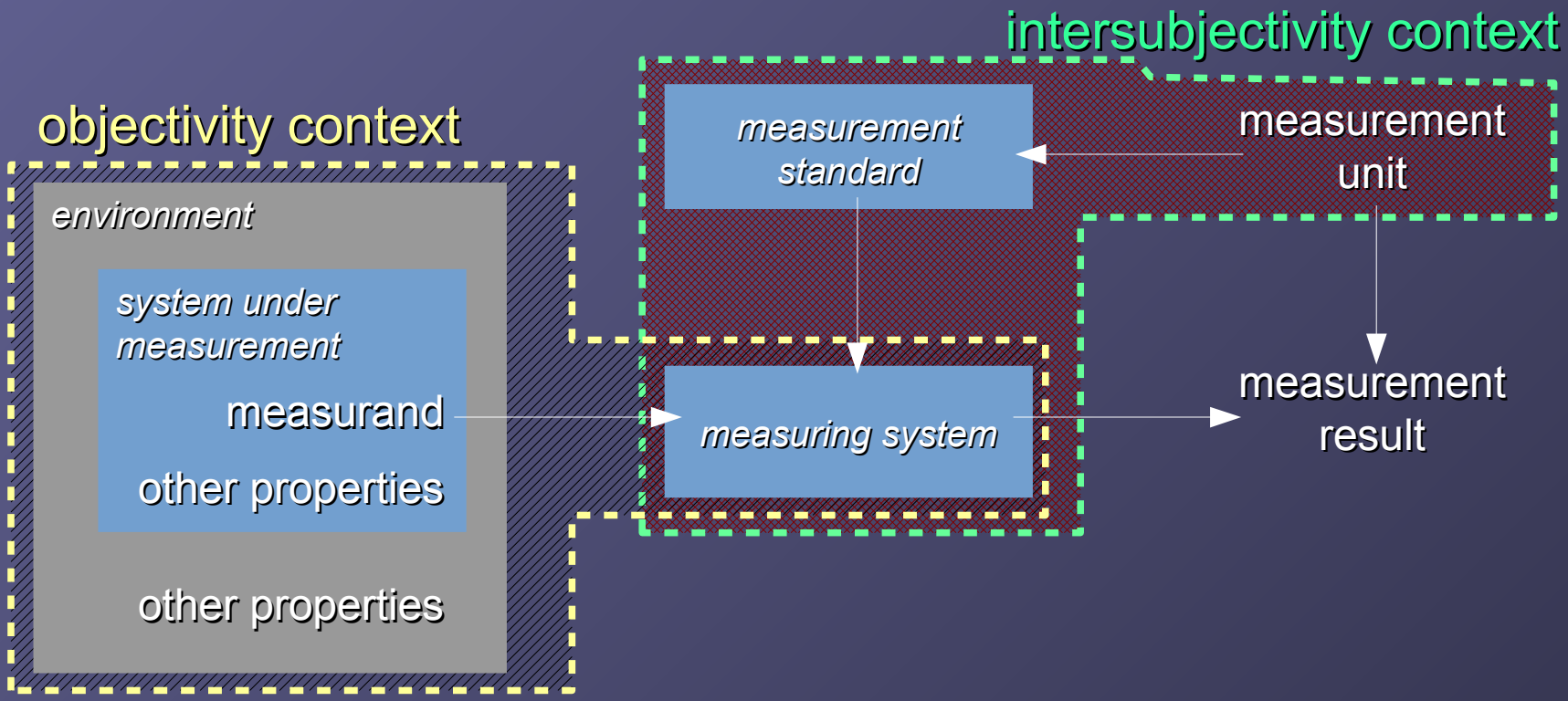
Measurement and measuring systems

When measuring a physical property, these conditions are guaranteed by the measurement system itself:

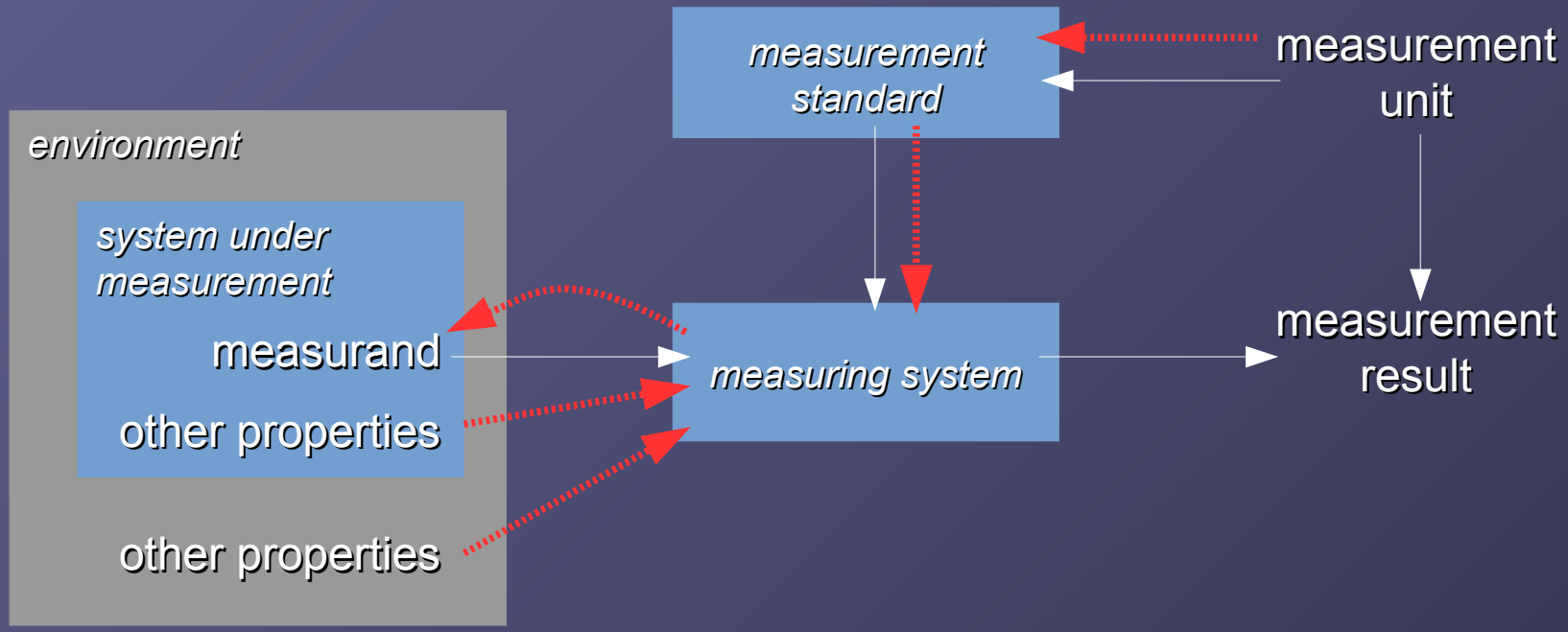
- the output of the measuring instrument ideally depends only on the property under measurement, and it is independent of all other properties of the empirical environment
  → **this confers objectivity to the provided information**

- the measuring instrument is calibrated against a measurement standard, thus making measurement results traceable so that different measuring instruments calibrated within the same metrological system provide compatible information
  → **this confers intersubjectivity to the provided information**

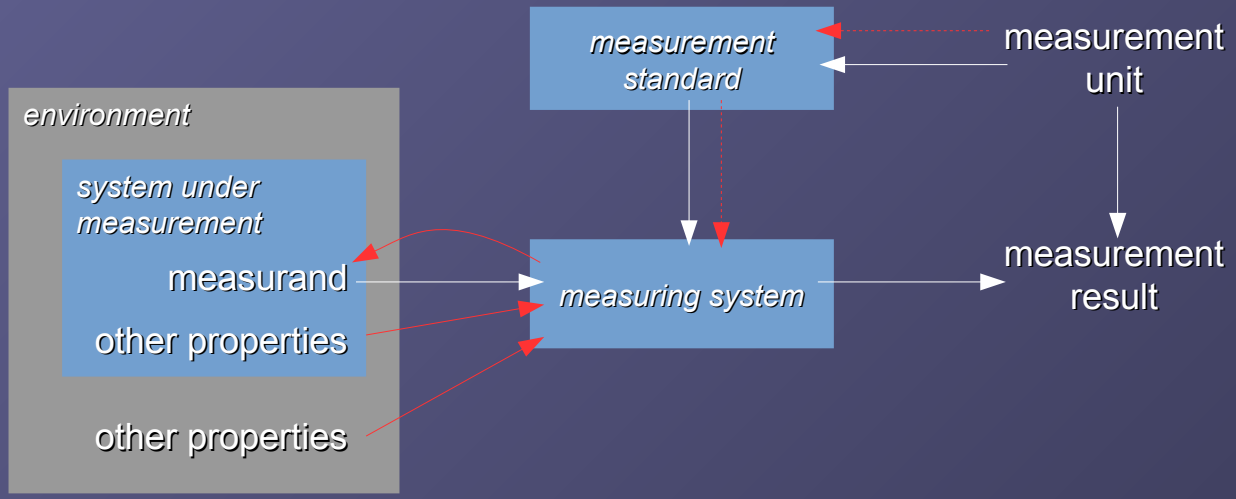
The structure of measurement



Realistic situation



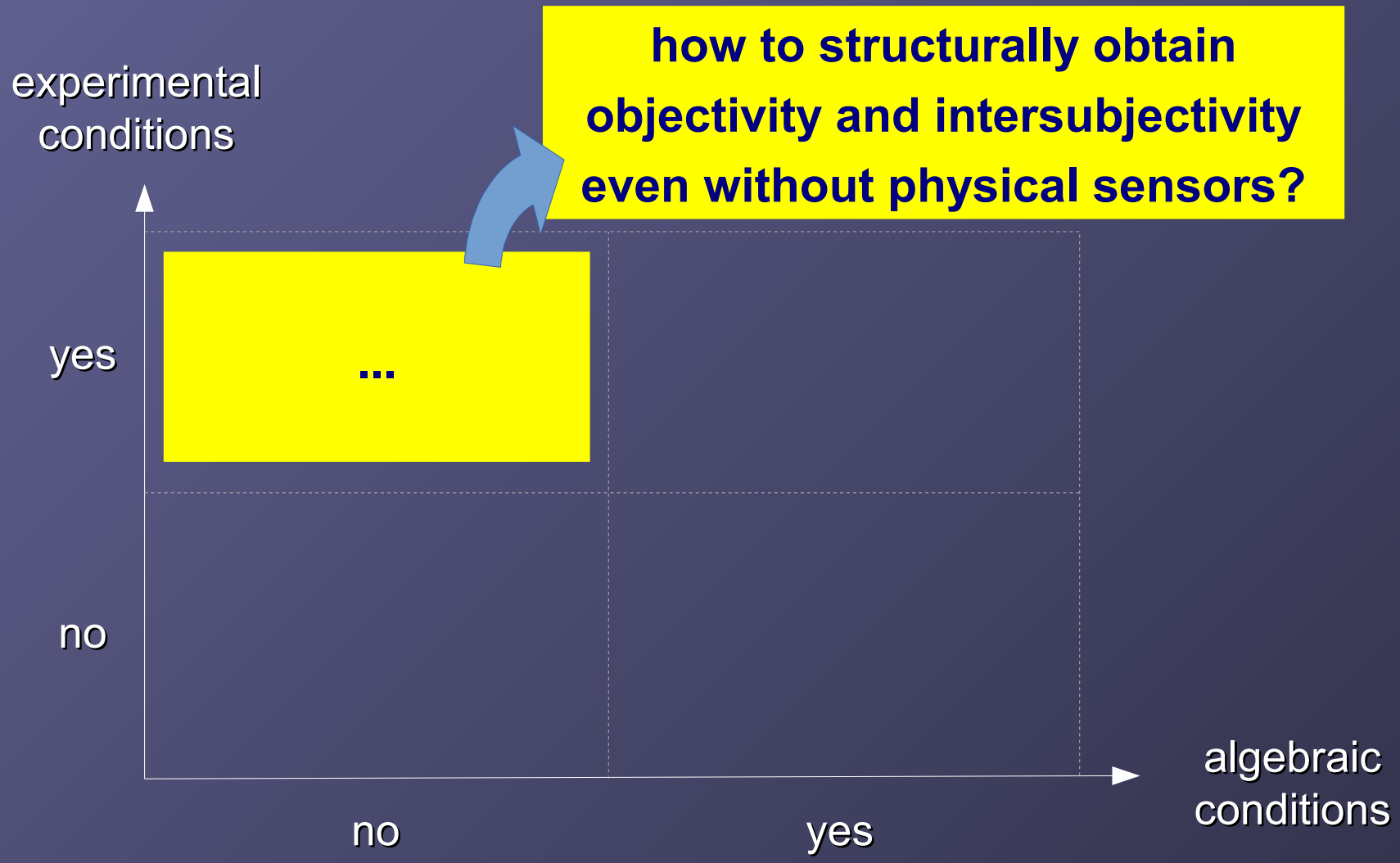
An issue



For physical quantities there is a long, well-established tradition about how to design, set up, and operate this system in order to maintain non-objectivities and non-intersubjectivities at an acceptable degree

What about non-physical quantities?

A R&D programme



A structural framework

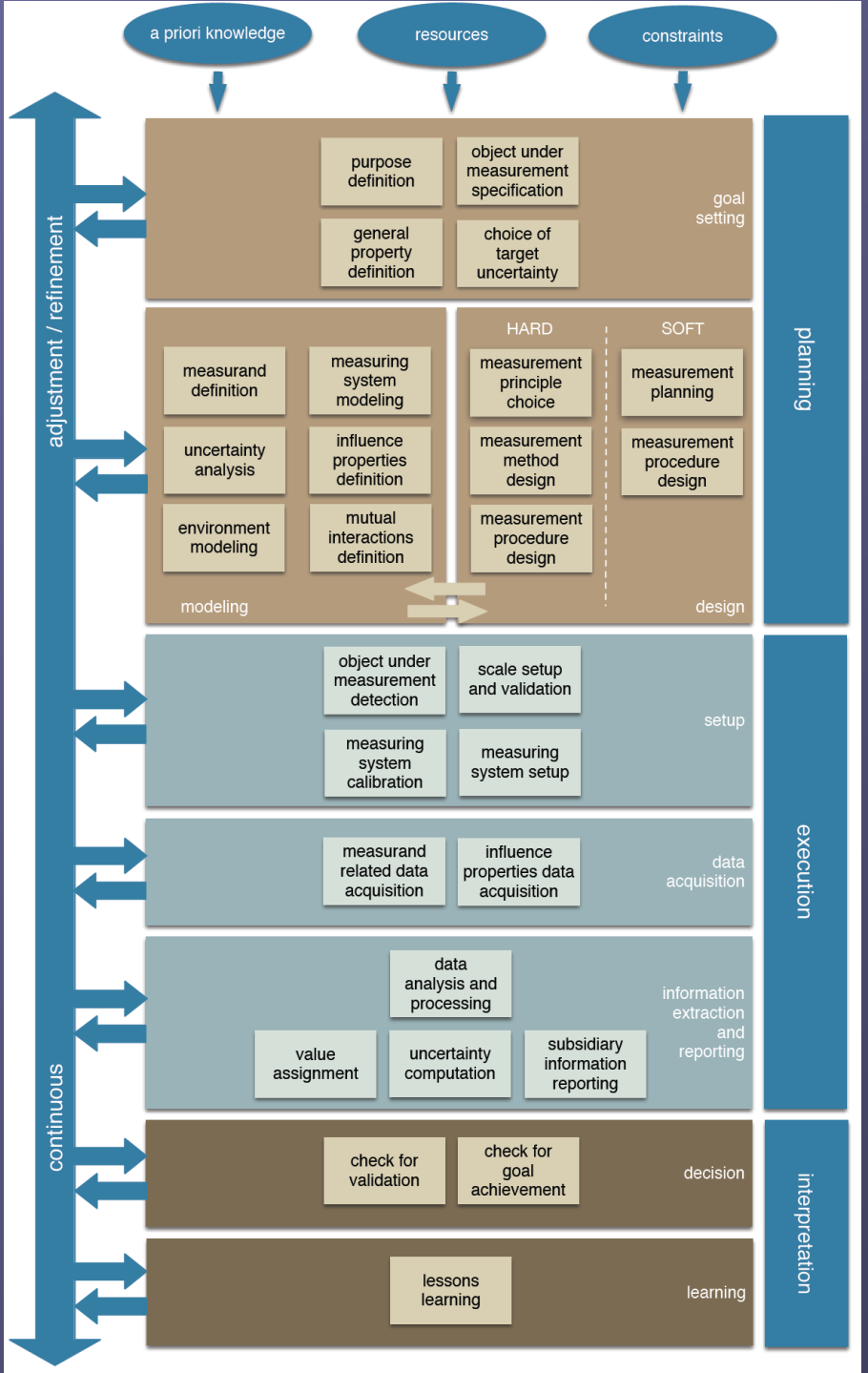
Measurement is a complex model-based goal-driven process

Multiple activities performed (some implicitly) can be organized in a structural framework inspired to both:

- the well-known Deming cycle (Plan-Do-Check-Act) and
- models used to represent product development processes in manufacturing or software engineering

In PDCA (and in FraMeD):

- tasks are executed according to a loose ordered sequence
- feedback is needed to refine activities until requirements are met



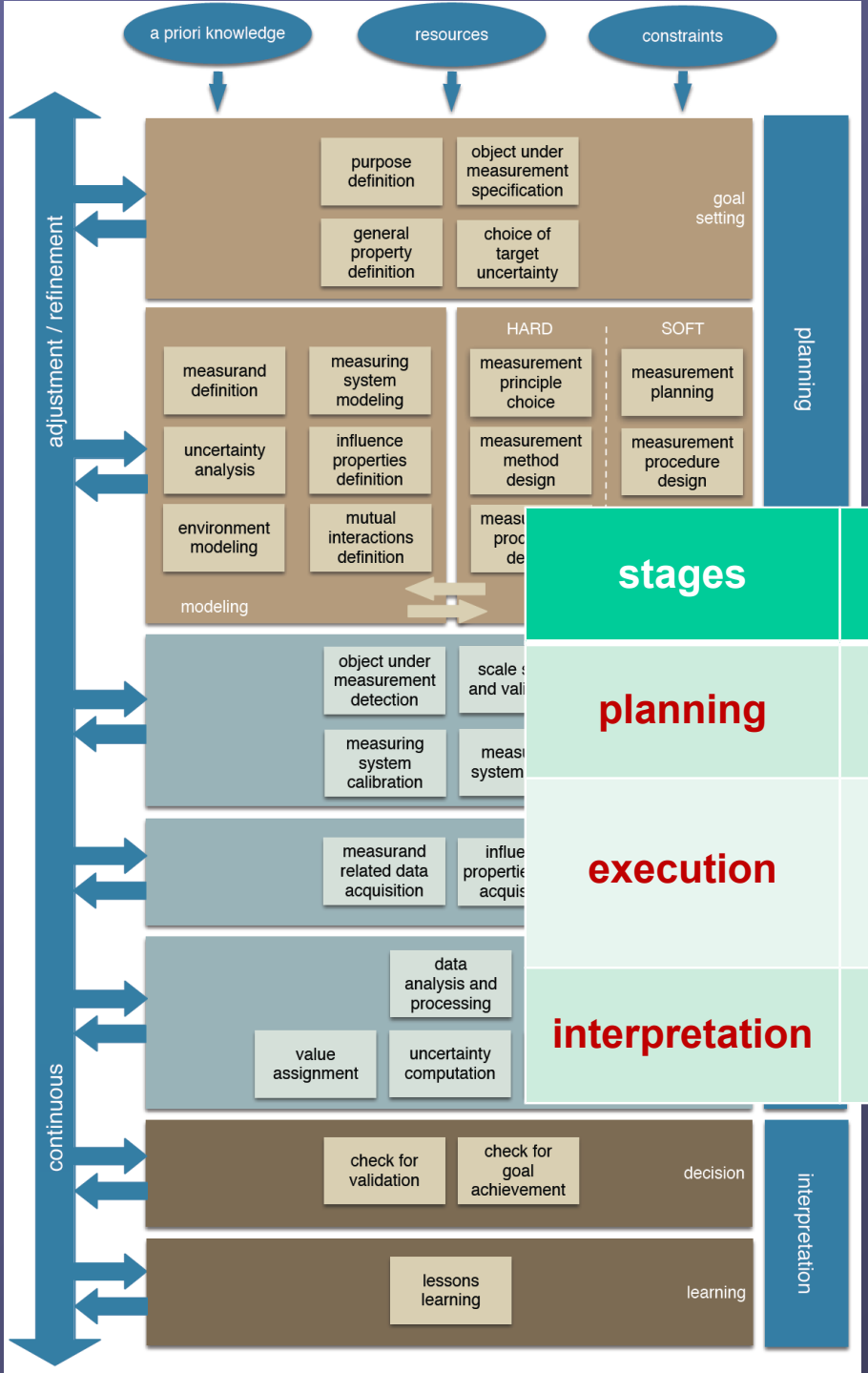
FraMeD: an overview

FraMeD interprets measurement as a three-level hierarchically structured process

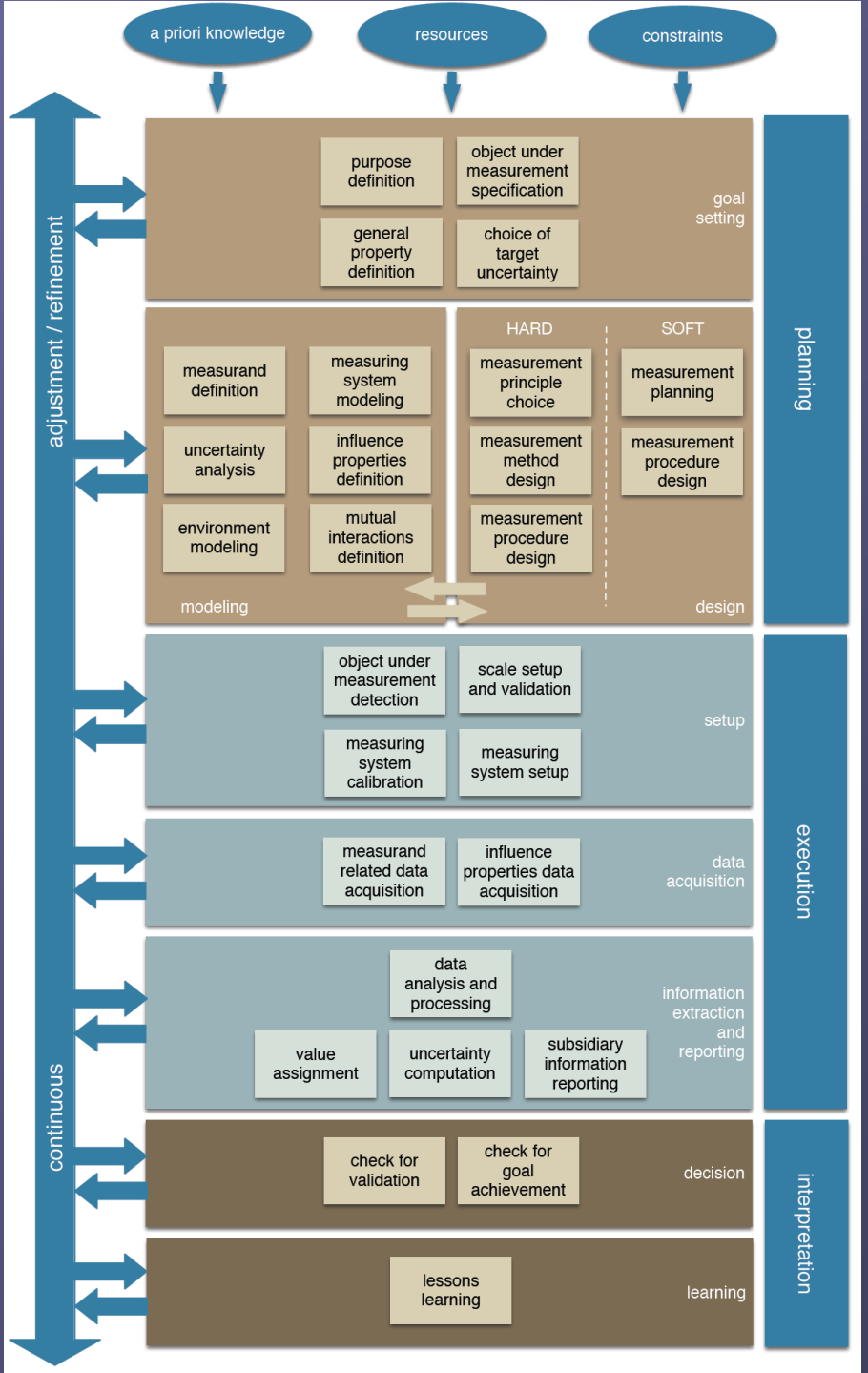
- comprising stages,
- each one composed of activities
- performed through multiple tasks

(see [Petri et al 2015])

FraMeD: an overview



stages	activities		
planning	goal setting	modeling	design
execution	setup	data acquisition	information extraction and reporting
interpretation	decision	learning	



FraMeD: an overview

A framework such as FraMeD is useful for

- discussing on concepts and identifying conceptual or operative issues in a shared context and with a shared vocabulary
- providing an analytical modeling approach even when math is not applicable
- encourage a structured methodology in designing and performing measurements

Concluding remark

The empirical task of data acquisition is necessary to measurement, but measurement is much more than just an empirical task

stages	activities		
planning	goal setting	modeling	design
execution	setup	data acquisition	information extraction and reporting
interpretation	decision		learning

Thank you
for your kind attention

Luca Mari

lmari@liuc.it

http://research.liuc.it/luca.mari

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