Software Metrics & Software Metrology

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Chapter 5
The Design of Software Measurement Methods

Agenda

This chapter covers:

- Linking software measurement & software metrology:
  - What is measured in software: the ‘measurand’ or a model of it?
  - The measurement foundation in metrology

- The activities for the design (& evaluation) of software measurement methods:
  1. Defining the measurement principle
  2. Determining the measurement method
  3. Post design activities: the measurement procedures

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Introduction

- This chapter presents the detailed the activities and related products required for the design (+ analysis & verification) of measurement methods.

- The approach integrates the concepts and vocabulary of metrology presented in chapter 3:
  - It provides definitions of the concepts as applied to the measurement of software, as well as
  - the activities and products related to the design of a measurement method.

- It gives an integrated view, involving both the practical side & the theoretical side of software measurement.

Linking Software Measurement and Metrology

- **The measurand: A physical object or a model?**
  - Although software products are most often viewed as intellectual artifacts, they are also representations (through models) of physical phenomena occurring inside a computer which can be comprehended (e.g. sensed) by the human eye.
  - The idea of making a distinction between software entities and engineering and scientific entities oversimplifies the nature of both software objects and engineering and scientific objects:
    - by no means all modern scientific entities are physical and tangible, and capable of being comprehended through direct perception.
    - Many more scientific entities than one might expect are related to the models scientists build to explain the physical world (e.g. modern physics models and laws related to light, atoms, electricity, etc.)
      - and these scientific entities are usually comprehended through instruments since they cannot be seen or sensed by a human!

Linking Software Measurement and Metrology

- Therefore, a central notion at the core of any measurement activity is the following:
  - The model represents the entity for which a given attribute is to be measured.
    - The choice of model for highlighting the target attribute is a determinant for the whole measurement life cycle, and this seems to be true for any engineering discipline, including software engineering.
    - Generally speaking, it appears that an attribute to be measured is comprehended through models that, at times, can vary from very simple to quite complex.

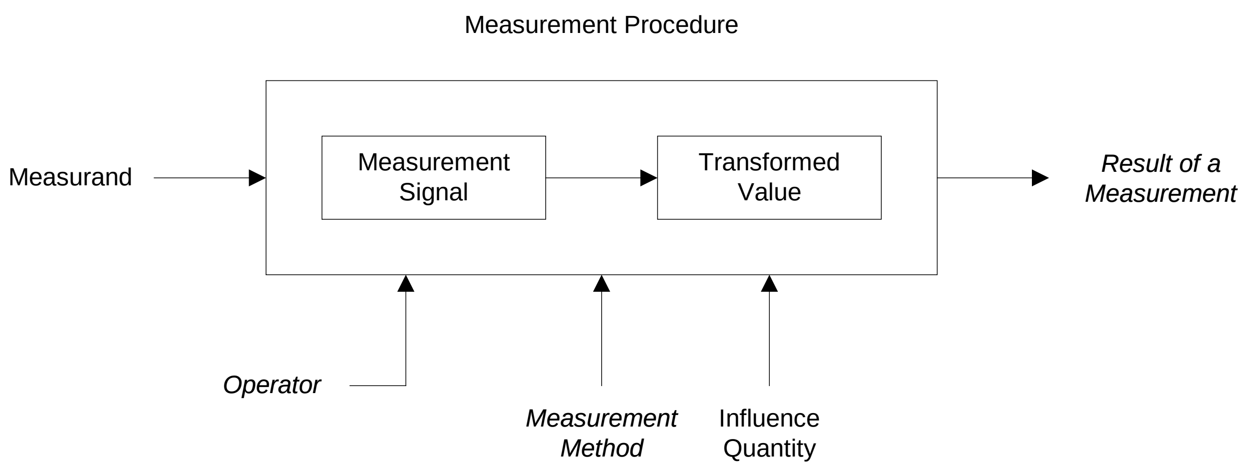
Examples of Models for Measurement Purposes

- The undulatory model of light is the determinant for the measurement of the speed of light, and the corpuscular model of light is the determinant for the measurement of the photoelectric characteristics of light.
- The modeling of a program as a flow graph is the determinant for the measurement of software complexity, according to [McCabe 1976].

- It is worth investigating such models: it is particularly important in the software domain because of the lack of consensual views about the models of software artifacts.

Linking Software Measurement and Metrology

- ***What is measured: the measurand or a model of it?***
  - In the physical sciences, is it the measurand that is measured directly, or one of its models?
    - In practice: it is often not the measurand itself that is measured, but one of its model.
    - In the VIM 2007, this is referred to as an 'input quantity in a measurement model – see Figure below:



Linking Software Measurement and Metrology

What is measured by a thermometer?

A thermometer does not measure temperature directly, but rather the *impact* of the temperature on something else captured by a measurement signal:

- The signal can be the expansion of lead, caused by a change in the ambient temperature (eg. The input quantity in a measurement model), and this input quantity is next compared visually against a graduated scale on the thermometer (the output quantity in this measurement model).

- The signal can be derived from the distinct expansion rates of two metals on the same rod (e.g. a thermometer in an oven): that is, a distinct measurement model in input.

- When, then, is the software the measurand?
  - Can it be measured directly?
  - Can it be measured indirectly through a measurement signal and a transformed value?
- If the answer to either question is yes, how can this be integrated into the design of a measurement method?

Linking Software Measurement and Metrology

How to measure software

- The measurement context model, which was presented in chapter 2, is reproduced in Figure below.

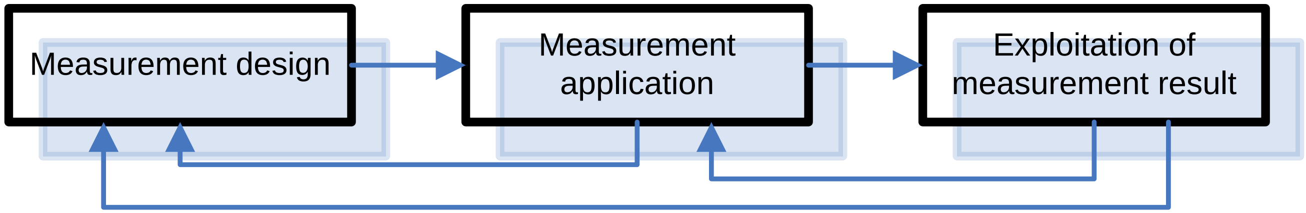


Figure: Measurement Context Model

Linking Software Measurement and Metrology

- To recap: the design step consists of a set of design activities & sub-steps, from the definition of what we are measuring to an operational description of the procedure(s) to be used.
  - Of course, if a measurement method already exists, this design step is skipped or considerably abbreviated. This is what happens in mature disciplines.
  - But, if a measurement method does not exist at all, as is frequently the case in the software domain, then this step must be performed prior to specifying a measurement procedure for a particular measurement context.

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  - **<u>The measurement foundation in metrology</u>**

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Linking Software Measurement and Metrology

- In practice:
  - viewing measurement as a mapping between 2 structures (real world & numerical world) does not give sufficient information about how to measure and how to have a sufficient degree of confidence in the measurement results.
    - To obtain that information, it is necessary to move beyond the theoretical definition of the mapping to an operational procedure.
  - The VIM describes this as the transition through 3 levels – see figure in next slide:
    1. measurement principle
    2. measurement method
    3. measurement through a measurement procedure

Linking Software Measurement and Metrology

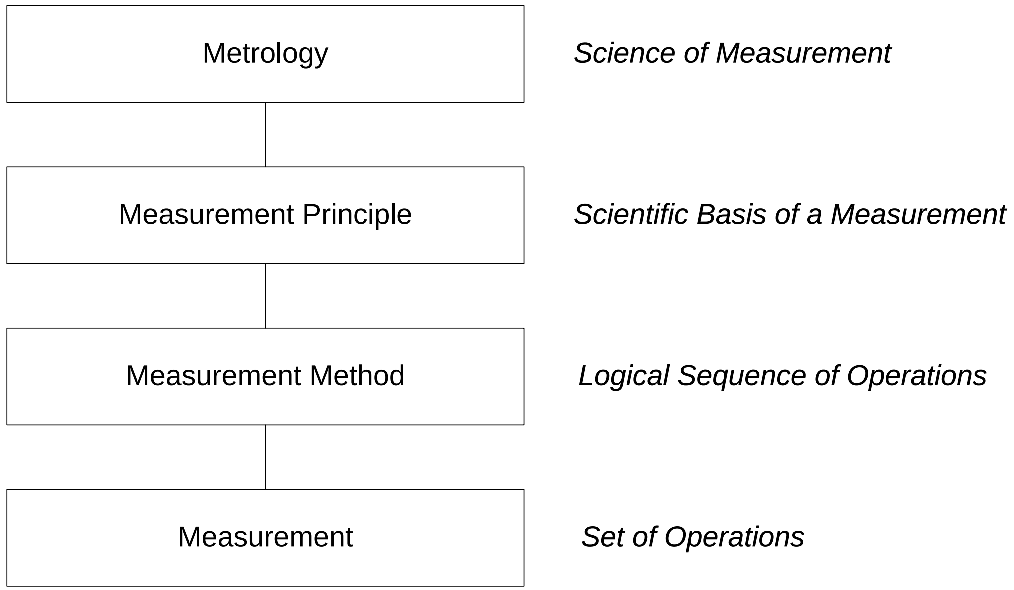

Figure: The levels in the measurement foundation in the VIM

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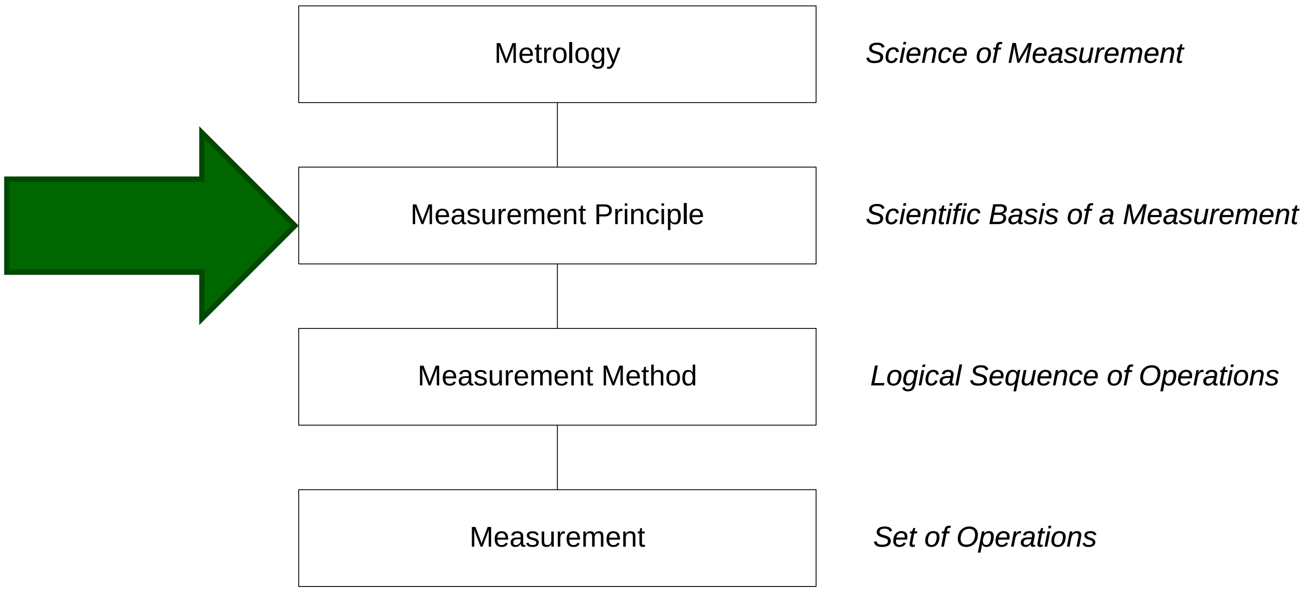

Figure: The levels in the measurement foundation in the VIM

1- Defining the Measurement Principle

- ***Context***
  - In the ISO metrology vocabulary, the measurement principle is defined as the phenomenon serving as the basis of a measurement.
    - In mature disciplines, the output of this phase is the information obtained experimentally and referenced to well-established theories and laws, on top of which measurement methods have to be designed.

Example in Electricity

Electrical theories define concepts (e.g. voltage, current, resistance and power inductance, capacitance, impedance) and propose their relationships through laws (e.g. Ohm's law).

Measurement methods in electrical engineering are based on similar theories and laws.

1- Defining the Measurement Principle

The question: How to determine what a measurement principle would look like in the software engineering domain?

- Classical works in software measurement generally follow the *representational measurement theory* [Fenton 1994, 1997; Zuse 1998], where measurement is viewed as a mapping between:
  - an empirical world (i.e. what we are going to measure) and
  - a numerical world (i.e. the world of numbers from which we expect the measurement results).

- This representational view is not sufficient, by itself, as a theory:
  - It does not impose any particular way of characterizing these 3 parts: the empirical world, the numerical world, and the mapping.
    - such a characterization is a fundamental part of the measurement principle and must be well specified.

1- Defining the Measurement Principle

- ***Describing the empirical world: characterization and modeling***
  - The attribute to be measured should be defined in a clear and precise way so that it is characterized sufficiently clearly and unambiguously. This characterization is referred to as the **attribute model**.
    - The definition activity determines what is really about to be measured.
    - In other sciences & in engineering:
      - the attributes to be measured have long been defined, and methods to measure them have long been established on the basis of precise and widely accepted definitions.
    - A definition of an attribute delimits the description of that attribute by specifying:
      - what it means and
      - what it does not mean.

1- Defining the Measurement Principle

In software measurement: Often immature definitions of attributes
In the software domain, it is not unusual to encounter measurement approaches (e.g. software metrics), where the attribute and/or the entity to be measured are unclear, or even not specified at all. See chapters 7 to 9 for examples.
There is usually a lack of agreement on the definitions of the attribute, and, consequently, on the related measurement methods and procedures.
The measurement of software complexity is a typical example of this.

- Another very important aspect of measurement is the development of consensus:
  - such a consensus widens progressively, ultimately to universal adoption of its object as an international standard.

Measurement = Consensus
Measurement is also about deriving a broad, documented consensus on: – what will be included in the measurement, and – what will be excluded.
Measurement is not only an aggregation of practitioners' knowledge, but also a consensual agreement on a set of definitions and on a measurement scale.

1- Defining the Measurement Principle

- According to Fenton [1994], models come in many different forms:
  - equations,
  - mappings, and
  - diagrams.
- These models lead to an understanding not only of how the measurement results are obtained, but also how to interpret them.

- To summarize, description of the empirical world involves:
  1. determining the entity under consideration,
  2. determining the attribute to be measured, and
  3. building an adequate model to characterize that attribute.

1- Defining the Measurement Principle

- Many technical and theoretical difficulties related to that modeling activity arise:
  - the choice of an adequate modeling language and/or technique,
  - the model's precision and completeness,
  - the model's adequacy with respect to the measurement goal,
  - the extraction of practitioners' knowledge about the entity and the attribute,
  - the selection of representative practitioners, and perhaps dealing with their conflicting viewpoints,
  - etc.

1- Defining the Measurement Principle

- ***Modeling techniques for describing the empirical world***
  - Many modeling techniques can be used to characterize aspects of the empirical world, such as:
    - A. Mathematical: these approaches use equations, or, more generally, logical axioms to characterize the attribute concerned [Whitmire 1997; Zuse 1997]
    - B. Conceptual modeling: these approaches are based mainly on graphics-based modeling languages.

  - The mathematical approaches derive from the formal view of software.
  - The conceptual approaches derive from conceptual modeling techniques (e.g. UML), which are very frequently used in software engineering.

1- Defining the Measurement Principle

A- Mathematical techniques.

- The empirical world can be modeled as a mathematical structure, including:
  - a set of entities, say A,
  - a collection of binary ordering relations, say R--1,…Rn, representing the order according to the different attributes of the entity considered, and
  - a collection of operations, say O--1,…Om, representing different possible compositions of entities from the universe of A.

Example of a mathematical structure
A could be the set of all object-oriented programs,
R_1 could be the relation "more complex than",
R_2 could be the relation "more maintainable than", and
O_1 could be the operation for adding classes of the program $a_1 \in A$ to the classes of program $a_2 \in A$, etc.

1- Defining the Measurement Principle

- Mathematical axioms describe some properties of entities:
  - in particular, they express properties of the order induced by the attribute being measured, like transitivity or symmetry.
  - Mathematical axioms also express the properties of some composition operation(s), like, for example, the additivity of operations on the entities.

- The advantage of mathematical axioms lies in their potential use as a basis for a formal reasoning about the attribute being measured, and hence about the measurement method based on that model.

Axioms in measurement
Axioms allow formal reasoning about some verification criteria according to the representational view of measurement [Whitmire 1997].

1- Defining the Measurement Principle

- More precisely, the representational view requires correspondence between:
  - the empirical world structure, as defined here, and
  - the numerical world structure.
- This correspondence could be expressed mathematically as the *homomorphism* of the mapping.

Correspondence - Homomorphism
This allows formal expression of:
– the criteria to be verified by the chosen scale types, as well as
– the operations allowed on the measurement result.

1- Defining the Measurement Principle

- However, such a mathematical description is not sufficient for the whole of the measurement life cycle.
  - In particular, it does not provide, by itself, a practical way to determine the entities to be measured, to identify them, etc.

Mathematical axioms

Mathematical axioms describe the properties of entities (in particular, the ordering properties like transitivity or symmetry induced by the attribute),

but…

they do not define them by extension – entity population models are usually infinite sets.

1- Defining the Measurement Principle

B- Conceptual modeling techniques

- Conceptual modeling techniques are used frequently in software engineering, to model:
  - (initially) data and data-centric systems (e.g. the basic entity-relationship diagrams [Chen 1976]),
  - (lagter) objects and object-based systems (e.g. UML diagrams), and,
  - (more recently) generically, to model the so-called ontology (i.e. any structural knowledge about a domain [Gruber 1993]).

- Roughly speaking, the idea is to identify a few basic concepts and a few possible relationships between them, and to build a representation of the system/domain/knowledge/etc. on the basis of those concepts and relationships.

1- Defining the Measurement Principle

- Graphical representations are used extensively:
  - as a practical way to model the knowledge we have about an entity type for which 1 (or more) attribute is to be measured; and
  - as a structural representation of the knowledge, in particular with a graphical view, which makes it easy understand the concept under consideration.
- Consequently, graphical representations can facilitate the reaching of that consensus, clearly identifying the building tools, as well as the concept under consideration.
  - Though some popular modeling techniques are limited to ad hoc graphical notation, conceptual modeling techniques could also have precise semantics associated with them, bringing them to the same level of precision as mathematical descriptions
    - – see [Harel 2000] for a discussion on the semantics of graphical notations.

1- Defining the Measurement Principle

Example of conceptual modeling in software measurement

The key concepts for a functional size measurement method have been defined by international consensus at the ISO level in ISO 14143 – see chapter 2 – Advanced Readings.

Measuring the functional size attribute in the COSMIC measurement method is based on the modeling of software functional user requirements, in that:

- it highlights concepts like functional processes (e.g. data movements – entry, exit, etc.), and
- it defines their relationships with one another.

In particular, the designers of the COSMIC measurement method analyzed a great deal of software to capture the knowledge about such a concept:

– by figuring out what was common across multiple contexts (and not what was specific to a particular context), and

– by defining what would be taken into account (data movements) and what would not be taken into account (data transformations).

The consensual definition and the characterization of functional size measurement constitute a fundamental part of the definition of the COSMIC measurement method. See also Chapters 11 and 12.

1- Defining the Measurement Principle

- Characterizing the empirical world can be achieved using different kinds of modeling approaches in a complementary way to take into account theoretical and practical needs.
- The characterization of the empirical world makes it possible to combine knowledge expressed by means of various techniques, typically:
  - representing the attributes to be measured by a conceptual model, obtained by consensus, which includes base definitions of the concept under consideration, as well as the characteristics that must, or must not, be taken into account;
  - the properties of the ordering relation induced by the attribute(s) to be measured and of the possible composition operations are described mathematically; and
  - using a representative ordered set as complementary knowledge for verification.

1- Defining the Measurement Principle

- ***Describing the numerical world: scale types and units***
  - Measurement is also viewed as a mapping of the empirical world to the numerical world:
    - It is important to define the numerical world to which the attribute description is to be mapped.

A reminder of what a mathematical structure is

A mathematical structure is:

– a set, along with

– a collection of defined relations on it.

Example

The target set could be:

– the Naturals, **N**, or the Reals, **R**, or a subset of one of these, along with

– operations on it (e.g. +, <, ≤, etc.).

1- Defining the Measurement Principle

- Describing the numerical world is related to the concept of scale type used in the classical measurement literature [Fenton 1997].
  - It is to be noted that the scale type indicates the type of admissible operations to be accomplished:
    - A scale type corresponds to 1 category of mathematical structures, the individuals in which can be mapped to one another by a homomorphic transformation
      - e.g. transforming a length scale in centimeters into a length scale in inches.

Convertibility as an homomorphic transformation

The intuitive idea behind convertibility is to consider a family of measurement targets (a family of numerical structures) which are structurally identical and which are related to one another by a so-called scaling transformation or a conversion between units.

1- Defining the Measurement Principle

- Scale types are closely dependent on measurement units.
- In software engineering, the scale types currently used are:
  - "nominal",
  - "ordinal",
  - "interval",
  - "ratio", and
  - "absolute".
- Some arithmetic operations are clearly inappropriate in some scales:
  - For example: it is inappropriate to add 2 values on an interval scale because the result is not significant.

1- Defining the Measurement Principle

Scale Type	Mathematical Structure (See also tables 3 and 4 in section 3.5 of Chapter 5)
Nominal	The mathematical structure of a nominal scale includes a finite set of values with no operations at all, since there is no magnitude associated with those values. The nominal scale corresponds to a very simple kind of measurement, and some authors consider that it is not a measurement at all. As it corresponds to a set on which we do not have even a weak order, there is no possible ordering at all for the elements of such a set; they can only be compared using the symbols = and ≠.
Ordinal	The mathematical structure of an ordinal scale includes a set of values with a weak ordering relation.
Interval	The mathematical structure of an interval scale is characterized by a weak ordering relation, and also includes an operation reflecting a notion of distance between elements (e.g. the operation of addition has meaning with this scale).
Ratio	The mathematical structure of a ratio scale is like that of an interval scale, but also includes a zero element (e.g. with this scale, measurement averages can be calculated).
Absolute	An absolute scale is like a ratio scale, except that an absolute scale is unique, in the sense that it does not admit any transformation into another structurally equivalent scale [Whitmire 1997].

1- Defining the Measurement Principle

- Defining the numerical world is:
  - not only about the kind of numerical structures we seek as a target (e.g. a particular scale type),
  - but also about the choice of the actual quantity values to be used, <u>which also include the underlying units</u>.

> **The unit in measurement**
>
> According to the VIM, the value of a quantity – the value of the attribute in our terminology – is not only a number, but also a number and a reference, where a reference could be a unit, the unit 1 (which is generally not written) or a measurement procedure and an ordinal number.

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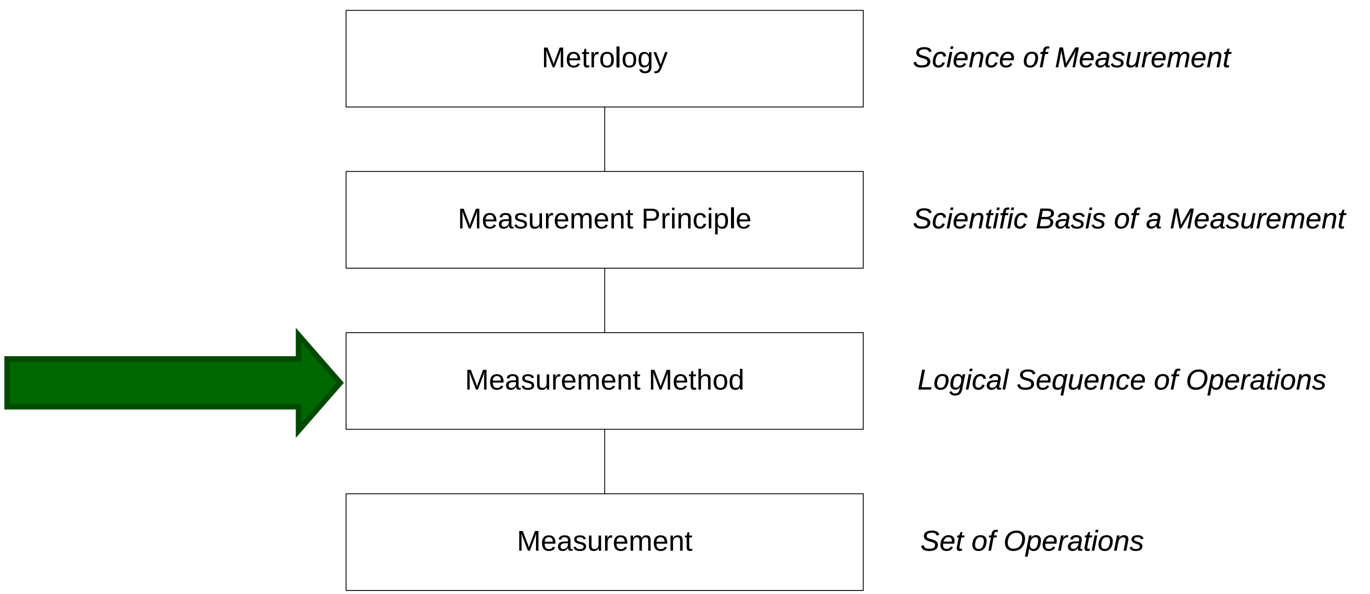

Figure: The levels in the measurement foundation in the VIM

2- Determining the Measurement Method

- ***An operational view: the numerical assignment rules***
  - According to the ISO metrology vocabulary of the VIM, a measurement method is defined as a generic description of a logical sequence of operations used in a measurement.
  - Therefore: it should give a first operational definition of the mapping described above, that is, an operational description:
    - of how to map a given empirical entity to its corresponding value;
      - corresponding to the *numerical assignment rules* in the measurement context model presented in chapter 2.

2- Determining the Measurement Method

- More precisely, these rules define how to find, in practice, the values associated with a particular attribute of an empirical entity (remember that a value is a number with a reference).
  - At this level, the description of the method should be given as a set of operations.

- The declarative properties of the level above (e.g. the measurement principle) characterize the mapping from empirical entities to numerical entities; but, in concrete terms, an operational process, such as counting, calculating, etc., should be performed to find the value corresponding to an entity attribute.
  - In other words, this part corresponds to the design of the operationalizable method according to which the measurement should be achieved.

2- Determining the Measurement Method

- If the measurement method involves some operations, then it describes the rules that should precisely determine:
  - how to distinguish the entities to be measured,
  - what should be disregarded,
  - how to perform the measurement, etc.
- If the measurement is to be performed through calculation from other values, such as other attribute measurement values, then the description of the method involves the rules that determine such a calculation.
- If the measurement process is to be carried out with a measuring device, a measurement method influences the kind of measuring instruments that can be considered, but does not necessarily call for a single kind of instrument.
  - In other words, at this level, general requirements as to the kind of measuring device that can be used are involved.

2- Determining the Measurement Method

Measurement method for temperature

If the attribute to be measured is the temperature of the air, for example, a method can be proposed to measure it through the phenomenon of liquid expansion. This method would be based on the laws of that phenomenon that determine the relationship between the two attributes: the air and the liquid.

Of course, those laws must be provided (that is, in the form of the scale of the relationship between the two attributes).

A family of tools, that is, thermometers, can be designed on the basis of this method.

Measurement of software

If the measured attribute is the complexity of an algorithm, and the measurement method proposed is to add the number of edges and nodes on the graph representing the algorithm, then the relationship between those two entities (the graph and the algorithm) and their corresponding properties should be described explicitly and analyzed (as would be done in the example of the thermometer, above).

This relationship is neither explicitly described nor analyzed in many software metrics, such as in the Cyclomatic complexity number – see also chapter 7 in this book.

Such an incomplete description of a measurement method is very frequently seen in the measurement of software, where different measurands (and models of measurands) are used interchangeably (e.g. a requirement document and its corresponding design schema, a piece of code, the flow graph representing the algorithm, etc.), avoiding any explicit analysis of the relationship between those measurands (and models of measurands), thereby avoiding tackling the potential problems underlying such relationships.

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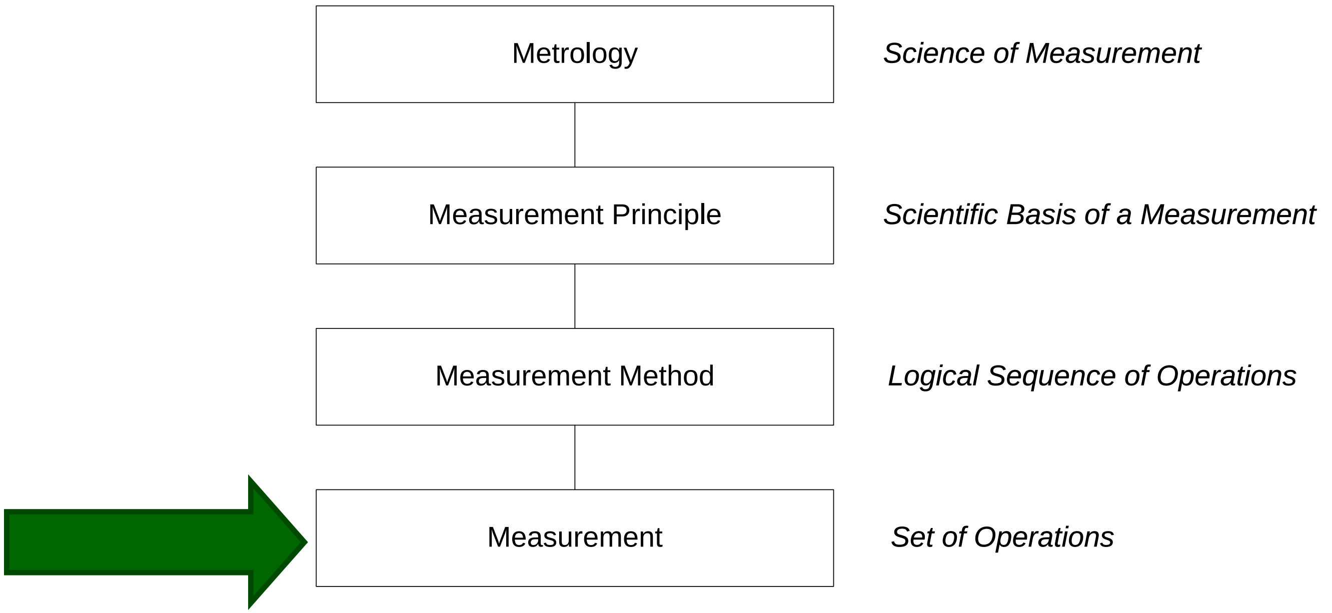

Figure: The levels in the measurement foundation in the VIM

3- Post Design Activity: Determining a Measurement Procedure

- An important aspect in measurement is to precisely describe the context in which the measurement procedure will take place. At a minimum, the parameters that should be taken into account are:
  - the purpose of the measurement process, and
  - the constraints under which the measurement will be performed.

  - Some constraints are related to a particular application of the measurement method:
    - e.g. existing measuring devices, the possibility of experimentation, available representative sets, etc.
  - Other constraints are related to the maturity of our knowledge of the attribute to be measured:
    - e.g. the quality of the models taken as the measurement principle.
    - As the maturity of software engineering measurement is far from that of the maturity of other disciplines, it can be expected that making such constraints explicit will allow practitioners to accept measurement method designs which can evolve with our knowledge of the domain

Summary

This chapter has covered:

- Linking software measurement & software metrology:
  - What is measured in software: the ‘measurand’ or a model of it?
  - The measurement foundation in metrology
- The activities for the design (& evaluation) of software measurement methods, including:
  - Defining the measurement principle:
    - through models of software
    - the numerical view
    - the mathematical view
  - Determining the measurement method
    - the practical operational view
  - Post design activities: the measurement procedures

- Additional material

Linking Software Measurement and Metrology

1. The definition of the **measurement principle**
   - The measurement principle should embody our knowledge or our understanding of the concept to be measured, that is: the entity & the attribute under consideration.
     - In other words, this activity gives the precise description of *what* we are going to measure.

For software entities (products), the measurement principle involves the model(s) used as a basis on which to describe the entity for which a given attribute is intended to be measured.

- modeling, as a central notion in software products, is at the same level as scientific principles in other sciences and in engineering.
  - the modeling activity (e.g. the activity that consists of describing the entity under consideration to highlight the attribute to be measured) corresponds to the activity of defining the measurement principle.

Linking Software Measurement and Metrology

2. The **measurement method** is defined on the basis of that principle.
   - It is a generic operational description, i.e. a description of a logical sequence of operations, of the way to perform a measurement activity (that is, to move from the attribute of an entity to be measured to the number representing the measurement result).
     - This activity gives a general description of *how* we are going to measure.
3. A measurement method should, in turn, be implemented concretely by a **measurement procedure to** describe a measurement according to one or more measurement principles and to a given measurement method.
   - It consists of concrete operations performed by means of measuring instruments and/or practical actions such as selection, calculation, comparison, etc.
   - It is more specific, more detailed, and more closely related to the environment and to the measuring instruments (e.g. tools) than the method, which is more generic.

1- Defining the Measurement Principle

- In the software domain, the need to understand and characterize the attribute to be measured leads to the necessity of precisely determining the entity under consideration.
  - One of the main distinctive features of software products is that they are initially perceived as abstract products, which:
    - are sometimes difficult to delimit clearly; and
    - can be changed from one form to another.

Examples in software: attributes and entities
In the software measurement literature, there is frequently talk of a single attribute which can qualify different software products (entities):
– The software attribute 'size' can be related to a program and to its requirements document.
– The software attribute's complexity can be related to a piece of code, to the algorithm that it implements, and to the graph representing it, etc.
Therefore, it is important to explicitly refer to the entity concerned.

1- Defining the Measurement Principle

- ***Representative elements***
  - Further complementary knowledge about the attribute to be measured can be given through a representative set of entities, such knowledge being useful mainly for verification purposes.

A representative set of entities
The idea is to ask experienced staff:
– to determine a set of entities that is representative of the attribute to be measured, and
– to rank those entities according to the value they would assign to that attribute.
Of course, the ranking should be consistent with the other knowledge available.
This knowledge corresponds to a very rough approximation based on subjective observations.
Therefore, it should be viewed only as a way to remedy the impossibility of giving an explicit ranking for an infinite set of entities.

1- Defining the Measurement Principle

- The implicit hypothesis is that the order on the infinite set of entities could be approximated by an ordering on the equivalence classes represented by the representative set:
  - Of course, this complementary knowledge is not sufficient by itself, but it can be helpful in quickly detecting problems arising during the design phase.

Testing measurement designs with a representative set
This is done if the measurement results obtained through the candidate measurement method are inconsistent with the ranking given by experienced staff.
Any problem with the candidate measurement method, or with the measurement principle itself, for example, must be identified and analyzed.

1- Defining the Measurement Principle

- Note: conceptual modeling is aimed at describing the attribute to be measured, and the model built represents a particular abstraction of the entity under consideration.

Abstraction and Measurement

The aim of the abstraction is to:

- highlight the attribute(s) to be measured,
- while ignoring others.

If the attribute to be measured is a person's height, a line will be an adequate abstraction (another geometrical abstraction would also be suitable, but only one dimension is needed).

- So, even though we have to take into account the entity, we should keep in mind the goal of the modeling, i.e. to make the abstraction that is to represent the attribute to be measured.
- In the design of a measurement method, it is important to keep in mind what is going to be measured (i.e. which attribute of which entity).

2- Determining the Measurement Method

- According to the representational view, measurement is, by definition, considered to be a mapping between the empirical world and the numerical world. A precise definition of those 2 worlds has been referred to as the measurement principle.
- A measurement method corresponds to a mapping between those 2 worlds.
  - So, after precisely determining both the numerical and the empirical world with their properties, what information about the mapping should be considered in terms of the measurement method?

2- Determining the Measurement Method

- ***A mathematical view of the mapping***
  - Mathematically, a minimum of information about the mapping is the property ensuring that the mapping preserves the structure of the empirical world in the numerical world. This corresponds to the requirement that the mapping be a homomorphism.
  - At the other extreme, a maximum of (very hypothetical) information about the mapping would involve having a complete, extensive definition of the mapping (i.e. as a list of couples, each empirical element along with one number representing its measurement result). Of course, this is not practicable, as the set of empirical elements, i.e. the entity population, is usually infinite.
  - On a more practical level, some other properties about the mapping can be given as a complement to the minimal requirement that the mapping be a homomorphism.

2- Determining the Measurement Method

Determining a Reference – Etalon
When a representative set of entities is defined, it could be given with the numbers representing the measurement values of the attribute for those entities.
To be significant, these numbers should be related to a reference standard.
(This corresponds to the general concept of the etalon in the ISO VIM 2007

- The simplest way to give such reference information is to assert that one particular entity, (i.e. the etalon in the restricted sense, as defined in the VIM) should have (by definition) the number 1 as the value of its measurement result.

Etalon: Consistency & Traceability
It is worth noting that the concept of the etalon has a more general purpose, which is to ensure the consistency and traceability of measurement.

2- Determining the Measurement Method

- The challenge is to produce measurement results which are consistent with both the scale and the etalon.
- For the sake of clarity, measurement scales are defined, by convention, with regard to the circumstances in which the measurement is carried out.
- Determining a measurement scale type is important, in order to highlight arithmetic operations applicable on the values of that scale, if a scale is associated with multiple and sub-multiple units (to give more precision to the measurement operation).

2- Products of the Measurement Design Phase

- The products associated with the design phase are summarized next.
  1. ***The measurement principle*** is a precise definition of:
     - the entities concerned, and
     - the attribute to be measured.
  - According to the representational approach of measurement, the measurement principle involves a description of the empirical world and the numerical world to which the entities are to be mapped.

2- Products of the Measurement Design Phase

a. ***The empirical world*** can be described through conceptual modeling techniques or through mathematical axioms, or both.

b. ***The numerical world*** can, in the general case, be any mathematical set, along with the operations performed on it.

- It can also be defined through the selection of one scale type (ordinal, interval, or ratio).
  - This also includes the definition of units [VIM 2007], and
  - other permitted composition operations on the mathematical structure.

2. ***The measurement method*** is a description of the mapping that makes it possible to obtain a value for a given entity. It involves some general properties of the mapping (declarative view), along with a collection of assignment rules (operational description).

a. ***Declarative mapping properties*** can include a description of other mapping properties, in addition to the homomorphism of the mapping. For instance:

- a unit axiom (the mandatory association of the number 1 with an entity of the empirical set);
- or, more generally, an adequate selection of a small finite representative set of elements ranked by domain practitioners.

2- Products of the Measurement Design Phase

b. ***The numerical assignment rules*** correspond to an operational description of the mapping, i.e. how to map empirical objects to numerical values, and include:
   - identification rules,
   - aggregation rules,
   - procedural modeling of a measurement instrument family,
   - usage rules, etc.

- The products of the design of a measurement method are then used to specify a ***measurement procedure***, which corresponds to:
  - a complete technical description of the *modus operandi* of the measurement method in a particular context (goal, precision, constraints, etc.) and with a particular measuring instrument.

3- Post Design Activity: Determining a Measurement Procedure

- According to the ISO metrology vocabulary of the VIM, a measurement procedure is defined as a detailed description of a measurement according to one or more measurement principles and to a given measurement method:
  - This level of description corresponds to a yet more operational and more practical definition of how to map an empirical entity to its corresponding number.
  - For practical purposes, a measurement procedure corresponds to a measurement report which gives a precise implementation of a given method for a specific context or set of contexts.
  - Moreover, if the measurement process goes through a measuring device, this level involves a precise description of that instrument, its calibration, and the documentation of its metrological properties, such as accuracy (VIM).