Software Metrics & Software Metrology

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Chapter 2:
From Measurement Methods to Quantitative Models: A Measurement Context Model

Agenda

This chapter covers:

- An overview of the differences across numbers, measures, and quantitative models
- A measurement context model
- A process model for the design of a software measurement method
- A discussion on the application of a measurement method and on the exploitation of measurement results in quantitative models

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Introduction: Numbers, Measures, and Quantitative Models

- Introduction: Numbers, Measures, and Quantitative Models
  - It is important to clarify, right from the start, the differences between:
    - a number in its mathematical sense;
    - a number obtained from a measurement exercise, and
    - a number obtained from a quantitative decision making model.

A number in its mathematical sense

- As youngsters, we learn our numbers from 1 on. As we progress through school, we learn the mathematical rules governing how to combine the numbers through valid mathematical operations: comparison, addition, division, real numbers, equations, etc.
- In this way, we learn to deal with numbers in a mathematical sense and, in so doing, to deal mostly with abstract concepts: there is no need to measure or assess anything in particular, or to take a decision.

Introduction: Numbers, Measures, and Quantitative Models

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Mathematics ≠ Decision making

Mathematics: When we deal with numbers only in a mathematical sense, we implicitly make the following assumption:

– We consider that there is no uncertainty tied to these numbers.

Decision making: When we have to make a decision, we must explicitly verify the uncertainties in the numbers used in the decision making process:

– We cannot take for granted the quality-related characteristics attached to measures, such as: accuracy, repeatability, reproducibility.

Introduction: Numbers, Measures, and Quantitative Models

A number obtained from a measurement exercise

- A number derived from a measurement exercise on a specific entity is more than a number, as it includes:
  - the measurement unit attached to that number; and
  - the specific measurement procedure followed to obtain it.
- This measurement result is the number assigned to the specific attribute of a specific entity:
  - It is represented by a number and its measurement unit, and there is also a degree of uncertainty as to its value, in terms of the various types of potential errors inherited from the measurement procedure:
    - such as random and/or systematic errors in the measurement process.
  - Similarly, the number obtained from a measurement exercise is limited to the characteristic being measured.

Introduction: Numbers, Measures, and Quantitative Models

Measurement of temperature

A temperature measurement tells us specifically about the temperature, in a quantitative manner and relative to a measurement scale (such as the Celsius scale).

However, such a measurement result does not tell us whether or not it is windy, whether or not it is raining, or whether or not we can play golf!

Introduction: Numbers, Measures, and Quantitative Models

A number obtained from a quantitative decision model

- Quantitative decision making models (& evaluation models) are a combination of (quantitative) numbers and rules on how to interpret numbers of different types concurrently

Decision Models

An informal model for deciding when to play golf will take into account not only the temperature (in degrees Celsius or Fahrenheit), but also other data, whether numerical or qualitative:

- What is the strength of the wind (does it exceed a threshold)?
- Is it raining?
- Is it a workday or not?
- Am I in shape today?
- Is there something important I should be doing today?

Software Decision Model

A model for deciding when to stop testing a piece of software will, for instance, take into account:

- the number of bugs,

as well as a number of additional parameters, such as:

- the size of the software,
- the number of tests,
- the testing period,
- the decreasing of number of bugs per period of time or per number of tests, and so on.

Introduction: Numbers, Measures, and Quantitative Models

- This chapter presents a measurement context model to highlight the differences between *measurement methods* and *quantitative models*.
- Management is mostly interested in quantitative models:
  - Such models cannot be expected to produce a reliable basis for decision making if their inputs are of poor quality, that is, if the models use as inputs numbers derived from:
    - unsound measurement methods, or
    - sound but improperly applied measurement methods, which leads to unreliable measurement results.
- Measurement methods & quantitative models are distinguished in this chapter by means of a measurement context model which clarifies the distinct steps from the design of a software measurement method to the exploitation of the measurement results in subsequent quantitative models, such as quality and estimation models.
- Here, the focus is on the steps for designing a measurement method.

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Measurement Context Model

- **Measurement terms in** day-to-day language and in literature in general, the term "measure" is used in different ways to mean different things:
  1. a method allowing the assignment of a numerical (or symbolic) value to an object in order to characterize one attribute of this object;
  2. the application of this method (e.g. the action of measuring);
  3. the result of the application of a measurement method;
  4. the use of the measurement result in describing <u>relationships across many different entities and attributes</u>
     - Ex: between size and effort in estimation models
     - Ex: between defects and maintainability in quality models
  5. the whole process from the design of a measurement method to its exploitation in quantitative models, whether the inputs to these models have been derived from:
     - a subjective judgment, or
     - rigorous application of a standardized measurement method.

Measurement Context Model

Measurement terms in technical texts

- In engineering in general, as well as in mature disciplines in which quantitative data are used (such as physics & chemistry), the terms “measure” and “measurement” should never be used alone, but be accompanied by the qualifiers that specify which specific measurement concepts are involved.

- In technical texts, the term “measurement” must only be used in expressions, such as:
  - “measurement method”,
  - “application of a measurement method”, and
  - “measurement results”.

Measurement Context Model

- ***Measurement Context Model***
  - Actually, the 3 uses of the term “measurement” listed above correspond to the 3 steps in the measurement context illustrated in next slide:

    Step 1: Before measuring, it is necessary to either select a measurement method if one already exists, or design one (if an existing method does not fit the need).

    Step 2: Once the measurement method has been designed, its rules are applied to software or a piece of software to obtain a specific measurement result;

    Step 3: The measurement result is exploited in a quantitative or qualitative model, usually in combination with other measurement results of different types
  - e.g. the productivity ratio for benchmarking purposes: output over input, O/I.

Measurement Context Model

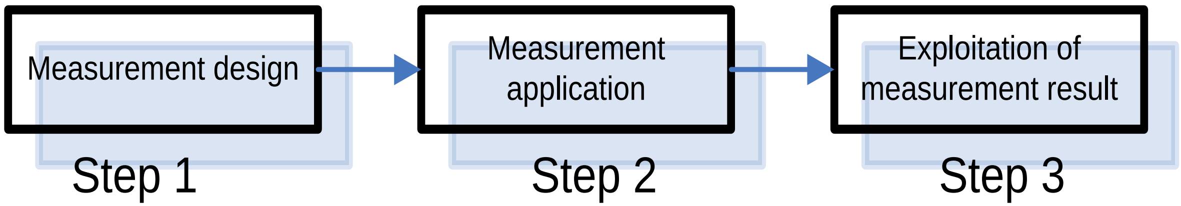


Figure : Measurement Context Model – The Design View

- The arrows in Figure 1 illustrate the sequencing of these steps during the process of designing a measurement method.
  - Of course, lessons learned in a subsequent step can be fed back to previous steps (in a feedback loop).

- Managers are mostly interested in Step 3:
  - managers use either informal or formal models for making a decision, and the models they use can be based on either qualitative or quantitative data, or both.
- This book deals
- mostly with the quantitative aspects of measurement, preferably with numbers with a ratio scale to which the usual mathematical operations (addition, multiplication, division) apply.
  - Qualitative models are out of scope in this book.

Measurement Context Model

A documented quantitative model for decision making

An estimation model based on an algorithm derived from a statistical regression on a set of completed projects.

An informal qualitative model for decision making

A contractor proposes to develop software for a client at an incredibly low price.

His decision model is not based on a published estimation model, but on some risk-taking, involving, for example:

– the opportunity to obtain more profitable contracts with this same client later on, or

– his ability (as he perceives it) to negotiate this price at a significantly higher level later, when the client will have no choice but to accept over-budget expenses.

Measurement Context Model

- Quantitative models can be very helpful in decision making, provided, of course, that their own designs are well structured and based on:
  - sound theory,
  - experimental or empirically verified foundations, and
  - input parameters that meet a number of quality characteristics.
- The manager's role is typically to use quantitative models in decision making (Step 3), rather than to carry the measurement application (Step 2) or design measures (Step 1).
  - However, it is vital to the manager that the measurement application has sufficient controls that he can trust the inputs to his quantitative decision making model, and that the design of the measures used be sound.

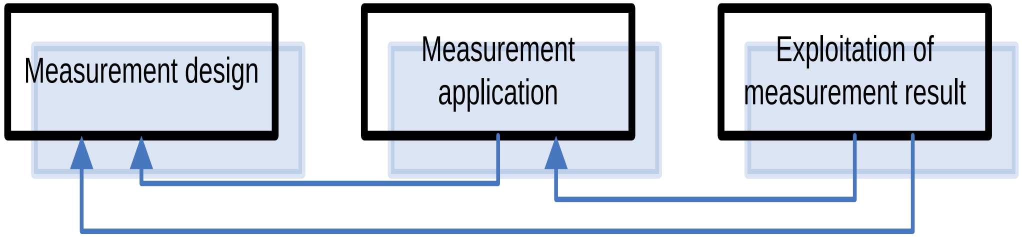


Figure : Measurement Context Model – The User/Manager View

Measurement Context Model

- In turn, it is the responsibility of the software engineer to ascertain that:
  - the quantitative models themselves are sound and that they provide a sound basis for decision making, with known constraints and limitations;
  - the inputs to these models are themselves sound (that is, the inputs can be trusted, and their levels of uncertainty and precision are known); and
  - the designs of these measures are themselves sound and meaningful.

- Examples of unsound designs and unsound applications of a measurement method are provided in side boxes.

Measurement Context Model

- Examples of unsound designs and unsound applications of a measurement method

Unsound Design of a Measurement Method

Example 1: When the measurement method includes a design that incorrectly mixes the scale types of its sub-components, numbers are produced, but such numbers are meaningless and their use in measurement models can only be meaningless (that is, they lead to meaningless models, which in turn provide managers with a false sense of well-being – that is, they increase risks, rather than reducing them).

(See Part 2 of this book – Chapters 6 to 9)

Example 2: When the design of the measurement method is limited to a single algorithm without clear definition of the parameters of that algorithm, it cannot be expected that different measurers measuring the same piece of code or documentation will produce similar numbers as measurement results.

Unsound Application of a Measurement Method

It is unreasonable to expect the numbers obtained in the following examples to be of high quality and precision:

Example 1: If the numbers are derived from an analysis of incomplete and ambiguous documentation.

Example 2: If the number of lines of code is derived from the wrong version of the software (from a lack of configuration control).

Measurement Context Model

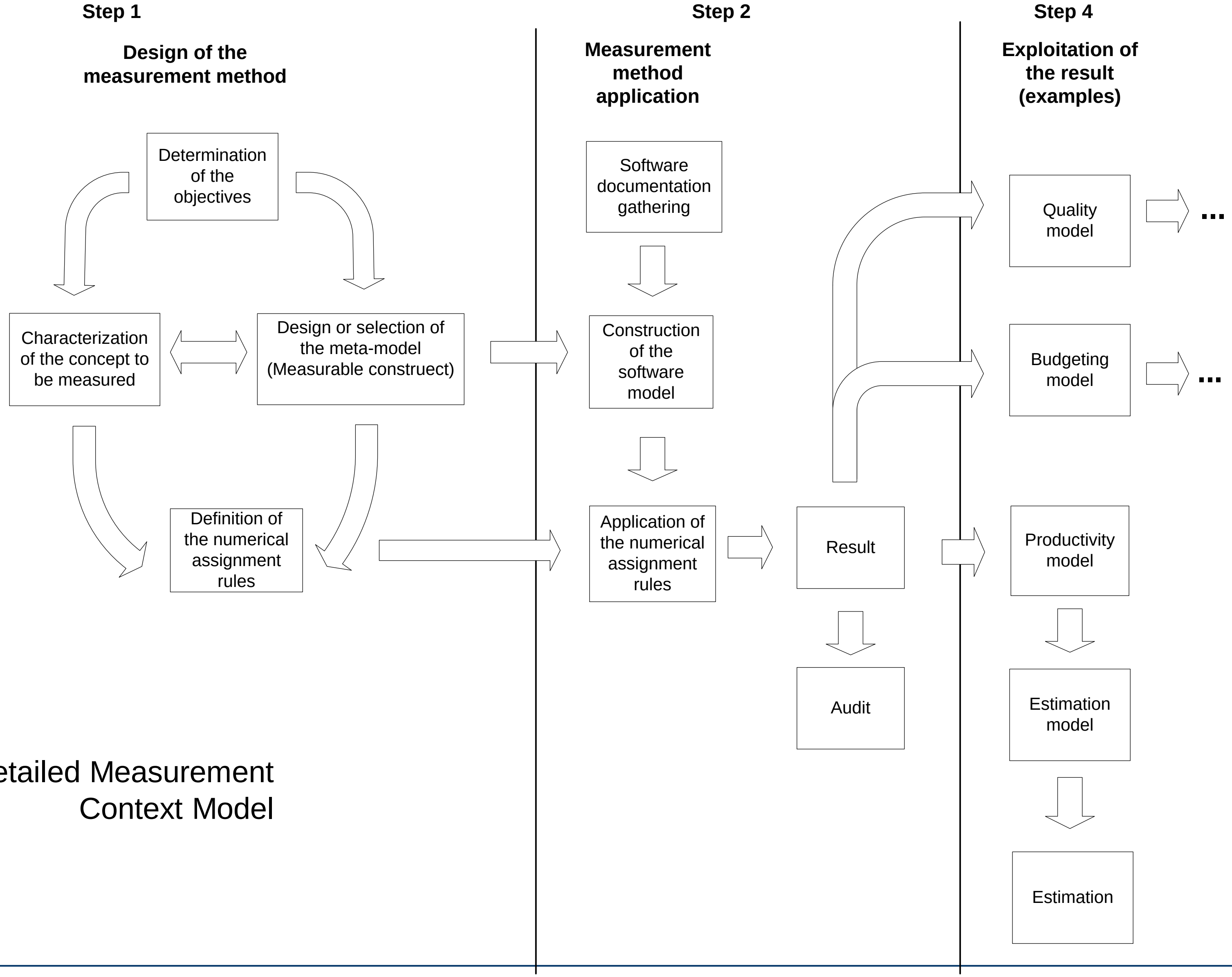
- In large software organizations, it is the responsibility of the software process improvement group to identify and address the specific weaknesses identified in software measures and in related quantitative models, and to develop improvement solutions.
  - While there exits a large body of knowledge on the development and use of quantitative models, including estimation models and quality models, and on how to recognize whether or not such models are good, very little has been published on how to design measures for software or on how to recognize whether or not a design is a good one, and if is not, how to improve it.

  - This book focuses on the foundation of this chain of measurement for decision making:
    - E.g. on the design of software measurement methods.

Measurement Context Model

- **Inputs and outputs in a measurement context model**
  - Next slide illustrates the various steps of the measurement context model, together with:
    - their inputs
    - intermediate steps and
    - corresponding outputs, as well as
    - the relationships between those steps.
  - This model helps in:
    - understanding the measurement chain
    - identifying the verification criteria necessary at each stage to ensure that the outcomes (for instance, the design of the measurement method in Step 1) are sound.

Measurement Context Model



Detailed Measurement Context Model

Measurement Context Model

1. *Design* of a measurement method.
    - The input to this step is a description of the measurement objective, and the set of concepts and techniques required for designing a measure constitute the resources.
    - The output is the identification of the measurable concepts and constructs, its measurement principle, and the description of its measurement method for the implementation of its numerical assignment rules.

- Of course, when a measurement method already exists, there is no need to design one.
    - However, software practitioners and managers should know enough about the design of a measurement method to have the ability to recognize if an available design is adequate for their purposes.

Measurement Context Model

2. *Application* of the measurement method in a specific context.

    - The inputs to this step are the entity to be measured and the generic measurement method.
        - Both are needed to set up a specific measurement procedure in a specific context to produce a measurement result.
    - The outcome is not only the measurement result, but also the insights into the quality of that measurement result:
        - such as an appreciation of the degree of uncertainty of the result and the factors that have influenced this uncertainty.

- This step also includes the gathering and documentation of measurement information:
    - could be used in future applications for verification and auditing purposes.

Measurement Context Model

3. *Exploitation* of the measurement result in an information context, often in relationship with other data, whether quantitative or qualitative, or both.
   - This includes analysis of the quantitative result of the model, usually for purposes of evaluation, statistics, comparison, or prediction.

- Different kinds of verification activities are carried out throughout the 3 steps:
  - each verification activity could detect anomalies which would, in turn, lead to backtracking to the previous activity, and so on.

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How to Design a Measurement Method

- The left-hand side of previous Figure shows 4 sub-steps required to design a measurement method:

  1. Determination of the measurement objectives.
  2. Characterization of the concept to be measured by specifying the entities to be measured and the characteristics to take into account.
  3. The setting up of the measurable construct, or of the meta-model, including the relationships across the concept to be measured.
  4. Definition of the numerical assignment rules.

- Sub-steps 2 and 3 are usually performed in parallel, each influencing the other.

How to Design a Measurement Method

Sub-step 1: Determination of the measurement objectives

- Before designing a software measurement method, it is important to know:
  - what we want to measure (what kind of software, which attribute, etc.),
  - what the measurement point of view will be (software user, software designer, etc.), and
  - who the intended users are of the measurement results.

- All these criteria have a strong influence on the design of the measurement method, and, of course, on the corresponding verification criteria.

How to Design a Measurement Method

Sub-step 2: Characterization of the concept to be measured

- To enable the measurable concept to be defined in a measurable construct, and, from that, to build the measurement method, <u>the concept to be measured must be clearly defined</u>.
- Once the attribute (or concept to be measured) has been chosen in the design of a measurement method, an (empirical) operational definition of this attribute must be given:
  - the concept must be characterized.
- This characterization can be made by first stating implicitly how the concept is decomposed into sub-concepts:
  - This decomposition describes what role each sub-concept plays in the constitution of the concept to be measured, and how these sub-concepts are themselves defined.
- In the concurrent sub-step 3, these interrelationships have to be organized into a measurable construct :
  - e.g. a meta-model of the measurable attribute

How to Design a Measurement Method

What do we measure: a concept or an object?

To measure distance, the concept of distance must be identified and a consensus developed and instantiated through a widely recognized definition: the concept of distance.

In our modern civilization, the concept of the distance between two points is now well defined. If we consider two distances, we are able to say whether these distances are equal or not, and, if they are not, which is bigger.

"Distance" is defined as the *direct path between two dimensionless points*.

A "point" is an abstract concept which is used as the foundation for the concept of distance.

Therefore, distance itself is indeed an abstract concept that is measured when we apply a measurement method to physical entities (or to models of these physical entities when they are represented, for instance, on geographical maps).

Software: an object or a concept?

Software is often referred to as an intangible product, that is, an *intellectual* product.

Notwithstanding this definition, software does exist in the physical world and is visible through multiple representations (e.g. a set of screens and reports for a user, a set of lines of code for a programmer, a set of software model representations for a software designer, etc.).

(Moreover, software is physically visible to the hardware through a series of *bits* in a computer, which have been created by a compiler or interpreter.)

For this physical software and its representations, measurable concepts are then defined, such as functional size, complexity, quality, etc.

How to Design a Measurement Method

- To characterize the concept to be measured, 2 types of concepts need to be determined:
  1. the type of entity to be measured:
     - E.g. the measurand on which to apply the measurement rules – Ex: code
  2. the attributes to be measured on this entity type:
     - E.g. the measurable concept itself
       - Ex: lines of code, as a representation of the size of the code

How to Design a Measurement Method

Sub-step 3: Design (or selection) of the meta-model (e.g. measurable construct)

- The set of characteristics selected to represent software or a piece of software, together with the set of their relationships, constitute the meta-model (e.g. measurable construct) of the software to which the proposed measurement method will be applied.
  - The meta-model should be described generically, that is, it should not be specific to a particular piece of a software and should be independent of the context of measurement while meeting the objective of the measurement.
  - The meta-model must also describe how to recognize the attributes to take into account to measure the entities involved in the measurement exercise.
  - The meta-model must also describe what role each sub-concept plays in the make-up of the concept measured, and how these sub-concepts are themselves defined.

How to Design a Measurement Method

Example 1: Cyclomatic Complexity Number

For the Cyclomatic complexity number of the software:

– the entity to be measured is the control flow graph of the software program, and

– the characteristics to take into account are described through a set of identification rules defined to recognize those characteristics as valid for its measurement purpose; that is, the edges and nodes in the control flow graph.

See also Chapter 6.

Example 2: Function Points

In the Function Point measurement method, an internal logical file (ILF) is an entity-type part of the implicit Function Point meta-model of the size of the software.

The Function Point Counting Practices Manual provides:
– a definition of this ILF entity type, as well as

– identification rules to ensure that each and every ILF can be clearly recognized within the software.

See also Chapter 8.

Example 3: COSMIC – ISO 19761

In the COSMIC functional size measurement method, an Entry is a piece of software of the entity type 'data movement', as recognized by the COSMIC method. This entity type is defined according to the explicit COSMIC meta-model of the software.

The COSMIC implementation Guide to ISO 19761 provides:

– the definition to the Entry entity type, as well as

– the identification rules that ensure that each and every Entry can be clearly recognized within the software and taken into account in the measurement procedure.

See also Chapters 11 and 12.

How to Design a Measurement Method

- **A note on sub-step 2 and sub-step 3:**
  - these 2 sub-steps, “definition of the concept to be measured” and “design of the meta-model”, are strongly related:
    - the definition of a concept cannot be achieved without a representation of the type of entity to be measured, i.e. without a meta-model;
    - the design of meta-models is itself partly dictated by the way the concept will be characterized.

- Because of the relationships between these 2 sub-steps, they are represented on the same level in Figure 3. Although different, they cannot effectively be performed separately.

How to Design a Measurement Method

Sub-step 4: Definition of the numerical assignment rules

- the numerical and mathematical one, consists in defining an empirical relational set[1].
- From a mathematical viewpoint, to characterize a concept is to define an empirical relational set.
  - This is achieved by defining numerical assignment rules.
  - This includes the selection (or design) of a measurement unit.

[1] See also chapter 5.

Measurement unit(s) for Distance

The concept of distance is not specific to a context of measurement.

However, in practice and over centuries, different units have been used to measure distance, whether on land, at sea, or in the air.

Notwithstanding the above, the selection of measurement units may vary, for practical reasons:

– the *mile* in the British system for the measurement of distance on land,

and

– the *nautical mile* for the measurement of distance at sea .

Of course, a single universal measurement unit for a measurable concept is much better, such as the *meter* for the measurement of distance.

How to Design a Measurement Method

- The basis for these numerical assignment rules is the proposed meta-model and the characterization of the concept.
- A numerical assignment rule can be described through:
  - a descriptive text (a practitioner's description), or
  - mathematical expressions (a formal theoretical viewpoint).

- The first type of description is used when the measurement method is applied in practice.
- The second is required to allow a mathematical analysis of the mathematical properties of the measurement method.
  - This analysis (carried out by establishing the relationships between the characterization of the concept and the mathematical description of the measurement method) will, among other things, enable determination as to:
    - whether or not the measurement method has been built consistently
    - which mathematical operations can be used on the results.

How to Design a Measurement Method

- The definition of units:
  - is related to the way an attribute is measured.
    - This means, of course, that some relationships exist between:
      - the unit,
      - the measurement method, and
      - the measured attribute.
  - The justification for the decision as to what unit to use in a measurement method should be provided (for example, by reference to a standard, to a theory, etc.).
    - If this is not done, then the rationale for the interpretation of the unit is not provided (For instance, what is a Function Point? [1])

- Table in next slide:
  - can be used as a work-in-progress template for recording the outcomes of each step and sub-step.

[1] See Chapter 8, section 6.4.

How to Design a Measurement Method

Table: Template for the design of a Measurement Method

Step – Sub-step	*Comments-Description*
Step 1: Determination of the Measurement Objectives	
What do we want to measure? What attribute of which entity type?	
From what measurement point of view? (user, developer, etc.)	
Intended uses of the measurement result?	
Step 2: Characterization of the concept to be measured: the measurable construct	
Clear definition of the concept to be measured (entity & attribute)	
The (empirical) operational definition of the attribute to be measured = characterization of the concept	
How the concept is decomposed into sub-concepts	
The definition of each sub-concept	
The type of entity to be measured (= the measurand)	
Step 3: Design(or selection) of the meta-model (the measurable construct) **Meta-model = set the of characteristics selected and the set of their relationships**	
Generic description of the meta-model= independent of the context of measurement while meeting the measurement objective	
Description of how to recognize the attributes to take into account to measure the entities involved	
Relationships between the sub-concepts (i.e. The roles of each sub-concept)	
Step 4: Definition of the numerical assignment rules	
Define an empirical relational set = defining the numerical assignment rules	
Selection of a measurement unit + The justification for this selection	
How each sub-concept contribute to the numerical assignment rules: - A descriptive text (a practitioner's description) - Mathematical expression (a formal theoretical viewpoint)	

How to Design a Measurement Method

End of the design step of a software measurement method

- The 4 distinct design sub-steps should have been completed by the end of every measurement method design process, and all their deliverables should be available and documented, that is:
  - objectives of the measurement
  - characterized concept and its decomposition,
  - the meta-model selected for the entities and attribute to be measured, and
  - the numerical assignment rules,

- all codified into a measurement method.

How to Design a Measurement Method

Is this design present in all software 'metrics'?

The four necessary sub-steps for the design of a measure (and its corresponding measurement method) are in marked contrast to current practices with various software metrics proposals.

Quite often the design of a software 'metrics' is incomplete, and limited to:

– the definition of some numerical assignment rules through an equation,

and then:

– attempts to analyze whether or not the resulting numbers bear some relationship to attributes other than the ones being measured!

In such a case, these software 'metrics' can hardly be qualified as *bona fide* measurement methods.

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Application of a Measurement Method

- Once the measurement method has been designed and all its design deliverables are available, it can be applied to measure specific software or a piece of software.
- In the specialized terminology of measurement, the 'application of the measurement method' to 'a specific context of measurement' corresponds to the design of a <u>measurement procedure</u> for a specific measurement exercise.
- The application of a measurement method is carried out through 5 sub-steps (when the application of the measurement method is not automated):
  1. Gathering of the software documentation;
  2. Construction of the software model to be measured;
  3. Assignment of the numerical rules;
  4. Presentation of measurement results;
  5. Verification of measurement results.

Application of a Measurement Method

These 5 sub-steps in the application of a measurement method are detailed below.

Measurement Method ≠ Measurement Procedure [VIM 2007]
Measurement method:
A measurement method is a logical sequence of operations, described generically, used in the performance of measurement.
Measurement procedure:
A measurement procedure is a set of operations, described specifically, used in the performance of particular measurements according to a given method.

Sub-step 1: Gathering of the software information

- The information required for the application of the measurement method is collected:
  - from the software to be measured, when the software is available;
  - from the documentation of the software; for instance, when the software has not yet been built.
- This information gathering process allows the second sub-step to be carried out, the modeling of the software
  - (when the appropriate model of this software is not readily available in the documentation).

Application of a Measurement Method

Sub-step 2: Construction of the software model to be measured

- Once this documentation has been gathered, the software model is built according to the rules of the measurable construct.
  - This model describes how the software to be measured is represented by the measurement method.

- The basis for the construction of the model is, of course, the proposed meta-model or measurable construct, and the rules to model it are the rules identifying the relevant components (entities and attributes) that will take part in the measurement.
  - If the appropriate model has already been built and is available from the previous sub-step, this second sub-step is bypassed.

Application of a Measurement Method

Sub-step 3:

- The numerical assignment rules are next applied to the software model derived from sub-steps 1 and 2.

Sub-step 4: Presentation of the measurement results

- Applying the measurement rules makes it possible to obtain a measurement result.
  - In order to be evaluated, this result should generally be documented with the following:
    - the measurement unit,
    - a description of the intermediate measurement steps,
    - a description of the measurement process,
    - the measurers,
    - the measurement procedure,
    - etc.

Application of a Measurement Method

Standards of Measurement Reporting
ISO 14143-1 states very precisely how to document the measurement results of an ISO recognized Functional Size Measurement method.

Sub-step 5: Verification and audit of the measurement results

- The measurement results should now be verified and audited, using various methods, to ascertain their quality.
  - For example: the tricky parts of mathematical calculations should be checked.
  - The results can also be compared with other well-known results in order to evaluate their correctness

Verification of Measurement Results
Example 1. For lines of code:
– Verification that all lines of code within the scope of the measurement have been included.
Example 2. For the COSMIC measurement method:
– Verification that all triggering events have been identified

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Exploitation of Measurement Results in Quantitative Models

- The results of the application of the measurement method can be used in many different ways:
  - in evaluation models, such as quality models,
  - in budgeting models,
  - in an estimation process, which is itself is based on:
    - a productivity model, and
    - an estimation model.

(many applications might not have been foreseen at the design stage of the measurement method)

Exploitation of Measurement Results in Quantitative Models

- **Evaluation models**
  - A quality model requires both the measurement results of the entity being evaluated and an interpretation scale and context for these results (e.g. a reference model).

CMMi Capability Model

The CMMi is an evaluation model for a software development organization.

If an organization obtains a measurement result of 3, how can this value be interpreted?

– If the organization had been evaluated at level 2, then a measurement result of 3 represents a significant organizational achievement; however, if the previous assessment result was 4, then the result of 3 represents a significant degradation in the capabilities of the organization.

– Similarly, a level 3 result represents a significantly better level of achievement when all the organization's competitors are at level 2, but certainly an underachievement if a number of its competitors have achieved a level of 5.

It must be noted that, in the CMMi instance, the numbers of the levels 1, 2, 3, 4, and 5 are not numbers in a mathematical sense, but only simple ordered labels which represent the following corresponding concepts: ad hoc, structured, managed, quantified, and optimized.

If the CMMi is considered as a maturity model, then each increasing level corresponds to a more *mature* organization.

If the CMMi is considered as a capability model, then each increasing level corresponds to a more *capable* organization.

Summary

This chapter has covered:

- An overview of the differences across numbers, measures, and quantitative models
- A 3-step measurement context model
- A 4-step process model for the design of a software measurement method
- A discussion on the application of a measurement method and on the exploitation of measurement results in quantitative models

- Additional material

Validation or Verification?

- The validation problem has been addressed from many different points of view. For example:
  - Schneidewind [1992] proposes a validation process based mainly on the analysis of the uses of the results of measurement methods, for example in prediction systems (Step 3 in Figure : Measurement Result Analysis).
  - Fenton [1991] suggest that, in order to be valid, a measurement method must satisfy the representation condition of measurement theory.
    - In other words, a validation process is proposed which addresses mostly the relationships between the two sub-steps, “characterization of the concept to be measured” and “definition of the numerical assignment rules”, of the Step 1 in Figure 2: Measurement Result Analysis.

Validation or Verification?

- Kitchenham [1995] propose a validation process addressing some parts of the 3 in Figure 2, but does not cover the full spectrum of the process model of measurement methods proposed here.
  - For example: it does not tackle the verification of the meta-model and of its relationships with the various components of measurement methods.

Verification or Validation?

- **Verification**: provision of objective evidence that a given item fulfills specified requirements [ISO VIM 2007].
- **Validation**: verification, where the specified requirements are adequate for an intended use [ISO VIM 2007].

Validation or Verification?

- In this book, use of the term *valid measurement* in a general sense is avoided, because of the diversity of the validation approaches in the literature which cover a wide spectrum of criteria at different levels.
  - To be as general as possible and to take into account the diversity of existing approaches, this book proposes instead a list of criteria which should be verified throughout the measurement context life cycle.
  - Verification activities are thus viewed as a continuous process taking place during the phases of the measurement life cycle; in particular, several verification criteria are to be identified during the design phase.
  - The rationale is that, in software engineering, most research is carried out on the use of numbers in software measures, and not enough on their design or on how to create them, even though the design of software measures is the fundamental phase of measurement.

Validation or Verification?

- Different kinds of verification activities should be applied in order to obtain verified measurement results with a sufficient degree of confidence, i.e. relying on quality results criteria such as accuracy, repeatability, reproducibility, etc.

Table 2: Verification activities for each step

1 – Design Step	2 – Application Step	3 – Exploitation Step
Verification of the design of a measurement method (with respect to the objective and measurement principle).	Verification of a practical application of the measurement procedures, including the measurement instruments or steps, and of results obtained.	Verification of the quality of the models of relationships across multiple measurement results.

Validation or Verification?

- For Step 1: verification of the design of a measurement method should ideally be performed only once, when the design in proposed.
- For Step 2: verification of the application of the measurement procedures should be performed every time a measurement exercise is carried out to ensure that the measurements results are accurate and to determine their degree of uncertainty when required.
  - In particular, Step 2 starts with the application of the measurement method on some chosen sample, followed by the detection, by the method, of one or more anomalies.
    - These anomalies, when encountered, will lead a measurer to reconsider the measurement instrument and its calibration, rework a part of the measurement procedure, or even alter the choice of the basic definitions of the measurement method if it is not mature enough.
- For Step 3: the quality of the models across multiple measurement results should not be verified every time a model is used:
  - however, the users of these models should have a good understanding of the strengths and weaknesses of the models they us

Validation or Verification?

- The approaches of the various authors, as well as the *validation* concepts being differently addressed by these authors, can be categorized depending on whether or not they addressed *verification* issues related to Steps 1 to 3 of the high level measurement context model (Figure 2).