Fundamentals of Testing

The role of Metrology, Sensors and Standards

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2. Methodology of Testing
3. Methodology of Measurement
4. Introduction to Sensor Technology
5. Combined Methodology of Testing and Measurement
6. Testing and Conformity Assessment
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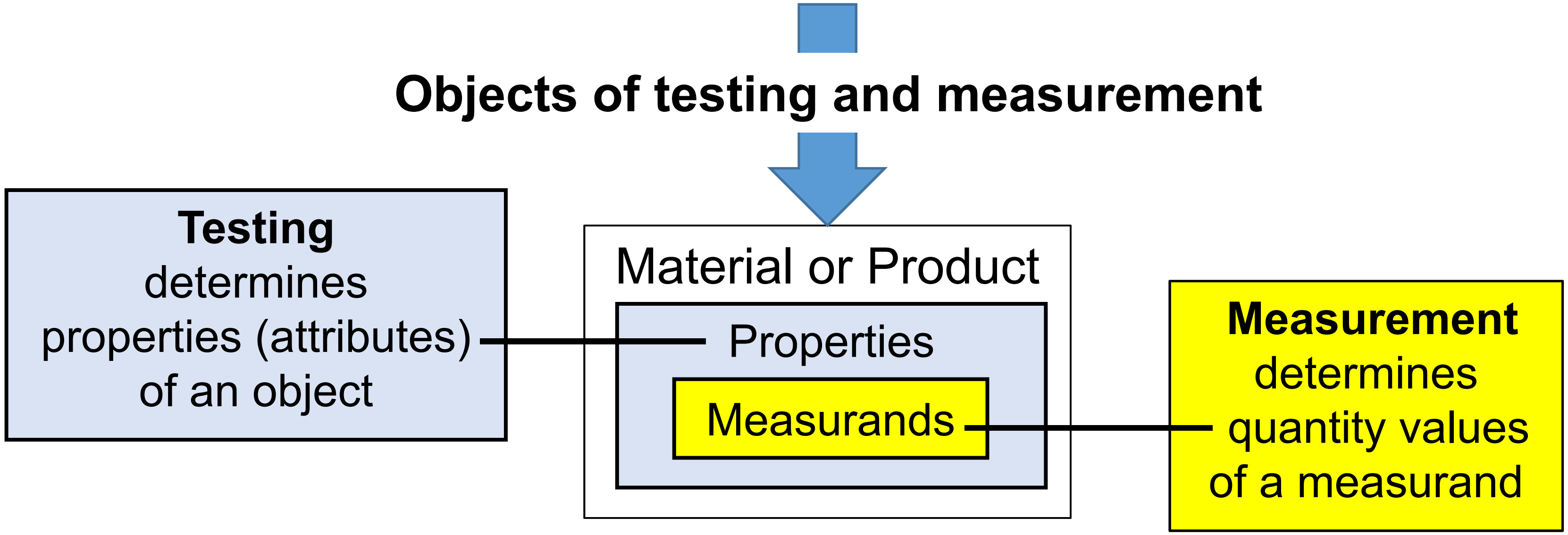
1. Introduction to testing and measurement

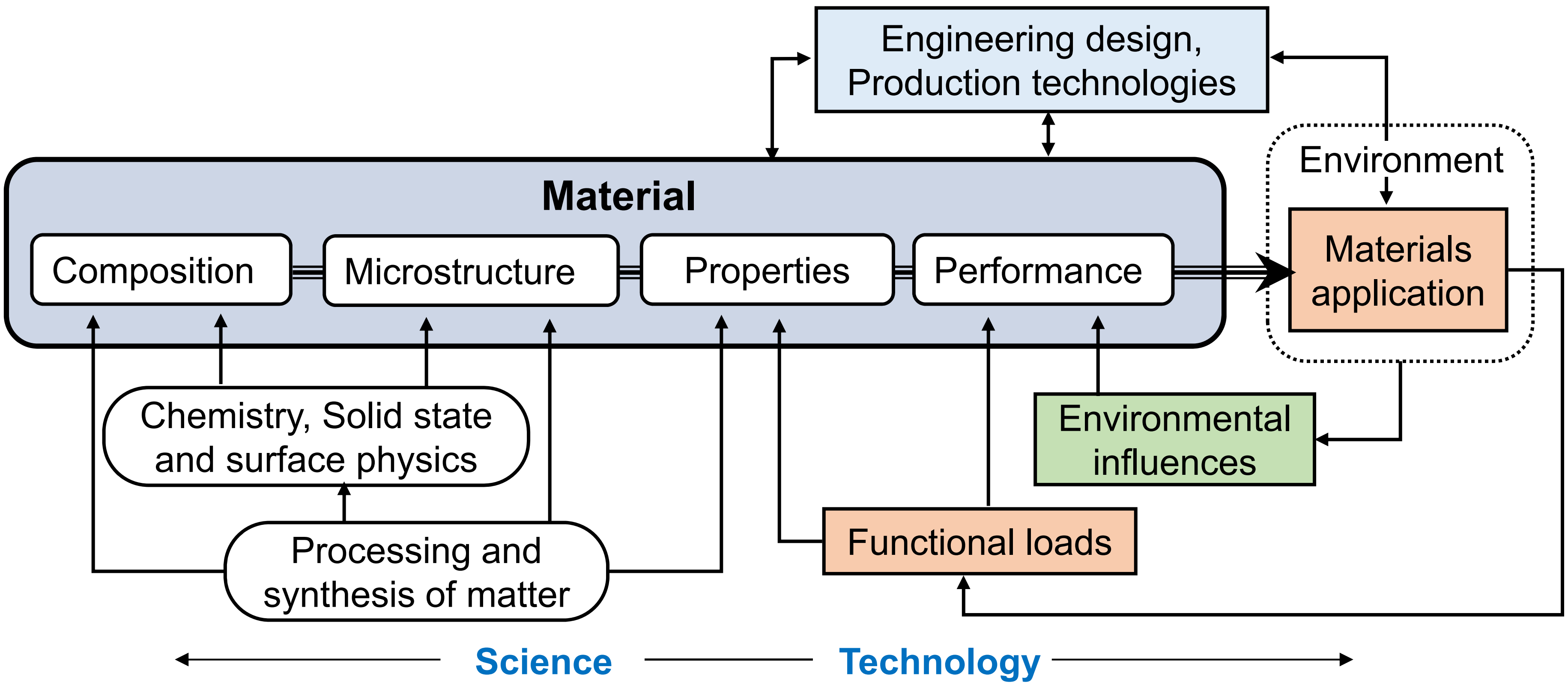
- **Testing** is a procedure to determine properties (attributes) of a given object and express them by qualitative and quantitative means.

- **Measurement** is the process of experimentally obtaining quantity values that can reasonably be attributed to a quantity. The quantity intended to be measured is called measurand.
  Reference: International Vocabulary of Metrology (www.bipm.org).



Materials as objects of testing and measurement

- Materials result from the processing and synthesis of matter, based on chemistry, solid state, and surface physics.
- Experience shows that the *properties* associated with a material are intimately related to its *composition* and *structure* at all scale levels. They are influenced also by the engineering component design and production technologies.
- P*erformance* denotes the behavior of materials – often as constituents of engineered products – under functional loads and environmental influences.

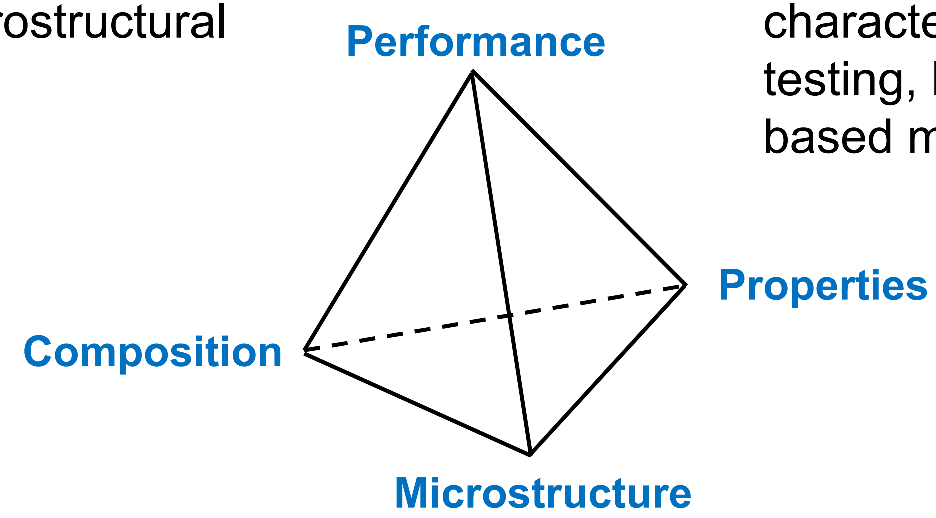


Principles for the characterization of materials

The characterization of materials has to consider four interlinked elements:
composition – microstructure – properties – performance.

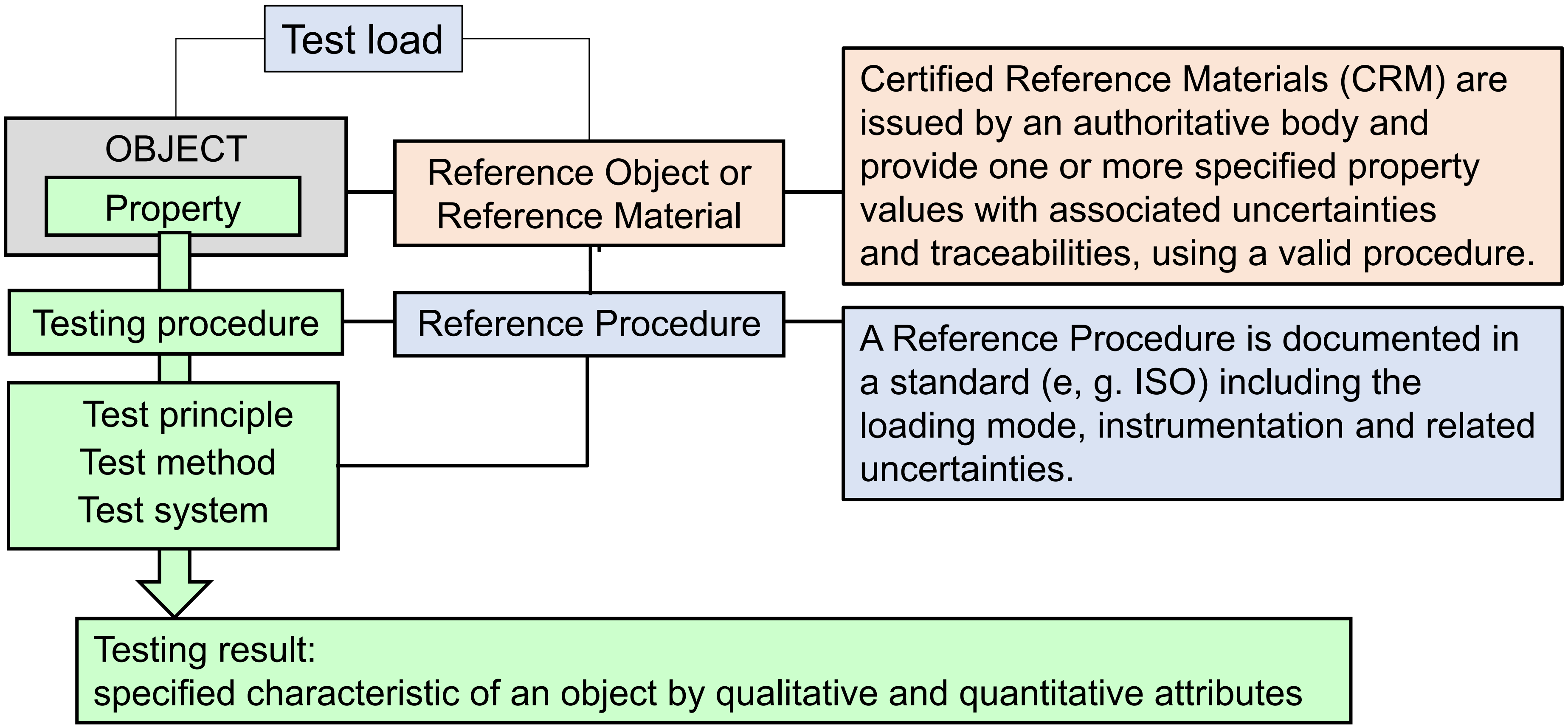
*M*aterials composition and microstructure are *intrinsic (inherent)* characteristics. They result from the processing and synthesis of matter.
→The determination of these characteristics requires chemical and microstructural analysis.

Materials properties and performance are *extrinsic (procedural) characteristics,* They describe the response of materials to functional loads and environmental influences.
→ The determination of these characteristics requires materials testing, backed-up by metrology-based measurements.



2. Methodology of testing

Testing begins with the definition of the property of an object to be determined. In the testing procedure, a mechanical, electrical, thermal, or another load is exerted in a defined procedure on a test object and the response is observed.



Presentation of test results

Test results are expressed in different ways,
depending on the object property to be characterized:

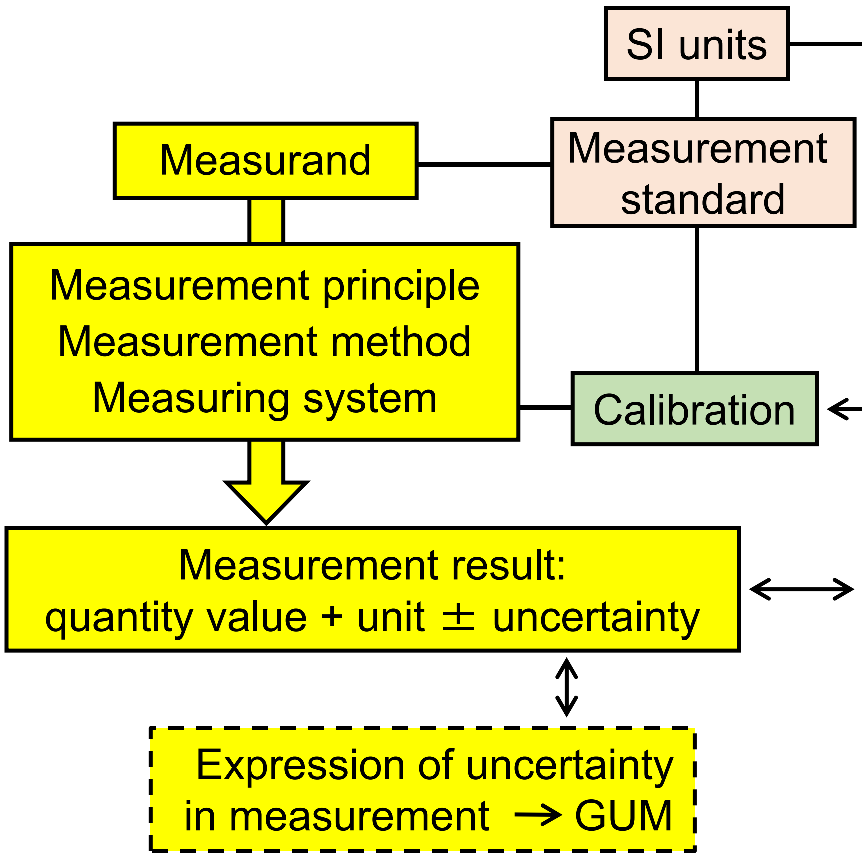
– some test results can only be captured in text and images,
– some test results, for example corrosion resistance, may be expressed as a ranking,
– some test results are Boolean, such as the ability to be recycled or not.

The numerical presentation of test results requires the application of metrology-based measurements.

→Note: “A laboratory performing testing shall evaluate measurement uncertainty”
(*General requirements for the competence of testing and calibration laboratories, ISO/IEC 17025:2017)*

3. Methodology of measurement

Measurement begins with the definition of the measurand, the quantity intended to be measured.



Base quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Calibration establishes a relation between indications of a measuring system and reference values of the measurand provided by a measurement standard.

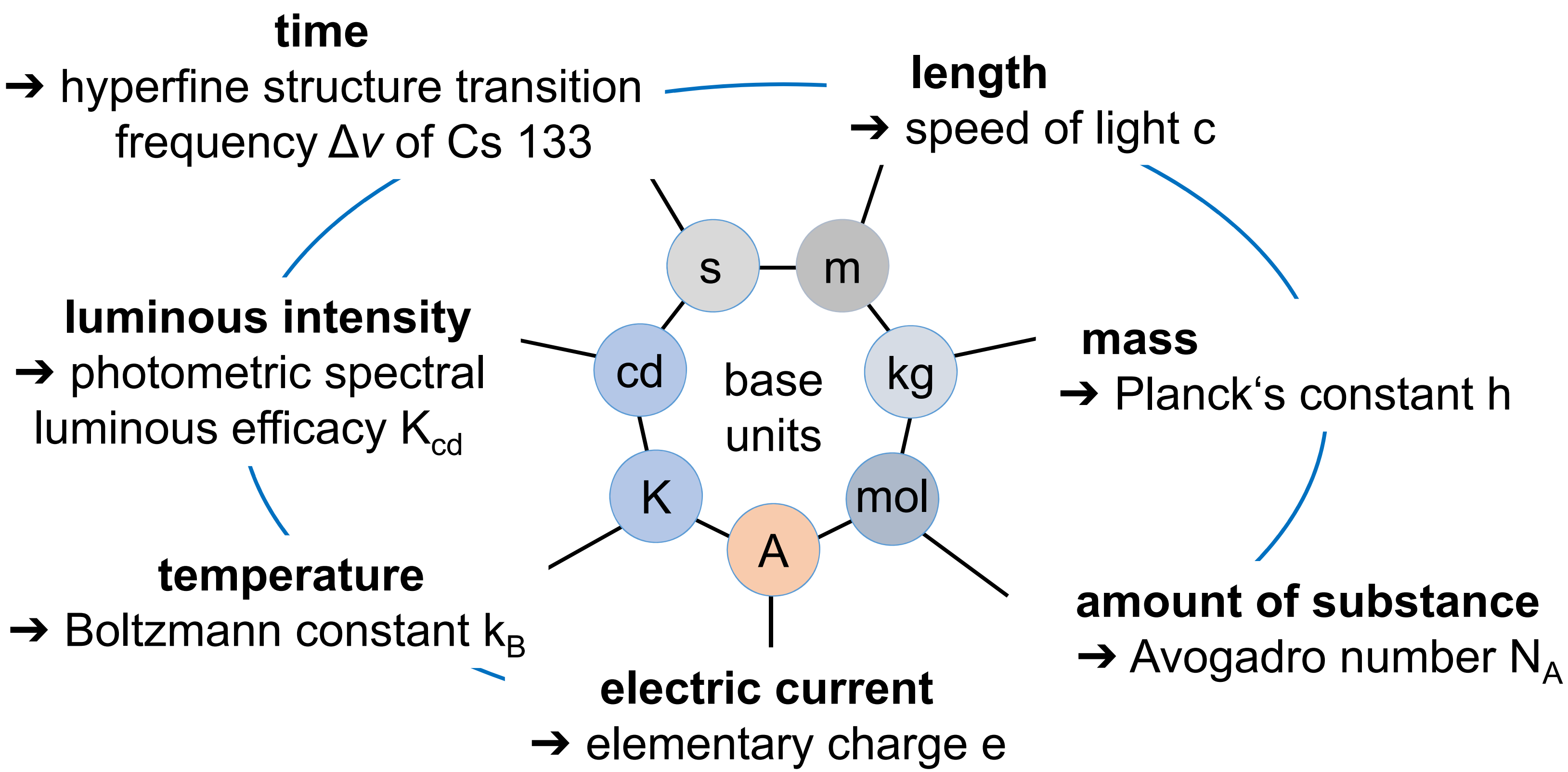
The measured quantity value must be related to a reference through a documented unbroken traceability chain, ending at the Primary Standard, based on the International System of Units, SI (Le Système International d'Unités).

Basic features of a measurement procedure

- **Measurement principle:** the phenomenon serving as a basis of a measurement.
- **Measurement method:** a generic description of a logical organization of operations used in a measurement.
- **Measuring system:** set of one or more measuring instruments and often other devices, including any reagent and supply. The measuring system must be calibrated against the measurement standard.
- **Measurement uncertainty:** nonnegative parameter characterizing the dispersion of the quantity values being attributed to a measurand.

The new International System of Units (SI)

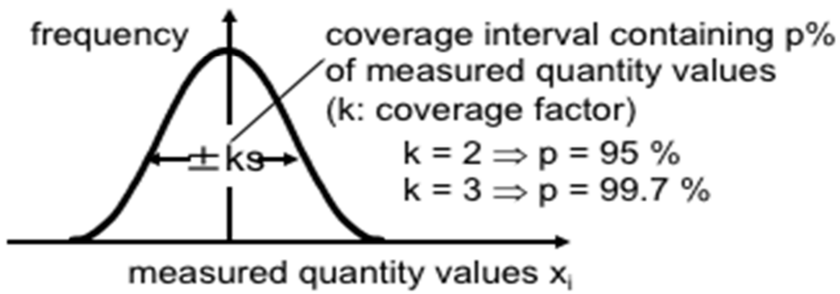
The International System of Units comprises a coherent system of units of measurement built on seven base units in terms of constants of nature. The new SI was put into effect on 20 May 2019.



Metrological concept of measurement uncertainty

- A measurement quantity is considered as a stochastic variable with a probability function. Often, it is assumed that this is a normal ("Gaussian") distribution.
- The result of a measurement is an estimate of the expectation value.
- Expectation (quantity value) and standard uncertainty are estimated either by statistical processing of repeated measurements (Type A, Uncertainty evaluation) or by other methods (Type B, Uncertainty Evaluation)
- The result of a measurement has to be expressed as a quantity value together with its uncertainty, including the unit of the measurand.

Uncertainty determination (Type A, GUM):
Statistical processing of repeated measurements (e. g. normal distribution)

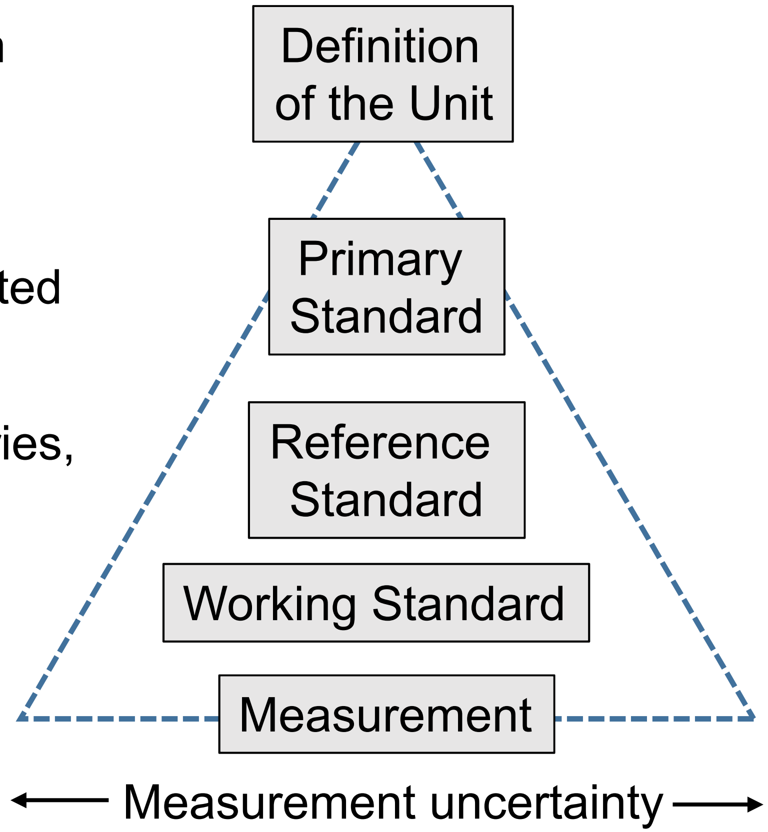


- measured quantity values x_i: $x_1, x_2, \ldots, x_n$
- arithmetic mean $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$
- standard deviation $s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$
- standard measurement uncertainty $u = s$
- expanded measurement uncertainty: $U = k \cdot u$

Reference: Guide to the Expression of Uncertainty in Measurement (GUM)

Metrological traceability

Traceability chain	Example: dimensional metrology
International System of Units SI	• SI unit meter
National metrology institutes or designated national institutes	• LASEr-interferometer
Calibration laboratories, often accredited	• Gauge block
Industry	• Micrometer screw
End users	Length measurement



Measurements accuracy, trueness, precision

The terms *accuracy*, t*rueness* and *precision* are defined in the International Standard ISO 3534. They can be used to characterise a measurement procedure.

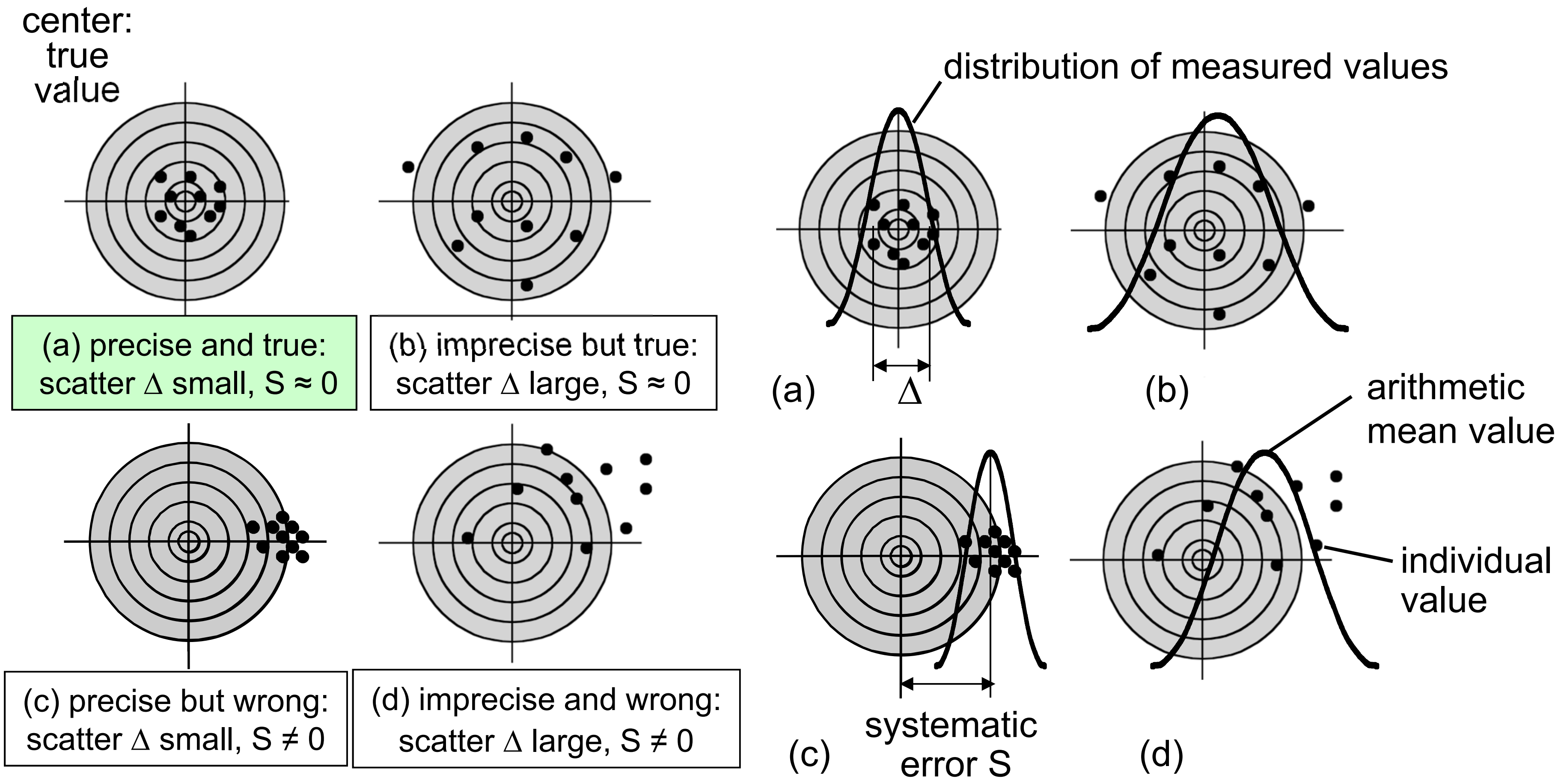
• **Accuracy** as an umbrella term characterizes the closeness of agreement between a measurement result and the true value of a measurand.

From a series of measurements, accuracy may be split up into trueness and precision.

– **Trueness** accounts for the closeness of agreement between the mean value of measurements and the true value.
– **Precision** accounts for the closeness of agreement between the individual values measured under specified conditions.

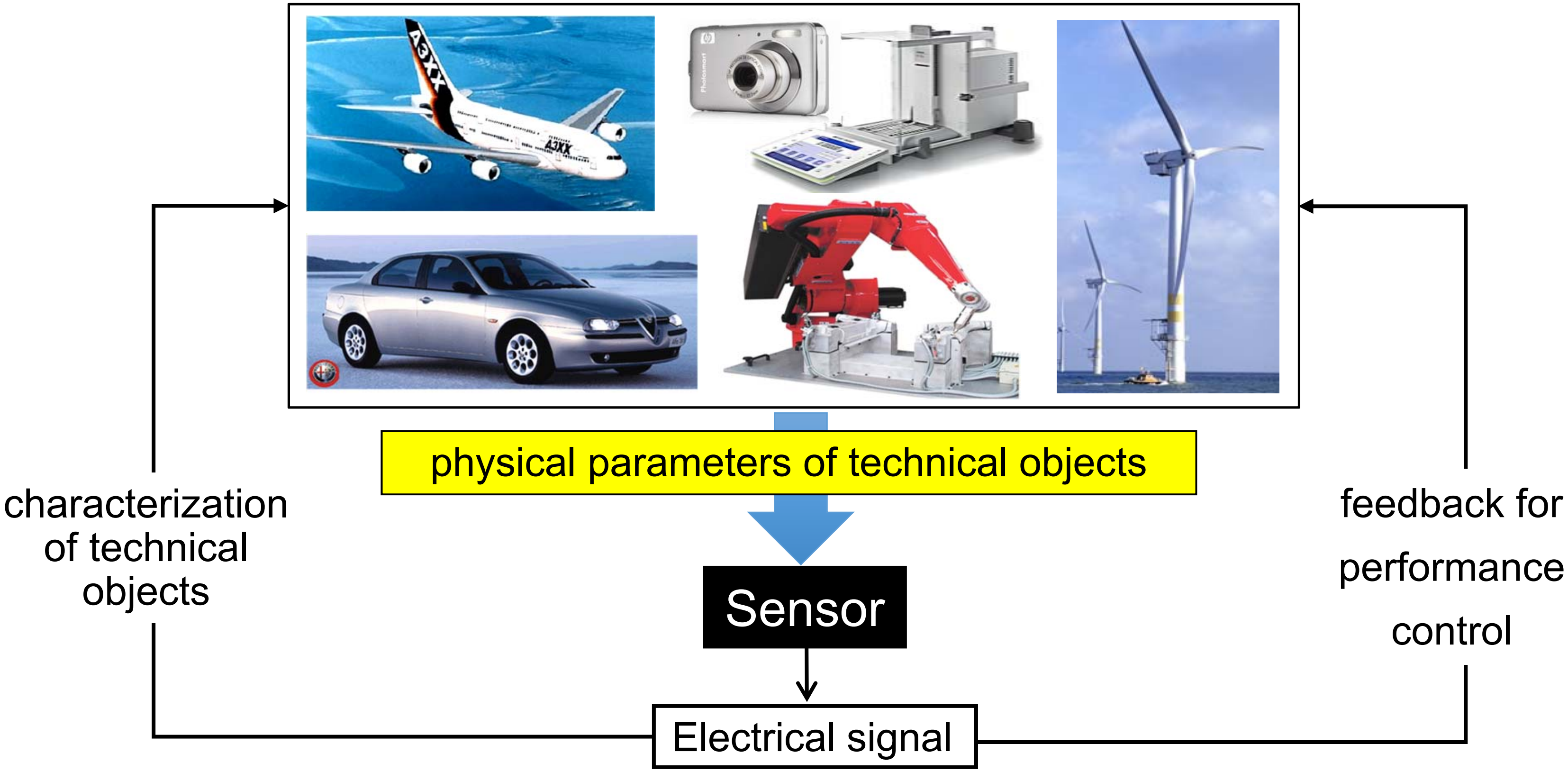
The different possible combinations of treuness and precision can be illustrated with the so-called target model.

Target model to illustrate trueness and precision



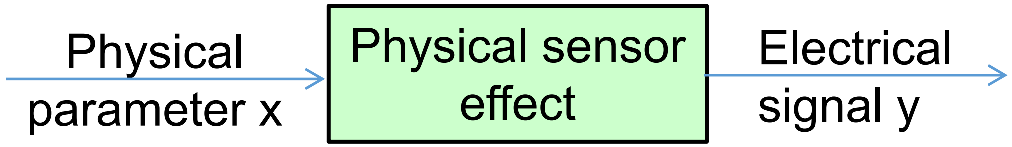
4. Introduction to Sensor Technology

Sensors are measurement transducers. They convert physical parameters – e. g. dimensional, kinematic, dynamic, thermal – into electrical signals that can be displayed, stored or further processed for applications in science and technology



Sensor principle

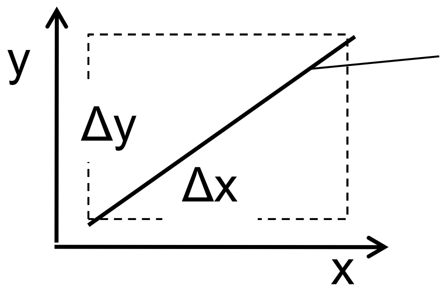
• A sensor is a device that detects a *physical parameter* as input x and converts it into an electrical signal as output y.



• The function of a sensor is described by a characteristic sensor line, which relates the output y to the input x. If there is a linear input-output relation, a sensor can be characterized by the sensitivity $\varepsilon = \Delta y/\Delta x$, or by its reciprocal, the input/output coefficient $c = \Delta x/\Delta y$.

• From the indication y (sensor output), the physical parameter x (sensor input) can be determined through the relation $x = c \cdot y$.

Sensor characteristics



sensor line (linearized)
sensitivity $\varepsilon = \Delta y/\Delta x$
input/output coefficient $c = \Delta x/\Delta y$

Sensor equations (stationary, linearized)

$$y = \varepsilon x$$
$$x = c y$$

Measuring chain for sensing

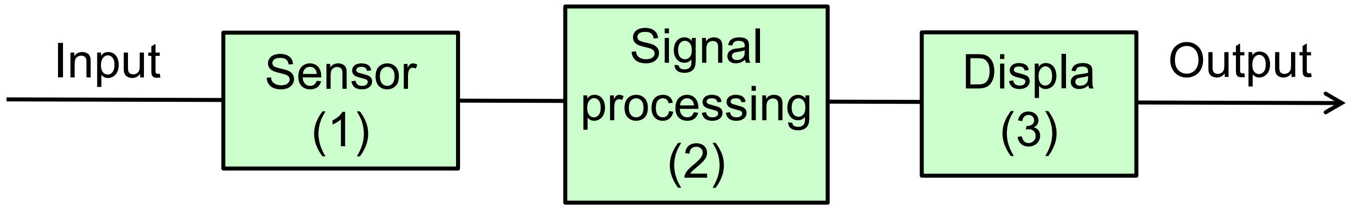
- For the application of sensors, a *measuring chain* has to be established. consisting in the simplest case of
  - (1) the sensor (sensitivity ε_1, uncertainty u_1)
  - (2) a signal-processing unit (sensitivity ε_2, uncertainty u_2)
  - (3) a display (sensitivity ε_3, uncertainty u_3)

- Sensitivity of a measuring chain (stationary operation):

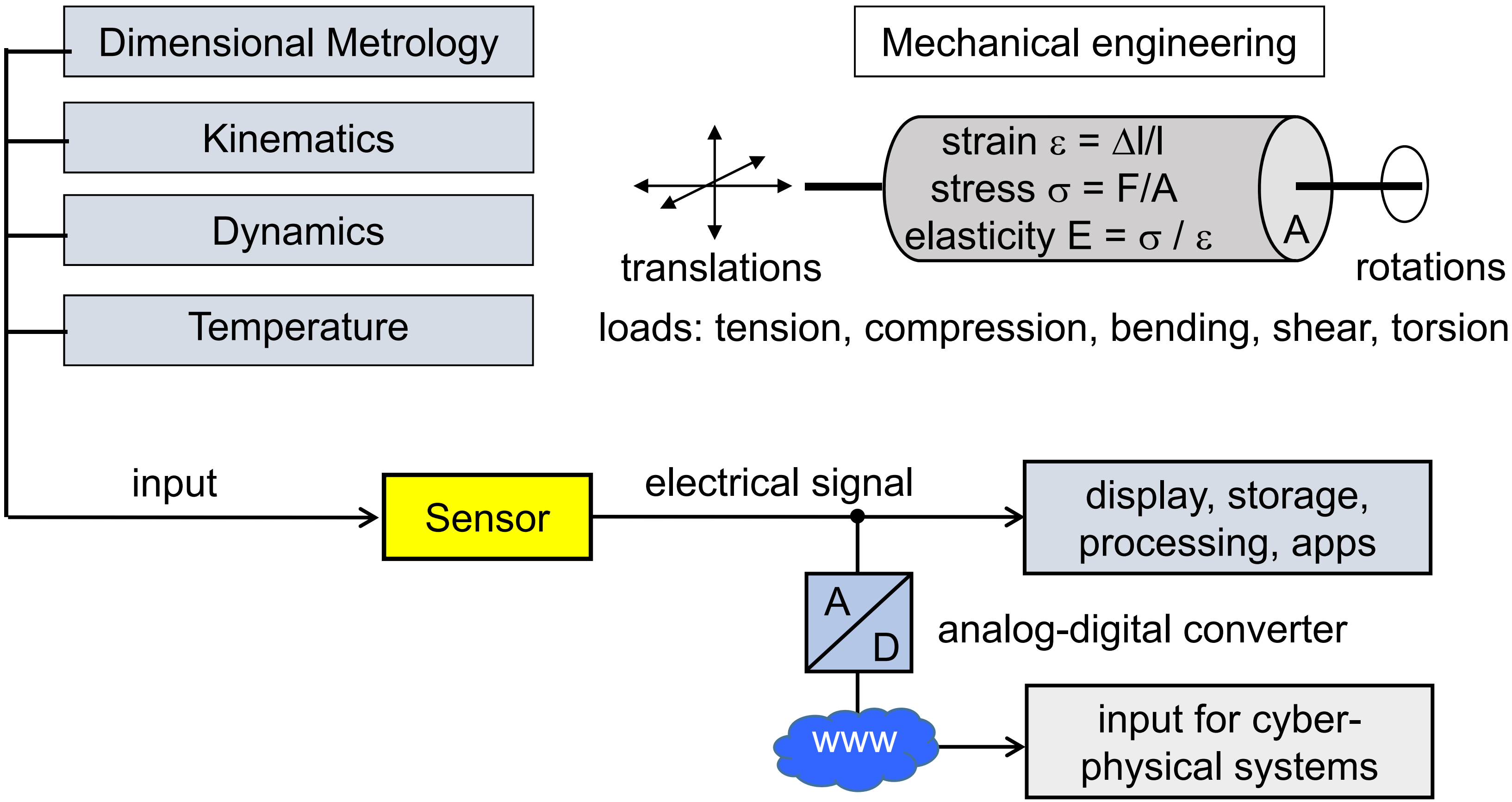
$$\varepsilon_{\text{measuring chain}} = \varepsilon_1 \bullet \varepsilon_2 \bullet \varepsilon_3$$

- Uncertainty budget of a measuring chain according to the propagation of uncertainties:

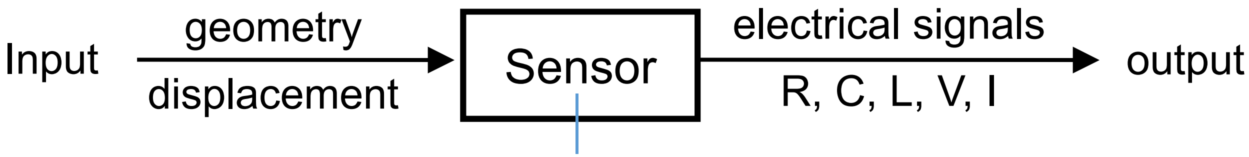
$$p_{\text{measuring chain}} = \sqrt{(u_1^2 + u_2^2 + u_3^2)}$$



Basic parameters of interest to be measured by sensors in testing



Example: Sensor principles for dimensional metrology

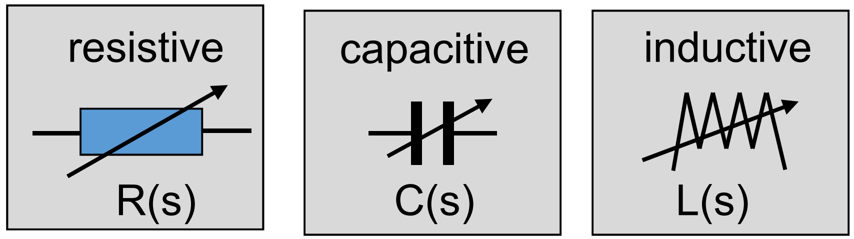


Sensor signal transformation principle

Sensor types

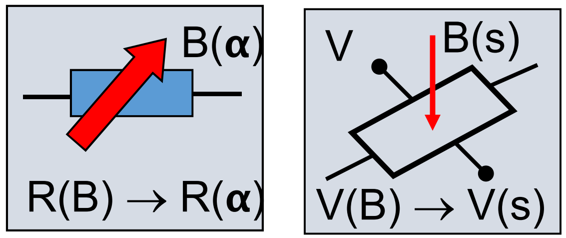
transformation principle

geometric input → electronic output



geometric input → magneto-electronic output

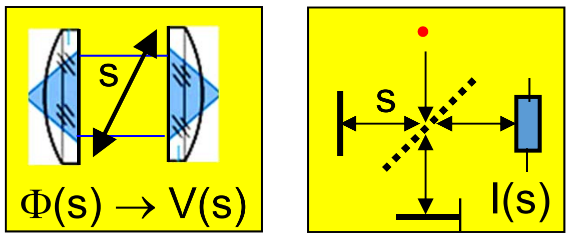
magneto-resistive sensors



Hall sensors

geometric input → optoelectronic output

light barrier sensors

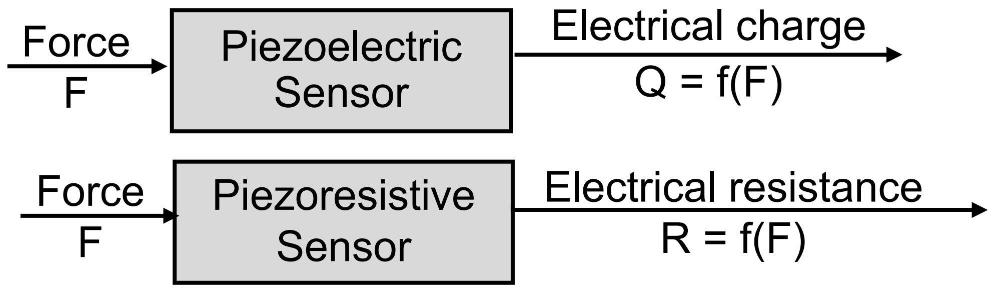


interferometer sensors

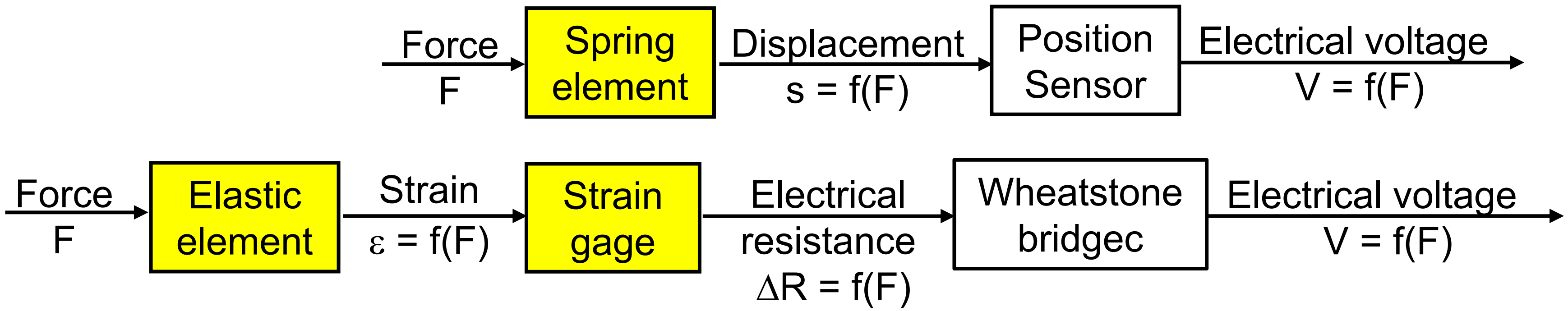
Example: Sensor principles for force measurements

Force is a vector with a direction and a magnitude. A force can only be determined by the response to its action. The design of force sensors utilizes the following principles:

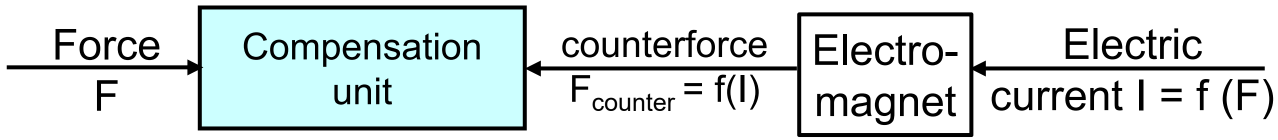
- **Direct force sensing**



- **Indirect force sensing**

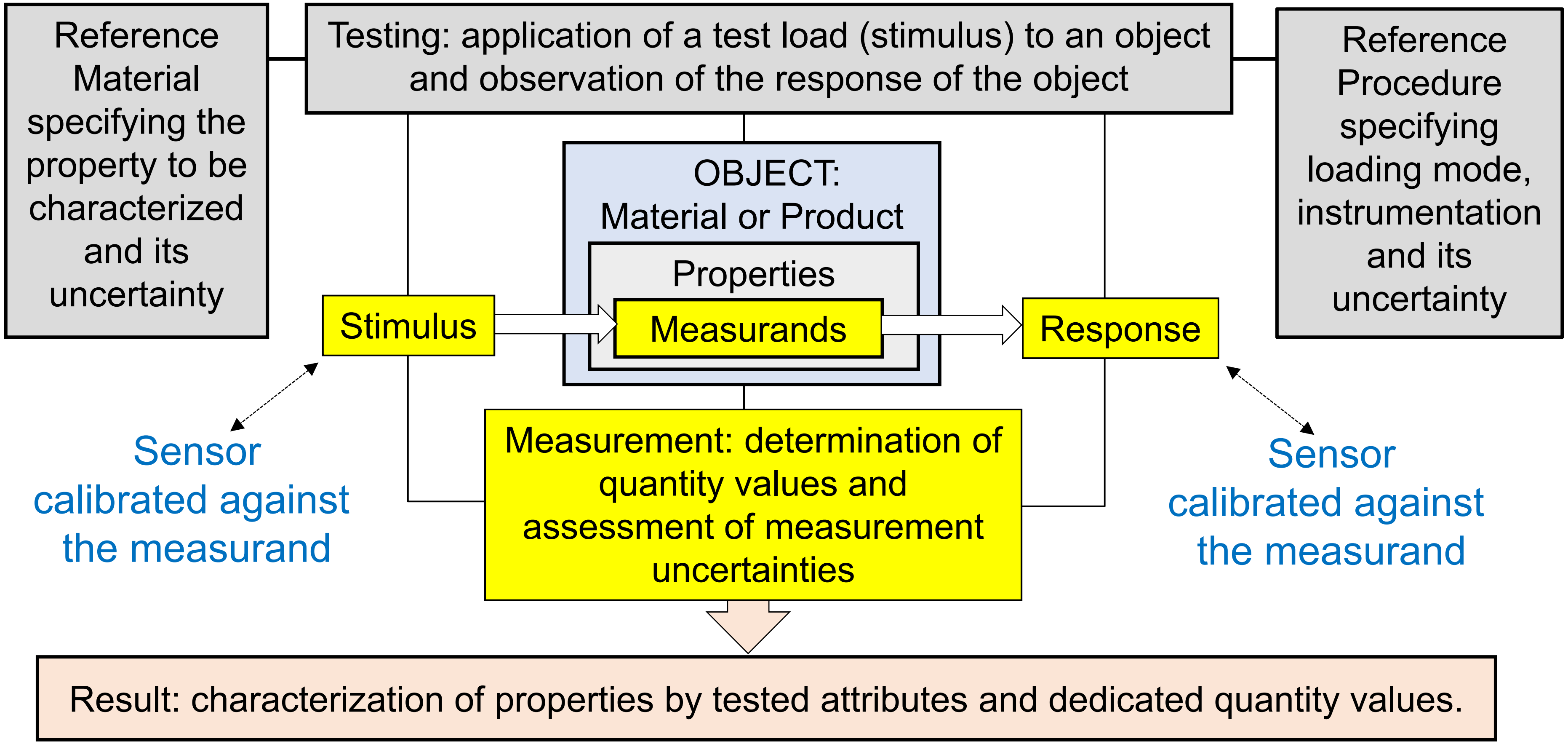


- **Force compensation principle**



5. Combined methodology of testing and measurement

The quantitative presentation of test results requires the combination of the methodologies of testing and measurement, it can be supported by sensors.



All relevant parameters are traceable to references, and the testing uncertainty can be expressed in an uncertainty budget of multiple parameters according to GUM and the requirement of ISO 17025.

Example of the combination of testing and measurement

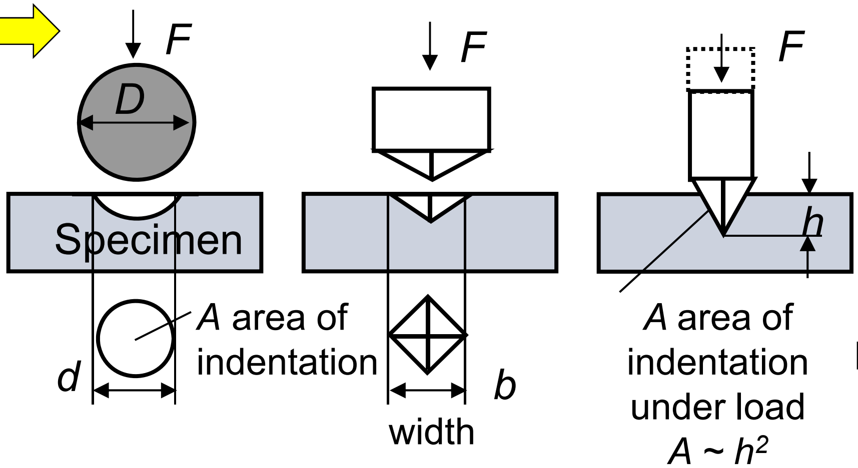
Reference Material with certified hardness quantity values

Hardness Testing

Reference Testing System specifying loading and instrumentation,

Brinell-Test Vickers-Test Martens-Test

Stimulus: force F, measured as quantity values with a calibrated forcemeter

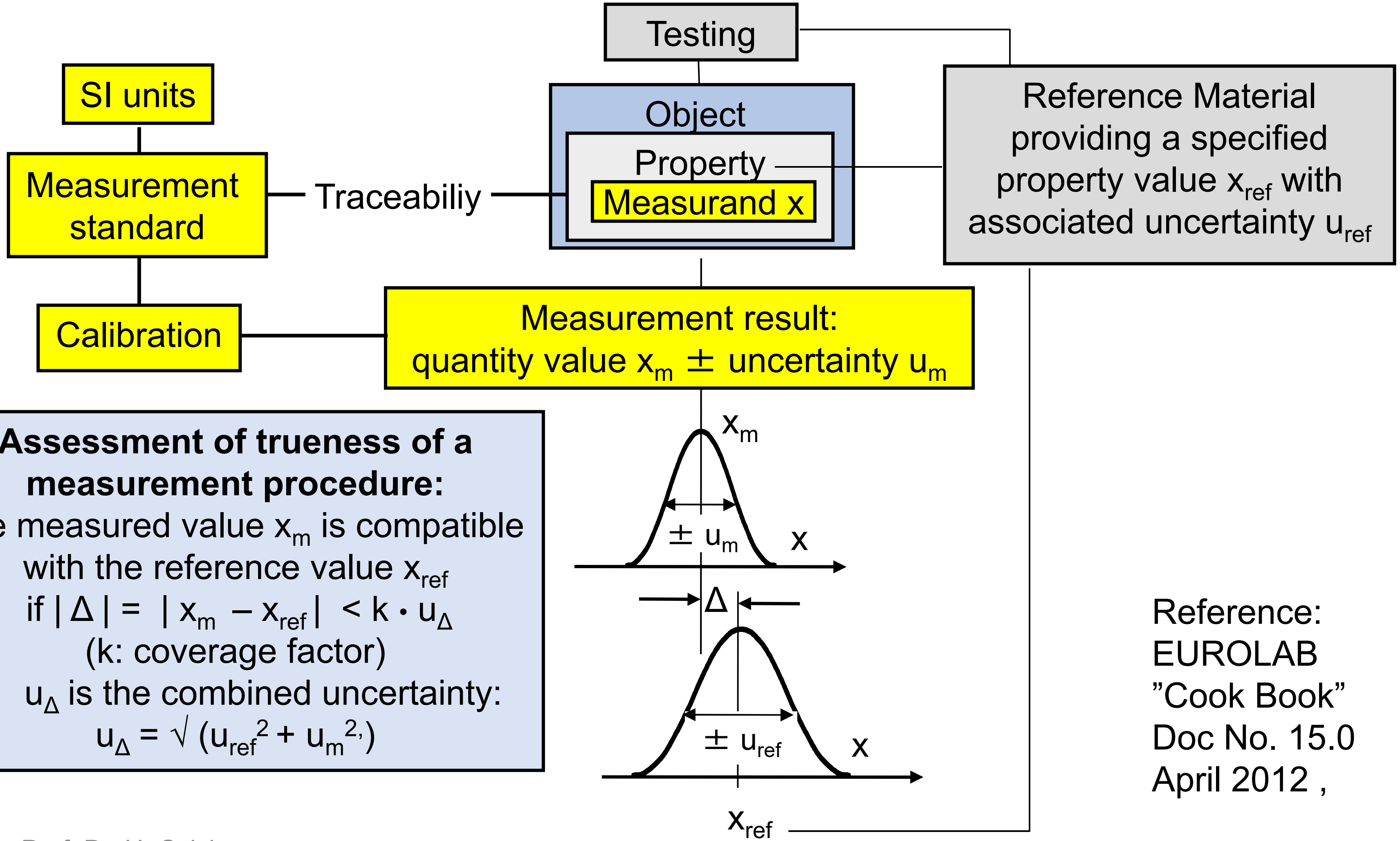


Response: quantity values of A, b, or h, measured with calibrated dimensional metrology instruments

Brinell Hardness $HB \sim F/A$	Vickers Hardness $HV \sim b$	Martens Hardness $HM \sim F/h^2$
stimulus/response relation	response value at stated stimulus	stimulus/response relation

Assessment of trueness of measurements in testing

Trueness of measurements in testing can be assessed if a reference material with the true quantity value x_{ref} and the associated uncertainty u_{ref} for the material property is available.



Assessment of trueness of a measurement procedure:
The measured value x_m is compatible with the reference value x_{ref}
if $|\Delta| = |x_m - x_{ref}| < k \cdot u_\Delta$
(k: coverage factor)
u_Δ is the combined uncertainty:
$u_\Delta = \sqrt{(u_{ref}^2 + u_m^2)}$

Reference:
EUROLAB
"Cook Book"
Doc No. 15.0
April 2012 ,

6. Testing and Conformity Assessment

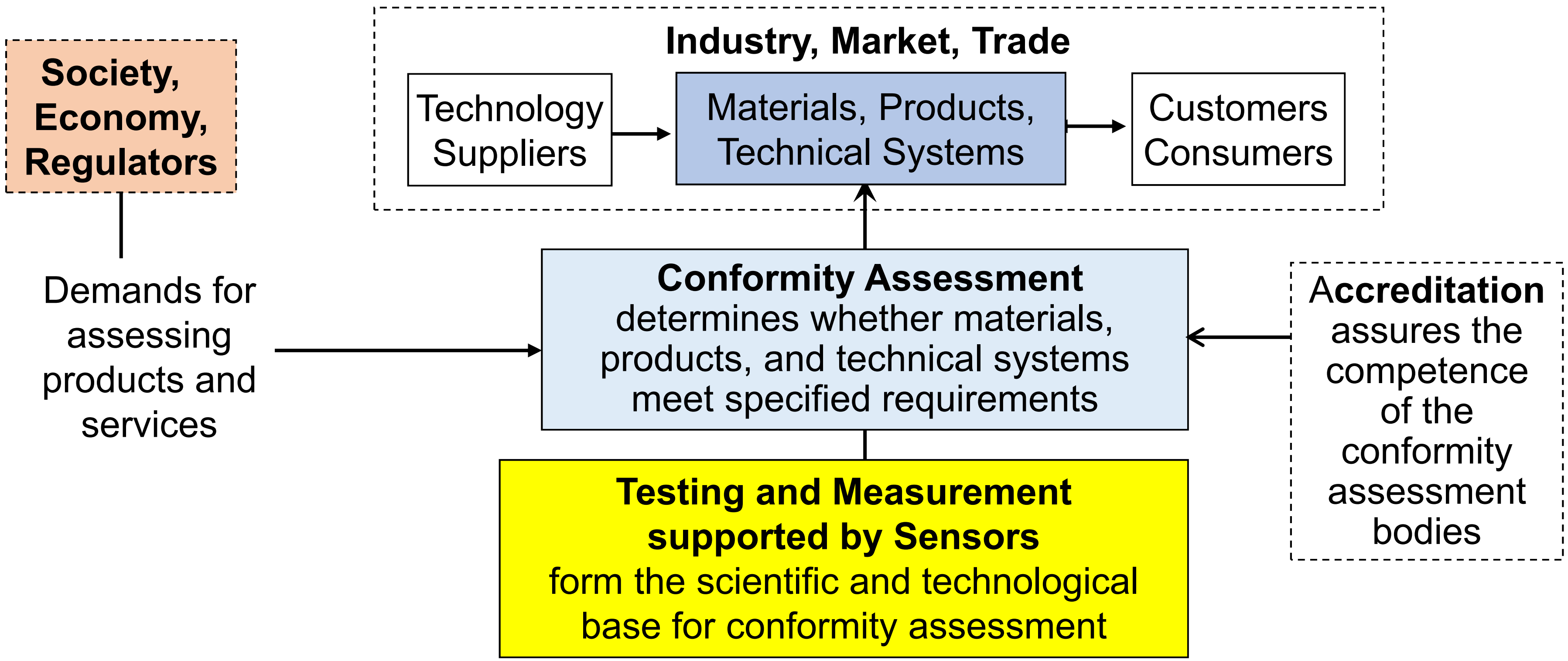
Testing is understood today as part of Conformity Assessment: activities to determine that a material or a product meets relevant technical standards and relevant requirements. .
Because different parties can be involved in testing activities, it is distinguished between

- first-party activities carried out by manufacturers and suppliers,
- second-party activities performed by buyers, users, retailers or consumers,
- third-party activities done by organizations independent of the above mentioned parties.

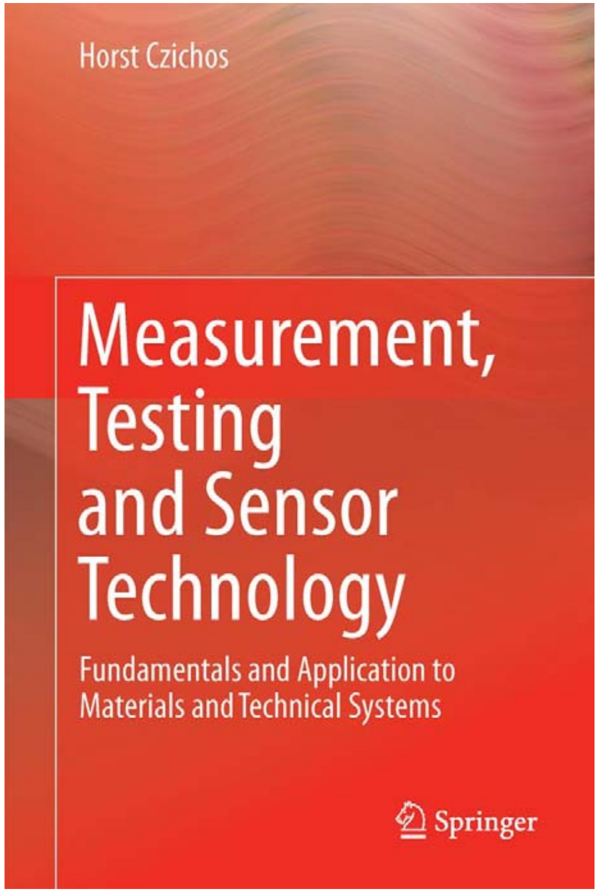
International Standards of conformity assessment tools

Tools for Conformity Assessment	First party: supplier, user	Second party: customers, trade asso-ciations, regulators	Third party: bodies independent from 1st and 2nd parties	ISO Standards
Supplier's Declaration	x			ISO/IEC 17050
Calibration Testing	x	x	x	ISO/IEC 17025
Inspection	x	x	x	ISO/IEC 17020
Certification			x	ISO 17021 ISO Guide 65

Conclusion:
testing and measurement as base of conformity assessment for the demand of industry, market and trade



7. The reference for this presentation



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