

# CIPM Forum on Metrology and Digitalization

Cornelia Denz | Chair

Hector Laiz, Georgette Macdonald | Co-Chairs

Gianna Panfilo | Executive Secretary

23rd meeting of NMI Directors and Member  
State Representatives | October 17-18, 2024

**B**ureau  
♦ **I**nternational des  
♦ **P**oids et  
♦ **M**esures





# Why a forum? | Facing the digital challenge





# Why a forum? | Facing the digital challenge

**I think with artificial intelligence  
we summon the demon.**

Elon Musk, Open AI & Neuralink

**The development of fully  
artificial intelligence could mean  
the end of the human race.**

Steven Hawking, Cambridge 2014 in BBC

**There is no reason and no way that a  
human mind will be able to keep up with  
an artificial intelligence by 2035.**

Gray Scott, Futurist & Techno-Philosopher, New York

**There is no alternative to digital  
transformation. Visionary companies will carve  
out new strategic options for themselves.**

Jeff Bezos, Amazon

**When digital transformation is done right,  
it's like a caterpillar turning into a  
butterfly.**

George Westerman, MIT Sloan Initiative  
on the Digital Economy

**The biggest part of digital transformation  
is changing the way we think.**

Monique Shivanandan, Chief data analyzer, HSBC

**Metrology is the heart of a successful digital transformation**

# Why a forum? | Facing the digital challenge

## • Ask the next generation

... we will have strong misuse if we are not able to set ethical rules quality standards

... digitalization will be used for environmental protection and better life

... schools will work with digital media only

... robots have all the features of humans

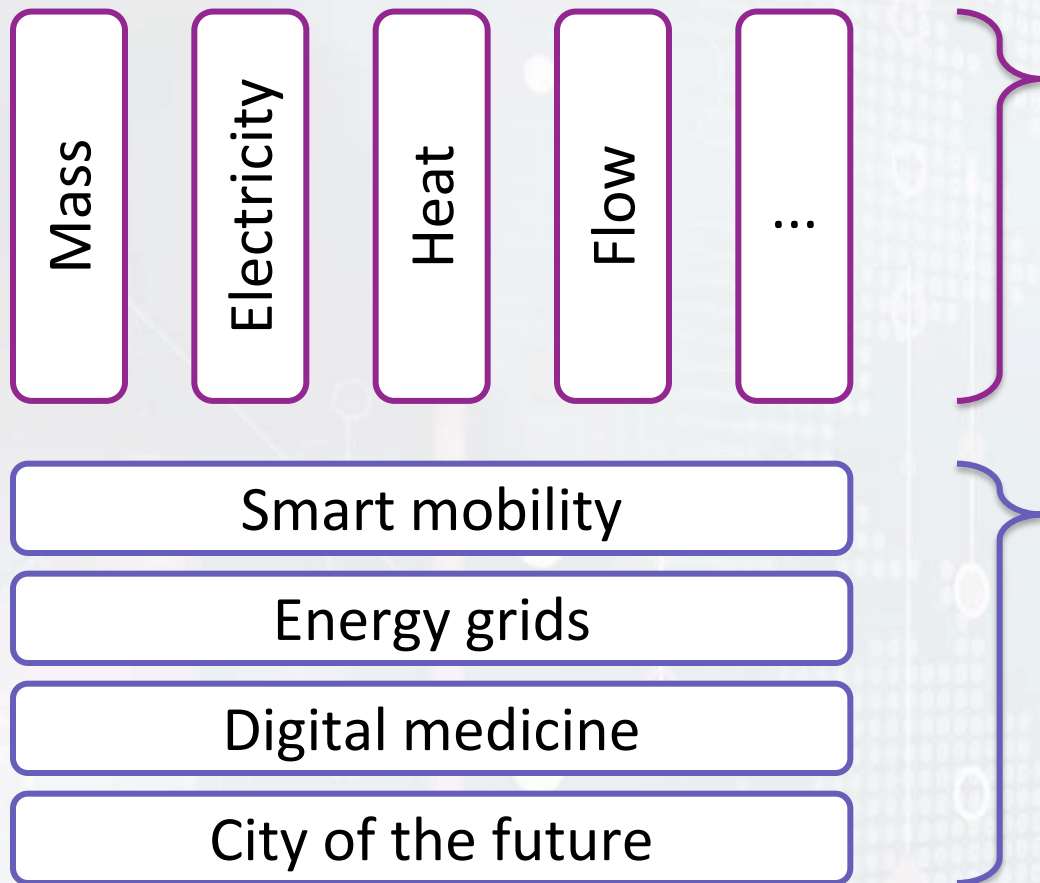
... face recognition on streets and for payment will be usual

... social life and real friendship will not be existing any more

**Metrology needs to be an anchor of trust also in the digital world**



# Why a forum? | Facing the digital challenge



## Classical metrology fields

- Digitalization of components and devices
- Important in regulated areas of legal metrology and in services for industry

## Emerging fields of metrology

- Questions on traceability, uncertainties, and on harmonization
- Combination of digitalization with AI
  - ▶ **Digitalization is relevant for all fields of metrology world-wide**
  - ▶ **International task of metrology**

# Why a forum? | How it started

- **Early CIPM Vision | Transforming the SI for a digital world**

*... ensure that the Metre Convention naturally extends its role as the globally accepted anchor of trust for metrology into the digital era ...*

Resolution 2 of the 27th CGPM (2022)

- Adoption of **FAIR principles** in digital metrological data
- **Machine-actionable functions** of the SI
- Facilitating use of **digital certificates**
  - ▶ **Digital transformation of all important services of BIPM**
  - ▶ **Horizontal theme of QI** ▶ **Formation of a horizontal forum**
  - ▶ **Extension to emerging digital needs of CIPM members**





# Agenda | Forum MD in a nutshell



How to prepare CIPM for digital challenges  
Forum MD concept & terms of reference



Task and working groups of Forum MD  
Six topic-oriented task groups & three working groups



Events & Activities  
Workshops, meetings & dissemination



Outlook into the future  
Digitalization in metrology for all





# How to prepare CIPM for digitalization

## Forum MD concept & terms of reference



# Forum on digitalization | Terms of reference

**To advise CIPM on the SI Digital Framework** and the wider implications of the global digital transformation for metrology and for the **international digital QI**

Adoption of **FAIR principles** for metrological data

Providing metrological input in **emerging areas**

Create **authoritative digital reference** for core SI

**Digitally transform services & products** of BIPM

Consider implications of digitalization on **CIPM-MRA**

**Objective 1:**  
**To harmonize internal processes** of digitalization of NMIs, CCs, RMOs, BIPM

**Objective 2:**  
**To act as a forum** to exchange information and to create **synergies and opportunities for collaboration** in this field

# Forum on digitalization | Participating institutions

- **Membership criteria adopted from general CIPM rules**

- Members should be recognized internationally as expert in the field
- Members should demonstrate competences by a record of international activities

- **Horizontal nature**

- More inclusive participation (observers are welcome) and invitation of experts
- Inclusion of liaisons: Signatories of the Joint Statement on Digital Transformation

Group	Organisations (decision of CIPM end 2023)
Members (11)	CENAM, METAS, INTI, MSL, NIM, NIST, NMIA, NPL, NRC, PTB, VNIIMS
Observers (15)	GUM, CEM, NPLI, CMI, VNIIM, INM Colombia, INMETRO, KRISS, LNE, NIMT, NIS, NMC A*Star, NMIIJ/AIST, RISE, SASO-NMCC, VSL
Liaisons (9)	CIE, CODATA, IEC, ILAC, IMEKO, ISC, ISO, NCSLI, OIML



# Forum on digitalization | Task and Working Groups

- **Chairs: Cornelia Denz (PTB) | Georgette McDonald (NRC) | Hector Laiz (INTI)**

• 6 Task Groups and 3 Working Groups, **established March 2024**



## **TG AI**

Secure and Trustworthy AI  
*Louis Wright (NPL)*



## **TG DQ**

Data Quality in Metrology  
*Mark Ballico (NMIA)*



## **WG CC**

Coord. between CCs  
*Peter Blattner (METAS)*



## **TG FM**

FAIR for Metrology  
*Robert Hanisch (NIST)*



## **TG H-DCC DRMC**

Harmonizing DCC & DRMC  
*Martin Koval (CMI)*



## **WG RMO**

Coord. between RMOs  
*Nikita Zviagin (VNIIM, interim)*



## **TG MS**

Metrological Semantics  
*Ryan White (NRC)*



## **TG SIDF**

SI-digital Framework  
*Anna Cypionka (BIPM)*



## **WG S**

Strategy  
*Cornelia Denz (PTB)*



# Task and working groups of Forum MD

Six topic-oriented task groups & three working groups



# Task groups | ToR for Secure and trustworthy AI

## • Respond to the growth of AI

### Metrology needs AI for effectiveness

- ▶ Address measurement challenges
- ▶ Improve e.g. conformity assessment

### AI needs metrology for confidence

- ▶ Demonstrate traceability of outputs
- ▶ Define uncertainties to measurands
- ▶ Define requirements for data quality

### Purpose: Providing guidance to CIPM on

- use of AI for metrological purposes
- provision of metrological services by AI

Assessment of existing legislation

Metrological data becoming “ready for AI”

Identification of standards governing AI

Interaction with international organizations



Presentation: Enhancing control of Generative AI through metrology,  
*Dr. Agnès Delaborde (LNE)*

# Task groups | ToR for Secure and trustworthy AI

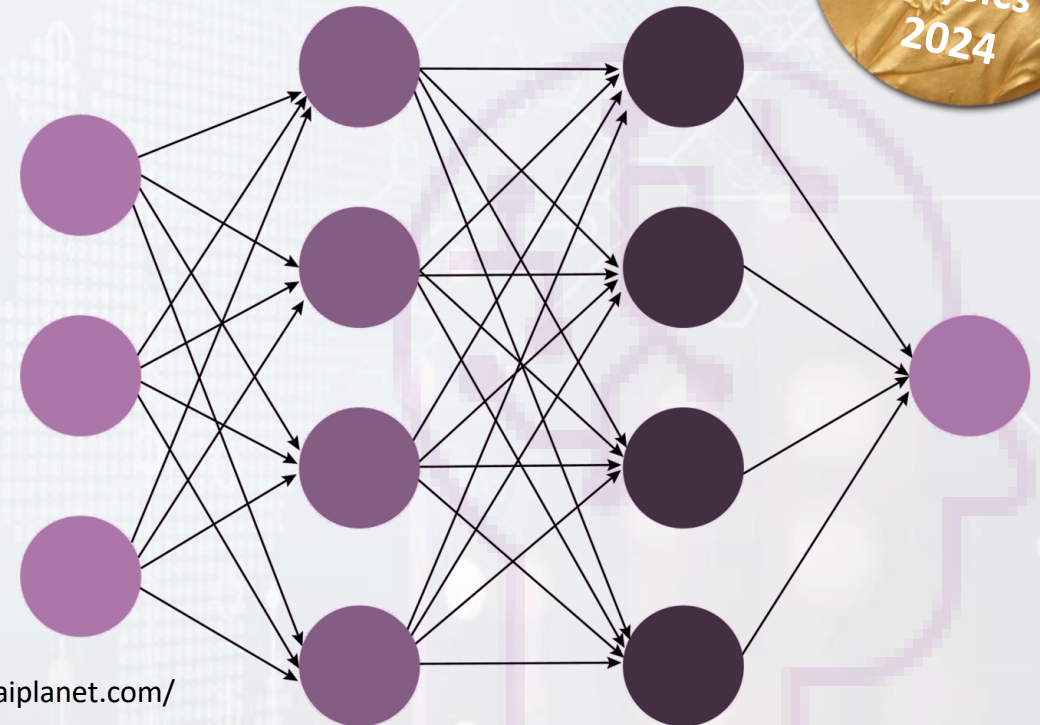
- **Example: Transparency & understanding of algorithms**

- **Neural network classes defined by learning algorithms**

- ▶ Supervised (deep) learning  
(Hebb 1949; Perceptron: Rosenblatt 1961)
- ▶ Competitive (self organized) learning  
(Kohonen 1984)
- ▶ Fully connected (deep) learning  
(Hopfield 1986; Boltzmann Machine: Hinton 1985)
- ▶ Unsupervised, free learning  
(Adaptive resonance: Carpenter, Grossberg 1987)

- **Today's data intensive approaches**

- ▶ Neuromorphic computing
- ▶ Convolutional neural networks
- ▶ Reservoir computing



Input layer

Hidden layer I

Hidden layer II

Output layer



# Task groups | ToR for Data quality in metrology

- **Develop data-quality guidelines & framework for data measurement**

## **Objective 1:**

### **Harmonizing existing standards**

- ▶ Take full advantage of the systems, knowledge & norms of metrology for **quality, traceability, uncertainty approaches**

## **Objective 2:**

### **Identification & gap analysis of existing frameworks**

- ▶ Examining the potential for **terminology harmonization**
- ▶ Define an **agreed set of metrics**

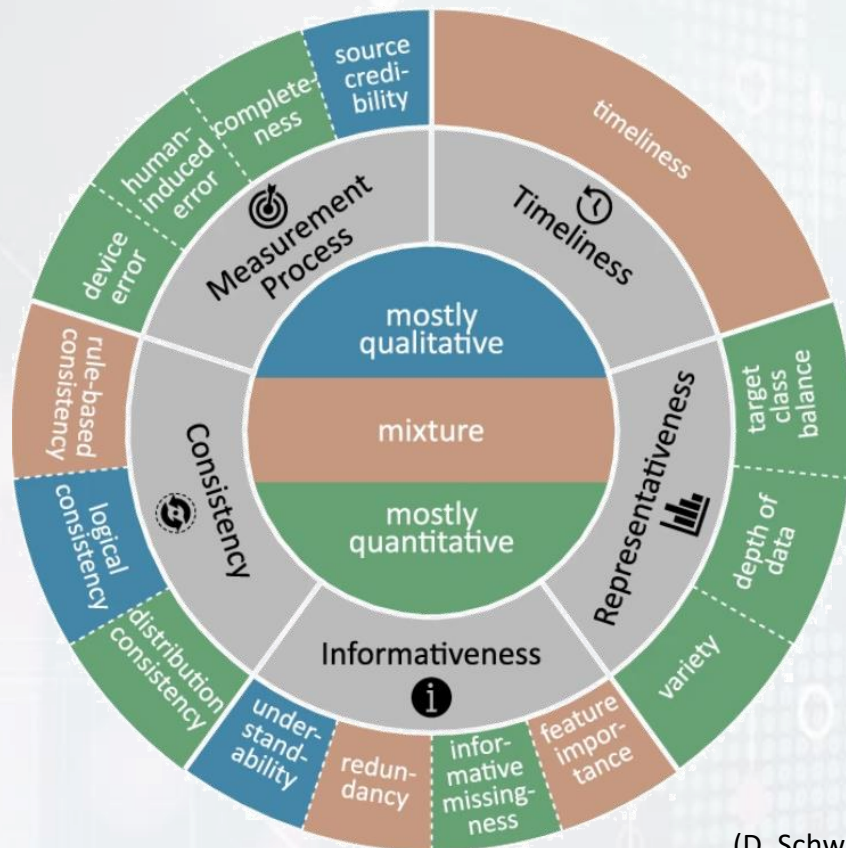
- ▶ Facilitating the **“fitness-for-purpose” assessment of data**



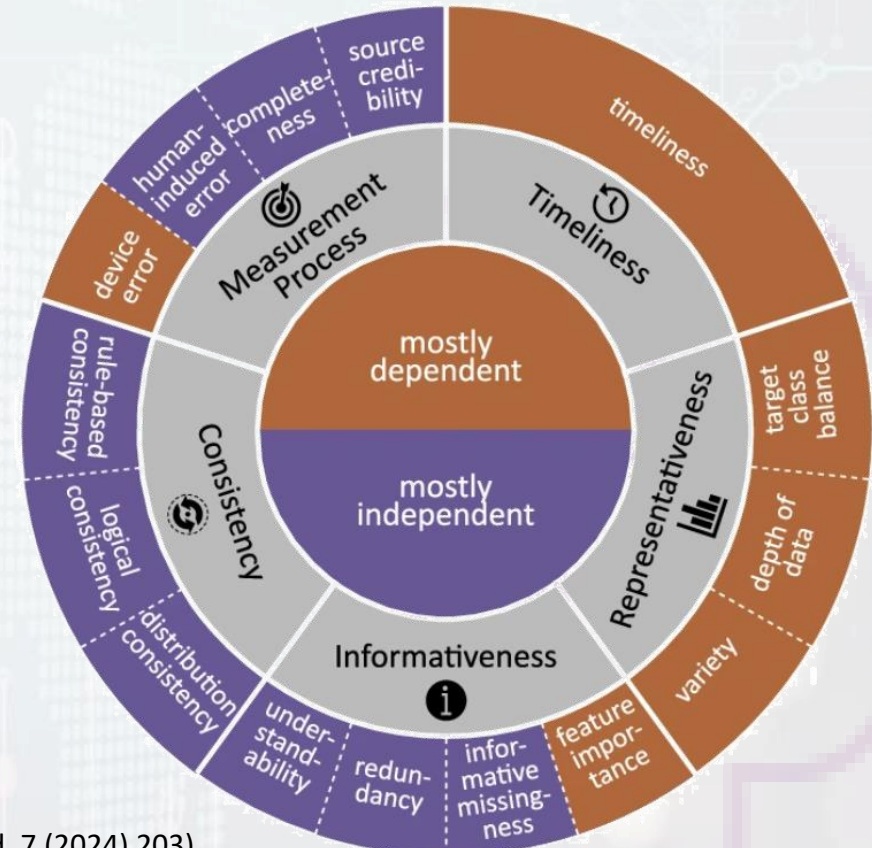
Presentation: Data quality metrics and reference data for AI  
*Prof. Dr. Tobias Schächter (PTB)*

# Task groups | ToR for Secure and trustworthy AI

- **Example: Metric categories for assessing data quality in medicine**



**Dimensions along the properties quantitative - qualitative**



**Dimensions along the properties dependent - independent**

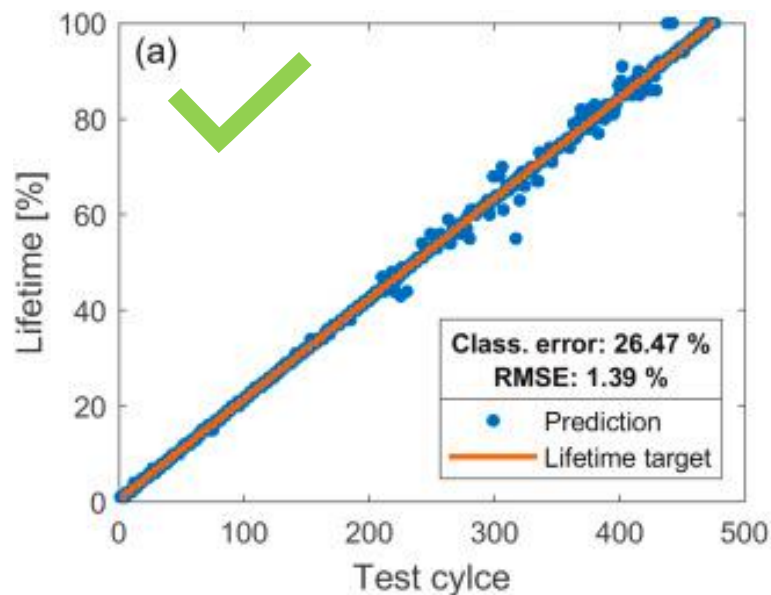
(D. Schwabe et al., npj Digit. Med. 7 (2024) 203)



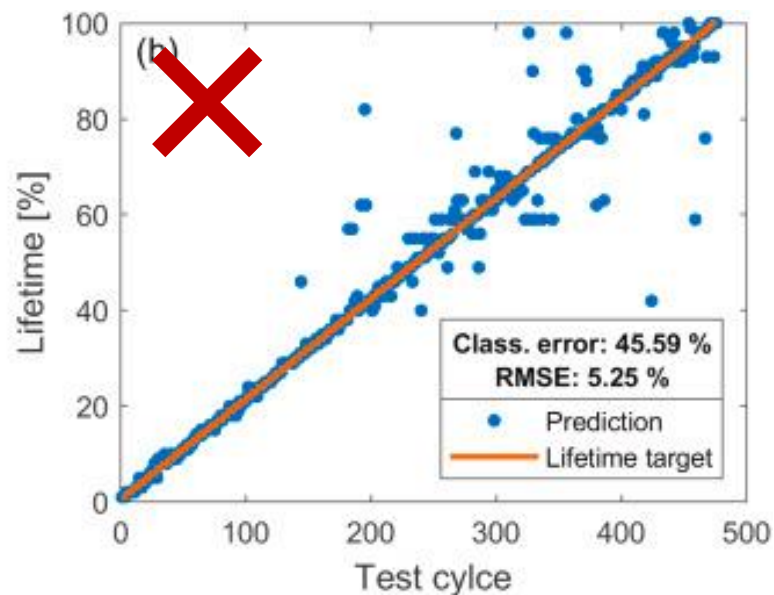
# Task groups | ToR for Data quality in metrology

- **Example: Lifetime estimation of electro-mechanical cylinder**
  - Fit for purpose?

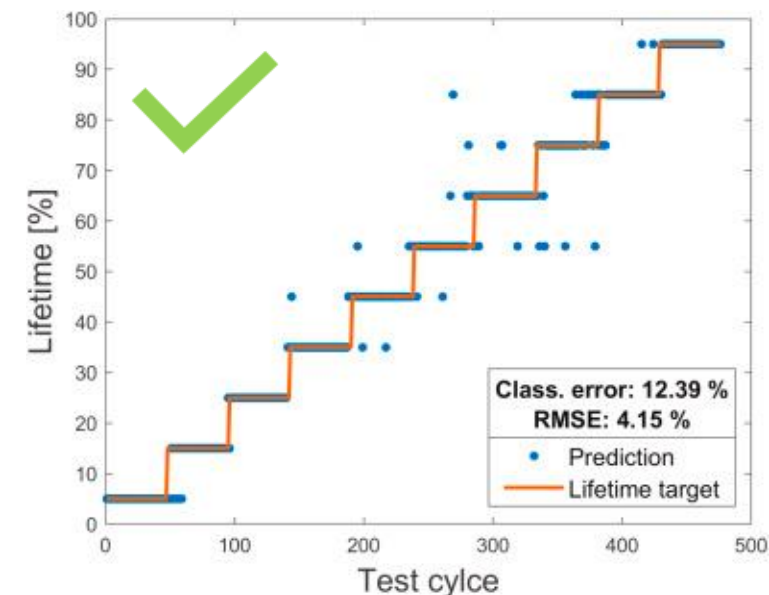
**High quality data**  
**High prediction resolution**



**Lower quality data**  
**High prediction resolution**



**Lower quality data**  
**Lower prediction resolution**



T. Dorst et al., Measurement: Sensors 22 (2022) 100376

# Task groups | ToR FAIR for Metrology

## • Implementation of the FAIR principles in a metrological context



Findable

+



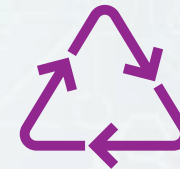
Accessible

+



Interoperable

+



Reusable

**Objective 1: Improving FAIRness** of metrology data for reproducibility & transparency

► **Streamline** key comparisons    ► Inclusion of community-wide **metadata standards**

**Objective 2: Examine** research practices & make recommendations

► Increase the value of FAIR metrology to the **broader community**    ► Prepare survey



Presentation: How to establish a resilient FAIR data system, *Dr. R. Hanisch (NIST)*

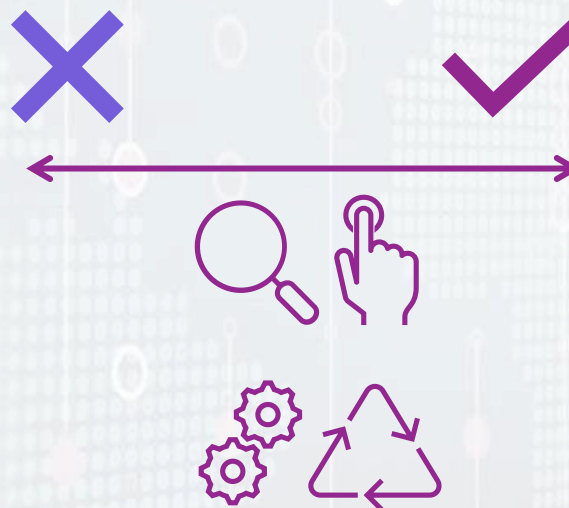


# Task groups | ToR FAIR for Metrology

My measurement data can be found  
on the shared internal folder  
cal\_data/2024\_10\_17/data.xlsx

	A	B	C	D	E	F	G
1	ref in K	dut in K	unc in K				
2	-20,00	19,90	0,50				
3	0,00	-0,05	0,20				
4	50,00	50,00	0,20				
5	100,00	100,25	0,80				
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							

Findable, accessible,  
interoperable, reuseable



[https://some.pid.example/dataset\\_1a4fb87](https://some.pid.example/dataset_1a4fb87)

```
{  "@context": "https://metrology.example/measurement_context.jsonld",
  "@type": "ex:data",
  "info": [
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      { "description": "Temperature measurement data",
        { "creation": "2024-10-17"}],
    "datasets": [
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        "label": "Temperature",
        "fields": [
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            "observedQuantity": "quantities:ITSK"},
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            "unit": "units:kelvin",
            "observedQuantity": "quantities:ITSK"},
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            "unit": "units:kelvin",
            "observedQuantity": "quantities:ITSK",
            "coverageFactor": 1.0}
        ],
        "datapoints": [
          [-20.00, 19.90, 0.50],
          [ 0.00, -0.05, 0.20],
          [ 50.00, 50.00, 0.20],
          [100.00, 100.25, 0.80]
```

# Task groups | ToR Harmonizing DCC & DRMC

- Develop user stories and value propositions for DCC & DRMC

**Purpose:** Harmonize procedures, improve understanding, prepare guidance documents

**Objective 1:** Identifying stakeholder needs

**Objective 2:** Developing common understanding & value proposition

**Objective 3:** Harmonizing DCC/DRMC & promoting DCC/DRMCs by user stories

CC  
CoC  
...

DCC  
DCoC  
DRMC  
DPP

AI



onable  
Storage

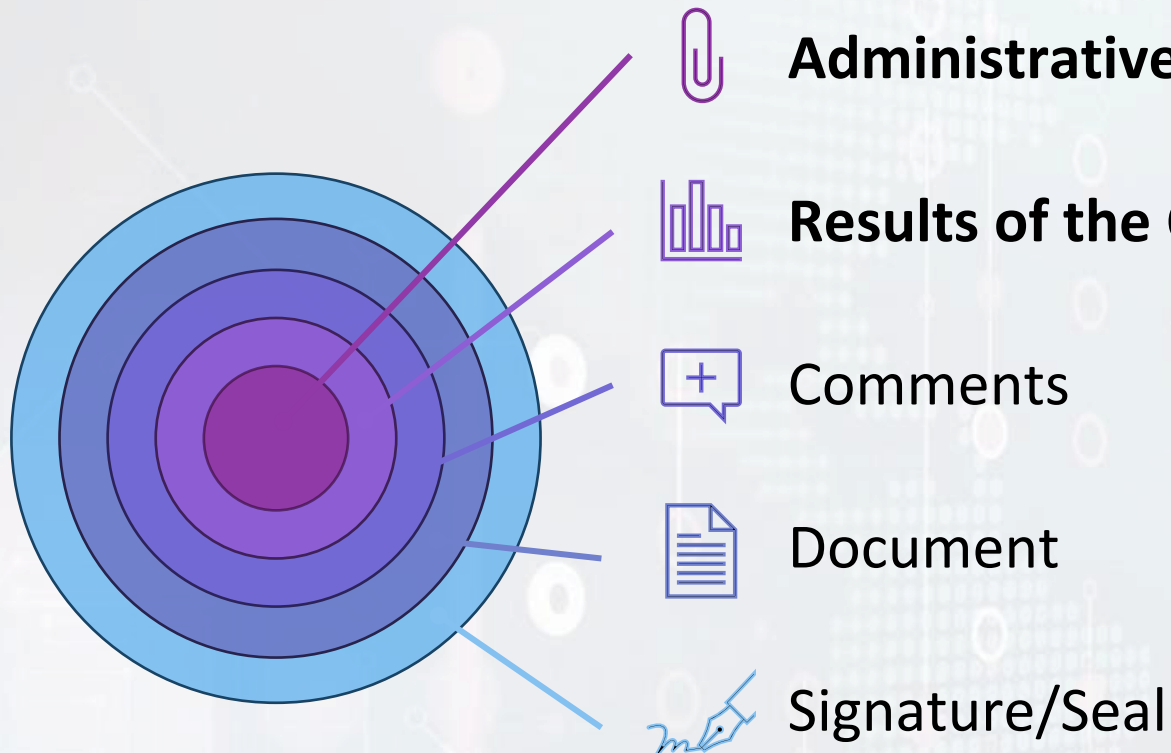
redictive  
aintenance



# Task groups | ToR Harmonizing DCC & DRMC

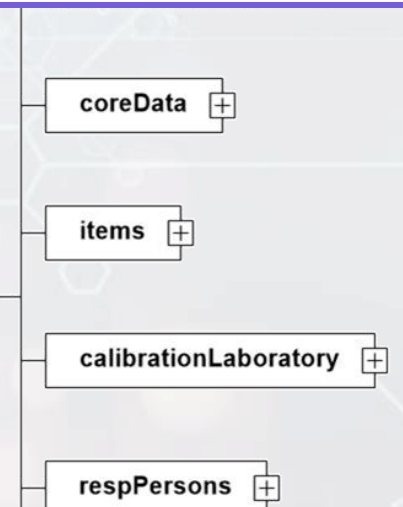
- **The structure and data-model of a DCC**

- Onion- or cell-like structure



If you thought that a PDF is a digital calibration certificate, think again!

<https://blog.beamex.com/>



**DCC** is the “**MP3 of metrology**”

- Revolutionizing processing industry as a flexible, secure game changer

# Task groups | ToR Metrological Semantics

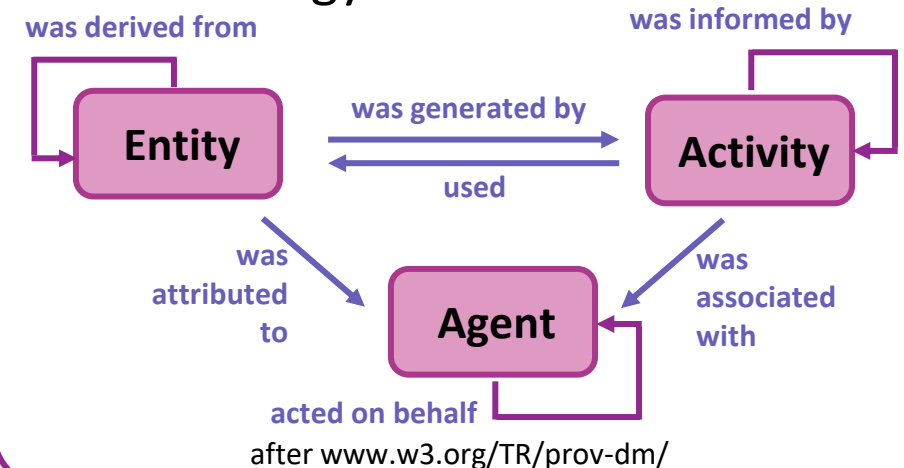
- **Foster harmonization and consistency in digitalization by semantics**

**Purpose:** Provide **conceptual modelling** and general software **architecture methodologies** for harmonization of digitalization

**Objective 1:** Develop **metadata models** for context to measurement data and QM system

**Objective 2:** Ensure **metadata models** to represent **broader concepts in QM systems** and model broadly applicable semantic concepts

**Example provenance** for assessment of quality, reliability, trust  
► **W3C PROV-DM model** with taxonomies, DCC namespaces, metrology semantics





# Task groups | ToR Metrological Semantics

- **Foster harmonization and consistency in digitalization by semantics**

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## **Example Enterprise Architecture**

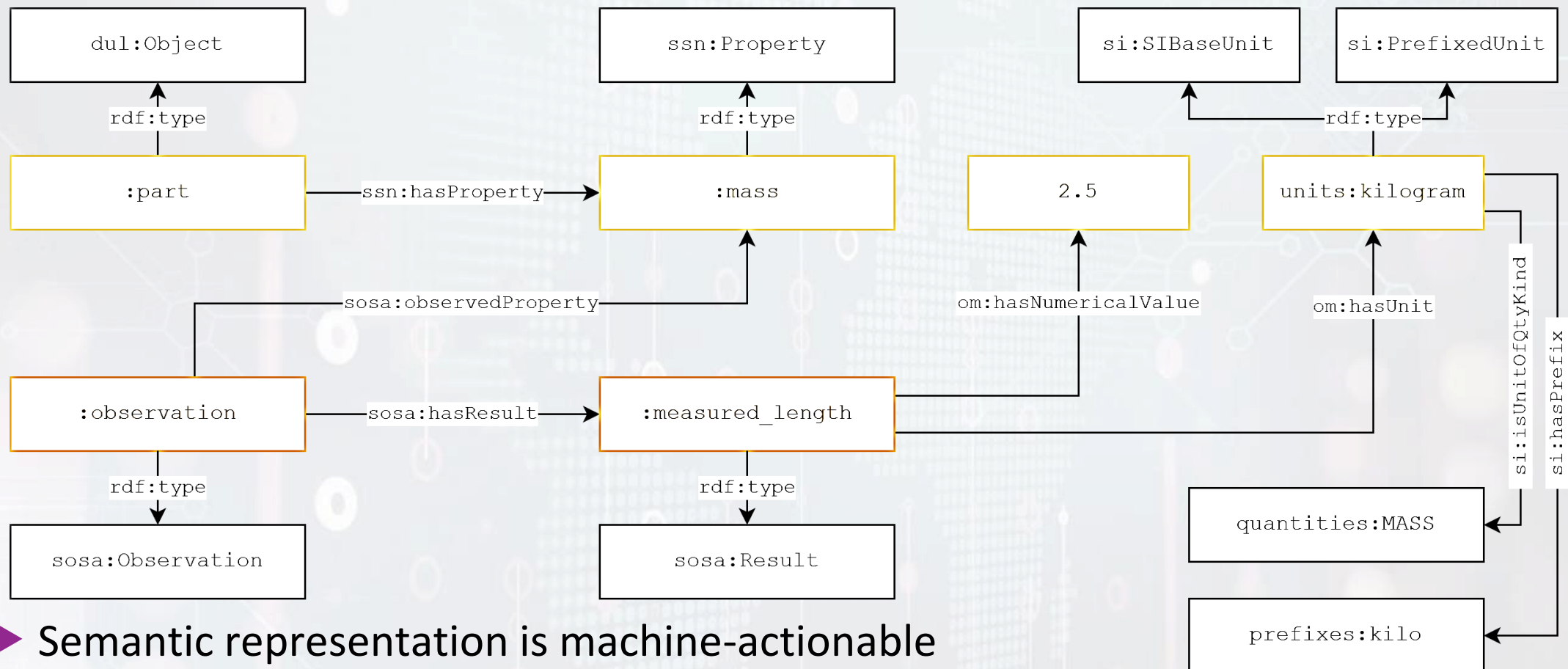
- ▶ Model complex systems and processes in metrology
- ▶ Provide guidance using an architecture framework
- ▶ E.g. adapt ISO 42010 to metrology

**ISO  
42010**

Software,  
systems and  
enterprise

# Task groups | ToR Metrological Semantics

- Example: knowledge graph of „The part has a mass of 2.5 kg”



► Semantic representation is machine-actionable



# Task groups | ToR SI-digital framework

## • Implementation of fundamental new digital metrological services

**Purpose:** Support the technical implementation of the SI Digital Framework (SIDF) as a user, test & feedback group

► **SI reference point**

<https://si-digital-framework.org/>

**Features of SI digital reference point**

- Standardized vocabularies for DCC, ...
- Coherent persistent identifier scheme
- Web services for software agents
- Web interfaces for humans


Provide technical and **strategic input**

Collaborate with CCU to **ensure align-ment** of the SIDF and the SI brochure

Advise the BIPM team & Forum MD


Review the work plan for the BIPM Digital Transformation Team


# Task groups | ToR SI-digital framework





Measurement  
Volume 187, January 2022, 110309

## Why a digital framework for the SI?

Richard J.C. Brown , Jan-Theodoor Janssen, Louise Wright

Show more 


+ Add to Mendeley  Share  Cite

<https://doi.org/10.1016/j.measurement.2021.110309> [Get rights and content](#)

### Abstract

There has been a significant quantity of debate recently about how metrology and the SI should embrace the emerging societal and scientific trends of digitalisation and the open data movement. Much of this discussion has focussed on 'how' this transition will be implemented, and recent conferences and significantly advanced this understanding (International Bureau of Weights and Measures, 2021 [1]). However, there has been little if any reflection on 'why' this transition is required. This deficiency is worth addressing to provide the evidence base for the 'why' and so drive forward faster progress with the 'how'. Analogy is drawn between the recent revision of the SI and the need to provide a similar step change in end users' experience of the benefits that digitalisation should bring.

### SI Digital Framework

Version: 1.0 Beta  last update: 2024-09-23

English

Units SI Prefixes Decisions Unit expressions Constants Quantities SPARQL Assistant

#### kelvin

[Back to list](#)

The kelvin, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant,  $k$ , to be  $1.380\,649 \times 10^{-23}$  when expressed in the unit  $\text{J K}^{-1}$ , which is equal to  $\text{kg m}^2 \text{s}^{-2} \text{K}^{-1}$ , where the kilogram, metre and second are defined in terms of  $h$ ,  $c$  and  $\Delta\nu_{\text{Cs}}$ .

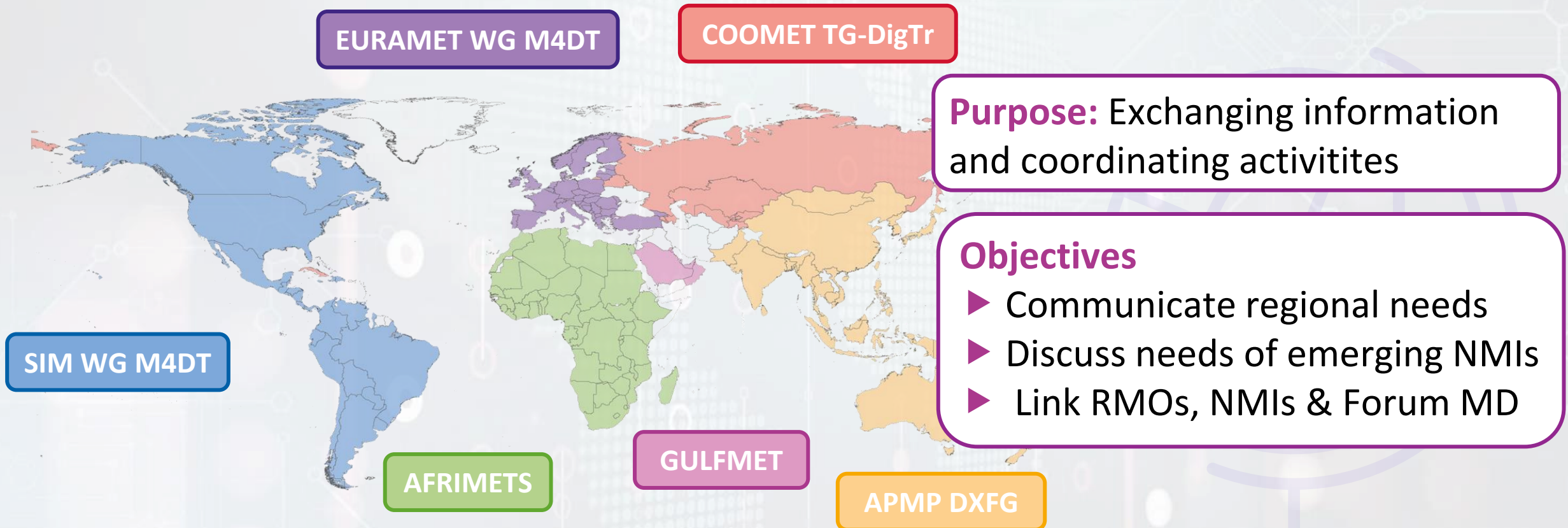
This definition is valid from 2019-05-20 [Previous Definition](#)

Unit	kelvin
Symbol	K
Quantity	<a href="#">thermodynamic temperature</a>
Defining Constant	<a href="#">Boltzmann constant</a>
Defining Resolution	<a href="#">CGPM Resolution 1 (2018)</a>
Unit Type	SI base unit
Defining Equation	$1 \text{ K} = \left( \frac{1.380\,649 \times 10^{-23}}{k} \right) \text{kg m}^2 \text{s}^{-2}$



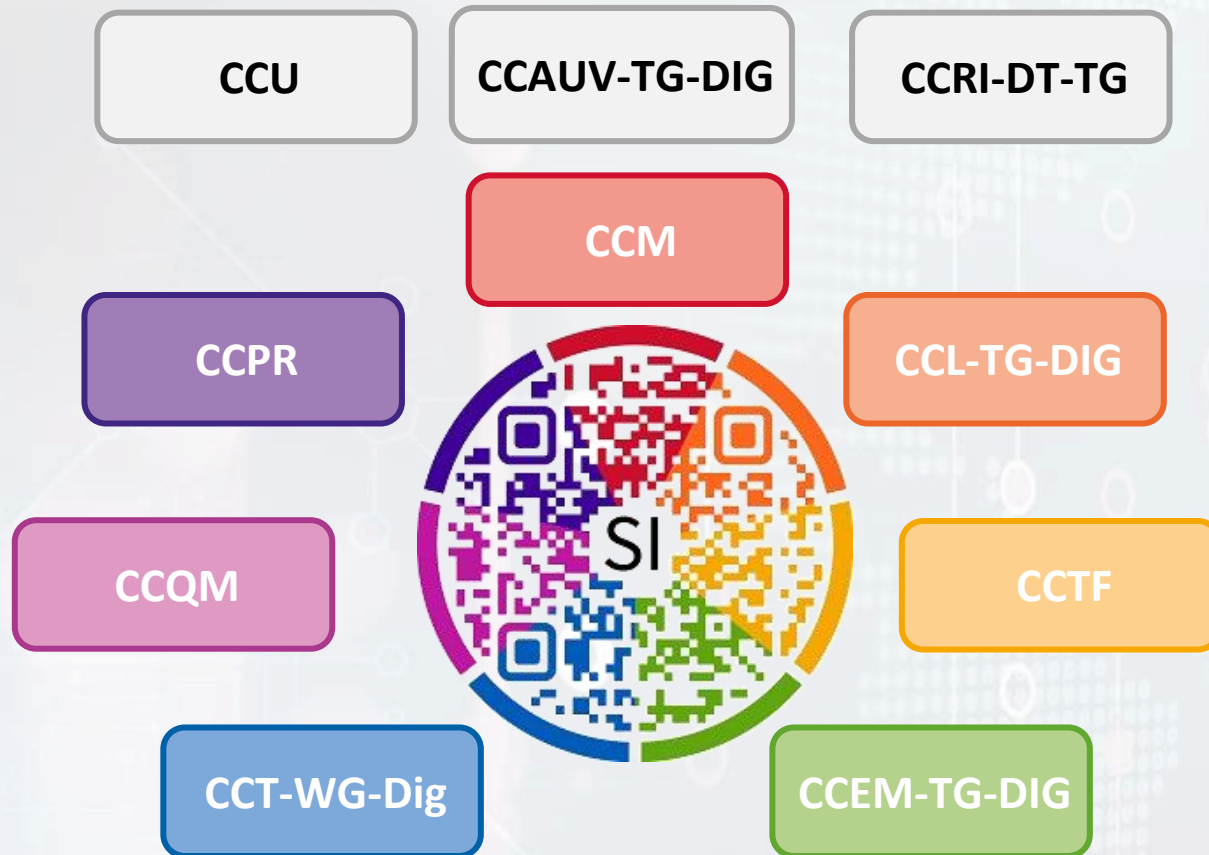
# Working groups | Coordination between RMOs

- Coordination of the activities of RMOs in digital transformation



# Working groups | Coordination between CCs

## • Coordination of activities of the CCs in digital transformation



**Purpose:** Exchanging information and coordinating activities

### Objectives

- Communicate CC digitalization
- Discuss needs of all CCs
- Provide feedback on opportunities, challenges, requirements of CCs to Forum-MD and link Forum-MD to **digital activities of CCs**



# Working groups | ToR Strategy

- **Strategy of Forum MD: Propose a long-term vision for Forum MD**

Monitor and react to relevant  
**developments** in digitalization

Ensure an **effective linkage**  
between organizations in liaison

Advise the FORUM-MD on its  
**optimal operational structure**

Prepare plenary meetings and propose  
conferences and other **events**





# Events and activities

Workshops, meetings & dissemination



# Events of CIPM | Focus themes on digitalization

- **This workshop | A multilateral view on all facets of digitalization**

- Session 1: Introduction, also report of F-MD & SIDF
- Session 2: Artificial Intelligence
- Session 3: Quantum Technologies
- Session 4: FAIR data & data quality



- **2<sup>nd</sup> general meeting of Forum MD**

- February 19, 2025: Workshop on **Emerging Topics in Digitalization of Metrology**
- February 20 and 21, 2025: Plenary reports of TGs & WGs, Reports of liaison group



# Events of Forum MD | Workshops

- **Workshop Metrological Traceability, IMEKO August 28th 2024**
  - Co-organized by the CIPM Forum MD in partnership with IMEKO TC6 (Digitalization), TC8 (Traceability in Metrology), and TC21 (Mathematical Tools for Measurements)
    - Organizers: Blair Hall & Frank Härtig, about 80 participants



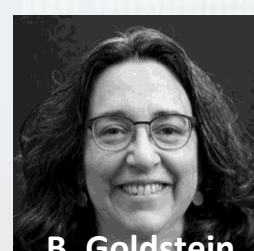
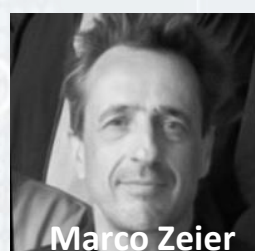
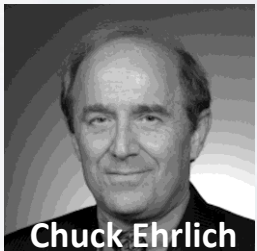


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  - ▶ Organizers: Blair Hall & Frank Härtig, about 80 participants
  - ▶ **Session 1: Foundational principles of metrological traceability** and how those principles can be architecturally modelled and implemented in the international quality infrastructure
  - ▶ **Session 2: Outlook into the future** how the core concepts of traceability are being applied to digital frameworks. With a special focus on **new developments in digital metrology**.

- **Speakers**



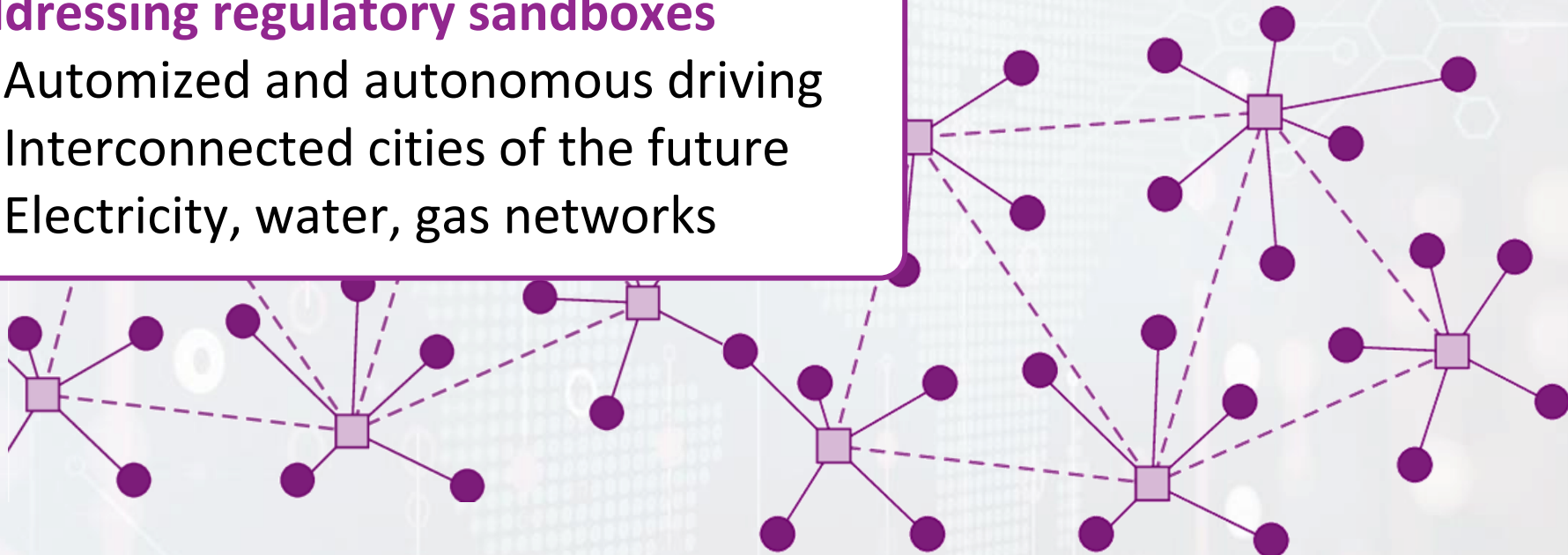
# Events of Forum MD | Workshops

- **Online Workshop on Complex sensor networks, February 11-12, 2025**

- Complex sensor networks of multiple (heterogeneous) sensors
  - ▶ **Organizers** Cui Shan, NMC and Chiyun Cho, KRISS, with Martin Koval, CMI, Sascha Eichstädt, PTB, Narin Chanthawong, NIMT, Aldo García González, CENAM

## Addressing regulatory sandboxes

- ▶ Automated and autonomous driving
- ▶ Interconnected cities of the future
- ▶ Electricity, water, gas networks







# Outlook into the future

## Digitalization in metrology for all

# Future Topics | Metrology for complex systems

- **Emerging metrology needs in complex systems**

- Extended & strongly coupled sensor networks of next generation
  - ▶ From large sensor networks to **sensor swarms** of small, simple sensors

## **Large heterogeneous sensor networks**

- ▶ Responsive, adaptive, self-organized
- ▶ Uncertainties needs to be defined
- ▶ **Self-traceability** by use of massive AI

## **Examples of sensor swarm applications**

- ▶ Gas detection wearables for safety
- ▶ **Spatio-temporal** climate monitoring
- ▶ Sensitive electric / magnetic field det.



Large swarms of sensors measure more than a single sensor  
as e.g. mapping pipelines @ <https://cordis.europa.eu/>



# Future Topics | Perceptual metrology

- **Emerging metrology needs in sensory and cognitive systems**
  - **Perceptual metrology** based on sensors of the human sensory systems
    - ▶ **Stimuli** from a large set as sight, hearing, touch, taste, smell

## Digital perceptual measurement approaches

- ▶ Translate subjective experiences into objective data by digital tools
- ▶ Metrology **to objectivate & quantify** human sensory responses
- ▶ **Digital or computer sensing** and responding to environment
- ▶ Next generation **perceptual human-machine interactions** need **digital QI**



# Future Topics | Metrology for quantum information & industry

- **Emerging metrology needs in quantum technology**

**Applications in quantum sensors, computers, communication**

- ▶ **Traceability & characterization** for new technology and devices
- ▶ Coordination for a coherent **international quantum ecosystem**



Presentation: Accelerating the adoption of Quantum Technologies through Measurements and Standards, *Dr.*

Report of BIPM Workshop on Accelerating the Adoption of Quantum Technologies through Measurements and Standards

*BIPM – March 21-22, 2024*





# Summary | Forum Metrology and Digitalization

## • New approaches of CIPM | Horizontal themes in a new structure

**Forum MD** brings together experts from different areas of metrology

- ▶ Address urgent **metrology questions of digitalization**

**Forum MD** complements and intertwines activities of Consultative Committees & Regional Metrology Organizations

**Forum MD** covers themes by **6 Task Groups**: FAIR data, data quality, metrological semantics, DCCs & DRMCs, SI digital framework, trustworthy AI

**Forum MD** covers **all aspects** of metrology with respect to **digital challenges**

- ▶ **Understanding & harmonization**
- ▶ **Dissemination & interaction**

# Summary | Forum Metrology and Digitalization

- New approaches of CIPM | Horizontal theme in a new structure

**Forum MD & CIPM** give answers to the most urgent issues in digitalization by metrological approaches





# Thank you!

Cornelia Denz, President  
Physikalisch-Technische Bundesanstalt  
Braunschweig and Berlin  
**[cornelia.denz@ptb.de](mailto:cornelia.denz@ptb.de)**

Innovation Cluster Digitalization



News on Digitalization

