NPL National Physical Laboratory

Bureau International des Poids et Mesures

SI DIGITAL FRAMEWORK

Digital references for FAIR measurement data

The SI Digital Framework: Underpinning FAIR measurement data

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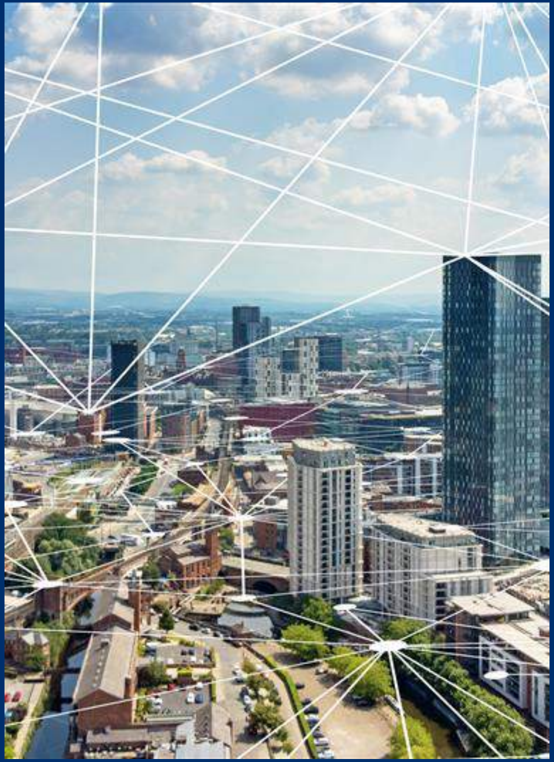
BCS FACS webinar

Tuesday 20 February 2024

NPL

About NPL

- UK’s National Metrology Institute founded in 1900
- A public corporation owned by the Department for Science, Innovation and Technology (DSIT)
- Based in Teddington (London) with locations in Glasgow, Surrey, Cambridge, Huddersfield and Solihull
- Strategic partners DSIT, the University of Surrey and The University of Strathclyde
- 800 scientists with a breadth and depth of metrology expertise.



National Challenges

Metrology improves the effectiveness and efficiency of science and trust in its outcomes, which in turn unlocks the potential of innovation, allowing faster routes to market. Evidence-based policy, regulation and decision making are heavily reliant on measurements and data, and NPL is key in providing and digitising that measurement infrastructure.

Measurement

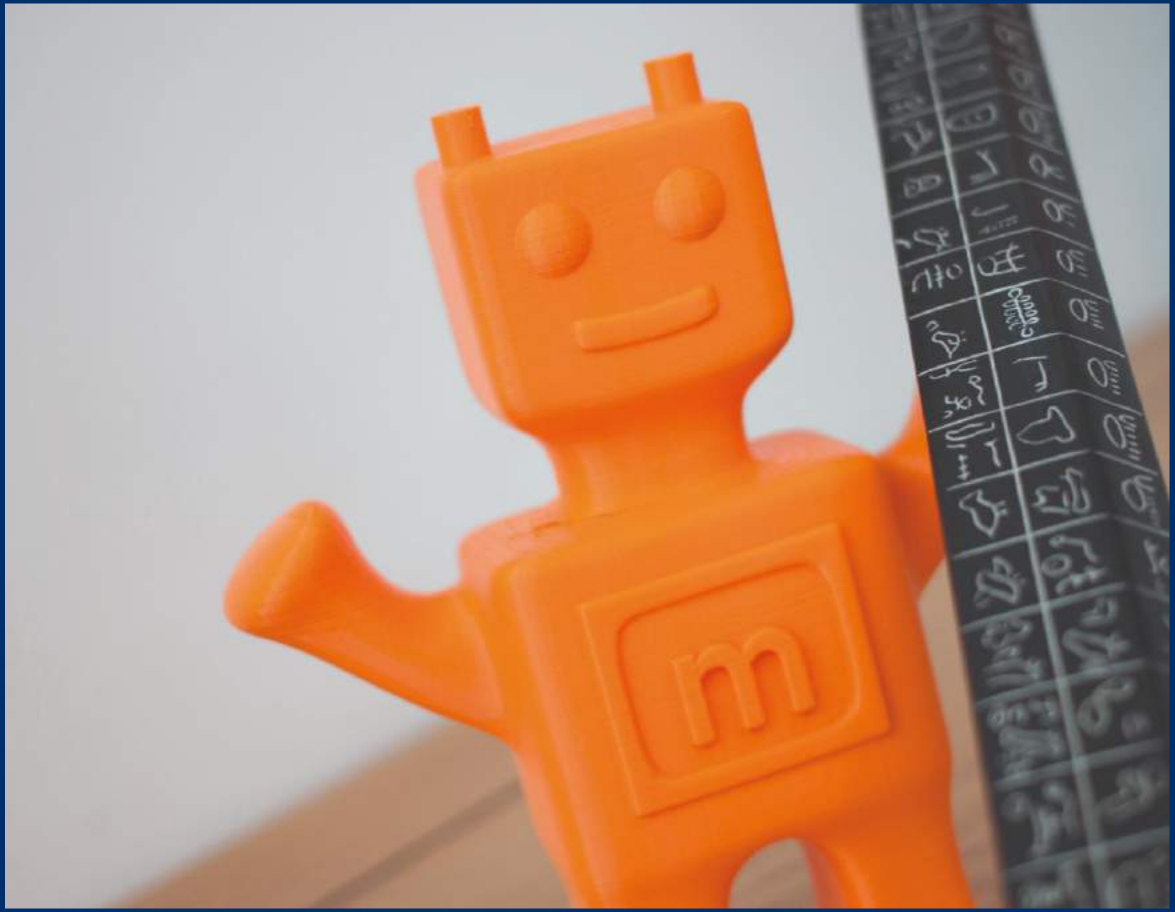
Measurement result = numerical value assigned to a physical property of an object

uncertainty value

20 cm ±1 cm, at 95%

unit

confidence level



https://www.npl.co.uk/gpgs/beginners-guide-measurement-uncertainty-gpg11

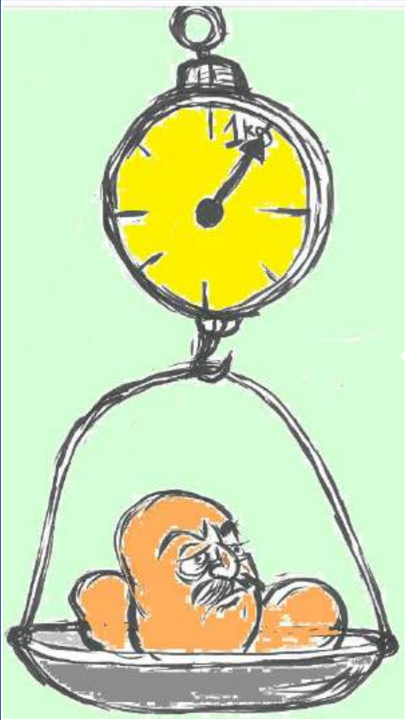
Metrology

Metrology:

- is the science of measurement
- cuts across all domains of science
- contributes to industry’s quality infrastructure
- has an essential role in reproducibility in evidence-based science

Traceability chain

1 kg of potatoes, weighed using retailer’s weighing scales



Retailer’s weighing scales calibrated against

Local trading standards weights

Calibrated against

UK national standard kilogram

International intercomparison

International prototype kilogram

Note: After 20 May 2019, the kilogram is defined in terms of the Planck constant rather than as the mass of the International Prototype of the Kilogram held at the BIPM

Credit: Keith Lines, NPL

The BIPM – an international organisation

The Metre Convention
was signed in Paris
by 17 nations on
20 May 1875

"TO ASSURE
THE INTERNATIONAL
UNIFICATION AND
PERFECTION OF
THE METRIC SYSTEM"

CGPM – Conférence générale des poids et mesures
Official representatives of Member States (and Associates as observers).

CIPM – Comité international des poids et mesures
14 then 18 members all from different nationalities and elected by the CGPM.

Administrative and technical secretariat/BIPM staff, (Sèvres, France)
- *Laboratory work carried out by the BIPM*
- *Liaison, Coordination, Communication and Promotion*
- *Capacity building*

1875

17 Member States

14 CIPM Members

Director + 2 Assistants

2024

64 Member States + 36 Associates

18 CIPM Members

Director + 70 staff

Credit: BIPM www.bipm.org

The BIPM

… is the **intergovernmental organization established by the Metre Convention in 1875,** through which Member States act together on matters related to measurement science and measurement standards

NPL


THE VISION AND MISSION OF THE BIPM

www.bipm.org

CENTRE for
<u>COLLABORATION</u>
Scientific and technical collaboration between Member States

<u>ADVOCACY</u>
Representing the world-wide measurement community

BIPM

<u>COORDINATION</u>
of the world-wide measurement system


THE OBJECTIVES OF THE BIPM

www.bipm.org

Laboratory activities

Calibrations | **Comparisons**

JCGM | **CIPM MRA** | **UTC**

CBKT | **JCTLM**

Established in 1875 when 17 States signed the Metre Convention, now with 64 Member States and 36 Associates, covering around 98 % of the world's GDP according to 2022 IMF data.

"to assure the international unification and perfection of the metric system"

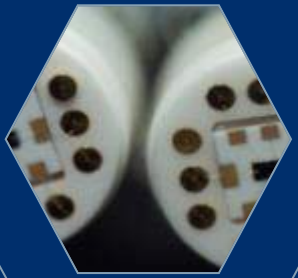
Credit: BIPM www.bipm.org

The BIPM – main technical roles

NPL

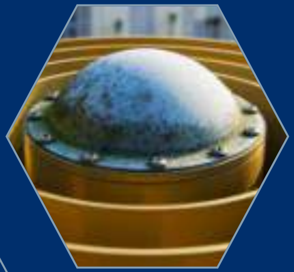
Travelling standards

Maintains travelling standards to compare fixed national references *e.g.*, Josephson Junctions for the volt, Quantum Hall devices for the ohm, etc.



Coordinated Universal Time

Realizes and disseminates Coordinated Universal Time (UTC) based on weighted averages of ~ 500 clocks from over 80 national laboratories world-wide.

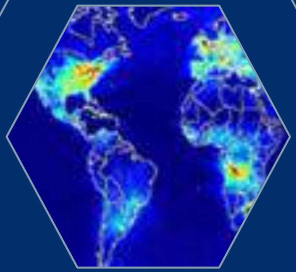


kilogram

Ensures metrological traceability of mass measurements based on the new definition of the kilogram in terms of a physical constant.

Coordinate comparisons

Organizes comparisons for physical and chemical quantities world-wide.



Unique world reference facilities

Maintains unique world reference facilities *e.g.*, SIR (ionizing radiation and isotopes), ozone spectrophotometers

Credit: BIPM www.bipm.org

Drivers: CIPM MRA

- CIPM Mutual Recognition Agreement (MRA) is:

  a mechanism for international comparability of measurement data

- CGPM 2022 resolution 2 recognized the need for

  “a full digital representation of the SI, including robust, unambiguous, and machine-actionable representations of measurement units, values and uncertainties”

https://www.bipm.org/en/cgpm-2022/resolution-2

Drivers: FAIR principles

The FAIR (Findable, Accessible, Interoperable, Reusable) guiding principles established in the seminal paper Wilkinson, M. D. *et al.* (2016) :

- To ensure credibility of research data
- To improve research data curation
- To achieve wider dissemination of scientific results
- To promote data-driven innovation

The SI Digital Framework will help measurement data producers adhere to the FAIR principles

Wilkinson, M. D. *et al.* (2016) ‘The FAIR Guiding Principles for scientific data management and stewardship’, *Scientific Data*, 3(1), p. 160018. doi: 10.1038/sdata.2016.18

Drivers: FAIR principles

Findability, Accessibility

The SI Digital Framework supports **Findability** through:

- Resolvable URI-based persistent identifiers
- Semantic Web language OWL

The SI Digital Framework supports **Accessibility** through:

- Standard web languages and protocols (OWL, SPARQL, REST APIs),
- Unique reference point under the root URI http://si-digital-framework.org/

Findable			
F1. (Meta)data are assigned a globally unique and persistent identifier	F2. Data are described with rich metadata (defined by R1)	F3. Metadata clearly and explicitly include the identifier of the data they describe	F4. (Meta)data are registered or indexed in a searchable resource
Accessible			
A1. (Meta)data are retrievable by their identifier using a standardised communications protocol		A2. Metadata are accessible, even when the data are no longer available	
A1.1 The protocol is open, free, and universally implementable	A1.2 The protocol allows for an authentication and authorisation procedure, where necessary		

Source: https://www.go-fair.org/fair-principles/

Drivers: FAIR principles

Interoperability, Reusability

The SI Digital Framework supports **Interoperability** through:

- A coherent network of OWL ontologies
- Resolvable URI-based ontology namespaces
- Relying on existing FAIR ontologies where possible

The SI Digital Framework supports **Reusability** through:

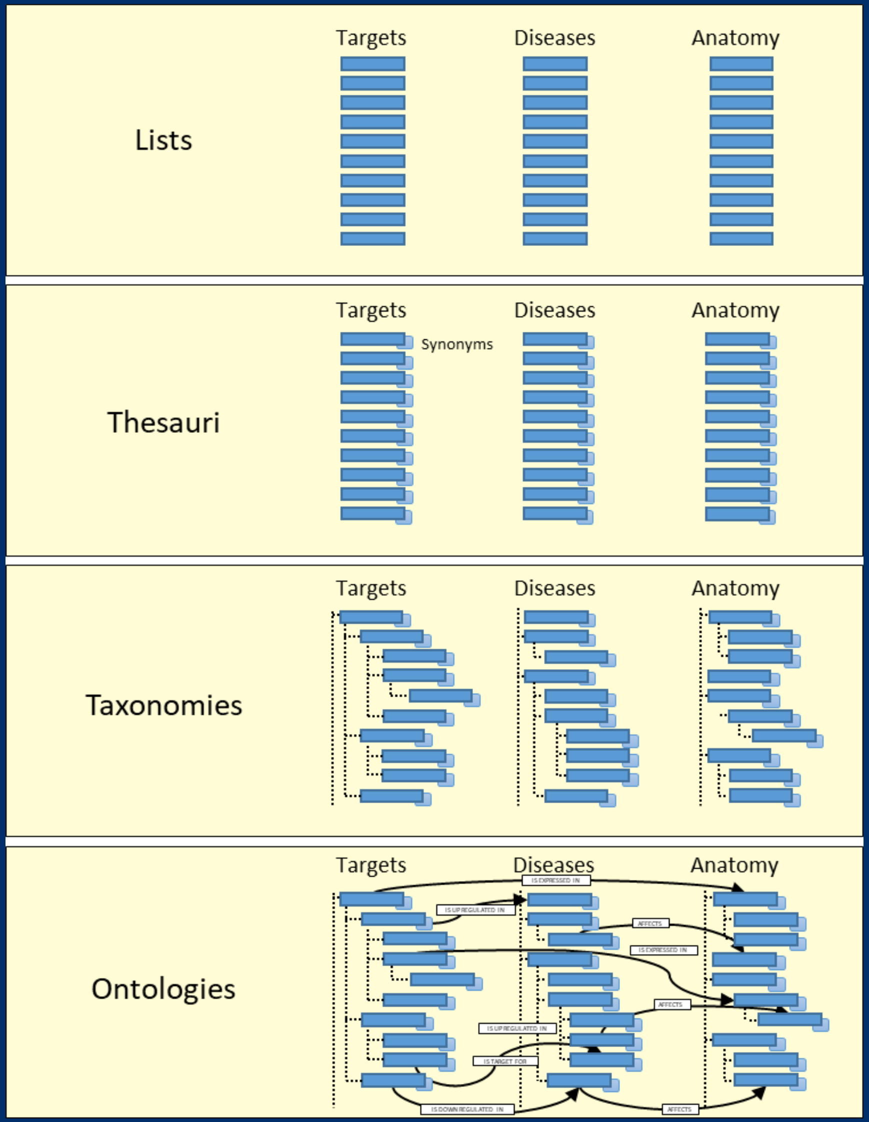
- Authoritative digital reference for the International System of Units
- Semantic description of decisions/resolution

Interoperable		
I1. (Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.	I2. (Meta)data use vocabularies that follow FAIR principles	I3. (Meta)data include qualified references to other (meta)data
Reusable		
R1. (Meta)data are richly described with a plurality of accurate and relevant attributes		
R1.1. (Meta)data are released with a clear and accessible data usage license	R1.2. (Meta)data are associated with detailed provenance	R1.3. (Meta)data meet domain-relevant community standards

Source: https://www.go-fair.org/fair-principles/

Ontologies

- Ontologies are shareable, reusable and computable representations of knowledge



- SI Digital Framework adopts the OWL language, a W3C standard for the semantic web

Image: Swain, M. (2013). Knowledge Representation. In: Dubitzky, W., Wolkenhauer, O., Cho, KH., Yokota, H. (eds) Encyclopedia of Systems Biology. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-9863-7_595

https://www.w3.org/OWL/

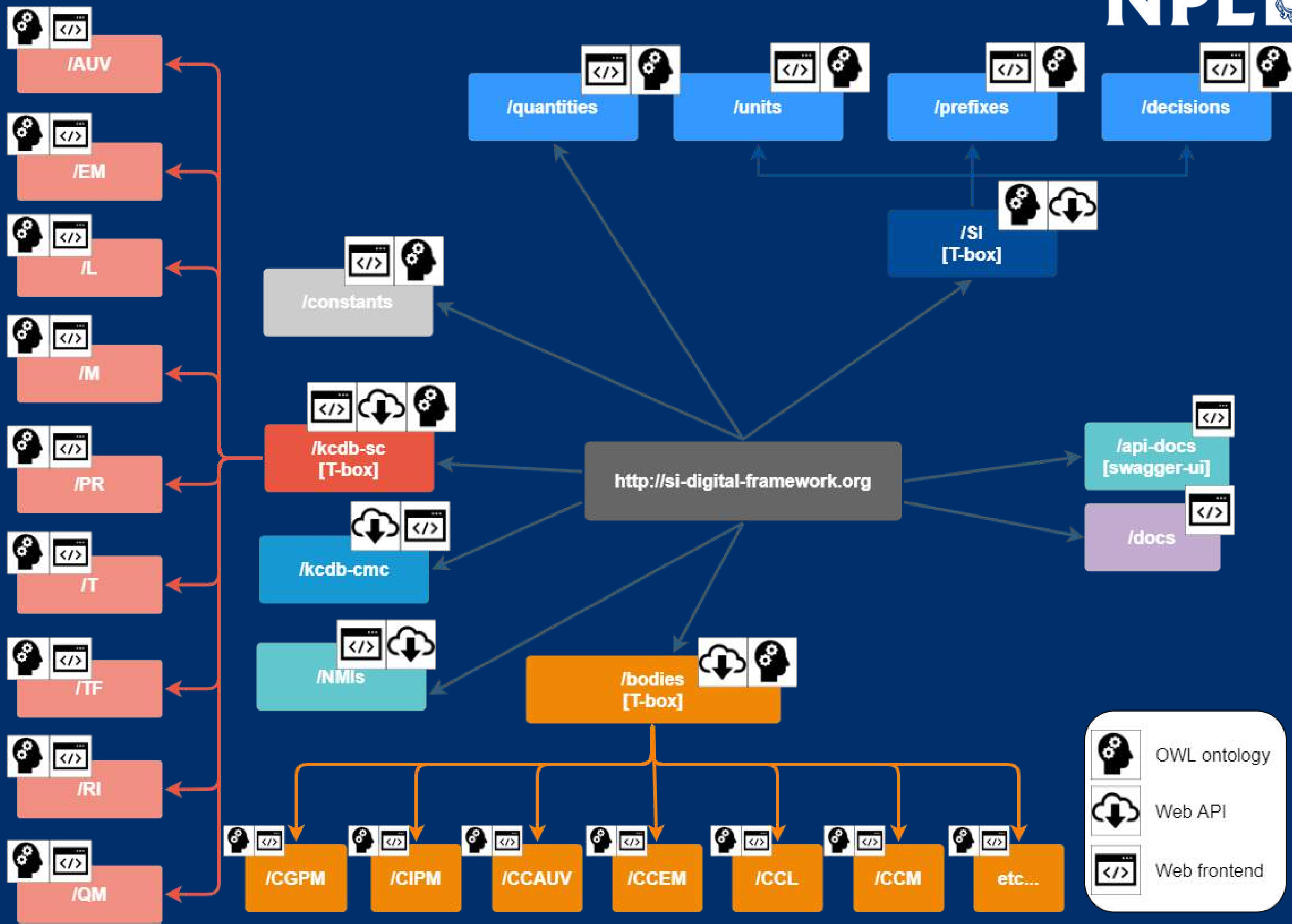
Drivers: Reproducibility and Quality assurance

Digital elements of the reproducibility and quality chain must be characterised:

- Datasets;
- Models (e.g., used to evaluate measurement uncertainty);
- Algorithms;
- Software.

Complete characterisation must include FAIR references to the International System of Units (SI)

SI Digital Framework namespace hierarchy



Notes

The SI Digital Framework is meant to:

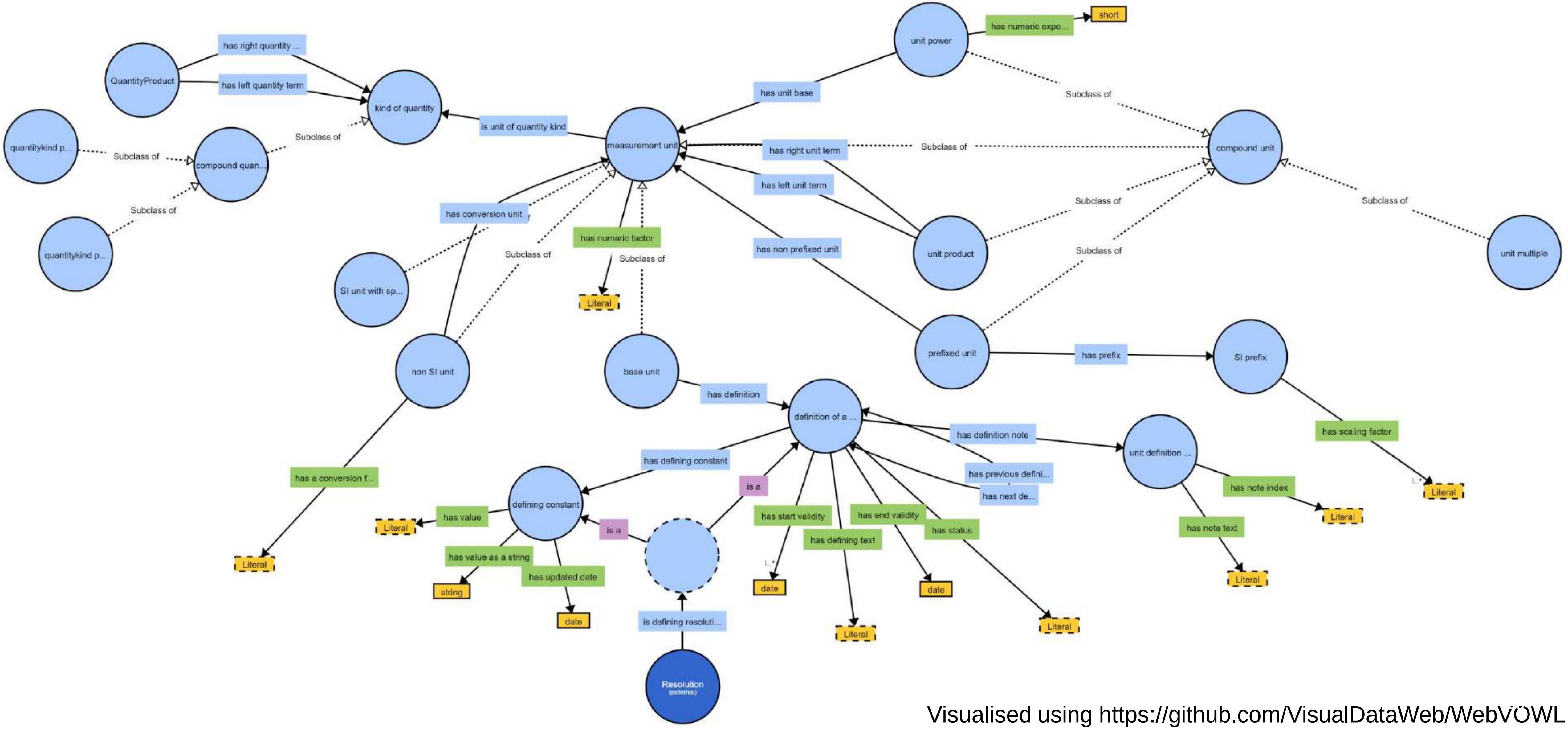
- Complement existing semantic resources, with authoritative, persistent and unique digital SI references
- Complement other aspects to measurement data quality
- First release, expecting feedback from the metrology community

Overview of the SI Reference Point

- Aims to provide unique digital references for the concepts and definitions of the International System of Units (SI)
- Source of content is mainly the SI Brochure
- Aims for machine-actionability:
  - Unique persistent identifiers for findability
  - Resolvable URIs for accessibility
  - Underpinned by OWL ontologies for interoperability

https://www.bipm.org/en/publications/si-brochure/

SI ontology



Visualised using https://github.com/VisualDataWeb/WebVOWL

SI Units

In the SI Brochure:

$$1\ \mathrm{Hz} = \frac{\Delta\nu_{\mathrm{Cs}}}{9\,192\,631\,770} \quad \text{or} \quad 1\ \mathrm{s} = \frac{9\,192\,631\,770}{\Delta\nu_{\mathrm{Cs}}}.$$


```
units:second a si:SIBaseUnit ;
    si:hasDefinition si:second1960,si:second1967,si:second2018 ;
    si:hasSymbol "s"^^xsd:string ;
    si:hasUnitTypeAsString "SI base unit"@en,"Unité SI de base"@fr ;
    si:isUnitOfQtyKind quantities:TIME ;
    skos:prefLabel "second"@en,"seconde"@fr .
```

- Second is an SI base unit
- It has had three definitions
- Its symbol is “s”

- It is the SI unit for quantity time

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

https://www.bipm.org/en/publications/si-brochure/

Unit definitions

```
si:second2018 a si:Definition ;
    si:hasDefiningConstant constants:HyperfineTransitionFrequencyOfCs-133 ;
    si:hasDefiningEquation "[1\\;{\\rm{Hz}} = [...]"^^xsd:string ;
    si:hasDefiningResolution cgpm:CGPM26-Res1 ;
    si:hasDefiningText "The second,defined by [...]"@en,
    si:hasDefinitionNote si:second2018note1,
        si:second2018note2,
        si:second2018note3,
        si:second2018note4,
        si:second2018note5 ;
    si:hasPreviousDefinition si:second1967 ;
    si:hasStartValidity "2019-05-20"^^xsd:date ;
    si:hasStatus "current"^^xsd:string ;
    si:prefixRestriction false ;
    skos:prefLabel "second2018"@en,
        "seconde2018"@fr .
```

- Second 2018 definition has this defining constant
- It has this defining equation (LaTeX string for now...)
- It has been decided by this resolution
- It has some definition notes
- The previous definition is 1967
- It has been valid since 20/05/2019 …

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Defining Constants

```
constants:HyperfineTransitionFrequencyOfCs-133 a si:Constant ;
    si:hasDatatype xsd:integer ;
    si:hasDefiningResolution cgpm:CGPM13-Res1 ;
    si:hasSymbol "$\\Delta\\nu_{\\rm{Cs}}$"^^xsd:string ;
    si:hasUnit units:hertz ;
    si:hasUpdatedDate "1967-10-13"^^xsd:date ;
    si:hasValue 9192631770 ;
    si:hasValueAsString "9 192 631 770"^^xsd:string ;
    skos:hiddenLabel "HyperfineSplitting"^^xsd:string ;
    skos:prefLabel "hyperfine transition frequency of Cs-133"@en,
        "fréquence de la transition hyperfine du césium"@fr .
```

- The hyperfine transition frequency of cesium 133 is an SI constant
- It has been defined in a CGPM resolution
- Its unit is hertz
- Its numeric value is this number

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Prefixes

```
prefixes:milli a si:SIPrefix ;
    si:hasDatatype xsd:decimal ;
    si:hasDefiningResolution cgpm:CGPM11-Res12 ;
    si:hasScalingFactor 0.001 ;
    si:hasSymbol "m"^^xsd:string ;
    skos:prefLabel "milli"@en,
        "milli"@fr .
```

- milli is an SI prefix
- It has been defined in this resolution
- Its scaling factor is 0.001
- Its symbol is “m”

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Prefixes (digression)

2019 9th edition

3 Decimal multiples and sub-multiples of SI units

Decimal multiples and submultiples ranging from 10^{30} to 10^{-30} are provided for use with the SI units. The names and symbols of these multiple and sub-multiple prefixes are presented in Table 7.

Prefix symbols are printed in upright typeface, as are unit symbols, regardless of the typeface used in the surrounding text and are attached to unit symbols without a space between the prefix symbol and the unit symbol. With the exception of da (deca), h (hecto) and k (kilo), all multiple prefix symbols are upper-case letters and all sub-multiple prefix symbols are lowercase letters. All prefix names are printed in lowercase letters, except at the beginning of a sentence.

The SI prefixes refer strictly to powers of 10. They should not be used to indicate powers of 2 (for example, one kilobit represents 1000 bits and not 1024 bits). The names and symbols for prefixes to be used with powers of 2 are recommended as follows:

kibi	Ki	2^{10}
mebi	Mi	2^{20}
gibi	Gi	2^{30}
tebi	Ti	2^{40}
pebi	Pi	2^{50}
exbi	Ei	2^{60}
zebi	Zi	2^{70}
yobi	Yi	2^{80}

Table 7. SI prefixes

Factor	Name	Symbol	Factor	Name	Symbol
10^{1}	deca	da	10^{-1}	deci	d
10^{2}	hecto	h	10^{-2}	centi	c
10^{3}	kilo	k	10^{-3}	milli	m
10^{6}	mega	M	10^{-6}	micro	µ
10^{9}	giga	G	10^{-9}	nano	n
10^{12}	tera	T	10^{-12}	pico	p
10^{15}	peta	P	10^{-15}	femto	f
10^{18}	exa	E	10^{-18}	atto	a
10^{21}	zetta	Z	10^{-21}	zepto	z
10^{24}	yotta	Y	10^{-24}	yocto	y
10^{27}	ronna	R	10^{-27}	ronto	r
10^{30}	quetta	Q	10^{-30}	quecto	q

2006 8th edition

…M (1960, Resolution 12; CR, 87) adopted a series of prefix names and …s to form the names and symbols of the decimal multiples and …f SI units, ranging from 10^{12} to 10^{-12}. Prefixes for 10^{-15} and 10^{-18} were …2th CGPM (1964, Resolution 8; CR, 94), for 10^{15} and 10^{18} by the …975, Resolution 10; CR, 106 and *Metrologia*, 1975, **11**, 180-181), and …10^{-21} and 10^{-24} by the 19th CGPM (1991, Resolution 4; CR, 185 and …92, **29**, 3). Table 5 lists all approved prefix names and symbols.

…ixes

…ame	Symbol	Factor	Name	Symbol
…eca	da	10^{-1}	deci	d
…ecto	h	10^{-2}	centi	c
…lo	k	10^{-3}	milli	m
…ega	M	10^{-6}	micro	µ
…ga	G	10^{-9}	nano	n
…ra	T	10^{-12}	pico	p
…eta	P	10^{-15}	femto	f
…xa	E	10^{-18}	atto	a
…etta	Z	10^{-21}	zepto	z
10^{24} yotta	Y	10^{-24}	yocto	y

These SI prefixes refer strictly to powers of 10. They should not be used to indicate powers of 2 (for example, one kilobit represents 1000 bits and not 1024 bits). The IEC has adopted prefixes for binary powers in the international standard IEC 60027-2: 2005, third edition, *Letter symbols to be used in electrical technology – Part 2: Telecommunications and electronics*. The names and symbols for the prefixes corresponding to 2^{10}, 2^{20}, 2^{30}, 2^{40}, 2^{50}, and 2^{60} are, respectively: kibi, Ki; mebi, Mi; gibi, Gi; tebi, Ti; pebi, Pi; and exbi, Ei. Thus, for example, one kibibyte would be written: 1 KiB = 2^{10} B = 1024 B, where B denotes a byte. Although these prefixes are not part of the SI, they should be used in the field of information technology to avoid the incorrect usage of the SI prefixes.

Prefixed units

```
units:kilogram a si:PrefixedUnit,si:SIBaseUnit ;
    si:hasDefinition si:kilogram1901,
        si:kilogram2018 ;
    si:hasNonPrefixedUnit units:gram ;
    si:hasPrefix prefixes:kilo ;
    si:hasSymbol "kg"^^xsd:string ;
    si:hasUnitTypeAsString "SI base unit"@en,
        "Unité SI de base"@fr ;
    si:isUnitOfQtyKind quantities:MASS ;
    skos:prefLabel "kilogram"@en,
        "kilogramme"@fr .
```

- Kilogram is an SI base unit, that is also a prefixed unit
- It has had two definitions
- Its corresponding non prefixed unit is gram
- Its prefix is kilo

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Quantities

```
quantities:TIME a si:QuantityKind ;
    si:hasUnit units:second ;
    skos:altLabel "TIME"^^xsd:string ;
    skos:prefLabel "time"@en,
        "temps"@fr .
```

Time’s unit is a simple SI unit: second

```
quantities:VELO a si:QuantityKind ;
    si:hasUnit [ a si:UnitProduct ;
            si:hasLeftUnitTerm units:metre ;
            si:hasRightUnitTerm [ a si:UnitPower ;
                    si:hasNumericExponent "-1"^^xsd:short ;
                    si:hasUnitBase units:second ] ] ;
    skos:altLabel "VELO"^^xsd:string ;
    skos:prefLabel "velocity"@en,
        "vitesse"@fr .
```

Velocity’s unit is a compound unit: metre per second

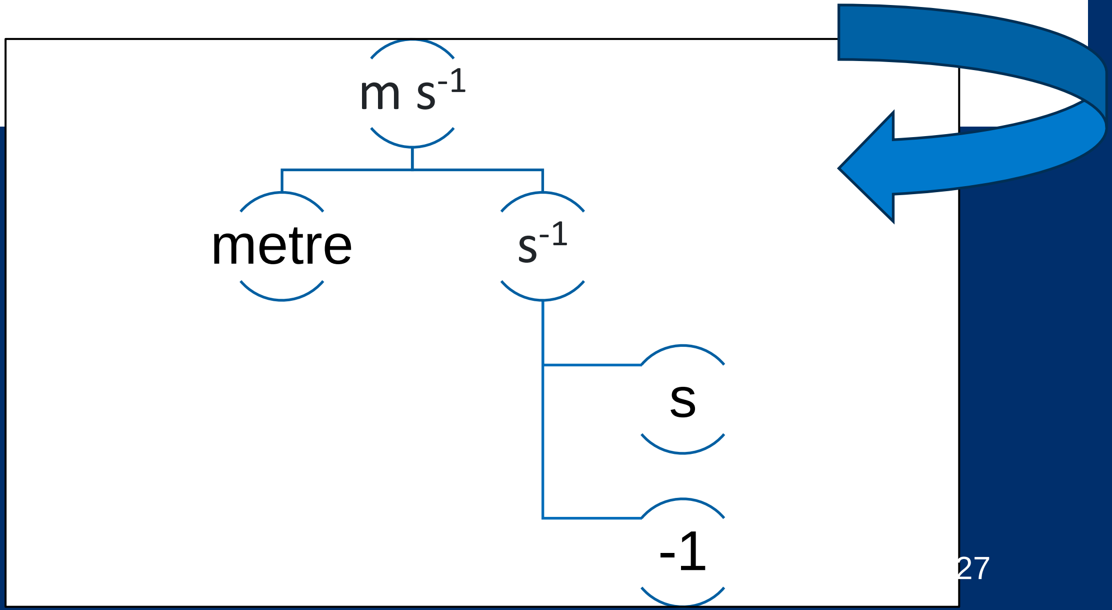
Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Compound units

NPL

Example for metre per second (m s^{-1})

```
[ a                       si:UnitProduct ;
  si:hasLeftUnitTerm      units:metre ;
  si:hasRightUnitTerm     [ a                         si:UnitPower ;
                            si:hasNumericExponent     "-1"^^xsd:short ;
                            si:hasUnitBase            units:second
                          ]
] .
```



This representation preserves the order:

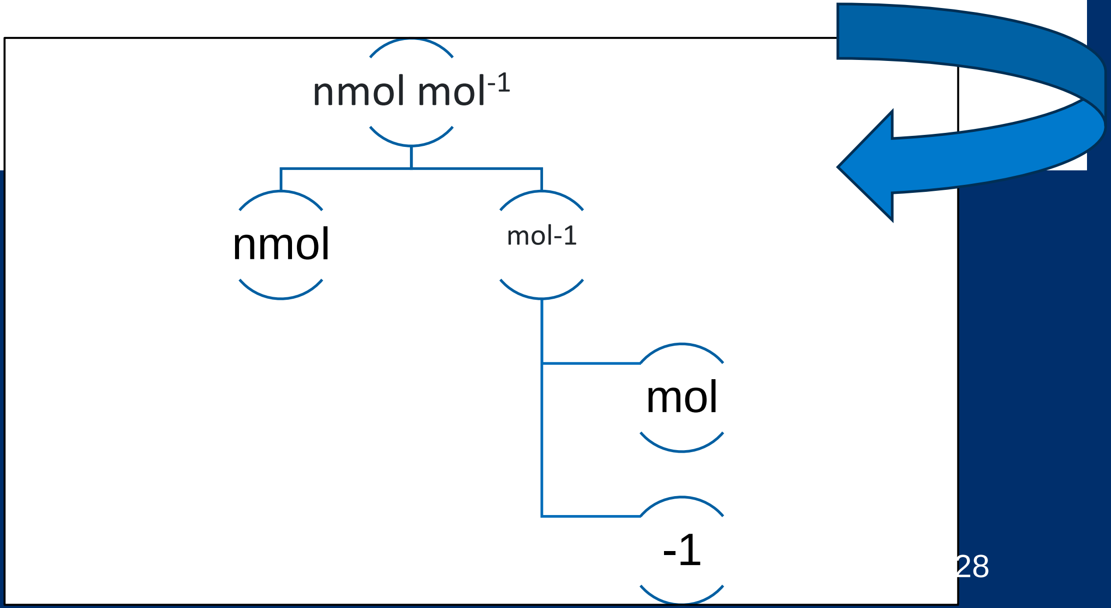
- s^{-1} m
  mathematically equal but never seen in practice

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Compound units

Example for nanomole per mole (nmol mol^{-1})

```
[ a                    si:UnitProduct ;
  si:hasLeftUnitTerm   [ a                      si:PrefixedUnit ;
                         si:hasNonPrefixedUnit  units:mole ;
                         si:hasPrefix           prefixes:nano
                       ] ;
  si:hasRightUnitTerm  [ a                      si:UnitPower ;
                         si:hasNumericExponent  "-1"^^xsd:short ;
                         si:hasUnitBase         units:mole
                       ]
] .
```



This representation preserves meaning:

- nmol mol^{-1}
  mathematically equal to 1
  (order is also important in this case, mol^{-1} nmol not seen in practice)

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Current limitations

Still to be resolved:

- Number π (Pi) semantic representation
- Logarithmic quantities
- Actionable defining equations

Calibration and Measurement Capabilities

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Now also accessible at **http://si-digital-framework.org/kcdb-cmc/EURAMET-M-AL-00000DS2-1**

KCDB-CMC Identifier: EURAMET-M-AL-00000DS2-1

Published in the KCDB

Approved on 20 July 2015

KCDB Service Category: M/Mass-1.1.1

Albania, DPM (Drejtoria e Pergjithshme e Metrologjise/General Directorate of Metrology)

Mass , Mass : **10 g to 100 g**

Mass standard

Absolute expanded uncertainty : **7.4 µg to 2.0E1 µg**

Comparison in air

The volume of the mass standards is known

Specified using SI Reference Point

30

Calibration and Measurement Capabilities

NPL

Now also accessible at **http://si-digital-framework.org/kcdb-cmc/**EURAMET-M-AL-00000DS2-1

KCDB-CMC Identifier: EURAMET-M-AL-00000DS2-1

Published in the KCDB

Approved on 20 July 2015

KCDB Service Category: M/Mass-1.1.1

Refers to CC classification of services

Albania, DPM (Drejtoria e Pergjithshme e Metrologjise/General Dire

Mass , Mass : **10 g to 100 g**

Mass standard

Absolute expanded uncertainty : **7.4 µg to 2.0E1 µg**

Comparison in air

The volume of the mass standards is known

CLASSIFICATION OF SERVICES IN MASS AND RELATED QUANTITIES

4 January 2022

METROLOGY AREA: MASS AND RELATED QUANTITIES

BRANCH: MASS

1. Mass
- **1.1 Mass standard**
  - 1.1.1 Mass standard[1]: *mass standard*

BRANCH: DENSITY

2. Density
- **2.1 Density of solid**
  - 2.1.1 Density of solid: *solid density artefact*
  - 2.1.2 Volume of solid: *solid artefact*
- **2.2 Density of liquid**
  - 2.2.1 Density measuring device
  - 2.2.2 Density of liquid
- **2.3 Refractive index of liquid**
  - 2.3.1 Refractive index of liquid

CC classifications of Service Categories

NPL

Consultative Committees agree on classifications for specific areas of metrology

Make the classifications machine-interpretable for the SI Digital Framework

CLASSIFICATION OF SERVICES IN MASS AND RELATED QUANTITIES

4 January 2022

METROLOGY AREA: MASS AND RELATE

BRANCH: MASS

1. Mass
- **1.1 Mass standard**
  - 1.1.1 Mass standard[1]: *mass standard*

BRANCH: DENSITY

2. Density
- **2.1 Density of solid**
  - 2.1.1 Density of solid: *solid density artefact*
  - 2.1.2 Volume of solid: *solid artefact*
- **2.2 Density of liquid**
  - 2.2.1 Density measuring device
  - 2.2.2 Density of liquid
- **2.3 Refractive index of liquid**
  - 2.3.1 Refractive index of liquid

Classification of services in Acoustics, Ultrasound and Vibration

Last update: *June 2018*

[1]**Metrology Area: Acoustics, Ultrasound and Vibration**

Branch: Sound in Air

1. Measurement microphones
   - 1.1 Pressure sensitivity level
     - 1.1.1. Modulus: *frequency*
     - 1.1.2. Phase: frequency
   - 1.2 Free-field sensitivity level
     - 1.2.1. Modulus: *frequency*
     - 1.2.2. Phase: *frequency*
     - 1.2.3. Directivity: *frequency*
   - 1.3 Diffuse field sensitivity level
     - 1.3.1. Modulus: *frequency*
     - 1.3.2. Phase: *frequency*
   - 1.4 Electrostatic actuator normalized response
     - 1.4.1 Modulus: *microphone type, frequency*

2. Sound calibrators
   - 2.1 Single frequency
     - 2.1.1. Sound pressure level: *microphone typ*
   - 2.2 Multi-frequency
     - 2.2.1. Sound pressure level: *microphone typ*

CLASSIFICATION OF SERVICES IN ELECTRICITY AND MAGNETISM

Version No 9 (dated 04 June 2020)

METROLOGY AREA: ELECTRICITY AND MAGNETISM

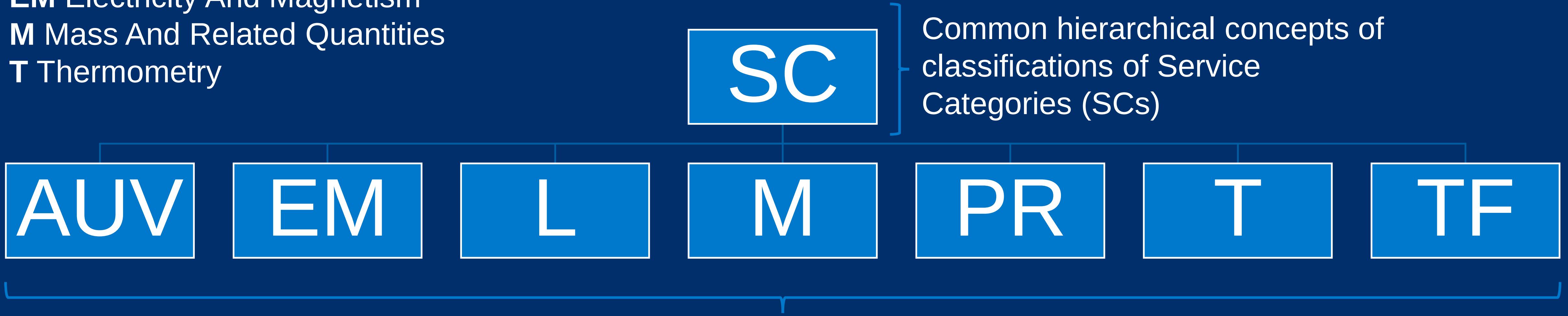
BRANCH: DC VOLTAGE, CURRENT, AND RESISTANCE

1. DC voltage (up to 1100 V, for higher voltages see 8.1)
- **1.1 DC voltage sources**
  - 1.1.1 Single values[1]: *standard cell, solid state voltage standard*
  - 1.1.2 Low value ranges (below or equal to 10 V): *DC voltage source, multifunction calibrator*
  - 1.1.3 Intermediate values (above 10 V to 1100 V): *DC voltage source, multifunction calibrator*
  - 1.1.4 Noise voltages (for noise currents see 3.1.5, for RF noise see 11.4): *DC voltage source, DC amplifier*
- **1.2 DC voltage meters**
  - 1.2.1 Very low values (below or equal to 1 mV): *nanovoltmeter, microvoltmeter*
  - 1.2.2 Intermediate values (above 1 mV to 1100 V: *DC voltmeter, multimeter, multifuntion transfer standard*
- **1.3 DC voltage ratios** (for input voltages up to 1100 V)
  - 1.3.1 Up to 1100 V: *resistive divider, ratio meter*
  - 1.3.2 Attenuation: *attenuators*

2. DC resistance
- **2.1 DC resistance standards and sources**

Designing a common model (for Physics)

AUV Acoustics, Ultrasound And Vibration
L Length
PR Photometry And Radiometry
TF Time And Frequency
EM Electricity And Magnetism
M Mass And Related Quantities
T Thermometry



Common hierarchical concepts of classifications of Service Categories (SCs)

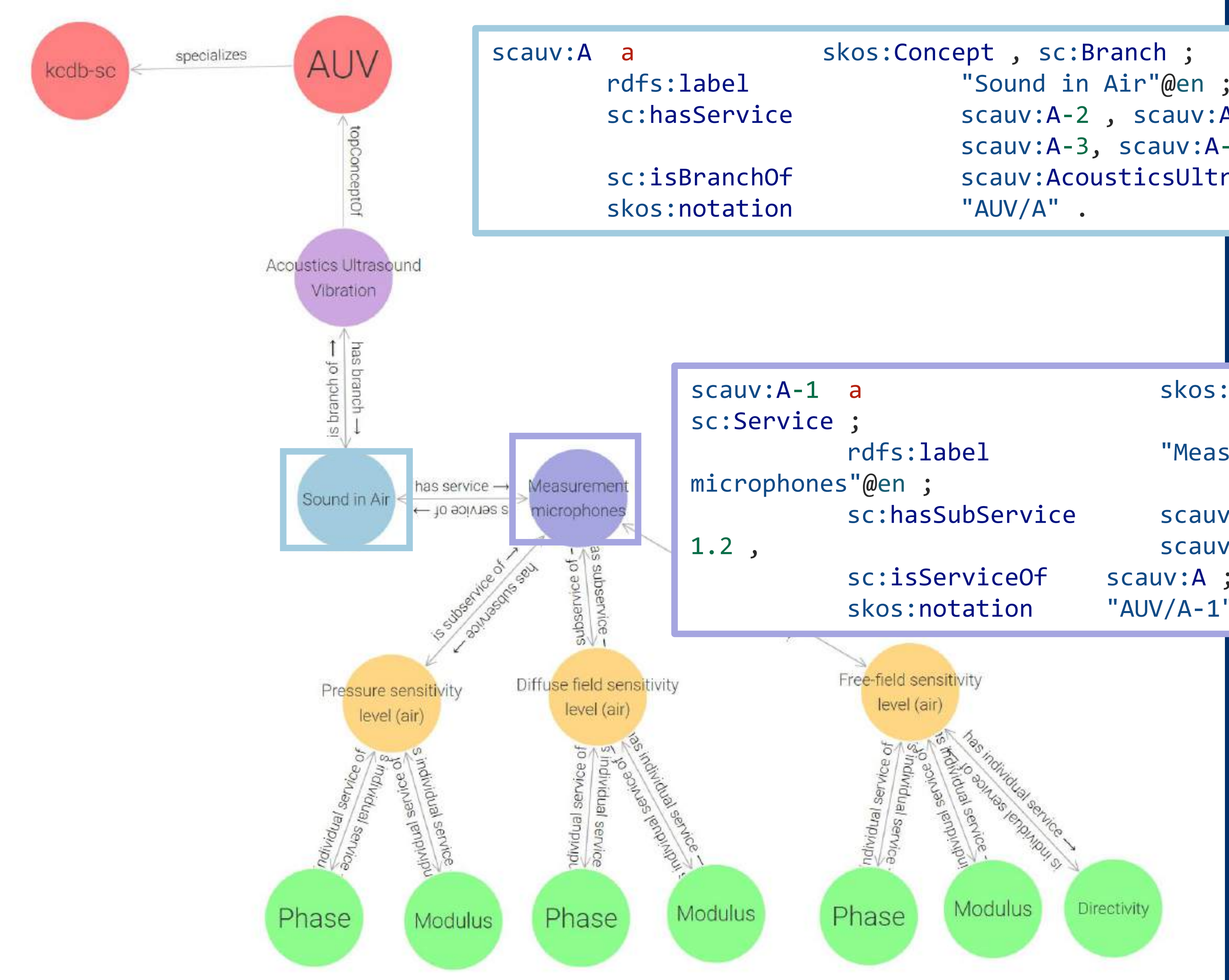
CC-specific classifications of SCs

Note: RI (IONIZING RADIATION) and QM (AMOUNT OF SUBSTANCE: METROLOGY IN CHEMISTRY AND BIOLOGY) have different models

https://www.bipm.org/en/committees/cc/

Example classification of service categories

Sound In Air is a branch of the AUV metrology area



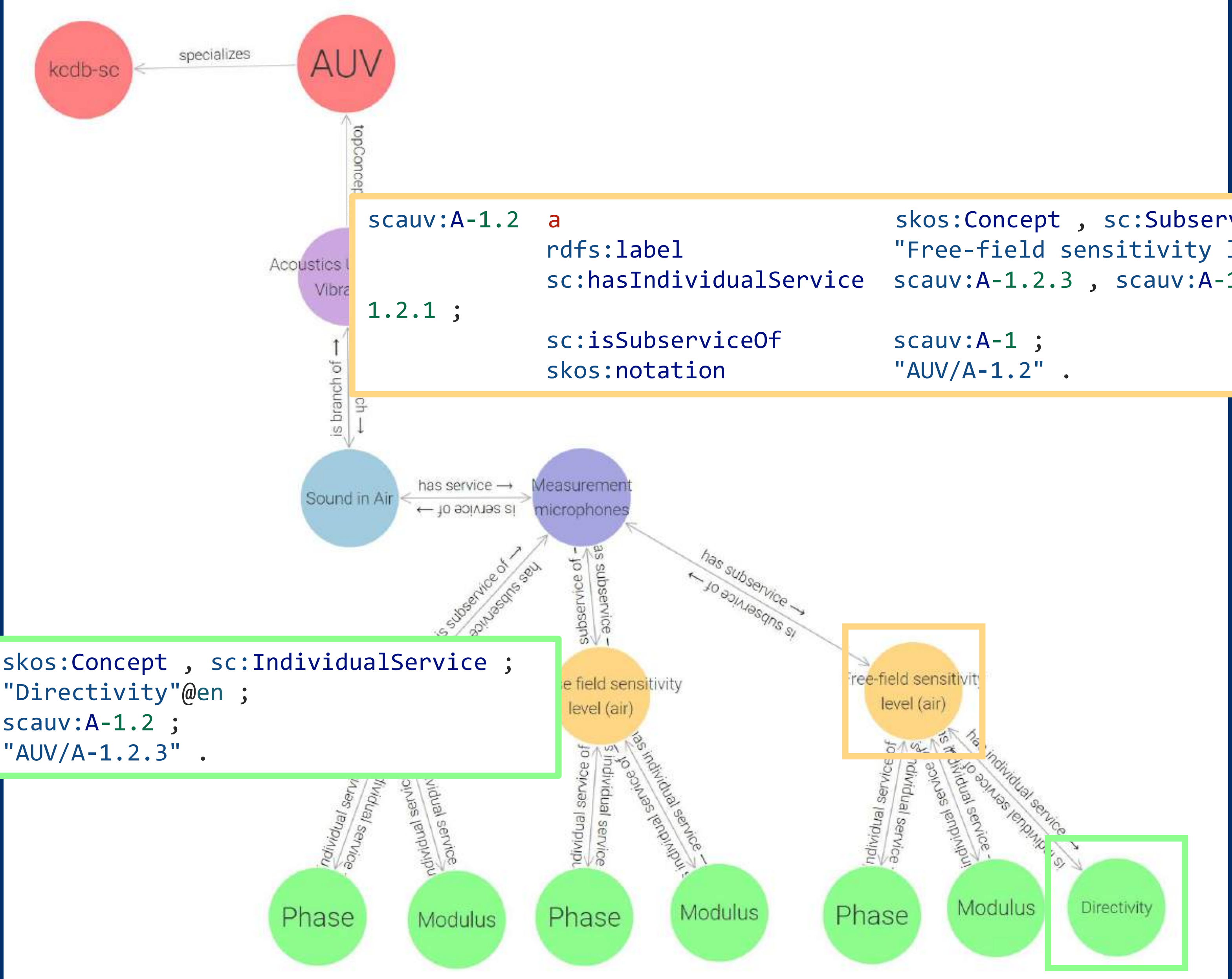

```
scauv:A   a                skos:Concept , sc:Branch ;
        rdfs:label                   "Sound in Air"@en ;
        sc:hasService                scauv:A-2 , scauv:A-1 , scauv:A-4 ,
                                     scauv:A-3, scauv:A-6 , scauv:A-5 ;
        sc:isBranchOf                scauv:AcousticsUltrasoundVibration ;
        skos:notation                "AUV/A" .
```

```
scauv:A-1  a                      skos:Concept ,
sc:Service ;
           rdfs:label             "Measurement
microphones"@en ;
           sc:hasSubService       scauv:A-1.3 , scauv:A-
1.2 ,                             scauv:A-1.1 ;
           sc:isServiceOf     scauv:A ;
           skos:notation      "AUV/A-1" .
```

Measurement microphones is a service of the Sound In Air branch

Examples use the TURTLE syntax https://www.w3.org/TR/turtle/

Example classification of service categories




```
scauv:A-1.2   a                        skos:Concept , sc:Subservice ;
              rdfs:label               "Free-field sensitivity level (air)"@en ;
              sc:hasIndividualService  scauv:A-1.2.3 , scauv:A-1.2.2 , scauv:A-
1.2.1 ;
              sc:isSubserviceOf        scauv:A-1 ;
              skos:notation            "AUV/A-1.2" .
```

Free-field sensitivity level (air) is a subservice of the Measurement microphones service

Directivity is an individual service of the Free-field sensitivity level (air) subservice

```
scauv:A-1.2.3   a                         skos:Concept , sc:IndividualService ;
        rdfs:label                 "Directivity"@en ;
        sc:isIndividualServiceOf   scauv:A-1.2 ;
        skos:notation              "AUV/A-1.2.3" .
```

Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

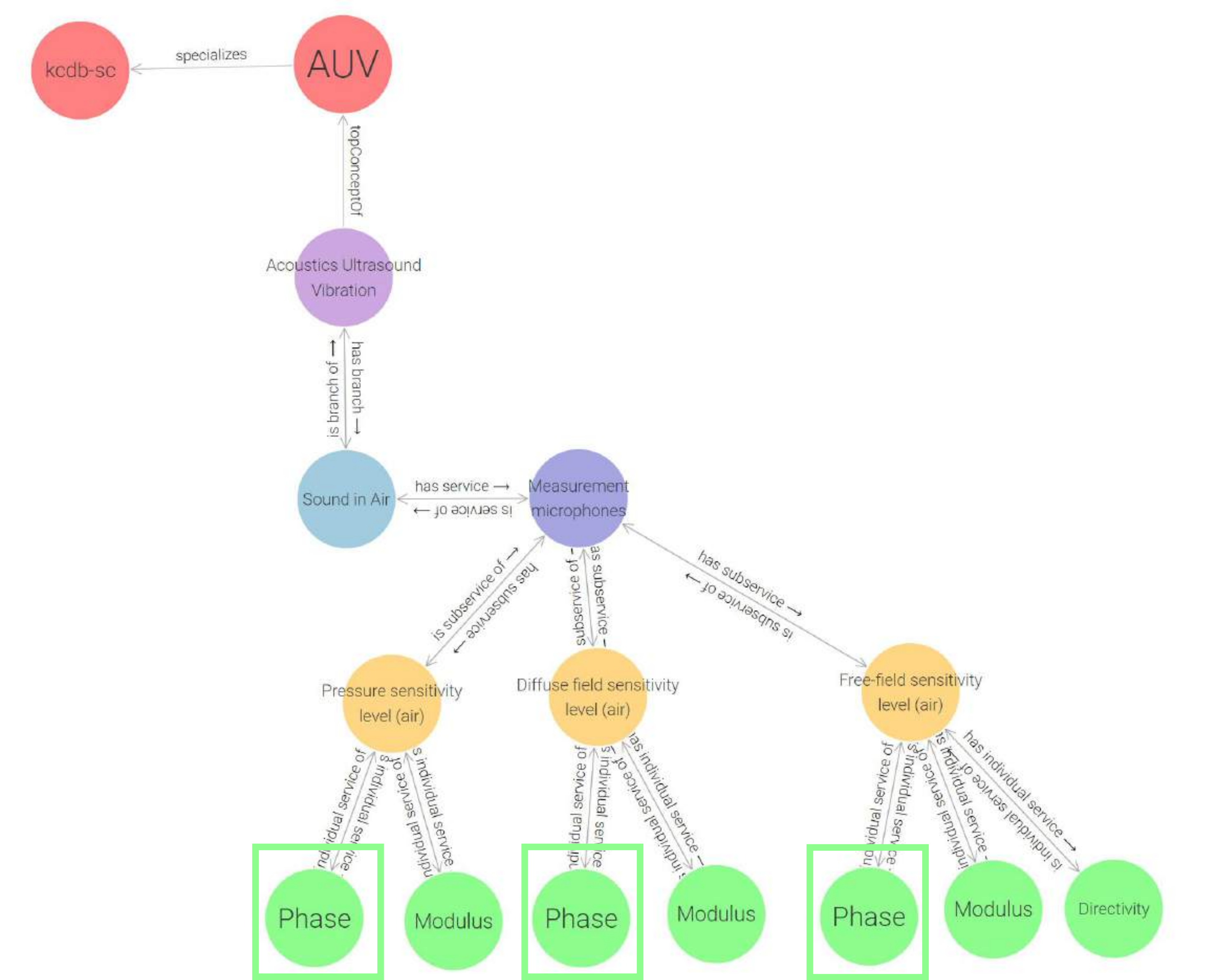
Note on label vs persistent identifier

Some service categories have the same label:

- They cannot be confused semantically (distinct position in the hierarchy)

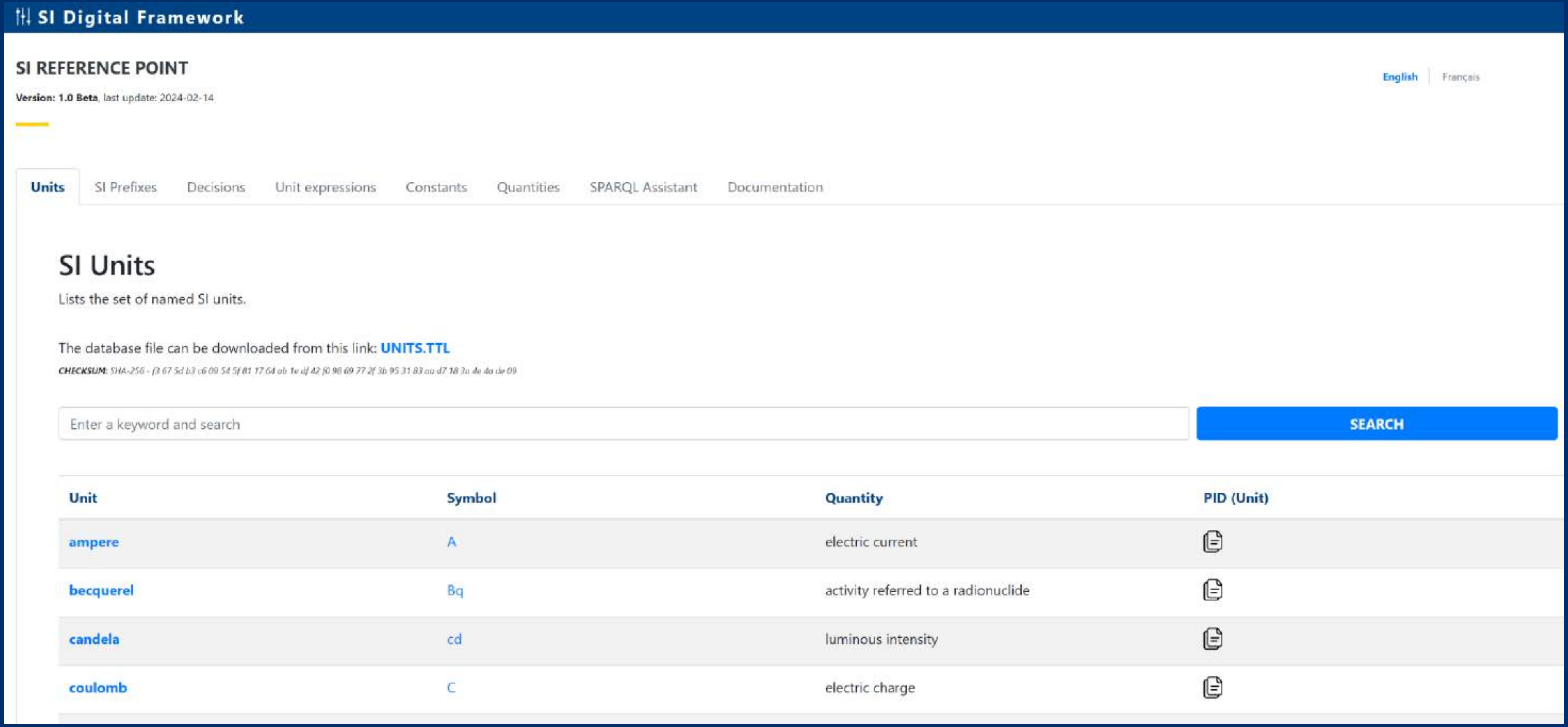
They have unique persistent identifiers

- http://si-digital-framework.org/kcdb-sc/AUV/A-1.1.2
- http://si-digital-framework.org/kcdb-sc/AUV/A-1.2.2
- http://si-digital-framework.org/kcdb-sc/AUV/A-1.3.2



Examples use the TURTLE syntax
https://www.w3.org/TR/turtle/

Browsing SI Reference Point



Browsing Service Categories

SI Digital Framework

CLASSIFICATION OF SERVICES

Version: 1.0 Beta , last update: 2023-09-11

Metrology Area: **Mass And Related Quantities** KCDB ↗

M/Mass Mass

M/Dens Density

M/Dens-2 Density

M/Dens-2.1 Density of solid

M/Dens-2.1.1 Density of solid	PID (Quantity)	PID (Unit)
M/Dens-2.1.2 Volume of solid	PID (Quantity)	PID (Unit)

M/Dens-2.2 Density of liquid

M/Dens-2.2.1 Density measuring device	PID (Quantity)	PID (Unit)
M/Dens-2.2.2 Density of liquid	PID (Quantity)	PID (Unit)

M/Dens-2.3 Refractive index of liquid

M/Dens-2.3.3 Refractive index of liquid	PID (Quantity)	PID (Unit)

SPARQL Querying

NPL

SPARQL Assistant

Allows running of custom SPARQL queries on the database.

Example 1: Units | Example 2: Prefixes | Example 3: Constants

```
PREFIX skos: <http://www.w3.org/2004/02/skos/core#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX si: <http://si-digital-framework.org/SI#>
SELECT  ?EnLabel ?FrLabel   (?PrefixSymbol AS ?Symbol) ?Factor ?dataType
WHERE { {
                ?SIPrefix si:hasSymbol ?PrefixSymbol ; skos:prefLabel ?EnLabel;  skos:prefLabel ?FrLabel; si:hasScalingFactor ?Factor ;  si:hasDatatype ?dataType .
}
 FILTER  (lang(?EnLabel)='en').  FILTER  (lang(?FrLabel )='fr').  }  order by ?Factor
```

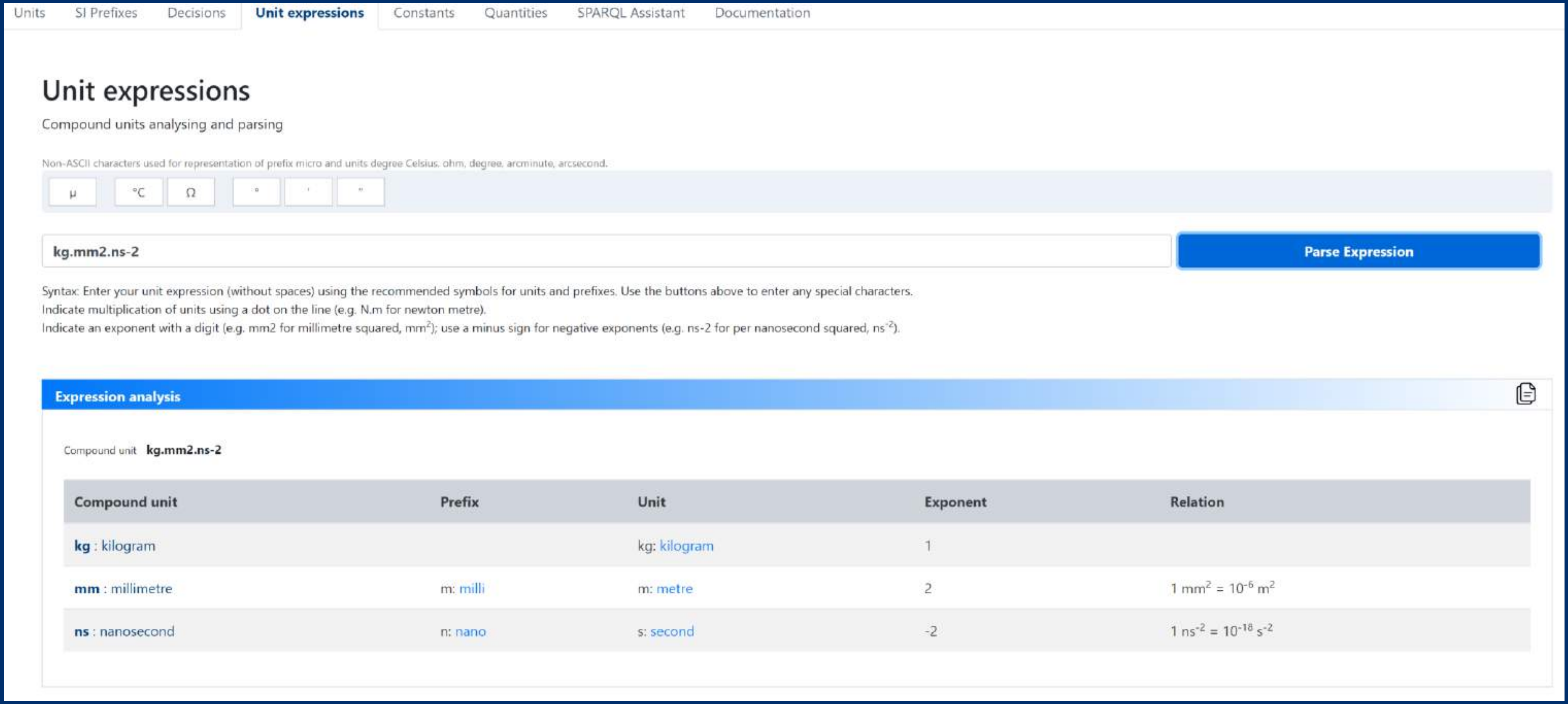
RUN

Results

Rows count: 24, Execution time: 0.004 s

FrLabel	EnLabel	Symbol	Factor	dataType
quecto	quecto	q	1e-30	http://www.w3.org/2001/XMLSchema#float
ronto	ronto	r	1e-27	http://www.w3.org/2001/XMLSchema#float
yocto	yocto	y	1e-24	http://www.w3.org/2001/XMLSchema#float

Unit expressions



Units | SI Prefixes | Decisions | **Unit expressions** | Constants | Quantities | SPARQL Assistant | Documentation

Unit expressions

Compound units analysing and parsing

Non-ASCII characters used for representation of prefix micro and units degree Celsius, ohm, degree, arcminute, arcsecond.

µ | °C | Ω | ° | ′ | ″

kg.mm2.ns-2

Parse Expression

Syntax: Enter your unit expression (without spaces) using the recommended symbols for units and prefixes. Use the buttons above to enter any special characters.
Indicate multiplication of units using a dot on the line (e.g. N.m for newton metre).
Indicate an exponent with a digit (e.g. mm2 for millimetre squared, mm^2); use a minus sign for negative exponents (e.g. ns-2 for per nanosecond squared, ns^{-2}).

Expression analysis

Compound unit **kg.mm2.ns-2**

Compound unit	Prefix	Unit	Exponent	Relation
kg : kilogram		kg: kilogram	1	
mm : millimetre	m: milli	m: metre	2	$1\ mm^2 = 10^{-6}\ m^2$
ns : nanosecond	n: nano	s: second	-2	$1\ ns^{-2} = 10^{-18}\ s^{-2}$

Unit expressions (continued)

NPL

Binary tree expression

```
@prefix prefixes: <http://si-digital-framework.org/SI/prefixes/> .
@prefix owl:   <http://www.w3.org/2002/07/owl#> .
@prefix rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix si:    <http://si-digital-framework.org/SI#> .
@prefix xsd:   <http://www.w3.org/2001/XMLSchema#> .
@prefix rdfs:  <http://www.w3.org/2000/01/rdf-schema#> .
@prefix units: <http://si-digital-framework.org/SI/units/> .

[ a                 si:UnitProduct ;
  si:hasLeftUnitTerm  [ a                  si:UnitProduct ;
                si:hasLeftUnitTerm   units:kilogram ;
                si:hasRightUnitTerm  [ a                  si:UnitPower ;
                          si:hasNumericExponent  "2"^^xsd:short ;
                          si:hasUnitBase       [ a                  si:PrefixedUnit ;
                                    si:hasNonPrefixedUnit  units:metre ;
                                    si:hasPrefix         prefixes:milli
                                  ]
                        ]
              ] ;
  si:hasRightUnitTerm  [ a                  si:UnitPower ;
                si:hasNumericExponent  "-2"^^xsd:short ;
```

Compound unit PID

http://si-digital-framework.org/SI/units/kilogram.millimetre2.nanosecond-2

Recap

SI Digital Framework

- To support digital transformation in metrology and beyond, reproducible science and quality chain

- Set of services for humans and software agents underpinned by semantic representations

- SI Reference Point just released, third service of framework, after CMC and Service Categories
- Expecting user feedback

What's next?

- Link Calibration and Measurement Capabilities with SI Reference Point
- Ontologies for RI and QM service categories
- Finalise mapping with SI Reference Point
- Expansion of knowledge graph for responsible bodies and decisions
- Improve interoperability with external (digital) references from stakeholders

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  - Stuart Chalk (UNF)
  - Gregor Dudle (METAS, now OST)
  - Maximilian Gruber (PTB)
  - Frédéric Meynadier (BIPM)

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