How do we build a digital infrastructure for metrology?

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Digital Transformation in Metrology Workshop

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Abstract

Since digital technologies emerged in the 20th century, people have continued to find useful applications. More and more things are now "digital".

The metrology community started to think about its digitalization journey quite late. That doesn't mean that the work is already done for us, but it does mean we can learn from the experience of others. Digitalisation encodes human activities so that systems, rather than people, can perform useful tasks. However, it's not easy to translate what people do into instructions for machines. The trick is to identify key bits and pieces of information. This is something that only metrologists can do, and it needs to be done properly or subsequent digitalisation will not go well.

This talk reflects on how to recognize important bits and pieces of information which may be so familiar in our work that we take them for granted. When people exchange data and work together, often usually already know what data represents. This understanding comes from years of study and work experience. However, we need to think about things differently now. We need to make explicit references to information and the semantics of data.

Outline

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A digital infrastructure for metrology:

Introduction
- expectations
- collaboration
- vocabulary and semantics

Example
- a clue
- semantic interoperability

Understanding symbols

Structured data

Identifiers
- for organisations
- for individuals
- CMCs for people
- CMCs for machines
- invisible identifiers

Scientific language
- and the GUM
- measurement models
- uncertain numbers
- scientific literacy

Final comments

The promise of digital transformation

Digitalisation and digital transformation promise efficiency and greater flexibility. Is this feasible in metrology?

The results of many digital transformations are considered unsatisfactory in the business world.

The key to success will be deliberate engagement and planning by senior metrologists.

Technologists will build infrastructure, but they do not yet know what needs to be done. They must be given clear logical instructions.

Metrologists need to describe metrological concepts thoroughly.

https://klexikon.zum.de/wiki/Internet

Programming is the art of telling another human being what one wants the computer to do. – Donald Knuth[a]

[a] Donald Knuth is an American computer scientist, mathematician, and professor emeritus at Stanford University. He is the 1974 recipient of the ACM Turing Award, informally considered the Nobel Prize of computer science.

Notes

NMI metrologists may be sceptical about the benefits of digital transformation in metrology. There is a belief that the knowledge, experience, and skills of a good NMI metrologist cannot be replaced by machines.

While this is undoubtedly true, digital technology can be applied to repetitive tasks so that people can do more interesting things. But there is a risk that digitalisation will be poorly executed, leaving jobs intensively 'digital' in nature and metrologists fighting with the technology. This sort of thing often happens in business.

Ignoring the problem, however, almost guarantees a poor outcome! How can we do better in metrology?

If you cannot explain a task—in detail—to a technologist, you cannot expect successful digitalisation.

We need to be able to analyse and describe our work, so that technologists are provided with clear, complete, logical models to work with.

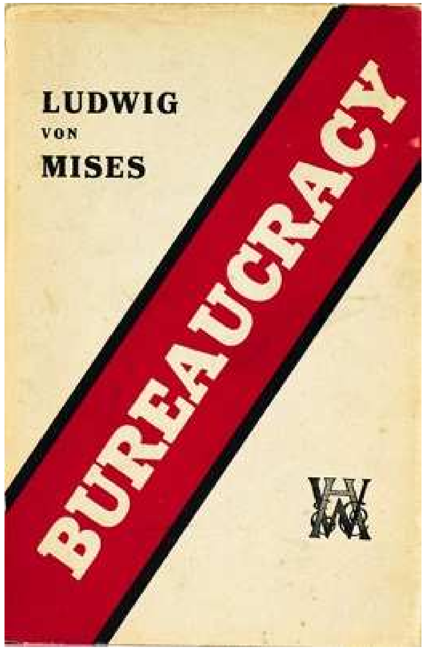
The modelling of metrological concepts is the responsibility of metrologists. We must be aware—at a high level—of how digital systems work. Technologists can then build what is needed.

The old fashioned way

We (people) collaborate to perform specific tasks. People contribute in different ways at different times and places.

But how do we ensure that everything turns out well?

- Processes can be described (stipulated)
- People are capable (knowledgeable, experienced, and skilful)
- People are empowered to make decisions
- Some people are given authority to supervise the work of others



https://en.wikipedia.org/wiki/Bureaucracy_(book)

Digitalisation can encode activities so that systems, rather than people, perform useful tasks. But it is not always easy to translate what people do into instructions for machines.

Notes

It's not always easy to translate what people do into instructions for machines. The trick is to identify the key bits and pieces of information.

When people work together (collaborate), they share (to some extent) an understanding about a complicated task (perhaps just their part). However, the activities of each individual need only provide what is needed by other people after them.

In metrology, the process of disseminating traceability is an example. Traceable measurement is a long, staged, process that is finally completed by an end user. The results are needed to inform important decisions, so accuracy is crucial. This involves many people:

- the CIPM defines units of measurement, which can be realised in NMIs;
- NMIs provide measurement services to calibration laboratories;
- calibration laboratories provide services to industry and society in general.

Few people are aware of the 'whole picture' of traceable measurement; most carry out processes within a supervised quality-controlled framework (e.g., 17025, CIPM-MRA). People tend to think they are performing a complete 'measurement' or 'calibration', but this is an illusion: in reality, people are performing intermediate steps that occur along a longer traceability chain. The steps themselves are only valuable because accurate information is needed at the end of the chain.

Digitalisation needs to look at the big picture and see how the outcomes of small intermediate processes contribute to an overall task (providing an accurate measurement result).

Senior metrologists have this viewpoint. So, senior metrologists need to collaborate to identify and describe the knowledge, experience, and skills involved in operating the international measurement system.

Elements of description

In ordinary language, vocabulary and grammar are combined to express ideas.

Words label ideas (things and actions); syntax provides rules for constructing meaningful phrases.

Meaning—*semantics*—is the significance of the phrases.

When we describe scientific (metrological) processes for the purpose of digitalisation, it is important to control *vocabulary* and capture *semantics*.

The semantics also relate to the **purpose** of processes and of intermediate steps.

The outcomes of digitalisation can **only** be properly evaluated (validation and testing) when the semantics are clear (does a digital system do what it is supposed to do?).

Digitalisation should not be undertaken without a clear and verifiable goal (purpose).

Notes

At present, we rarely stipulate the purpose and meaning explicitly associated with tasks in the quality system. We tend to reply on the tacit knowledge of senior people to ensure that things are done properly. This is not satisfactory. Digitalisation cannot succeed unless the metrological semantics are brought the surface and clearly defined.

Finding meaning in data—an example

The following data is meaningful (I promise you). But, to whom?


```
0A202020202231312025222C0A20202020
22636F6C20647520476C616E646F6E222C
0A20202020223220 6B6D222C0A20202020
22313731302 06D220A
```


The data consists of decimal digits 0–9 and letters A–F. Knowing that, technologists can provide digital protocols for transmitting data in this format from one system to another.

But, while technical exchange is possible, no **purpose** or **meaning** is conveyed. The recipient must already know what to do with the data.

We could say that such communication (exchange of data) demonstrates *interoperability*—one of the FAIR principles.

However, people with access to data must share an understanding of the semantics; no sensible use of the data is possible unless we know what it means.

Notes

There is a distinction between *syntactic interoperability* and *semantic interoperability*.

Syntactic interoperability is the ability of different systems to exchange data without transmission errors.

Semantic interoperability is achieved when the meaning attributed to some set of data is preserved, without human intervention, as data passes from one system to another.

Finding meaning in data—a clue

The data on the previous slide is a hexadecimal encoding of these ASCII characters.

```
"11 %",
"col du Glandon",
"2 km",
"1710 m"
```

Is the data meaningful now? Not really.

We now see that there are four distinct elements, and that some of these are SI expressions of quantity values. But, we don't yet know what it all means.

It is also worth noting that the syntax for expressing quantity values and the vocabulary of SI unit symbols are things already known to us—we recognise them and know what they mean—without understanding what the data describes.

So, what we understand now depends on something called **tacit knowledge**. Digital systems don't have any tacit knowledge: they must have explicit instructions!

Computers are good at following instructions, but not at reading your mind. – Donald Knuth

Notes

Recognising tacit knowledge, so that it can be made explicit for machines, is a huge challenge for digitalisation of metrology.

One of the objectives of this talk is to make you aware that you expect other people to already know some things when information is shared. Digital systems will need to be explicitly given this tacit knowledge in some form.

Finding meaning in data—context is everything

This picture has meaning for most people. It triggers recall of tacit knowledge about: location, steepness of roads, height above sea level, etc.

We now understand that "$1710\,\mathrm{m}$" is the altitude at the location of the milestone and "$11\,\%$" is a measure of the gradient, over the next "$2\,\mathrm{km}$", to a place called "*Col du Glandon*", further on up the road (indicated by the upward arrow head).

The image helps people to understand the data, which seems almost self-explanatory.

This is called *semantic interoperability*, because people who have not seen the milestone before can still use the data on it.

Notes

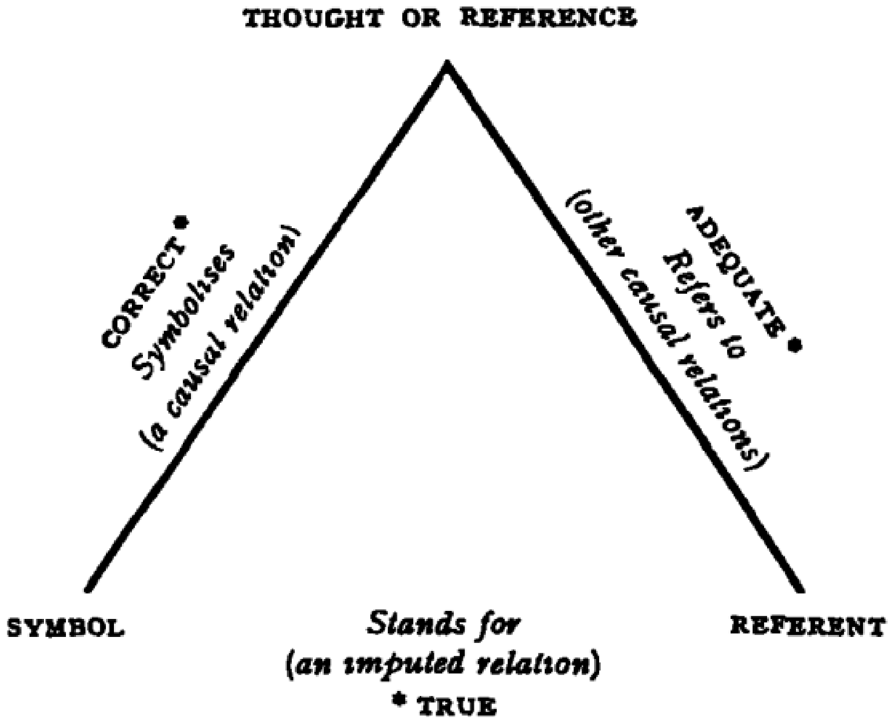
The inscription on the stone contains several syntax errors, which were corrected in the slides. Can you spot them?

This is interesting, because a machine might not be able to process the faulty data correctly (if syntax-error-correction was not designed into the system).

So, this representation of data might fail to meet requirements for syntactic interoperability (and certainly fail to provide semantic interoperability). Yet people can still understand what the data is and what it means.

The ability of people to deal with non-conforming data sets and other ambiguities is hard to reproduce in machines. That is why it is very important to recognise the strict requirements for data and data processing when considering digitalisation.

A model of understanding



(Ogden and Richards, 1923, *The meaning of meaning: A study of the influence of thought and of the science of symbolism*)

To understand symbols, we need our own ideas (we must learn what symbols mean).

Ideas link symbols to things (referents): there is no link across the base of the semantic triangle.

For example, there are many words for dog (in different languages). We understand that a dog is referred to when we recognise one of these words.

The milestone data was always available, but we needed particular ideas to understand it.

Notes

Semantics are important because we must ensure that the different metrological ideas we use to relate symbols to things in our work are well understood and properly described in logical terms.

This is certainly not the case at present.

That is why senior metrologists must engage in digitalisation.

Labels do not encode semantics

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Some data formats label data. Examples, include XML and JSON (shown opposite).

Labels are just more symbols; people may recognise them, but machines will not.

People need to know what the different labels mean and how they relate to each other.

Formats like XML and JSON can define rules for composite data structures.

But this is like checking grammar: even if expressions are 'well-formed', they are not necessarily meaningful.

```
{
    "type": "milestone",
    "gradient": "11 %",
    "next location": "col du Glandon",
    "distance to location": "2 km",
    "altitude": "1710 m"
}
```

```
<influenceCondition>
    Temparature : (22 ± 3)C,
    Relative Humidity : (50 ± 10)%
</influenceCondition>
```

Notes

We can imagine that everyone reaches agreement on meanings for a set of labels (tags). This is usually what happens when digital data is shared. The designers of different systems know what to expect for data associated with each label (more likely, data will not be labelled, rather thee will be some sort of predictable format in which it is stored).

Often this information can be put in formal documentation, so that people can read about the structure of data being exchanged, and systems can be designed to act appropriately.

However, there is a lot of work involved and the result is a fairly narrowly defined system. The more general we want to make something like this, the more complicated the system becomes, and the harder it is to adapt the system to new situations. Technologists say that complicated systems can become *brittle*, meaning that small changes tend to break them.

The answer is to work with components that are relatively self-contained (modular design). This is what engineers do: they decompose a problem into blocks that can be assembled from reusable or reconfigurable components.

How do we do this in metrology?

We need to think about our vocabulary and we need to describe processes. Our terminology will reflect the sorts of components we need to describe (so that representations of them can be built and used by technologists).

Unique identifiers

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We will need to some identify unique entities, such as:

- a laboratory
- an individual
- a measurement procedure
- a measurand
- a unit
- a quantity value
- etc.

This is fundamentally important.

Computer systems handle references with things called unique identifiers (UIDs).

DOIs will always point (link) to the document (the identifier is *persistent*).

MSL Technical Guide 43

The MD5 Checksum for an MSL Report

Version 2, November 2023

DOI: 10.5281/zenodo.10067456

Websites and emails are unique, but not persistent (they change over time)

Website:	measurement.govt.nz
E-mail:	info@measurement.govt.nz
Prepared by:	B D Hall

Researcher ORCIDs are persistent.

Notes

How does this work in the world of people?

Names must be unambiguous. For example, “Richard” will be unambiguous in certain narrow contexts, “Richard Feynman” will be less ambiguous, and “Richard Feynman” is an effectively unique reference to the Nobel prize winning physicist (using a link to wikidata).

Our terminology must be carefully controlled. We need to share an understanding of what our working terms mean: *measurand*, *traceability*, *uncertainty*, etc.

Without this, people cannot understand each other.

That is why the JCGM Guides in metrology and the SI Brochure are important documents.

Identifiers for organisations

Measurement Standards Laboratory of New Zealand

https://ror.org/04022gq47

Measurement Standards Laboratory of New Zealand

ORGANIZATION TYPE

Government

OTHER NAMES

MSL

WEBSITE

https://www.measurement.govt.nz

RELATIONSHIPS

Parent Organization(s)

Callaghan Innovation

LOCATION

Lower Hutt (GeoNames ID 2188164)

New Zealand

OTHER IDENTIFIERS

ISNI 0000 0004 9527 8573

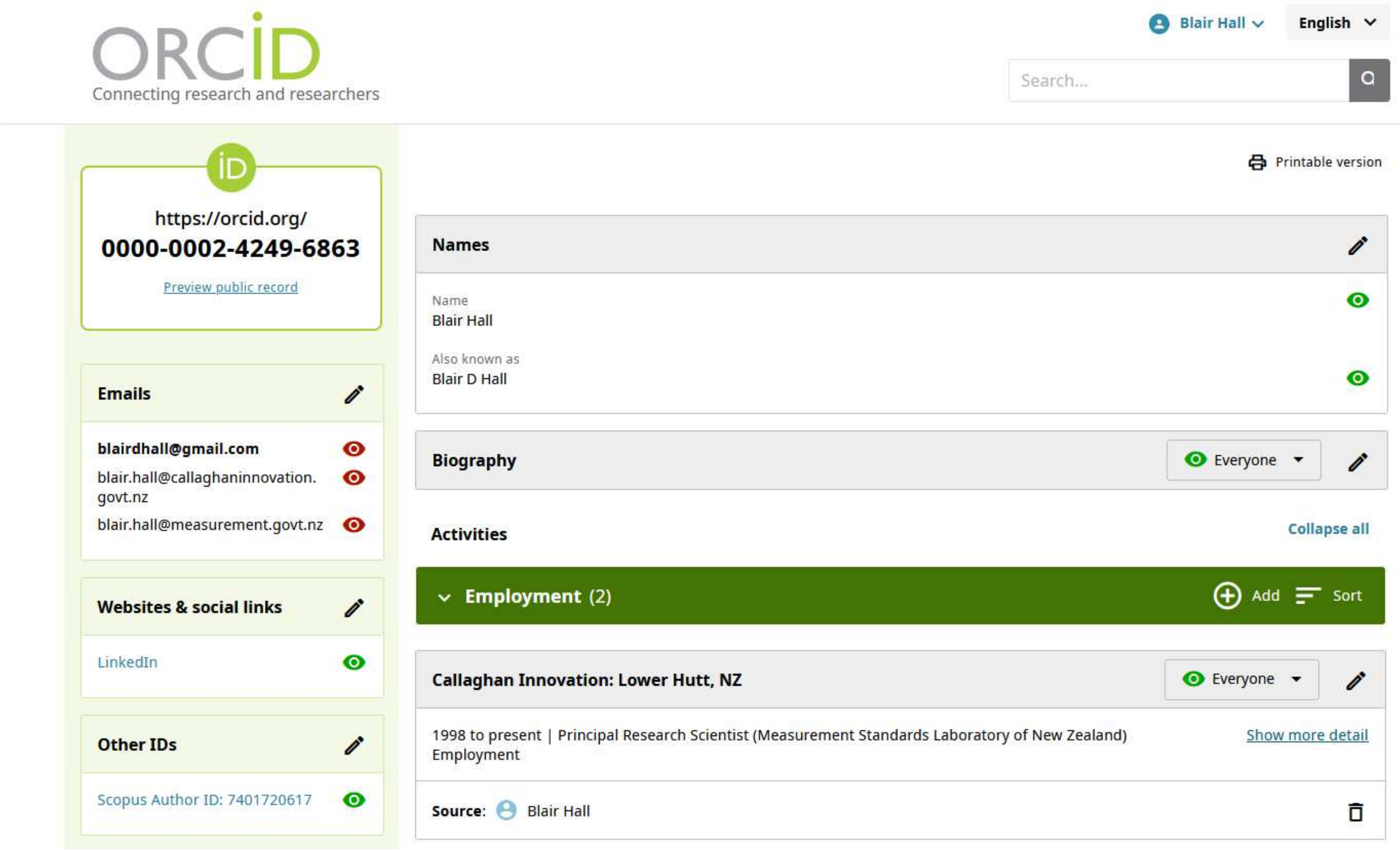
Wikidata Q111449920

Notes

In addition to this version, which is intended to be read by someone, there is an API for machines. Writing the query https://api.ror.org/organizations?query=%22Measurement%20Standards%20Laboratory%22 in a browser returns this data:


```
{"number_of_results":1,"time_taken":6,"items":[{"id":"https://ror.org/04022gq47",
"name":"Measurement Standards Laboratory of New Zealand","email_address":null,"ip_addresses":[],
"established":1992, "types":["Government"],"relationships":[{"label":"Callaghan Innovation","type":"Parent",
"id":"https://ror.org/02n25sf77"}],"addresses":[{"lat":-41.21667,"lng" 174.91667,"state":null,
"state_code":null,"city":"Lower Hutt","geonames_city":{"id":2188164,"city":"Lower Hutt",
"geonames_admin1":{"name":"Wellington","id":2179538,"ascii_name":"Wellington","code":"NZ.G2"},
"geonames_admin2":{"name":"Lower Hutt City","id":7910049,"ascii_name":"Lower Hutt City","code":"NZ.G2.046"},
"license":{"attribution":"Data from geonames.org under a CC-BY 3.0 license",
"license":"http://creativecommons.org/licenses/by/3.0/"},"nuts_level1":{"name":null,"code":null},
"nuts_level2":{"name":null,"code":null},"nuts_level3":{"name":null,"code":null}},"postcode":null,
"primary":false,"line":null,"country_geonames_id":2186224}],"links":["https://www.measurement.govt.nz"],
"aliases":[],"acronyms":["MSL"],"status":"active","wikipedia_url":null,"labels":[],
"country":{"country_name":"New Zealand","country_code":"NZ"},
"external_ids":{"ISNI":{"preferred":"0000 0004 9527 8573","all":["0000 0004 9527 8573"]},
"Wikidata":{"preferred":"Q111449920","all":["Q111449920"]}}}],
"meta":{"types":[{"id":"government","title":"Government","count":1}],
"countries":[{"id":"nz","title":"New Zealand","count":1}],
"statuses":[{"id":"active","title":"active","count":1}]}}
```

Identifiers for people



Notes

ORCID provides an API too. However, it requires registration and so I didn't try to use it.

CMC information for people ...

Radio frequency measurements , Scattering parameters: transmission coefficient (Sij) in coaxial line, magnitude : **-80 dB to 0 dB**
Passive device
Absolute expanded uncertainty : **1.0E-2 dB to 0.28 dB**
Uncertainty table
Vector network analyser
Frequency : 9 kHz to 116.5 GHz
Connector : BNC 50 ohm,
Type-N 75 ohm,
4.3-10
Type-N 50 ohm,
PC-7 mm,
NEX10,
PC-3.5 mm,
PC-2.92 mm,
PC-2.4 mm,
PC-1.85 mm,
PC-1.0 mm
S11 and S22 : < 0.1
Approved on 04 January 2022
Institute service identifier : 217.01.03
KCDB ID : EURAMET-EM-CH-00000GFA-5

… and for machines

Response body


```
{
  "versionApiKcdb": "1.0.7",
  "pageNumber": 0,
  "pageSize": 20,
  "numberOfElements": 2,
  "totalElements": 2,
  "totalPages": 1,
  "data": [
    {
      "id": 35070,
      "status": "Published",
      "statusDate": "2022-01-04",
      "kcdbCode": "EURAMET-EM-CH-00000GFA-5",
      "domainCode": "PHYSICS",
      "metrologyAreaLabel": "EM",
      "rmo": "EURAMET",
      "countryValue": "Switzerland",
      "nmiCode": "METAS",
      "nmiName": "Federal Institute of Metrology",
      "nmiServiceCode": "217.01.03",
      "nmiServiceLink": "",
      "quantityValue": "Scattering parameters: transmission coefficient (Sij) in coaxial line, magnitude
      "cmc": {
        "lowerLimit": -80,
        "upperLimit": 0,
        "unit": "dB"
      },
      "cmcUncertainty": {
```

Notes

There is a person-friendly API interface at https://www.bipm.org/api/kcdb/swagger-ui/index.html?configUrl=/api/kcdb/v3/api-docs/swagger-config#/cmc-search-data-controller/advancedSearchPhysics

The data shown in the slide were obtained by executing a query on this page with the following 'physics search criteria'


```
{
  "page": 0,
  "pageSize": 20,
  "showTable": false,
  "metrologyAreaLabel": "EM",
  "branchLabel": "EM/RF",
  "physicsCode": "11.3.3",
  "keywords": "scattering",
  "countries": ["CH"],
  "publicDateFrom": "2005-01-31",
  "publicDateTo": "2023-06-30"
}
```

Invisible identifiers

Computers use identifiers for many things, but keep them hidden.

Computers present a more intuitive representation to users.

The purpose of identifiers (in computers) is to keep track of entities in memory.

However, those entities and their identities are not *persistent*; they change from one session to another.

However, we can store entities and preserve their identity.

This allows correlations along the traceability chain to be properly accounted for.

```
>>> x = 5
>>> y = 5
>>> id(5)
2729242067312
>>> id(x)
2729242067312
>>> id(y)
2729242067312
>>> y=10
>>> id(y)
2729242067472
>>> 
```

Notes

The most familiar example may well arise from measurement comparisons.

Sometimes participants obtain traceability through services supplied by another NMI. When several participants do this, the results are inevitably correlated, which complicates the comparison analysis. However, participants are always asked to supply enough information to allow this effect to be properly accounted for. It is hard work for the people doing the analysis though.

The issue of handling correlations in comparisons and in comparison linking is one that can be streamlined by proper digitalisation of participant's reports.

MSL has shown that data analysis is much easier and more informative when uncertainty budgets are reported using unique digital identifiers for all influence terms. This is not difficult to do, but implies that each participant can describe a full measurement model of their procedure.[1]

[1] B. D. Hall and A. Koo, *Digital Representation of Measurement Uncertainty: A Case Study Linking an RMO Key Comparison with a CIPM Key Comparison*, Metrology, 2021, **1**(2), 166–181. DOI:10.3390/metrology1020011

“Science is either Physics or stamp collecting”

Our labels are like parts of a classification system for people to catalogue entities.

No semantics, just labels for data (structured data).

If a few people decide which labels to use, other people must know how information is catalogued.

Rutherford famously referred to this as stamp collecting (e.g., biology and botany).

Metrological terminology should be captured in controlled vocabularies and shared.

If a language has no dictionary (to explain what words mean) or formal rules of grammar, people can only learn the language informally, from other people who use it.

This is what metrology tends to do at present. We need a more formal approach.

Notes

Yes, I know that the postage stamp shows Niels Bohr, the famous Danish physicist, not Ernest Rutherford, the famous New Zealand physicist. However, I chose the stamp because it also shows the famous relation

$$h\nu = \varepsilon_1 - \varepsilon_2 \ .$$

My point is that it is not enough to just perform measurements, we must also describe them. This is a fundamental necessity because information must be passed along traceability chains.

What would a stamp commemorating a great metrologist look like, and what, if any, equation might be used in the art work?

Rutherford may have scorned sciences that involved extensive classification schemes. However, those schemes were extremely well constructed.

The language of the GUM

Many measurable properties of interest to metrology are physical quantities.

The laws of physics apply and the language of science can describe measurement procedures.

We must take advantage of (logical) mathematical descriptions.

The GUM provides generic notation and terminology

$$\begin{array}{ccl} Y & : & \text{the measurand} \\ y & : & \text{measured value} \\ f(\cdots) & : & \text{measurement equation} \end{array}$$

GUM guidelines should be incorporated in the digitalisation of metrology.

Notes

Whatever happens, digitalisation is going to create algorithmic procedures; however, it would be better to create correct ones!

The GUM is very widely accepted.

It stipulates that a measurement model shall be developed and analysed to evaluate measurement uncertainty.

But there is a challenge in understanding the purpose of the GUM guidance. Without that, we cannot expect to digitalise effectively.[2]

When the rigorous logic of mathematical expressions is coupled with explicit identifiers for terms, we have exactly what computer systems need to encode metrological procedures.

An added bonus is that mathematical language is universal. So, this scientific aspect of digitalisation will not be affected by local languages.

[2] This is discussed in a recent article by Rod White, et al. A preprint is available The Purposes of Measurement Uncertainty.

Is it too complicated? Here's an example

Light meter calibration measures the deviation of a particular meter from perfect behaviour. The measurand, $1 - E_\mathrm{rel}$, is described in a measurement model

$$
\begin{aligned}
1 - E_\mathrm{rel} &= \frac{I}{i_\mathrm{cal} - o_\mathrm{cal} - E_\mathrm{off} - E_\mathrm{res} - E_\mathrm{rep}} \\
&= \frac{i_\mathrm{ref} - E_\mathrm{ref}}{i_\mathrm{cal} - o_\mathrm{cal} - E_\mathrm{off} - E_\mathrm{res} - E_\mathrm{rep}} \\
&= \frac{i_\mathrm{ref}}{i_\mathrm{cal} - o_\mathrm{cal}} \left(\frac{1 - \frac{E_\mathrm{ref}}{i_\mathrm{ref}}}{1 - \frac{E_\mathrm{off}}{i_\mathrm{cal} - o_\mathrm{cal}} - \frac{E_\mathrm{res}}{i_\mathrm{cal} - o_\mathrm{cal}} - \frac{E_\mathrm{rep}}{i_\mathrm{cal} - o_\mathrm{cal}}} \right) \\
&\approx \frac{i_\mathrm{ref}}{i_\mathrm{cal} - o_\mathrm{cal}} \left(1 - \frac{E_\mathrm{ref}}{i_\mathrm{ref}} + \frac{E_\mathrm{off}}{i_\mathrm{cal} - o_\mathrm{cal}} + \frac{E_\mathrm{res}}{i_\mathrm{cal} - o_\mathrm{cal}} + \frac{E_\mathrm{rep}}{i_\mathrm{cal} - o_\mathrm{cal}} \right) .
\end{aligned}
$$

The subscript 'cal' has been added to i (the meter indication) and o (the meter offset) to indicate values during calibration; i_ref is the nominal applied reference value.

Terms with a capital E are residual influence errors—estimated t be zero but with some uncertainty. Terms in lower case are numbers.

Notes

We use capital letters for physical quantities (that will never be exactly known) and lower case letters for terms where we will have a numeric value for calculations.

The last line has four terms with a capital E. These are residual influence quantities. We estimate their value as zero, but attribute some uncertainty to that estimate.

All terms in the equations are identifiers (for mathematicians): they label entities involved in mathematical operations. Without them, people would not know how to perform calculations.

People often use simplified notation when working on some small part of a bigger calculation. But detailed notation is needed to describe all terms in bigger calculations.

Digital systems have no difficulty creating unique identifiers for data. However, it is our responsibility to use identifiers correctly. We must adopt and document unambiguous notations.

Metrology deals in uncertain numbers

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In metrology, measured values are never exact.

Numbers estimate a quantity but there is uncertainty in that estimate.

The GUM describes the mathematical relationships involved.

Digitalisation of the GUM procedure yields . . .

Uncertain numbers: a data type (e.g., integer, real, etc.) for metrology, encapsulating (automating) formal mathematics and providing persistent unique identifiers for contributions to uncertainty along a traceability chain.

The reading is x_i, but the quantity of interest is uncertain due to residual effects

$$X_i = (1 + E_{\mathrm{rel}} + E_{\mathrm{rel}\cdot i})\, x_i - E_{\mathrm{off}} - E_{\mathrm{off}\cdot i}$$

```
>>> E_rel = ureal(0,8E-4,label='E_rel')
>>> E_off = ureal(0,5E-5,label='E_off')

>>> vm = VM(E_off=E_off,E_rel=E_rel,
        u_off_i=8E-5,u_rel_i=5E-5)

>>> V1 = vm.measure(5.1)
>>> show(V1)
ureal(5.1,0.004119201985822011,inf)
    E_rel: 0.00408
    E_off: 0.0005
    E_rel_1: 0.000255
    E_off_1: 8e-05
```

Notes

Data processing can be programmed by starting from equations that describe a measurement model. The details of the GUM processes are automated.

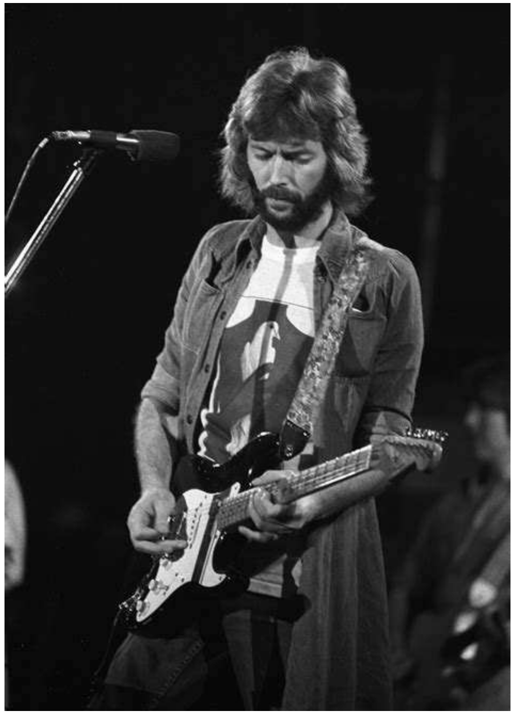
Uncertain-number results contain GUM-compliant details about the estimate and its uncertainty. They can be stored (serialised) and used down stream in the traceability chain.

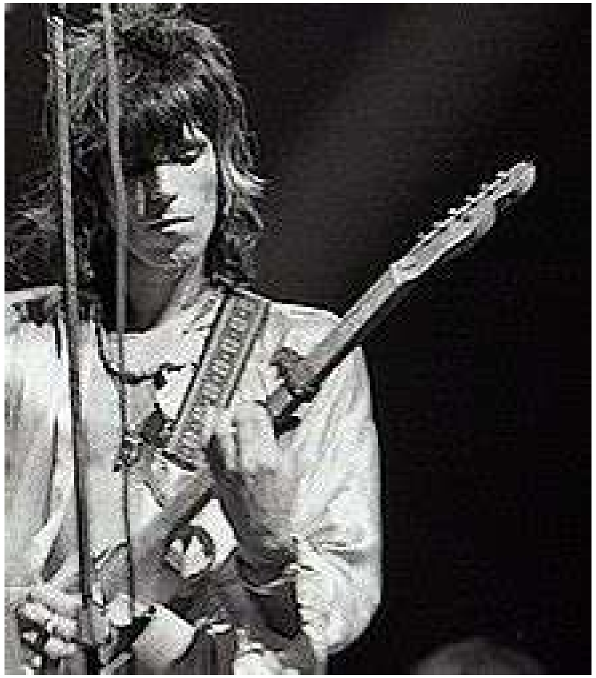
There is already software that implements uncertain-number data processing. Further information is available.[3][4]

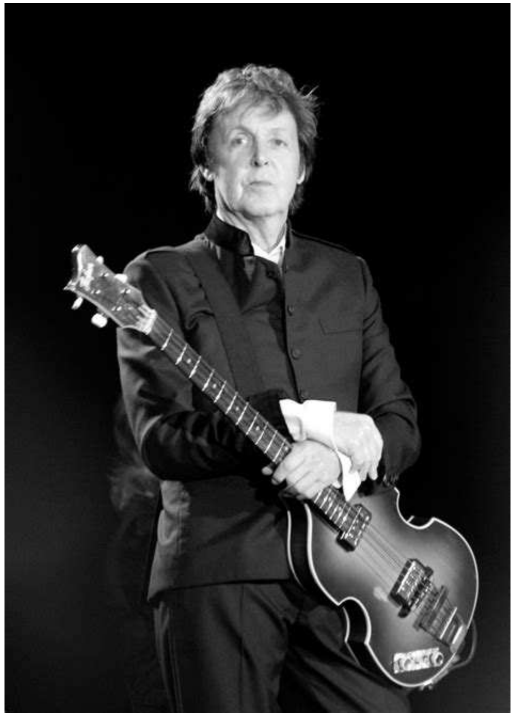
[3] B. D. Hall, *The GUM Tree Calculator: A Python package for measurement modelling and evaluating measurement uncertainty*, Metrology, 2022, 2, 128–149. DOI:10.3390/metrology2010009.

[4] B. D. Hall, *Automating metrological data processing*, Digital Transformation in Metrology Workshop: DCC for developer and its implementation in NQI (21-23 August 2023, Bangkok, Thailand) DOI:10.5281/zenodo.8275150.

Literacy isn't everything!







What do these famous musicians have in common?

They can't read or write traditional musical notation.

Notes

Scientific literacy involves an understanding of scientific principles, scientific method, and the ability to critically evaluate information. A scientifically literate individual should be able to articulate scientific ideas in ways that other scientists can understand.

Scientists and engineers are trained to use quantity equations during their studies, but most NMI metrologists eschew mathematical forms of scientific language.

People come to metrology from different fields of science and engineering and learn the job from more experienced people. This favours 'doing' rather than 'describing'. There is almost no formal tuition in 'metrology', and so there is no common curriculum of ideas (common scientific language) for metrologists. This is a very different situation to any other scientific discipline.

Metrology apprenticeship is important, but inefficient. It creates technical cliques that hamper knowledge sharing. It is making digitalisation harder, because people are not comfortable discussing their work in the general (abstract) terms that underpin metrology.

The level of skill needed to describe measurement procedures is not high. However, encouragement and leadership is needed to instil this as a necessary part of metrology best-practice.

Final comments

Digitalisation is going to be a long and disruptive experience. More and more processes and information will be digitalised—it is going to be impossible to avoid digitalisation.

Technical scientific leadership needs to get involved

- Competent high-level oversight of technical projects
- Defined performance (validation and acceptance) criteria

Where to start?

- Vocabulary (controlled terminology)
- Identifiers (for entities—but not for the kitchen sink!)
- Measurement models (also for the benefit of others)
- Processes (described logically)

Always remember that there's usually a simpler and better way to do something than the first way that pops into your head. – Donald Knuth

Notes

The work of digitalisation needs to be shared between metrologists and technologists. Metrologists need to oversee technical projects and make sure they meet expectations.

The place to start is modelling metrology concepts and capture terminology. This should allow digitalisation to be described at increasingly higher levels.