M-Layer Registry Prototype

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1 Introduction

This document sketches a high-level prototype data model that lists the elements comprising a prototype M-layer registry without regard to any particular data technology. As a draft design, all the information herein remains subject to and open to change. BIPM or another designated organization and various mirror servers would host the main registry if adopted. Others might host ancillary registries for use in particular areas or industries. Each registry should likely have some type of persistent ID reference for consistent world-wide access.

Section 2 provides some definitions. Sections 3, 4 and 5 cover the data model, interface and M-layer usage, respectively.

2 Definitions

aspect—quantity kind generalized to any measurement scale type [1]

FAIR—findable, accessible, interoperable, reusable [2]

measurement information infrastructure (MII)—set of normative standards that unambiguously define data structures, taxonomies, service protocols and security for locating, communicating and sharing measurement information [3]

M-layer—registries of data related to quantities and measurement units with an access scheme such as an API [4–6]

PID—persistent Identifier

MR—machine-readable

3 Registry Data Model

An M-layer registry would tentatively include the tables and fields defined hereafter, roughly in order of importance. The terms "table" and "field" herein do not imply any particular data technology such as SQL tables and columns. *Indicates fields that potentially, in place of the actual data, contain PIDs or some other link to external data such as an ontology [7, e.g.] where adequate existing FAIR systems exist (TBD). The first field listed in each table represents its unique key unless otherwise determined and the name fields should have uniqueness constraints. In addition to details to follow, the overall registry would require administrative detail such as version control.

3.1 Table: Aspects

Aspects contains the registered aspects, the key to the M-layer concept. Everything stems from uniquely identifying measurands by their aspect. See Table 1. This scheme uses AspectID as a unique key, while the paper [6] suggests the AspectID-ScaleTypeID combination as a unique index. Performance considerations may determine which to use, but in either case the name should remain unique to the AspectID-ScaleTypeID combination.

The M-Layer vision at present does not include a registry for specific aspects. It does not divide, for example, the general aspect ⟨length⟩ into radius, distance, flatness et al. The MII taxonomy fills that function with taxons such as `Measure.Length.Radius.Outside`, which should tie to the general aspect ⟨length⟩ using its AspectID. Using the MII taxons as metadata in digital documents will uniquely identify the measurands.

Table 1. Aspects data model.

Data Element	Description	Example
AspectID	unique identifier-index representing the aspect $\langle q \rangle$ in MR documents and data	⟨length⟩
*Name	registered name	length
Symbol	mathematical symbol markup (e.g., LaTeX, MathML [8])	l
*Definition	textual description or external pointer	PID to ontology entry length.definition?
Dimension	ordered list of exponents corresponding to the BaseDimensions definitions (tab-BaseDimensions)	0, 1, 0, 0, 0, 0, 0
ScaleTypeID	index to the aspect's scale type	RatioScaleID
Nature	intrinsic or extrinsic, perhaps other categorizations also	extrinsic

3.2 Table: QuantitySystems

QuantitySystems (Table 2) registers the various quantity systems to and from which the M-layer supports mapping: the ISQ (in various revisions as required), Imperial, natural, CGS, etc. Some quantity and unit systems may not (TBD) have a published one-to-one correspondence. Any unit systems not linked to defined quantity systems would use the M-layer aspect names, as would individual undefined quantities within a quantity system. More than one unit system may use the same quantity system. The M-layer itself has no QuantitySystems entry—Aspects handles that.

Table 2. QuantitySystems data model.

Data Element	Description	Example
QuantitySystemID	unique identifier-index	ISQ ID
Name	quantity-system name as published	International System of Quantities (ISQ) [9]
UnitSystemID	the corresponding unit system if any	SI 9th Ed. ID [10]

3.3 Table: UnitSystems

UnitSystems (Table 3) registers the various unit systems from and to which the M-layer supports conversions and rendering: the SI (in various revisions as required), Imperial, natural, CGS, etc. The M-layer itself has no UnitSystems entry.

Table 3. UnitSystems data model.

Data Element	Description	Example
UnitSystemID	unique identifier-index	SI9 ID
Name	unit-system name as published	The International System of Units (SI), 9th Edition [10]
QuantitySystemID	the corresponding quantity system if any	ISQ ID [9]

3.4 Table: Units

Units (Table 4) contains the measurement units which the registry provides for human-machine interfaces and the symbolic conversion functions that relate them to and from the M-Layer. Note that this M-Layer data scheme does not require explicit definitions for its own units, only an implicit definition, e.g., coherent SI9 or SI10 units, depending on adoption time. That would establish an unchanging reference for past, current, and future unit systems.

Each unit shall define a conversion both to and from an M-layer unit. In order to avoid $O(n^2)$ relations for n units, conversions between non-M-layer units will require using one unit's ConversionToML and the other unit's ConversionFromML expressions.

Non-ratio scales, in general, require arbitrary mathematical expressions for conversion rather than simple multiplication factors. Supporting arbitrary numerical precision requires symbolic expressions such as $\pi/180$ for converting from angular degrees to radians, where π appears in the registry as a symbol, not a precision-limited numeric value. Expressions may only contain numeric values defined as exact and included as text to avoid human-decimal and machine-binary rounding. Alternatively, the expressions might substitute symbols for exact constants defined in a separate table.

Table 4. Units data model.

Data Element	**Description**	**Example**
UnitID	unique identifier-index	inch ID
Name	unit name	inch
Symbol	unit symbol†	in
QuantitySystemID	quantity system identifier	Imperial ID
UnitSystemID	unit system identifier	Imperial ID or an ID based on NIST SP-1038 [11], for example
ConversionToML	expression converting a value x referenced to this unit to a value referencing the M-Layer unit (e.g., LaTeX, MathML [8])	$x/0.0254$
ConversionFromML	expression converting a value x referencing the M-Layer unit to a value referenced to this unit (e.g., LaTeX, MathML)	$x * 0.0254$

†Simple text may suffice, with the understanding that client systems render quantity values per applicable guidance documents [10, 12].

3.5 Table: ScaleTypes

ScaleTypes (Table 5) registers the scales that apply to M-layer aspects and units. For the aspect temperature for example, we may process measured values on various scales such as a {"low", "nominal", "high"} ordinal scale, Celsius or kelvin interval scales, the ITS-90 empirical scale, or the actual thermodynamic ratio scale.

Table 5. ScaleTypes data model.

Data Element	**Description**	**Example**
ScaleTypeID	unique identifier-index	ratio-scale ID
Name	scale description	ratio†
DataType	data type for aspect values belonging to this scale	numeric

†Entries include ratio, interval, cyclic or modular, logarithmic, ordinal, and nominal scales.

3.6 Table: ScaleOperations

ScaleOperations (Table 6) defines the legal operations for values on a given scale type and the resulting value's scale type. Ordinal scales for example, support comparisons but not arithmetic; interval scales may support addition but not multiplication.

Table 6. ScaleOperations data model.

Data Element	Description	Example
ScaleOperationID	unique identifier-index	addition ID
Name	operation performed on the data	addition
Operand1	first operand's ScaleTypeID	ratio-scale ID
Operand2	optional second operand's ScaleTypeID	interval-scale ID
Result	operation's resulting ScaleTypeID	ratio-scale ID
ApplicableNatures	aspect types allowed	extrinsic

3.7 Table: BaseDimensions

BaseDimensions (Table 7) defines the M-layer's base dimensions for purposes of dimensional analysis. For example, dimensions provide a redundant check on aspect equations used in digital systems and the relations defined in Table 8 or elsewhere. The ISQ and the SI use the base dimensions time T, length L, mass M, electric current I, thermodynamic temperature Θ, amount of substance N, luminous intensity J. The order matters only for defining an aspect's overall dimension as a vector of base-dimension exponent values as in $(-1, 1, 0, 0, 0, 0, 0)$ for L/T (velocity). If implemented that way, BaseDimensions might benefit from indexing the dimension table entries $0, 1 \ldots, n$. The M-layer might include other dimensions such as angle A to differentiate the dimensions of work and torque aspects, for example. The M-layer disambiguates aspects by AspectID, however, so it does not require dimensional analysis.

Table 7. BaseDimensions data model.

Data Element	Description	Example
BaseDimensionID	unique identifier-index	length dimension ID
Name	dimension description	length
Symbol	dimension symbol	L

3.8 Table: AspectRelations

AspectRelations (Table 8) registers quantity equations that relate aspects. The discussion in Section 3.4 regarding numeric and symbolic values applies here also. This (optional) table would provide a resource of physical relations and some digital systems might use this in place of hard-coding quantity calculations.

Table 8. AspectRelations data model.

Data Element	Description	Example
AspectRelationsID	unique identifier-index	Ohm's Law ID
Name	name of the encoded physical law or relation	Ohm's Law
Relation†	encoded (e.g., LaTeX, MathML [8]) equation with AspectIDs indicating the variables	$\langle$voltage$\rangle$ = $\langle$current$\rangle$ $\times$ $\langle$resistance$\rangle$

†This field likely requires supplementary AspectID fields for querying relations by aspect.

4 Interface

Digital systems would access the M-layer through an interface such as an API. Some use cases might query the M-layer operation by operation, but most systems would cache a local copy for efficient processing. Other use cases might include retrieving the structure or data, e.g. ScaleOperations (3.6), to build a class library or inform a code generator at application design time.

The following lists a small subset of potential queries:

- Retrieve a registry copy.
- Retrieve an aspect list with ID, name, symbol, definition.
- Retrieve a unit system list with ID, name.
- Retrieve a unit system's units with ID, name, symbol and conversions.
- ... TBD

Any or all queries may support conditions and parameters.

5 M-Layer Usage

In human-readable documents, quantity values appear with two components: q, the numeric value and $[Q]$ the unit symbol, as in 2.446 mm. Humans rely on a textual quantity description or the context to determine the actual measurand. Since that methodology fails for machine processing, the M-layer would extend this with a third element, $\langle q \rangle$ that uniquely identifies the quantity. The full form would then become $2.446\,\mathrm{mm}\langle\text{length}\rangle$.

However, machines do not require multiple units or prefixes for internal processing or communication. Therefore, an M-layer aspect requires only one unprefixed unit, in which case the aspect would uniquely determine the unit and we may drop the unit entirely from the data. This means digital systems may simply carry the numeric value q and the aspect $\langle q \rangle$ in computations and data. In our example, the data would simply contain $2.446 \times 10^{-3}\langle\text{length}\rangle$, assuming M-layer documentation defines the SI9 meter as the M-layer length unit. The data model then allows digital systems to render this in the expected form: Length, 2.446 mm or using any other unit the user requests.

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TBD

7 References

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8 Version History

Version	**Date**	**Changes**
0.00	2022.03.15	Initial draft, adapted from discussions around [4–6] and MII working meetings