NASA QUDT Handbook

Ontology-based Specification of Quantities, Units, Dimensions and Types

The 15th NASA-ESA Workshop on Product Data Exchange
Colorado Springs, USA, 21-23 May 2013

Ralph Hodgson TopQuadrant CTO and
NASA QUDT Ontologies Lead

Jack Spivak TopQuadrant Associate

v10:10-Oct-2013

Roadmap (AKA Whirlwind Tour)

- ✓ Introductions
- ✓ Quantities, Units and Dimensions 101
- ✓ NASA QUDT Handbook
- ✓ QUDT Ontology Models
- ✓ How the QUDT Handbook was produced
- ✓ Next Priorities

- ✓ **25 minutes / 44 slides !!**

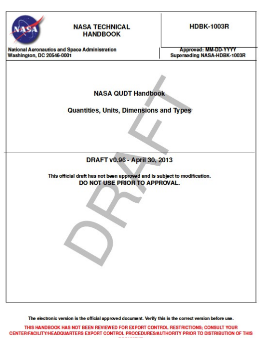
Introductions

Ralph Hodgson

- *co-founder and CTO of TopQuadrant, Inc., a US-headquartered company that specializes in semantic technology consulting, training, tools and platforms;*
- *NASA QUDT Ontologies and Handbook Lead*

Jack Spivak

- *TopQuadrant Associate. NASA QUDT Ontologies and Handbook Author. Background in 3D solid modeling and information exchange in medical product design. Founding member, Perceptions Collaborative – a consultancy specializing in business strategy, operations, and planning.*



NASA TECHNICAL HANDBOOK | HDBK-1003R

National Aeronautics and Space Administration
Washington, DC 20546-0001

Approved: MM-DD-YYYY
Superseding NASA-HDBK-1003R

NASA QUDT Handbook

Quantities, Units, Dimensions and Types

DRAFT v0.96 - April 30, 2013

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QUDT (… and Ontology)

- *A NASA-sponsored initiative to formalize Quantities, Units of Measure, Dimensions and Types using ontologies expressed in RDF/OWL so that multiple representations can be generated including a NASA QUDT Handbook*

What is QUDT ?

- ✓ A NASA HQ sponsored project for a "semantically enhanced" version of Standard Engineering Tables

- ✓ QUDT is a published body of curated work:
  - for humans: as the NASA QUDT Handbook (PDF)
  - for machines: as RDF/OWL Ontologies at www.qudt.org

- ✓ Web Delivery of Guidance, Education, Mentoring
  - Experienced engineers can enter commonly used units – other engineers benefit and start at higher level
  - ex. Sample quantities offered for work on heat shield, mass properties

- ✓ Envisioned QUDT Web Services
  - Conversions
  - Error detection - consistency and correctness auditing for engineering reviews, reports and even software code
  - Dimensional analysis

Motivations for "Model Driven" QUDT

Problem: Communication Needs to be good and often isn't.

- ✓ Communication is core to interoperability and collaboration.
- ✓ Inaccurate or confusing communication can be disastrous
- ✓ Confusion is minimized by shared meaning.

Solution: Create consistent context of shared meaning.

Motivations for "Model Driven" QUDT

Example 1:

- ✓ 07_25_52 (a part #)
- ✓ 07_25_52 (a filename)
- ✓ 07_25_52 (my birthday)

Example 2:

- ✓ Lead (a metal)
- ✓ Lead (a sales opportunity)
- ✓ Lead (a short wire on an electronics package)
- ✓ Lead (to show the way)

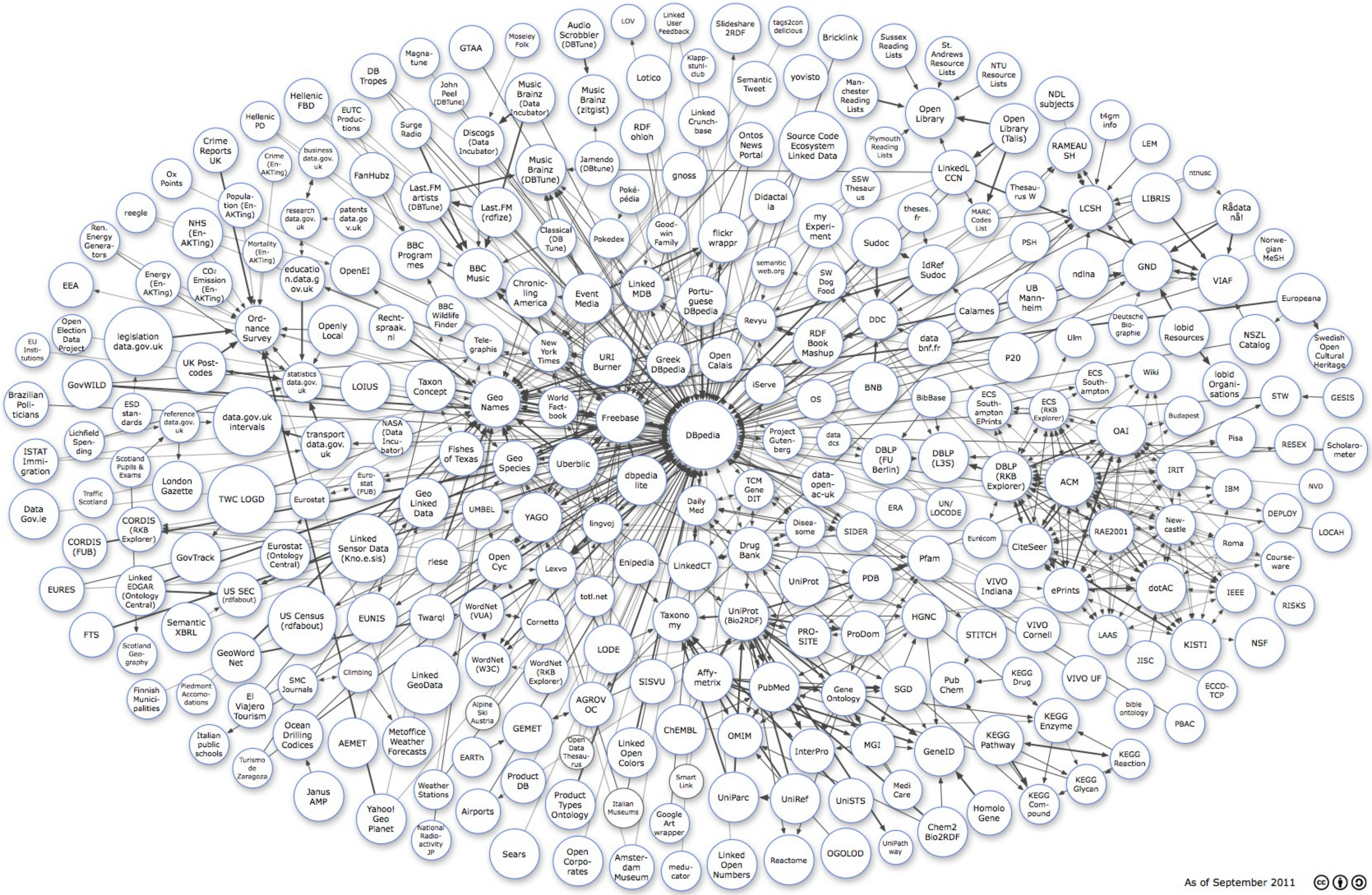
Motivations for "Model Driven" QUDT

An Ontology:

- ✓ ***Rigorously creates a consistent "context of shared meaning".***
- ✓ ***Is a "Specification for a Conceptualization"***
- ✓ ***Shares meaning across diverse fields, functions, domains of practice***
- ✓ ***Explicit, inherent interoperability***

Motivations for "Model Driven" QUDT

The Linking Open Data cloud diagram



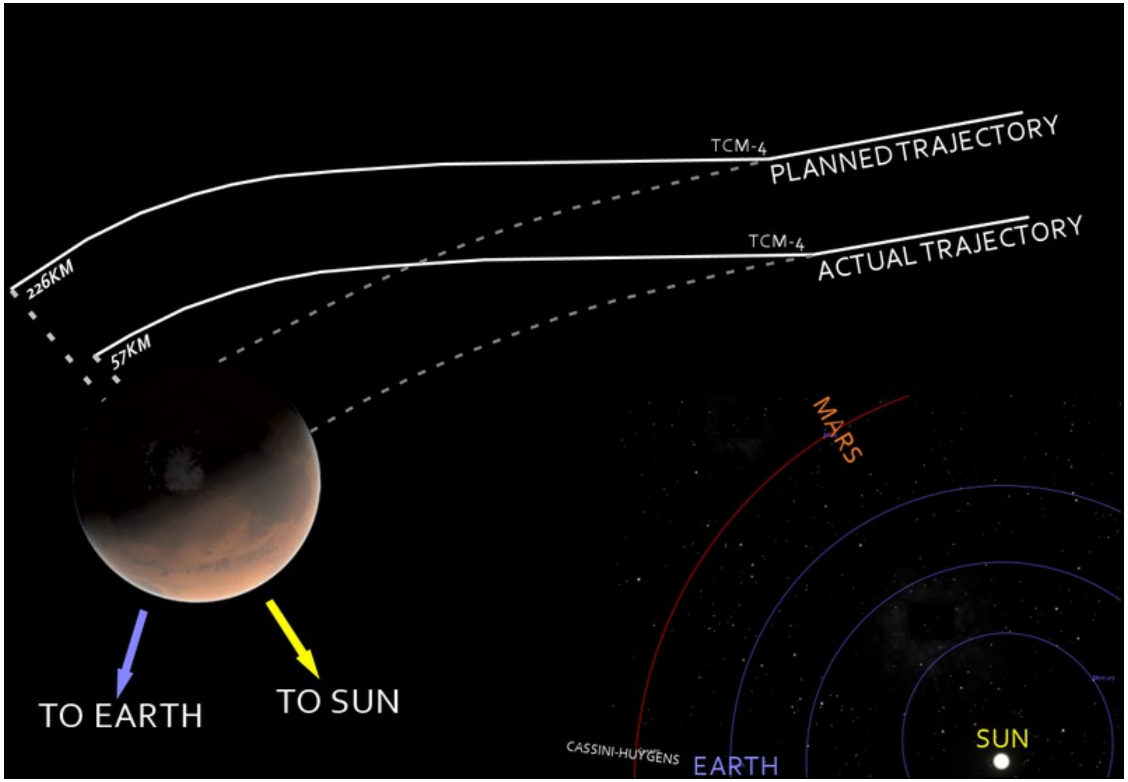
Motivations for "Model Driven" QUDT

- ✓ Motivations for formal representation include:
  - Create and maintain consistent data elements with legitimate values
    - **"Things not Strings" (GOOGLE quote)**
  - Standardize data structures
  - Standardize specification of queries for information retrieval
  - Improve integration of data and interoperability of processes and tools across the life cycle

QUDT: "Real World" Benefits

- ✓ Consistency and compatibility of analyses and communication across:
  - inter-program,
  - inter-function,
  - inter-departmental and
  - inter-organizational activities;
- ✓ Mitigation of errors and their associated impacts on:
  - Budgets,
  - schedules,
  - quality of deliverables and
  - mission safety.
- ✓ Satisfying the life-cycle development and operational needs of the science and engineering communities;
- ✓ Structured and web-based access to additional model-based QUDT information, tools and services.

"Real World" Benefits (2)



NASA's metric confusion caused Mars orbiter loss

Web posted at: 1:46 p.m. EDT (1746 GMT)

(CNN) -- NASA lost a $125 million Mars orbiter because one engineering team used metric units while another used English units

"Specifically, thruster performance data in English units instead of metric units was used in the software application code titled SM_FORCES (small forces). The output from the SM_FORCES application code as required by a MSOP Project Software Interface Specification (SIS) was to be in metric units of Newtonseconds (N-s)."
(NASA Mishap Investigation Board)

Roadmap (AKA Whirlwind Tour)

- ✓ Introductions
- ✓ Quantities, Units and Dimensions 101
- ✓ NASA QUDT Handbook
- ✓ QUDT Ontology Models
- ✓ How the QUDT Handbook was produced
- ✓ Next Priorities

Kinds of Physical Quantities

- ✓ A ***Quantity Kind*** characterizes the physical nature or type of a measured quantity . (E.g. length, mass, time, force, power, energy, etc.)
- ✓ ***Derived Quantity Kinds*** are defined in terms of a small set known as ***Base Quantity Kinds*** using physical laws.
- ✓ A ***System of Quantities*** is a specification, typically developed and maintained by an authoritative source:
  - Choice of the base quantity kinds for the system;
  - The formulas expressing each derived quantity kind in the system in terms of the base quantity kinds:
    - Force = Mass * Acceleration
    - Velocity = Length / Time
    - Electric Charge = Electric Current * Time
  - Example: International System of Quantities is the system of quantities used with the International System of Units. The ISQ is defined in ISO/IEC80000.

# of Measure

- A ***Unit of Measure*** establishes a reference scale for a quantity's dimension.
- ***System of Units*** is a choice of base units and derived units, together with their multiples and submultiples, defined in accordance with given rules, for a given system of quantities.
  - **Base units:** Units corresponding to the base quantities in a system of quantities.
    - SI Base Units: Metre (Length), Kilogram (Mass), Second (Time), Ampere (Electric Current), Kelvin (Thermodynamic Temperature), Mole (Amount of Substance), Candela (Luminous Intensity)
  - **Derived units:** Units corresponding to the derived quantities in a system of quantities.
  - **Coherent units:** When coherent units are used, equations between the numerical values of quantities take exactly the same form as the equations between their corresponding quantity kinds. Thus if only units from a coherent set are used, conversion factors between units are never required.

Dimensions and Dimensional Analysis

- ✓ ***Dimensions*** are used to characterize quantities in terms of their dependence on a chosen set of base quantity kinds. The dimension of each base quantity kind is represented by its dimension symbol:
  - SI Dimensions: Length (L), Mass (M), Time (T), Current (I), Temperature (Θ), Amount of Substance (N), Luminous Intensity (J).

- ✓ The dimension of any quantity can be expressed as a product of the ***base dimension*** symbols raised to a rational power. For example, velocity can be expressed as length divided by time:
  - V = L/T = L^1T^(-1)
  - Thus, velocity has the dimensions L^1T^(-1).

- ✓ Dimensional Analysis:
  - Only quantities with the same dimensions may be compared, equated, added, or subtracted.*
  - Quantities of any dimension can be multiplied or divided. The dimensionality of the resultant is determined by analyzing the product or quotient of the operands.**

Quantities need a Standard Vocabulary

Basic physical quantities, forces & moments examples

Data-Name Identifier	Description	Definition	Symbol (Units)	Units
Potential	Potential	$\nabla \varphi = q$	L2/T	SI
StreamFunction	Stream function (2-D)	$\nabla \times \psi = q$	L2/T	SI
Density	Static density	*(ρ)*	M/L3	SI
Pressure	Static pressure	*(p)*	M/(LT2)	SI
Temperature	Static temperature	*(T)*	**Θ**	SI
EnergyInternal	Static internal energy per unit mass	*(e)*	L2/T2	SI
Enthalpy	Static enthalpy per unit mass	*(h)*	L2/T2	SI
Entropy	Entropy	*(s)*	ML2/(T2Θ)	SI
EntropyApprox	Approximate entropy	*(sapp = p / ργ)*	(L(3γ-1))/((M(γ-1)).T2)	SI
DensityStagnation	Stagnation density	*(ρ0)*	M/L3	SI
PressureStagnation	Stagnation pressure	*(p0)*	M/(LT2)	SI
TemperatureStagnation	Stagnation temperature	*(T0)*	**Θ**	SI
EnergyStagnation	Stagnation energy per unit mass	*(e0)*	L2/T2	SI
EnthalpyStagnation	Stagnation enthalpy per unit mass	*(h0)*	L2/T2	SI
EnergyStagnationDensity	Stagnation energy per unit volume	*(ρe0)*	M/(LT2)	SI
VelocityX	x-component of velocity	*(u = q · **ex**)*	L/T	SI
VelocityY	y-component of velocity	*(v = q . **ey**)*	L/T	SI
VelocityZ	z-component of velocity	*(w = q . **ez**)*	L/T	SI
VelocityR	Radial velocity component	*(q . **er**)*	L/T	SI

Data-Name Identifier	Description	Units
ForceX	*Fx* = ***F*** · *ex*	**ML/T2**
ForceY	*Fy* = ***F*** · *ey*	**ML/T2**
ForceZ	*Fz* = ***F*** · *ez*	**ML/T2**
ForceR	*Fr* = ***F*** · *er*	**ML/T2**
ForceTheta	*Fθ* = ***F*** · *eθ*	**ML/T2**
ForcePhi	*Fφ* = ***F*** · *eφ*	**ML/T2**
Lift	*L* or *L*'	**ML/T2**
Drag	*D* or *D*'	**ML/T2**
MomentX	*Mx* = ***M*** · *ex*	**ML2/T**
MomentY	*My* = ***M*** · *ey*	**ML2/T**
MomentZ	*Mz* = ***M*** · *ez*	**ML2/T**
MomentR	*Mr* = ***M*** · *er*	**ML2/T**
MomentTheta	*Mθ* = ***M*** · *eθ*	**ML2/T**
MomentPhi	*Mφ* = ***M*** · *eφ*	**ML2/T**
MomentXi	*Mξ* = ***M*** · *eξ*	**ML2/T**
MomentEta	*Mη* = ***M*** · *eη*	**ML2/T**
MomentZeta	*Mζ* = ***r*** · *eζ*	**ML2/T**
Moment_CenterX	*x*0 = ***r***0 · *ex*	**L**
Moment_CenterY	*y*0 = ***r***0 · *ey*	**L**
Moment_CenterZ	*z*0 = ***r***0 · *ez*	**L**

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- ✓ ~3,800 pages of PDF
- ✓ Model-Generated
  - From RDF/OWL Ontologies
  - Using SPARQL to LaTeX Transformations

Formal Model: Quantities and Units in OWL

✓ Quantities, Units and Values: Main classes for describing quantities and their values.

- quantity:Quantity
- quantity:QuantityValue
- unit:Unit

✓ Quantity Structure: Main classes characterizing physical properties of quantities and determine commensurability between quantities (Dimensional analysis).

- quantity:QuantityKind
- quantity:Dimension

✓ Systems: Main classes used to describe existing agreements and standards establishing systems of quantities and units.

- quantity:SystemOfQuantities
- unit:SystemOfUnits

/hat is an Ontology?

- ✓ **A formal representation of a domain of knowledge in a rigorous and standardized way (RDF, OWL)**
  - Describes things and relationships explicitly using unique identifiers (URI's)
  - Descriptions are expressed as simple “sentences” (Subject, Verb, Object)
  - Sentences are linked together into a larger “graph” upon which logical inferences can be performed (Machine processable representation)
  - Extensible - Graphs are represented in any of several “neutral formats” that can be joined
  - These graphs can be queried (SPARQL) to discover patterns
  - “Crowd-Sourced” - can be developed, extended and maintained collaboratively

What is an Ontology? (2)

"A Specification for a Conceptualization"

- ✓ Grammar: Subject – Verb - Object
- ✓ English: A quantity has a unit
- ✓ OWL: "triples"

quantity:Quantity – quantity:hasApplicableUnit - unit:Unit

Key Requirements: QUDT Ontologies

OWL ontologies of physical quantities and units of measure must satisfy these requirements:

- The ontologies should support interoperability
  - between different stakeholders using quantities and units
  - by providing controlled vocabularies and
  - through mutually agreed definitions of shared concepts.

- The ontologies should expose enough structure about the quantities and units
  - to support conversion between commensurate units and
  - to perform dimensional analysis on the products and quotients of dimensional quantities.

The Units ontologies use a model based on dimensions and quantities.

Benefits of QUDT Ontologies

- ✓ **Actionable Information:**
  - Model based representation allows multiple representations (other ontology lang, UML, SysML)
  - Unambiguous meaning
    - Communication and Interactivity unimpeded by semantic "Collisions"

- ✓ **"Integral Schema"**
  - Schema can be queried using same language as instances
  - Representation Improves Interoperability, Eases Repurposing, Reduces maintenance

- ✓ **Machine based inference**

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QUDT Scope

The purpose of the QUDT handbook is to provide a consistent approach to the specification and use of Units, Quantity Kinds, Dimensions (of Units), and Datatypes.

This consistency is achieved by having a model-driven approach.

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1 SCOPE

1.1 Purpose

The purpose of this handbook is to provide a consistent approach to the specification and use of *Units*, *Quantity Kinds*, *Dimensions* (of Units), and *Datatypes*. This consistency is achieved by having a model-driven approach. Through this consistency and correctness, some key benefits derive:

- Consistency and compatibility in inter-program, inter-function, inter-departmental and inter-agency analyses and communication;
- Mitigation of errors and their associated impacts on budgets, schedules, quality of deliverables and mission safety.
- Satisfying the life-cycle development and operational needs of NASA's science and engineering community;
- Structured and web-based access to additional model-based QUDT information, tools and services.

1.2 Applicability

This handbook is intended to be of broad application in the domains of science, engineering and program management. Practically, it will be useful for activities including, but not limited to, research, development, design, validation and verification, communication and collaboration, project management, requirements analysis and definition, specification, purchasing and contract activities and failure modes and effects analysis.

The audience for this document includes the entire range of disciplines within NASA's scientific, engineering, management, technical and support communities. Disciplines represented include but are not limited to the examples below:

QUDT: "Real World" Benefits

- ✓ Consistency and compatibility of analyses and communication across:
  - inter-program,
  - inter-function,
  - inter-departmental and
  - inter-organizational activities;
- ✓ Mitigation of errors and their associated impacts on:
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NASA QUDT Handbook Content

NASA QUDT Handbook

Quantity Kind Domains

- SYSTEMS OF QUANTITIES
- QUANTITY KIND TABLES
  - Atomic Physics Quantities
  - Acoustics Quantities
  - Physical Chemistry and Molecular Physics Quantities
  - Electricity and Magnetism Quantities
  - Information Science and Technology Quantities
  - Light Quantities
  - Mechanics Quantities
  - Solid State Physics Quantities
  - Space and Time Quantities
  - Telebiometrics Human Physiology Quantities
  - Thermodynamics Quantities
  - Propulsion Quantities
  - Characteristic Numbers (as Quantities)

NASA QUDT Handbook

Example: Propulsion Quantity Kinds

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11.12 Propulsion Quantities

Action Time
Ambient Pressure
Angle Of Attack
Angular Distance
Apogee Radius Of An Elliptical Orbit
Average Head End Pressure
Average Specific Impulse
Average Vacuum Thrust
Bevel Gear Pitch Angle
Buckling Factor
Burn Rate
Burn Time
Characteristic Velocity
Closest Approach Radius
Combustion Chamber Temperature
Cross-sectional Area
Density In Combustion Chamber
Density Of The Exhaust Gases
Distance Traveled During a Burn
Drag Coefficient
Drag Force
Dynamic Pressure
Earth Closest Approach Vehicle Velocity
Eccentricity Of Orbit
Effective Exhaustvelocity
Electric Power
Electrical Power To Mass Ratio
Elliptical Orbit Apogee Velocity
Elliptical Orbit Perigee Velocity
Exhaust Gas Mean Molecular Weight
Exhaust Gases Specific Heat
Exhaust Stream Power
Exit Plane Cross-sectional Area
Exit Plane Pressure
Exit Plane Temperature
Expansion Ratio
Fast Fission Factor
Fission Core Radius To Height Ratio
Fission Fuel Utilization Factor
Fission Multiplication Factor
Flight Path Angle
Gravitational Constant
Head End Pressure
Horizontal Velocity
Ignition interval time
Initial Expansion Ratio
Initial Nozzle Throat Diameter
Initial Velocity
Ion Current
Ion Density
Ionic Charge
Lift Coefficient
Lift Force
Mach Number
Mass Of The Earth
Max Operating Thrust
Max Sea Level thrust
Maximum Expected Operating Pressure
Maximum Expected Operating Thrust
Maximum Operating Pressure
Neutron Diffusion Length
Nozzle Throat Cross-sectional Area
Nozzle Throat Diameter
Nozzle Throat Pressure
Nozzle Walls Thrust Reaction
Orbital Angular Momentum per Unit Mass
Orbital Radial Distance
Over-range distance
Payload Ratio
Permittivity Of Free Space
Pressure Burning Rate Constant
Pressure Burning Rate Index
Propellant Burn Rate
Propellant Mean Bulk Temperature
Propellant Temperature
Resonance Escape Probability For Fission
Rocket Atmospheric Transverse Force
Specific Heats Ratio
Specific Impulse
Structural Efficiency
Thermal Utilization Factor For Fission
Thrust Coefficient
Thrust To Weight Ratio
Thruster Power To Thrust Efficiency
True Exhaust Velocity
Universal Gas Constant
Vacuum Thrust
Vehicle Velocity
Vertical Velocity
Web Time
Web Time Average Pressure
Web Time Average Thrust

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11.12.66 Orbital Angular Momentum per Unit Mass

Angular momentum of the orbit per unit mass of the vehicle

TABLE 11-1566 ORBITAL ANGULAR MOMENTUM PER UNIT MASS

ORBITAL ANGULAR MOMENTUM PER UNIT MASS	
Property	**Value**
abbreviation	
dimensions	
symbol	h
QName	quantity:OrbitalAngularMomentumPerUnitMass
identifier	
designator	

View as:

Example: an ISO-80000 QuantityKind

Electric Charge Line Density Quantity Kind

Ontology-generated table using SWP to produce LaTeX

Machine-processable representations: OWL/RDF, Turtle, XML, JSON, CSV

11.4.18 Electric Charge Line Density

In electromagnetism, charge density is a measure of electric charge per unit volume of space, in one, two or three dimensions. More specifically: the linear, surface, or volume charge density is the amount of electric charge per unit length, surface area, or volume, respectively. The respective SI units are \$C ·\$,m^{-1}, $C \cdot m^{-2}$ or $C \cdot m^{-3}$.

Source(s)

1. http://en.wikipedia.org/wiki/Charge_density

Belongs to *System(s) of Quantities*: International System of Quantities

TABLE 11-375 ELECTRIC CHARGE LINE DENSITY

ELECTRIC CHARGE LINE DENSITY	
Property	**Value**
abbreviation	
dimensions	$A \cdot s/m$, $I \cdot T/L$
symbol	λ where λ is `\lambda`, the unicode character u1D706, see www.charbase.com and www.fileformat.info.
applicable units	coulomb-per-meter
QName	quantity:ElectricChargeLineDensity
identifier	
designator	

DRAFT

View as:

QUDT Name, Identifier and Usage Rules

Rules for the construction and usage of quantities, units of measure, dimensions and data types.

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6 QUDT NAME, IDENTIFIER AND DESIGN RULES GUIDANCE

This section defines rules for the construction and usage of quantities, units of measure, dimensions and data types. The section is structured into subsections that organize categories of rules.

Each category may have sub-categories, in which case an index is built with links to further sub-divisions of rules. These links are provided in a two-column rounded-corner grey box. The first level of rule categories are as follows:

Grammar Rules stipulation of required or recommended practices for capitalization, use of singular or plural forms, punctuation, spacing and hyphenation.

Naming Rules guidance on how to construct names, symbols, abbreviations and identifiers

QUDT Rules an index of all the rules that extend SP811 specifically for QUDT

SP811 Rules an index of all NIST SP811 Rules

Type-Setting Rules guidance on how names, symbols, abbreviations, identifiers and values should be printed

Usage Rules guidance on how to use math operators, symbol names, quantity names, quantity values and units of measure

6.1 Rules Index

The QUDT Naming, Design and Usage rules have been based on the NIST rules as documented in NIST 811.

Source(s)

1. http://www.nist.gov/pml/pubs/sp811/index.cfm

Example of a Rule

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6.2.51 R-UNU-001: Applying mathematical operations to unit names

Because it could possibly lead to confusion, mathematical operations are not applied to unit names but only to unit symbols. (See also NIST SP811 Secs. 6.1.7 and 9.5.)

Source(s)

1. http://physics.nist.gov/Pubs/SP811/sec09.html#9.8

Example

Mathematical Operations on Unit Symbols but not Unit Names

joule per kilogram or J/kg or $\mathrm{J \cdot kg^{-1}}$ but not: joule/kilogram or $\mathrm{joule \cdot kilogram^{-1}}$

Model-Driven Traceability

The Ontologies and PDF Content are fully linked, including 'where-used' links. All references and their attribution are also included in the models.

Example: Electric Charge Quantity Kind

Where Used

Has reference	From Subject	Instance(s)
has base quantity kind	Dimension Vector	$Q^0, Q^0, Q^0, Q^0, Q^0, Q^0, Q^0, Q^1, Q^1, Q^1, Q^1, Q^1, Q^1, Q^1, Q^2, Q^2, Q^2, Q^2, Q^2, Q^2, Q^2, Q^3, Q^3, Q^3, Q^3, Q^3, Q^3, Q^3, Q^4, Q^4, Q^4, Q^4, Q^4, Q^4, Q^4, Q^5, Q^5, Q^5, Q^5, Q^5, Q^5, Q^5, Q^6, Q^6, Q^6, Q^6, Q^6, Q^6, Q^6, Q^7, Q^7, Q^7, Q^7, Q^7, Q^7, Q^7, Q^8, Q^8, Q^8, Q^8, Q^8, Q^8, Q^8, Q^9, Q^9, Q^9, Q^9, Q^9, Q^9, Q^9, Q^{-1}, Q^{-1}, Q^{-1}, Q^{-1}, Q^{-1}, Q^{-1}, Q^{-1}, Q^{-2}, Q^{-2}, Q^{-2}, Q^{-2}, Q^{-2}, Q^{-2}, Q^{-2}, Q^{-3}, Q^{-3}, Q^{-3}, Q^{-3}, Q^{-3}, Q^{-3}, Q^{-3}, Q^{-4}, Q^{-4}, Q^{-4}, Q^{-4}, Q^{-4}, Q^{-4}, Q^{-4}, Q^{-5}, Q^{-5}, Q^{-5}, Q^{-5}, Q^{-5}, Q^{-5}, Q^{-5}, Q^{-6}, Q^{-6}, Q^{-6}, Q^{-6}, Q^{-6}, Q^{-6}, Q^{-6}, Q^{-7}, Q^{-7}, Q^{-7}, Q^{-7}, Q^{-7}, Q^{-7}, Q^{-7}, Q^{-8}, Q^{-8}, Q^{-8}, Q^{-8}, Q^{-8}, Q^{-8}, Q^{-8}, Q^{-9}, Q^{-9}, Q^{-9}, Q^{-9}, Q^{-9}, Q^{-9}, Q^{-9}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}, Q^{10}$
has quantity kind	System of Quantity Kinds	ISO System of Quantities (ISQ)
has reference quantity kind	Dimension	$DIM_{CGS-EMU}(L^{0.5}M^{0.5})$, $DIM_{CGS-ESU}(L^{1.5}M^{0.5}T^{-1})$, $DIM_{CGS-GAUSS}(L^{1.5}M^{0.5}T^{-1})$, $DIM_{ISO}(TI)$, $DIM_{PLANCK}(Q)$, $DIM_{SI}(TI)$
quantity kind	Electric Charge Unit	Elementary Charge, abcoulomb, ampere-hour, atomic unit of charge, attocoulomb, centi-coulomb, coulomb, decacoulomb, decicoulomb, exacoulomb, faraday, femtocoulomb, franklin, gigacoulomb, hectocoulomb, kilocoulomb, megacoulomb, microcoulomb, millicoulomb, nanocoulomb, petacoulomb, picocoulomb, planck-charge, statcoulomb, teracoulomb, yoctocoulomb, yottacoulomb, zeptocoulomb, zettacoulomb
system derived quantity kind	System of Quantity Kinds	CGS-EMU System of Quantities, CGS-ESU System of Quantities, CGS-Gauss System of Quantities, International System of Quantities

Continued on next page

QUDT Industry & Standards Alignment

- ✓ CODATA
  - "CODATA Recommended Values of the Fundamental Physical Constants: 2006" . Committee on Data for Science and Technology (CODATA).
- ✓ BIPM
  - "International System of Units (SI), 8th Edition". Bureau International des Poids et Mesures (BIPM).
- ✓ NIST
  - "NIST Reference on Constants, Units, and Uncertainty". National Institute of Standards and Technology (NIST).
- ✓ ISO
  - ISO 80000 Standards for Units and Quantities
- ✓ UNECE
  - e-Commerce codes alignment

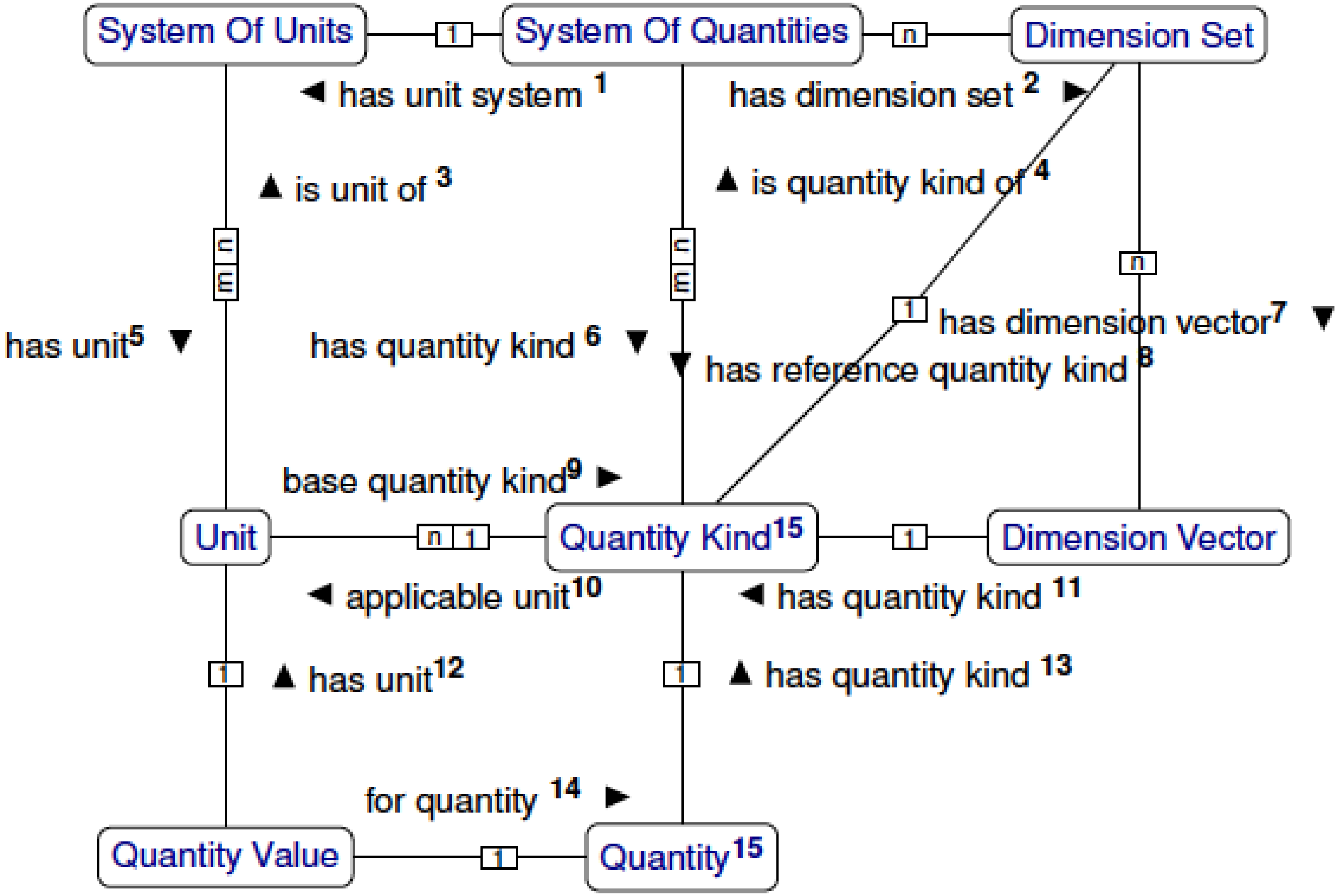
QUDT models ISO-80000

1. ISO-80000-01 2009 ISO 80000-1:2009 Quantities and units – Part 1: Generals
2. ISO-80000-01 2009/Cor 1:2011 ISO 80000-1:2009 Quantities and units – Part 1: General (Correction 1)
3. ISO-80000-02 2009 ISO 80000-2:2009 Quantities and units – Part 2: Mathematical signs and symbols to be used in the natural sciences and technology
4. ISO-80000-03 2006 ISO 80000-3:2006 Quantities and units – Part 3: Space and time
5. ISO-80000-04 2006 ISO 80000-4:2006 Quantities and units – Part 4: Mechanics
6. ISO-80000-05 2007 ISO 80000-5:2007Quantities and units – Part 5: Thermodynamics
7. ISO-80000-06 2008 IEC 80000-6:2008 Quantities and units – Part 6: Electromagnetism
8. ISO-80000-07 2008 ISO 80000-7:2008 Quantities and units – Part 7: Light
9. ISO-80000-08 2007 ISO 80000-8:2007 Quantities and units – Part 8: Acoustics
10. ISO-80000-09 2009 ISO 80000-9:2009 Quantities and units – Part 9: Physical chemistry and molecular physics
11. ISO-80000-09 2009/Amd 1:2011 ISO 80000-9:2009/Amd 1:2011
12. ISO-80000-10 2009 ISO 80000-10:2009 Quantities and units – Part 10: Atomic and nuclear physics
13. ISO-80000-11 2009 ISO 80000-11:2008 Quantities and units – Part 11: Characteristic numbers
14. ISO-80000-12 2009 ISO 80000-12:2009 Quantities and units – Part 12: Solid state physics
15. ISO-80000-13 2008 IEC 80000-13:2008 Quantities and units – Part 13: Information science and technology
16. ISO-80000-14 2008 IEC 80000-14:2008 Quantities and units – Part 14: Telebiometrics related to human physiology
17. ISO/DIS 80003-02 ISO/DIS 80003-2 Physiological quantities and their units – Part 2: Physics
18. ISO/DIS 80003-03 ISO/DIS 80003-3 Physiological quantities and their units – Part 3: Chemistry
19. ISO/NP 80003-02 ISO/NP 80003-7 Physiological quantities and their units – Part 7: Physicopharmacology
20. ISO/NP 80003-06 ISO/NP 80003-8 Physiological quantities and their units – Part 8: Chemopharmacology
21. ISO/NP 80003-08 ISO/NP 80003-8 Physiological quantities and their units – Part 8: Chemopharmacology

Roadmap (AKA Whirlwind Tour)

- ✓ Introductions
- ✓ Quantities, Units and Dimensions 101
- ✓ NASA QUDT Handbook
- ✓ QUDT Ontology Models
- ✓ How the QUDT Handbook was produced
- ✓ Next Priorities

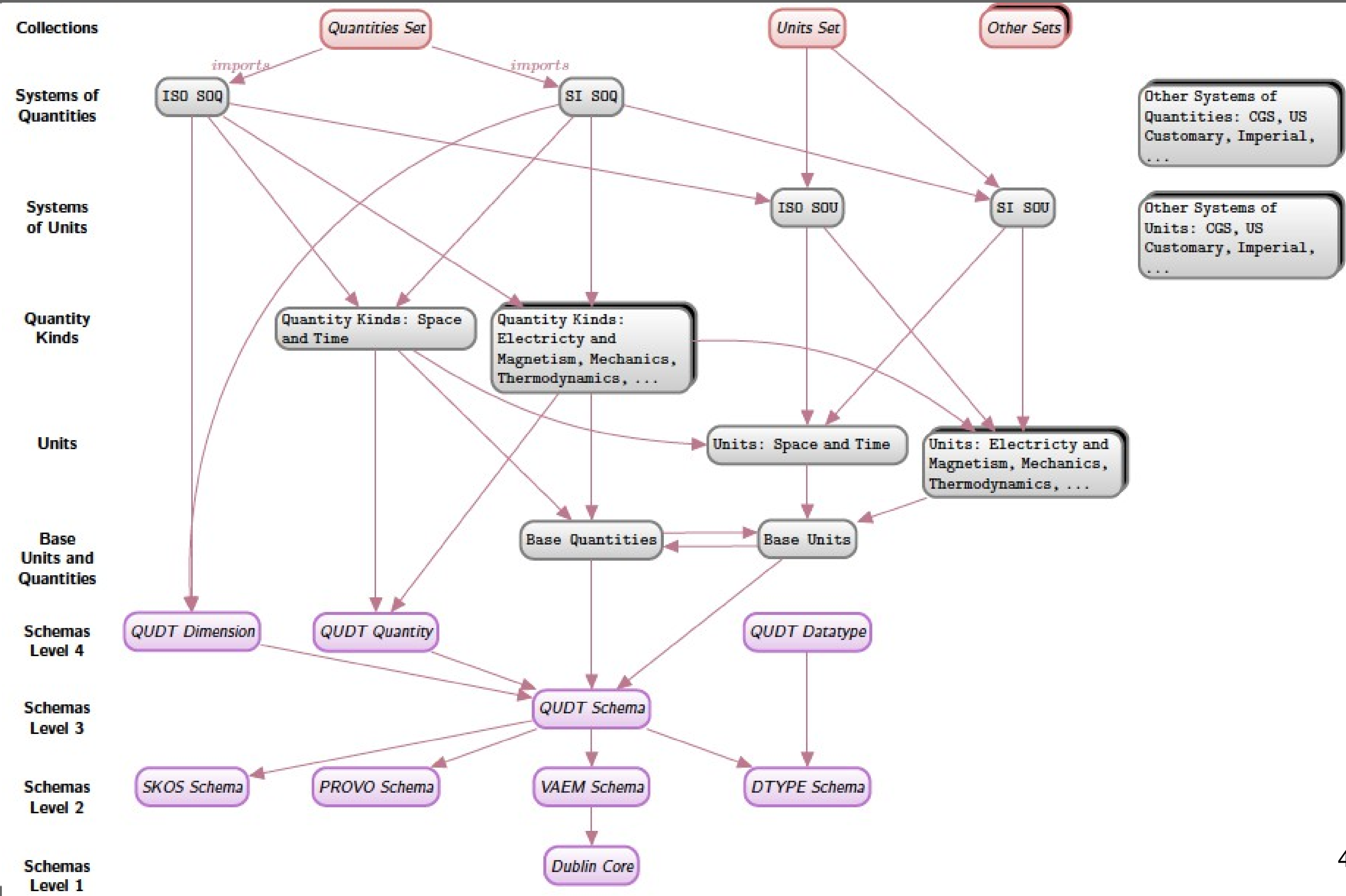
Conceptual Model of QUDT



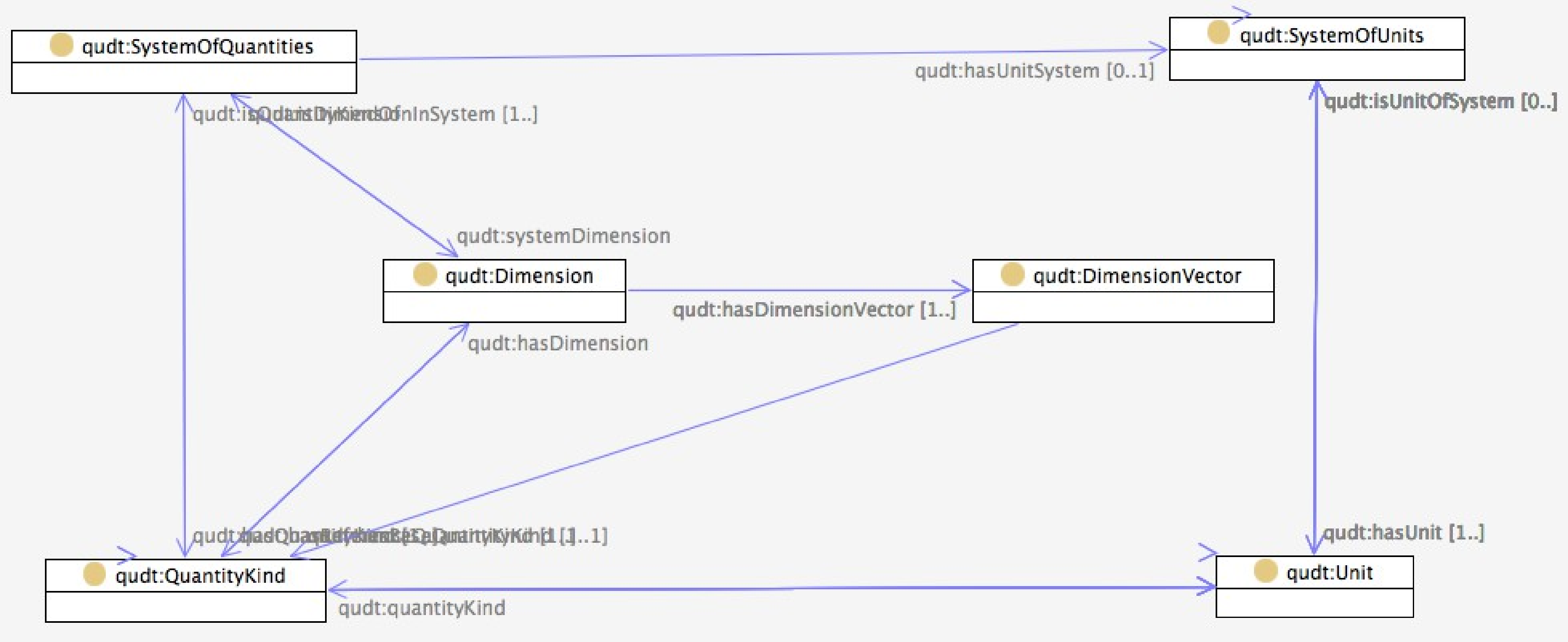
Conceptual Model of QUDT (Notes)

1 There is a one to one relationship between a **System of Quantities** and a **System of Unit**
2 A **System of Quantities** has its own set of **Dimensions**
3 A **Unit** belongs to one or more **Systems of Units**
4 A **Quantity Kind** belongs to one or more **Systems of Quantities**
5 A **System of Units** has one or more **Units**
6 A **System of Quantities** has one or more **Quantity Kinds**
7 A **Dimension Set** has up to eight **Dimension Vectors**
8 A **Dimension Set** has exactly one reference **Quantity Kind**
9 A **Unit** has exactly one base **Quantity Kind**
10 A **Quantity Kind** has one or more applicable **Units**
12 A **Quantity Value** is of exactly one **Unit** of Measure
13 A **Quantity** is of exactly one **Quantity Kind**
14 A **Quantity Value** is a measure for a specific **Quantity**
15 A **Quantity** is a *Value-bearing* entity whereas a **Quantity Kind** is a *Type* construct

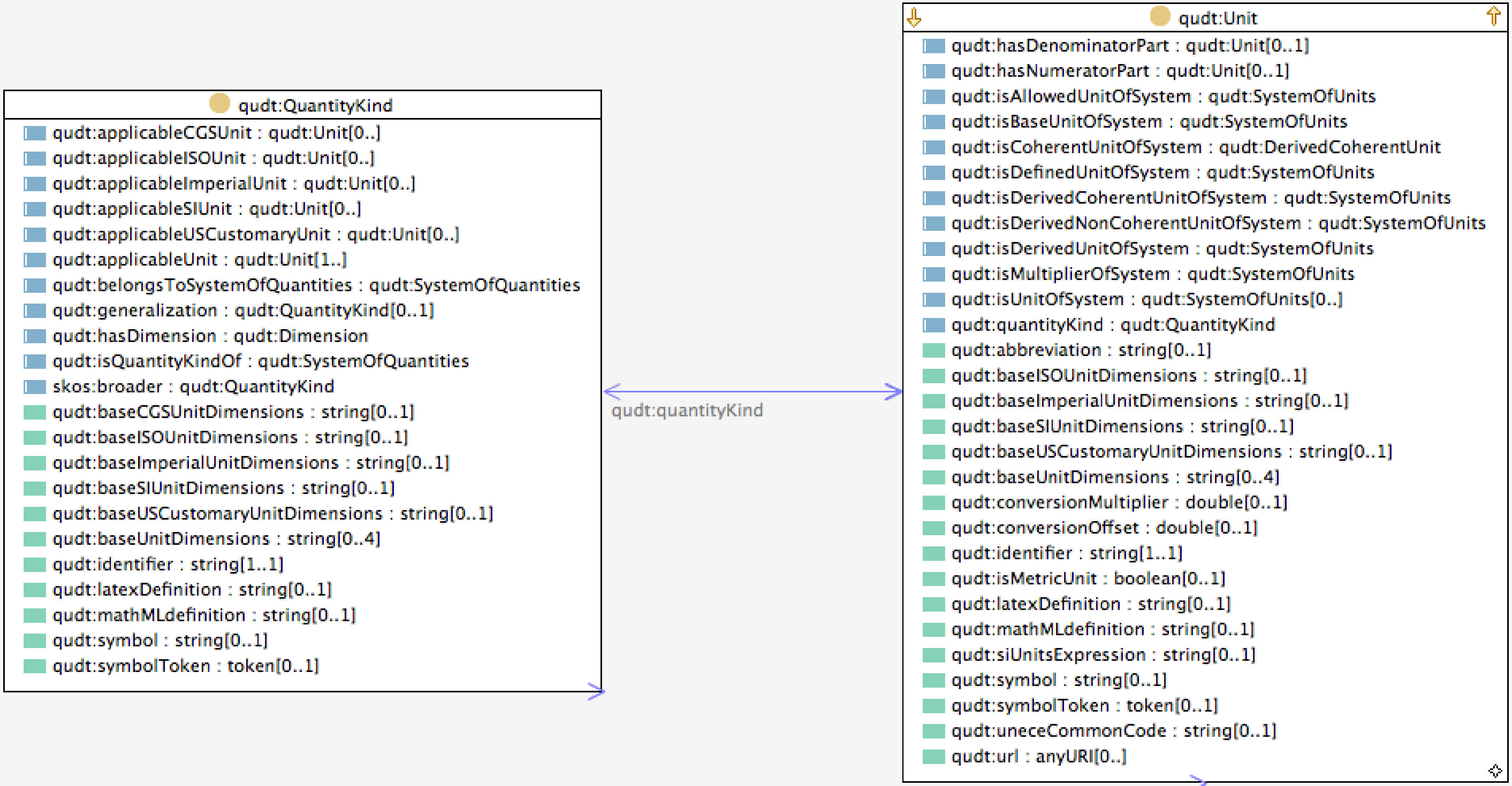
QUDT Information Architecture



Ontology Example: Quantity Kinds and Units (1)



Ontology Example: Quantity Kinds and Units (2)



Roadmap (AKA Whirlwind Tour)

- ✓ Introductions
- ✓ Quantities, Units and Dimensions 101
- ✓ NASA QUDT Handbook
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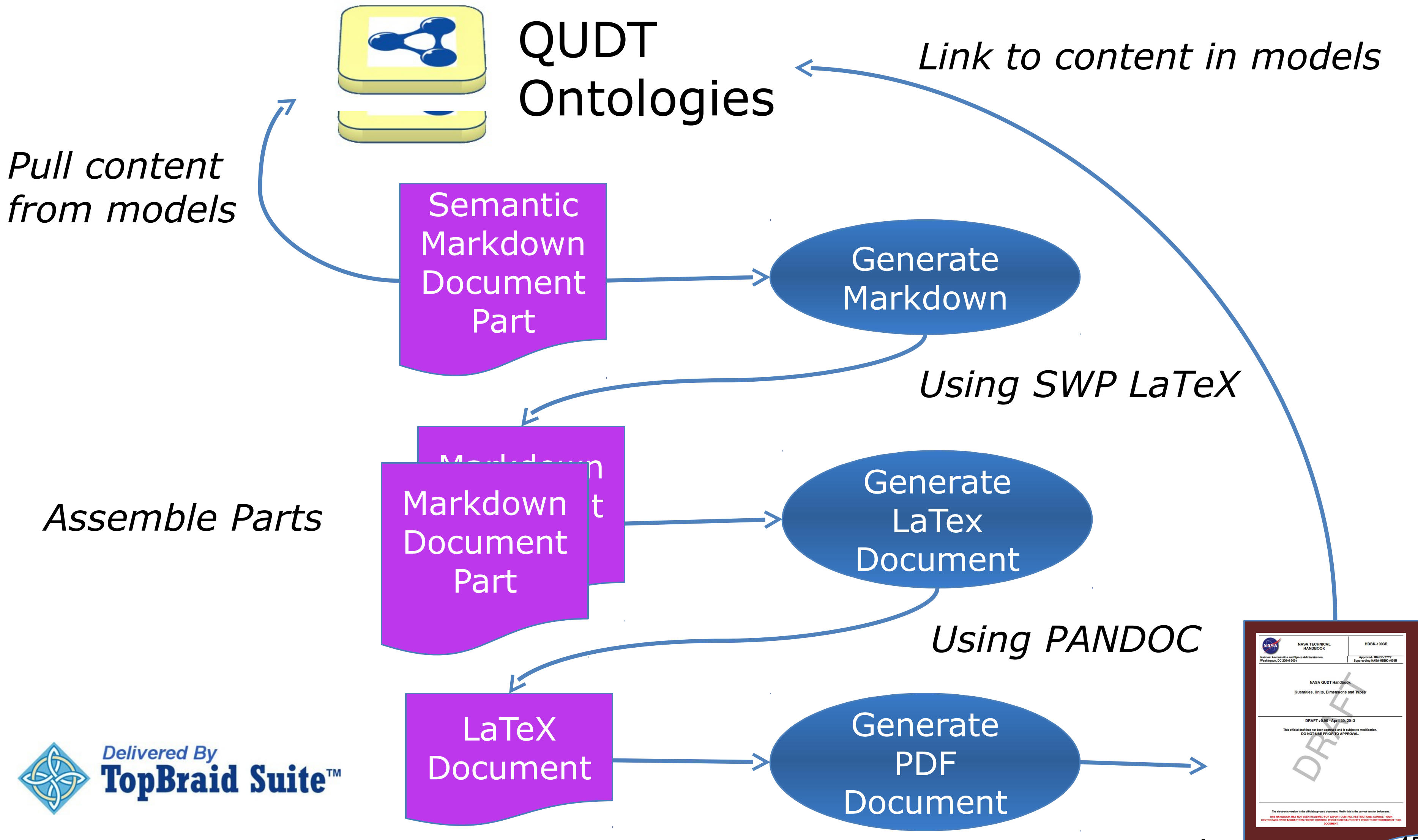
- ✓ How the QUDT Handbook was produced
- ✓ Next Priorities

How the QUDT Handbook was produced



All automated using bash scripts

Example of Semantic Markup

```
\section{SCALES OF MEASURE}
\label{sec:scales-of-measure}

<ui:group>
  {= spl:object(qudt:ScaleType,dc:description)}
</ui:group>

Appropriate and consistant use of scales is s
the NASA science and engineering commun
A wide variety of scales are used on a regul
Some support analysis, measurement, com
tasks across the NASA lifecycle.
Others might serve as enumerations that be

Table \ref{tbl:scaletypes} summarizes the k
by the Handbook.

<ui:group>
  <qudt:LatexScaleTypesTable
      arg:resource="qudt:ScaleType"
      arg:caption="SCALE TYPES"
      arg:label="tbl:scaletypes"/>
</ui:group>

\subsection{Types of Scale}
\subsubsection{Nominal scale}
```

9 SCALES OF MEASURE

Scales, or scales of measurement (or categorization) provide ways of quantifying measurements, values and other enumerated values according to a normative frame of reference. Four different types of scales are typically used. These are interval, nominal, ordinal and ratio scales.

Appropriate and consistant use of scales is significant to work done within the NASA science and engineering communities. A wide variety of scales are used on a regular basis. Some support analysis, measurement, communication and classification tasks across the NASA lifecycle. Others might serve as enumerations that become pick-lists and code-lists.

Table 9-1 summarizes the kinds of scales currently covered by the Handbook.

TABLE 9-1 SCALE TYPES

Scale Type	Permissible Maths	Permissible Transformation	Data Structure
Interval Scale Type	Correlation, Mean, Regression, Standard Deviation, Variance Analysis	Affine transformation	Affine line
Nominal Scale Type	Chi-squared, Mode	Equality	Standard unordered set
Ordinal Scale Type	Median, Percentile	Monotonic ordering	Totally ordered set
Ratio Scale Type	Coefficient of Variation, Correlation, Geometric Mean, Harmonic Mean, Logarithms, Mean, Regression, Standard Deviation, Variance Analysis	Positive Similarities	One dimensional vector space

9.1 Types of Scale

9.1.1 Nominal scale

Roadmap (AKA Whirlwind Tour)

- ✓ Introductions
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Next Priorities

- ✓ Editorial Review at NASA Headquarters
- ✓ Extended review of the NASA QUDT Handbook within NASA
- ✓ NIST Review
- ✓ Publication of release 2 of the RDF/OWL models
- ✓ QUDT Community Site

How to Find out More

- ✓ QUDT Website – www.qudt.org
- ✓ NASA QUDT Handbook (after review)
- ✓ Technologies and Tooling
  - RDF - http://www.w3.org/RDF/
  - OWL – www.w3.org/2004/OWL/
  - SPARQL – www.w3.org/TR/rdf-sparql-query/
  - SPIN – www.topquadrant.com/products/SPIN.html
  - SWP (Semantic Web Pages) – www.topquadrant.com/swp/
  - TopBraid Tooling - www.topquadrant.com/products/TB_Suite.html
  - LaTeX - http://www.latex-project.org
  - Pandoc - http://johnmacfarlane.net/pandoc/

Thank You

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