SmartCom

D-SI (Draft v1.2, all)

-for final discussion-

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SmartCom WP 1 aims

D-SI*

D-SI = Digital System of Units

=

Universal data model for transfer of metrological data via digital communication

- Format must be
- unambiguous
- universal
- safe
- uniform

Metrology Standards

IT Standards

* European figurative mark and word mark proposed

v1.2

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Review of version 1.1

The review comprises feedback from

- 12 SmartCom partners
- additional feedback from stakeholders

PTB recieved around

- 30 comments about the data model for real quantities
- 15 comments about the data model for complex quantities
- 30 comments about the data model for lists of real and complex quantities

All comments and resulting changes are listed in the Excel table

„2019-06-18_SmartCom_A1.2.2_review.xlsx“.

Each change is associated with an ID.
(IDs used for traceability of changes)

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To prevent confusion

The data model denotes fundamental definitions of structures for metrological data by „atomic“. An „atomic“ statement of a length quantity will provide for example the numerical value and a length unit but not information about measurement uncertainty.

The data models defined as „extended“ are the „atomic“ data models with additional components for providing measurement uncertainty.

The header of each slide provides the following meta data with review information

Orange box: IDs of changes identified in the review

Blue box: Ids of XML examples used on the slide

Green box: version of the data model

If you activate the Power Point „Comment“ tool, you are also able to see additional remarks on each slide that explain changes that were made for version 1.2.

v1.2

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Overview

v1.2

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Overview

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Overview

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real - review

What we discussed

- definition of time stamp and distribution meta data
- GUM relevant information for real quantities

Changes that were made

- **encapsulation of uncertainty statements** in sub-types
- Discussion of providing a component for **standard uncertainty for probabilistic symmetric coverage interval** that is necessary for linear propagation of uncertainty.
- **removed the shortest coverage interval type**. In cases of multimodal distributions this interval requires to be represented by multiple disjoint intervals.
- **clear definition of the time stamp** for measured quantities by local UTC time.
- Changed order of components in real

Any other upcoming changes

- It was asked to introduce some list (enumeration) of identifiers for distributions. Here **all SmartCom partners are asked if they know a suitable format** (that is machine-readable) which we may use.

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Uniform data format

Minimum requirement

Maximum information

$Y = y$ [SI] $U_{95}(k)$ distribution UTC

- Coordinated Universal Time
- type of distribution normal, uniform, …
- coverage factor
- measurement uncertainty + confidence interval
- Si-unit
- measurement value

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Real format: Atomic

Y = *y* [SI] $U_{95}(k)$ distribution UTC

real *quantity type* *atomic*	**components** (of the real quantity type)			
	label	value	unit	dateTime
basic real quantity (atomic)				

mandatory | optional

- SI unit format
- VIM
- ISO 80000
- CODATA
- IEEE 754
- RFC 362 (UTF-8)
- ISO 8601

- value and unit are the minimum requirement
- optional label and dateTime information

(details on data types on the next slides)

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Definition of data-types I

component	data type	description
value	decimal number format	**numerical value** of the real quantity (details outlined on following slides)
unit	SI-unit format	String of characters providing **the unit** of the quantity (details outlined in section 3)
label	String of characters	An unregulated text field for the **identification of the real element**. A label may for example provide the name of the underlying quantity. Specific vocabularies (and/or ontologies) of the application for which the data format is used may be defined by users.
dateTime	ISO 8601 UTC time	**local time** with an information about the **offset to UTC time** (details outlined on following slides)

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decimal number format

Basic number format:

- decimal numbers only with the dot as separator

  3.14 +67. -0.0 .678 -0.978

- integer exponent in scientific form allowed

  9.e3 0.2E-5 -3E10 -4.17e+4

- also representation of integer numbers allowed

  0 12 7689 -23

- recommendation to be conform to IEEE 754 double precision

- no NaN, INF, null

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dateTime (ISO 8601)

ISO 8601(2004) format for time stamp

2019-06-03T11:30:01.04+02:00

local time with offset to UTC time (Coordinated Universal Time)

decimal value for second part

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UTF-8 encoding (RFC 362)

Background:

- All data in IT is encoded binary.
- There exist different code tables that describe how to encode human-readable letters in binary form.
- Well known code tables are ASCII, Unicode, UTF-8, UTF-16,…
- If for example the encoding is Unicode but the decoding in human read-able form is ASCII, then one may get gibberish output.

Resulting requirement

- Make sure to use UTF-8 encoding and decoding to always have the correct interpretation of character data
- UTF-8 = Universal Code Character Set Transformation Format 8-bit
- ASCII encoding is a subset of UTF-8 encoding
- UTF-8 is supported by many software tools, browsers, …

Change: P1/10 & S4

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Real format: Extended

Y = y [SI] $U_{95}(k)$ distribution UTC

real *quantity type* *extended*	components (of the real quantity type)					
	label	value	unit	dateTime	expandedUnc (S)	coverageInterval (S)
Basic real with expanded measurement uncertainty	optional	mandatory	mandatory	optional	mandatory	
Basic real with coverage interval (probabilistic-symmetric)	optional	mandatory	mandatory	optional		mandatory

(S) sub type — mandatory — optional

- uncertainty information now encapsulated by the elements „expandedUnc" and „coverageInterval"
- Details on the elements on the following slides.

GUM

SI unit format

VIM

ISO 80000

CODATA

IEEE 754

RFC 362 (UTF-8)

ISO 8601

Expanded measurement uncertainty

Y = y [SI] $U_{95}(k)$ distribution UTC

sub type - expandedUnc *expanded measurement uncertainty for real quantity*	**components** (of the expandedUnc type)			
	uncertainty	coverageFactor	coverageProbability	distribution
expanded measurement uncertainty				

mandatory	optional

GUM

VIM

IEEE 754

RFC 362 (UTF-8)

- mandatory and optional components for statement of uncertainty as before but all is encapsulated in the element „expandedUnc“
- „uncertainty“ is half width of coverage interval

Change: P1/10 & S4

v1.2

Expanded measurement uncertainty

sub type - coverageInterval *coverage interval for uncertainty of real quantity*	**components** (of the coverageInterval type)				
	stdUncertainty	intervalMin	intervalMax	coverageProbability	distribution
probabilistic-symmetric interval					

mandatory | optional

GUM

VIM

IEEE 754

RFC 362 (UTF-8)

- probabilistic-symmetric coverage interval encapsulated in type „coverageInterval"
- The coverage interval can be provided with the additional component „stdUncertainty" for the standard uncertainty. (propagation of uncertainty)
- The standard uncertainty is needed for application of GUM's Law of Propagation of Uncertainty.

Change: P1/4, P1/5, P1/7 & P1/2

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Definition of data-types II

Data types in „expandedUnc“ and „coverageInterval“ elements:

component	data type	description
uncertainty	constraint decimal number format	Value of the expanded measurement uncertainty (half length of coverage interval) – positive decimal number
coverageFactor	constraint decimal number format	positive decimal number greater or equal to „1“ – no scientific exponent
coverageProbability	constraint decimal number format	positive decimal number within the interval [0,1] – no scientific exponent
intervalMin	decimal number format	upper bound of probabilistic symmetric coverage interval
intervalMax	decimal number format	lower bound of probabilistic-symmetric coverage interval
distribution	String of characters	textual definition of the distribution of the measured quantity value

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Examples: real extended

Example: XML implementation of real with expanded uncertainty

```xml
<si:real>
    <si:label>temperature</si:label>
    <si:value>20.10</si:value>
    <si:unit>\degreecelsius</si:unit>
    <si:expandedUnc>
        <si:uncertainty>0.50</si:uncertainty>
        <si:coverageFactor>2</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal</si:distribution>
    </si:expandedUnc>
</si:real>
```

Example: XML implementation of real with coverage interval

```xml
<si:real>
    <si:label>temperature</si:label>
    <si:value>20.10</si:value>
    <si:unit>\degreecelsius</si:unit>
    <si:coverageInterval>
        <si:stdUncertainty>0.25</si:stdUncertainty>
        <si:intervalMin>19.60</si:intervalMin>
        <si:intervalMax>20.60</si:intervalMax>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal</si:distribution>
    </si:coverageInterval>
</si:real>
```

basic real

expanded uncertainty

coverage interval

Change: S4 & S2

Git: *EXAMPLE-11-2-D-SI-Buch*

v1.2

Units of uncertainty values

unit of real

```
<si:real>
    <si:label>temperature</si:label>
    <si:value>20.10</si:value>
    <si:unit>\degreecelsius</si:unit>
    <si:coverageInterval>
        <si:stdUncertainty>0.25</si:stdUncertainty>
        <si:intervalMin>19.60</si:intervalMin>
        <si:intervalMax>20.60</si:intervalMax>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal</si:distribution>
    </si:coverageInterval>
</si:real>
```

- the local unit in „real“ is also applied to the numerical values that give the uncertainty.
- In the example above, these numerical values are „stdUncertainty“, „intervalMin“ and „intervalMax“.
- In the case of the expanded uncertainty the component „uncertainty“ must have a numerical value in the unit of „real“.

Change: S2

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Real constants

mathematical constants and **fundamental physical constants** (CODATA)

constant *quantity type*	components (of the constant quantity type)					
	label	value	unit	dateTime	uncertainty	distribution
constant quantity with an exact value	optional	mandatory	mandatory	optional		
constant quantity with an uncertainty	optional	mandatory	mandatory	optional	mandatory	optional

(S) sub type	mandatory	optional

(examples on next slide)

- **Values of fundamental physical constants:**
  - component „uncertainty“ is the standard deviation of a experimentally defined constant.
  - For constants from CODATA, „uncertainty“ is the uncertainty reported in the CODATA list.

- **Values of mathematical constants that must be rounded (i.e. PI):**
  - „uncertainty“ is the standard deviation of a rectangular distribution that contains the exact value of the constant with 100% probability

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Constant: examples

Example: XML representation of math. constant pi:

```
<si:constant>
    <si:label>pi</si:label>
    <si:value>3.140</si:value>
    <si:unit>\one</si:unit>
    <si:uncertainty>0.003</si:uncertainty>
    <si:didtribution>rectangular</si:didtribution>
</si:constant>
```

„uncertainty“ of rounded value (≈0.005/sqrt(3))

Example: XML representation of Planck constant before 2019-05-20:

```
<si:constant>
    <si:label>planck constant</si:label>
    <si:value>6.626070040e-34</si:value>
    <si:unit>\kilogram\metre\tothe{2}\second\tothe{-1}</si:unit>
    <si:dateTime>2018-11-16T12:30:01.67-01:00</si:dateTime>
    <si:uncertainty>8.1e-42</si:uncertainty>
    <si:distribution>normal</si:distribution>
</si:constant>
```

CODATA 2014 value

Example: XML representation of Planck constant since 2019-05-20:

```
<si:constant>
    <si:label>planck constant</si:label>
    <si:value>6.62607015e-34</si:value>
    <si:unit>\kilogram\metre\tothe{2}\second\tothe{-1}</si:unit>
    <si:dateTime>2019-05-21T02:00:00.10-01:00</si:dateTime>
</si:constant>
```

new SI value

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SI units- review

What we discussed

- further existing specifications for unit representation
- requirements for implementation of the unit format (i.e. in XML)

Changes that were made

- closer to SI unit groups in BIPM SI brochure (depricated SI++ group)
- unit identifiers case sensitive –> all lower case
- added rules for the combination of units, prefixes and exponents according to IEC/TS 62720 (2018-04)
- deprecated operator “per”

Any other upcoming changes

- We have the 9th edition of BIPM SI brochure now. It depricates the non-SI units for experimentally obtained quantities like electron volt or dalton.

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SI units – unit identifiers

Unit type	Unit example	Symbol	SmartCom identifiers
SI base units	metre kilogram	m kg	\metre \kilogram
SI derived units with own symbol	radian dimension number newton degree Celsius gram	rad N °C g	\radian \one \newton \degreecelsius \gram
non-SI units allowed with the SI	degree hour arcminute	° h ′	\degree \hour \arcminute
SI prefix	micro	µ	\micro
Exponent operator	metre squared	m^2	\metre\tothe{2}

- All identifiers are lower case
- unit „one“ is the unit for dimension number (i.e. for counts and for ratios of quantities of the same unit)

Change: P1/5, S1 & S3

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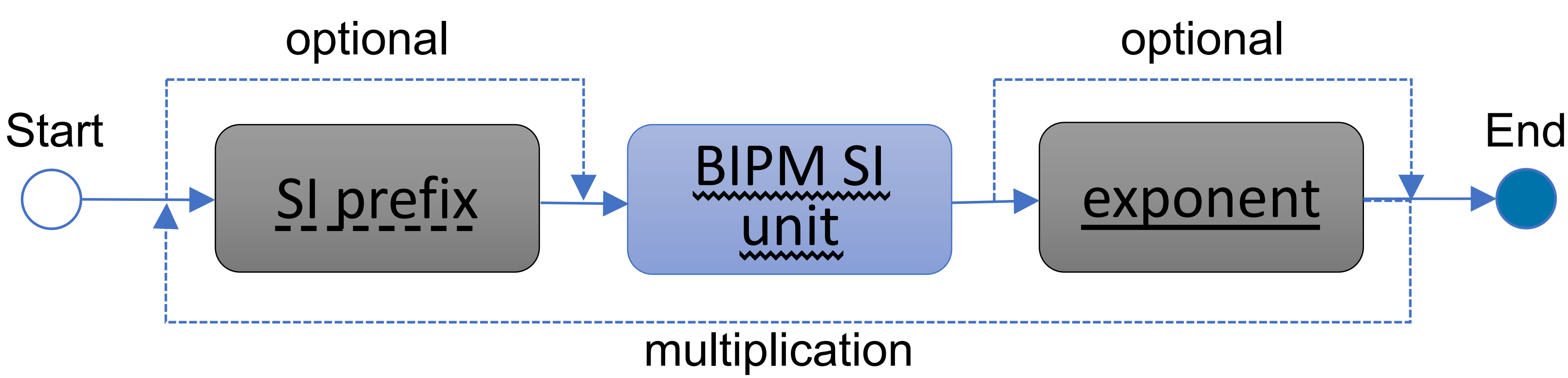
SI unit syntax

Changes:

- Syntax reduced to combination of prefix, unit, exponent and multiplication
- Deprecated „\per“ operator for division of units
- no blank spaces, tabs or carriage returns before, within or after the unit expression.

Unit language for BIPM SI brochure

$\frac{\mathrm{km}}{\mathrm{h}}$ → \kilo\metre\hour\tothe{-1}



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SI-units syntax rules

- Further syntax rules adapted to IEC/TS 62720 that extend the rules from BIPM SI brochure:

  - each unit shall have only one prefix (i.e. no „\milli\kilo\metre“)
  - decimal multiples of the mass unit are build with a SI prefix and the unit identifier „\gram“ (i.e. „\milli\gram“)
  - the SI base unit for mass shall not be combined with a prefix (i.e. no „\nano\kilogram“)
  - The unit for quantities of dimension number shall not be combined with a prefix (i.e. no „\kilo\one“)
  - Furthermore, a prefix is not permitted for the following units: \degree, \degreecelsius, \kilogram, \mmhg, \minute, \hour, \day,
    \second\tothe{-1} (rotation), \minute\tothe{-1} (rotation)
  - If a unit is assigned with an exponent, then the exponent is applied to the unit and the prefix that is defined for the unit (i.e. „\kilo\metre\tothe{3}“ is equivalent to 10^9 $m^{3)}$

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SI-units syntax rules

- Further syntax rules adapted to IEC/TS 62720 that extend the rules from BIPM SI brochure (continued from previous slide):
  - unit of dimension number shall not have an exponent (i.e. no „\one\tothe{3}“
  - If a unit is combined by two ore more units that build a ratio of units, then it is allowed to have either one prefix in the nominator, one prefix in the denominator or one prefix in each of the both components of the ratio (i.e. allowed „\millli\metre\nano\second\tothe{-1}“). To have two ore more prefixes in either the nominator of the unit or in the denominator of the unit is forbidden.

D-SI implementation requirements

The D-SI data model is the unique structure for the exchange of metrological data.

The implementation of the D-SI data model is the realization of this structure in a data format like XML, JSON, CSV and many more.

The implementation may have additional requirements such as:

- Canonic and unique representation of units
- Enumeration of allowed units with fixed identifiers
- Enumeration of allowed distributions with fixed values
- Considerations on application specific requirements (i.e. strict rules for application of some cryptographic algorithms)

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coverage region - review

What we discussed:
Discussion of GUM Supplement 2 requirements (estimate, covariance, coverage region, propagation of uncertainty)

Changes that were made:

- major changes of coverage region made:
  - hyper-rectangular region and hyper-ellipsoidal region now have the full covariance matrix information for multivariate quantities
  - representation of covariance matrix changed from an upper triangular matrix to a full (and column-wise) representation of the matrix.
  - each covariance matrix value provides its unit too.

- minor changes made
  - correct equation for ellipsoidal coverage region.
  - improvement of examples concerning correct values of covariance matrix, coverage probability, distribution …

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Application of coverage regions

Coverage regions for multivariate quantities

Application of the coverage regions:

- provide bivariate uncertainty for complex quantities
- provide multivariate uncertainty for vectors of real & complex quantities

Coverage regions in our metadata format and wording:

- GUM S2: elliptical coverage region & hyper-ellipsoidal coverage region
  -> D-SI: ellipsoidalRegion
- GUM S2: rectangular coverage region & hyper-rectangular coverage region
  -> D-SI: rectangularRegion

Not considered in our format:

- GUM: smallest coverage region
  -> D-SI: subject to modeling using fundamental components and lists from the metadata format

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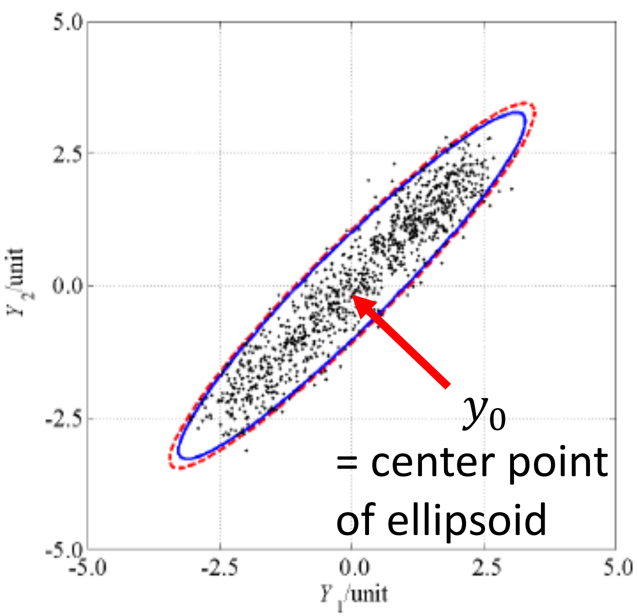
GUM S2 requirements

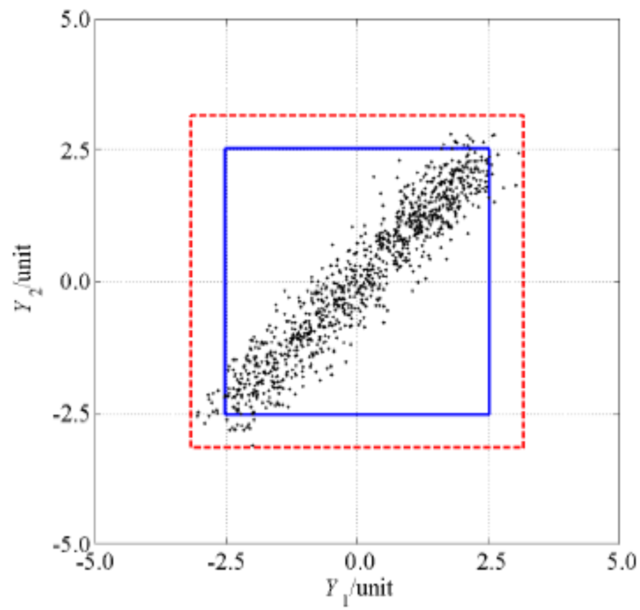
Hyper-ellipsoidal region

- $(y - y_0)^T \boldsymbol{U}_y^{-1}(y - y_0) = k_p$
- $\boldsymbol{U}_y$ (covariance matrix)
- p (coverage probability)
- k_p (coverage factor / ellipsoid size scale factor)



Hyper-rectangular region

- $y_j \pm k_q u(y_j)$
- $u(y_j)$ $(j = 1, \ldots, m)$ (std. uncert.)
- k_q (coverage factor)
- $q = 1 - (1 - p)/m$
- p (coverage probability)



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Hyper-ellipsoidal region

sub type - **ellipsoidalRegion** *hyper-ellipsoidal coverage region*	**components** (of the ellipsoidalRegion type)			
	covarianceMatrix (S)	coverageFactor	coverageProbability	distribution
n-dimensional ellipsoidal region	dimension n x n	mandatory	mandatory	optional

(s) sub-type — mandatory / optional

- In the revised definition of the hyper-ellipsoidal coverage region, the covariance information is encapsulated within a „covarianceMatrix" element.
- The covariance information can be used to apply the law of propagation of uncertainty according to GUM supplement 2 on the data.
- The components that define the covariance matrix have been completely changed in comparison to older versions of the data model (see the slide after the next slide).

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Hyper-rectangular region

sub type - rectangularRegion *hyper-rectangular coverage region*	**components** (of the rectangularRegion type)			
	covarianceMatrix (S)	coverageFactor	coverageProbability	distribution
n-dimensional rectangular region	**dimension n x n**			

(s) sub-type	**mandatory**	**optional**

- The revised definition of the hyper-rectangular coverage region does also allow to apply the law for the propagation of uncertainty from GUM supplement 2.
- Therefore, the covariance matrix was introduced as a component of the coverage region (see definition on the next slides).
- The bounds of the coverage region are calculated from the variance values within the covariance matrix.

Covariance matrix

- The covariance matrix is a fundamental part of information on uncertainty of multivariate quantities according to GUM supplement 2.
- Hence, the covariance matrix was defined as independent data type.
- The hyper-ellipsoidal and hyper-rectangular coverage region are both deduced from the values in the covariance matrix.

Change: P2/1 & P2/2

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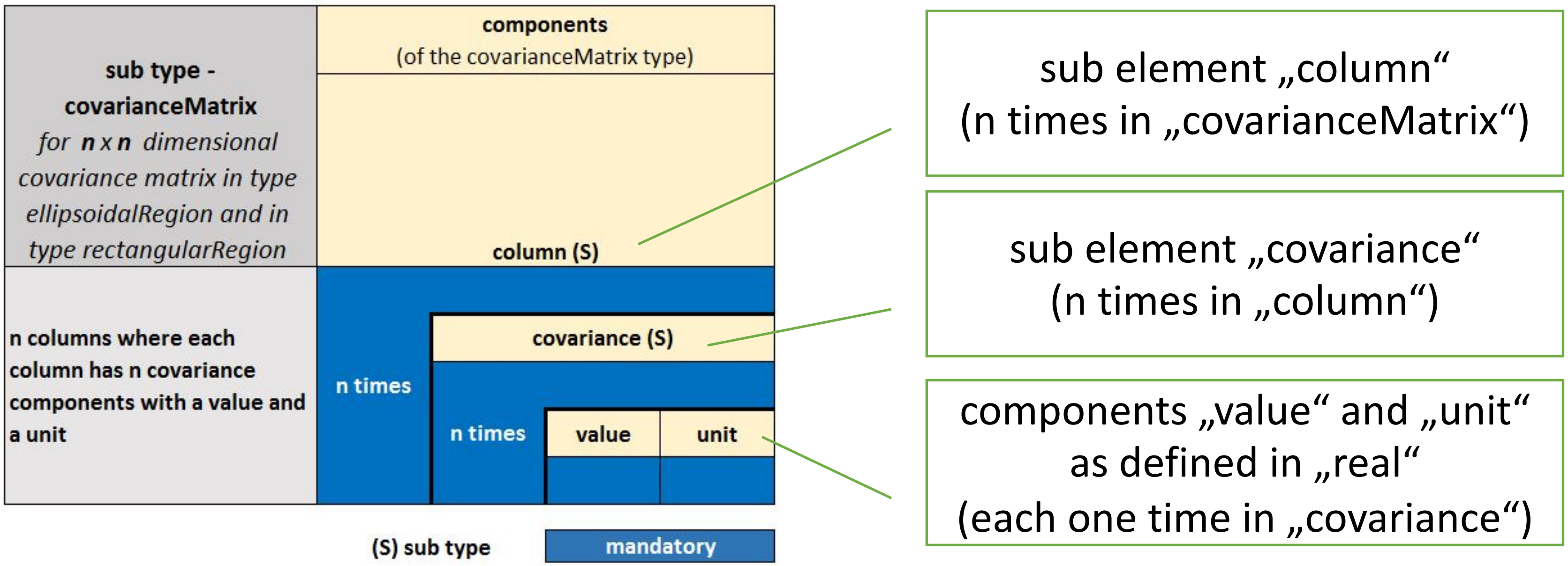
Covariance matrix



- The originally proposed definition of the covariance matrix (in the ellipsoidal coverage region) was simplified to a column-wise representation of the data in the covariance matrix.
- Each covariance (and variance) value must provide a numerical value an a unit (data types as for components in definition of “real”).
- how to write the data from a covariance matrix into the sub type “covarianceMatrix” is explained on the next slide

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Covariance matrix

Serialization of a 2x2 covariance matrix into a XML structure

XML serialization of covariance matrix

```
<si:covarianceMatrix>
    <!-- first (left) column of matrix -->
    <si:column>
        <si:covariance>
            <si:value>0.212</si:value>
            <si:unit>\metre\metre</si:unit>
        </si:covariance>
        <si:covariance>
            <si:value>0.051</si:value>
            <si:unit>\second\metre</si:unit>
        </si:covariance>
    </si:column>
    <!-- second (right) column of matrix -->
    <si:column>
        <si:covariance>
            <si:value>0.051</si:value>
            <si:unit>\metre\second</si:unit>
        </si:covariance>
        <si:covariance>
            <si:value>0.101</si:value>
            <si:unit>\second\second</si:unit>
        </si:covariance>
    </si:column>
</si:covarianceMatrix>
```

$\begin{pmatrix} u_1^2 \\ c_{21} \end{pmatrix}$ first column

covariance matrix

$$\boldsymbol{U}_y = \begin{pmatrix} u_1^2 & c_{12} \\ c_{21} & u_2^2 \end{pmatrix} = \begin{pmatrix} 0.212\ \mathrm{m}^2 & 0.051\ \mathrm{ms} \\ 0.051\ \mathrm{sm} & 0.101\ \mathrm{s}^2 \end{pmatrix}$$

$\begin{pmatrix} c_{12} \\ u_2^2 \end{pmatrix}$ second column

(u_1^2, u_2^2 are variance values where u_1, u_2 are std. uncertainty values; c_{21}, c_{12} are covariance values)

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Definition of data types III

component	data type	description
value (in covarianceMatrix)	constrained decimal number format	Must be a positive value in case of a variance. Else, the absolute value of correlation associated with the covariance value must be lesser or equal to 1.
unit (in covarianceMatrix)	SI-unit format	Product of the units that are associated by the covariance value
coverageFactor (in coverage region types)	constraint decimal number format	positive decimal number (for “rectangularRegion” the value of k_q with $q = 1 - (1 - p)/m$, coverage probability p and dimension of quantity m.
coverageProbability (in coverage region types)	constraint decimal number format	positive decimal number within the interval [0,1] – no scientific exponent
distribution (in coverage region types)	String of characters	textual definition of the distribution of the measured quantity value

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Changes in complex

What we discussed

- how to distinguish between Cartesian and polar coordinate form
- the way to represent uncertainties of complex quantities

Changes that were made

- introduction of explicit names “valueReal”, “valueImag”, “valueMagnitude” and “valuePhase” for numerical values of complex quantities
- Voting for option 2 for statement of the uncertainty with the elements “ellipsoidalRegion” and “ractagularRegion” (for definition see section 4)
- further minor changes:
  - usage of notion „magnitude“ instead of „amplitude“ in polar coordinate form according to GUM supplement 2
  - correction of errors in some of the figures and examples
  - recommendation to use a Cartesian coordinate form
  - unit “\one” not allowed for phase angle value in the polar coordinate form

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Atomic complex

complex *quantity type* *atomic*	components (of the complex quantity type)							
	label	valueReal	valueImag	valueMagnitude	valuePhase	unit	unitPhase	dateTime
Cartesian coordinate form (atomic)	optional	mandatory	mandatory			mandatory		optional
Polar coordinate form (atomic)	optional			mandatory	mandatory	mandatory	mandatory	optional

mandatory | optional

Math:
a (real part)
b (imaginary part)
i (imaginary number)
Cartesian: $z = a + ib$

r (magnitude)
φ (phase angle)
Polar: $z = re^{i\varphi}$
$(r = \sqrt{a^2 + b^2})$

- A Cartesian coordinate form and a polar coordinate form are allowed
- The Cartesian coordinate form is recommended to be used
- Cartesian form with numerical values “valueReal” for the real part and “valueImag” for the imaginary part of the complex quantity
- Polar coordinate form with components “valueMagnitude” for the amplitude value and “valuePhase” for the phase angle value
- Each complex quantity has only one physical unit which is set by the component “unit”. This unit applies for the real and imaginary part as well as for the magnitude value.

Change: Q2 (P2/9) & Q5 (P2/9)

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Definition of data types IV

component	data type	description
valueReal, valueImag, valueMagnitude, valuePhase	decimal number format	**numerical values** of the components of a complex quantity
unit (in complex)	SI-unit format	String of characters providing **the unit** of the quantity (details outlined in section 3)
unitPhase (in complex)	constrained SI-unit format	String of characters providing **the unit** of the phase angle of the complex quantity in polar coordinate form. The unit must represent an angular unit. Unit “\one” is not allowed. (details next slide)
label	String of characters	An unregulated text field for the **identification of the complex element**. A label may for example provide the name of the underlying quantity.
dateTime	ISO 8601 UTC time	**local time** with an information about the **offset to UTC time**

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Angular units in complex

Angular units in the SI format that can be used for „unitPhase“:

- **Units for angle in radian unit:**
    - „\radian“ or „\metre\tothe{0}“ or „\metre\metre\tothe{-1}“
    - combinations of the unit „\radian“ with a SI prefix
- **Units for angle in degree and associated units**
    - „\degree“, „\arcminute“, „\arcsecond“

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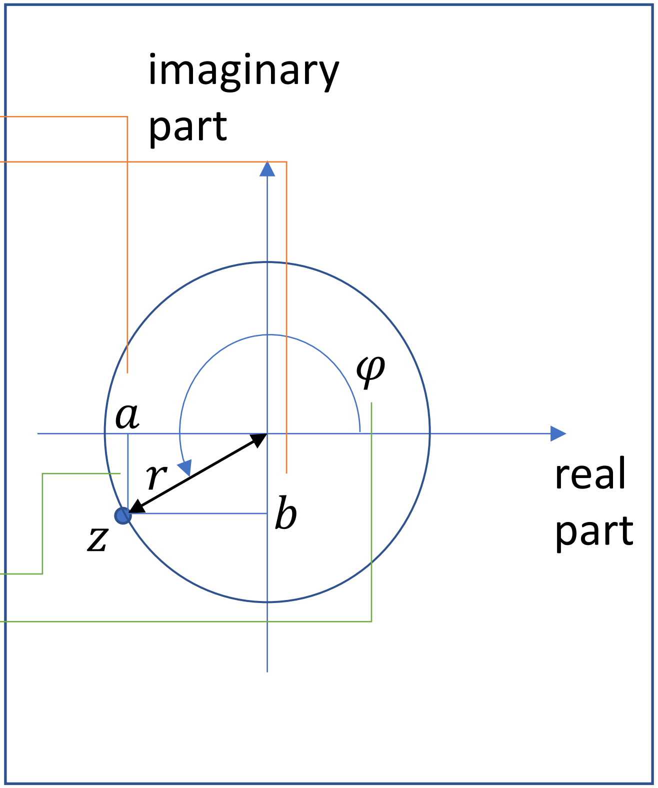
Examples complex I

Example: XML implementation of Cartesian complex quantity

```
<si:complex>
    <si:label>amplifier signal</si:label>
    <si:valueReal>-10.310</si:valueReal>
    <si:valueImag>5.010</si:valueImag>
    <si:unit>\volt</si:unit>
</si:complex>
```

Example: XML implementation of polar coordinate complex quantity

```
<si:complex>
    <si:label>amplifier signal</si:label>
    <si:valueMagnitude>11.463</si:valueMagnitude>
    <si:valuePhase>2.689</si:valuePhase>
    <si:unit>\volt</si:unit>
    <si:unitPhase>\radian</si:unitPhase>
</si:complex>
```



Complex value z in 2D complex space

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Extended complex

complex *quantity type* *extended*	components (of the complex quantity type)									
	label	valueReal	valueImag	valueMagnitude	valuePhase	unit	unitPhase	dateTime	ellipsoidalRegion (S)	rectangularRegion (S)
Cartesian coordinate form with hyper-ellipsoidal coverage region	optional	mandatory	mandatory			mandatory		optional	dimension 2 x 2 (mandatory)	
Cartesian coordinate form with hyper-rectangular coverage region	optional	mandatory	mandatory			mandatory		optional		dimension 2 x 2 (mandatory)
Polar coordinate form with hyper-ellipsoidal coverage region	optional			mandatory	mandatory	mandatory	mandatory	optional	dimension 2 x 2 (mandatory)	
Polar coordinate form with hyper-rectangular coverage region	optional			mandatory	mandatory	mandatory	mandatory	optional		dimension 2 x 2 (mandatory)

(S) sub type — mandatory — optional

- Similar to the case of real quantities the uncertainties are encapsulated within the „ellipsoidalRegion“ and „rectangularRegion“ sub type (definition in section 4).
- The “ellipsoidalRegion” component must provide a bivariate uncertainty with a covariance matrix of dimension 2x2
- The “rectangularRegion” component must provide a bivariate uncertainty with a covariance matrix of dimension 2x2

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Examples complex II

Example: XML implementation of complex with ellipsoidal coverage region

```
<si:complex>
    <si:valueReal>-10.310</si:valueReal>
    <si:valueImag>5.010</si:valueImag>
    <si:unit>\volt</si:unit>
    <si:ellipsoidalRegion>
        <si:covarianceMatrix>
            <si:column>
                <si:covariance>
                    <si:value>0.050</si:value>
                    <si:unit>\volt\volt</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>-0.003</si:value>
                    <si:unit>\volt\volt</si:unit>
                </si:covariance>
            </si:column>
            <si:column>
                <si:covariance>
                    <si:value>-0.003</si:value>
                    <si:unit>\volt\volt</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.105</si:value>
                    <si:unit>\volt\volt</si:unit>
                </si:covariance>
            </si:column>
        </si:covarianceMatrix>
        <si:coverageFactor>2.45</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal-bivariate</si:distribution>
    </si:ellipsoidalRegion>
</si:complex>
```

atomic complex
Cartesian form

ellipsoidal
coverage region

covariance matrix

additional data of
coverage region

v1.2

SmartCom

Overview

SmartCom

Application of lists

Vector quantities from GUM Supplement 2:

- vector quantity of real components
  → D-SI: implementation as list of real quantities
- vector quantity of complex components
  → D-SI: implementation as list of complex quantities

Further features of vector quantities according to GUM supplement 2:

- optional multivariate uncertainty statements by using hyper-ellipsoidal and hyper-rectangular coverage regions (definition in draft part 2/3)
- optional global statement of measurement units that are valid for all components in the list
- optional global statement of a univariate uncertainty for lists of real quantities and a global bivariate uncertainty for lists of complex quantities

Recursive list (composite design: "a list of lists"):

- for implementation of data models with dimension two and higher (e.g. a matrix or a tensor)
- for implementation of individual data models (e.g. data of a Monte Carlo simulation or data representing a smallest coverage region)

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List: atomic data model

list *of quantities type* atomic	components (of the list type)				
	label	real (S)	complex (S)	list (S)	dateTime
basic list of real (atomic)		n times			
basic list of complex (atomic)			n times		
recursive list of lists				n times	

(S) sub type | mandatory (blue) | optional (green; the label and dateTime columns are green in all rows)

- „real“ from section 2
- „complex“ from section 5
- „label“ and „dateTime“ data types as defined for „real“

- either a list of only „real“ quantities, only „complex“ quantities or only „list“ components
- optional „label“ of list and „dateTime“ component for a time stamp that may state the data when the list was recorded.
- the list of real and complex can be extended with additional uncertainty statements (see sections 7 & 8)

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Examples: atomic list

Example: list of two real quantities

```
<si:list>
    <si:real>
        <si:value>1.00</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
    <si:real>
        <si:value>1.00</si:value>
        <si:unit>\second</si:unit>
    </si:real>
</si:list>
```

Example: list of two complex quantities

```
<si:list>
    <si:complex>
        <si:valueReal>-10.310</si:valueReal>
        <si:valueImag>5.010</si:valueImag>
        <si:unit>\volt</si:unit>
    </si:complex>
    <si:complex>
        <si:valueReal>-10.510</si:valueReal>
        <si:valueImag>5.510</si:valueImag>
        <si:unit>\volt</si:unit>
    </si:complex>
</si:list>
```

Example: list of two lists with real quantities

```
<si:list>
    <si:list>
        <si:real>
            <si:value>2.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>3.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
    </si:list>
    <si:list>
        <si:real>
            <si:value>4.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>5.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
    </si:list>
</si:list>
```

General aspects of lists

1. data overhead reduction: global statement of units and uncertainties for real and complex quantities that are provided in a list (must have two ore more real or complex components)
2. Global statements of univariate uncertainty (real) or bivariate uncertainty (complex) only in combination with global units allowed
3. If global unit or uncertainty is provided, then no local unit and/or uncertainty within real and respectively complex are allowed.
4. global multivariate uncertainty statements are allowed for lists of real and complex elements
5. local and global label and dateTime elements are both allowed to be used.
6. no global units and/or uncertainty for list of lists
7. unlimited depth of list nesting (recursive nesting)

more details in section 7 & 8

v1.2

SmartCom

Overview

1. Outline of previous review and changes
2. Real quantity
3. Structure for SI units
4. Coverage regions
5. Complex quantity
6. List Data Model (general)
7. List of real quantities
8. List of complex quantities
9. Further application examples

v1.2

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list of real - review

What we discussed

- if we may encourage the use of global units
- requirements for when to use global univariate and multivariate uncertainty

Changes that were made

- Changed global unit element name from „unit“ to „globalUnit“.
- Introduced elements for global univariate uncertainty
- allow both global and local time stamps (dateTime) in list
- improved rules for the usage of global units and global uncertainty statements

Any other information

- We would recommend to use global units and uncertainty statement if the data allows it.

extended list of real

basic real list from section 6

list *of real quantities type extended*	components (of the list of real quantities type)						
	label	real (S)	dateTime	globalUnit	globalUnivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
real quantities with an optional global unit		n times		replaces unit in real			
independent real quantities with a global univariate uncertainty		n times		replaces unit in real	replaces uncert. in real		
multivariate vector of real quantities with a hyper-ellipsoidal coverage region		n times		replaces unit in real		dimension n x n	
multivariate vector of real quantities with a hyper-rectangular coverage region		n times		replaces unit in real			dimension n x n

(S) sub type | mandatory | optional

Additional components in „list“ that can only be used with „real“:

- globalUnit
- globalUnivariateUnc

Additional components in „list“ that provide a global multivaraite uncertainty:

- ellipsoidalRegion
- rectangularRegion

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features of list of real

- Is a list of real quantities (at least one real quantity must be contained)

- Allows the specification of a **global unit** („globalUnit“)
  - only if two ore more real quantities are contained in the list
  - if a global unit is specified, then the local units in the „real“ components must not be provided

- Allows the definition of a **global univariate uncertainty**
  - only if two or more real quantities that are also independent
  - only in combination with a global unit
  - only if the uncertainty of all real quantities in the list can either be expressed by the expanded measurement uncertainty or by the coverage interval

- Allows to state a **multivariate uncertainty** that is valid for all real quantities and that expresses correlation between the real quantities in the list. Requires at least two real quantities in the list.

Details on these aspects are outlined on the next slides.

Change: Q6, Q8 & P3/8

v1.2

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Global unit

- The unit in the component „globalUnit“ is the reference unit of all „real“ quantities in the „list“.
- It is not allowed to provide a „unit“ component in the „real“ components in the „list“, if the „list“ provides a „globalUnit“.
- A global unit can be combined with a global univariate uncertainty statement (described under global univariate uncertainty)
- A global unit can also be combined with a global multivariate uncertainty statement for a list of real quantities (described under global multivariate uncertainty)
- The difference between using the global unit and local units is outlined on the next slide.
- It is recommended to use a global unit if the data allows it.

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Examples: list of real I

difference betwee global and local unit

Example: XML implementation of the list data model with three real components.

```
<si:list>
    <si:real>
        <si:value>2.34</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
    <si:real>
        <si:value>3.34</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
    <si:real>
        <si:value>4.34</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
</si:list>
```

local units

Example: XML implementation of the list data model with three real components. A global unit is stated.

```
<si:list>
    <si:real>
        <si:value>2.34</si:value>
    </si:real>
    <si:real>
        <si:value>3.34</si:value>
    </si:real>
    <si:real>
        <si:value>4.34</si:value>
    </si:real>
    <si:globalUnit>\metre</si:globalUnit>
</si:list>
```

global unit

Change: Q8

v1.2

Global univariate uncertainty (1/3)

list *of real quantities type extended*	components (of the list of real quantities type)						
	label	real (S)	dateTime	globalUnit	globalUnivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
real quantities with an optional global unit		n times		replaces unit in real			
independent real quantities with a global univariate uncertainty		n times		replaces unit in real	replaces uncert. in real		
multivariate vector of real quantities with a hyper-ellipsoidal coverage region		n times		replaces unit in real		dimension n x n	
multivariate vector of real quantities with a hyper-rectangular coverage region		n times		replaces unit in real			dimension n x n

(S) sub type — mandatory — optional

- global uncertainties encapsulated in the component „globalUnivaraiteUnc“ in a list of real quantities
- global uncertainty must be stated together with global unit
- definition of type “globalUnivariateUnc” on next slide

Global univariate uncertainty (2/3)

sub type - globalUnivariateUnc *for global univariate uncertainty in list of real quantities*	**components** (of global univariate uncertainty type): expandedUnc (S)	**components** (of global univariate uncertainty type): coverageInterval (S)
Basic real with expanded measurement uncertainty	mandatory	
Basic real with coverage interval (probabilistic-symmetric)		mandatory

(s) sub-type — **mandatory** (blue cell)

- Selection of either expanded measurement uncertainty („expandedUnc“) or coverage interval („coverageInterval“) for global uncertainty of a list of real quantities.
- The data types of the uncertainty data models are those defined in section 2 for „real“ quantities.
- The global unit is also the reference unit for “uncertainty” in the “expandedUnc” type.
- The global unit is also the reference unit for „stdUncertainty“, “intervalMin” and “intervalMax” in the „coverageInterval“ type.

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Example: list of real II

Example 4:

XML implementation of the list data model with local univariate uncertainty components

```
<si:list>
    <si:real>
        <si:value>2.34</si:value>
        <si:unit>\metre</si:unit>
        <si:expandedUnc>
            <si:uncertainty>0.01</si:uncertainty>
            <si:coverageFactor>2</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal</si:distribution>
        </si:expandedUnc>
    </si:real>
    <si:real>
        <si:value>3.34</si:value>
        <si:unit>\metre</si:unit>
        <si:expandedUnc>
            <si:uncertainty>0.01</si:uncertainty>
            <si:coverageFactor>2</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal</si:distribution>
        </si:expandedUnc>
    </si:real>
</si:list>
```

local unit

local expanded uncertainty

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Example: list of real III

Example 5:

Example from previous slide simplified by global unit and uncertainty statement.

```
<si:list>
    <si:real>
        <si:value>2.34</si:value>
    </si:real>
    <si:real>
        <si:value>3.34</si:value>
    </si:real>
    <si:globalUnit>\metre</si:globalUnit>
    <si:globalUnivariateUnc>
        <si:expandedUnc>
            <si:uncertainty>0.01</si:uncertainty>
            <si:coverageFactor>2</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal</si:distribution>
        </si:expandedUnc>
    </si:globalUnivariateUnc>
</si:list>
```

global unit

global expanded uncertainty

real list with multivariate uncertainty

list *of real quantities type extended*	components (of the list of real quantities type)						
	label	real (S)	dateTime	globalUnit	globalUnivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
real quantities with an optional global unit		n times		replaces unit in real			
independent real quantities with a global univariate uncertainty		n times		replaces unit in real	replaces uncert. in real		
multivariate vector of real quantities with a hyper-ellipsoidal coverage region		n times		replaces unit in real		dimension n x n	
multivariate vector of real quantities with a hyper-rectangular coverage region		n times		replaces unit in real			dimension n x n

(S) sub type — mandatory — optional

- Representation of a vector quantity with “real” components and an multivariate uncertainty statement by a hyper-ellipsoidal coverage region or a hyper-rectangular coverage region.

- The uncertainty components “ellipsoidalRegion” and “rectangularRegion” refer to the data models for coverage regions in section 4

Examples: list of real IV

Example: XML implementation of the list data model with two real components and a global ellipsoidal coverage region.

```
<si:list>
    <si:real>
        <si:value>2.340</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
    <si:real>
        <si:value>3.340</si:value>
        <si:unit>\second</si:unit>
    </si:real>
    <si:ellipsoidalRegion>
        <si:covarianceMatrix>
            <si:column>
                <si:covariance>
                    <si:value>0.212</si:value>
                    <si:unit>\metre\metre</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.051</si:value>
                    <si:unit>\second\metre</si:unit>
                </si:covariance>
            </si:column>
            <si:column>
                <si:covariance>
                    <si:value>0.051</si:value>
                    <si:unit>\metre\second</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.101</si:value>
                    <si:unit>\second\second</si:unit>
                </si:covariance>
            </si:column>
        </si:covarianceMatrix>
        <si:coverageFactor>2.45</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal-multivariate</si:distribution>
    </si:ellipsoidalRegion>
</si:list>
```

multivariate uncertainty

Example: XML implementation of the list data model with two real quantities and a global rectangular coverage region.

```
<si:list>
    <si:real>
        <si:value>2.340</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
    <si:real>
        <si:value>3.340</si:value>
        <si:unit>\second</si:unit>
    </si:real>
    <si:rectangularRegion>
        <si:covarianceMatrix>
            <si:column>
                <si:covariance>
                    <si:value>0.212</si:value>
                    <si:unit>\metre\metre</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.051</si:value>
                    <si:unit>\second\metre</si:unit>
                </si:covariance>
            </si:column>
            <si:column>
                <si:covariance>
                    <si:value>0.051</si:value>
                    <si:unit>\metre\second</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.101</si:value>
                    <si:unit>\second\second</si:unit>
                </si:covariance>
            </si:column>
        </si:covarianceMatrix>
        <si:coverageFactor>2.24</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal-multivariate</si:distribution>
    </si:rectangularRegion>
</si:list>
```

multivariate uncertainty

Example: units of multivariate regions

Example: “list” with two real quantities and a multivariate ellipsoidal coverage region.

```
<si:list>
    <si:real>
        <si:value>2.340</si:value>
        <si:unit>\metre</si:unit>
    </si:real>
    <si:real>
        <si:value>3.340</si:value>
        <si:unit>\second</si:unit>
    </si:real>
    <si:ellipsoidalRegion>
        <si:covarianceMatrix>
            <si:column>
                <si:covariance>
                    <si:value>0.212</si:value>
                    <si:unit>\metre\metre</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.051</si:value>
                    <si:unit>\second\metre</si:unit>
                </si:covariance>
            </si:column>
            <si:column>
                <si:covariance>
                    <si:value>0.051</si:value>
                    <si:unit>\metre\second</si:unit>
                </si:covariance>
                <si:covariance>
                    <si:value>0.101</si:value>
                    <si:unit>\second\second</si:unit>
                </si:covariance>
            </si:column>
        </si:covarianceMatrix>
        <si:coverageFactor>2.45</si:coverageFactor>
        <si:coverageProbability>0.95</si:coverageProbability>
        <si:distribution>normal-multivariate</si:distribution>
    </si:ellipsoidalRegion>
</si:list>
```

unit A

unit B

units of real components

units of covariance matrix values

unit A*A

unit B*A

unit A*B

unit B*B

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Overview

1. Outline of previous review and changes
2. Real quantity
3. Structure for SI units
4. Coverage regions
5. Complex quantity
6. List Data Model (general)
7. List of real quantities
8. **List of complex quantities**
9. Further application examples

list of complex - review

What we discussed

- if we may encourage the use of global units
- requirements for when to use global bivariate and multivariate uncertainty

Changes that were made

- Changed global unit element names from „unit“ to „globalUnit“ & “unitPhase” to “globalUnitPhase”.
- Introduced elements for global bivariate uncertainty
- allow both global and local time stamps (dateTime) in list
- improved rules for the usage of global units and global uncertainty statements

Any other information

- We would recommend to use global units and uncertainty statement if the data allows it.

Change: Q10, Q12, Q13 & Q14

v1.2

extended list of complex quantities I

list *of complex quantities in Cartesian coordinate form type extended*	**components** (of the list of complex quantities type)						
	label	complex	dateTime	globalUnit	globalBivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
complex quantities in Cartesian coordinate form with an optional global unit	optional	n times (mandatory)	optional	replaces unit in complex (optional)			
independent complex quantities in Cartesian coordinate form with a global bivariate uncertainty	optional	n times (mandatory)	optional	replaces unit in complex (mandatory)	replaces uncert. in complex (mandatory)		
multivariate vector of complex quantities in Cartesian coordinate form with a hyper-ellipsoidal coverage region	optional	n times (mandatory)	optional	replaces unit in complex (optional)		dimension 2n x 2n (mandatory)	
multivariate vector of complex quantities in Cartesian coordinate form with a hyper-rectangular coverage region	optional	n times (mandatory)	optional	replaces unit in complex (optional)			dimension 2n x 2n (mandatory)

(S) sub type | mandatory | optional

For the Cartesian coordinate form

- Most aspects of the definition of a list of complex quantities are the same as for the list of “real” quantities (section7).
- Components “label” and “dateTime” can both be provided global and local.
- The extended list allows a global unit “globalUnit”, a global bivariate uncertainty or a multivariate uncertainty.
- All „complex“ components must be in the Cartesian coordinate form!

extended list of complex quantities I

list *of complex quantities in polar coordinate form type - extended -*	**components** (of the list of complex quantities type) label	complex	dateTime	globalUnit	globalUnitPhase	globalBivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
complex quantities in polar coordinate form with an optional global unit		n times		both components replaces unit in complex				
independent complex quantities in polar coordinate form with a global bivariate uncertainty		n times		both components replaces unit in complex		replaces uncert. in complex		
multivariate vector of complex quantities in polar coordinate form with a hyper-ellipsoidal coverage region		n times		both components replaces unit in complex			dimension 2n x 2n	
multivariate vector of complex quantities in polar coordinate form with a hyper-rectangular coverage region		n times		both components replaces unit in complex				dimension 2n x 2n

(S) sub type — mandatory — optional

For the polar coordinate form

- Most aspects of the definition of a list of complex quantities are the same as for the list of "real" quantities (section7).
- Components "label" and "dateTime" can both be provided global and local.
- The extended list allows the global units "globalUnit" & "globalUnitPhase, a global bivariate uncertainty or a multivariate uncertainty.
- All „complex" components must be in the polar coordinate form!

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features of list of complex

- Is a list of complex quantities (at least one complex quantity must be contained)

- Allows the specification of **global unit(s)** („globalUnit“ & “globalUnitPhase”)
  - only if two ore more complex quantities are contained in the list
  - if global units are specified, then the local units in the „complex“ components must not be provided

- Allows the definition of a **global bivariate uncertainty**
  - only if two or more complex quantities that are also independent
  - only in combination with a global unit(s)
  - only if the uncertainty of all complex quantities in the list can either be expressed by the ellipsoidal region or by the rectangular region (Sect. 4)

- Allows to state a **multivariate uncertainty** that is valid for all complex quantities and that expresses correlation between the real quantities in the list. Requires at least two real quantities in the list.

Details on these aspects are outlined on the next slides.

Examples: list of complex I

difference betwee global and local units for list of complex

Example: XML implementation of the list data model with two complex components (polar form).

```
<si:list>
    <si:complex>
        <si:valueMagnitude>-10.30</si:valueMagnitude>
        <si:valuePhase>1.50</si:valuePhase>
        <si:unit>\ampere</si:unit>
        <si:unitPhase>\radian</si:unitPhase>
    </si:complex>
    <si:complex>
        <si:valueMagnitude>-12.30</si:valueMagnitude>
        <si:valuePhase>1.80</si:valuePhase>
        <si:unit>\ampere</si:unit>
        <si:unitPhase>\radian</si:unitPhase>
    </si:complex>
</si:list>
```

Example: XML implementation of the list data model with two complex components (polar form) and global units are stated

```
<si:list>
    <si:complex>
        <si:valueMagnitude>-10.0</si:valueMagnitude>
        <si:valuePhase>1.50</si:valuePhase>
    </si:complex>
    <si:complex>
        <si:valueMagnitude>-12.30</si:valueMagnitude>
        <si:valuePhase>1.80</si:valuePhase>
    </si:complex>
    <si:globalUnit>\ampere</si:globalUnit>
    <si:globalUnitPhase>\radian</si:globalUnitPhase>
</si:list>
```

local units

global units

Change: Q10, Q12, Q13 & Q14

v1.2

Global bivariate uncertainty (1/2)

list *of complex quantities in Cartesian coordinate form type extended*	**components** (of the list of complex quantities type)						
	label	complex	dateTime	globalUnit	globalBivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
complex quantities in Cartesian coordinate form with an optional global unit		n times		replaces unit in complex			
independent complex quantities in Cartesian coordinate form with a global bivariate uncertainty		n times		replaces unit in complex	replaces uncert. in complex		
multivariate vector of complex quantities in Cartesian coordinate form with a hyper-ellipsoidal coverage region		n times		replaces unit in complex		dimension 2n x 2n	
multivariate vector of complex quantities in Cartesian coordinate form with a hyper-rectangular coverage region		n times		replaces unit in complex			dimension 2n x 2n

(S) sub type | mandatory | optional

- Global units and global bivariate uncertainty are mandatory.
- All complex components must be independent.
- All „complex“ components must be of the same type (either Cartesian or polar coordinate form)
- Structure of sub type „globalBivaraiteUnc“ explained on next slide.

Global bivariate uncertainty (1/2)

sub type - globalBivariateUnc *for global bivariate uncertainty in list of complex quantities*	**components** (of global bivariate uncertainty type)	
	ellipsoidalRegion (S)	rectangularRegion (S)
hyper-ellipsoidal coverage region	dimension 2 x 2	
hyper-rectangular coverage region		dimension 2 x 2

(s) sub-type — mandatory

- The sub types „ellipsoidalRegion“ and „rectangularRegion“ are those defined in section 4.
- Both „ellipsoidalRegion“ and „rectangularRegions“ must have a covariance matrix of dimension 2 x 2 (bivariate quantity).
- The global units that are stated together with the global bivariate uncertainties must also be the units for the components of the covariance matrix inside „ellipsoidalRegion“ and repsectively inside „rectagularRegion“.

Examples: list of complex II

Example: XML implementation of the list data model with local bivariate uncertainty

```
<si:list>
    <si:complex>
        <si:valueReal>-10.310</si:valueReal>
        <si:valueImag>5.010</si:valueImag>
        <si:unit>\volt</si:unit>
        <si:ellipsoidalRegion>
            <si:covarianceMatrix>
                <si:column>
                    <si:covariance>
                        <si:value>0.050</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                </si:column>
                <si:column>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.105</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                </si:column>
            </si:covarianceMatrix>
            <si:coverageFactor>2.45</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal-bivariate</si:distribution>
        </si:ellipsoidalRegion>
    </si:complex>
```

```
    <si:complex>
        <si:valueReal>-10.510</si:valueReal>
        <si:valueImag>5.510</si:valueImag>
        <si:unit>\volt</si:unit>
        <si:ellipsoidalRegion>
            <si:covarianceMatrix>
                <si:column>
                    <si:covariance>
                        <si:value>0.050</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                </si:column>
                <si:column>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.105</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                </si:column>
            </si:covarianceMatrix>
            <si:coverageFactor>2.45</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal-bivariate</si:distribution>
        </si:ellipsoidalRegion>
    </si:complex>
</si:list>
```

local bivariate uncertainty

Change: P3/2 & P3/9

Git: EXAMPLE-209-4

v1.2

Examples: list of complex III

```
<si:list>
    <si:complex>
        <si:valueReal>-10.310</si:valueReal>
        <si:valueImag>5.010</si:valueImag>
        <si:unit>\metre</si:unit>
    </si:complex>
    <si:complex>
        <si:valueReal>-10.510</si:valueReal>
        <si:valueImag>5.510</si:valueImag>
        <si:unit>\metre</si:unit>
    </si:complex>
    <si:globalUnit>\volt</si:globalUnit>
    <si:globalBivariateUnc>
        <si:ellipsoidalRegion>
            <si:covarianceMatrix>
                <si:column>
                    <si:covariance>
                        <si:value>0.050</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                </si:column>
                <si:column>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.105</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                </si:column>
            </si:covarianceMatrix>
            <si:coverageFactor>2.45</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal-bivariate</si:distribution>
        </si:ellipsoidalRegion>
    </si:globalBivariateUnc>
```

Example: XML implementation of the list data model with global bivariate uncertainty

global unit

global bivariate uncertainty

Change: P3/2 & P3/11

Git: EXAMPLE-209-5

v1.2

Examples: list of complex IV

```
<si:list>
    <si:complex>
        <si:valueMagnitude>11.463</si:valueMagnitude>
        <si:valuePhase>2.689</si:valuePhase>
    </si:complex>
    <si:complex>
        <si:valueMagnitude>10.543</si:valueMagnitude>
        <si:valuePhase>1.937</si:valuePhase>
    </si:complex>
    <si:globalUnit>\volt</si:globalUnit>
    <si:globalUnitPhase>\radian</si:globalUnitPhase>
    <si:globalBivariateUnc>
        <si:ellipsoidalRegion>
            <si:covarianceMatrix>
                <si:column>
                    <si:covariance>
                        <si:value>0.050</si:value>
                        <si:unit>\volt\volt</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\radian\volt</si:unit>
                    </si:covariance>
                </si:column>
                <si:column>
                    <si:covariance>
                        <si:value>-0.003</si:value>
                        <si:unit>\volt\radian</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.105</si:value>
                        <si:unit>\radian\radian</si:unit>
                    </si:covariance>
                </si:column>
            </si:covarianceMatrix>
            <si:coverageFactor>2.45</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal-bivariate</si:distribution>
        </si:ellipsoidalRegion>
    </si:globalBivariateUnc>
</si:list>
```

global unit A

global unit B

unit A*A

unit B*A

unit A*B

unit B*B

Example: units in the global bivariate uncertainty statement

(polar coordinate form)

(for Cartesian coordinate form trivial units in covariance matrix – always A*A)

units of complex components

units of covariance matrix values

Change: P3/2

v1.2

complex list with multivariate uncertainty

list *of complex quantities in Cartesian coordinate form type extended*	**components** (of the list of complex quantities type)						
	label	complex	dateTime	globalUnit	globalBivariateUnc (S)	ellipsoidalRegion (S)	rectangularRegion (S)
complex quantities in Cartesian coordinate form with an optional global unit	optional	n times (mandatory)	optional	replaces unit in complex (optional)			
independent complex quantities in Cartesian coordinate form with a global bivariate uncertainty	optional	n times (mandatory)	optional	replaces unit in complex (mandatory)	replaces uncert. in complex (mandatory)		
multivariate vector of complex quantities in Cartesian coordinate form with a hyper-ellipsoidal coverage region	optional	n times (mandatory)	optional	replaces unit in complex (optional)		dimension 2n x 2n (mandatory)	
multivariate vector of complex quantities in Cartesian coordinate form with a hyper-rectangular coverage region	optional	n times (mandatory)	optional	replaces unit in complex (optional)			dimension 2n x 2n (mandatory)

(S) sub type | mandatory | optional

- Amount of **2** to **n** „complex“ components required.
- All „complex“ components must be of the same type (either Cartesian or polar coordinate form)
- A global unit is optional.
- The elements “ellipsoidalRegion” and “rectangularRegion” (definition in section 4) must have a covariance matrix of dimension **2n** x **2n**.
- No global bivariate uncertainty allowed with multivariate uncertainty.

Examples: list of complex VI

Example: XML implementation of a list with two complex components an a multivariate hyper-ellipsoidal uncertainty.

```
<si:list>
    <si:complex>
        <si:valueMagnitude>11.463</si:valueMagnitude>
        <si:valuePhase>2.689</si:valuePhase>
        <si:unit>\ampere</si:unit>
        <si:unitPhase>\radian</si:unitPhase>
    </si:complex>
    <si:complex>
        <si:valueMagnitude>10.543</si:valueMagnitude>
        <si:valuePhase>1.937</si:valuePhase>
        <si:unit>\volt</si:unit>
        <si:unitPhase>\degree</si:unitPhase>
    </si:complex>
    <si:ellipsoidalRegion>
            <si:covarianceMatrix>
                <si:column>
                    <si:covariance>
                        <si:value>0.050</si:value>
                        <si:unit>\ampere\ampere</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.244</si:value>
                        <si:unit>\radian\ampere</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.007</si:value>
                        <si:unit>\volt\ampere</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.000</si:value>
                        <si:unit>\degree\ampere</si:unit>
                    </si:covariance>
                </si:column>
```

unit A
unit B
unit C
unit D

multivariate uncertainty
(continued on next slide)

column 1 of covariance matrix

$$\begin{pmatrix} 0.050 & 0.244 & 0.007 & 0.000 \\ 0.244 & 0.105 & 0.051 & 0.109 \\ 0.007 & 0.051 & 0.076 & 0.002 \\ 0.000 & 0.109 & 0.002 & 0.602 \end{pmatrix}$$

units in the covariance matrix

$$\begin{pmatrix} A*A & A*B & A*C & A*D \\ B*A & B*B & B*C & B*D \\ C*A & C*B & C*C & C*D \\ D*A & D*B & D*C & D*D \end{pmatrix}$$

Examples: list of complex VI (continued)

```
<si:column>
    <si:covariance>
        <si:value>0.244</si:value>
        <si:unit>\ampere\radian</si:unit>
    </si:covariance>
    <si:covariance>
        <si:value>0.105</si:value>
        <si:unit>\radian\radian</si:unit>
    </si:covariance>
    <si:covariance>
        <si:value>0.051</si:value>
        <si:unit>\volt\radian</si:unit>
    </si:covariance>
    <si:covariance>
        <si:value>0.109</si:value>
        <si:unit>\degree\radian</si:unit>
    </si:covariance>
</si:column>
<si:column>
    <si:covariance>
        <si:value>0.007</si:value>
        <si:unit>\ampere\volt</si:unit>
    </si:covariance>
    <si:covariance>
        <si:value>0.051</si:value>
        <si:unit>\radian\volt</si:unit>
    </si:covariance>
    <si:covariance>
        <si:value>0.076</si:value>
        <si:unit>\volt\volt</si:unit>
    </si:covariance>
    <si:covariance>
        <si:value>0.002</si:value>
        <si:unit>\degree\volt</si:unit>
    </si:covariance>
</si:column>
```

```
                <si:column>
                    <si:covariance>
                        <si:value>0.000</si:value>
                        <si:unit>\ampere\degree</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.109</si:value>
                        <si:unit>\radian\degree</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.002</si:value>
                        <si:unit>\volt\degree</si:unit>
                    </si:covariance>
                    <si:covariance>
                        <si:value>0.602</si:value>
                        <si:unit>\degree\degree</si:unit>
                    </si:covariance>
                </si:column>
            </si:covarianceMatrix>
            <si:coverageFactor>3.08</si:coverageFactor>
            <si:coverageProbability>0.95</si:coverageProbability>
            <si:distribution>normal-multivariate</si:distribution>
        </si:ellipsoidalRegion>

</si:list>
```

column two of covariance matrix
column three of covariance matrix
column four of covaraince matrix

v1.2

SmartCom

Overview

1. Outline of previous review and changes
2. Real quantity
3. Structure for SI units
4. Coverage regions
5. Complex quantity
6. List Data Model (general)
7. List of real quantities
8. List of complex quantities
9. Further application examples

SmartCom

Future perspective

- **Development of design guides for commonly used data structures** like

  - shortest coverage interval for real quantity
  - smallest coverage region for vector quantity (list)
  - different types of Monte Carlo Simulation Data
  - mapping to formats that are established in particular areas (i.e. METAS UncLib / VNA Tool format)
  - scales, intervals and value ranges
  - …

- These data structures exceed the minimum required „real“ and „complex“ data models from SmartCom but they can be expressed by using the „list“ structure in the D-SI data model.

- Examples are provided here for a Tensor and simple Monte Carlo Simulation data. These examples are presented on the next two slides.

SmartCom

Recursive usage of lists

Example: XML implementation of a 2x2 matrix (tensor) using recursive lists and real components.

```
<si:list>
    <!-- list with column one -->
    <si:list>
        <si:real>
            <si:value>2.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>3.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
    <si:list>
    <!-- list with column two -->
    <si:list>
        <si:real>
            <si:value>4.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>5.34</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
    <si:list>
<si:list>
```

interpretation of values

	column 1	column 2
row 1	2.34 m	4.34 m
row 2	3.34 m	5.34 m

Example: Monte Carlo Data

Example:

XML implementation of Monte Carlo simulation data in the generic list data model. The data comprises Monte Carlo Samples and a Monte Carlo result that was calculated from arithmetic mean and standard deviation of the samples.


```xml
<si:list>
        <si:label>Monte Carlo Simulation Data</si:label>
        <si:list>
            <si:label>Simulation Result</si:label>
            <si:real>
                <si:value>0.998714286</si:value>
                <si:unit>\metre</si:unit>
                <si:coverageInterval>
                    <si:stdUncertainty>0.003450328</si:stdUncertainty>
                    <si:intervalMin>0.997</si:intervalMin>
                    <si:intervalMax>1.002</si:intervalMax>
                    <si:coverageProbability>0.95</si:coverageProbability>
                </si:coverageInterval>
            </si:real>
        </si:list>
```

```xml
    <si:list>
        <si:label>Monte Carlo Samples</si:label>
        <si:real>
            <si:value>1.002</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>1.001</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>0.998</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>1.001</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>0.997</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>0.992</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
        <si:real>
            <si:value>1.000</si:value>
            <si:unit>\metre</si:unit>
        </si:real>
    </si:list>
</si:list>
```

v1.2

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Project

Start	June 2018
Duration	3 Year
Partner	NPL, CMI, Aalto, UM, Unicas, NIM, ITRI, KRISS, Ostfalia, Hexagon, Mitutoyo, Sartorius, Mettler-Toledo, Zeiss
Contact	smartcom@ptb.de