Survey of software for Measurement Uncertainty evaluation

Francesca Pennecchi (INRIM)

Mathmet Activity MU Training
Impact Workshop
Online, 14.03.2024

Aim of the survey

- **Obective 1:** *To develop new material for measurement uncertainty training (WP 1). This material will be reviewed and freely available, it will include short introductory videos to increase the understanding of measurement uncertainty, as well as a systematic overview of available courses, examples and software to guide potential trainees.*
- A **critical overview of available software** for evaluating measurement uncertainty was performed by stating their characteristics such as the status (commercial, freeware, open source), the kind of methods they implement or some operating conditions.
- **Raw data available:** on the “For Trainees - Measurement Uncertainty Training” webpage (https://www.euramet.org/european-metrology-networks/mathmet/activities/measurement-uncertainty-training-activity/for-trainees-measurement-uncertainty-training)

MATHMET

The analyzed SW

- **50 selected SW** for MU evaluation
- **35 analyzed** by INRIM, NPL, LNE, IPQ, IMBiH, METAS, POLITO and MSL
- **Info collected**:
  - *General information*
  - *Technical features*
  - *Adherence to JCGM-WG1 documents*:

JCGM 100:2008 (the GUM) "Evaluation of measurement data"

JCGM 101:2008 "Supplement 1 – Propagation of distributions using Monte Carlo method"

JCGM 102:2011 "Supplement 2 – Extension to any number of output quantities"

Name
Dakota (A Multilevel Parallel Object-Oriented Framework
error propagation calculator – Laffer.net
Excel add-in for Uncertainty Calculation (SGUM)
Fussy
GUM Tree Calculator (GTC)
GUM Workbench
GUM_MC
gvar
LNE MCM
LNE Uncertainty
Mathos Laboratory Uncertainty Calculator
MCM Alchimia
METAS UncLib
metRology
MetroloPy
MSL Uncertainty Calculator
Muse
NIST Uncertainty Machine
NPLUnc_101 (applications)
NPLUnc_101 (published)
NPLUnc_102 (applications)
Numbers with Uncertainty (Wolfram Language)
OpenTURNS
Persalys
Propagate
QMSys GUM Educational
soerp
Suncal
UncertainRealNumbers.R
Uncertainties package
Uncertainty Calculator
Uncertainty Calculator; Wilfrid Laurier University
Uncertainty Quantification with python (UQpy)
UncertaintyWrapper
UQLab

General information

MATHMET

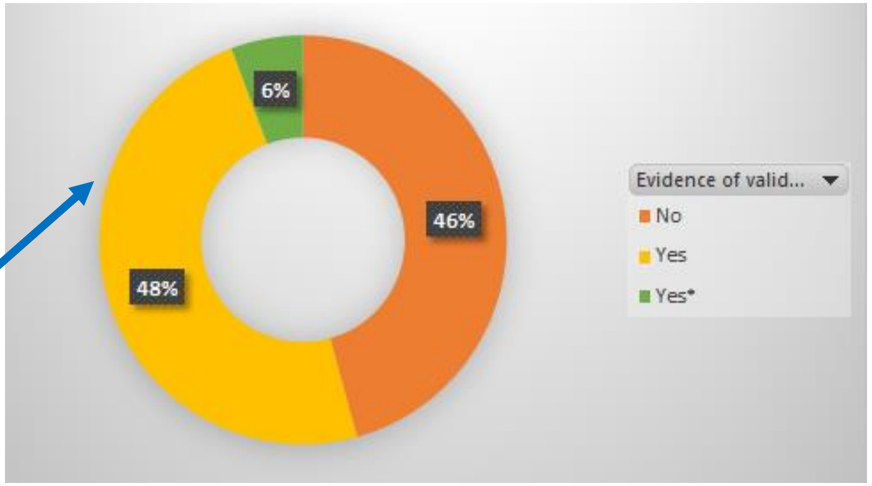
SW range from:

- basic uncertainty calculators to quite complex/broad-scope software;

- user-friendly web applications to comprehensive collections of libraries and tools for UQ.

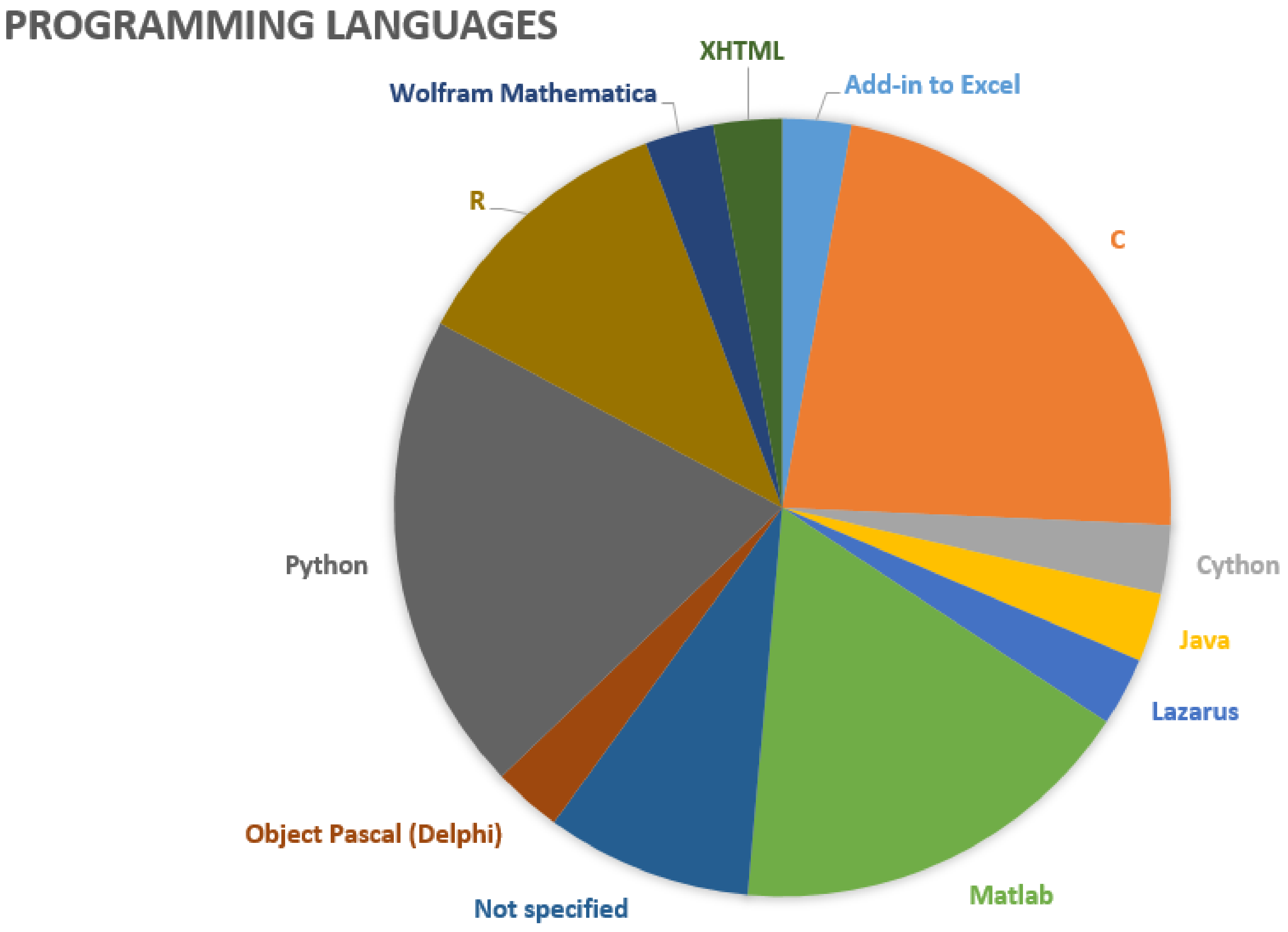
General information
Name of the software
Website
Short description/main aim
License
Programming language
Cross-platform (i.e., designed to work in several computing platforms)
Current version (or last updated, in case the software is no longer maintained)
Computer-based software/web application
Language/s
Author/s and affiliation/s
Documentation
Evidence of validation
Reference contact

- **74 % cross-platform**
- **85 % computer-based software**
- **54 %** provide some **evidence of validation**



- All SW are available in **English version** (some also in other languages, like French, Italian, German, Bulgarian, Hungarian, Spanish, Portuguese, Japanese, Ukrainian, Russian)

General information cont.



MATHMET

Technical features

- Well covered: correlated input quantities, multiple output quantities, nonlinear models, output export
- Poorly covered: complex quantities, implicit models, measurement units, symbolic evaluation, repeated input observations, input of previous analysis, uncertainty budget table
- Note: 46 % SW have a GUI

NOTE: «Yes*» means «Partially addressed»

	Handles correlated input quantities	Handles more than one output quantity	Handles complex quantities	Handles implicit models	Handles nonlinear models	Handles units	Symbolic uncertainty evaluation
Percentage	%	%	%	%	%	%	%
No	14	43	77	91	11	77	71
Yes	80	54	20	9	83	20	29
Yes*	6	3	3	0	6	3	0

	Other relevant features	Graphical user interface	Repeated observations as input	Import of previous analyses as input	Uncertainty budget table as output	Export of output results
Percentage	%	%	%	%	%	%
No	77	54	63	57	66	46
Yes	23	43	34	40	29	51
Yes*	0	3	3	3	6	3

MATHMET

Adherence to JCGM 100:2008 (GUM)

- Well covered: LPU, sensitivity coefficients, expanded unc.
- Poorly covered: LPU from higher-order Taylor series expansion, effective degrees of freedom, output reporting according to GUM Sec. 7.2

NOTE: «Yes*» means «Partially addressed»

	LPU, eq. (10) (first-order Taylor series approximation - no input correlations)	**LPU, eq. (13) (first-order Taylor series approximation - with input correlations)**	**LPU from higher-order Taylor series approximation**	**Calculation (analytical or numerical) of sensitivity coefficients**
Percentage	%	%	%	%
No	29	46	86	46
Yes	71	51	14	49
Yes*	0	3	0	6

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)$$

$$+ \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\frac{1}{2} \left(\frac{\partial^2 f}{\partial x_i \partial x_j} \right)^2 + \frac{\partial f}{\partial x_i} \frac{\partial^3 f}{\partial x_i \partial x_j^2} \right] u^2(x_i) u^2(x_j)$$

	Provision of a summary of standard uncertainty components	**Calculation of the effective degrees of freedom, eq. (G.2b)**	**Provision of an expanded uncertainty at a prescribed coverage probability**	**Reporting (e.g. export of a word file) according to sec 7.2 supported**
Percentage	%	%	%	%
No	54	57	46	80
Yes	46	43	51	14
Yes*	0	0	3	6

7.2.1 When reporting the result of a measurement, and when the measure of uncertainty is the combined standard uncertainty $u_c(y)$, one should

a) give a full description of how the measurand Y is defined;

b) give the estimate y of the measurand Y and its combined standard uncertainty $u_c(y)$; the units of y and $u_c(y)$ should always be given;

c) include the relative combined standard uncertainty $u_c(y)/|y|$, $|y| \neq 0$, when appropriate;

d) give the information outlined in 7.2.7 or refer to a published document that contains it.

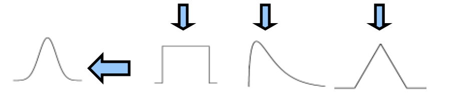
If it is deemed useful for the intended users of the measurement result, for example, to aid in future calculations of coverage factors or to assist in understanding the measurement, one may indicate

— the estimated effective degrees of freedom ν_{eff} (see G.4);

— the Type A and Type B combined standard uncertainties $u_{cA}(y)$ and $u_{cB}(y)$ and their estimated effective degrees of freedom ν_{effA} and ν_{effB} (see G.4.1, Note 3).

Adherence to JCGM 101:2008 (Propagation of distributions using a MC method)

$$Y = f\left(X_1, X_2, \ldots, X_N\right)$$



- **Well covered**: input pdfs, MCM estimation of measurand and unc. evaluation
- **Poorly covered**: coverage intervals, adaptive MC procedure, validation of GUM by MCM

NOTE: «Yes*» means «Partially addressed»

	Maximum number of MC trials	Maximum number of input quantities ("No" means "Not defined", "Yes" means "Maximum number explicitely mentioned")	Probability density functions for the input quantities as in Sec. 6	Estimate of the output quantity and the associated standard uncertainty, eqs. (16) and (17)	Coverage interval for the output quantity at a prescribed coverage probability
Percentage	%	%	%	%	%
No	83	77	40	40	54
Yes	17	20	51	57	46
Yes*	0	3	9	3	0

	Probabilistically symmetric 100p % coverage interval as in Sec. 7.7.2	Shortest 100p % coverage interval as in Sec. 7.7.2	Adaptive Monte Carlo procedure as in Sec. 7.9	Validation of the GUM uncertainty framework using MCM as in Sec. 8
Percentage	%	%	%	%
No	60	74	83	77
Yes	40	26	14	23
Yes*	0	0	3	0

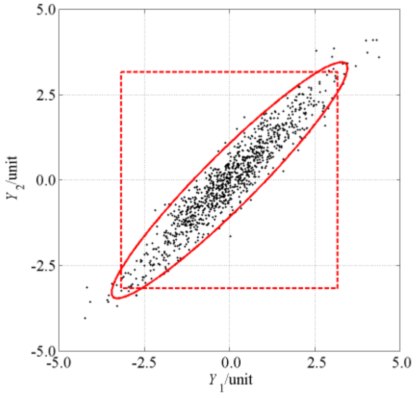
Adherence to JCGM 102:2011 (Extension to any number of output quantities)

- Well covered: none
- Poorly covered: all aspects of both multivariate LPU and MCM

NOTE: «Yes*» means «Partially addressed»

	Maximum number of output quantities	LPU for explicit multivariate measurement models, eq. (3)	LPU for implicit multivariate measurement models, eqs. (9) and (10)	Coverage region for a vector output quantity as in Sec. 6.5	Joint probability density functions for the input quantities as in Sec. 5.3	Estimate of the output quantity and the associated covariance matrix as in Sec. 7.6	Coverage region for a vector output quantity as in Sec. 7.7	Adaptive Monte Carlo procedure as in Sec. 7.8	Validation of the GUM uncertainty framework using MCM as in Sec. 8
Percentage	%	%	%	%	%	%	%	%	%
No	89	80	94	91	83	69	91	91	91
Yes	0	17	6	3	3	11	6	3	3
Yes*	11	3	0	6	14	20	3	6	6

$$\boldsymbol{U_y} = \boldsymbol{C_x}\boldsymbol{U_x}\boldsymbol{C_x}^\top$$



$$\widetilde{y} = \frac{1}{M}(y_1 + \cdots + y_M)$$

$$U_{\widetilde{y}} = \frac{1}{M-1}[(y_1 - \widetilde{y})(y_1 - \widetilde{y})^\top + \cdots + (y_M - \widetilde{y})(y_M - \widetilde{y})^\top]$$

Conclusions

MATHMET

➢Pros:

- Large variety of SW dedicated to MU evaluation
- Good covering of LPU framework (sensitivity coefficients, combined standard uncertainty and expanded uncertainty – but contradicting poor covering of effective degrees of freedom)
- Satisfactory covering of MCM framework (input pdfs, estimation of measurand and uncertainty evaluation)

➢Cons:

- Not many SW (54 %) provide some evidence of validation
- Only 46 % provide MCM coverage intervals at a prescribed coverage probability
- A very few SW cover aspects of multivariate LPU and MCM (despite 57 % deal with multivariate models)

NOTE:

The results of the present analysis were enclosed in
F. R. Pennecchi and P. M. Harris, Mathmet Measurement Uncertainty Training activity – Overview of courses, software, and classroom examples, ACTA IMEKO 12 (2), 2023

Thank you for the attention!
Any question?