Overview of the verification of mathematical software using the TraCIM system

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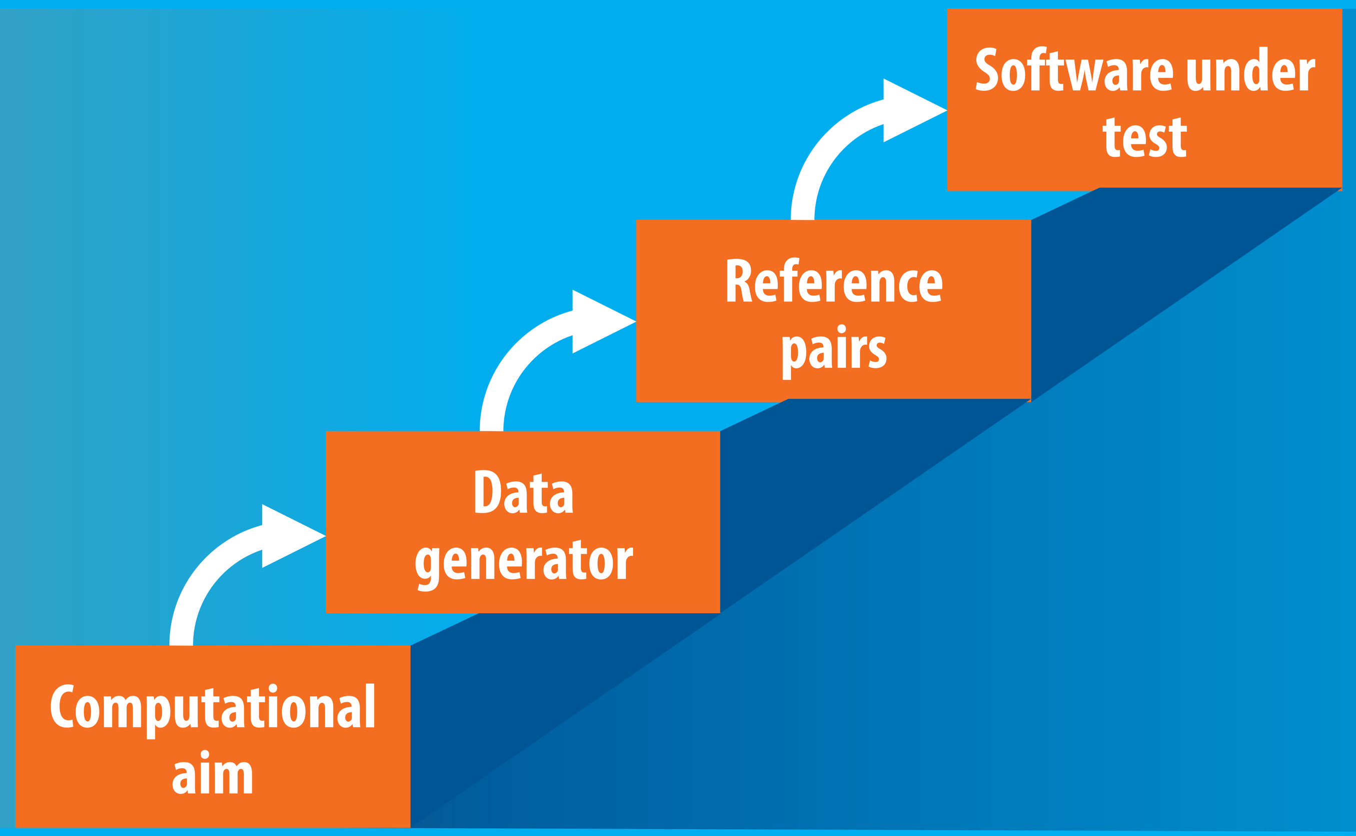
The need for verification

Measured data increasingly provides the foundation for decision making. Mathematical software, i.e., software that implements mathematical calculations, is a key link in the chain that converts measured data to decisions. In many cases, mathematical software may be embedded within a measurement system. It is imperative that mathematical software undergoes appropriate verification, i.e., testing to demonstrate that it implements calculations correctly, to ensure its fitness for purpose.

The TraCIM project

The research project "Traceability for Computationally-Intensive Metrology" (short name "TraCIM") [1], funded by the European Union, ran from 2012 to 2015. In the context of this project, the term "traceability" refers to the provision of an unbroken chain that links a number of components within the software verification process.

Within the TraCIM project, six European National Metrology Institutes (NMIs), including NPL and PTB, were tasked with developing a framework for the verification of mathematical software in the field of measurement. The framework was successfully applied to develop verification services for software executing a number of calculations commonly implemented within coordinate measuring machines (CMMs). The TraCIM approach is based upon 3 key aspects: computational aims; reference pairs; and an information and communications technology (ICT) infrastructure.



1. Computational aims

A complete and unambiguous description of the calculations to be undertaken is fundamental to the verification of a mathematical software component. Such a description is referred to as a "specification of the computational aim" (for brevity shortened to "computational aim"). Within the TraCIM project, a procedure was developed that allows a computational aim to be stored as a Portable Document Format (PDF) file. Additionally within the project, the "Computational Aims Database" [2] was developed that stores specifications of computational aims. The database was populated by project partners with specifications of computational aims for a number of common measurement problems.

Language
Title
Keywords
Mathematical area
Dependencies
Input parameters
Output parameters
Mathematical model
Signature
Properties
References
Notes
History

TraCIM: Computational Aims Database

en/-/0/000008	Gaussian areal filter	Gaussian filter for calculating surface texture areal parameters
en/-/0/000009	Gaussian profile filter	Gaussian filter for calculating surface texture profile parameters
en/-/0/000010	Arithmetical mean deviation Pa of assessed profile	Amplitude surface texture parameter for primary profile
en/-/0/000011	Arithmetical mean deviation Ra or Wa of assessed profile	Amplitude surface texture parameter for roughness or waviness profile

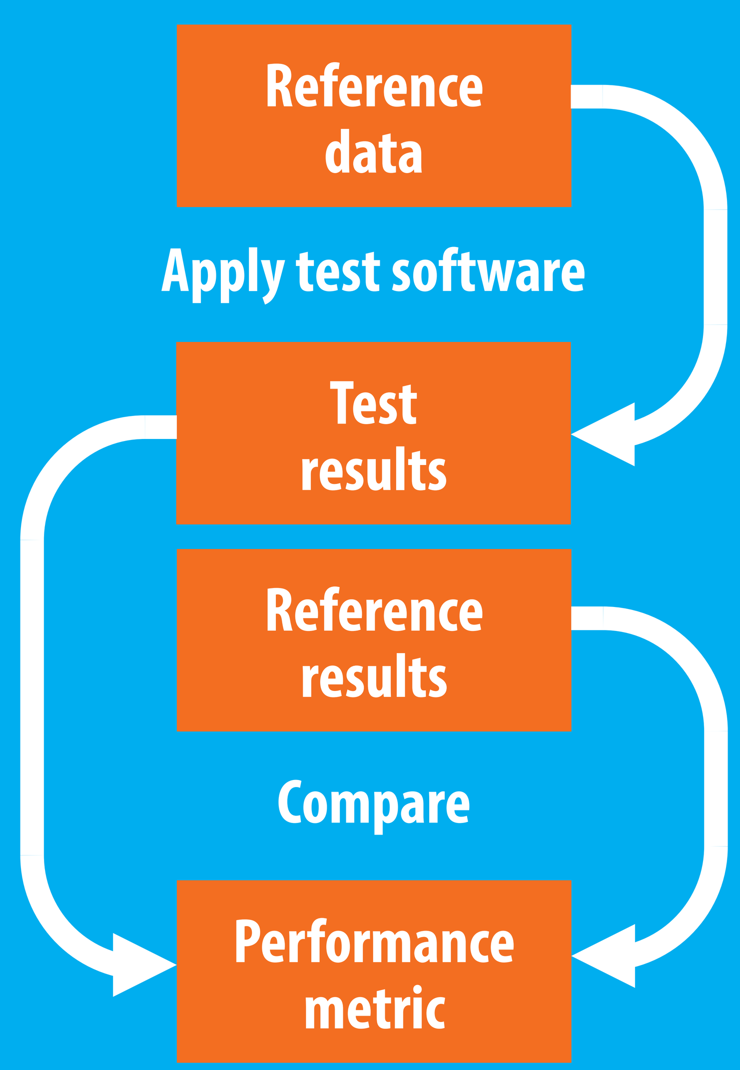
2. Reference pairs

A reference pair for a given computational aim comprises reference data and corresponding reference results [3]. Reference pairs, generated using a data generator, are used as follows:

- Software under test is applied to reference data to generate test results.
- The test results are compared, in an appropriate way, with the reference results allowing the numerical performance of the software for that reference pair to be assessed.
- The process is repeated for a "large" number of reference pairs allowing an overall assessment of the software to be made. Reference data is typically chosen to span the space of inputs to which the software is intended to be applied.

For each reference pair, one or more "performance metric", i.e., numerical measure of the performance of the software, is evaluated, e.g., the number of decimal digits of precision by which test and reference results differ.

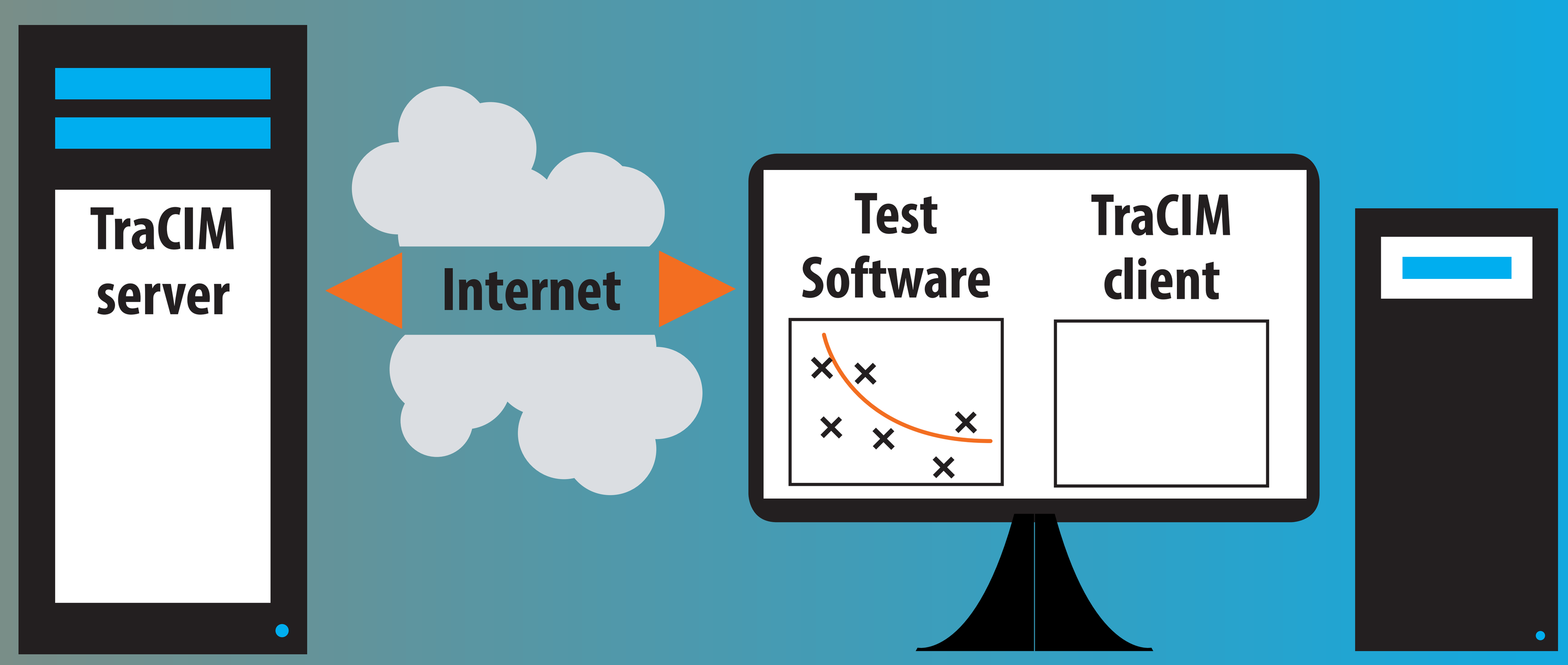
Performance metrics for a large number of reference pairs are then combined to evaluate a "single figure of merit".



3. ICT infrastructure

The "TraCIM system", the ICT infrastructure developed within the TraCIM project, allows communication between the provider of a verification service ("service provider") and the user of that service ("service user") using the internet. The TraCIM system comprises the following elements:

- The "TraCIM server" – the core software module that manages all of the operating data and controls the flow of data to other modules. The TraCIM server is typically hosted by an NMI.
- The "TraCIM client" – a software module, implemented by the service user, that allows communication with the TraCIM server using the internet.



The ValTraC project

While the TraCIM project had a particular focus on mathematical software used within metrology, the TraCIM system developed within the project is equally applicable to mathematical software used in any field and for which the reference pairs approach to verification is appropriate. The follow-on Project "Validation of software development and analysis tools using TraCIM" (short name "ValTraC"), also funded by the European Union, is concerned with demonstrating the application of the TraCIM approach to general mathematical software.

Standalone and integrated TraCIM clients

If the software environment within which the software under test is running is unable to communicate with the TraCIM server, the service user has to use a "standalone" TraCIM client, i.e., a TraCIM client that runs in a software environment that does allow such communication. Otherwise, an "integrated" TraCIM client may be implemented. Integrated TraCIM clients often offer the advantage of minimising, or removing completely, the need for human interaction when using a verification service.

References

[1] A. B. Forbes, I. M. Smith, F. Härtig and K. Wendt. Overview of EMRP Joint Research Project NEW06 "Traceability for Computationally Intensive Metrology". Advanced Mathematical and Computational Tools in Metrology and Testing X (2015).

[2] TraCIM Computational Aims Database. www.tracim-cadb.npl.co.uk.

[3] M. G. Cox, P. M. Harris, Design and use of reference data sets for testing scientific software. Analytica Chimica Acta, Vol. 380, issues 2-3, pages 339–351 (1999).

Acknowledgments

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