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Computing with confidence

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The advent of accessible high-speed computing has revolutionised engineering which has been utterly transformed from a largely solitary pencil-and-paper endeavour to a collective enterprise based on computer calculations and widely shared software tools. These tools now pervade engineering across all its tasks: analysis, simulation, planning and design, optimisation, sensitivity analysis, validation, and decision making.

In 2004, Rafi Muhanna at Georgia Tech and Robert Mullen at the University of South Carolina founded a series of biennial workshops on Reliable Engineering Computing (REC) with funding from the National Science Foundation. They highlighted several sources of errors that could diminish the reliability of computing within engineering, including modelform uncertainty, discretisation error, uncertainty about parameters, and errors arising from finite-precision arithmetic on computers.

REC2018 (www.rec2018.uk), the eighth workshop in this series, was hosted by the Institute for Risk and Uncertainty at the University of Liverpool. The papers of this special issue of International Journal of Approximate Reasoning are associated with this workshop and accompany the papers in the workshop proceedings which, like all the REC proceedings, are freely accessible on line.

Although the goal of reliability in computing seems inarguable or even anodyne, the issue of how to achieve reliability is highly controversial. Scholars in engineering are still divided on how to quantify uncertainty. Many believe it can be achieved completely within the traditional probabilistic paradigm. But the existence of non-probabilistic or trans-probabilistic methods such as interval analysis, Dempster–Shafer theory, belief theory, possibility theory—which are collected under the rubric 'imprecise probabilities'—imply that there is a kind of uncertainty that cannot be expressed by probability alone. Some probabilists jealously argue that this idea is nonsense, that there is only one coherent theory of uncertainty which is probability. But some scholars think a more general theory of uncertainty is needed to quantify confidence in a way that is verifiable and practicable.

Many scholars likewise argue that the expected utility decision theory of von Neumann and Morgenstern is the only sensible way to make rational decisions in the face of uncertainties characterised by probabilities. Although it is well established descriptively that humans do not actually make decisions based on expected utility in practice, some argue that they should normatively. Interestingly, relaxing a single axiom yields a decision theory with imprecise probabilities that can be fully consistent but allows for rational agents to decline to make decisions when their uncertainties preclude comparing all possible options. This theory allows agents to avoid sure loss, but doesn't force them to profess more than they know. Alternative decision rules based on alternative theories of uncertainty can be valid despite deviating from the traditional assumptions.

Two-hundred years ago, mathematicians discovered non-Euclidean geometry. In trying to prove as a theorem the fifth Euclidean postulate which they considered to be not self-evident as a postulate should be, they realised that consistent geometries could be defined that deny this postulate. Although perfectly valid, this idea seemed manifestly ridiculous to many. Geometers had universally held that the fifth postulate was true throughout the preceding two thousand years, and the non-Euclidean geometers were subjected to harsh criticism and even ridicule. The mathematical community eventually realised that non-Euclidean geometries were legitimate, and they have turned out to have many important applications despite the early derision.

Reliable engineering computing is today at a similarly exciting crossroads in which there is broad controversy about what theories of uncertainty should be, what they are capable of, and what a unification would look like. Hints of this controversy are evident in the papers of this special issue. We believe that probabilists will come to understand and embrace, and eventually depend on, the ideas behind imprecise probabilities, just as mathematicians emerged through their turmoil two centuries ago to understand that non-Euclidean thinking enriches geometry and greatly increases its applications. Just as the emergence of the new geometries did not replace or obviate the use of Euclidean geometry, no one doubts that traditional probability theory, and expected utility decision theory, will continue to be widely used for a host of problems in and beyond engineering.

Two great arcs are now bending through history as the theory of imprecise probabilities matures as a discipline and engineering incorporates it into regular practice. The first sees scientists and engineers developing technologies for making calculations that require only the assumptions they feel comfortable making, rather than their being forced to make untenable assumptions in order to get any quantitative answer at all. The second great arc is that everyone who must do calculations will come to understand that computation does not require infinitely precise numbers, that uncertainty analysis is fully half the story in almost any computation, and that it is possible and worthwhile to compute with what we actually know, rather than making pretend-calculations with what we would like to know. As these arcs weave together they create the context where we can compute with confidence to achieve reliable engineering computing.

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