DIV GRAD CURL ARE DEAD - ARE THEY?

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Being inspired by the title of Burke's unpublished book [1] we ask ourselves: What is the future role of physics-based modeling, simulation and optimization (MSO) in the age of machine learning (ML) and artificial intelligence (AI)? As a matter of fact, the use of simulation has seen continual double digit percentage growth annually for about 30 years until 2008 To continue this success story during the next decade, MSO needs to become *"increasingly fit for purpose, smart, integrated, and transparent"* (Joe Walsh, NAFEMS2015). Mathematical key technologies to enable such progress will be highlighted in this talk.

We start by considering industry: what is the role of mathematics and what are topical needs? Sustaining Moore's law necessitates parallel computing. For example, multi-objective optimization with evolutionary algorithms is embarassingly parallel. The computation of eddy current losses in the winding heads of electrical machines by large-scale high performance computing serves as another example.

Along with Moore's law in hardware goes a similar evolution of algorithms. Multi-domain, multi-scale and multi-fidelity simulations, in short multi-X, are coming within reach now, with powerful simulation frameworks. We demonstrate this for quench propagation in superconducting accelerator magnets [2], by employing the port-Hamiltonian approach. We also discuss the co-evolution of Computer-Aided Design and Finite-Element Analysis into Isogeometric Analysis. This makes the exact geometry accessible for numerical analysis, for example for computing resonant electromagnetic modes in superconducting accelerator cavities [3].

We conclude that data-driven models based on ML and AI will not render physical domain-specific models obsolete. In contrast, both model classes complement each other very well in hybrid approaches. Div, Grad, Curl will be going stronger than ever!

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