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# ADAPTIVE AUTOMATED FINITE ELEMENT HPC FRAMEWORK WITH APPLICATIONS IN TURBULENT FLOW AND FLUID-STRUCTURE INTERACTION

**Johan Jansson*[12], Bärbel Janssen[3], Niclas Jansson[4], Rodrigo Vilela de Abreu[5], Jeannette Spühler[6], Cem Degirmenci[7], Kaspar Müller[8], Aurélien Larcher[9] and Johan Hoffman[10]**

[1] Basque Center for Applied Mathematics, Mazarredo 14., 48009 Bilbao, Spain, jjansson@bcamath.org, bcamath.org
[2] Department of High Performance Computing and Visualization (HPCViz), KTH Royal Institute of Technology, SE-10044 Stockholm, Sweden, jjan@kth.se, www.csc.kth.se/~jjan
[3] HPCViz, KTH barbel@kth.se, www.csc.kth.se/~barbel
[4] HPCViz, KTH njansson@kth.se, www.csc.kth.se/~njansson
[5] HPCViz, KTH rvda@kth.se, www.csc.kth.se/~rvda
[6] HPCViz, KTH spuhler@kth.se, www.csc.kth.se/~spuhler
[7] HPCViz, KTH ncde@kth.se, www.csc.kth.se/~ncde
[8] HPCViz, KTH kasparm@kth.se, www.csc.kth.se/~kasparm
[9] HPCViz, KTH larcher@kth.se, www.csc.kth.se/~larcher
[10] HPCViz, KTH jhoffman@kth.se, www.csc.kth.se/~jhoffman

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Developing multiphysics finite element methods (FEM) and scalable HPC implementations can be very challenging in terms of software complexity and performance, even more so with the addition of adaptive error control. To manage the complexity we have developed *general* adaptive stabilized methods and the FEniCS-HPC *automated* software framework [2, 3, 5, 4, 6, 1], taking the weak form of the partial differential equation (PDE) as input and automatically generating low-level source code for assembling tensors and a posteriori error estimates and indicators for adaptive error control.

We give an overview of the methodology and the FEniCS-HPC framework, components of the framework include:

1. **Automated discretization** where the weak form of a PDE in mathematical notation is translated into a system of algebraic equations using code generation.
2. **Automated error control**, ensures that the discretization error e = u - U in a given quantity is smaller than a given tolerance by adaptive mesh refinement based on duality-based a posteriori error estimates. An a posteri error estimate and error

indicators are automatically generated from the weak form of the PDE, by directly using the error representation.

3. **Automated modeling**, which treats the fluid and solid as one continuum with a phase indicator function and moving mesh mesthods for tracking phase interfaces and implicityly modeling contact in fluid-structure interaction. Another aspect is a residual based implicit turbulence model, where the turbulent dissipation comes only from the numerical stabilization.

We demonstrate optimal strong scaling for the whole adaptive framework applied to turbulent flow on massively parallel architectures up to at least 5000 cores, which means that doubling the amount of cores halves the computation time for a fixed problem size.

We also present several applications in turbulent flow and fluid-structure interaction: adaptive simulation of aerodynamic forces on a full aircraft at realistic take-off and landing conditions, fluid-structure simulation of self-oscillating vocal folds with contact [7], among others.

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