NUCLEAR ENERGY UNIVERSITY PROGRAMS

High-Fidelity Space-Time Adaptive Multiphysics Simulations in Nuclear Engineering

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Project Number: 09-795

Initiative/Campaign: AFCI/Modeling & Simulation

Abstract

Many physical phenomena occurring in nuclear reactors, such as neutronics/thermal-hydraulics or fuel pellet thermo-mechanics, are inherently tightly coupled under both normal and accident situations. Furthermore, the length and time scales of the various physics components may greatly vary and evolve during a transient. Yet most of the algorithms employed today to solve such complex physical phenomena rely on simple data exchanges between mono-disciplinary codes and employ fixed grids in space and time. The current approach presents two serious drawbacks that significantly impede a science-based approach for the accurate simulation and prediction of nuclear system behaviors. First, failure to resolve the nonlinearities between coupled physics codes can lead to a loss of accuracy and even stability in the numerical simulations. Second, the lack of space-time adaptive meshes may prevent the accurate resolution of relevant physical phenomena, or worse, may ignore localized features.

This project will address both the consistency of the nonlinear simulation and the accuracy of the spatio-temporal discretization, by developing a novel mathematical methodology and the associated algorithmic framework and software architecture. Researchers will employ space-time adaptive high-order monolithic discretization of non-linear time-dependent multiphysics equations to address some representative challenges arising in the modeling of nuclear systems: coupled neutronics/thermal-hydraulics, thermal stress, and oxygen diffusion in uranium oxide fuel pellets. This technique will make it possible to:

- Employ high-order spatially adaptive discretizations (possibly different for each physical field if the fields exhibit significantly different phenomena or different spatial scales).
- Use high-order automatically adaptive implicit time-stepping schemes (also possibly different for each field in the case of multiple time scales).
- Discretize arbitrary combinations of non-linearly coupled physics in a monolithic fashion via standard Newton and Jacobian-Free Newton-Krylov (JFNK) methods; systematically investigate various types of preconditions for the JFNK methods for several multiphysics situations and compare JFNK methods with standard Newton methods for these problems.