Development of a Scientific Visualization System

Thesis submitted in fulfillment of the requirements for the award of the degree of

Doctor in de ingenieurswetenschappen (Doctor in Engineering) by ***Dean Vučinić***

Public defense to be held on September 5, 2007 at 17:00

Abstract

This thesis describes a novel approach to create, develop and utilize software tools for visualization in scientific and engineering applications. These *Scientific Visualization (SV)* tools are highly interactive visual aids which allow analysis and inspection of complex numerical data generated from high-bandwidth data sources such as simulation software, experimental rigs, satellites, scanners, etc... The data of interest typically represent physical variables -- 2- and 3-dimensional scalar, vector and tensor fields on structured and unstructured meshes in multidomain (multiblock) configurations. The advanced *SV* tools designed during the course of this work permit data extraction, visualization, interpretation and analysis at a degree of interaction and effectiveness that was not available with previous visualization techniques.

The *Object-Oriented Methodology* (*OOM*), which is the software technology at the basis of the approach advocated in this thesis, is very well adapted for large-scale software development: *OOM* makes SV tools possible and makes them a usable, innovative investigation instrument for the engineer and the researcher in all areas of pure and applied research. The advanced *SV* tools that we have developed allow the investigator to examine qualitatively and quantitatively the details of a phenomenon of interest, in a unified and transparent way. Our SV tools integrate several well-known algorithms -- such as the cutting plane, iso-surface and particle trace algorithms -- and enhance them with an ergonomic graphical user interface. The resulting *SV* system implements the reusability and encapsulation principles in its software components, which support both space discretization (unstructured and structured meshes) and continuum (scalar and vector fields) unconstrained by the grid topology. New implementation mechanisms applied to the class hierarchies have been developed beyond existing object-oriented programming methods to cover a broader range of interactive techniques. A solution was found to the problem of developing, selecting and combining classes as reusable components. The object-oriented software development life-cycle was mastered in the development of these classes, which were finally packaged in a set of original class libraries.

A main outcome of our approach was to deliver one of the first frameworks, which integrates *3D* graphics and windowing behavior based on the software components implemented in *C++* only. This framework ensures maximal portability to different hardware platforms and establishes the basis for reusable software in industrial applications, such as an integrated *Computational Fluid Dynamics* (*CFD)* environment (pre-post processing and the solver). The important outcome of this work is an integrated set of VS tools -- the *Computational Field Visualization System (CFView*) -- available for investigators in field physics in general, and specifically for *CFD* researchers and engineers. Several *CFD* examples are presented and discussed to illustrate the new development techniques for scientific visualization tools.