Interactive Visual Analysis in Engineering: From an Early Prototype to Commercially Available Applications

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Abstract

We report the results of a long standing ongoing research collaboration with AVL company to develop new exploration and analysis techniques for parameter space exploration and analysis of multiple simulation runs. The results of our collaboration are published in several research papers and are incorporated in AVL's suite of comprehensive simulation software tools for automotive industry.

1 Introduction

Modern engineering design, such as car design, depends on simulation. The conventional approach is to define a simulation model, run the simulation, and analyze results. Depending on analysis results additional simulation runs (with different sets of parameters or modified models) might be needed. Advancements in computing and storage technology reduce the simulation time significantly and allow a relatively novel concept of multiple simulation runs. The main idea is to run multiple simulation runs (hundreds, thousands, or even tens of thousands) using a same model with different set of control parameter values. However, novel exploration and analysis methods are needed. Together with domain experts from AVL, we have recognized new possibilities of multiple simulation runs concept and the need for advanced analysis methods. AVL is the world's largest independent company for the development of powertrain systems with internal combustion engines as well as instrumentation and test systems, and related simulation tools.

We have proposed to use interactive visual analysis and coordinated multiple views as powerful methods to cope with complex data and analysis tasks. We, an interdisciplinary team of engineering, simulation, and visualization experts, started with a first prototype development, improved the prototype and analysis methodology, and, eventually, it became a standard part of AVL's software suite. This proves that interactive visual analysis was a right choice.

We describe the development of methodology and different case studies done in recent years which led to a commercially available tool. The development started with a simple data model and injection system analysis and then extended the data model to cope with complex data (families of curves and surfaces). We have analyzed common rail and direct injection systems [2, 7], elastohydrodynamic (EHD) lubrication bearing [6], chain drives [1], and hybrid vehicles [3]. We also supported the interactive visual steering [5], including an automatic optimization method [4].

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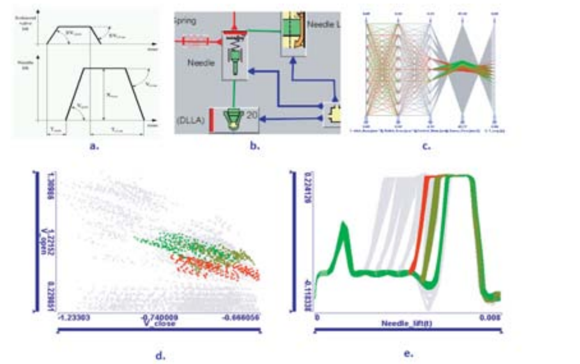

Figure 1: Aggregation of a state variable and various snapshot from interactive visual analysis of Diesel injection systems.

2 The Development Story

The first step in simulation is a simulation model creation. The simulation model consists of various elements and each element has some control parameters and computes different state variables. We vary the control parameters and compute state variables for each simulation run. The control parameters are (in our case) scalars, and state variables computed can be scalars of functions of time. As conventional table data as used in visualization, as well as the most of automatic optimization methods, support only scalar items, different aggregates are computed for each time dependent state variable.

Figure 1a shows one state variable and aggregates computed in order to analyze results. Once all runs are computed the analysis can start. In our case [7] we varied six control parameters and computed 19,440 simulation runs to get six response parameters. We used a coordinated multiple views system in order to analyze results and identify three basic exploration patterns: *Finding Invalid Combinations of Control Parameters*, *Finding Control Parameter Combinations Providing Desired Results*, and *Exploring Tendencies*. Linking and brushing and basic Information Visualization views were used. Figure 1b-c shows a part of the simulation model and view from analysis.

2.1 Families of Curves and Families of Surfaces

Simulation generates different curves which we aggregate prior to analysis. We soon realized that curve shapes play an important role. The domain experts simply did not have tools and methodology to cope directly with complex simulation data. We have proposed a new data model where we allow function graphs or curves to be basic items. For each simulation run we have a record which consists of a set of scalar control variables, set of scalar state or result variables, and a set of function graphs. We call function graphs belonging to a single dimension across all runs *a family of function graphs*. In order to analyze such complex data we introduced a curve view

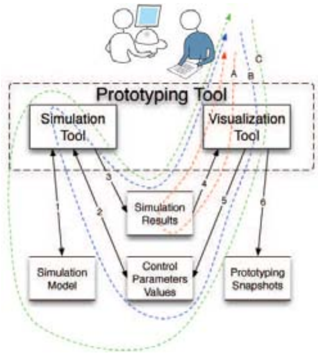

Figure 2: Simulation steering workflow process loops.

to the coordinated multiple views system. The curve view depicts all curves at once using a density mapping. We also introduced a line brush to select curves in the curve view. The newly identified analysis patterns [2] include: *Black Box Reconstruction*, *Analysis of Families of Function Graphs*, *Multidimensional Relations*, and *Hypothesis Generations via Visual Analysis*. For the first time we were able to focus on curve shapes in the analysis without scaler aggregates. It improved significantly the whole workflow. We used the newly proposed technique to explore and tune a Diesel common rail injector based on 4,375 simulation runs (Figure 1d,e).

We used the same data model with a new segmented curve view to analyze chain drives with focus on invalid parameters combinations, parameter sensitivity evaluation, and interactive optimization [1]. A very positive feedback and successful case studies motivated us to continue out research. We have extended the data model even further, to include surfaces or functions of two variables as basic items. As we can not show all surfaces at once, we proposed a three levels approach in analysis. We use projections, and, besides surfaces, we use curves (reduction by one dimension), and scalars (reduction by two dimensions), derived from original surface data. We have successfully analyzed 225 simulation runs containing seven families of data surfaces, three independent parameters, and numerous scalar and curve outputs [6].

2.2 Simulation Steering — Closing the Loop

If number of simulation parameters is large, we sparsely sample the parameter space and then run additional simulations on demand. We need to integrate the simulation and interactive visual analysis tools. The new simulation runs are requested interactively. This opens new possibilities for exploration of complex systems. We call the newly proposed methodology interactive visual steering [5]. A user can request additional runs or can vary additional control parameters. The number of rows in data table is increased in the first case, and the number of columns in the second. Figure 2 illustrates identified process loops. The user smoothly changes between the loops during the analysis. Finally, for very complex systems we have coupled interactive visual steering with an automatic optimization based regression models [4].

2.3 AVL Software Suite

AVL provides a suite of comprehensive simulation software tools for automotive industry. Several new tools have been developed recently (inspired by our research) and added to the AVL's suite. The creation of multiple simulation runs was a tedious, manual task. The AVL Design Explorer, a powerful tool for the coordination and creation of designs of experiments and for automatic optimization is a standard part of the AVL suite. Impress xD, AVL's coordinated multiple views exploration tool relies heavily on the principles described here. The forthcoming Cruise M uses novel energy flow diagrams in the simulation model and an advanced 3D view combined with conventional Information Visualization views [3]. All these tools, resulted from a long term cooperation between VRVis Research Center and AVL, are used by many car manufacturers.

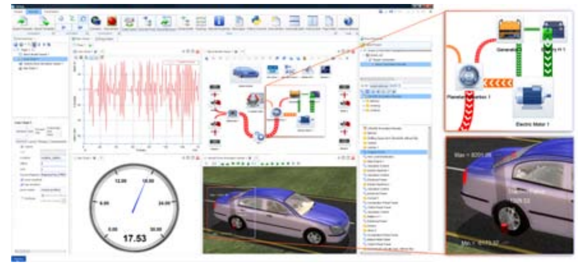

Figure 3: A screenshot from forthcomming AVL Cruise M, showing a snpashot from a hybrid-vehicle analysis.

3 Conclusion

Interactive Visual Analysis is crucial for analysis of complex, multiple runs, simulation data. We have developed (with a full support from AVL company) exploration and analysis techniques for parameter space exploration and analysis of multiple simulation runs. We have learned how important it is to have interested and supporting domain experts. Without AVL support and vision this research would not be possible. The joint efforts over several years (our first joint publication was over eight years ago) resulted in a novel, commercial software tools for expert users in automotive industry. Our ongoing collaboration focuses on improving optimization integration and using hierarchical simulation models.

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