The MEDEA Experiment
Can You Accelerate Simulation-based Learning by Combining Information Visualization and Interaction Design Principles?

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Abstract: The intent of the multipurpose display engineering analysis (MEDEA) experiment was to apply the principles of computer-mediated learning and "play" in the context of high-performance computing (HPC) modeling analysis. Our approach involved the development of software workflow based on interaction design principles using a team of graphic artists, experts in graphics- and touch-based displays, computer programmers, and scientists. The desired outcome was to develop software to overcome perceived HPC modeling usage and learning barriers common to scientific modeling and visualization. Using multiple interaction types, a variety of user workflow experiences were captured (novice/learner, analyst, expert) resulting in a more intuitive and enjoyable experience with a workflow which fosters accelerated learning.

1 INTRODUCTION

High-performance computing (HPC) simulation codes have been developed to study both simple and complex physical phenomena such as gravity, motions of springs, electricity and magnetism, weather, and fluid motion. Due to their pedigree these codes invoke an antiquated workflow paradigm to setup and execute a simulation. A simulation "input deck" is the ASCII maturation of a "card deck" once used to program computers (Jones, 2014). An input deck can contain hundreds of lines of specialized syntax (sometimes cryptic) which a software input parser then interprets to select the appropriate physics, define the computational domain, establish boundary and initial conditions, initialize materials and their geometry, and specify variable definitions and output frequency. The input deck driven simulation workflow can be summaryzed as both functional and miserable from an interaction design point of view.

Interaction design entails "designing interactive products to support the way people communicate and interact in their everyday and working lives" (Preece, Sharp, and Rogers, 2015). In the most successful cases, interactive software is designed with the user experience in mind (resulting in

engagement and enjoyment). Learnability is a key element of interaction design as users commonly dislike spending a lot of time learning how to use the software.

The typical HPC simulation code workflow involves the disjointed steps of editing an input deck, exiting, executing the code (via command line), and then using an external software package for results visualization. Novice users experience multiple barriers to using HPC codes. These barriers include access to machines with the required operating systems to run the codes (e.g. Linux), lack of familiarity with editing software on those platforms, command line syntax, as well lack of familiarity with sophisticated visualization software (e.g. Paraview, Visit, GiD).

Contrast the novice HPC code user experience with a user installing and running an application on their smartphone. The level of sophistication of the smartphone application is not comparable to a HPC code, however there is a precedent for ease-of-installation, ease-of-use (or learnability) and complete functionality contained within the application. Smartphone applications are not designed to stovepipe workflow such that the user has to enter information in one application, then exit, and then enter another application to run or post-

process. In fact, the smartphone application drive for quality visualization, interaction, speed, and availability has been established by feedback from the two-thirds of the American population (Smith, 2015) who own smartphones and a median value of 54% of smartphone users (billions) in emerging or developing countries (Poushter, 2015).

It is clear that new application interaction and design practices which are commonly accepted in social and recreational smartphone application activities are a paradigm beyond traditional approaches (Ito, 2009) for HPC modeling. These new interaction design practices impact what forms of learning younger generations value and potentially point the way for new workflow practices to be adopted. Adoption of these new practices can improve the quality of the workflow for more mature generations and creates workflow which is already natural to the younger developing generations.

The intent of the MEDEA experiment was to establish a seamless workflow between the user and the HPC code. To the extent possible the input deck paradigm should be transparent to the user, requiring only key values of parametric input and a "run button". Post-processing of results should be provided as part of the workflow with elements that are aesthetically pleasing. Part of the MEDEA experiment also involved the creation of the team with the right expertise to make interaction design and visualization choices to improve the HPC code user workflow.
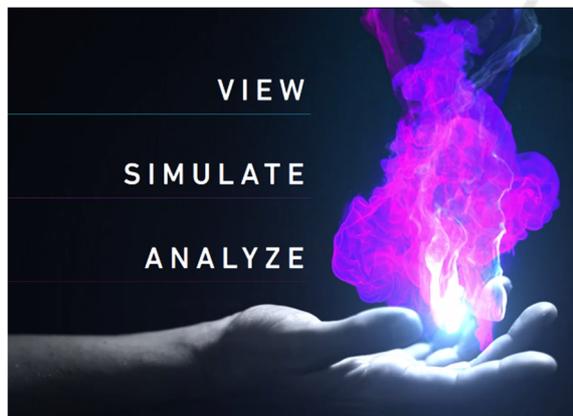

Figure 1: MEDEA introductory view. Placing the power in the hands of the user is the metaphor being invoked. The user selects from the three options listed.

2 MEDEA DESIGN OBJECTIVES

Prior to the coding of MEDEA, design objectives were identified which shaped the development of the application. There was a strong desire to place the final tool in the hands of the user in such a way that the disenfranchised (Ito, 2015) who saw nothing but barriers to HPC code simulation would become excited and want to explore physical phenomena using simulation. The user experience had to bypass both issues with operating system availability (run on Microsoft Windows) and the hundreds of lines in the input deck. Simulation execution should entail simple and clean parameter input and one-touch simulation execution.

Advancing the ease-of-use (learnability) of the application was important. Previous efforts to teach HPC code users have involved days of training. Training using simplified input decks with variables defined within the top 25 lines could take 20 minutes to teach someone how to run the code. The objective of MEDEA was to determine if the time to learn how to load a simulation model and enter the required input could be reduced to minutes, or even tens of seconds.

Another important element to MEDEA was that the interface and results should look "cool". Spectacle and fun are commonly used in children's software to demonstrate style and status, they are part of the economy of "cool" (Ito, 2009). Children's software typically employs "fun" in order to maintain focus for a sufficient amount of time in order to solve problems (exploration). Enthusiasm associated with fun involves sharing and demonstrating with others. These are inherent responses we wished to evoke with scientific simulation visualization. The child may say a view looks "cool". To the more mature individual it is "cool" not only because of aesthetics but because it provides visualizations that can be used to explain physical phenomena and why you obtained a certain level of system performance. An experience is also "cool" when one can easily learn from it which is also pleasing. Learning with increased ease is "fun".

View establishment and simplicity was also a desired objective. For a given simulation type there might exist a commonly accepted view of the results. This type of analysis should be able to generated easily and should be a natural result from the simulation. In the case of a new analysis which might have been published or presented in another forum, that view should be easily appended to the views already generated. In either case, the views should not be cluttered and the user should be allowed to interact with the resulting analysis in order to query points, make comparisons, or simultaneously view multiple variables and how they relate to one another.

3 INTERACTION DESIGN PRINCIPLES

The workflow for MEDEA was selected in order to foster user activities in the areas of instruction, manipulation, and exploration (Preece, Sharp, & Rogers, 2015). The introductory screen for MEDEA (see Figure 1) allows the user to select from three options. These options allow the user to 1) experience views of information vital to simulations, 2) select and run a simulation, or 3) analyze results from a simulation through pre-defined visualizations.
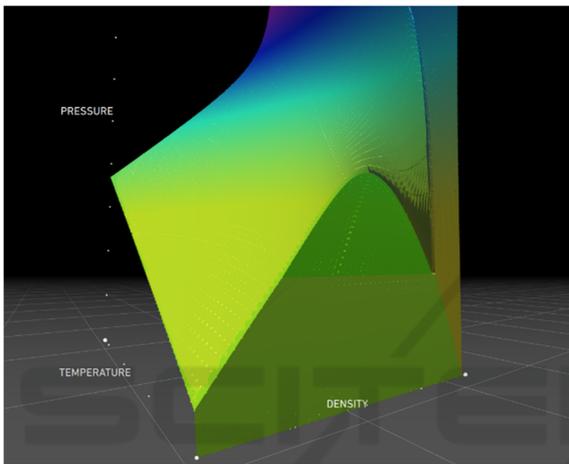

Figure 2: MEDEA view option image. The equation of state surface which relates pressure to density and temperature is shown. Distinct boundary lines represent material phase changes incorporated into the material model. The user can interact with the 3D surface in terms of orientation as well as querying points on the surface using the mouse or touch-screen device.

3.1 View Option

High-performance computing models of physical phenomena require representations of material properties (equations of state or constitutive relationships) as a means of specifying physically-meaningful responses from materials (e.g. density, phase changes, temperature, pressure). The resulting quality of a numerical simulation (which can distort material both geometrically and through multiple phase changes) is directly related to the accuracy of the physics description (discretized mathematically) as well as the accuracy of the material model representation. The accessibility of material models to the user community is typically limited to a list of available material models with terse descriptions of tabulated numerical bounds. This method of operating leaves the user in "in the dark" with respect to the actual details and assembly of the material model.

MEDEA's view option allows the user to directly access and visualize a material model. The simple act of viewing the material model itself with ease is a major leap forward for the HPC community. The experience is expanded by allowing the user to interact with and explore the material model using either mouse- or touch-based manipulation. Details of the tabulated numerical values can be easily accessed by selecting points on the three-dimensional surface (see Figure 2).

Examination of the material model surface shows areas with both smooth and discontinuous transitions. For this particular example these transitions are a result of phase changes of the material. This view immediately fosters a learning experience including which phase transitions have been captured, their location, and potential regions where the table is valid (extrapolation off of the table is often allowed but not necessarily physically meaningful). The view section was also planned to be used to present two-dimensional performance data generated by an individual or a community which can be used for informational purposes, or to be used in comparison with numerical results.
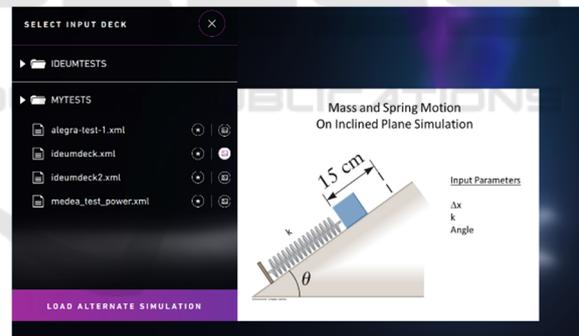

Figure 3: View of MEDEA's simulate options. Each XML file has a corresponding PNG file which provides a summary of the purpose of the simulation.

3.2 Simulate Option

For some user communities, the simple steps required to access, read, and edit a HPC code input deck are so unfamiliar that they form a barrier to utilization. Attempts to modify already existing input decks so that the user only has to vary parameter values at the top few lines of the input deck have equally failed to overcome the distasteful workflow of editing, exiting, and then invoking other commands (typically on a Linux command

line) to run the code. It was concluded that a simple set of interactive parameters with no view of the input deck was desired to overcome the perceived barrier.

The simulate option begins by providing a user with a list of available simulation types to run. Each option represents an input deck which a super-user has created for the larger community. In conjunction with the HPC code input deck is a MEDEA XML file which specifies which variables require input values (as well as their default values) and the correct execution command for the HPC code. Users can identify which simulation template they desire to run via PNG file images with graphical and text information detailing the purpose of the simulation (see Figure 3). Once a template is selected variable groupings are displayed (with default values inserted) which can then be altered using the keyboard or a touchscreen editor (see Figure 4). Execution of the template is accomplished by the user selecting the "simulate" bar.
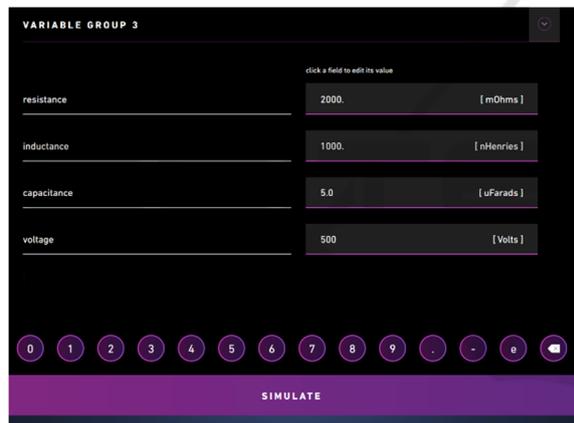

Figure 4: Example of MEDEA's simulation input option. The variables and units for this view are established via keywords in the XML file. A single or multiple pages of variable grouping can be established. Once completed the user selects the "simulate" bar to execute the simulation.

3.3 Analyze Option

Visualization of simulation output can occur immediately after a simulation has been initiated by the user, or if a user selects a previously completed simulation. The visualization is created via output commands listed in the same MEDEA XML file which contained information as to which variables should be input and sent to the HPC simulation. Prescribed visualizations were chosen to be displayed immediately after the simulation is executed. MEDEA currently supports 2D & 3D plotting of X-Y and surface data.

Visualization is an inherent part of the MEDEA workflow. A novice can begin to study the results of a simulation as well as obtain views which have been generated by a super-user (an individual with greater experience associated with the simulation). The prescribed views highlight variables of interest as well as causal relationships between the variables thus providing a learning experience via visualization. Experimental results can also be read into the visualization in order to perform validation comparisons (see Figure 5).
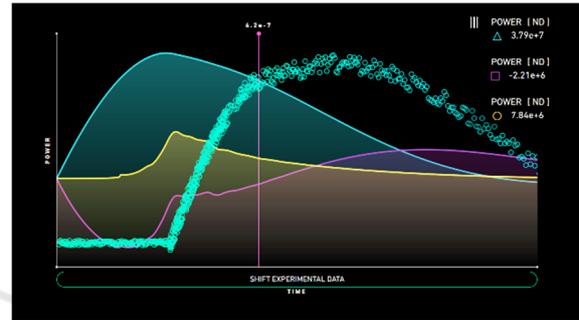

Figure 5: Visualization of a simulation as prescribed by output commands in the MEDEA XML file. Experimental data (circles) has been added to the image and can be shifted horizontally in time using the mouse or touch-screen.

Using the flexibility in the XML file, more advanced users can then create new visualizations based on the simulation output. Once created, these new images can be appended to the previous view descriptions stored in the XML file. Users have access to both multiple plots per view as well as multiple views per analysis. Views can be accessed by clicking or touching the arrows at the bottom of the screen.

Highly sophisticated views allowing the user to perform detailed analysis of the simulation simultaneously with the material view are also possible (see Figure 6). On the left of the image is the material phase view surface. Added to the phase view is the trajectory of the simulation along the surface (white dotted line). The nearly vertical red line indicates the corresponding time between the surface view and the X-Y plots on the right-hand side. The right-hand side contains a summary view of more detailed views which can be accessed using the horizontal arrows. Each view can be time-correlated with the surface image by touching any of the summary plots, thereby moving the time-slider (vertical bar). The size of the right-hand image can also be expanded by grabbing the right-hand view and dragging to the left. With simultaneous views of
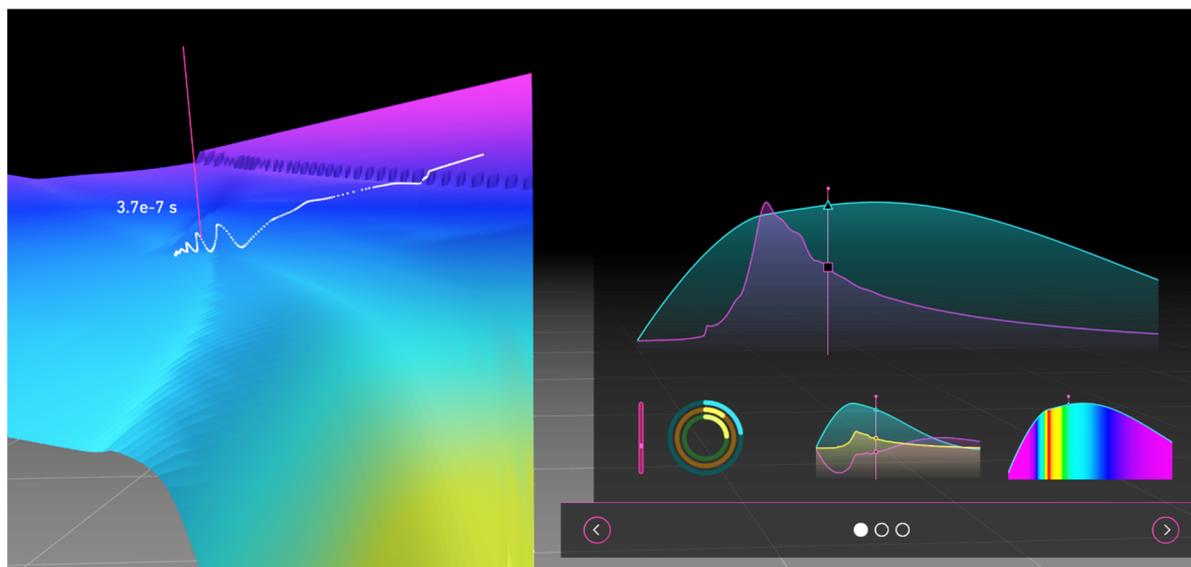
Figure 6: Example of highly sophisticated MEDEA analysis comparing the material model (left) with the simulation trajectory (white line) with multiple time-based performance summaries (right).

material properties, trajectory on the material model surface, and correlation to time using other output seen in the right-hand window, the user can begin to identify how material property variations impact the global quantities of the simulation. This type of detailed analysis is readily available to the user and can be setup by the super-user in the XML file with relative ease.

4 PORTABILITY & INTERACTIVITY

MEDEA is an interface to HPC codes which should provide the already existing simulation community the opportunity to more effectively run simulations and analyze their output. From a computing platform standpoint this can occur using a Windows desktop or even laptop computer. However, MEDEA was also designed with increased portability in mind so that it could also be deployed on a tablet device such as the Microsoft Surface Pro.

Two portability scenarios were envisioned when creating MEDEA. First, for a laboratory technologist or experimentalist to run a simulation of their experiment immediately prior to execution in order to prepare for waveform magnitude and timing. Second, the ability for a user to run a simulation during a conference or meeting setting in order to immediately assess performance based an assertion made by the presenter.

This type of portability for HPC codes and the ability to have accelerated cycles of learning is viewed as a future path forward for high-performance computational simulation. MEDEA attempts to encapsulate both the best-practices setup for simulations as well as corresponding visualizations. This paradigm helps the novice user obtain solution quickly and serves as a repository for institutional knowledge on performance evaluation and analysis. MEDEA was designed to assist both the computational community as well as members of the experimental community who want to perform a quick analysis with minimal additional overhead.

5 CONCLUSIONS

The intent of the MEDEA experiment was to radically change the workflow for a HPC code user. Interaction design principles were incorporated with information visualization techniques in order to establish a seamless workflow akin to experiences found with smartphone applications. For HPC codes which are input deck driven, the MEDEA interface can be used to run those applications with little additional overhead. MEDEA's use of an XML file to handle input and output from the HPC code provide a simple interface which generates a seamless workflow for the user. This seamless and aesthetically pleasing workflow is a result of multidisciplinary collaboration between artists, programmers, and scientists. Novice users can now

be introduced to HPC code simulations using the MEDEA interface and can learn in 10's of seconds what would previously have taken hours to learn. Since visualization is integral to the MEDEA workflow the user's time-to-result has been reduced to minutes, thereby allowing the user to sample more input conditions and thereby obtain accelerated learning on parametric sensitivity.

ACKNOWLEDGEMENTS

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