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A Multitier System for the Verification, Visualization and Management of CHIMERA

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Abstract

CHIMERA is a multi-dimensional radiation hydrodynamics code designed to study core-collapse supernovae. The code is made up of three essentially independent parts: a hydrodynamics module, a nuclear burning module, and a neutrino transport solver combined within an operator-split approach. Given CHIMERA's complexity and pace of ongoing development, a new support system, Bellerophon, has been designed and implemented to perform automated verification, visualization and management tasks while integrating with other workflow systems utilized by CHIMERA's development group. In order to achieve these goals, a multitier approach has been adopted. By integrating supercomputing platforms, visualization clusters, a dedicated web server and a client-side desktop application, this system attempts to provide an encapsulated, end-to-end solution to these needs.

Keywords: supernovae; visualization; regression test; code verification; multitier system

1. Introduction

Core-collapse supernovae are nature's mechanism for producing the elements heavier than oxygen, which make up our bodies and the world around us. By designing and implementing multi-dimensional, multi-physics codes, like CHIMERA [1], scientists can leverage the power of supercomputing platforms to explore this phenomenon. Similar to the three-headed beast in mythology, CHIMERA consists of three, separate, rather mature codes: a hydrodynamics module, a nuclear burning module, and a neutrino transport solver, which are combined within an operator-split approach. In order to maintain CHIMERA's pace of development, we are creating a system, Bellerophon, to assist in the verification, visualization and management of the code. ^a

^a In legend, Bellerophon, riding upon the flying horse, Pegasus, slayed the Chimera by using a spear tipped with a block of lead. When the hero launched his spear into the throat of the fire-breathing beast, the lead mass melted and suffocated it. We have a quite different aim in mind using our Bellerophon.

The initial goal of Bellerophon is to provide CHIMERA's development team with a system that addresses verification, visualization, and management needs from one central, online portal. Bellerophon's multitier architecture provides a robust stage for developing solutions to these needs by combining the power of supercomputing platforms and visualization clusters with a dedicated web server and a sophisticated client-side desktop application. Since its developers are also its users, Bellerophon is being designed specifically for the CHIMERA code. This near-complete overlap of user base and developer team has been the primary design consideration for Bellerophon to this point. The aim has been to provide a "one-stop shop" for both code development and scientific workflow management. Once an initial suite of software tools has been developed, Bellerophon will be generalized for other codes and platforms. The next step in this generalization is to apply the Bellerophon system to GenASiS [2,3], a computational astrophysics code under development at ORNL. Following the successful adaptation of Bellerophon to GenASiS, the system will be developed further to suit the needs of a broad array of scientific applications.

In the CHIMERA use case, the system accomplishes verification by performing automated regression testing of both the 2D and 3D versions of the code on supercomputing platforms and making the results of these tests accessible via the Regression Test Explorer software tool. Results of the regression tests not only indicate problems with the code, but also possible issues with the testing platforms. Bellerophon's visualization utility is comprised of two subcomponents, chimera2silo and spearhead. Currently under development is a completely automated system, which will use these subcomponents and others to generate visualization concurrent with running CHIMERA simulations. Bellerophon also integrates with other workflow systems already utilized by the group. These workflow systems include a Subversion code repository [5] and a Trac project management system [6]. Lastly, the system assists the CHIMERA team with management tasks by providing access to code repository statistics, supercomputing platform status and direct links to other external workflow features.

Other systems have been created to address some of these code development issues. Bell and others have implemented an automated regression test suite for CASTRO [7, 8], another multiphysics code used for stellar astrophysics simulations. In that work, a regression test system, written using the Python language, executes a series of verification test problems and compares the results to current benchmarks. A web page detailing regression test results by date is also generated. Hudson, et al. [9] have also recently presented their architecture for a simulation management and analysis (SMA) system for data produced by the FLASH code [10]. The FLASH SMA is mainly concerned with data management and analysis, as opposed to the FlashTest regression test system that has been previously released. For general-purpose workflow construction, Kepler [11], is a free and open source framework for generating and executing customized scientific workflows across different platforms and protocols. Kepler's Java-based graphical user interface enables users to create, modify, manage and visualize sophisticated workflows and their data products quickly from prebuilt and user-defined components. The Electronic Simulation Monitoring dashboard (eSiMon) [12] is a web-based system enabling researchers at the Oak Ridge Leadership Computing Facility (OLCF) to monitor simulation runs and analyze, archive and share the results with collaborators. The graphical user interface for eSiMon is a cross-platform Flash application, which interfaces to backend services through code implemented in PHP.

2. Architecture

As previously stated, Bellerophon is a multitier software system comprised of supercomputing platforms, visualization clusters, a central web server and a client-side desktop application. These components not only provide the data, logic and presentation tiers commonly employed in n-tier system architectures, but also a new tier called the *scientific computing tier*. A schematic representation of these components and tiers is seen in Figure 1. Bellerophon's scientific computing tier utilizes resources available at Oak Ridge National Laboratory's National Center for Computational Sciences (ORNL NCCS) and the National Institute for Computational Sciences (NICS) at the University of Tennessee. The supercomputing platforms at the NCCS and NICS, Jaguar XT4/5 and Kraken, are used to execute automated regression testing of CHIMERA. The results of these tests are archived using High Performance Storage Systems (HPSS). Both the NCCS and NICS provide an HPSS for users. Bellerophon's

visualization needs are currently satisfied in part by the Lens data analysis and visualization cluster at the NCCS. Future development of these capabilities will incorporate Nautilus, a new resource provided by the NICS Remote Data Analysis and Visualization Center (RDAV).

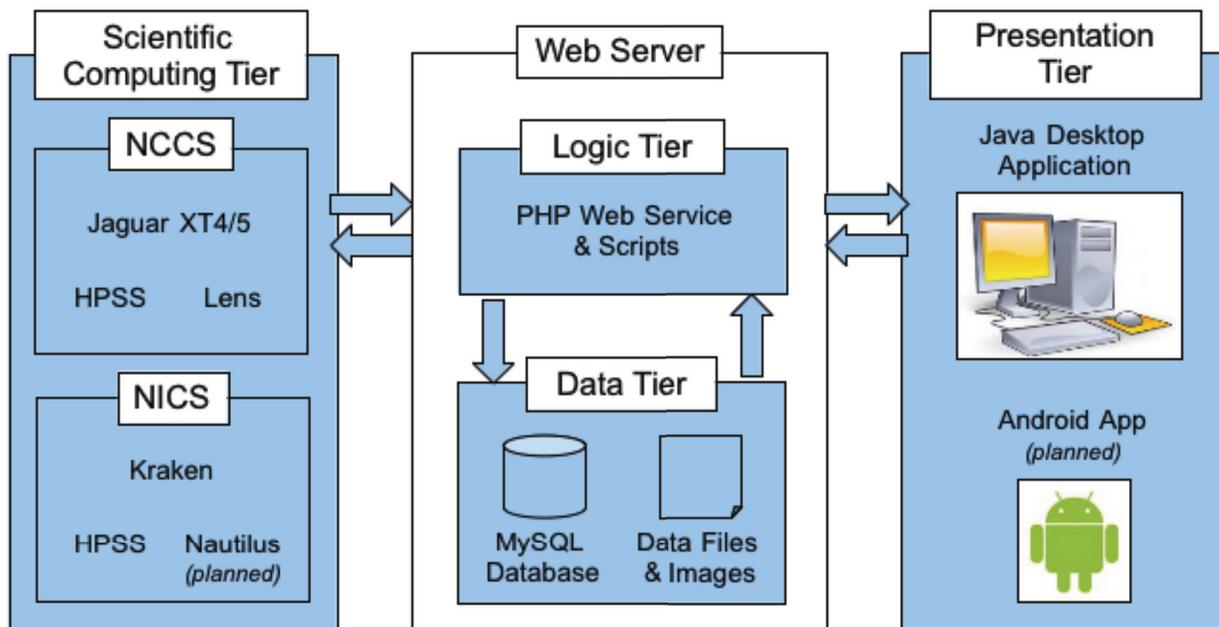


Figure 1. A schematic representation of Bellerophon's multitier architecture.

Besides using HPSS for data archiving and long term storage, the primary components to Bellerophon's data tier consist of a MySQL database and a hierarchal system of indexed directories on a dedicated web server. The database consists of indexed records of metadata pointing to regression test datasets and visualization sets stored in the hierarchal directory system. The database also stores user account information and active sessions, as well as logs of past sessions, client/server exchanges, server errors, and client-side exceptions.

The logic tier consists of a web service and other scripts, written in PHP, to consume data transmitted from the scientific computing tier. When regression test datasets or visualization sets are transmitted to a temporary storage area on the web server, scripts running as cron jobs archive the raw data sets and consume the data sets by creating database records using the set's metadata profile. It then moves the processed data into the indexed storage area. The main purpose of the logic tier is to provide a web service allowing secure access to the data tier by the presentation tier. The logic tier also provides mechanisms for sending automated emails to the development team in the event of a regression test failures, server errors or client-side exceptions.

The presentation tier of Bellerophon's architecture consists of a web-deliverable, cross-platform Java desktop application. This digitally signed application uses Java WebStart technology [13], which enables installation and execution by simply clicking a hyperlink in a web page. If enabled, the user can also choose to install a shortcut to the application in the Applications folder for Mac OS users or the Start menu for Windows users. If not, the user may continue to load the application from the hosting web page. There are several advantages to this approach. Whether the user launches the application from a hyperlink or from the desktop, Java WebStart will automatically check for Bellerophon updates on startup. The *dashboard* design of the application employs the WYSIWYG approach to graphical user interface development, which simplifies the experience for the user. The client application communicates with the logic tier's web service by making asynchronous calls via *multipart/form-data* web transmissions over the network.

3. Verification

Verification of CHIMERA is performed by an automated regression test system, which spans all components of Bellerophon’s architecture beginning with the scientific computing tier. A series of PBS scripts test the 2D and 3D versions of CHIMERA’s code on the Jaguar XT4/XT5 and Kraken platforms daily, archives the results in the associated HPSS and copies the results along with the necessary metadata to the data tier. Automation of this process is achieved by using scripts that resubmit themselves to the job submission queue on a daily basis. The regression test system checks out the head revision of each code from CHIMERA’s repository, configures several input files using a small Java program, and attempts compilation and execution. The results of a test, the associated metadata file and the job’s standard output and error file are compressed and transferred to the web server. The compressed regression test archive is also moved to HPSS for long-term storage.

On the web server, a regression test processing script checks for new data every hour. When new data is detected, the script consumes the regression test data by creating a database record and moving the data to an associated directory. If a compilation or execution error is detected, an email is sent to all developers who have contributed to the code since the last successful revision. An email is also sent if a particular test is the first successful test after a series of failures. In the event of an execution failure, Bellerophon attempts to create a stack trace of the issue using the *addr2line* Linux utility. The email is populated with a stack trace constructed of hyperlinks, which point directly to the file, line number and revision of the code in CHIMERA’s Trac code repository browser, and sent to developers who have modified the code since the last successful revision.

The screenshot shows the 'Regression Test Explorer' interface. At the top, there are navigation buttons: 'Regression Test Explorer', 'Visualization Set Explorer', 'Visualization Set Editor', 'SVN Statistics On-Demand', 'Important Links and Information', and 'Log Out and Exit Bellerophon'. The main area is titled 'Regression Tests' and contains a table with the following columns: Index, Revision, Job ID, Code Type, Date, Owner, Platform, and Result. The table lists various test runs with their respective details. To the right of the table is a 'Search Filter' panel with dropdown menus for Index (1558), Revision (568), Job ID (1041598), Code Type (Chimera 3D), Date (03/03/11), Owner (Bellerophon), Platform (Jaguar XT5), and Result (Execution Success). Below the search filter are buttons for 'Search Filter OFF', 'Refresh Test Table', and 'Explore Test Data'.

Index	Revision	Job ID	Code Type	Date	Owner	Platform	Result
1559	576	1041878	Chimera 3D	03/01/11	Bellerophon	Jaguar XT4	Execution Success
1558	576	1041878	Chimera 3D	03/01/11	Bellerophon	Jaguar XT4	Execution Success
1557	571	1041598	Chimera 3D	02/28/11	Bellerophon	Jaguar XT4	Execution Success
1556	571	1041598	Chimera 3D	02/28/11	Bellerophon	Jaguar XT4	Execution Success
1550	570	1041283	Chimera 3D	02/27/11	Bellerophon	Jaguar XT4	Execution Success
1549	570	1041283	Chimera 3D	02/27/11	Bellerophon	Jaguar XT4	Execution Success
1544	570	1040896	Chimera 3D	02/26/11	Bellerophon	Jaguar XT4	Execution Success
1543	570	1040896	Chimera 3D	02/26/11	Bellerophon	Jaguar XT4	Execution Success
1536	568	1040331	Chimera 3D	02/25/11	Bellerophon	Jaguar XT4	Execution Success
1535	568	1040331	Chimera 3D	02/25/11	Bellerophon	Jaguar XT4	Execution Success
1532	567	1039821	Chimera 3D	02/24/11	Bellerophon	Jaguar XT4	Execution Success
1530	565	1039432	Chimera 3D	02/23/11	Bellerophon	Jaguar XT4	Execution Success
1526	564	1039193	Chimera 3D	02/22/11	Bellerophon	Jaguar XT4	Execution Success
1523	559	1038377	Chimera 3D	02/21/11	Bellerophon	Jaguar XT4	Execution Success
1522	559	367490	Chimera 3D	02/21/11	Bellerophon	Jaguar XT5	Execution Success
1520	559	1038079	Chimera 3D	02/20/11	Bellerophon	Jaguar XT4	Execution Success
1518	559	367253	Chimera 3D	02/20/11	Bellerophon	Jaguar XT5	Execution Success
1515	555	366652	Chimera 3D	02/19/11	Bellerophon	Jaguar XT5	Execution Failure
1514	555	1037742	Chimera 3D	02/19/11	Bellerophon	Jaguar XT4	Execution Failure
1512	551	1037211	Chimera 3D	02/18/11	Bellerophon	Jaguar XT4	Compilation Failure
1511	551	366428	Chimera 3D	02/18/11	Bellerophon	Jaguar XT5	Compilation Failure
1508	547	1036977	Chimera 3D	02/16/11	Bellerophon	Jaguar XT4	Execution Success
1507	547	365772	Chimera 3D	02/16/11	Bellerophon	Jaguar XT5	Execution Success
1506	547	1026934	Chimera 3D	02/16/11	Bellerophon	Kraken	Execution Failure
1500	545	1036256	Chimera 3D	02/15/11	Bellerophon	Jaguar XT4	Execution Success
1499	545	363921	Chimera 3D	02/15/11	Bellerophon	Jaguar XT5	Execution Success
1497	544	363510	Chimera 3D	02/14/11	Bellerophon	Jaguar XT5	Execution Success
1494	544	1035810	Chimera 3D	02/14/11	Bellerophon	Jaguar XT4	Execution Success
1493	544	1035526	Chimera 3D	02/13/11	Bellerophon	Jaguar XT4	Execution Success
1491	544	362642	Chimera 3D	02/13/11	Bellerophon	Jaguar XT5	Execution Success
1489	537	361965	Chimera 3D	02/11/11	Bellerophon	Jaguar XT5	Execution Success
1488	543	1035261	Chimera 3D	02/12/11	Bellerophon	Jaguar XT4	Execution Success
1487	543	361967	Chimera 3D	02/12/11	Bellerophon	Jaguar XT5	Execution Success
1486	537	1035260	Chimera 3D	02/11/11	Bellerophon	Jaguar XT4	Execution Success
1481	537	1034632	Chimera 3D	02/11/11	Bellerophon	Jaguar XT4	Execution Failure

Figure 2. A screenshot of the Regression Test Explorer’s test selection interface.

The Regression Test Explorer software tool provides users with the ability to select, compare and investigate regression test results. The regression test selection interface of the tool allows users to filter tests by regression test index, code revision, job id, code type (2D or 3D), test date, owner, test platform, and final test result. Users may also sort regression test records by these attributes. After selecting one or more records, the user can explore the results of the selected regression tests. Each regression test has a directory of files available for viewing which include the makefile, input/output files and metadata files. The user can view, copy, save and print any file as well as download the entire regression test directory as a compressed archive. If an execution failure occurred and a stack trace for the failure could be generated, a file called *addr2line* is made available for inspection. Like the previously mentioned email, this file also contains hyperlinks that point directly to the file, line number and revision of the code in CHIMERA’s Trac code repository browser. Another capability allows the user to directly access the selected revision’s changeset and log entry in Chimera’s online Trac system. Figures 2 and 3 show the regression test selection and inspection graphical user interfaces, respectively.

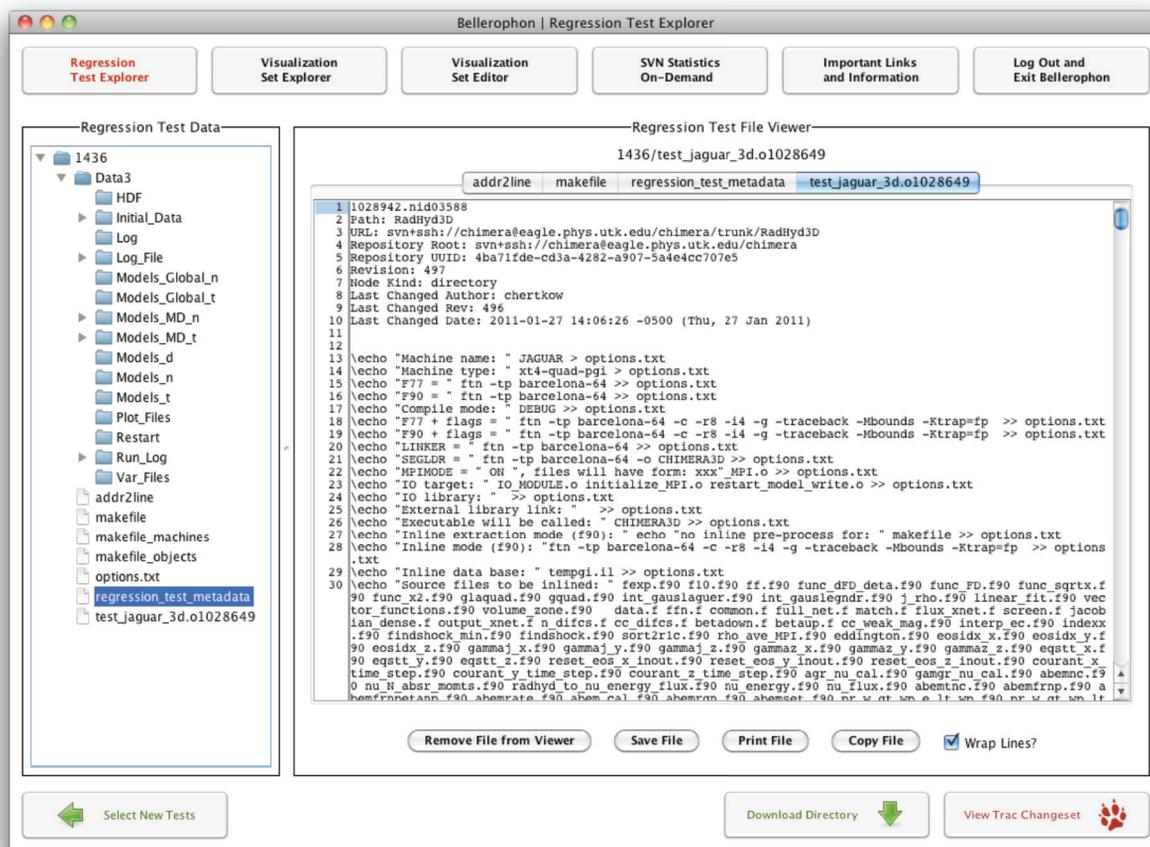


Figure 3. A screenshot of the Regression Test Explorer’s test inspection interface.

4. Visualization

The VisIt Visualization Tool is used to generate series of images for animations of CHIMERA data. The VisIt tool accepts input data to be in one of several acceptable formats. For CHIMERA, the Silo input data format has been selected. Two new tools have been developed to facilitate the visualization process for 2D results. The first

tool, *chimera2silos*, converts 2D binary output data into the Silo format. This tool consists of two components, an executable written in C, which converts data at each frame into a silo file, and a Java program, which parses configuration files and generates a list of arguments required by the converter. Currently, only scalar variables can be converted, but development is underway to generate silo files containing vector and matrix data types. The second tool, *spearhead*, automates the process of generating images from the silo files using the VisIt Python API. The tool is a scripting system, which parses parameters from configuration files, dynamically generates the Python code required to create a series of images and then executes the Python code serially to generate the images.

The *chimera2silos* and *spearhead* components are a central part of an automated visualization system, which is currently under development. We are designing and developing a system whereby a CHIMERA user will be able to generate and view animations of data through the Bellerophon client while the job is being executed on a supercomputing platform such as Jaguar or Kraken. The ability to apply this automated system to archived data sets is also being developed. The system will be introduced in two phases. The first phase will apply to the 2D version of the code and the second to the 3D version.

Our plan for concurrent 2D visualization can be seen in the Figure 4. When a user starts or restarts a CHIMERA 2D simulation, a script called the *silos_generator* will be executed from the simulation's PBS batch script and will monitor the generation of new CHIMERA 2D data. When new data is available, *chimera2silos* is called by *silos_generator* to convert the data into the silo format. The *silos_generator* script will archive the silo files into HPSS and transmit the files and associated metadata to a temporary storage area on the web server. Scripts running in the logic tier will consume the silo files and generate images using the *spearhead* system.

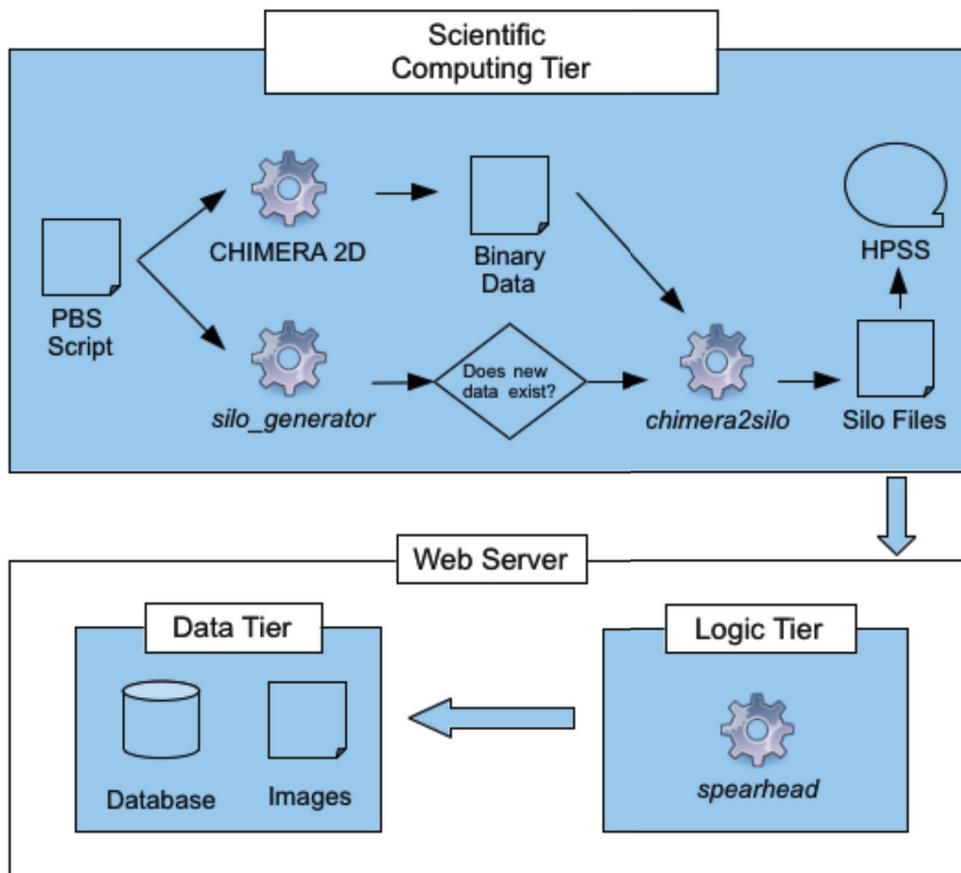


Figure 4. A schematic representation of Bellerophon's automated visualization process, which is under development.

In order to provide Bellerophon with the information required to generate and access animations from simulation results, the user must first use the Visualization Set Editor software tool, which is also under development. The Visualization Set Editor allows the user to create a *visualization set* for a particular simulation and enables the user to save notes, prescribe a unique 60-character simulation identifier and to dictate the variables that will be visualized. Several attributes of each animation are configurable including the animation's range and domain, color table and color table range. Once submitted to Bellerophon's web service, the user receives a unique visualization set index, which is then used as an argument to the `silos_generator` script. The logic tier will use this index to identify silo files or images when they are transmitted to the web server.

Another desktop application tool under develop, the Visualization Set Explorer, enables the user to examine and compare animations from different visualization sets (see Figure 5). Using this tool the user can select multiple visualization sets and filter visualization sets by visualization set index, simulation identifier, creator, creation date, progenitor source and mass, and resolution. After making the selections, the user can use the tool to load and play animations with a custom viewer while accessing visualization set and simulation metadata. The user also has the ability to download the current frame as a PNG and the entire animation as a QuickTime-compatible MP4 movie.

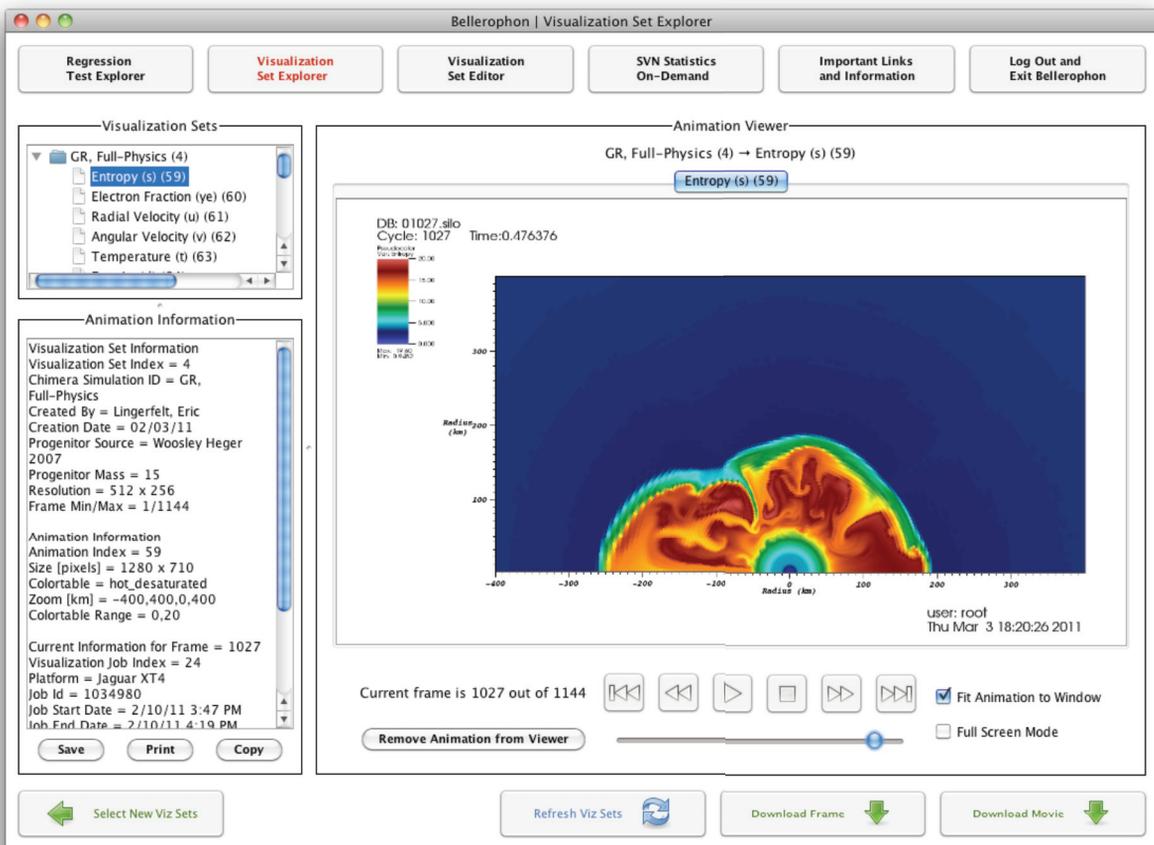


Figure 5. A screenshot of the Visualization Set Explorer's animation viewer interface loaded with an animation of entropy data from a 512 x 256 CHIMERA 2D simulation with a 15 solar mass Woosley-Heger 2007 progenitor [14].

Given the size of CHIMERA 3D results and the computing power required to render 3D images and animations, it is untenable to transfer the data across the network and generate images on a common web server. Therefore, in phase II, we plan on using the NCCS Lens cluster and the new NICS RDAV resource, Nautilus, to access the data in place and render 3D images using VisIt. These images will then be transferred to the Bellerophon web server where they will be consumed by the logic tier and made available to users via the Visualization Set Explorer.

5. Management

Bellerophon addresses management needs through the SVN Statistics On-Demand software tool and the Important Links and Information feature. SVN Statistics On-Demand allows users to execute the StatSVN [15] code repository statistics generator via Bellerophon's web service. StatSVN generates a set of interlinking HTML pages with tables and plots detailing statistical information about a project's code development. With SVN Statistics On-Demand, the user can configure the statistical output by selecting either the CHIMERA 2D or 3D code and a mixed range of revisions and dates. The tool also displays the log entry for a selected revision to assist the user in determining the correct range. The Bellerophon web service generates the content on the server using StatSVN and downloads the content to a selected directory on the user's computer. The Important Links and Information feature as seen in Figure 6 provides direct links to CHIMERA's 2D and 3D Trac repository browser, its public and private wikis and the NCCS and NICS homepages. With this tool, a user can post to the CHIMERA mailing list, browse the mailing list archives and create a new Trac ticket as well as receive real time updates of NCCS and NICS systems status.

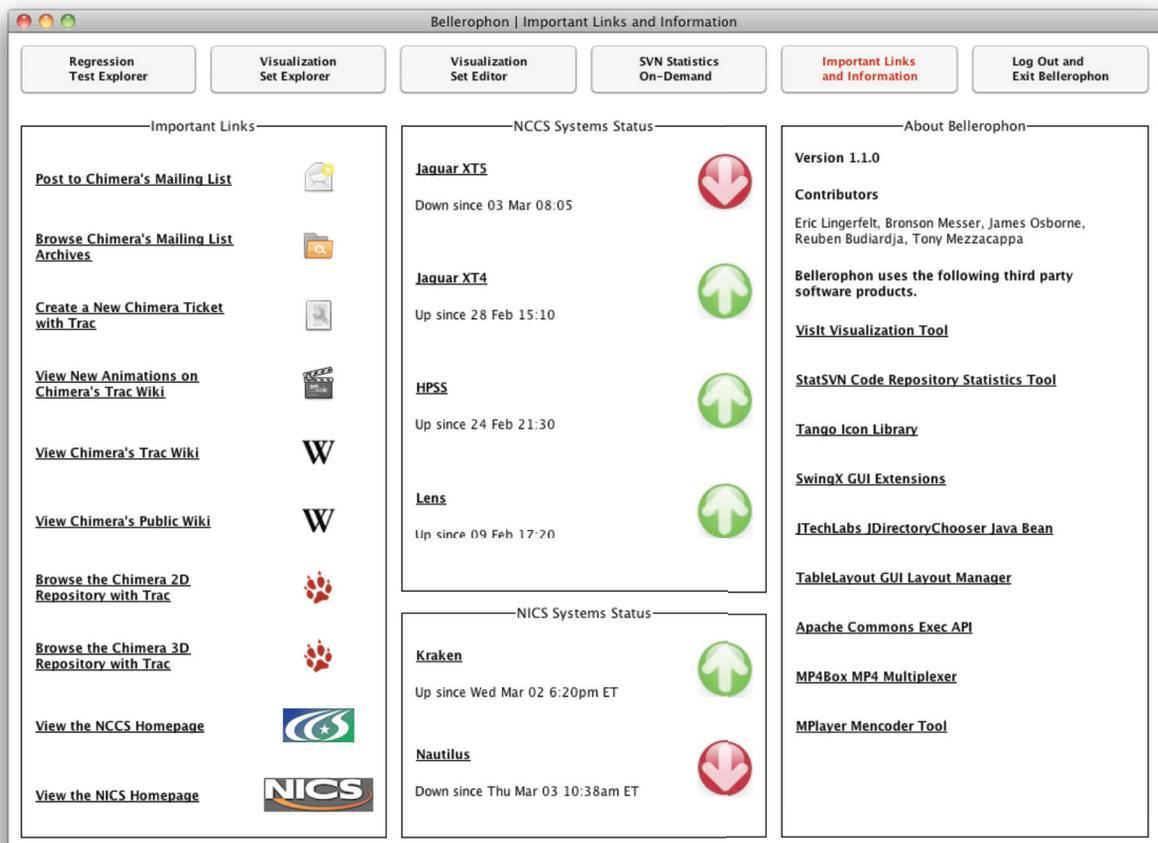


Figure 6. A screenshot of the Important Links and Information feature.

6. Future Developments

Future enhancements include expanding regression test capabilities by introducing an array of verification test problems for both the 2D and 3D codes and comparing results of these new tests to benchmarked solutions. A new tool, Regression Test On-Demand, is also slated for development. This new tool will provide CHIMERA's developers the ability to perform a regression test over a selection of verification test problems and compare the results with previous revisions. Once Bellerophon's automated visualization system is fully implemented for CHIMERA 2D data sets, it will be expanded to include 3D results. We also plan to develop the capability to post animations created with Bellerophon's visualization system directly to CHIMERA's private group wiki using the Visualization Set Explorer. Future developments also include an Android app enabling mobile interaction with the web service.

7. Conclusion

Bellerophon is an integrated solution for the verification, visualization and management needs for the multi-dimensional core-collapse supernova code, CHIMERA. Its multitier architecture combines supercomputing resources, visualization platforms, a dedicated web server and a web-deliverable, cross-platform desktop application. An automated regression test system and tools to facilitate the generation of visualization content have been developed. Bellerophon's desktop application enables users to investigate regression test results, generate code repository statistical information and access important external links and other workflow tools. After this initial development phase, we intend to generalize Bellerophon to other codes and platforms. We believe that this development cycle – the construction of an overall system expressly tailored to the needs of the CHIMERA collaboration, followed by a generalization cycle to other multiphysics HPC codes – has, most importantly, produced a product that meets our current needs to enable leadership-scale computational science with CHIMERA. We also believe that the multitier architecture of Bellerophon affords us considerable advantage regarding future generalization, as relatively coarse-scale modules can easily be traded in and out of Bellerophon based on particular code requirements.

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Excluding the VisIt Visualization Tool and the StatSVN Code Repository Statistics tool, Bellerophon uses the following third-party software products:

Tango Icon Library (http://tango.freedesktop.org/Tango_Icon_Library)

SwingX GUI Extensions (<https://swingx.dev.java.net>)

JTechLabs Directory Chooser Java Bean (<http://www.jtechlabs.com/components/jdirectorychooser>)

TableLayout GUI Layout Manager (<https://tablelayout.dev.java.net>)

Apache Commons Exec API (<http://commons.apache.org/exec>)

FFmpeg (<http://www.ffmpeg.org/>)

X264 (<http://www.videolan.org/developers/x264.html>)

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