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Optika: A GUI Framework for Parametrized Applications (Report style, strict)

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Optika: A GUI Framework for Parametrized Applications (Report style, strict)

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Abstract

In the field of scientific computing there are many specialized programs designed for specific applications in areas like biology, chemistry, and physics. These applications are often very powerful and extraodinarily useful in their respective domains. However, many suffer from a common problem: a poor user interface. Many of these programs are homegrown, and the concern of the designer was not ease of use but rather functionality. The purpose of Optika is to address this problem and provide a simple, viable solution. Using only a list of parameters passed to it, Optika can dynamically generate a GUI. This allows the user to specify parameters values in fashion that is much more intuitive than the traditional ”input decks” used by many parameterized scientific applications. By leverageing the power of Optika, these scientific applications will become more accessible and thus allow their designers to reach a much wider audience while requiring minimal extra development effort.

Acknowledgment

Thanks to Dr. Mike Heroux and Jim Willenbring. Their mentoring has been crucial to the development of Optika. Also, many thanks to the entire Trilinos Community in which Optika has found a welcoming home.

The format of this report is based on information found in [40].

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Nomenclature

Dependency A relationship ship between to parameters in which the state or value of one parameter depends on the state or value of another.

Dependee The parameter upon which another parameter state or value dependes.

Dependent A parameter whose state or value is determined by another parameter.

Parameter An input needed for a program.

Parameter List A list of parameters and other parameter lists.

RCP Refernce counted pointer. RCPs refered to in this document reference the RCP class located in the Teuchos package of Trilinos.

Sublist A parameter list contained within another parameter list.

Widget A GUI element, usually used to obtain user input.

Validator An object used to ensure a particular parameter's value is valid.

Chapter 1

Introduction

This report is comprised of two main sections. The first section discusses the development of Optika. Design choices and problems that arrised during development are discussed in this section. The second section is intended to be a manual on how to use Optika. If the reader desires simple to learn how to use Optika, it is suggested he/she skip to the second section.

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Chapter 2

Development of the Optika package

This section of the report discusses the developement of the Optika package.

Initial Planning

In Fall of 2008 Dr. Mike Heroux identified a need for the Trilinos framework to include some sort of GUI package. Dr. Heroux wanted to give users of the framework the ability to easily generate GUIs for their programs, while still providing a good experience for the end-user. Based on previous GUI work done for the Tramonto project, a few initial problems were identified:

- How would the GUI be laid out?
- Different types of parameters require different methods of input. How would the program decide how to obtain input for a particular parameter?
- What GUI framework would would be used to build the GUI?
- How would the application developer specify parameters for the GUI to obtain?
- How would the application developer specify dependencies between parameters. This was a crucial problem/needed-feature that was identified in previous development of an unsuccessful Tramonto GUI.

After some deliberation, the following initial solutions were decided upon:

- The GUI would be laid out in a hierarchical fashion as shown in Figure 2.1. Parameters would be organized into lists and sublists. This would allow for a clear organization of the parameters as well as intrinsically demonstrate the relationships between them.
- It would be required that all parameters specify their type and the following types would be accepted:

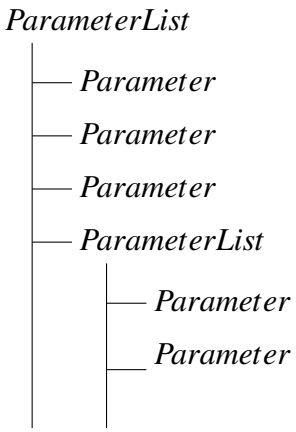


Figure 2.1. The hierarchical layout of the GUI

- int
- short
- float
- double
- string
- boolean
- arrays of int, short, double, and string

For number types, a spin box would be used as input. If the valid values for a string type were specified, a combo box would be used. Otherwise a line edit would be used. For booleans, a combo box would also be used. For arrays, a pop-up box containing numerous input widgets would be used. The widget type would be determined by the array type (e.g. a spinbox is the type was numerical).

(a) A Spin Box **(b)** A Combo Box **(c)** A Line Edit

Figure 2.2. Some of the various widgets used for editing data [36]

- QT was chosen as the GUI framework for several reasons:
  - It is cross-platform.
  - It is mature and has a comprehensive set of development tools.
  - It has a rich feature-set.
  - It has been used by Sandia in the past.
  - The Optika lead developer was familiar with it.

- Initially it was decided that the application developer would specify parameters via an XML file. A DTD would be created specifying the legal tags and namespaces.
- Dependencies would be handled through special tags in the DTD.

Early Development

The first several months of development were spent on creating and implementing the XML specification. The name of the XML specification went through several revisions but was eventually called Dependent Parameter Markup Language (DPML).

After several months of development it was realized that creating an entirely new way of specifying parameters might hinder adoption of Optika. It was also pointed out that Trilinos actually had a ParameterList [39] class in the Teuchos package. The ParameterList seemed to be better than DPML for several reasons:

- It was already heavily adopted.
- It had the necessary hierarchical nature.
- It was serializable to and from XML.

For these reasons, DPML was scrapped in favor of using Teucho's ParameterLists. Development moved forward with the goal of creating a GUI framework that, in addition to meeting all the challenges outlined above, would also be compatible with any existing program using Teuchos's ParameterLists.

Heavy development

Starting in May 2009 a more heavy focus was put on development of the Trilinos GUI package. With the back-end data-structure of the Teuchos's ParameterList already in place, attention was turned to developing the actually GUI portions of the framework. A key technology provided by Qt was it's Model/View framework [1]. Using the Model/View paradigm, a wrapper class named TreeModel [32] was created around the ParameterList class by subclassing QAbstractItemModel [34].

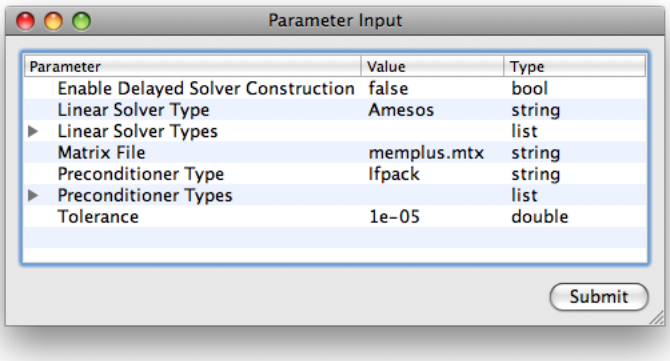
However, in subclassing the QAbstractItemModel it was realized that the ParameterList class fell short in terms of providing cretain features. The main issue was that a given ParameterEntry [38] located within a ParameterList or a given sublist located within a ParameterList was not aware of it's parent. This was an issue because Qt's Model/View framework requires items within a model to be aware of their parents. In order to circumvent this issue the TreeItem [31] class was

created. Now the TreeModel class became more than just a simple wrapper class. A TreeModel was created by giving it a ParameterList. It would then read in the ParameterList and create a structure of TreeItems. Each TreeItem then contained a pointer to it's corresponding ParameterEntry. This allowed parent-child relationship data to be maintained while still using ParameterLists as the true backend data-structure.

Once the TreeModel and TreeItem class were complete, an appropriate delegate to go between and View and the TreeModel was needed. A new class simply called Delegate [30] was created to fill this role by subclassing QItemDelegate [35]. As specified above, the delegate would return the appropriate editing widget based on the datatype carried within a given TreeItem.

With the model and delegate classes in place, an appropriate view could be applied. At first a simple QTreeView [37] was applied to the model. Later, as aditional functionality was added the View class needed to perform more functions. To fill these needs, the QTreeView [37] class was subclassed, creating the TreeView [33] class. Its main duties were to show and hide parameters as need and handle and bad parameter values that might come up during the course of the GUI excution. These features were needed due to requirements that arose from dependencies (something that will be discussed later).

Finally, the OptikaGUI [20] class was created. It had one static function, getInput. A ParameterList is passed to this function, a GUI is gereated, and all end-user input is stored in the ParameterList that was passed to the function. When the end-user hits the submit button the GUI closes and the ParameterList that was passed to the getInput function now contains all of the end-user input. The end result was something like that in 2.3(a).



(a) A Tree View

Advanced Features

With the basic framework in place, the development team was now able to move on to more advanced features. As these advanced features were developed various refactorings were made to

the already existing code in order to support these new features.

Validators

One of the goals of Optika is to make life easier for the end-user. It's not enough to simply give the end-user information, it must be conveyed in a meaningful way. Validators are a great way of informing end-user what the valid set of values for a particular parameter are. Teuchos ParameterLists already came with built in validator functionality, but the default validators that were available were sorely lacking in capability. Three initial sets of validators were created to help deal with the short comings of the available validator classes:

EnhancedNumberValidators allowed for validating various number types [12]. EnhancedNumberValidators have the following abilities:

- Set min and max.
- Set the step with which the number value was incremented.
- Set the precision with which the number value was displayed.

StringValidator allowed the specification of a particular parameter as only accepting string types and allowed for specifying a valid list of values [25].

ArrayValidators allowed for all validator types to be applied to an array of values. The validator that is applied to each entry in the array is called the prototype validator [4].

A fourth Validator type, a FileNameValidator [14], was added later. This validator designates a particular string parameter as containing a file path and allows the developer to indicate whether or not the file must already exist.

By interpreting these validators, Optika could either put certain restrictions on the input widget for a parameter or entirely change the type of input widget used. For instance: with EnhancedNumberValidators the min, max, step, and precision of the EnhancedNumberValidator are all used to directly set their corresponding values in the QSpinBox class. But with the FileNameValidator a QFileDialog would appear instead of the normal QComboBox or QTextEdit used for string validators.

Dependencies

Many times the state of one parameter depends on the state of another. Common inter-parameter dependencies and their requirements include:

Visual Dependencies: One parameter may become meaningless when another parameter takes on a particular value. In this case the end-user no longer needs to be aware of the meaningless

parameter and it's best to just remove it from their view entirely so they don't potentially become confused. Visual dependencies should allow the developer to express that "if parameter x takes on a particular value, then don't display parameter y to the end-user anymore."

Validator Dependencies: Sometimes the valid set of values for one parameter changes if another parameter takes on a particular value. Validator Dependencies should allow the developer to express that "if parameter x takes on a particular value, change the validator on parameter y."

Validator Aspect Dependencies: Sometimes the developer doesn't want to change the validator on a particular parameter, but rather just a certain aspect of it. Validator Aspect Dependencies allow the developer to express that "if parameter x takes on a particular value, change this aspect of the validator on parameter y in such a fashion as relating to the new value of parameter x"

Array Length Dependencies: Sometimes the length of an array in a parameter changes based on the value of another parameter. Array Length Dependencies should allow the developer to express that "if parameter x changes its value, change the length of the array in parameter y in such a fashion as relating to the new value of parameter x."

Coming up with a way for the developer to easily express these concepts was not easy. The first problem that had to be solved was how to keep track of all the dependencies. They couldn't just be stored in a ParameterList as a class member because of the recursive structure of ParameterLists. Eventually, it was decided that a data structure called a dependency sheet [11] would hold all the dependencies used for a certain ParameterList. Each Dependency [10] would at minimum specify the dependent parameter and the dependee parameter. However, a complication arose. Because the development team wanted dependencies to be able to have arbitrary dependents and dependees, the development team needed a way to uniquely identify the dependee and the dependent. While within a particular ParameterList names of parameters are unique, names are not necessarily unique across a set of sublists. Therefore, in order to uniquely identify a parameter and allow dependencies across sublists the program would need to know both the parameter name and the parent list containing it[1].

So it became that every dependency, along with needing the names of the dependee and dependent, also needed their respective parent lists. The dependency sheet also needed the root list which contained all of the dependees and dependents. This was so the program could recursively search for the parameters and their parent sublists (the only way to find them using our method of identification). The following Dependency classes were created to address the use cases above (shown as a hierarchy of classes):

Dependency: Parent class for all Dependencies [10].

NumberArrayLengthDepednency: Changes an array's length [16] .

[1]The astute reader will notice that if there are two sublists with different parent lists and each sublist has a parameter with the same name, then the program will not be able to uniquely identify the dependent and the dependee. This is such an edge case that the development team decided to ignore it and not implement any way to handle it

NumberValidatorAspectDependency<T>: Changes various aspects of an EnhancedNumberValidator [18].

ValidatorDependency: Changes the validator used for particular parameter [28].

BoolValidatorDependency: Changes the validator used for a particular parameter based on a boolean value [7].

RangeValidatorDependency<T>: Changes the validator used for a particular parameter based on a number value [23].

StringValidatorDependency: Changes the validator used for a particular parameter based on a string value [26].

VisualDependency: Shows or hides a particular parameter [29].

BoolVisualDepedency: Shows or hides a particular parameter based on a boolean value [8].

NumberVisualDependency<T>: Shows or hides a particular parameter based on a number value [19].

StringVisualDependency: Shows or hides a particular parameter based on a string value [27].

Some of these dependencies have some sick-awesome capabilities. Namely, the NumberArrayLengthDepednency, NumberValidatorAspectDependency, and NumberVisualDependencies can all take a pointer to a function as an argument. In the case of the NumberArrayLengthDepednency, this function can be applied to the value of the dependee parameter. The return value of this function is then used as the length of the array for the dependent parameter. For NumberValidatorAspectDependencies, the function is applied to the dependee value and used to calculate the value of the chosen validator aspect. And in the NumberVisualDepenency class, if the function when applied to the dependee value returns a value greater than 0 the dependent is displayed. Otherwise, the dependent is hidden.

The algorithm for expressing dependencies in the GUI is as follows:

1. A parameter's value is changed by the end-user.
2. The Treemodel quieries the dependency sheet associated with it as to whether or not the parameter that changed has any dependents.
3. If the parameter does have dependents, the Treemodel requests a list of all the dependencies in which the changed parameter is a dependee.
4. For each dependency, the evaluate function is called. The dependency makes any necessary changes to the dependent parameter and the Treemodel updates the Treeview with the new data.
5. If any dependents now have invalid values, focus is given to them and the end-user is requested to change their value to something more appropriate.

Custom Functions

Normally, in Optika the end-user configures the ParameterList, hits submit, the GUI disappears, and the program continues with execution. However, an alternative to this work flow was desired. A persistent GUI was needed. The development team added the ability to specify a pointer to a function that would be executed whenever the end-user hit submit. The function needed to have the signature foo(Teuchos::RCP<const ParameterList> userParameters).

Various Niceties

Various niceties were added to the GUI as well. The ability to save and load ParameterLists was added. The Optika GUI class was expanded to allow for customization of the window icon and use of Qt Style Sheets to style the GUI. Checks were also added so that if the end-user tried to exit the GUI without saving. In such a case they would be warned and given the option to save their work. Tooltips were added so when ever the end-user hovered over a parameter, it's documentation string would be displayed. Also, the ability to search for a parameter was added.

Waiting For Copyright

All of the above features were completed around or shortly after the end of August 2009 and Optika was officially given its name. Optika was then submitted for copyright. It took Optika a little over six months to complete copyright. Since it was not yet copyrighted, it could not be included in the Trilinos 10 release in October 2009. This made the primary developer extraordinarily frustrated and he tried very hard to contemplate what could possibly be taking so long. During the time Optika spend in copyright limbo, little development on Optika was done. Most of development was cleaning up various pieces of code, adding examples, and adding documentation. Finally, in March 2010 Optika completed copyright and was ready to be included in Trilinos. It was released to the public with the Trilinos 10.2 release.

User Feedback

In the summer of 2010, Optika got it's first user. Dr. Laurie Frink began using Optika to create a GUI for Tramonto. There had been a pervious attempt to build a GUI for Tramonto, but it had been largely unsuccesful.

Initial feedback was very positive. Dr. Frink is a C programmer and while she had some issues picking up Optika (which is C++ based) most were easily and quickly addressed. Her questions also lead to the creation of some great examples. For the most part Dr. Frink found Optika to be quite adequate for her purposes. However, Dr. Frink did have one rather major feature request:

she needed the ability to specify multiple dependents and in some cases even multiple dependees. This was quite a task and required a large reworking of the Dependency part of the framework.

Adding support for multiple dependents was fairly trivial. Instead of specifying a single dependent to the constructor of a Dependency, a list of Parameters was now passed. If the developer only needed one dependent then he/she could just pass a list of length one. This simple list worked in the case of all the dependents having the same parent list. If they had different parent lists, then a more complex data structure which mapped parameters to parent lists would be used. Convenience constructors were also made for simple cases where just one dependent was needed. The algorithm used for evaluating dependencies changed very little with these modifications. The only addition needed was and extra loop for evaluating each dependent in a dependency for a given dependee.

Adding support for multiple dependents was much harder. There was actually only one specific use case where multiple dependents were needed/appropriate. Dr. Frink needed the ability to test the condition of multiple parameters to determine whether or not a particular parameter should be displayed. So a new VisualDependency class called ConditionVisualDependency [9] was created. ConditionVisualDependencies evaluated a condition object to determine the whether or not a set of dependents should be hidden or shown. The set of condition classes created are as follows (shown as a hierarchy of classes):

Condition : Parent class of all conditions.

- **ParameterCondition** : examines the value of a particular parameter and evaluates to true or false accordingly [22]. Types of ParameterConditions include:
  - **BoolCondition:** examines boolean parameters [6].
  - **NumberCondition<T>:** examines number parameters [17].
  - **StringCondition:** examines string parameters [24].
- **BinaryLogicalCondition:** examines the value of two or more conditions passed to it and evaluates to true or false accordingly [5]. Types of BinaryLogicalConditions include:
  - **AndCondition:** returns the equivalent of performing a logical AND on all conditions passed to it [3].
  - **EqualsCondition:** returns the equivalent of performing a logical EQUALS on all conditions passed to it [13].
  - **OrCondition:** returns the equivalent of performing a logical OR on all conditions passed to it [21].
- **NotCondition:** examines the value of one condition passed to it and evaluates to the opposite of what ever that condition evaluates [15].

Through the recursive use of BinaryLogicalConditions the developer can now chain together an arbitrary amount of dependents.

ConditionVisualDependencies are the only dependencies which allow for multiple dependents. So while support was added for multiple depdents at the Dependency parent class level, Condi-

tionVisualDependency is the only class which actually implements the functionality. In the case of multiple depdnents the algorithm for evaluating dependencies didn't need to change at all.

At the time of this publication, the Optika team is still waiting to hear back from Dr. Frink as to whether or not these new features meet her needs.

Future Development

There are three main development goals for Optika in the near future. The first is to be able to completely write and Optika GUI (with dependencies and validators) solely in XML. This requires that XML serialization for all of the validator and dependency related classes be developed. Currently, XML serialization for validators is almost finished after which serialization for the dependency and dependency sheet class will begin.

The second goal is to develop a stand-alone version of Optika. The development team believes that the potential audience for Optika is much larger than just user base of Trilinos. However, creating a stand-alone version presents the problem of keeping source code consistent between the Optika that exists in Trilinos and the stand-alone version. No doubt python scripting will come in handy when solving this problem.

The third is to create a standalone Optika based executable that acts as a generic ParmaterList configurator. It would take in a ParameterList in XML format, allow the user to configure the ParameterList, and then either output the entire ParameterList again with the new settings or output a ParameterList only containing the parameters that were changed.

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