Development of Software for Geothermal Applications through Integration Technologies

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We introduce two systems developed for geothermal applications, and illustrate the techniques used for their development. SIGMA is an integrated system for management, processing and visualisation of geomagnetic, gravimetric and electrical resistivity data, integrating public domain codes for filtering with commercial interpolation routines. IPOGEO is an integrated system for the management and processing of seismic data. Several algorithms have been integrated to produce synthetic seismograms and seismic tomographies.

We used a re-engineering process, which allows to take programs embodying significant domain knowledge and improve some of the characteristics of those programs, supporting geophysicists in their work, hiding unnecessary implementation details in the integration mechanism.

We present the technique and the software environment we used for re-engineering and integration of programs. Our methodology is centred around the idea of software model, which is a description of a set of software components, their activation modalities and their interconnections. Requirements have been derived though the use of hypertext for rapid prototyping. We used a well-defined software architecture and a set of C++ libraries specifically designed to support integration.

1. Introduction

In the field of scientific applications, several algorithms and application codes have become a standard for the level of functionality they provide. In other words they solve extremely well some specific problems and it would be useless and risky to try to substitute them. On the other hand, they do not conform to today's standards of usability (e.g. they have character-oriented user interfaces); moreover, it is quite difficult to use several of them together, for instance because their data formats are incompatible.

In a coordinated effort among geothermal researchers and software specialists, we developed two applications, SIGMA and IPOGEO, that integrate existing software tools in a coherent, user-friendly, graphical environment. They are discussed in more detail in the next two sections.

Afterwards we briefly outline the software techniques used for integration of the components. The last section describes some ongoing work.

2. Sigma

Sigma is an integrated system for the management and processing of magnetometric, gravitational and geoelectrical data. The processing of such data types is a well-established geophysical technique used to infer positions and shape of bodies characterized by anomalous properties.

respectively magnetic susceptibility, mass density and electric conductivity. Information obtained through these techniques are used to formulate hypotheses about geothermal reservoirs and surrounding geological structures.

The main objective of Sigma is to make easy the manipulation of heterogeneous data sets, their interpolation and filtering and the production of maps of various fields.

2.1. Metaphor and User Interface

Sigma exploits the desktop metaphor: the user sees on the screen a stylized desktop, populated by icons representing data sets and/or folders, which may contain more data sets and/or folders.

![SIGMA Desktop](image)

The user may select one or more data sets with the mouse, may move them around the desktop and perform operations on the data sets by choosing appropriate menus.

Data sets have a type, in the sense that certain operations are allowed only on certain classes of data: for instance, the bandpass filter can work only on gridded data and not on scattered data. The interface is aware of interconnections among data and operations, enabling only the menu items corresponding to operations applicable to the currently selected data sets. Operations that are not compatible with the current selection are disabled and cannot be activated.

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2.2. Data Types

Sigma currently handles three families of data sets:

- **magnetic**, whose meaning is the magnetic anomaly in a given point of the surface of the Earth
- **gravimetric**, referring to the gravimetric anomaly
- **geoelectric**, referring to resistivity measures centred in a given point; the Schlumberger arrangement is used, providing for each point considered a curve relating the resistivity with the same distance of the electrodes.

Each basic family has three subfamilies:

- **scatter set**: a set of measures actually taken in a set of points (stations). Usually these measures result from geophysical surveys.
- **grid**: a set of interpolated values, aligned on a rectangular array of points. Sigma handles grids aligned with the kilometre UTM (or Gauss-Boaga) recital, allowing for different grid steps in the NS and EW directions. Grids are the result of the interpolation of scatter sets or of transformation of other grids.
- **profile**: a set of interpolated values along a straight line segment.

For the purpose of producing useful maps of the fields, it was necessary to add the Auxiliary data set class, which includes topographic features such as cities, polygons (for rivers, mountains and the like), wells and labels.

2.3. Operations

We classified the available operations in several groups; sketched below.

2.3.1. Data management

It is possible to import data files in a few common formats; each data file becomes a scatter data set, which is stored in Sigma's internal database. Scatter sets can also be manually input and modified. Scatter values and topographical data may also be input through a graphic tablet.

In the set-theoretical sense, it is possible to take the union of two data sets: a new data set will contain the values of both sets, making it possible to combine the results of different surveys. Moreover, given a data set, it is possible to build another set by selecting only the measurements belonging to a smaller area, thereby increasing the speed of further processing.

2.3.2. Preprocessing

Scatter data may be interpolated over two-dimensional grids or along straight lines. We used a commercial interpolation package (Linaris) to provide both local-fit and triangulation-based interpolation. Grids may further be preprocessed calling the USGS computing code fitl1/new (FFT), which features the following transformations:

- **passband filtering**, to eliminate from the observed anomaly field components of undesired wavelengths, for instance it is useful to cut short-wavelength anomalies, related to very small bodies, retaining only components relating to bodies of dimensions relevant for the current investigation.
- **vertical derivatives** ($1^{\text{st}}$ and $2^{\text{nd}}$), which can delineate boundaries of anomalous bodies, through processing of magnetic and gravimetric data.

- **reduction to the Pole**, used for interpretation of magnetic data. It is well known that at middle latitudes an anomalous magnetic body produces two anomalies, one positive and one negative. The reduction to the Pole computes the anomaly that could affect the magnetic field at Pole, where the magnetic field vector is vertical, so that the anomalous body would produce a unique anomaly (maximum or minimum).

- **pseudo-gravimetric and pseudo-magnetic transformation**, assuming that a body has anomalous magnetic or gravimetric properties, it is possible to compute the magnetic anomaly from the gravimetric field, and vice-versa. For instance, comparing a magnetic anomaly with a pseudo-magnetic, the interpreter can state whether a body has both magnetic and gravimetric anomalous properties.

- **directional filtering**, which has purposes similar to those of passband filtering. However, in this case the desired (or undesired) components are those characterized by their orientation on the horizontal plane. This filter is used to extract (or to eliminate components whose minima/maxima have a certain orientation.

We also added a polynomial filter, which fits a polynomial of arbitrary degree to the given grid in the least squares sense.

Another possibility is the linear combination of grids. It is possible, for instance to subtract a regional anomaly polynomial from the anomaly grid, obtaining a sharper local anomaly map. Or, it is possible to add a gravity anomaly grid with a pseudo-gravity grid derived from a magnetic grid from the same area, obtaining a stacking effect with some noise cancellation.

2.3.3. Visualisation

The visualisation tools include a profile tool and a map tool. The profile tool is quite simple, and displays a x,y representation of the variation of a quantity along a straight line.

![Figure 2: SIGMA profile tool](image.png)

The map tool is richer and allows to display simultaneously two grids, a scatter set and a topographic set. The first grid is contoured in colour while the second grid is represented as isolines.
3.1. Metaphor and User Interface

Ipogeo adopts the 3D metaphor: the user sees a local portion of the Earth simultaneously from three different points of view. From above, from a side and as an axonometry. The system visualises both physical objects, as well as seismic sources and receivers, and non-physical objects, such as 2-D and 3-D velocity models.

In the following figure, the map is the upper left portion of the window, the side view as in the lower left, and the axonometry is on the right.
4. Integration Environment

For Iposee and Sigma, the MI integration environment, developed by Ismei SpA, was adopted. Its characteristics are sketched in his paragraph. For a more complete discussion, the reader is referred to [Spa] and [Sal].

The general aim of MI is to make it simple for project leaders and programmers to develop a new application in the scientific and engineering area, using existing components.

Every MI application shares a common structure, shown in the following figure.

![Diagram of MI integration environment]

There are two main layers: the component layer, which contains the software tools to be integrated, and the integration layer, which maps the original components to a model of interaction that may be very different from the original one.

4.1. Software component layer

The software components to be integrated are usually at the granularity level of a program. Often they are available only at the executable level, even when source code is available, they are untouched. As far as possible, when necessary, a capsule is built around several components, making them look like a single complex component; sometimes the same program is used by several different capsules.

4.2. Integration layer

The focus point of the architecture is the software model, which is an abstraction of the existing components and provides for presenting them to the user. The model uses some communication mechanisms for interacting with the user and with the software components. In other words, the model translates the components in a visual language understandable by the user, and translates to turn the user commands into input and activation commands for the components. [Talk]

Software models are not constrained to a specific formalism; support for various typologies of models is instead provided. Models are built with C++ linguistic constructs and are, in this sense, object oriented. For instance, one possible model is a hierarchical model: the system is a tree, whose nodes are functions; more levels of functions are decomposed into sub-functions, which in turn are decomposed into sub-sub-functions, going down to the leaves, which are connected with individual programs. This model has been used to impose some degree of classification over a set of programs coming from different sources, by collecting them in families of tools. From the user viewpoint, the model visualizes itself as a cascade of expanding windows. A different visualization of the same model may be a hierarchy of menus.

Often, the model the user has of the system is not coincident with the actual physical structure of the software, and it is useful to present it as a single functionality a complex sequence of invocations of components.
conversely, it might be convenient to show the same component as a set of different functions, differing for some invocator parameter. Moreover, for some applications, data-driven models are better than functionality-driven ones, however, existing software components are usually hind-genium, functionality-oriented programs, and must be mapped to a data-driven model of operation.

Software models are clients of mechanisms for communication with the components, through an abstraction of the Unix and VMS concepts of process, and with the computer-human interface, through some abstractions over the concepts of interactor and form.

Different models may feature different levels of integration; typically, data-driven models are more amenable for data integration, while functionality-driven models aim at control integration.

4.3. MIL libraries

The MIL libraries provide C++ classes for implementing:

- software models;
- communication between models and components;
- communication between models and the user interface;
- common types and data structures.

The computer-human interface layer uses a standard platform (X11), a public domain toolkit (InterViews 2.6, [Vii]), and a set of custom classes.

5. Discussion and Work in Progress

The use of integration techniques has allowed to respect the applicative knowledge content of state-of-the-art codes, while building a modern user-friendly interface. Moreover, the integration of heterogeneous functionalities has brought, as a side-effect, new functionalities related to the possibility of visualising an image environment different from disparate sources. The only alternative would have been to develop all applications from scratch, with prohibitive time and cost requirements.

Currently, Sigma is being expanded so as to handle a new dam family, namely the earthquake localizations. It will be therefore possible to superimpose earthquake locations with magnetic, gravitational, and electric dam. Moreover, a new tool will allow to visualise localisations projected over a vertical plane.

Other variables which will be visualised are various seismic statistics, such as the frequency of earthquakes, at a 2-dimensional field.

6. References


