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Open Plot Project: an open-source toolkit for 3-D structural data analysis

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Abstract

In this work we present the Open Plot Project, a software for structural data analysis including a 3-D environment. This first alpha release represents a stand-alone toolkit for structural data analysis and, due to many import/export facilities and to the presence of a 3-D environment, also candidates as a tool to be incorporated in workflows for 3-D geological modelling.

The software (for both Windows and Linux O.S.), the User Manual, a set of example movies, and the source code are provided as Supplement. It is our purpose that the publication of the source code sets the base for the development of a public and free software that, hopefully, the structural geologists community will use, modify, and implement. The creation of additional public controls/tools is strongly encouraged.

1 Introduction

In the last years the rising availability of new technologies and high-quality 3-D seismic data has implied the increasing use of truly 3-D geological models. Contextually, new methodologies have been developed to integrate surface and sub-surface geological data to build geologically constrained 3-D models (e.g. Fernández et al., 2004; Carrera et al., 2009; Jessel et al., 2010). However, information used for building 3-D models commonly includes a limited suite of available data, particularly for data collected in the field. The geometries of geological surfaces, like faults and layers, are by far considered the most important data. Methodologies for the construction of geological models rarely incorporate other information, like the attributes of the deformation pattern, which can be crucial for extrapolating data into the undersampled portions of the aimed model (e.g. Thorbjornsen and Dunne, 1997; Tavani et al., 2006). Moreover, the tools for structural data analysis implemented in commonly used 3-D CAD-like geological modelling software, have limitations in the interactive data selection, managing, and subsequent analysis. This also affects the managing of bedding attitude

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data. Robust methodologies for 3-D reconstruction based on consistent bedding data interpolation and extrapolation require the use of in-house developed tools (e.g. Carrera et al., 2009). In addition, widely used software for structural data analysis do not incorporate 3-D tools (or these are quite basic) and the “communication” between 3-D modelling software and structural data analysis tools is frequently neither simple nor direct. Therefore, the whole process of 3-D reconstruction requires frequent and time-consuming passages between different CAD-like tools, software for structural data analysis, and in-house developed routines (e.g. Fernández, 2004).

In this work we present the Open Plot Project software, a stand-alone structural data analysis software including a 3-D tool for data managing. The intents of Open Plot Project are: (1) reducing the gap between CAD-like software for 3-D modelling and structural data analysis tools, and (2) providing an advanced toolkit for structural data analysis. The software is entirely written in RealBasic 2009r2 (RealSoftware Inc, 2009), a multi-platform basic language (running on Linux, Windows and Mac), which includes a 3-D control and represents an optimal compromise between speed, 3-D graphic quality and programming easiness. The last point is particularly important to us, as the main intent of Open Plot Project is that of providing an open source code (the code is here provided as Supplement). A set of functionalities are provided in this first release being, however, the main purpose that of inviting the structural geology community to modify/implement the code, returning it to the community.

2 Summary of software architecture and functionalities

The complete description of functions and procedure for importing, saving, managing and exporting data is illustrated in the User Manual, which is attached to this work. In this section we summarise the internal workflow of the software.

The working philosophy of Open Plot Project is schematically illustrated in Fig. 1. Three different types of data can be loaded, converted in the Open Plot format (eventually saved) and plotted. Structural data, basic 3-D objects and complex objects.

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- Structural data are punctual objects and include lineations, planes (eventually with slickenlines), and tensors. For these elements each record can include user-defined attributes. As an example, a joint with associated spacing, orientation, author, date, lithological information, etc., is a structural datum.
- 5 – Basic 3-D objects include “simple” 3-D surfaces (i.e. planar polygons and vertical panels/multipanels), polylines, vectors and triangles. The record associated with vectors, triangles, polygons and polylines can include user-defined attributes and, in all the cases, orientation data are computed for them. On the contrary, vertical multipanels are purely geometrical objects with no attributes. These are used to create and save selections, drape images (like seismic sections or geological cross sections), and to project structural data along the multipanel trace (i.e. to create structural transects, e.g. Wise and McCroy, 1982; Tavani et al., 2006).
- 10 – Complex objects include triangular meshes and images. In particular, three types of images can be loaded. (1) Textures: non-georeferenced images, which can be draped on vertical panels. (2) Map: georeferenced images, which can be draped on meshes. (3) Image lists: arrays of images (typically photos of outcrops).
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Structural data and basic 3-D objects can be saved in both *.stv and *.spj format. On the contrary, complex objects can be saved only in *.spj format. The first format is, in few words, a $N \times M$ matrix of strings, with an initial header where the number of columns and rows is specified. Such a format allows to easily import an *.stv file in a spreadsheet, modify and re-import it in Open Plot Project (with a simple copy and paste procedure). Data editing and modification in external spreadsheets is thus recommended, although a data editing tool is provided within the software. The structure of *.spj files is, in its first part (where structural data and basic 3-D objects are stored), identical to that of *.stv files. In the second part of the file points and triangles of meshes (if present) are listed first, and then, in binary format, all the images.

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Structural data and basic 3-D objects can be selected by filtering their attributes, and plotted in five windows: Frequency analysis, 2-D Scatterplot, 3-D Scatterplot, Stereoplot and 3-D View. In the first three cases a new matrix, including only the selected portion of the dataset, is generated. This new matrix is sent to the corresponding plotting window, just for data displaying and analysis, not for editing or modification. In the case of stereoplot, the corresponding temporary matrix is linked to the main one and many operations can be performed on the selected portion of the dataset. These include the selection of a new sub-dataset, the assignation of new attributes, and the “storage” of directions that can be used in the 3-D View window to create new data. The functionalities of the 3-D View window are much more complex. Structural data, basic 3-D objects, and complex objects can be displayed in this window. Similarly to the Stereoplot window, the displayed objects are linked to the main matrix. Basic 3-D objects can be created/erased here (also with the aid of tools present in the Stereoplot window) and many operations can be performed on the selected dataset. These operations include the projection of data along panels and the selection of sub-dataset, which can be directly sent to the other plotting windows.

As previously described, structural data and basic 3-D objects can be directly imported in a spreadsheet by opening the corresponding *.stv file. Many 3-D objects, including polylines, meshes and planar polygons can be exported in *.DXF format.

Additional functionalities, which do not require the loading of data, are present in Open Plot. Like, for example, the computation of fault slip direction from Riedel structures (Riedel, 1929).

3 System requirements

Open Plot Project derives from a basic software developed to work in the field with the first low-cost netbooks. Open Plot Project preserves the capability of its ancestor of running on computers with low-cost components (tested down to 900 Mhz Intel Celeron M processor, 512 MB of RAM, Intel GMA 900 graphic card) and with both Windows XP

and Ubuntu8.04 or higher OS (it “should” also run in other Linux distribution, provided that GTK +2.8 is installed and the window version run on Linux under Wine). The version for Mac OS is not provided. However, Mac users can easily compile the code. Although most of the windows are correctly displayed on 800 × 480 screens, a minimum screen resolution of 1024 × 600 is recommended.

4 Case studies

In this section is briefly illustrated the application of Open Plot Project in two case studies. The procedures described in these examples can be followed in the relatives movies, provided in the Supplement, named Sibillini.mp4 and Pobla.mp4, respectively.

The first example is from the Sibillini anticline, Northern Apennines (Italy). The “structural” problem is that of evaluating the variability of pressure solution cleavage frequency in different structural positions of an anticline characterised by a variable axis orientation. The input dataset is from a spreadsheet including measurements collected in the field, like cleavage strike, dip, spacing and, as in this anticline the cleavage is stratabound, the thickness of the hosting layer. Scatterplot of cleavage spacing (S) vs. host-layer thickness (H) shows that these parameters are related and, accordingly, H/S should be used to quantify the cleavage frequency (e.g. Tavani et al., 2006). The *.stv file is thus imported in a spreadsheet, a new column is added, named “./HvsS” (the “./” characters will indicate the software that this is a numeric field), and the number of columns is updated in the header. Now the entire file, including reserved fields (see user manual) and the header, is copied. Import from clipboard procedure will recognise the header, and will load data without passing through the “boring” import procedure. In the data selection window bedding surfaces and pressure solution cleavages are selected and then plotted in the 3-D window. To evaluate the variability of cleavage HvsS across the fold strike, data have to be projected onto an across-strike panel. However, as the anticline is characterised by a slightly variable axial trend, data should be projected using the local axis orientation. To do this we manually select a

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region and send the data included in this region (both bedding and cleavage data) to the stereonet. Here a tensorial analysis is performed only on bedding data. In the tensorial analysis results, we click “apply K3”, this assigns to entire selected dataset (including cleavages) the orientation of the local best-fit cylindrical axis. The same operations are performed for another region. We end up with two regions with different cylindrical axes. Data now are projected onto the across-strike panel using “eigen-vector” option, such that, data are projected using the local axis orientation. A new 2-D scatterplot window will open up, including data that have been previously selected (i.e. bedding surfaces and cleavages). Two new attributes are added to each datum, namely the X and Z coordinates along the panel. In this scatterplot window we plot the “X-position along panel” versus “HvsS”, result shows that cleavage frequency varies along the panel (i.e. across the fold) and, in particular, it roughly decreases toward the central portion of the transect (i.e. in the crestal sector).

The second example is from La Pobla de Segur (Spanish Pyrenees). Here it is illustrated how Open Plot can be used to create dip-domains. Traces were previously digitalised onto a georeferenced orthophoto draped on a DEM. In the planar regression tab of the drawing options window we define the parameters for the trace analysis procedure. This is a recursive procedure that finds, for each selected polylines group, a set of best-fit dip-domains (see user manual). In this window we also activate the dip-domains evaluation option, which will allow us to evaluate the “quality” of the automatically extracted dip-domains. Once the dip-domains are extracted from polylines, axial surfaces can be created. This allows constructing portions of a given layer surface, which can be later exported as DXF 3-D faces and then imported in CAD-like software.

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5 Discussion and conclusions

The possibility of easily import different data types from spreadsheets, text files, and other file formats, including meshes and polylines from DXF files, coupled with the simple STV file structure and the presence of a DXF export facility, allow to: (1) easily use Open Plot Project as a sort of structural add-on of CAD software, (2) use Open Plot together with other structural tools; (3) use it as a stand-alone toolkit.

In the first case, Open Plot Project represents an external add-on allowing to import from different sources and manage together both georeferenced structural data and 3-D objects (like meshes and polylines), thus allowing to bypass the limitations of many CAD-like software in the import and management of “structural” data. These limitations can include, for example, the difficulties in making spatial or attribute queries, the difficulties in importing user-defined data attributes, the possibility of customizing the extraction of dip-domains from polylines, the handling of axial surfaces, and the definition of projection directions. These and others limitations can be partially (even totally) bypassed by acquiring specifically-developed add-ons that, however, in the most part of the cases are neither free nor open source. Consistent and structurally-validated dip-domains created within Open Plot Project can be exported as DXF meshes and then imported in CAD software, where tools not present in Open Plot Project can be used to create and manage consistent volumetric models from these and other information.

The possibility of selecting data according to (1) user-defined numeric and alphanumeric attributes, (2) spatial distribution, and (3) attitude, together with the possibility of digitalising vectors and polylines on DEM or georeferenced images (including geological map), allows to “export” selected data also toward structural software including analysis tools not yet implemented in Open Plot Project (like fault data inversion). Once a sub-dataset is selected, if data are saved as *.stv, the state (i.e. selected or deselected) of each datum will be written. Importing data in a spreadsheet allows to manage data and export the desired portion of the dataset with the desired data fields. This sub-dataset, in turn, can be imported in structural software with specific analysis tools but less developed selection facilities.

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On the other hand, the presence of widely-used data analysis tools (stereonet, tensorial regression, histograms with frequency analysis tools, 2-D and 3-D scatter-plots with data density contouring, transect analysis), efficient and different filtering options, 3-D environment, rather fast import/export procedures, coupled with the intrinsic advantages of an open source software, support the use of Open Plot Project as the main platform for data management.

Supplementary material related to this article is available online at:
<http://www.solid-earth-discuss.net/2/375/2010/sed-2-375-2010-supplement.zip>.

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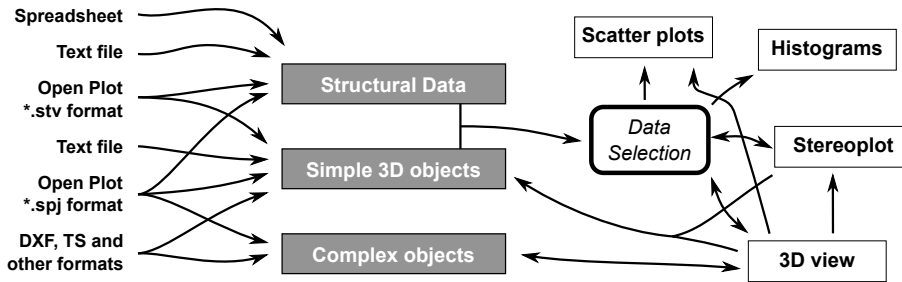


Fig. 1. Schematic working philosophy of Open Plot.

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