# Integration of 3D petroleum datasets in commercial GIS

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## ABSTRACT

*This paper describes the use of ArcGIS as an integration tool for 3D petroleum datasets. Whilst the use of 3D visualisation and analysis tools in the petroleum industry is widespread, the integration of data from these tools with other spatial data held within an organisation is far from straightforward. Using multipatch features in a geodatabase, complex three-dimensional features can be stored in a geodatabase and visualized within the ArcGIS environment in 3D. This allows the integration of complex 3D objects from geological, engineering or survey sources with standard spatial data from conventional GI sources.*

**KEYWORDS:** *3D visualisation, petroleum, data integration*

## INTRODUCTION

Recent advances in interoperability and standards, in addition to the breakout of GIS from a specialist application towards being a widespread desktop tool, has meant that it is now in an ideal position to provide powerful spatial data integration. Many industries however, such as meteorology, environmental management or oil and gas, deal with complex three-dimensional spatial data. In order to provide full integration GIS must be capable of handling the three-dimensional (3D) data types and spatial representations which exist in the various disciplines within these industries.

This paper will examine the place of GIS as a 3D data integration tool, outline the current state of 3D data storage in the ESRI suite of products, and give examples of the incorporation of numerous disparate data types into a comprehensive pilot dataset within ArcGIS. Using the oil and gas industry as a case study, it will also describe how this data can be analysed and visualised within the ESRI environment as used by Shell International Exploration and Production, the sponsors of this research.

## REQUIREMENT FOR INTEGRATION

The use of 3D modelling, analysis and visualisation software in the oil and gas industry is widespread. Amongst geoscientists, 3D views of the world are an important tool for increasing understanding, improving communication and simulating complex geological and petrophysical structures and processes. Amongst planners and engineers 3D visualisation is an important way of assessing the impact of projects, examining numerous implementation options and ensuring health and safety requirements are met. Be it on land, under the sea or under the ground, the ability to visualise, analyse and interact with objects of interest in 3D is of great value.

Most of these 3D visualisation, analysis, and modelling capabilities are today provided by specialised software applications, with functionality geared towards specific analyses, provided on specialist hardware (such as UNIX-based geological modelling software). Whilst these applications are not viewed as GIS by their users, there is no doubt that the majority deal with geo-spatial data, spatial representations of real world objects and with spatial analysis. These systems could therefore be viewed as simply ‘specialised GIS’. These systems, however, tend not to support complex spatial analysis function, or concepts such as topology.

In addition to the geological field, three-dimensional data is also utilised in many other application areas. 3D CAD models are often created during the design and construction of large infrastructure, such as offshore platforms or drilling rigs. Well engineers utilise 3D visualisation and modelling in the well design process, ensuring the trajectories which they design meet criteria for minimum curvature and avoidance of subsurface obstacles. Offshore surveyors generate huge volumes of three-dimensional data during the process of surveying the seabed for pipeline inspections, offshore rig locations or construction projects.

Despite this proliferation of three-dimensional visualisations and analyses, and the enabling software, integration is still a problem faced by geoscientists. The separation of people and systems is a huge barrier to true cross-organisation working and team interaction, and the difficulties in encouraging integration and cooperation in the geosciences are well documented (Abel et al, 1994; Breunig, 1999). This is mainly due to the software-led and discipline-led development of proprietary data formats, spatial models and representations, in a very similar vein to that which mainstream GIS industry historically followed. Some strides have been taken towards integrating various subsurface modelling packages (such as the OpenSpirit initiative (OpenSpirit, 2005)), but the true integration of all data available from surface and subsurface is still not directly possible.

Conversely, mainstream GIS vendors, such as ESRI, have begun to move away from the strictly proprietary data formats which were historically used. Geo-interoperability initiatives have been established in recent years (such as OGC, GML) to provide open, extensible and standardised spatial representation that encourages interoperability amongst all parties in the spatial community. Other advances, such as the inclusion of the Safe Software FME extension into ArcGIS 9.0, allow the conversion of data between numerous formats from disparate vendors and applications, enabling a vast array of data to be incorporated into GIS projects.

In addition to these advances in geo-spatial data standards and interoperability, the use of GIS is also becoming more widespread. The migration of GIS from specialist workstations and complex software to a user-friendly application capable of running on almost any desktop PC has meant that in large organisations its use is no longer the preserve of cartographers, planners and data managers. In the petroleum industry, for example, GIS is now used by many branches of the organisation from geologists and petrophysicists through to project managers.

With these advances in flexibility and status, along with the traditional strengths of coordinate system support and spatial analysis, mainstream GIS now finds itself in an ideal position to serve as the primary integration tool for spatial data (and especially in the oil and gas industry). In order to provide full integration however, GIS must be capable of handling the complex three-dimensional data types and spatial representations which exist in the various disciplines within the industry.

## STORAGE OF 3D FEATURES IN GIS

Much research has been undertaken into the storage of ‘true 3D’ features (volumes) in GIS, detailing various models for 3D spatial objects (e.g. Molenaar 1990, Pilouk 1996, de la Losa and Crevelle 1999), which are built up from a set of common primitives. Data structures constructed from these primitives are either object oriented or topology oriented, depending on whether the application which will use the data is geared towards visualisation or analysis of the data. Topological representations expressly store the relationships between any object and its neighbours, whilst object-oriented models store the structure of the objects, deriving the topology, and therefore spatial relationships as and when required (Zlatanova et al, 2002).

The aim of this research was to provide a common integration environment, allowing the input and output from numerous specialist software packages into a generic storage environment. The aim was not to replicate the complex analysis and modelling capabilities of the originating software. Therefore an object-oriented approach was seen to be the most suitable, providing a generic object which can be exported to any number of applications in any format in order to undertake this analysis if required.

Many large organisations, such as oil and gas companies, have invested huge sums of money in spatial data infrastructure, including GIS software and DBMS such as Oracle. It is important that any solution implemented in such an organisation fits seamlessly with this current infrastructure and therefore integrates with other processes and applications. Since this research was conducted on behalf of Shell, it was essential that their geo-information strategy be followed. This requires a common infrastructure to be implemented with ArcGIS providing desktop GIS capabilities and data storage being handled through ArcSDE in an Oracle database. Whilst this system is quite specific, the approach of utilising large corporate data stores providing data to desktop GIS is very common.

## 3D Features From Standard Spatial Representations

Arens, Stoter and van Oosterom (2003) and Gröger, G., Reuter, M., and Plümer, L. (2004), outline the storage of 3D features in a standard relational DBMS (in these cases Oracle 9i Spatial) using polygon features to create a 3D primitive. This ensures that features are stored within current workflows and as standard feature types. However in order to create the 3D primitive, numerous 2D features are required (using a multi-polygon approach or using linking tables). Whilst this is acceptable in Oracle 9i Spatial, the ESRI environment does not support multiple geometries for features. In order to allow the visualisation of the integrated dataset in Arc GIS, and thus follow the Shell geo-information strategy, any solution for the storage of 3D features must follow the ESRI requirements.

The use of ArcSDE provides for the storage of ESRI feature types (OGC compliant) in a relational database. This ensures that the storage solution is independent of the underlying database and is compatible with any existing GIS functionality for analysis, querying and visualisation. ArcSDE tables support a number of geometry types, including the standard point, line and polygon feature types. The limitation of using these geometries in the construction of a 3D primitive within the ESRI environment is that, although 3D coordinates are permitted in the definition of a feature, the final geometry must adhere to existing 2D constraints. For example, a polygon feature may be constructed from numerous points with z values, but two points making up the polygon may not have the same (x,y) value. This is because all topological operators acting on the polygon at the time of its creation (to ensure the polygon has no edges which cross, for example) act solely in two dimensions.

One practical example of this is the attempt to construct a box from a polygonal representation in an ESRI geodatabase. In the real world, a box can be created from a simple ‘net’, which itself can be represented in a GIS as a polygon feature. This feature is perfectly valid in 2D, or in 2.5D, but once an attempt is made to ‘wrap up’ the polygon to form the box, the topological operators will remove any ‘duplicate’ (x,y) points which form the vertical sides of the box (despite the fact that they are distinct vertices with different z values) as the feature is invalid. Therefore complex 3D objects cannot be stored using standard geometry types within the ESRI environment, even if these geometries have 3D (x,y,z) coordinates.

## ‘TRUE 3D’ FEATURES IN THE ESRI ENVIRONMENT

In addition to the point, line and polygon feature types in their geodatabase definition, ESRI provides a ‘*multipatch*’ geometry. This builds on the OpenGL 3D primitives of triangles, allowing features to be defined by collections of triangles in strips and fans (see Fig 1). Storing 3D features in the ESRI geodatabase as a multipatch geometry allows for a standard table structure with a single geometry field. This overcomes the limitation that ESRI does not support models requiring multiple geometry fields for a single record, whilst still providing the ability to store complex three-dimensional features. The multipatch facilitates a polyhedron approach to representing 3D objects – a collection of faces enclosing a space.

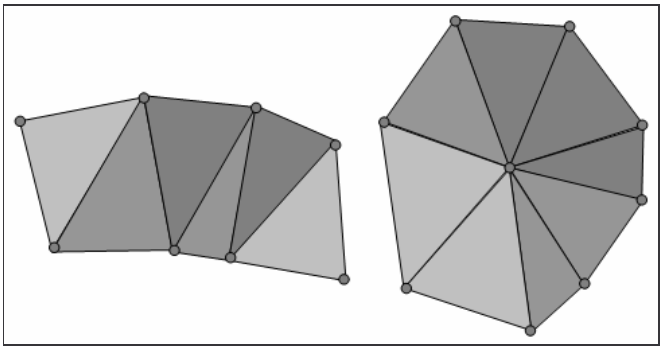

***Fig 1:*** Triangle Strip and Triangle Fan

Whilst the multipatch geometry is useful for defining the boundary and shape of a 3D feature, and its inherent structure gives an economical representation (without repeating points in the boundary), the resultant feature has no knowledge of volume or interior. This makes the multipatch geometry ideal for visualisation purposes but rather limited for analysis or complex operations. The basic GIS spatial analysis functions, such as spatial querying or intersection, are only supported in two dimensions, acting on the 2D footprint of the three-dimensional feature. Simple three-dimensional analysis has been written, computing the intersection of a well path with a reservoir model for example. Since the main purpose of integration in this case is to provide a common data store and allow the visualisation of disparate datasets in the desktop GIS environment this is not a major drawback. Any complex analysis, such as calculating reservoir flows, can be undertaken in more suitable software, as the generic representation can be exported in numerous formats.

## Creating Multipatch Features

Unlike CAD software, GIS editing is mainly undertaken in two dimensions and therefore the creation of three dimensional features is not directly supported through the editing interface. 3D features are therefore usually created from existing data by a number of methods (e.g. extrusion from 2D footprints). The data in this study has already been modelled and 3D features created in the source software. This removes an extremely complex step in the 3D data flow line, requiring simply the import and export of existing and well-defined 3D features from other sources, rather than the creation of the features within the rather limited ArcGIS environment.

Multipatch features must therefore be created from the input data using scripting with ArcObjects (ESRI, 2004), either as a VBA (Visual Basic for Applications) macro within the ArcGIS environment, or through a standalone application written with a COM language. This requires knowledge of the structure of any input data which will be visualised in the GIS in order to ensure that the output features are correct. In the oil and gas industry, and particularly the geological application area, a great deal of data transfer is done in the form of ASCII text files representing features as a series of x,y,z points. It is extremely important to have knowledge of the order of the x,y,z points in any input data as this impinges directly on the way that the multipatch is built up from the raw data.

For example, for data concerning a pipeline it is reasonable to assume that the x,y,z points will be ordered such that each point is sequenced along the feature. Conversely, with a complex geological feature, the array of x,y,z points provided from the source software could represent a limitless number of complex 3D shapes, dependent upon the order of these points. Therefore a separate input and output routine must be written to create the generic 3D features in the common data store and write these features back to specialist data formats of the geological software. However, once the generic storage model is in place there is no limit to the number of input or output routines which can utilise it, and the writing of these becomes a trivial task (assuming the structure of the input and output file format is well understood).

## EXAMPLE – RESERVOIR PROPERTY MODEL

It was decided to test the suitability of multipatch features as a means of storing 3D features by importing a reservoir property model created in Schlumberger's geological modelling software Petrel (Schlumberger, 2004) into ArcGIS. Petrel uses 'faulted grids' in its reservoir property models, which allow the user to define irregular variations throughout a solid structure. These grids are composed of three-dimensional cells of irregular shape and size, the number of rows, columns and layers throughout an object being constant rather than cell size.

A model was exported from Petrel in Eclipse ASCII grid format, which defines the two opposite corner points of each cell. These, in conjunction with the corner points of neighbouring cells, can be used to build up the irregular structure of the 'faulted grids'. The corner points of each cell were loaded into ArcGIS as XYZ Points. A number of nested loops were then written in ArcObjects to parse each cell and the corresponding neighbours in the correct order, adding each point to a Triangle Strip as before. A Multipatch feature was created for each cell, allowing each an individual record in the geodatabase table, and there allowing the assignment of attributes on a cell-by-cell basis. A multipatch representation of one such grid is shown in Fig. 2, complete with well trajectories displaying log data for each well using 3D symbology.

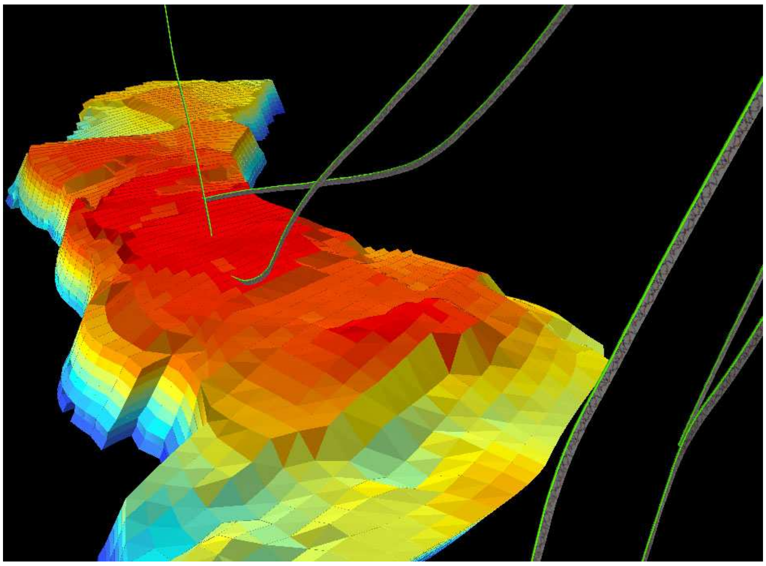

***Fig. 2.*** Petrel reservoir property model visualised in ArcGIS with well trajectories

Once multipatch features have been created within the ESRI geodatabase, their behaviour in ArcMap or ArcScene is essentially identical to any other feature type. The symbology of a multipatch feature may be set as normal, allowing the user to alter the display of the multipatch dependent upon any of the attributes in the geodatabase table. Whilst in most geological modelling software each cell is assigned only one property (or attribute), ArcGIS allows the storage of multiple attributes about each cell and the interactive display of these properties through symbology. It is also possible for the user to specify which components of the complete model are actually made visible in the 3D view by using SQL definition queries.

With the inclusion of a fourth geometry type in the ESRI geodatabase, it is now possible to store a collection of point, line and polygon features from standard GI sources alongside complex 3D objects from geological, engineering or surveying sources. This allows the integration of the standard 2D data found in many organisations with data from specialist geological modelling software, CAD data, or laser scanning data, providing the data formats and spatial representations of these input sources are known.

## MULTIPLE SPATIAL REPRESENTATIONS

In some cases the storage of a complex three-dimensional representation of a feature in a database is unnecessary. The overheads associated with the creation and storage of the sometimes thousands of triangles needed to accurately represent an object are not always outweighed by the benefits of improved visualisation and analysis capabilities they provide. On some occasions it is more efficient to store the location of a feature as a more simple standard geometry and utilise attribute information to link this location to the three-dimensional representation of the object.

For example, a pipeline feature can be stored as a simple polyline geometry in the database table but symbolised with a tube-like representation in the 3D view. The location of the pipeline is obtained from the polyline geometry, the diameter of the tube and any colour codes based on attributes in the associated table. This removes the need for the creation and storage of a 3D feature, but still delivers the required 3D representation when visualised. In ArcGIS 9.0, 3D symbology allows the representation of 2D features in three-dimensions in this way. This also removes the complication of representing 3D features cartographically in a 2D view.

The use of 3D symbology also allows for inclusion of more complex 3D representations since the symbols may be loaded from numerous CAD and 3D modelling formats (such as DXF, OpenFlight™ or VRML). This gives the ability to include more sophisticated primitives, such as cylinders or curved surfaces, and provide more realism through the application of texture images to the symbol. It also overcomes the lack of 3D editing capability within the GIS environment. Again, location, scale and orientation information can be obtained from the attribute table, determining how the simple feature is visualised in 3D. Using this approach, complex features, such as an oil drilling rig, can be stored in the database as a single point geometry and visualised with a true representation in the 3D view (see Fig. 3). The complex representation can still be queried and yield the full set of attributes for the point feature. Using a standard library of 3D models, linked to the attributes of the features ontologically, further improves the efficiency of the system. These 3D geometries are not utilised in spatial analysis functions, such as buffering or spatial queries, but are ideal for creating simple and effective 3D project overviews of all assets in a given area of interest.

***Fig. 3.*** OpenFlight™ drilling rig model representing a point feature

## CONCLUSIONS

We have shown that through the use of multipatch geometries it is possible to provide a generic data store for 3D objects in a standard ESRI environment. This allows the input of data from numerous complex 3D modelling and analysis packages into a standard commercial data store (in this case ArcSDE), facilitating the integration of these 'specialist' objects with other more traditional spatial data. From this common store, 3D features can be visualised and queried in two or three dimensions through ArcGIS or exported to any other specialist software for more complex analysis. The use of 3D symbology further enhances our visualisation by allowing the representation of simple point and line features with additional realism in the three dimensional view. Fig. 4 shows an example integrated dataset, displaying well trajectory data, surface data (including buildings, CAD representations of derricks and 3D models of trees) and geological data in the form of a subsurface reservoir. All data in this view is stored in a single ESRI geodatabase and visualised in ArcScene, within the ESRI environment. These developments allow GIS to position itself as a true integration tool, in both two and three dimensions, thus providing the ideal means for project management, data archiving and decision support.

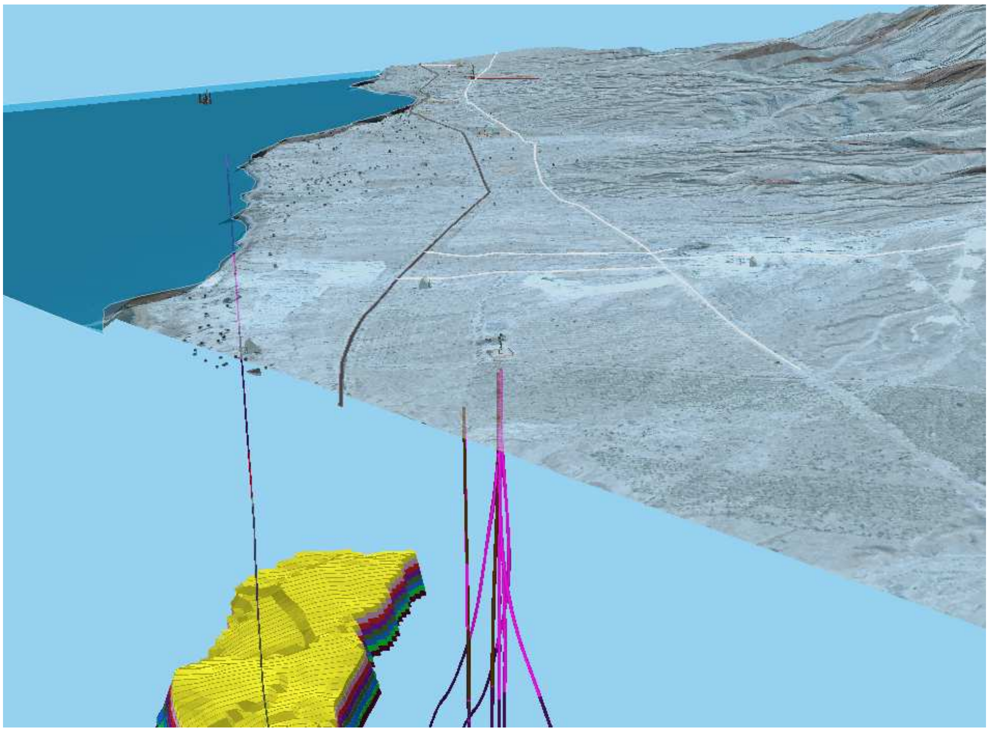

***Fig. 4.*** Example integrated dataset

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