Lecture 1 - Introduction to GIS

This lecture will cover:

- What GIS is
- What GIS does
- What GIS does not do
- GIS and archaeology
- Data structures:
  - Vector
  - Raster
- Mapping systems and projection
- GIS software packages:
  - ArcGIS
  - GRASS
  - Others
- Sources of data

What is GIS?

Today we shall be talking about what GIS is and how it is structured. The use of GIS is now widespread in archaeology, but in order to understand why and what it can do for us as archaeologists, we first need to understand what it actually is. As an acronym, GIS is usually taken to stand for either Geographic Information Systems or Geographic Information Science. Unfortunately, there is some disagreement over what actually defines a GIS, with some people even arguing that the term itself is not useful at all. However, the software exists and performs many tasks of great use when studying the past. As such, we can follow Wheatley and Gillings' definition of GIS as “computer systems whose main purpose is to store, manipulate, analyse and present information about geographic space.” This is a definition that could also describe other technologies, such as CAD: however, the key difference with GIS is in its abilities to both integrate multiple sources of data and to analyse space.

What does GIS do?

What, therefore, does GIS actually do? Several things, in fact:

- It allows users to map multiple different sources of geographic data within a single computerised environment. Different data sources are usually treated as layers, which may be reordered and switched on and off at will, set to varying transparencies, and manipulated through tools such as zooming, panning, and sometimes rotating.
- It allows users to employ many different and powerful tools to analyse the spatial distribution of their data. This spatial analysis can provide a route into discovering and unlocking previously unseen patterns in our data, shedding new light on unknown aspects of the past.
• It also allows users to produce paper and electronic maps for inclusion in their work and for the dissemination of their results to the wider archaeological, historical and public communities. Depending on the GIS software used, this might include animations or interactive maps delivered over the internet.

Thus, essentially, GIS provides the tools to integrate spatial data, to analyse spatial data, and to present spatial data to a wider audience. GIS works best when its users take a question based approach. In other words, if you have a question you wish to ask of your data, you should think about if GIS can help you to answer that question, which particular tools and other sources of data would be needed to begin that analysis, and whether the potential benefits outweigh the potential cost in time (and sometimes in frustration). Examples of archaeological questions with which GIS can aid might include:

• Where have 2nd century AD coins been found in Oxfordshire?
• What is the relationship between Neolithic stone axe find spots and quarries?
• Is there any spatial relationship between known Iron Age sanctuary sites and modern spring sites?
• Was there any relationship between the spread of farming across Europe and the availability of navigable rivers?
• What is the likelihood of archaeological disturbance involved in the building of a new theme park?

This final question is one that we shall attempt to investigate through the practical element of this course.

What does GIS not do?

However, GIS is not a panacea that can solve all of our problems. It has several drawbacks and difficulties that must be borne in mind by any user who wishes to produce good quality, authoritative results:

• It is easy to disguise poor quality data by entering it into a GIS, resulting in maps that convey an undue authority. Users should make very clear any concerns that they have about data quality, either in the description of any published map, and preferably also through the use of appropriate symbology. For example, any uncertainties associated with objects can be graphically expressed through careful choice of symbols (e.g. half filled squares for possible Roman fort sites), or through the intelligent use of transparency.

• Electronic maps output from a GIS may need tweaking in picture editing software to produce the best results for publication. For example, it can sometimes be difficult to persuade a GIS to achieve the best clarity in the labelling of objects, and so some labelling may be better performed using a picture editor. If too much picture editing is likely to be required and the production of publication quality maps is the only aim, it can sometimes be easiest to simply produce your maps using drawing software, rather than going through the often lengthy process of entering data into a GIS.

• Many of the tools provided by GIS packages can be applied to data where their use would not be appropriate. GIS tools can be used to support distinctly spurious ideas and to cloud what might normally be seen as unconvincing conclusions. Furthermore, it is very easy to produce results using GIS tools that look very pretty, but convey very little substantive content. As such, the application of spatial analysis tools should only be undertaken where appropriate: you can determine this by reference to the tool documentation, GIS textbooks, and from the results and methods of comparable studies undertaken by other researchers.
Finally, the most widespread GIS packages only express a fraction of the true spatial complexity of the world around us. This is because the third dimension is only just starting to be properly represented and, furthermore, time is entirely absent from the majority of conventional GIS packages. Time is what separates geography from geometry, so current GIS software will remain incomplete until their developers begin to integrate temporality. This is an issue that should not unduly concern new users of GIS, but they should remember that any maps that they produce using the software will always be a simplification of the true complexity of the world in which humanity lives and has lived.

Nevertheless, if we approach our use of GIS with a proper questioning and considered attitude, the benefits of its usage can be legion.

**GIS in archaeology**

As mentioned earlier, GIS is now very widely used amongst archaeologists and it also has increasing relevance to members of other historical disciplines. Many different types of data can be integrated into an archaeological GIS project, and many different forms of analysis appropriately applied to them. Common data types include:

- Background map data, taken from national mapping agencies or other sources.
- Digital Elevation Models (DEM) of terrain (more on which later).
- Aerial photographs of archaeological sites.
- Satellite images, used to display background geographic context, modern vegetation patterns, or to discover new sites (particularly in barren, desert locations).
- The results of geophysical surveys, such as resistivity, magnetometry, ground penetrating radar, etc.
- Field survey results, showing survey transects / sites and including their quantified contents.
- Excavation data recorded using Computer Aided Design (CAD) tools.
- Sites and monuments records, and other equivalents.
- Environmental data, such as soil maps, hydrology, climatic data, etc.

All of these and many other types of spatial data may be combined, and studied together in a GIS. GIS-literate archaeologists may then use various analytical methodologies to explore and test these data sets, commonly including:

- Viewsheds showing the visible terrain from a particular site.
- Predictive modelling of areas of archaeological sensitivity.
- Cost surfaces used to plot possible past travel routes through the landscape.
- Trend surfaces used to estimate the average state of a variable (such as artefact deposition) across a landscape.
- Spatial and attribute querying of data, and statistical analyses.
- Analysis of clusters, territories, and site catchments.
- Hydrological and palaeoenvironmental modelling.

These have their own varied problems and advantages, which will be discussed in the next lecture. For now, suffice it to say that there are many GIS tools available that are commonly applied to archaeological material. The main criticism of archaeological GIS is that it can result in an unacceptable degree of environmental determinism in its results. This will be discussed in the following
lecture, but should again not provide any great problem to archaeologists who apply GIS methods with an appropriate question-based approach and considered attitude.

The process of analysing spatial data using GIS should begin with an assessment of what data you have, what you would need to gather yourself, and what you would need to obtain from other people and organisations. You should also at this stage consider whether the application of GIS methods would be useful and cost-effective, and what particular tools would be likely to produce interesting results in the context of the data you will possess and the questions you wish to consider. Following that assessment, the first stage of entering your own data into a GIS is to decide which data model best fits the nature of each item of your material.

**Data structures**

Spatial data entered into a GIS always fits into one of two main data structures, being either raster or vector data. Taking the raster data model first, it represents space as a continuous field consisting of squares (called pixels) of a standard size, like the picture on a computer monitor or TV screen. It is thus most appropriate when used to represent continuous data. Common examples of data that fit into the raster data model in archaeology include aerial photographs, satellite images, geophysics results, soil maps, scanned maps such as early edition Ordnance Survey maps, and DEMs, etc. For clarity, a DEM or Digital Elevation Model is a raster grid that gives the height of the ground surface for each grid cell. These may be recorded directly using aeroplane-mounted LIDAR or from orbit, or may be estimated from other elevation data such as contour maps. Whilst it is also possible to record discontinuous data such as river or road systems as a raster grid, it may result in a large amount of data redundancy, and will also likely result in a reduction in data quality. However, it might be necessary to do so in order to conveniently apply particular analytical tools. The greatest difficulty when dealing with raster datasets is that they can become very large: a 20 x 20 kilometre DEM consisting of 10 x 10 metre grid squares would contain 40,000 cells; increasing the resolution to 1 x 1 metre would result in a raster containing 400,000,000 cells (i.e. 400 megapixels). Most computers would struggle to display such a raster with anything approaching a usable speed, so care should be taken to avoid dealing with raster material that is of a higher resolution than needed to accurately answer the questions that you wish to ask.

By contrast, the vector data model represents material as points, lines, and areas. Thus, it is most appropriate when used to represent discontinuous data. Common examples of data that fit into the vector data model in archaeology include Ordnance Survey topographic data, rivers, lakes, coastlines, roads, administrative areas, field survey transects, CAD files, find spots, sites and monuments records, and soil maps again, etc. Vector data is more amenable to zooming in and out than raster data (which can become very blocky at high magnifications), and copes much better with the linking of multiple attribute fields to geographic objects. This is especially the case when the attachment of text fields is necessary. It is much easier to link a data table to a map of find spots recorded using the vector data model than it would be if they were recorded as a raster. This ease of linking to attributes is probably the greatest strength of the vector data model, as rasters are more conveniently associated with just one or a handful of numeric fields for each cell (such as the red, green and blue bands in a colour aerial photograph). The vector data model also allows the explicit recording of topology: that is the logical geometrical relationships between objects. Common topological relationships would include being inside or outside of a polygon, the nature of a road or river crossing (i.e. which went above which,
or junction priority, etc.). By way of example, the Harris matrix familiar to most British archaeologists forms a topology, as does the London Underground map. The recording of topology can be important when using a GIS to study travel networks, river flows, etc. and it is also an important step in the building of a robust vector dataset.

In the past, different GIS software systems were needed to study raster or vector data, but modern systems tend to provide the capacity to study both together. However, the raster or vector origins of the software package used will often be reflected in the greater provision of tools for the study of data that fits their original data model (more on which later). The choice between representing data in raster or vector format will usually be determined by the type of data represented, as particular types of data lend themselves to one or other of the two models. However, it remains possible to represent much data using either model, if the circumstances merit it. Generally speaking, users will find that their data model has already been determined by whoever originally created the data that they are using. Nevertheless, they should be aware of the different ways in which the two data models behave and the different analyses that can be applied to them (more on which in the next lecture). Furthermore, when creating their own datasets, users should take care to pick the most appropriate data model, both in respect of the type of data being analysed, and the questions that the user wishes to use it to answer. In essence, rasters are better for recording and analysing continuous field type variables, and vectors are better where many attributes need to be studied. Most projects will involve a mix of raster and vector data.

**Mapping systems and projection**

Once you have your data computerised in a suitable format, you will encounter perhaps the most difficult aspect of GIS for non-geographers to conceptualise: map projection. If you are only going to work with UK mainland data, then it is best if you just record everything using Ordnance Survey National Grid co-ordinates, as that will minimise any thought you would have to give to projection. However, for GIS entry, you will have to record the easting and northing elements in separate fields and, if you are dealing with data that spans more than one of the large 100 x 100 kilometre grid squares designated by the OS using letters you will have to convert them to numeric values (instructions on how to do this are included as part of this course). Nevertheless, the convenient shape and extent of the British Isles allows the use of a single national grid, thus making GIS analysis much simpler than would otherwise be the case.

However, if you work with non-UK data or with UK data recorded using latitude and longitude, you will have to deal with projection. Map projection is the method by which the curved surface of the Earth is mapped onto a flat plane for representation on a paper map or computer screen. A simple experiment to see why projection is necessary is to attempt to wrap a rectangular piece of paper around a ball: you will soon discover that it is impossible to do so without significant folding of the paper or the tearing out of sections. As a result, any attempt to map the curved surface of the globe onto a flat map must inevitably involve some form of compromise.

There are two basic categories of map coordinates: geographic and projected. Geographic coordinates are expressed in degrees of longitude and latitude, and accurately place any object on the Earth’s surface. However, any apparently flat line on a map
constructed from geographic coordinates is, in fact, a curve when mapped back onto the Earth. As a result, making calculations of distances and areas becomes prohibitively complicated. It is much easier if we can use a map where a straight line on the map reflects an apparently straight line on the ground. This is where projected coordinates come in. There are many different types of map projection, but all have the same basic aim: to make it possible to measure particular variables without the need for overly complex mathematics. Some projections maintain angles, some distances, and some areas. Furthermore, most projections will only work for a small area of the Earth’s surface: if you lay a flat piece of paper on a ball, you can see how you could closely trace any patterns on the ball’s surface at the point of contact, but that distortion will increase as you move away from that area. Wrapping the paper round the ball as a cone or a cylinder improves the situation, but still results in distortion. This is how most projection systems work and is also why it is convenient to work in the UK, as the British mainland is small enough to be projected using a single system without encountering too much distortion. People working in larger countries will have greater difficulty.

Therefore, it is almost always best and simplest to work with projected coordinates whenever possible. However, many data sources will output geographic coordinates. This is particularly the case for archaeologists when collecting data using GPS, which conventionally output in degrees latitude and longitude. Any such data source will have to be converted to projected coordinates before any spatial analyses can be accurately performed. If you are working outside of the UK, it is usually easiest to ask other local archaeologists what projections they use, and to then follow suit. A good catch-all choice when unable to determine which projection you should use is the Universal Transverse Mercator. Projection using a GIS is fairly straightforward, but becomes much more complex when an area is too large geographically to accurately fit within a single projection.

There are also political issues over choice of projection. Think of a normal map of the world: this is likely to be in the traditional Mercator projection, as it maintains bearings for navigation. However, this particular projection greatly distorts in area as you head towards the poles. As a result, western Europe, Russia and North America all become greatly exaggerated in size when compared to countries closer to the equator. This is, understandably, a real bone of contention in the growing powerhouse nations such as China, Brazil and India due to their closer proximity to the equator, and also elsewhere in the world. As such, if working in equatorial regions, it could potentially diminish the respect your local colleagues have for your work if you select a map projection that so diminishes the relative size of their countries. Take advice and choose wisely.

Once you have your data integrated into your GIS and have, if necessary, projected it into a suitable coordinate system, you can finally start your analysis. We shall discuss that in the next lecture.

**GIS software packages**

Another choice to make is which software to use, as many different GIS packages exist. This course is based around ESRI’s ArcGIS, as that is widely available to university-based archaeologists. However, it is not a cheap product, so alternative packages may be considered more appropriate in some circumstances. Some universities use the similar MapInfo software produced by Pitney Bowes. Many commercial archaeological units will also use one or other of these software packages. ArcGIS and MapInfo
both began life as vector GIS packages and, as a result, arguably possess better tools for the analysis of vector data. However, both also now possess extensive raster tools.

However, a product with raster origins and, thus, stronger raster tools is GRASS. GRASS was originally developed by the US armed forces, but has the significant advantage of now being open-source and distributed for free. Being open-source means that the program code is available to anyone for adaptation. When combined with a related product called QGIS, GRASS provides a fully-featured no-cost alternative to the major commercial products mentioned earlier. Oxford Archaeology are particular supporters, as part of their initiative to move all of their computer systems over to open-source software. GRASS is often found to be less user friendly than ArcGIS, but this situation is improving rapidly. Other largely raster-based alternatives are IDRISI and ERDAS IMAGINE.

ArcGIS is the current market leader. Both it and GRASS also possess a large number of user-generated extensions to add functionality to the core software. As such, ArcGIS is a good choice if you can get hold of it, but GRASS may be a stronger choice for those who need to keep working with the same data and software post-university. It is possible that you might be able to get hold of a copy of ArcGIS for home installation from your university’s IT services, or it may be available over your network. Local installations tend to be more stable and to include more functions.

Sources of data
As a final note, the practical handout contains a list of websites where you can find geographic data that you may find useful. You may also be able to obtain data from your colleagues, or you may need to gather data yourself. The easiest way today to gather spatial information in the field is through the use of GPS, especially if you have access to accurate high-grade equipment. However, it also is possible to integrate data gathered using any more traditional method into your GIS, it will just take a little more work. When gathering your own data, you should take care to record what is known as metadata: that is data about data that describes the nature and quality of your dataset. This will be discussed in the final lecture.

To conclude, GIS provides a powerful tool for archaeologists and others to explore the spatial dimension of their data, and to produce good quality maps for publication. It has its own particular strengths and weaknesses, but if approached inquisitively can produce insights into our material that might otherwise have remained hidden. The next lecture will discuss exploring your data, and the final lecture will discuss preparing your maps for presentation to the wider world.