Viewsheds

Techniques for spatial data analysis
Last week

- We looked at how we could measure error propagation and one way of making calculations that dealt with vagueness and uncertainty
  - We saw how we could approximate errors for simple systems with Taylor series
  - We looked at how Monte Carlo Simulation allowed us to explore uncertainty for a range of standard GIS outputs and a complex process model
  - We used Regionalised Variable Theory to remember that spatial autocorrelation might be important in MCS
  - Finally, we looked at one simple overlay example of the use of Fuzzy Set methods
Outline

• What is a **viewshed** – what can we use them for?
• Basic concepts of **viewshed algorithms**
• How viewshed algorithms **work in detail** – does it matter?
• **Alternative viewshed** representations
• **Applying** viewsheds in spatial analysis

• Remember that I talked about viewshed uncertainty analysis last week too - i.e. as an example for *Monte Carlo Simulation*
Learning objectives

You will:

• **know** what a **viewshed** is, and can **explain** how it can be **calculated**;

• be able to **give examples** where the use of a **binary viewshed** is a poor choice, and can **explain** how we can improve our **representation of viewsheds**; and

• be able to **describe** and **discuss** **hypotheses** that can be **tested** by the use of **viewsheds**.
What is a viewshed?

• A viewshed is the calculation of **all the places** in a landscape visible from **a single location**

• Generally, viewsheds are represented with a point being either visible or not from a particular location (binary)

• How often can you see Mt. Rae from Calgary?

• Is Mt. Rae in the viewshed from Crescent Heights or not?

Viewsheds in Anjeni

The green places are visible from the river (as calculated by ArcGIS)

Draw the slope along the red line..
What is the profile curvature?

You could compare the viewshed here with the catchment
What can we use viewsheds for?

[Images of different scenes, each with a source URL]

©National Wind Power
Calculating viewsheds - concepts

• To calculate a viewshed we test the visibility of every point in a landscape from some viewpoint.
• We test this visibility by drawing a line of sight (LOS) from the viewpoint to the point being tested.
• If the LOS does not intersect any terrain the point is visible – otherwise it is not.
Calculating viewsheds – concepts (2)

• We have three different viewsheds for the same terrain – we applied a vertical offset to the viewer or the viewed objects and got a set of **binary answers**

• What would happen if an **offset object** (e.g. tree) obscured the next object?

• How **sensitive** is our viewshed to the point we choose to test?
Fisher and viewsheds

• **Peter Fisher** wrote a series of articles investigating viewsheds

• He was interested in a number of aspects of viewshed, including:
  - How do **results** vary according to the **algorithms** used to derive viewshed?
  - How sensitive are the results to **errors in elevation**?*
  - How useful is the basic concept of viewshed in different fields and **how can it be extended**?

• We are going to look at Fisher’s results for each of these 3 aspects in turn…

*) you remember the article I uploaded on MCS for viewsheds
Algorithms for viewsheds – raster data

• The basic algorithm is simple
  – For every point in the landscape to be tested draw a line of sight (LOS) from the viewpoint
    • Test for intersection of that LOS with the surface at some interval – if intersection is found point is invisible
    • If no intersections are found point is visible
  – These operations must be repeated for every point we want to test

• The principles are the same whether the data structure is a raster or a TIN
Deconstructing the algorithm

- Although the algorithm is very simple to express there are **different ways** in which it can be implemented.
- We will consider the raster case (although the questions for a TIN are similar):
  1. Are we treating the viewpoint and the test points as **points** or **cells**? (This also determines the LOS used)
  2. How do we **calculate elevation** as we travel along our LOS?
  3. How do we calculate if a **particular location** is **above or below** the point being viewed?
1: Viewpoint as point or cell?

In tests with more than one LOS what is our test for visibility?

Once, twice, more than 50% ??

Here we simply test whether we can see a point from a point.

Here we test for a cell – we test each corner for visibility.

Fisher’s experiments use more than once means visible.

This is just the reciprocal of the above case.

If we test for cell to cell there are 16 LOS if we use the corners!
2: What elevations should we test?

Here we test every time we cross a line. The value at the crossing is simply the linear interpolation between the next points of the grid (a).

In this case we add “faces” by triangulating. Again we test every time we cross a line. Note that the triangulation changes from point to point, so different elevation values are implied… (b)

Finally we can consider each cell as a horizontal plane with the same value everywhere and abrupt changes at the edges (c).

The red cross sections give a schematic idea of the variation in elevation along the LOS.
If any of the following is true then **C is not obscured by E** (where C is higher than A):

- $AD > AE$
- $DF > EF$
- $\text{Angle ACB} < \text{Angle AEF}$
- $\text{Angle BAC} > \text{Angle FAE}$
- $\frac{AC}{BC} > \frac{AE}{FE}$

We can calculate these tests in different ways which could give rise to different results... (through rounding, integer arithmetic etc)
Does it matter?

• These might all seem relatively trivial concerns
• BUT – which does ArcGIS use?
• Fisher implemented the different algorithms and compared the viewable areas for 2 test sites on 100x100 DEMs
• He found that for the first two alternative sets of implementation significantly different results were obtained
• The last – how we do the actual height calculation was much less sensitive
Fisher’s results (visible cells)

<table>
<thead>
<tr>
<th>Viewing point</th>
<th>Test site 1</th>
<th>Test site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point to point</td>
<td>2381</td>
<td>2034</td>
</tr>
<tr>
<td>Cell to point</td>
<td>3328</td>
<td>2271</td>
</tr>
<tr>
<td>Point to cell</td>
<td>2707</td>
<td>2666</td>
</tr>
<tr>
<td>Cell to cell</td>
<td>3970</td>
<td>2907</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elevation approx.</th>
<th>Test site 1</th>
<th>Test site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grid (a)</td>
<td>2381</td>
<td>2034</td>
</tr>
<tr>
<td>Triangulation (b)</td>
<td>2312</td>
<td>1917</td>
</tr>
<tr>
<td>Stepped (c)</td>
<td>656</td>
<td>92</td>
</tr>
</tbody>
</table>

Are these results what you would expect?

How could we test the significance of these results?
What is the impact of errors in elevation on viewshed?

• Fisher also wished to examine how error in height values could influence viewshed generation.

• He applied random errors multiple times to the same DEM (= Monte Carlo Simulation) and compared the viewshed areas from the set generated with the original viewshed.

• He found that the viewshed in the DEMs with error was consistently smaller in area than in the DEM with no error (= original).
What do Fisher’s results mean?

• Fisher found that the actual algorithm used and error in the DEM could both lead to significant variation in the viewshed calculated.

• He argues that treating viewshed as a binary surface is inappropriate, and rather that we should assign a probability of a location being seen.

• He shows how probability viewsheds can be generated using Monte Carlo Simulation (what I showed last week)…
More from Fisher...

• Fisher spent a lot of time working on these ideas
• This prompted him to think about what we were actually using viewshed for (Fisher 1996)
• We use viewshed to model something else than the basic algorithm is for, for instance:
  - To position a tower for observing forest fires – here we are concerned about our ability to spot fires, not the ground. Seeing smoke is a good indicator of fire!!
  - To decide on the visual intrusion of a planned building or object – in this case a location on the skyline (horizon) is much more visually intrusive than one against the skyline
We can see fire smoke for some distance beyond the horizon...

Small palace on skyline has most impact

Development above skyline has great impact

Palace beyond horizon but above skyline still has impact

Development in view but below skyline
Example: Fire Lookout Towers

Based on a 6' tall person, assuming a 45' high smoke column

http://www.nps.gov/archive/meve/fire/viewshed.jpg
Alternative representations of viewsheds

• Fisher (1996) proposes alternative viewsheds which give more information about such problems, two of these are:
  
  1: **Horizons viewshed**: visibility analysis results:
      • a location is in view (1),
      • a local horizon (for example, a hill top) (2),
      • a global horizon (3)
      • or not in view (0)
  
  2: **Global offset viewshed**: if in view report the offset to the global horizon, if not in view report the negative offset to the global horizon
These viewsheds give **alternative sets of information** which can be used to further inform our interpretation of viewsheds.

Such ideas further demonstrate how we can explore what appears to be a single GIS command...

You should think about problems where we could use these... (LO: 3)
Summary

• Viewsheds are usually binary surfaces telling us what is seen and not seen.
• We calculate viewsheds using lines of sight from a viewpoint to every point in a landscape.
• If a line of sight intersects terrain before the point we are trying to view, it is not visible.
• The way we define these lines and the viewed and viewing points has impacts on our defined viewshed.
• Fisher suggests a probable viewshed is a more sensible proposition.
• He also presents some alternative definitions of viewsheds.
Viewshed examples

• In the first half of the lecture we explored the viewshed function in some detail
• In the second half we will look at three examples of the use of viewshed in spatial analysis:
  – Archaeology
  – Studying corridors through a landscape
  – Assessing impact of forest operations from a visibility perspective
A - Using GIS in archaeology

• Archaeologists are often interested in **spatial patterns**

• Viewshed analysis has been used by archaeologists to try to **explain position** of ceremonial, defensive and settlement sites

• For instance, they ask questions like:
  - Are **stone circles** positioned to allow **viewing a particular part of the sky** or landscape?
  - Are **forts** positioned to **guard against attack** from one direction?
  - Do **settlement sites** provide the best locations for spotting potential “prey”? 
Using viewshed in archaeology (1)

• A paper by Lake et. al. (1998) explains that archaeologists often use viewsheds to examine whether one site is visible from another.

• He states that

  “At present archaeologists run the risk of letting the software, as designed for non-archaeological applications, dictate the questions they ask of the data and how they go about answering them.”
Using viewshed in archaeology (2)

- If sites are *intervisible* this is then used to suggest that their *siting* was in some way influenced by visibility
- However, Lake points out that if we wish to ascribe importance to intervisibility *we must show* that the sites in question are *unusual in their viewsheds* with relation to the rest of the area
- This is of course basic science – but we often forget it!
Using viewshed in archaeology (3)

• Lake et al. demonstrate the idea by forming a hypothesis

• For 8 Mesolithic sites on Islay they asked the question:
  – Is the view at these sites any more extensive than would be expected by chance alone?

• In order to test this they needed to know the number of cells visible from every location in the landscape (this is often called the cumulative viewshed)

• The cumulative viewshed is computationally intensive to calculate

• The null hypothesis is that there is no difference between the viewsheds selected at random from the landscape and the settlement sites
From: http://www.ministryofpropaganda.co.uk/blogimages/20050402-islay-jura-big.jpg
Implementing their tests

- The sites were located in an area 390 km²
- The viewsheds were calculated for a 50m DEM
- thus, viewshed calculation has to be performed for 156,000 times (= cells)
- The experiments compared a random sub-set (5%) of data with the sites
- The authors considered edge effects (edge cells of the DEM), but found these to have no influence for this case
Results

• There was no visible difference between the sites and randomly selected non-sites in distribution of viewshed size.

• As the authors said “…there is no evidence that Mesolithic sites on the Rhinns of Islay were sited preferentially with respect to commanding views.”

From 40% of cells, up to 2000 cells are visible.
B: Viewsheds for Least Cost Paths

- **Least cost paths**: the route between two locations that **accumulates the minimum possible cost**
- Where all values have the same cost, the least cost paths is a straight line
- Lee and Stucky (1998) illustrate the use of viewshed in calculating cost paths
Aside - Identification of Least cost paths...

Steep slopes

Near tourism

Far from roads

Far from railway

Cost surface

Cost path
Using viewshed in cost paths (1)

• If we calculate the viewshed at every point in our landscape, we can calculate for every cell the number of cells visible (again, the **cumulative viewshed**)

• We can also calculate the number of **cells from** which the cell is visible (**inverse** cum. viewshed)

• These two numbers are only the same if the height of the viewpoints and the viewed points is the same with respect to each other e.g:

I can see your head
I can’t see your feet!

My feet can’t see your feet

I can see your head
I can see your feet!

My feet can’t see your feet
Using viewshed in cost paths (2)

- Lee and Stucky define these two grids as:
  - viewgrid (VG): for each cell how many cells are visible
  - dominance viewgrid (VD): how many cells is each cell visible from

- They then define **4 paths** through the landscape:
  - **Hidden path** – *the path between two points which minimises being seen*
    \[
    \min \sum_{k=1}^{n} VD_k
    \]
  - **Scenic path** – *the path which maximises what you see*
    \[
    \min \sum_{k=1}^{n} VG_k^* \quad \text{where for each cell } \ VG_k^* = \max VG + \min VG - VG_{ij}
    \]
    Note that since we must find a **least cost path** we actually need to **invert the values** for the scenic path
Two more cost paths

- **Strategic path** – the path between two points which maximises what you can see, whilst minimising how much you are seen

\[ \min \sum_{k=1}^{n} V_k \text{ where for each cell } V_k = \max(VD, VG^*) \]

This equations sets the worst case for each cell and then the least cost path attempts to minimise it (i.e. the maxima) in each case

- **Withdrawn path** – the path which is not only minimally visible but also sees the minimum amount possible

\[ \min \sum_{k=1}^{n} V_k \text{ where for each cell } V = \max(VD, VG) \]
Euclidean – cyan
Scenic – blue
Strategic – red
Withdrawn – green
Hidden – yellow

Note that no path is allowed to cross slopes steeper than 50°

Lee and Stucky (1998)
What could we use these for?

• All four of these paths might be useful in **planning** or considering paths

• What might we use
  – The **hidden path** for?
  – The **scenic path** for?
  – The **strategic path** for?
  – The **withdrawn path** for?
  (... besides military applications)

• Note that in these results **edge effects** seem to cause problems in some of the scenarios
C: Quantifying forest visibility

• Wing and Johnson (2001) investigated forest use and visibility
• They collected questionnaire data to find out which routes people took in the forest and then calculated which area of the forest were seen by the most visitors from their linear routes
• This information can then be used in forest management – by using statistics on visits to the forest it is possible to identify in which areas timber harvesting will have the most visual impact with respect to recreational forest use…
More on the forest

- The area is small (29km²)
- **Tree height is important** in visibility analysis(!!) – information was digitised about tree height in small polygons and these heights added to the DEM heights…
- The study assumes that users travelling along a road constantly look in all directions (dangerous 😐 and unlikely!)
- However, this study is a useful attempt to use viewsheds in a **practical management application**
Summary

• We saw three applications of viewshed
• You should think about what sorts of spatial analysis was going on
• None of them used a simple binary viewshed from a single point
• They all used some kind of cumulative viewshed to make decisions or describe landscape properties
• All of these examples extended the concept of viewsheds in a useful way…
Next week

• We are going to look at the use of databases in GIS
• Firstly, we will define some basic, aspatial, database terminology
• Then I will look at some spatial database ideas and how they can be used
• Finally, we might look at some practical examples of the use of spatial databases (and carry this on to the following week, where we look at GIS and mashups)
References


