THANK YOU!

http://www.rnn.ed.ac.uk/
http://archaeologicalnetworks.wordpress.com/

Acknowledgements

Prof Stuart Erry - Dr Guiseppe Masi - Carlo Lettieri - the vienna network - ANDR - Dr David Whitley - Ge Coop - Dr Greg Johnson - University of Guelph - Department of Forestry and Resource Economics - University of Sherbrooke - Department of Environmental Sciences - University of Biarritz - Department of Geology - University of Cambridge - Department of Archaeology - University of Mainz - Department of Prehistory - Prof Antonio Piccioni - Prof Antonello Fronza - Dr José Miguel Rodríguez-Hidalgo - Dr Lavinia Quaglia - Dr Tomás Aquino - Universidad de Barcelona - Digital Earth - The University of Oxford
Exploring visibility networks in Iron Age and Roman Southern Spain with Exponential Random Graph Models (ERGM)

Tom Brughmans, Simon Keay, Graeme Earl
Archaeological Computing Research Group
University of Southampton

Digital Classicist, London, 7 June 2013
http://connectedpast.soton.ac.uk/
Aims

1) changing interactions between urban settlements, as reflected through patterns of inter-viability.
2) a method for bridging static and dynamic spatial network approaches.
Aims

1) changing interactions between urban settlements, as reflected through patterns of inter-visibility.

2) a method for bridging static and dynamic spatial network approaches.
A method for bridging static and dynamic spatial network approaches.
Aims

1. changing interactions between urban settlements, as reflected through patterns of inter-visibility.
2. a method for bridging static and dynamic spatial network approaches.
Study Area
Research Questions
Processes of emerging inter-visibility

I aim to evaluate the probability that inter-visibility was considered an important aspect of site location.

Endogenous processes

"If the visibility patterning that we have observed was the only reason for selecting site location, what then would be the process that is most likely to have led to the observed patterning?"

Exogenous processes

"To what degree were these processes influenced by site attributes and previous states?"

(urban status, transport networks, Iberian origins)
Processes of emerging inter-visibility

I aim to evaluate the probability that inter-visibility was considered an important aspect of site location.

Endogenous processes

"If the visibility patterning that we have observed was the only reason for selecting site locations, what then would be the process that is most likely to have led to the observed patterning?"

Exogenous processes

"To what degree were these processes influenced by site attributes and previous states?"

(urban status, transport networks, historic origins)
Research Questions
Issues in visibility studies
(from Wheatley and Gillings 2000)

Multi-sensorial information gathering
Movement
Dominance of vision
Western biases
Geomorphological processes
Topographical models
Atmospheric conditions
Past vegetation
Closeness of the observer to the feature
Object-background clarity
Observer

Combined method
Introducing variability
Higuchi viewshed
Fuzzy viewshed
Probable viewshed
Cumulative viewshed
Total viewshed
Multiple viewer points

Defining visibility

“past cognitive/perceptual acts that served to not only inform, structure and organise the location and form of cultural features, but also to choreograph practice within and around them.”
(Wheatley and Gillings 2000, 3)

My assumptions

The presence as well as the absence of a line of sight from one urban settlement to another reflects the possibility that (i) this was intentional, (ii) it structured the surrounding space, and (iii) that the way in which it structured space might reveal aspects of the roles ascribed to it in the past.
Issues in visibility studies
(from Wheatley and Gillings 2000)

Multi-sensorial information gathering
Movement
Dominance of vision
Western biases
Geomorphological processes
Topographical models
Atmospheric conditions
Past vegetation
Closeness of the observer to the feature
Object-background clarity
Observer
Combined method
Introducing variability

Higuchi viewshed
Fuzzy viewshed
Probable viewshed
Cumulative viewshed
Total viewshed
Multiple viewer points

Defining visibility

"past cognitive/perceptual acts that served to not only inform, structure and organise the location and form of selected features, but also to integrate and co-ordinate them into a unified whole"
Defining visibility

“past cognitive/perceptual acts that served to not only inform, structure and organise the location and form of cultural features, but also to choreograph practice within and around them”
(Wheatley and Gillings 2000, 3)

My assumptions

The presence as well as the absence of a line of sight from one urban settlement to another reflects the possibility that (i) this was intentional, (ii) it structured the surrounding space, and (iii) that the way in which it structured space might reveal aspects of the roles ascribed to it in the past.
Issues in visibility studies
(from Wheatley and Gillings 2000)

Multi-sensorial information gathering
  Movement
  Dominance of vision
  Western biases
Geomorphological processes
  Topographical models
  Atmospheric conditions
  Past vegetation
  Closeness of the observer to the feature
  Object-background clarity
  Observer

Combined method
Introducing variability

Higuchi viewshed
Fuzzy viewshed
Probable viewshed
Cumulative viewshed
Total viewshed
Multiple viewer points

Defining visibility

“...past cognitive/perceptual acts that served to not only inform, structure and organise the location and form of cultural features, but also to choreograph practice within and around them”
(Wheatley and Gillings 2000, 3)

My assumptions

The presence as well as the absence of a line of sight from one urban settlement to another reflects the possibility that (i) this was intentional, (ii) it structured the surrounding space, and (iii) that the way in which it structured space might reveal aspects of the roles ascribed to it in the past.
Visibility?
DEM interpolated from points and contours
'Topo to Raster' ArcGIS 9.3
35m resolution
RMSE of 3.37m
Single observation point per site

Site Attributes
Iron Age origins
Urban status (municipia, coloniae)
Road and river networks
(Via Augusta, Guadalquivir, Genil)

Chronology

- **400 BC to 250 BC**
  - Hannibal
  - Carthaginian
- **250 BC to 200 BC**
  - Roman occupation
  - Punic Wars
  - Carthaginian
  - Roman
- **200 BC to 100 BC**
  - Roman expansion
  - Roman occupation
- **100 BC to 0 AD**
  - Roman cities
- **0 AD to 100 AD**
  - Roman cities
  - Roman road networks
- **100 AD to 400 AD**
  - Roman cities
  - Roman roads
  - Roman expansion
- **400 AD to 600 AD**
  - Roman cities
  - Roman roads
  - Roman influence
DEM interpolated from points and contours 'Topo to Raster' ArcGIS 9.3
35m resolution
RMSE of 3.37m

Single observation point per site
Chronology

5-3cBC
Iberian (Late Iron Age)
early 5th c. BC to late 3rd c. BC

3-1cBC
Roman Republican
late 3rd c. BC to late 1st c. BC

1cBC-3cAD
Early Imperial
late 1st c. BC to early 3rd c. AD

3-4cAD
Middle Imperial
eyear 3rd c. AD to early 4th c. AD

4-5cAD
Late Imperial
eyear 4th c. AD to late 5th c. AD
Site Attributes

Iron Age origins
Urban status (municipia, coloniae)
Road and river networks
(Via Augusta, Guadalquivir, Genil)
DEM interpolated from points and contours
'Topo to Raster' ArcGIS 9.3
35m resolution
RMSE of 3.37m
Single observation point per site

Site Attributes
Iron Age origins
Urban status (municipia, coloniae)
Road and river networks
(Via Augusta, Guadalquivir, Genil)

Chronology
[Event descriptions and dates]

[Map with chronological timeline]
Method
Probable viewshed

(a) line of sight as probable viewshed = 5m. (b) observer point site A and target point for observer site E. (c) line-of-sight with probability p from observer A to target point site E. (d) observer height = 1.5m. (e) view-visibility network where site A is connected to site B with probability p and site B is connected to site A with probability 1-p.

Exploratory network analysis

<table>
<thead>
<tr>
<th>Global measures</th>
<th>Local measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>Clustering coefficient</td>
</tr>
<tr>
<td>Number of arcs</td>
<td>Integree</td>
</tr>
<tr>
<td>Clustering coefficient</td>
<td>Outdegree</td>
</tr>
<tr>
<td>Average degree</td>
<td></td>
</tr>
<tr>
<td>Connected components</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td></td>
</tr>
<tr>
<td>Average shortest path length</td>
<td></td>
</tr>
</tbody>
</table>

Exponential Random Graph Models (ERGMs)
Probable viewshed

(a) random error in probable viewshed = 5m; (b) observer point site A and target point for observer site B; (c) line-of-sight with probability pa from observer A to target point site B; (d) observer height = 1.7m; (e) inter-visibility network where site A is connected to site B with probability pa and site B is connected to site A with probability pb.
Exponential Random Graph Models (ERGMs)
Endogenous hypotheses

(i) communication or signalling --> inter-visibility
(ii) visual control --> outgoing lines
(iii) visually prominent --> incoming lines
(iv) invisible --> isolation

Exogenous hypotheses

(i) Iron Age settlements continuing in occupation
(ii) Roman urban status
(iii) river and road transport network
Probable viewshed

Exemplary network analysis

<table>
<thead>
<tr>
<th>Global measures</th>
<th>Local measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of nodes</td>
<td>Clustering coefficient</td>
</tr>
<tr>
<td>Number of arcs</td>
<td>Indegree</td>
</tr>
<tr>
<td>Clustering coefficient</td>
<td>Outdegree</td>
</tr>
<tr>
<td>Average degree</td>
<td></td>
</tr>
<tr>
<td>Connected components</td>
<td></td>
</tr>
<tr>
<td>Diameter</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td></td>
</tr>
<tr>
<td>Average shortest path length</td>
<td></td>
</tr>
</tbody>
</table>
Method
Results
Exploratory network analysis

Global exploratory network analysis

A strong degree of similarity and conformity in modularity patterns.
A decrease in the number of main and network density through time.
High probability lines of sight are significantly more frequent in Blocks and Subblocks than Long distance lines of sight (especially those larger than 50km). Maximum density was in the expected periods.
The proportion of short-distance lines of sight (shorter than 50km) is higher in the expected periods.

ERGMs attributes

- Only early (periods <55km)
- All models show many more significant effects than without attributes.

The three level model does not show any significant attributes effects.
- Transport networks do not explain modularity networks.

The urban, urban, and suburban output model has a positive significant node size effect.
- No visual control but not null.

Both also have a negative and significant threshold effect.

Exponential Random Graph Models

Random networks

All observed networks are significantly different from randomly generated networks with the same number of nodes and edges.

10,000 random networks generated per observed network. 1000 samples. Maximum, mean, and minimum of configurations were calculated. Significant T-score p-values are lower than mean 0.05.

But the maximum values of the late (period 4) period network limited to 20km was not significantly different.
Global exploratory network analysis

A strong degree of similarity and continuity in visibility patterns.
A decrease in the number of arcs and network density through time.
High probability lines of sight are significantly more frequent in Iberian and Republican times.
Long-distance lines of sight (especially those longer than 50km) become extremely rare in the imperial periods.
The proportion of short distance lines of sight (shorter than 20km) is higher in the Imperial periods.
--> the networks fragment through time, but local clusters become denser.
Exploratory network analysis

<20km
The key clusters in these networks are areas with a high density of sites. Many visually prominent sites that occupy a key position in the networks are occupied in the Iberian and Republican periods but cease to be so in the Imperial periods.

<50km
Lines of sight with a length between 20 and 50km have a significantly different role in structuring the cultural landscape than shorter lines of sight.

Coloniae and municipia are not visually prominent.
Exponential Random Graph Models

Random models:

All observed networks are significantly different from randomly generated networks with the same number of nodes and arcs.

(50 million random networks generated per observed network, 1000 samples. Minimum, average and maximum counts of configurations were considered. Student's T-test p-values all lower than α-level 0.05)

BUT the maximum values of the Late Imperial period network limited to 20km was not significantly different.
ERGMs <20km

Visibility network
Undirected
All periods
20km radius
>50% probability
Reciprocity --> inter-visibility

Many incoming lines: Iberian, Republican and Early Imperial
Many outgoing lines: Iberian
--> hubs
2-path: Iberian
--> sites that are visually prominent are also good vantage points

Isolates: negative in Iberian, positive in Imperial
ERGMs <50km

Reciprocity --> inter-visibility
Reciprocity $\rightarrow$ inter-visibility

Many incoming lines: Iberian
Many incoming lines: Iberian
ERGMs attributes

Only Early Imperial networks < 20km

All models show many more significant effects than without attributes.
--> attributes matter

The river or road model does not show any significant attribute effects.
--> transport networks do not explain visibility networks

The urban status and Iberian origins model has a positive significant out-2-star effect.
The urban status and Iberian origins model has a positive significant out-2-star effect. --> visual control but not as hubs

Both also have a negative and significant 2-path effect.
Results
Conclusions
Continuity:
Inter-visibility is common throughout time, both in short and long distance networks.

Not random:

Iberian:
Tendency towards hubs
Long distance lines

Later:
Tendency towards lower degree hubs
Short distance lines

Attributes?
Transport networks --> NO
Urban status --> YES
Iberian origins --> YES

--> The role of sites changes through time

--> Visibility patterns and site locations require different explanations in the Iron Age compared to Roman times

Make assumptions and hypotheses explicit
Explore their implications
Stay close to observed data

Future work:
Multiple viewer points
Longitudinal analysis
ERGMs as a starting point for ABMs
Continuity:
Inter-visibility is common throughout time, both in short and long distance networks.

Not random

Iberian:
Tendency towards hubs
Long distance lines

Later:
Tendency towards lower degree hubs
Short distance lines

Attributes?
Transport networks --> NO
Later:
Tendency towards lower degree hubs
Short distance lines

Attributes?
Transport networks --&gt; NO
Urban status --&gt; YES
Iberian origins --&gt; YES

--&gt; The role of sites changes through time

--&gt; Visibility patterns and site locations require different explanations in the Iron age compared to Roman times
Make assumptions and hypotheses explicit
Explore their implications
Stay close to observed data

Future work:
Multiple viewer points
Longitudinal analysis
ERGMs as a starting point for ABMs
Continuity:
Inter-visibility is common throughout time, both in short and long distance networks.

Not random:

Iberian:
Tendency towards hubs
Long distance lines

Later:
Tendency towards lower degree hubs
Short distance lines

Attributes?
Transport networks --> NO
Urban status --> YES
Iberian origins --> YES

--> The role of sites changes through time

--> Visibility patterns and site locations require different explanations in the Iron age compared to Roman times

Make assumptions and hypotheses explicit
Explore their implications
Stay close to observed data

Future work:
Multiple viewer points
Longitudinal analysis
ERGMs as a starting point for ABMs
Conclusions
THANK YOU!

http://connectedpast.soton.ac.uk/
http://archaeologicalnetworks.wordpress.com/

Acknowledgements

Prof. Simon Keay - Dr. Graeme Earl - Claire Lemercier - the networks network - AHRC - Dr. David Wheatley - Cat Cooper - Dr. Leif Isaksen - University of Southampton - Departamento de Prehistoria y Arqueología de la Universidad de Sevilla - Delegacion Provincial de Sevilla de la Consejeria de Cultura de la Junta de Andalucia - Istitucion Andaluz de Patrimonio Historico - Prof. Antonio Caballos Rufino - Dr. Victor Hurtado Perez - Professor Francesca Chaves Tristan - Sr. Jose Manuel Rodriguez Hidalgo - Dr. Jose Beltran Fortes - Dr. Fernando Amores Carredano - Iza Romanowska - Digital Classicist - The Connected Past