Imperial College London

Complexity Science

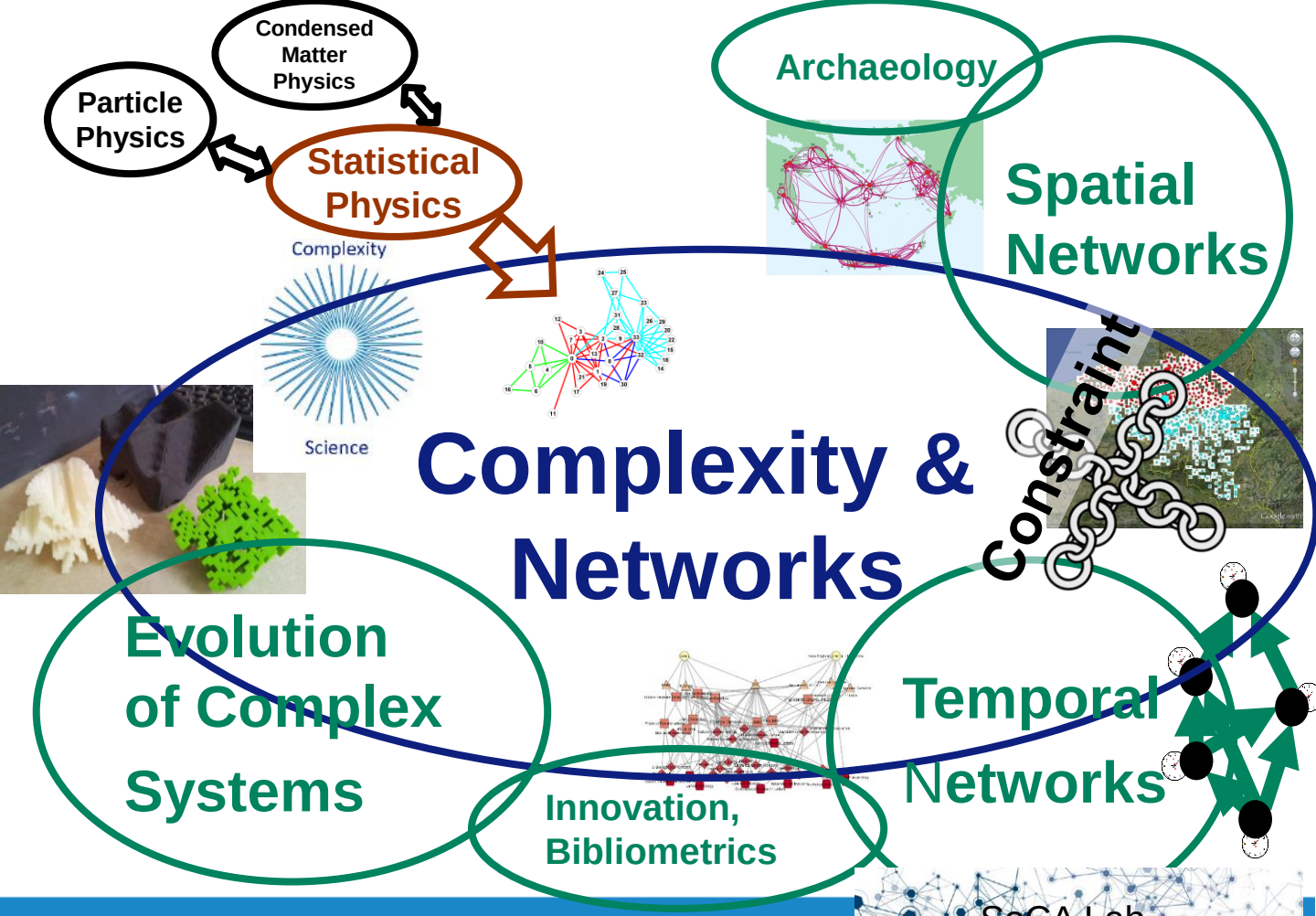
Complexity Science and Past Complex Systems, a
TORCH PastNet workshop, Oxford
18th November 2019
Slides at http://doi.org/10.6084/m9.figshare.10316723

seven-gated

Was Thebes Really Necessary? Uncertainty in Spatial Modelling

Tim Evans

- Introduction
- Uncertainty
- Spatial Modelling
- Example: Central Greece
- Missing Sites Examples



SoCA Lab,
Data Science Institute

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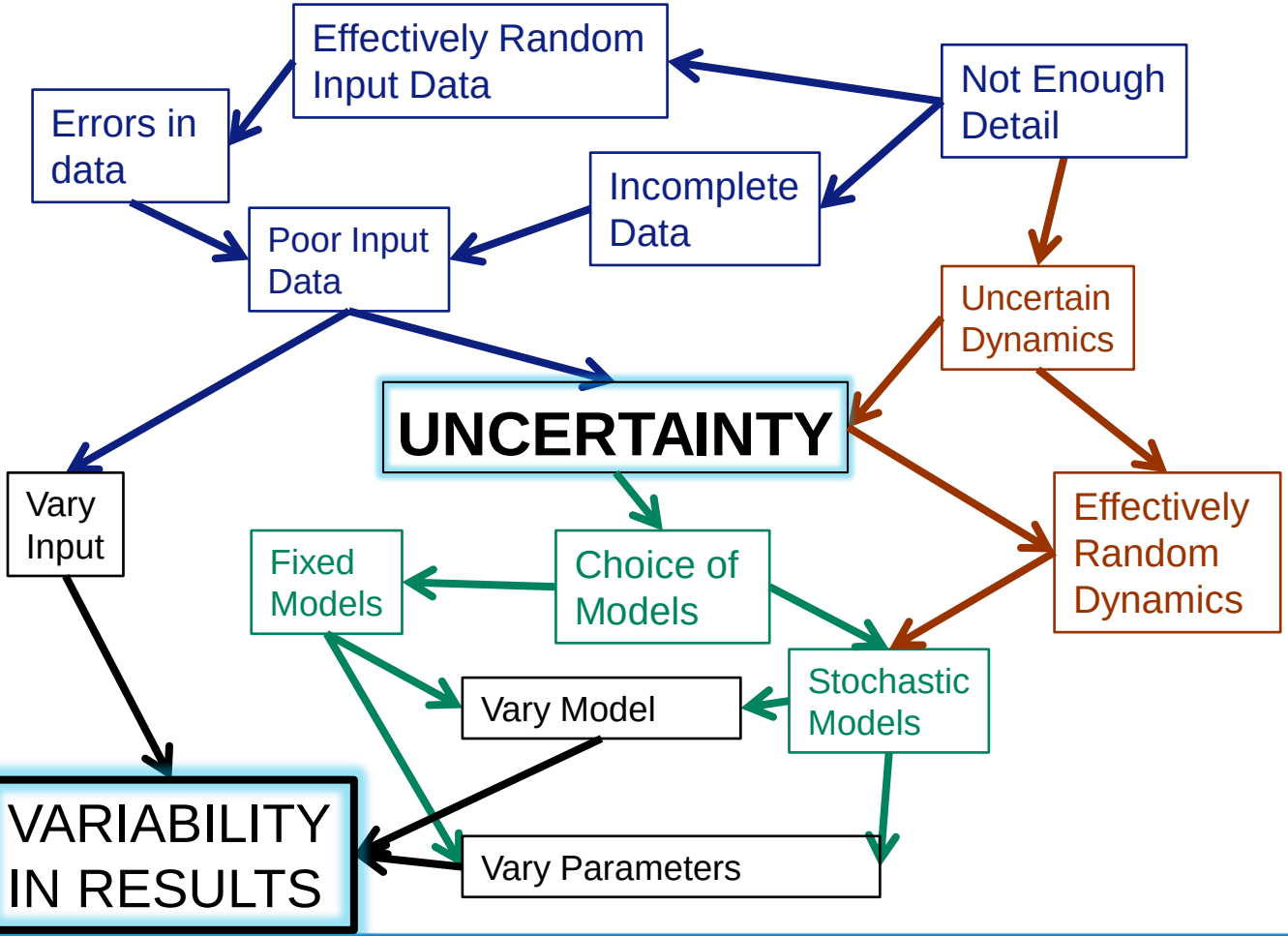
Effectively Random Input Data
Errors in data
Not Enough Detail
Incomplete Data
Poor Input Data
Uncertain Dynamics
UNCERTAINTY
Vary Input
Fixed Models
Choice of Models
Effectively Random Dynamics
Stochastic Models
Vary Model
VARIABILITY IN RESULTS
Vary Parameters

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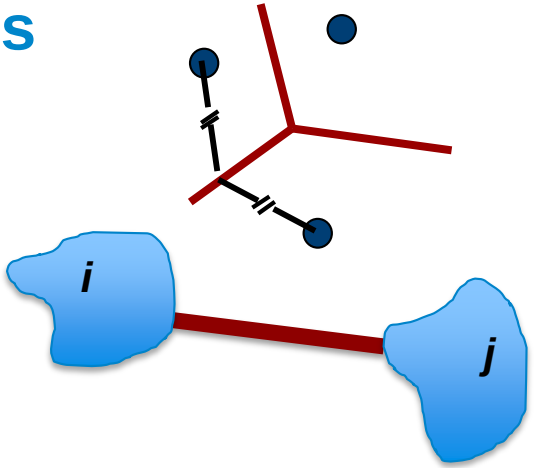
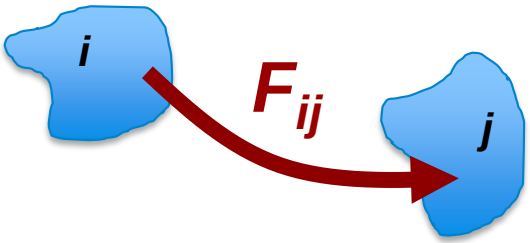
Interactions between sites

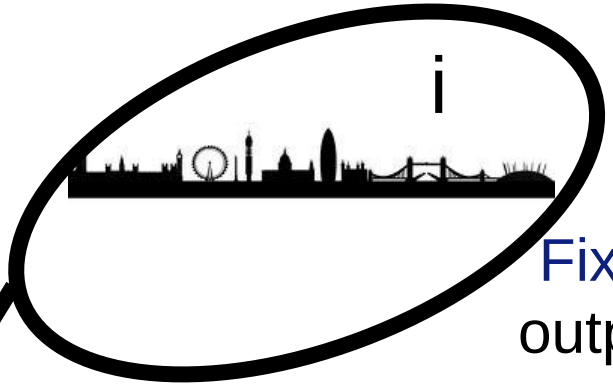
- Boundaries between sites
- Model binary interactions
  ⇒ SPATIAL NETWORKS
- Model flows
  ⇒ SPATIAL INTERACTION MODELS



Could be exchange of:-
- Bulk Goods
- Elite goods
- Social Exchange
- Political Exchange



Network Description



Fixed output site size O_j

Fixed distance d_{ij}

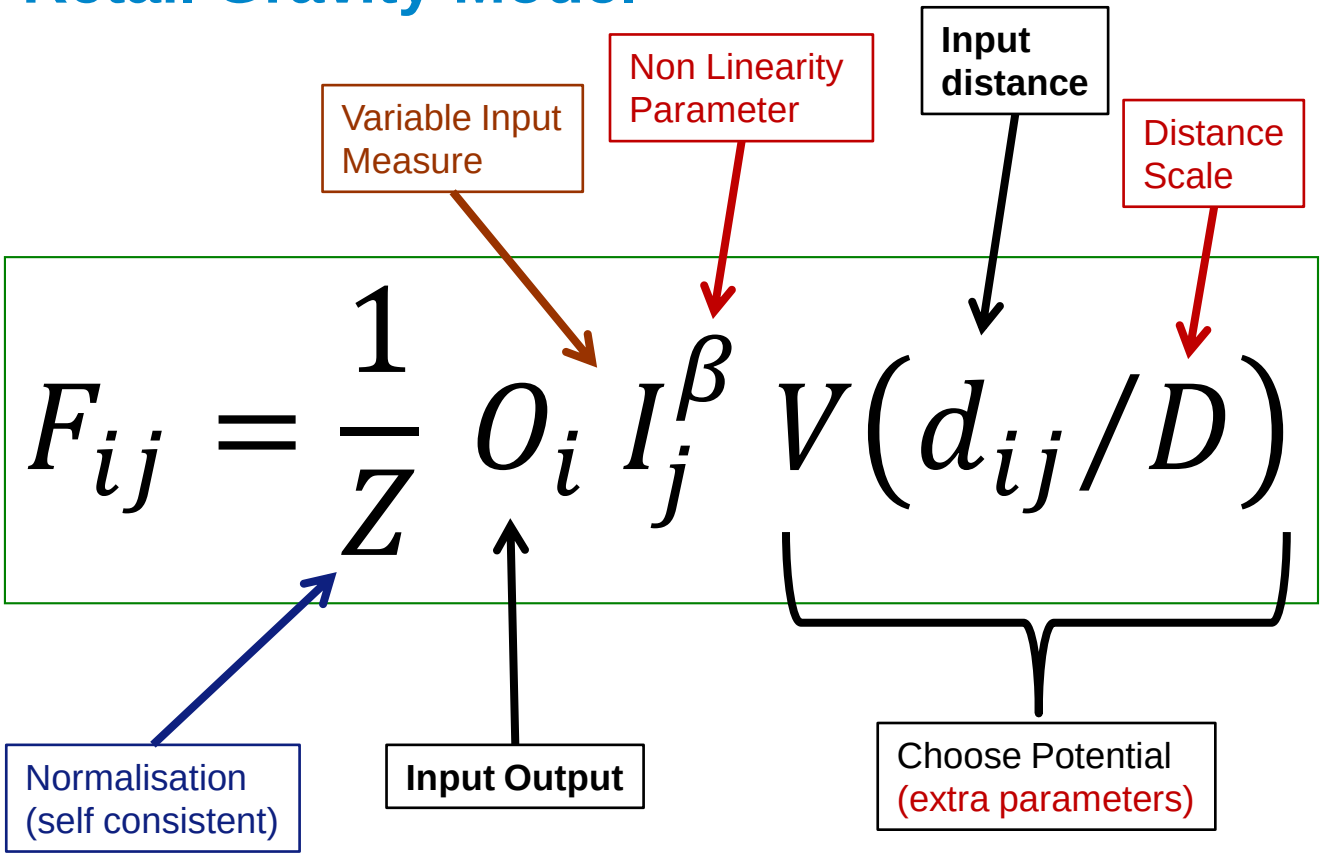
F_{ij}

Variable flow

Variable input site size I_j

Retail Gravity Model

[Harris & Wilson, 1978]



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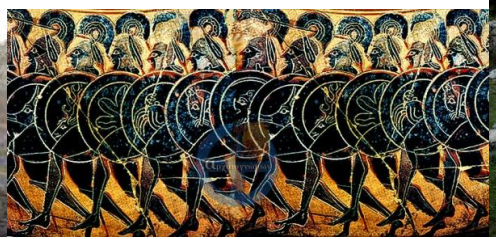
Should Thebes exist?

Thebes is one of the leading cities in classical Greece C5th BCE

Question: Was it inevitable that Thebes emerges as a regional centre due to its location?

Example of how one can add include when modelling.

- Early study **RW** = **Rihll & Wilson** 1987 & 1991
- Later study Evans & Rivers 2017



Data

- Same data set as **RW** Rihll and Wilson 1987, 1991 (**RW87** & **RW91**)
- Late Geometric Period
- Part of central southern mainland Greece
  - Boeotia, Attica, Isthmus, Argolid
- RW aim to look at rise of unequal cities from equal sized settlements
  - Thebes, Athens, Corinth, Argos

Sites

Boeotia
Euboea
Attica
Isthmus
Argolid
THEBES
ATHENS
KORINTH
ARGOS
Akraiphnion
Khalkis
Mykalessos
Medeon
Aulis
Onchestos
Koroneia
Kabirion
Potniai
Eutresis
Kromna
Tenea
Kallithea
Koropi
Kalyvia
Vouliagmeni
Prosymnia
Berbati
Argive Heraion

RW Procedure

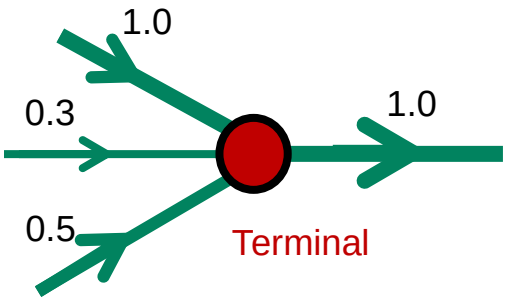
https://doi.org/10.6084/m9.figshare.868961

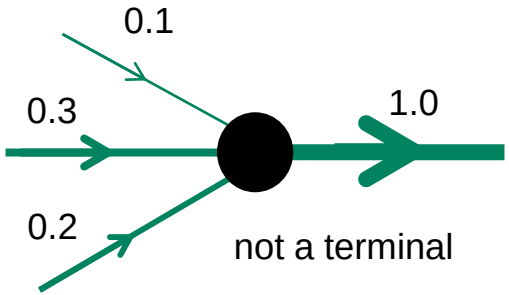
- Take 109 important sites at start of period.
- Find the distances between these sites
- Assume all sites equally important initially
- Run the model to produce site importance
- Visualise and analyse

[Nystuen & Dacey 1961,
Rihll & Wilson 1991]

Sparsification using Terminals

- Rihll & Wilson define **Terminal Sites**





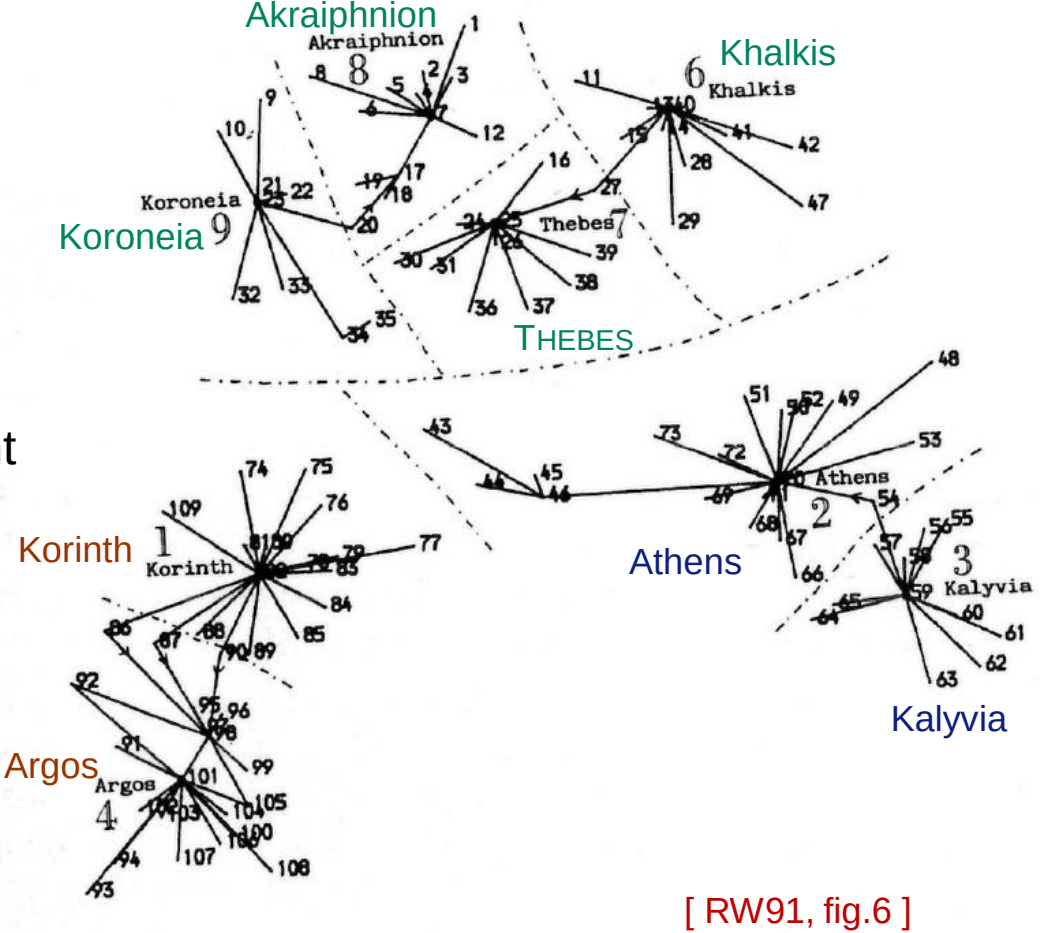
Terminal sites satisfy

Total Flow In > Largest Single flow out

More people owe you than you owe others

Terminals Dominant

Rihll & Wilson identify terminal sites as dominant sites emerging from equal sized villages



[RW91, fig.6]

Figure 6: $\alpha = 1.05$ $\beta = 0.175$ $T = 8$ $\geq 75\%$ max. debit

Uncertainty

- Rihll & Wilson looked at several parameter values but typically found similar results
  - Thebes and Athens always identified
  - Korinth and Argos or close neighbours often identified
  - Other centres also found in addition

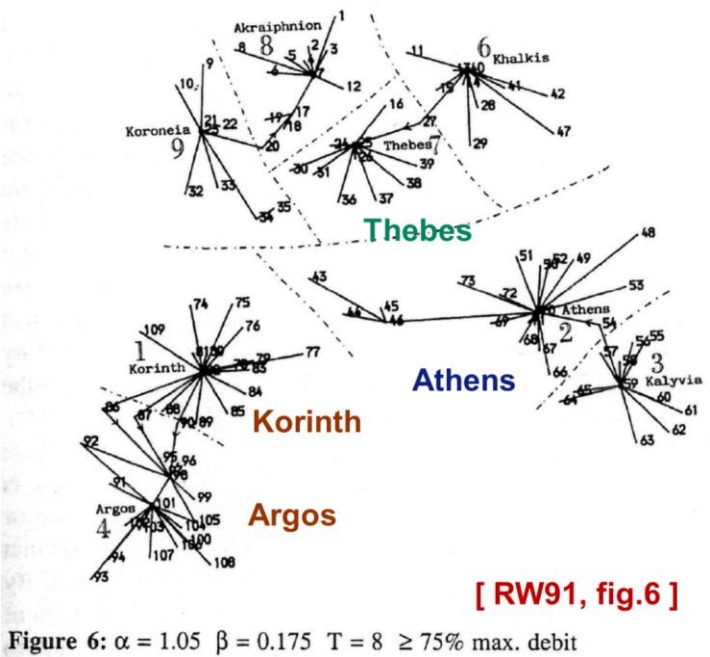


Figure 6: $\alpha = 1.05$ $\beta = 0.175$ $T = 8$ $\geq 75\%$ max. debit

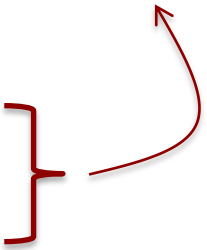
Uncertainty in Results

- Remarkably stable key results
- Only qualitative assessment of uncertainty
- Only one form of distance potential used
  pure exponential $\mathbf{exp}\,(-\boldsymbol{d_{ij}/D})$
- No uncertainty in site locations of distances
- Unverifiable
  - no comprehensive list of site locations and distances used

until now

Evans & Rivers Procedure

Derived from figure in RW
https://doi.org/10.6084/m9.figshare.868961



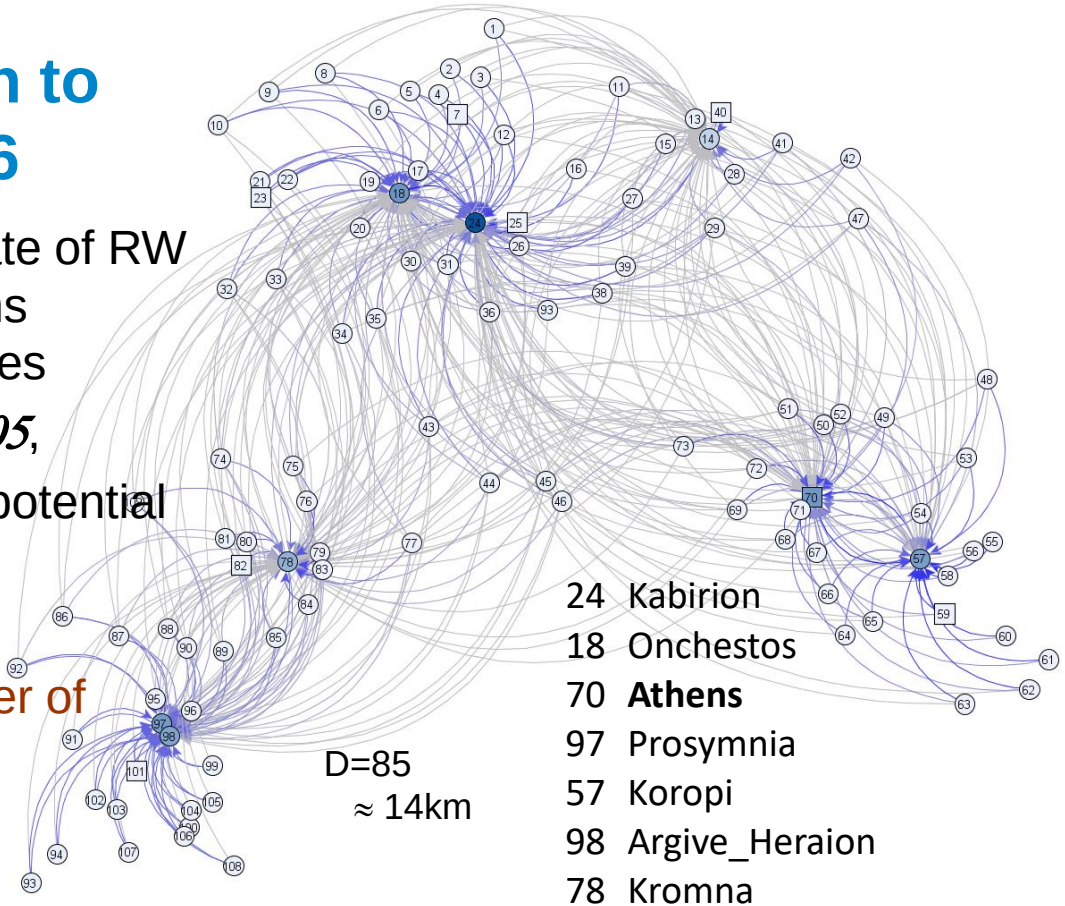
- Take 109 important sites at start of period.
- Find the distances between these sites
- Assume all sites equally important initially
- Run the model to produce site importance
- Visualise and analyse

- Try moving locations slightly ✗
- Try different definitions of distance ✓
- Try different Models ✗
- Try Different Model Parameters ✓

Best match to RW91 Fig 6

- Best estimate of RW site locations and distances
- Same $\beta=1.05$,
- Same **exp** potential
- vary distance ***D***

⇒ same number of terminals ***8***

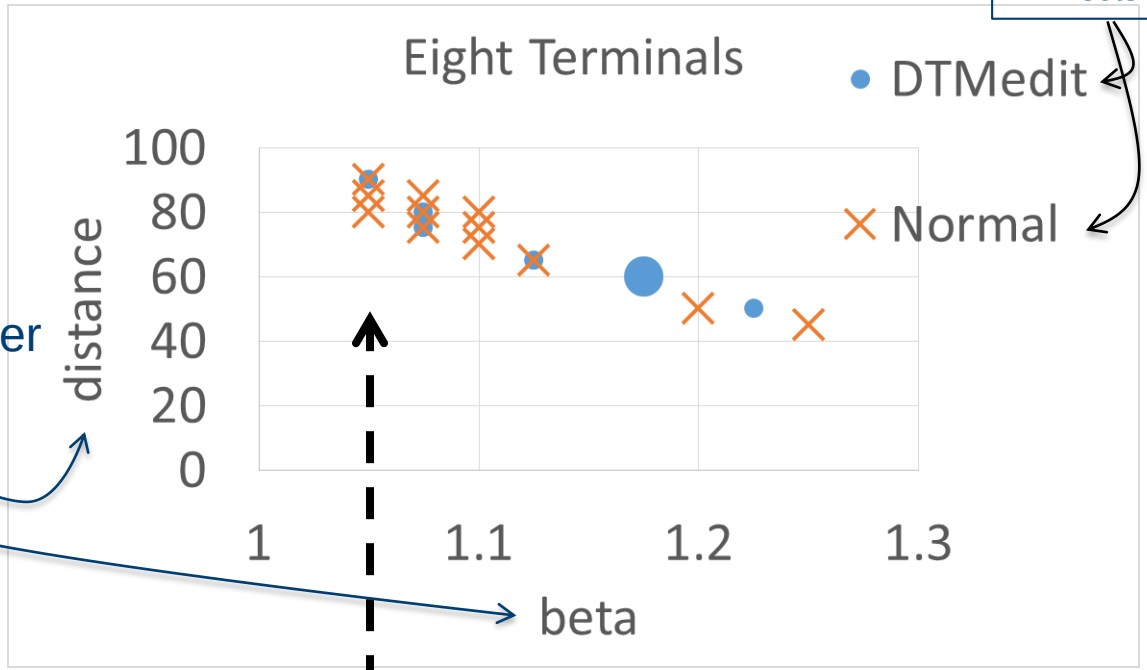


D=85
≈ 14km

24 Kabirion
18 Onchestos
70 **Athens**
97 Prosymnia
57 Koropi
98 Argive_Heraion
78 Kromna
14 Aulis

Eight Terminal Parameter Regions

Two different distance sets

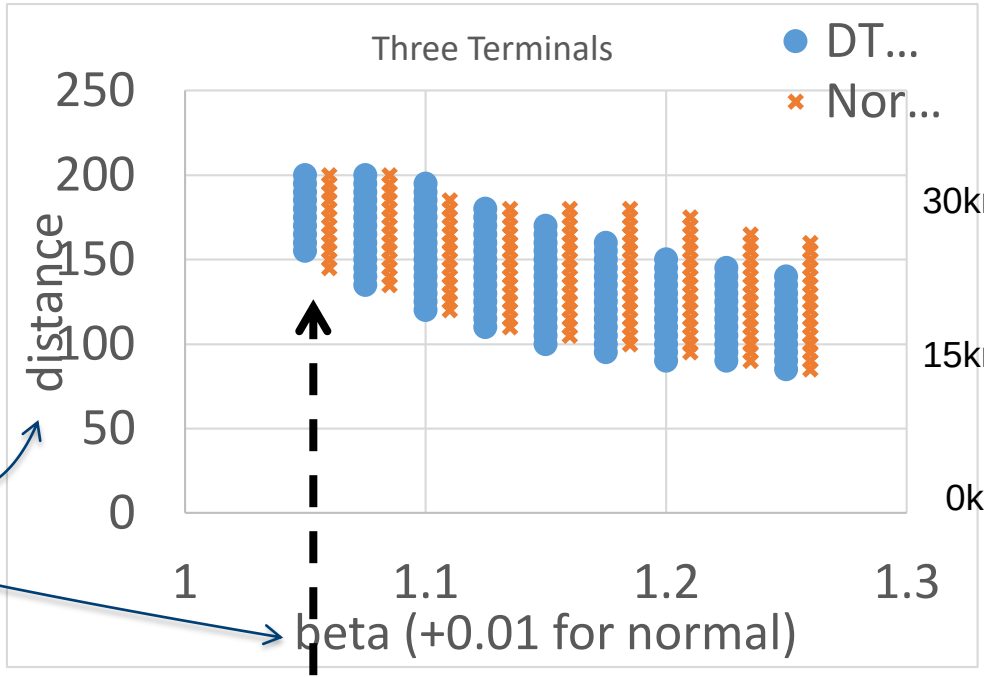


Various parameter values give same number of terminals

RW91 Fig.6

Three Terminal Parameter Regions

Various parameter values give same number of terminals



RW91 Fig.6

Stronger Binding

8 Terminals

Now we have ‘error bars’

Ranges of uncertainty

30km

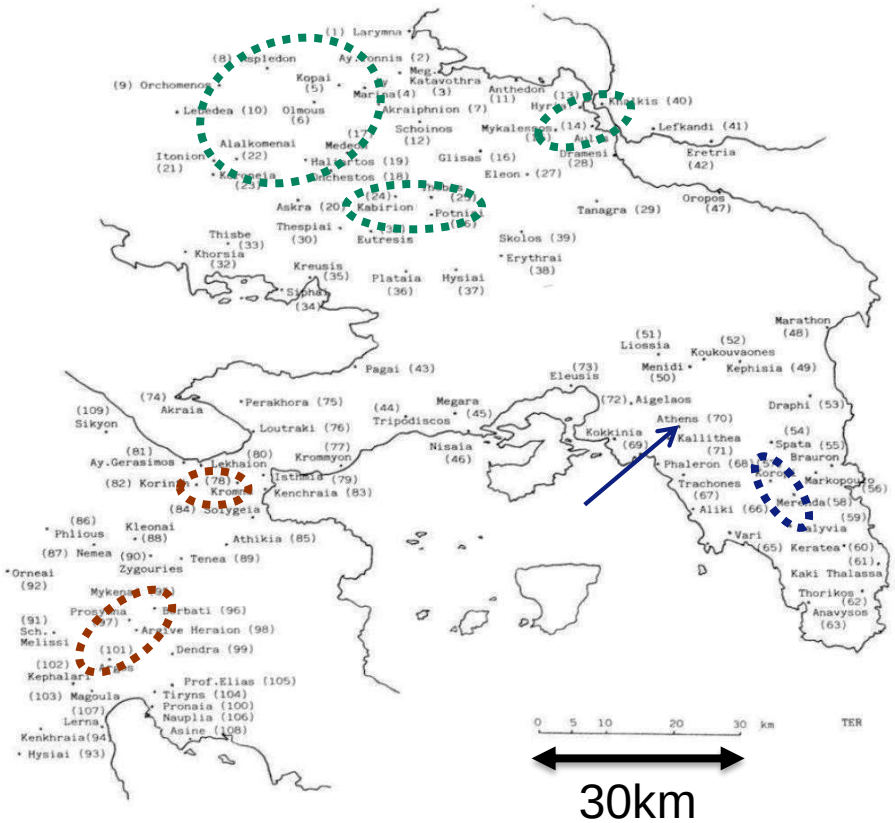


FIGURE 1

3 & 8 Terminals

Ranges of uncertainty

Grey =
8 Terminals

Coloured =
3 Terminals

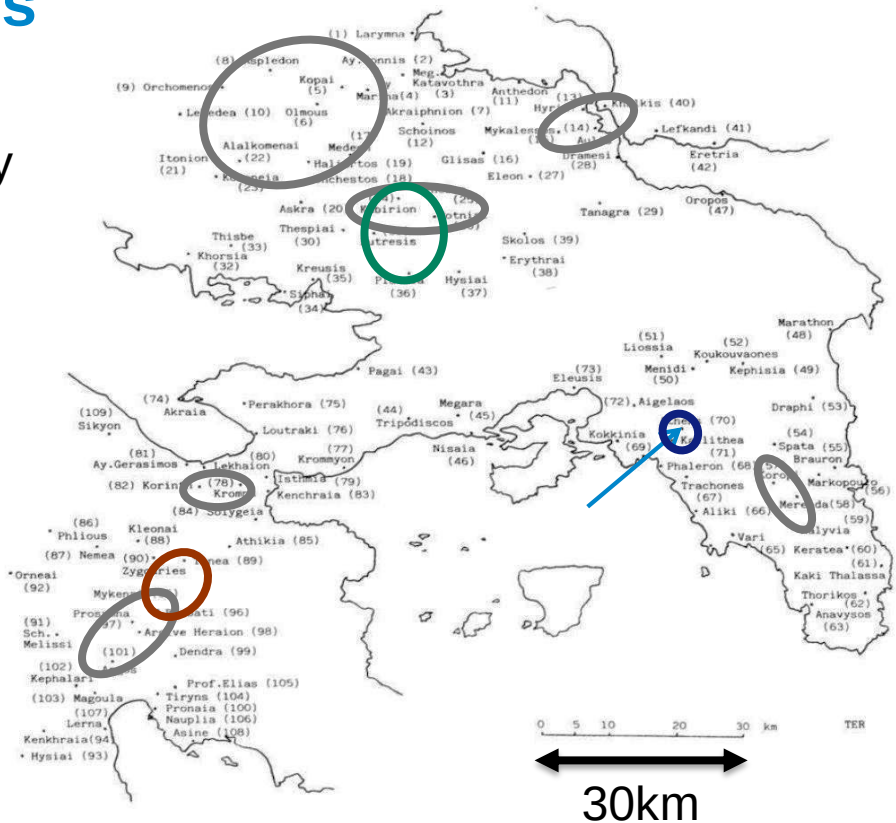


FIGURE 1

Summary

- Uncertainty should be reflected in results
- Should see “errors” – variability measures
  - Vary initial conditions ✓
  - Stochastic dynamics ✗ (but `ariadne/ERG`)
  - Vary parameters ✓
  - Different Models ✓
- Illustration with Rihll and Wilson data (1987, 1991)

Related Slides: http://dx.doi.org/10.6084/m9.figshare.3840249

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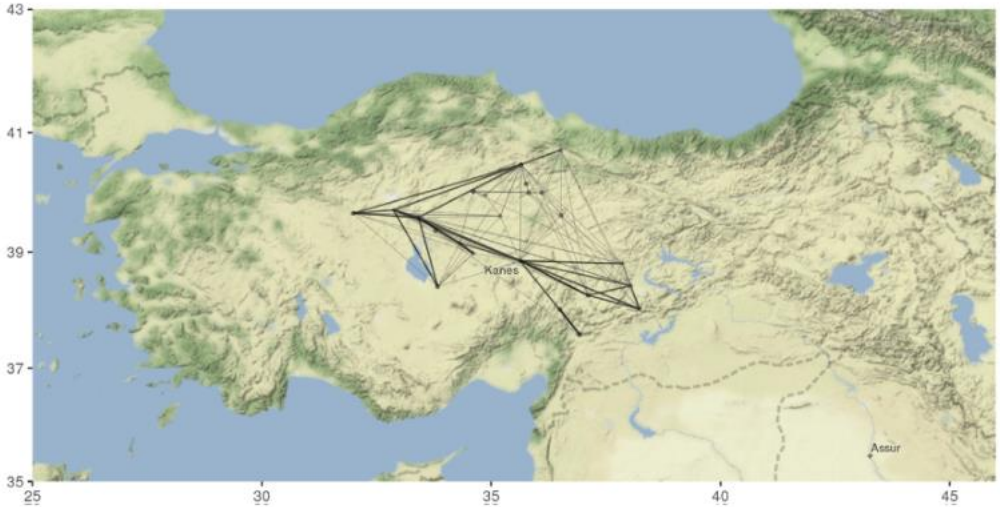
Missing Sites

For example

- Assyrian [Barjamovic et al, 2019]
- Minoan Crete, [Palliou & Bevan 2016]

Missing Sites

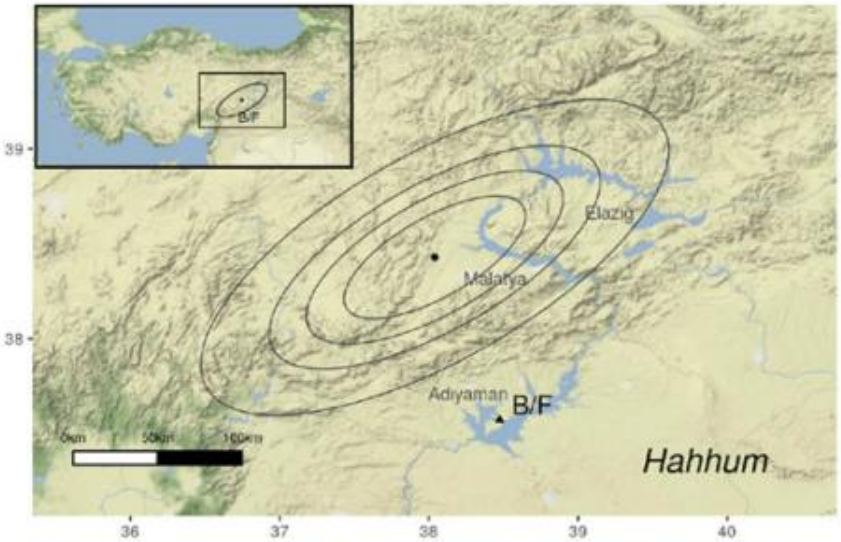


Assyrian Cities, Bronze age in Anatolia, Turkey

- 15 known sites, 10 unknown
- 198 Tablets with 227 itineraries

[Barjamovic et al, 2019]

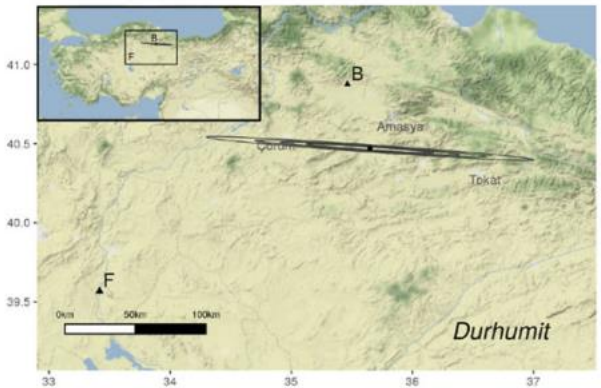
Missing Sites

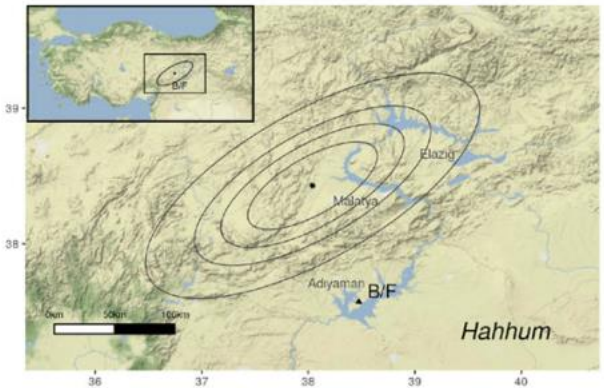


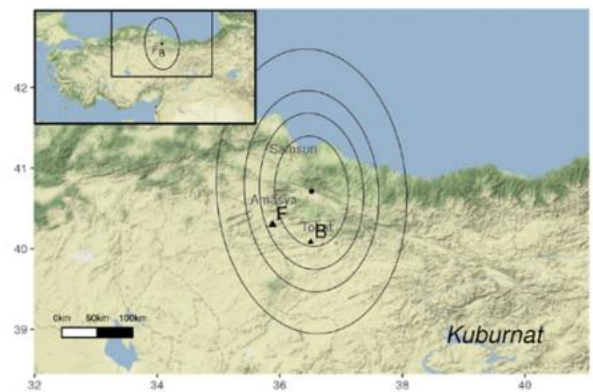
- Assign locations to missing sites
- Flows modelled with form of the gravity model
  - Interesting economic theory derivation
- Match to data on shipment counts
- NLLS estimators to optimise missing site locations
- Includes uncertainties (typical error 0.5º ~50km)

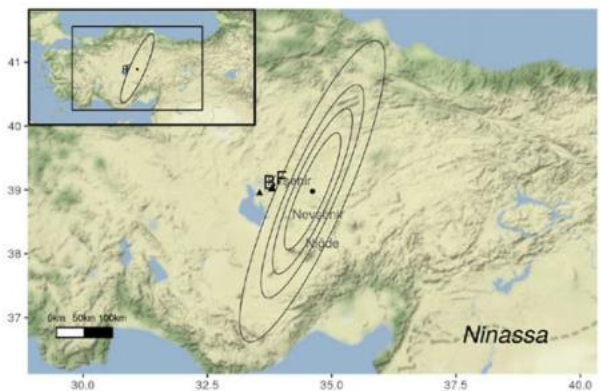
[Barjamovic et al, 2019]

Missing Sites









Summary

- Use of modelling networks is increasing in archaeology
- Many models very simple but sufficient
- Role of geography relatively easy to study
- Comparing against finds much harder
- **Many options remain to be explored**

All my work done with
Carl Knappett (Toronto)
Ray Rivers (Imperial)

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Extra Slides

8 Terminals – in order of 'hierarchy'

DTMedit D90	Normal D90	Normal D85	Normal D80	RW91 Fig 6
Potniai 26	Kabirion	Kabirion	Kabirion	Thebes (25)
Medeon 17	Athens	Onchestos	Onchestos	Akraiphnion (7), Koroneia (23)
Berbati 96	Prosymnia	Athens	Athens	Athens
Koropi 57	Koropi	Prosymnia	Koropi 57	Kalyvia 59
Athens 70	Argive Heraion	Koropi	Prosymnia 97	Argos (101)
Korinth 82	Onchestos	Argive Heraion	Argive Heraion 98	Argos (101)
Argive Heraion 98	Kromna	Kromna	Kromna 78	Korinth (82)
Mykalessos 15	Aulis	Aulis	Aulis 14	Khalkis (40)

8 Terminals – ordered by location

DTMedit D90	Normal D80, D85, D90	RW91 Fig 6	Wider Location
Mykalessos 15	Aulis 14	Khalkis 40	Euboea environs
Potniai 26	Kabirion 24	Thebes 25	Neighbourhood of Thebes
Medeon 17	Onchestos 9	Akraiphnion 7 Koroneia 23	Northern Boeotia
Athens 70	Athens 70	Athens	Athens
Koropi 57	Koropi 57	Kalyvia 59	S.Attica
Korinth 82	Kromna 78	Korinth 82	Neighbourhood of Corinth
Berbati 96	Prosymnia 97	Argos (101)	Neighbourhood of Argos
Argive Heraion 98	Argive Heraion 98		

Largely consistent on scale of about 10km

3 Terminal Sites – Exponential Potential

Distance Data	Distance D	Terminal Sites		
		Boeotia	Attica	Isthmus/ Argolid
Normal	150	24 Kabirion	70 Athens	96 Berbati
Normal	155, 160, 165, 170, 175, 180	31 Eutresis	70 Athens	96 Berbati
Normal	185	31 Eutresis	70 Athens	89 Tenea
Normal	190,200	36 Plataia	70 Athens	89 Tenea
DTMedit	155,160,170, 175	26 Potniai	71 Kallithea	96 Berbati
DTMedit	180,190,200	26 Potniai	71 Kallithea	89 Teneai

Exponential potential

Archaeological Data

- Excavations necessarily partial
  - Unknown sites
  - Sites destroyed
  - Sites unreachable e.g. under modern site
- Large amounts of material
  - Documented artefacts only a tiny fraction
  - Representative items not all items
  - No universal parameters or standards
- Biased sample
  - Materials biodegrade
  - Social biases
- Paper Records
  - tiny fraction published

Lots of data! NOT Big Data

Small/Dirty Data!

Archaeological Data on Exchange

Exchange is hard to measure

- Most artefacts locally produced,
  - exchange a small fraction of that small fraction
  - ~10% of artefacts imported at Akrotiri
- Exchange difficult to identify by source
  - Analysis Expensive
  - Not always conclusive
- Direct Evidence Rare
  - Texts have biases

Uluburun Shipwreck 1300BC

Site-Site Interactions

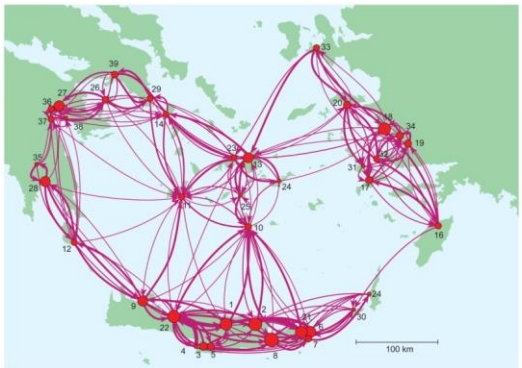
- Archaeology can be "SITE CENTRIC"
  - Regional and global interactions hard to consider

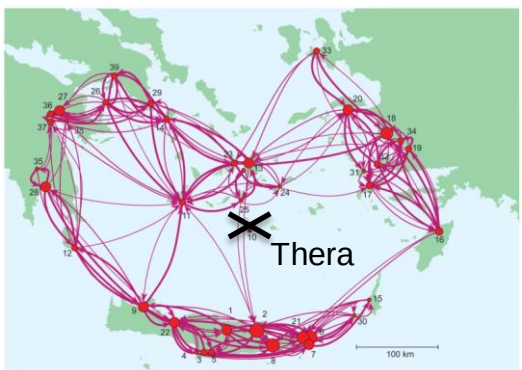
- Models can emphasise interactions
  - Mesoscopic picture
  - Macroscopic effects

What did archaeological models ever do for us?

- Importance of Sites
  - Network centrality
  - Location of missing sites
- Regions of Influence
  - Political
  - Economic
- Comparisons
  - Null models
  - Evolution in time
  - Different effect of social, geographical, economic factors

⇒ Proof or Narrative ?





[Knappett, TSE, Rivers, Antiquity 2012]

What is a Site?

Issues of scale:-

- Any Settlement
- Large Settlement
- Important Building e.g. shrine, fortification
- Region e.g. Valley defined by geography – GIS methods

The scale of a settlement is not always obvious

- Missing sites
- Sites now underwater
- Size of sites beneath modern cities

Different Spaces

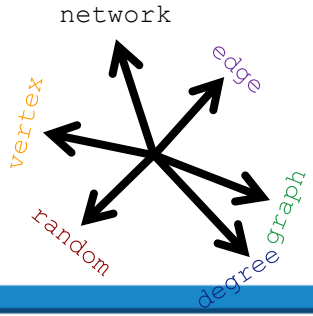
Looking at relationships between "nodes" embedded in space

Focus here on two-dimensional geographical space

- Euclidean distance
- Cost of trip
- Ranked distance, intervening opportunities

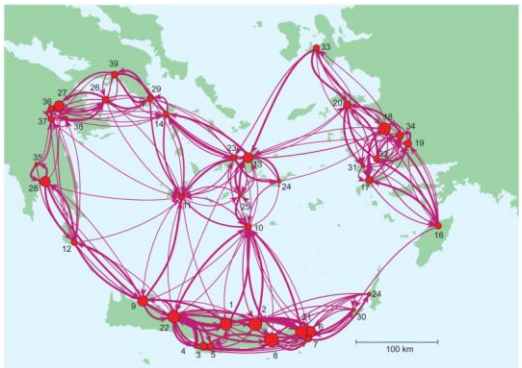
Can apply to artefact spaces

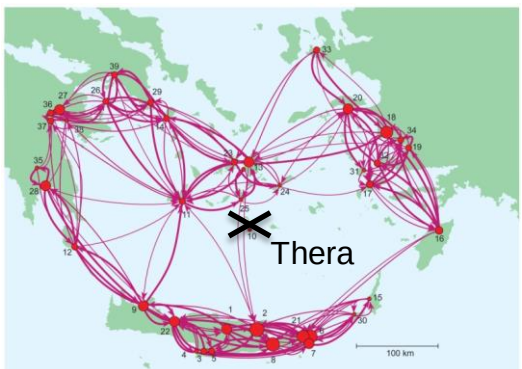
- Artefact count
- Word frequency



What did Simple Spatial Interaction Models ever do for us?

- Test Basic Principles
  - e.g. is city attractiveness a non-linear function of population? [Bettencourt at al. 2007]
- Look at general properties
  How does space effect system
- Comparisons, Null Models
  - e.g. Spatial Clustering [Expert at al. 2011]
- General Predictions
  - e.g. destruction of Thera only weakens Aegean networks





[Knappett, TSE, Rivers, Antiquity 2012]

Proof by Example

Will illustrate some of these ideas by highlighting a few examples.

- Personal Favourites
- Several other examples of similar types of analysis
- Many other types of analysis not covered here

For more examples see

- [Brughmans 2010]
- “The Connected Past”
- Proceedings of CAA