Urban and regional models: achievements and challenges

Alan Wilson

Centre for Advanced Spatial Analysis

University College London

- modelling urban and regional systems and their evolution is one of the grand challenges of 21C science
- we can now see that we have been at the leading edge of complexity science; and the wider developments will now help us
- discuss in turn:
    - what has been achieved
    - current challenges and prospective breakthroughs

ACHIEVEMENTS

- interaction models – the 40th anniversary of Entropy in Urban and Regional Modelling!
- Lowry and post-Lowry modellers: Putnam, Wegener, Echenique, Mackett,...
- demographics
- input-output
- the 'dynamics' hypothesis
- generalising the classics
- micro-simulation and agent-based modelling
- information systems/GIS/visualisation/geodemographics
- applications.....

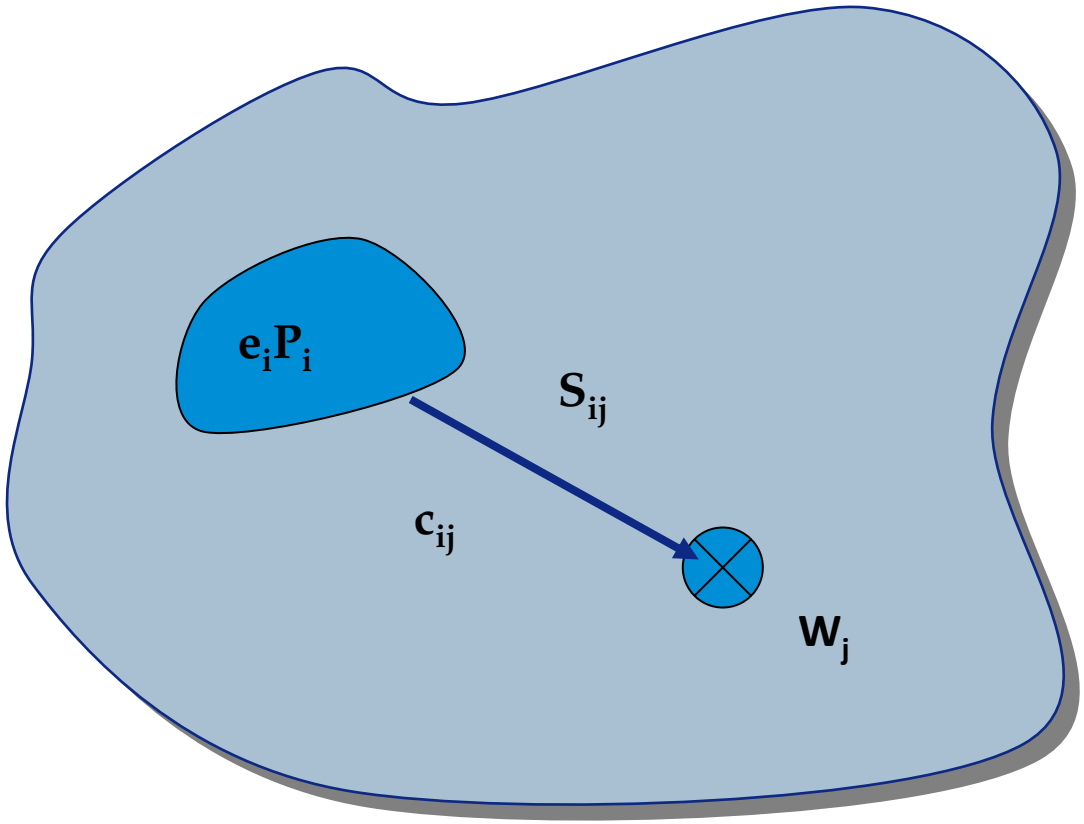
CHALLENGES

- the basics: what can be made routine should be – access to data, presentation, analysis, modelling, planning; sub-model development
- the next steps
  - extending the underlying data warehouse
  - layers of disaggregation
  - the evolution of structure
    - phase transitions and path dependence
    - urban typologies based on underlying structures: the 'DNA' argument
- implications for planning

Layers of disaggregation

- upper layer modelling as a framework – particularly in relation to possible rates of development:
  - nations within the international system
  - regions within a nation
  - cities within a region/nation
  - intra-urban
- have we been underestimating upper-layer constraints?
- demography and input-output dominate the upper layers; interaction and spatial structure models, the lowest.

The retail archetype



e_iP_i - demand in zone i

W_j - attractiveness of zone j

S_{ij} - flows between i and j

c_{ij} - cost of travel between i and j

The retail model – spatial interaction

$$S_{ij} = A_i e_i P_i W_j^{\alpha} e^{(-\beta m_j c_{ij})} \qquad A_i = \frac{1}{\sum_k W_k^{\alpha} e^{(-\beta m_j c_{ik})}}$$

- S_{ij} : consumers living in zone i and shopping in zone j
- e_i : average income in zone i
- P_i : population in zone i
- W_j : retail floor space in zone j
- α : impact of retail zone size on consumer decisions
- β : impact of travel cost on consumer decisions
- c_{ij} : travel cost from zone i to zone j
- m_j : public transport multiplier for zone j

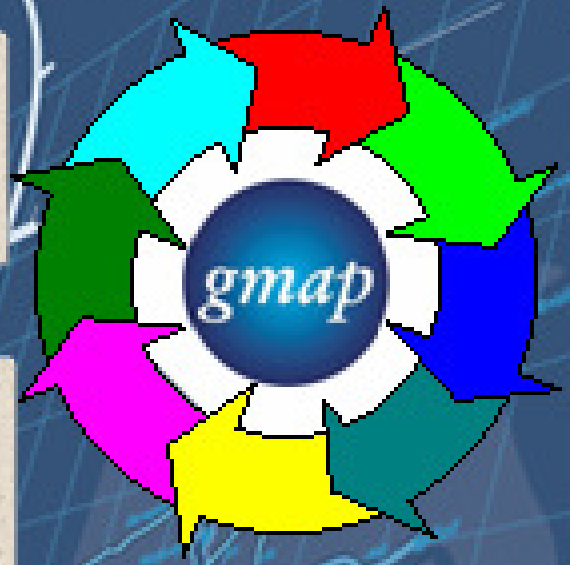
Sector specialists

Financial Services

Halifax, Nationwide, Alliance & Leicester, Bank of Scotland, Co-op

Automotive

Ford, Jaguar, Nazda, Volvo, Land Rover, Daimler-Chrysler



Retail Petroleum

Exxon Mobil, BP, Total Fina

Telecoms

Telewest, Marconi, THUS, OnCue, Bulldog

Retail

Asda, Dixons, Sainsbury's, Oxfam IKEA, Our Price

Other

Aventis, Warner-Lambert, DTI, Leeds TEC

The retail model – structural dynamics

$$\frac{dW_j}{dt} = \varepsilon\left(D_j - KW_j\right)$$

- ε : rate at which retail zones respond to profit levels
- D_j : total income of retail zone j
- K : costs per m^2 in retail zone j
- W_j : retail floor space in zone j

Evolving to equilibrium during a single time step

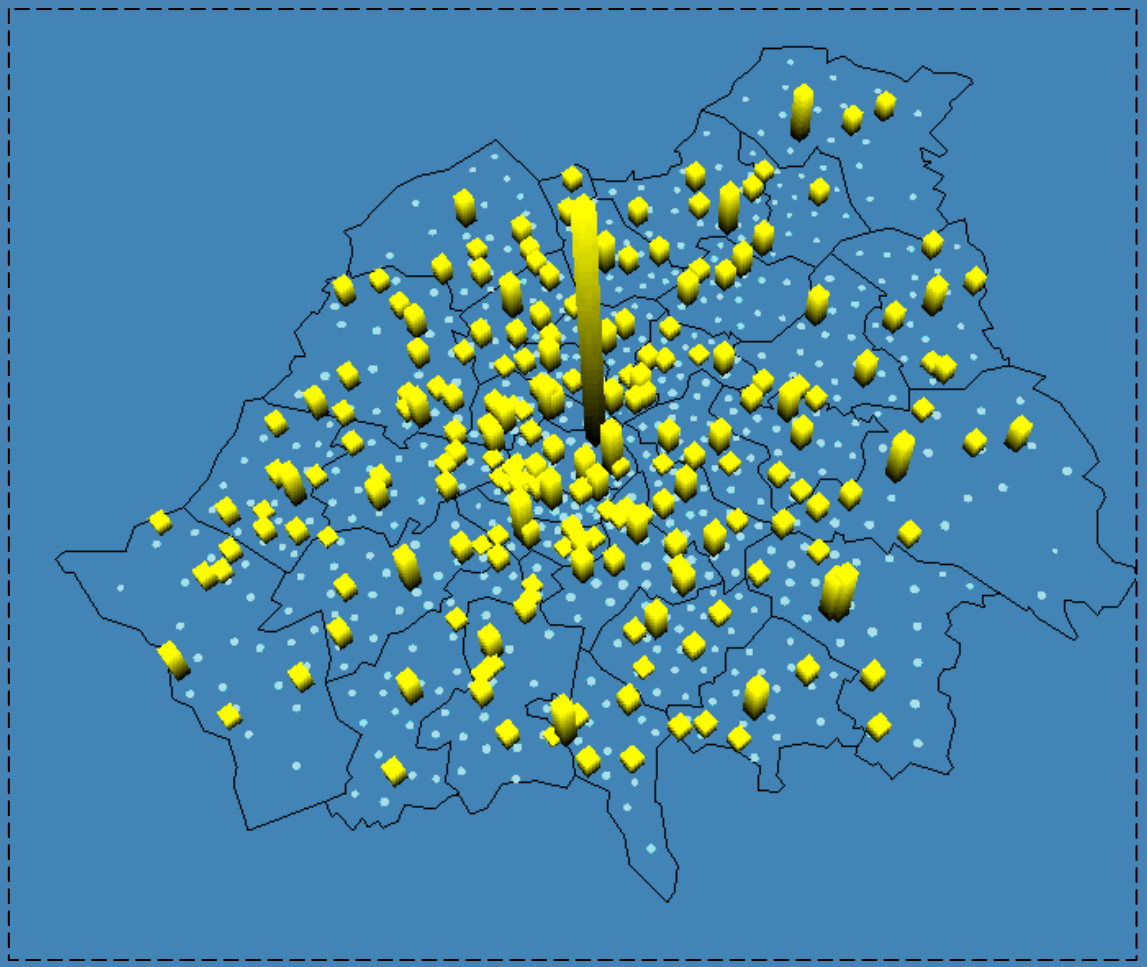
KEY

Retail centre growth

- Growing
- Stable
- Shrinking

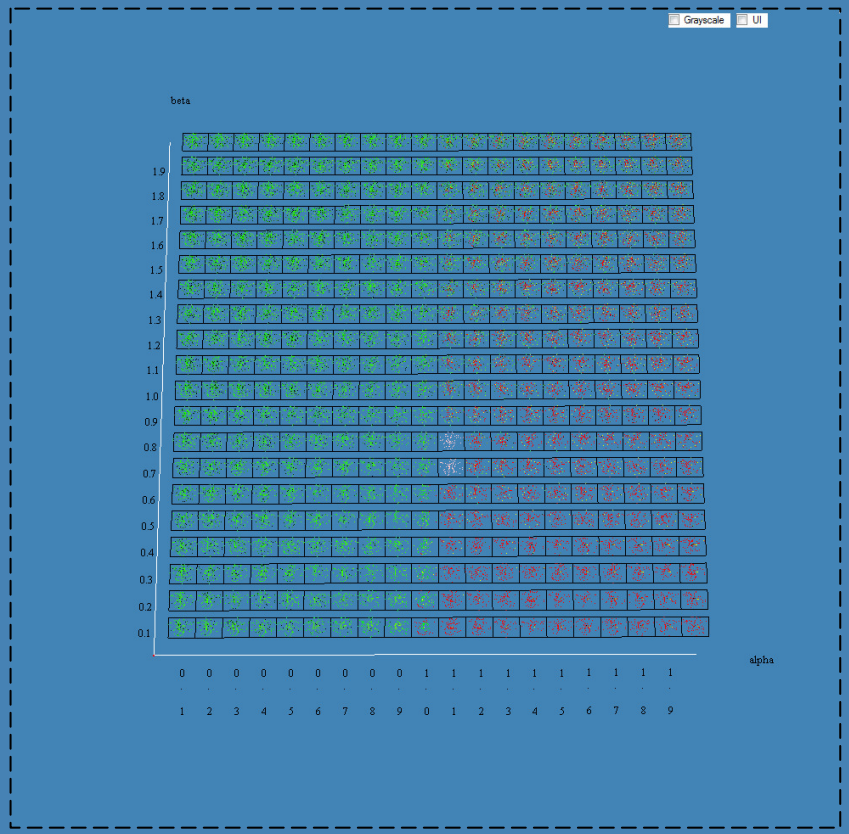
Consumer spending flow size

- £1,000
- £10,000
- £100,000
- £1,000,000



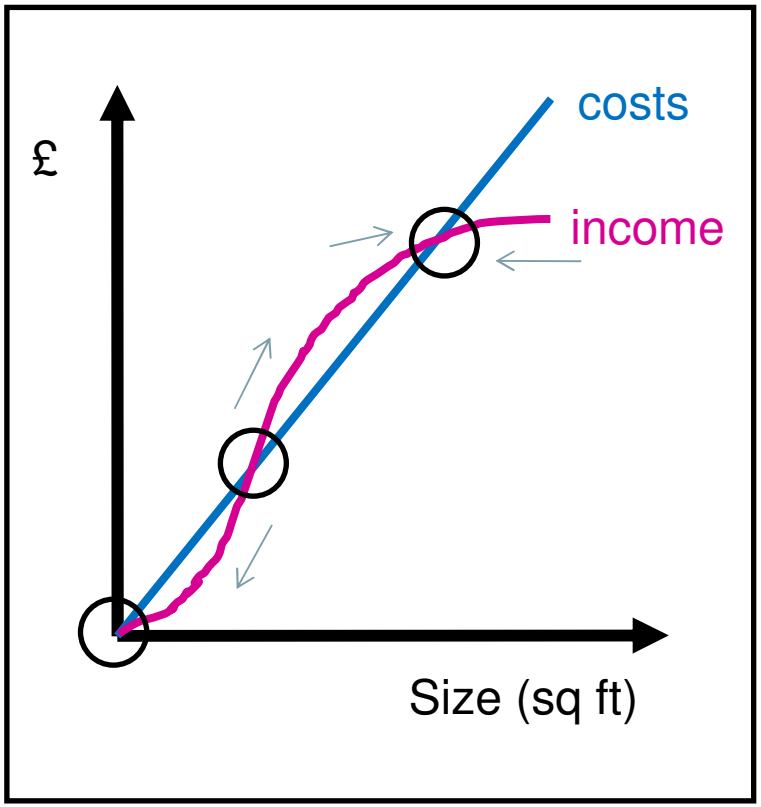
Results grid overview

- For a **<u>single time step</u>**
  - vary two parameters over a short range, e.g.:
    - *x* => **alpha:** benefit of visiting a large retail centre
    - *y* => **beta:** Impact of travel cost
  - run the model to equilibrium for each possible combination of model parameters
  - present the results on a grid

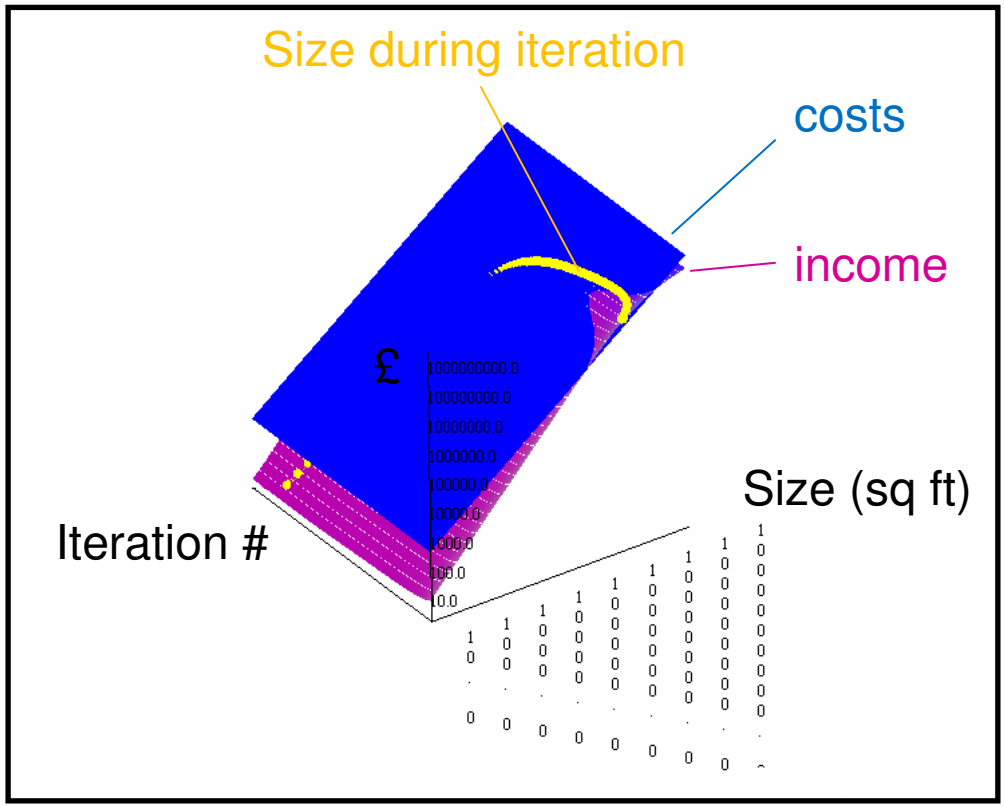


Income-costs zone graph

Explains behaviour during one iteration



…but changes every iteration



A new idea: DNA and path dependence

$$[\{S_{ij}\}, \{W_j\}, \{m_j\}, \{e_i\}, \{P_i\}, \alpha, \beta, \varepsilon]$$

$[\{S_{ij}\}]$

Endogenous ***Fast*** *Dynamics*

$[\{W_j\}]$

Endogenous ***Slow*** *Dynamics*

$[\{m_j\}, \{e_i\}, \{P_i\}, \alpha, \beta, \varepsilon]$

Exogenous parameters

SYSTEM DNA

Path dependence in urban systems

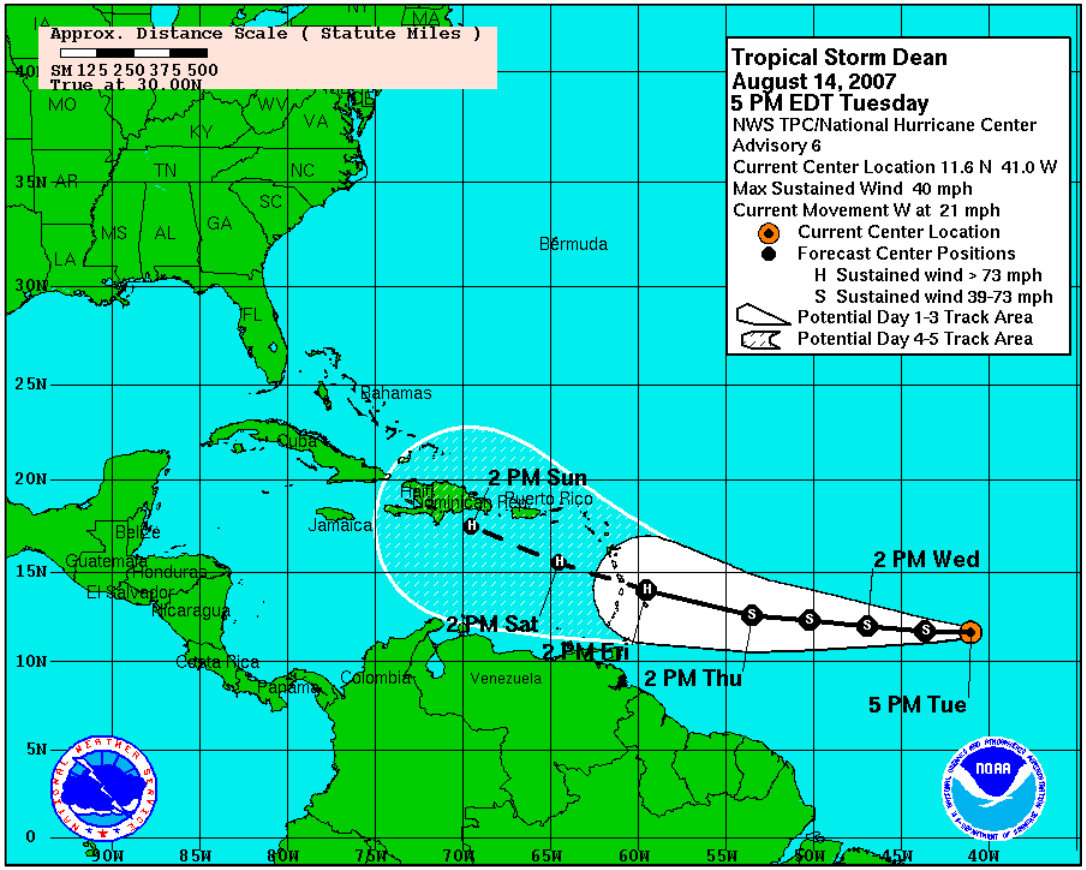
- we define path dependence as:
  - A sequence of initial conditions
  - Each set influencing possibilities of development

Challenges for forecasting

- Properties of nonlinear systems
  - Multiple equilibria
  - Discontinuities – phase transitions
  - Path dependence
- Emergent behaviour
- So not simply deterministic

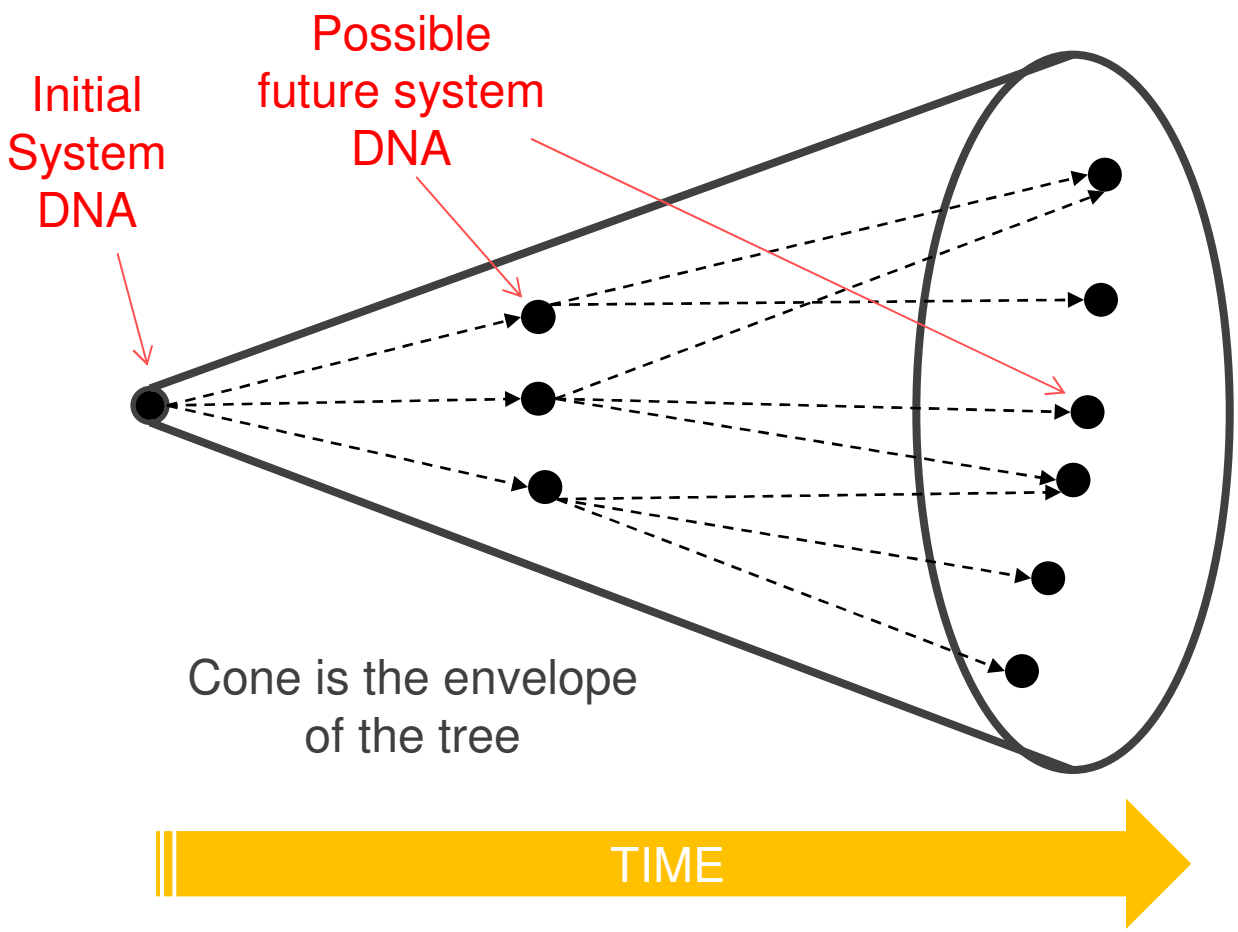
Hurricane forecast tracks*

- 5-Day Track Forecast Cone forecast
- uncertainty is conveyed by the track forecast "cone“
- Can we produce a similar possibility-cone for an urban system?

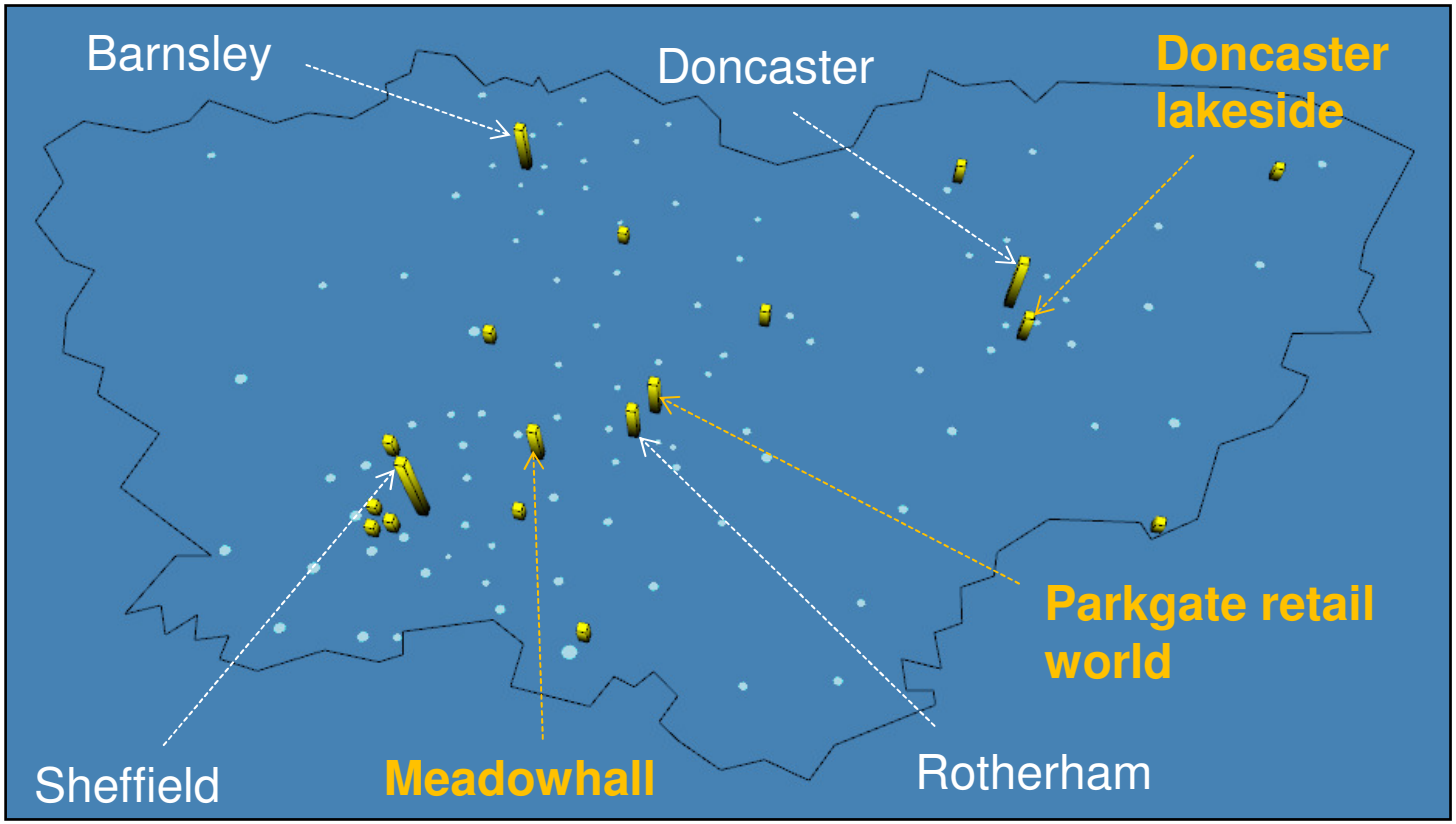


Source: National Oceanic and Atmospheric Administration

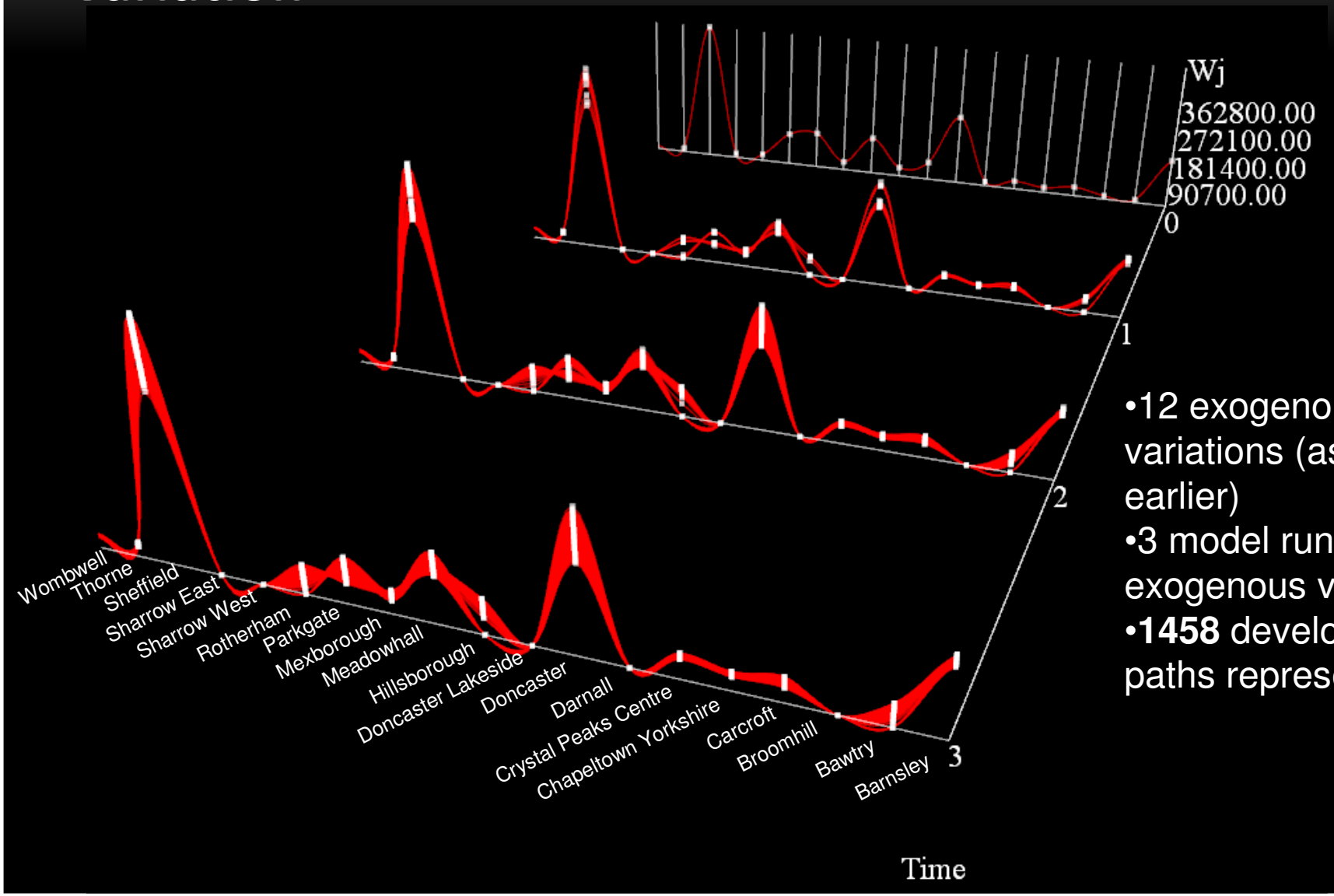
Building a possibility-cone: structure



South Yorkshire example: root DNA



South Yorkshire : multi-step with exogenous variation

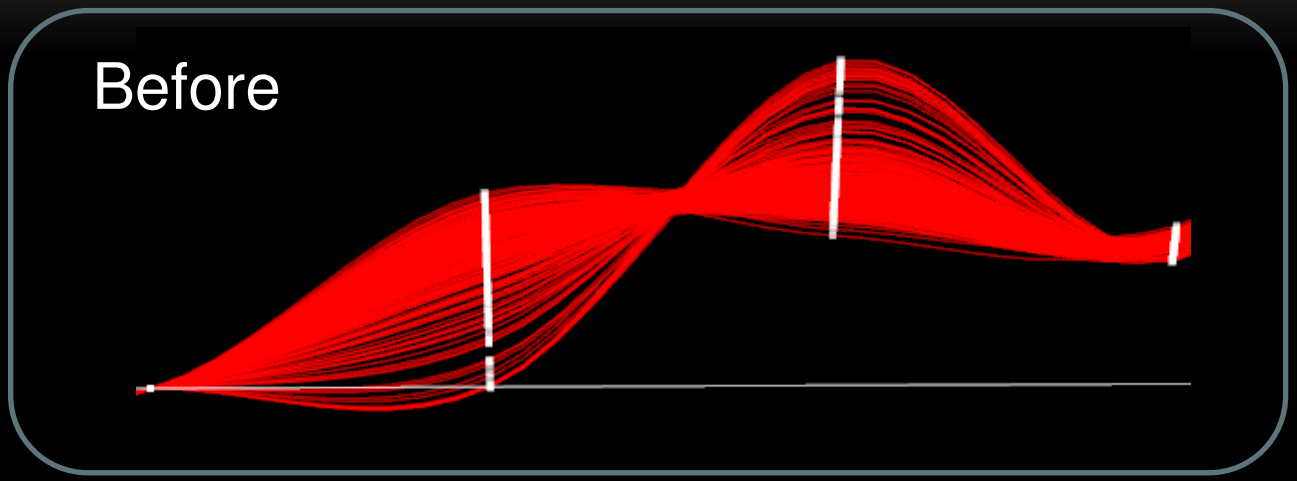


- 12 exogenous variations (as defined earlier)
- 3 model runs per exogenous variation
- **1458** development paths represented

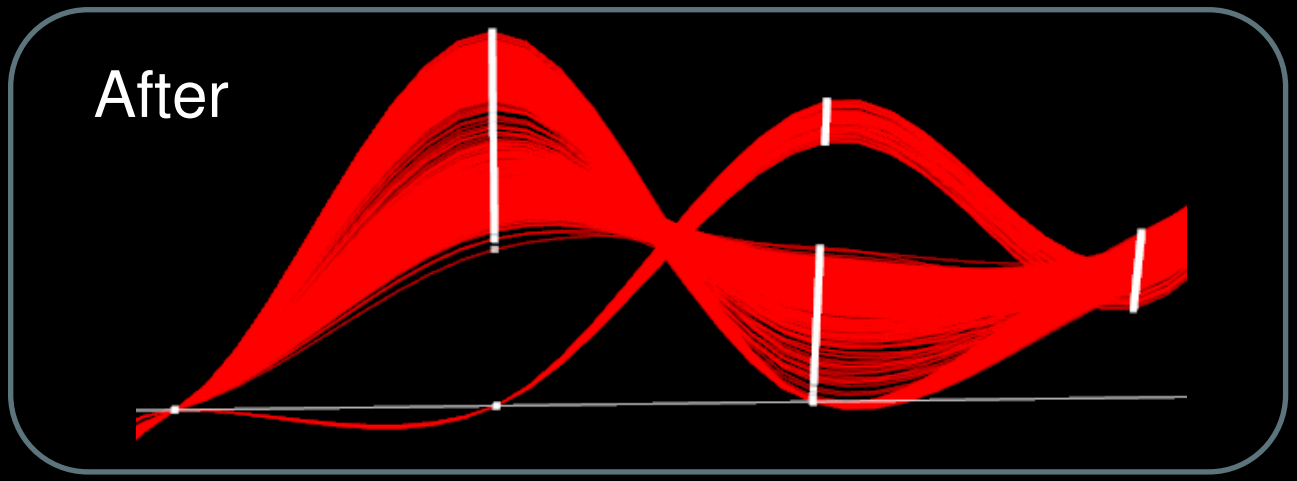
Urban "genetic medicine": Rotherham

- Extend the DNA idea to "genetic medicine"
- Rotherham town centre is in decline
  - 30% of high street boarded up in March 2009
  - Competition with out of town shopping centres
- What changes do we need to make to the DNA that ensures this centre is more stable?

The result of intervention



Rotherham Parkgate

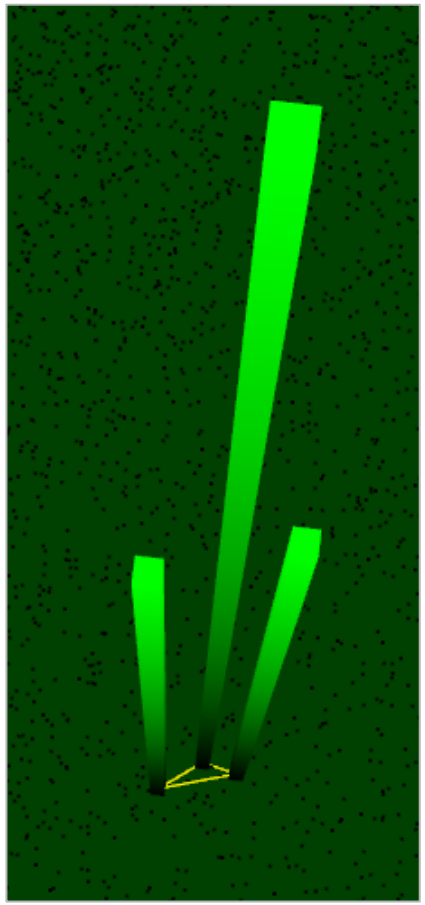


Agent based modelling approaches

- Is it possible to make ABM equivalent to any BLV model?
- How can BLV models inform development of rules for ABMs?
- Retail agent based model
  - South Yorkshire (population approx. 1.2 million)
  - Agents:
    - 500 independent retailers (each owning a single shop)
    - 50,000 consumers (mini-aggregation: 24 people represented by each agent)

Detecting emergent retail centres

- Near = walking distance (200m)
- We detect closed groups of shops where each member is near to at least one other member of that group
- We consider each group a separate emergent retail centre
- A group of three shops showing **retail centre boundary** ➔



Probability of consumer *i* visiting shop *j*
(two alternative versions of the model)

Alternative 1

$$p_{ij} = \frac{R_j^{\alpha} e^{-\beta c_{ij}}}{\sum_k R_k^{\alpha} e^{-\beta c_{ik}}}$$

R_j = Number of other shops within walking distance of j

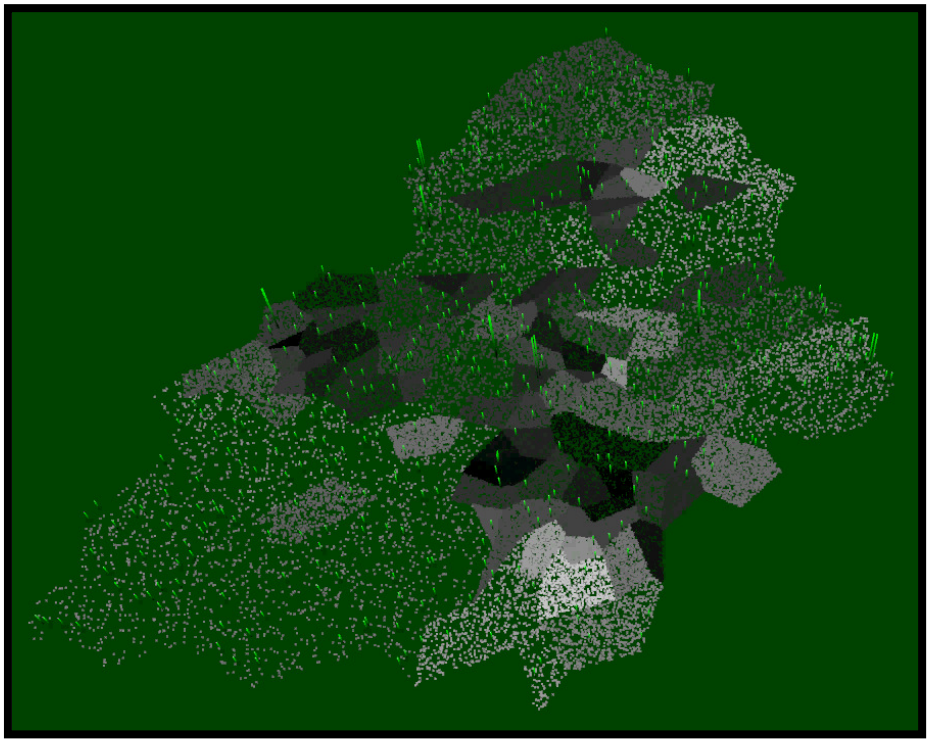
Alternative 2

$$p_{ij} = \frac{W_j^{\alpha} e^{-\beta c_{ij}}}{\sum_k W_k^{\alpha} e^{-\beta c_{ik}}}$$

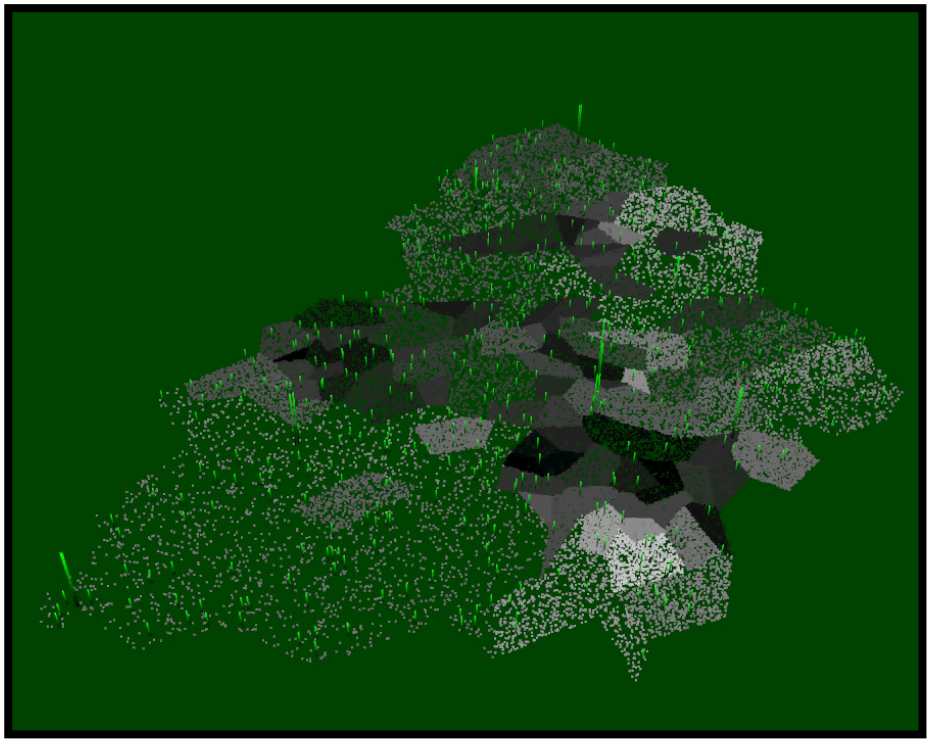
W_j = Number of shops in same emergent retail centre as j

Emergence of structure

R_j function



W_j function



- Start with random uniform distribution of shops
- Consumer agents generated from 2001 census data + CACI paycheck

Exploring the Nineteenth Century evolution of Chicago: model overview

An urban retail model translated to system of cities scale

Added population dynamics

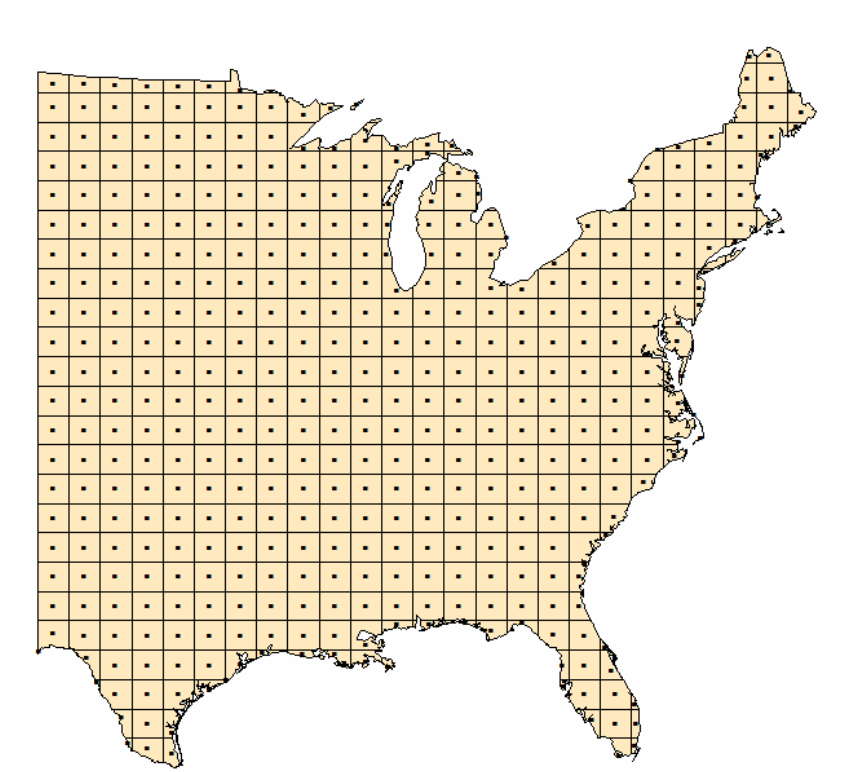
- Economic migrants
- Natural population growth

A spider network represents the transport network

Model area and period

- East coast to Midwest
- 1790 to 1870
- Focuses on the development of Chicago as the major city in the Midwest

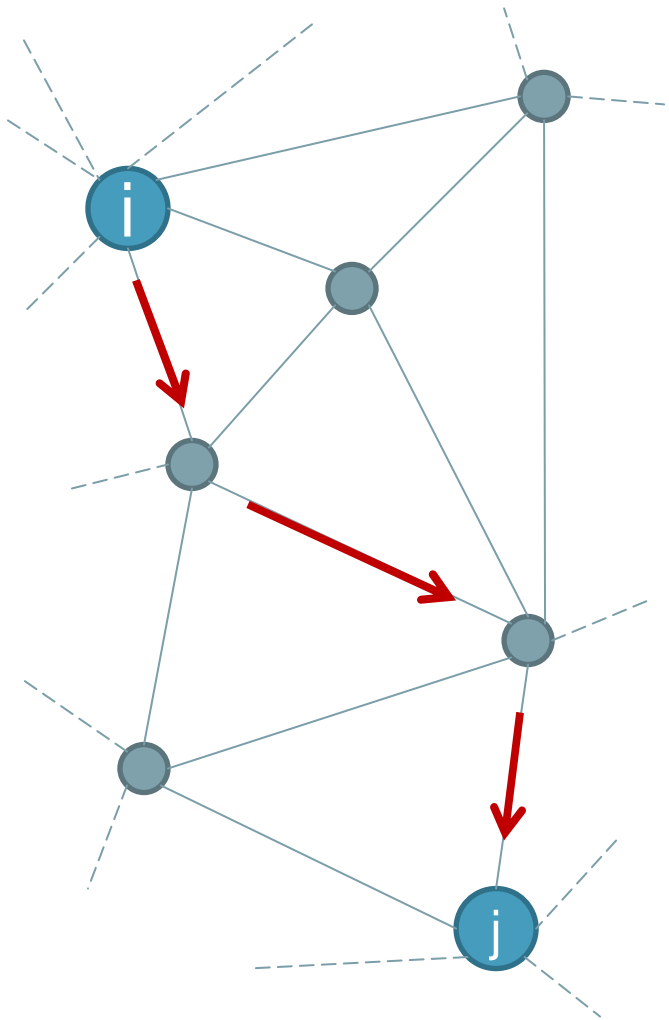
Data for calibration



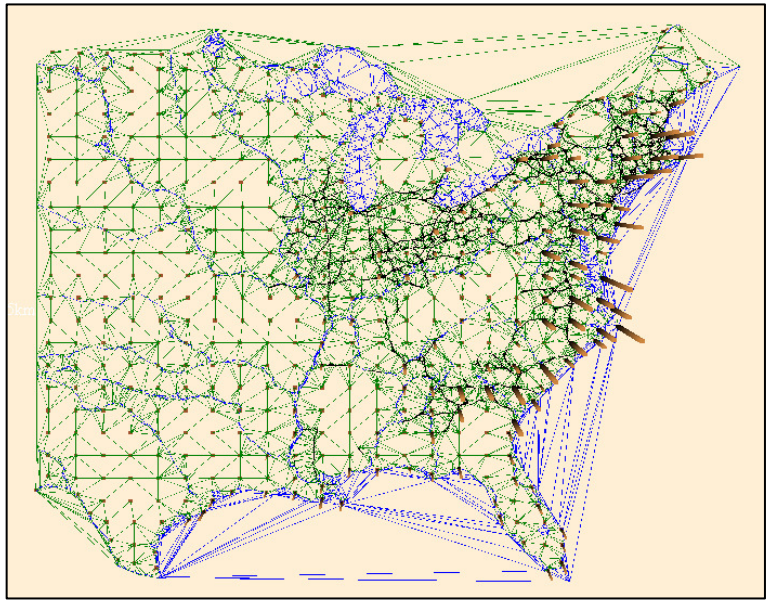
- Population data at county level from historical census (1790 to 1870) – source: NHGIS (www.nhgis.org)
- County boundaries change each decade
- Aggregated to a regular grid
- 434 cells
- Aggregated "settlements" are grid square centroids

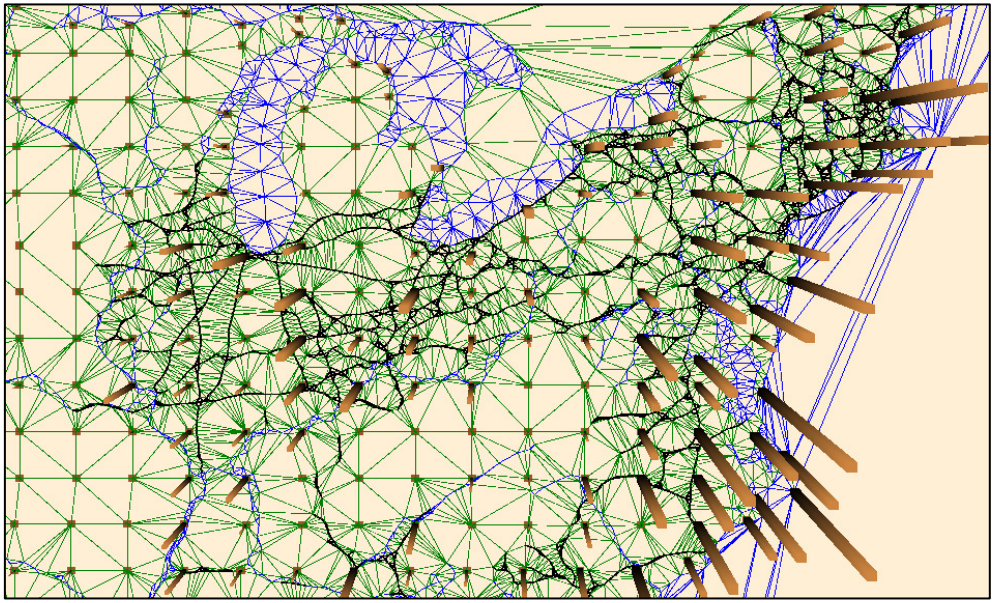
Spider network

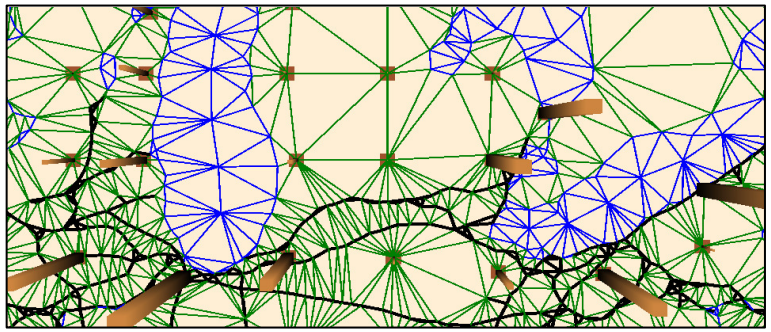
- We use a spider network to represent the transport system
- The travel cost from settlement i to settlement j is then the cost of shortest path through the spider network
- When railways construction occurs (either exogenously or endogenously) the link costs change and the shortest paths are recalculated.

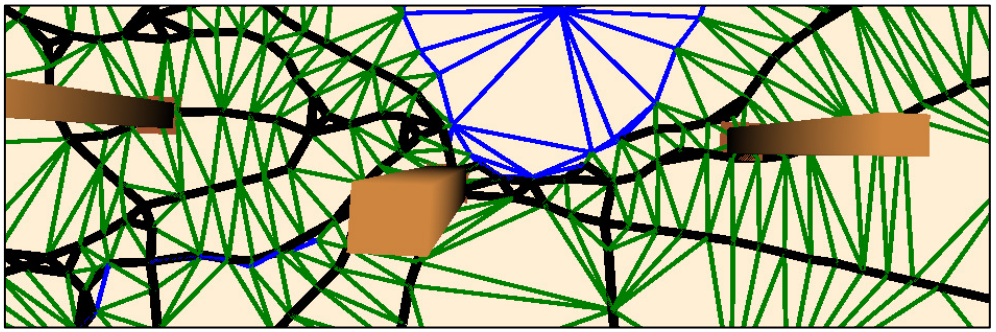


Detail of the spider network for 1870 with land, water and railroads

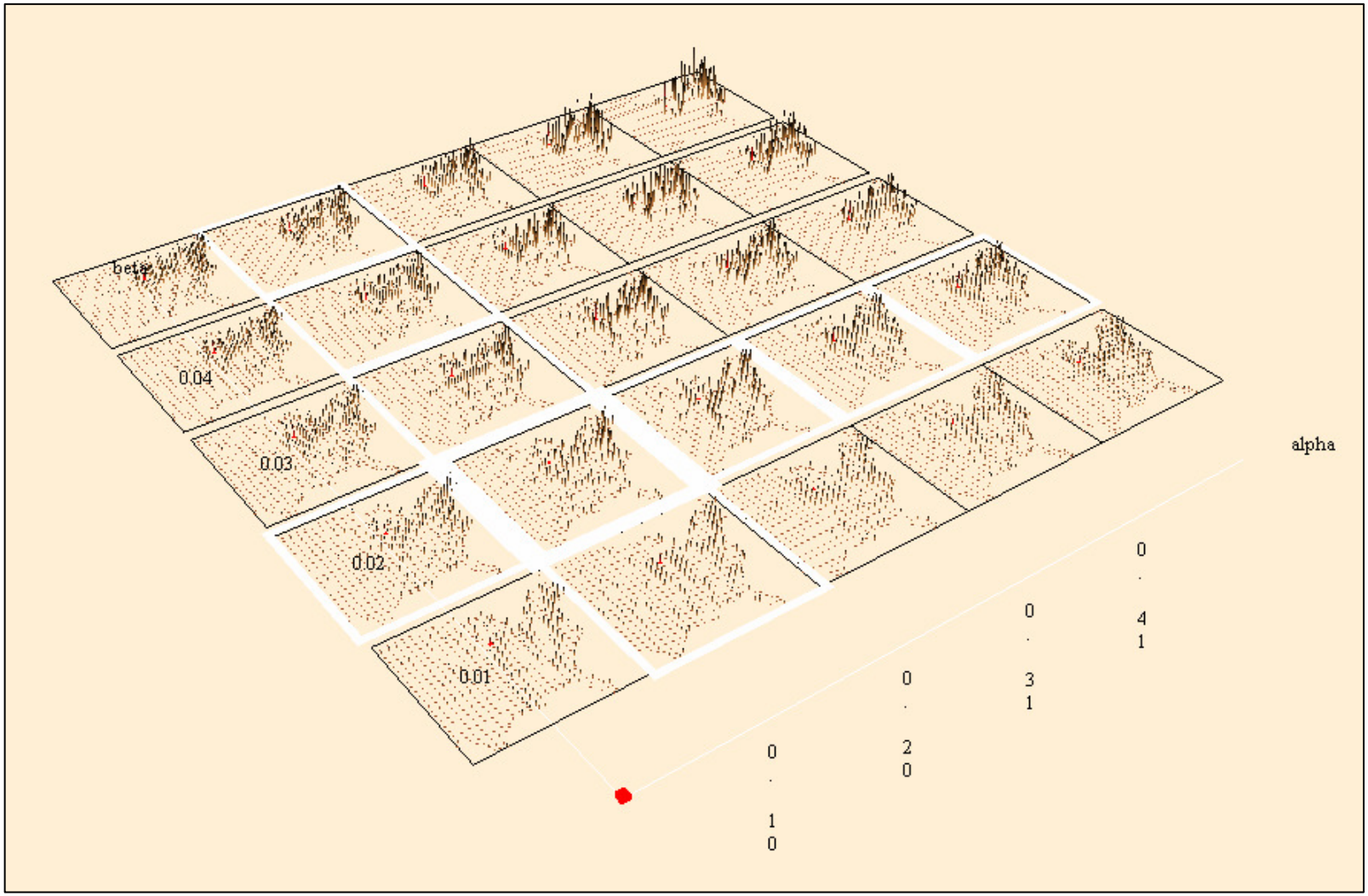


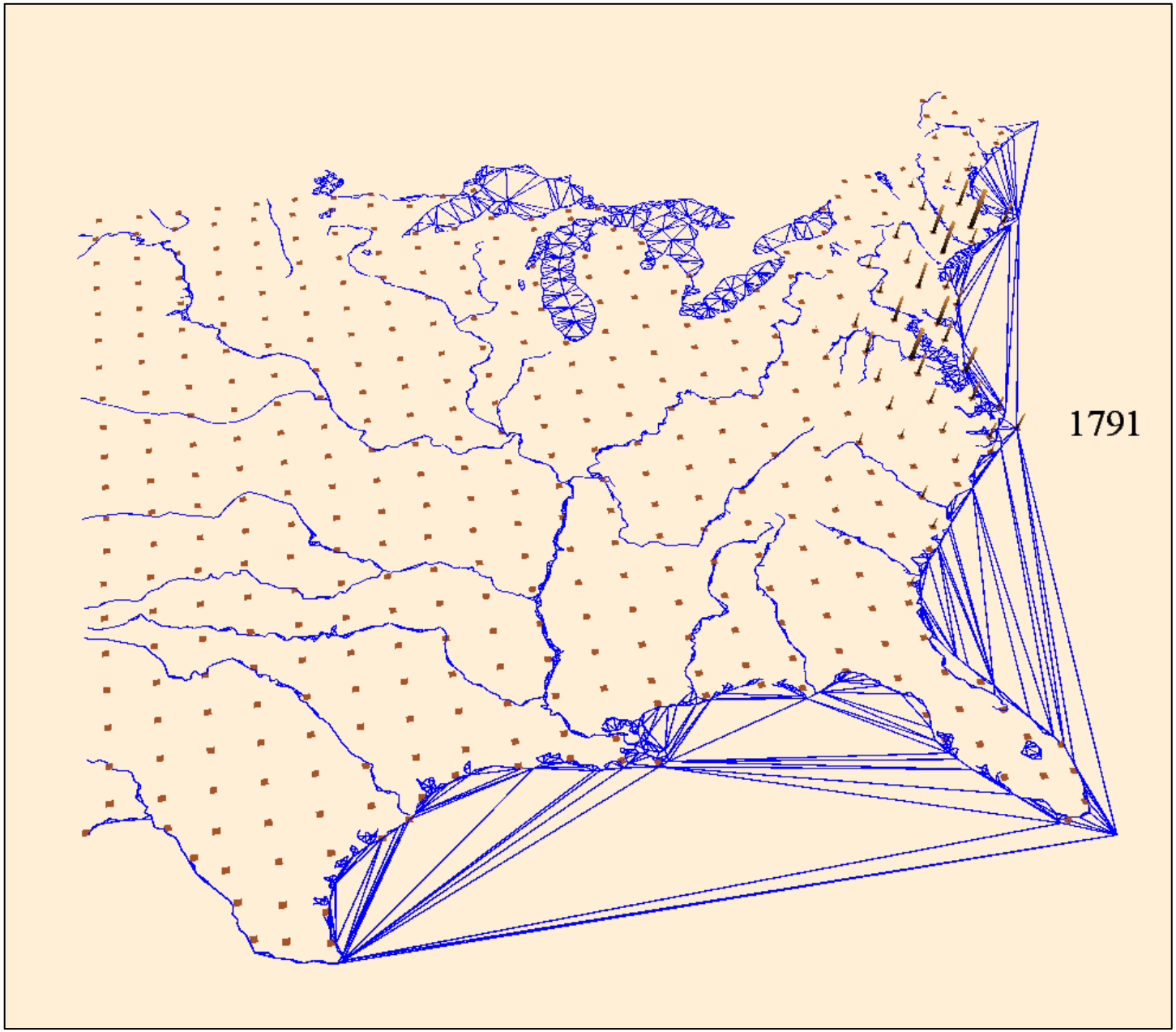


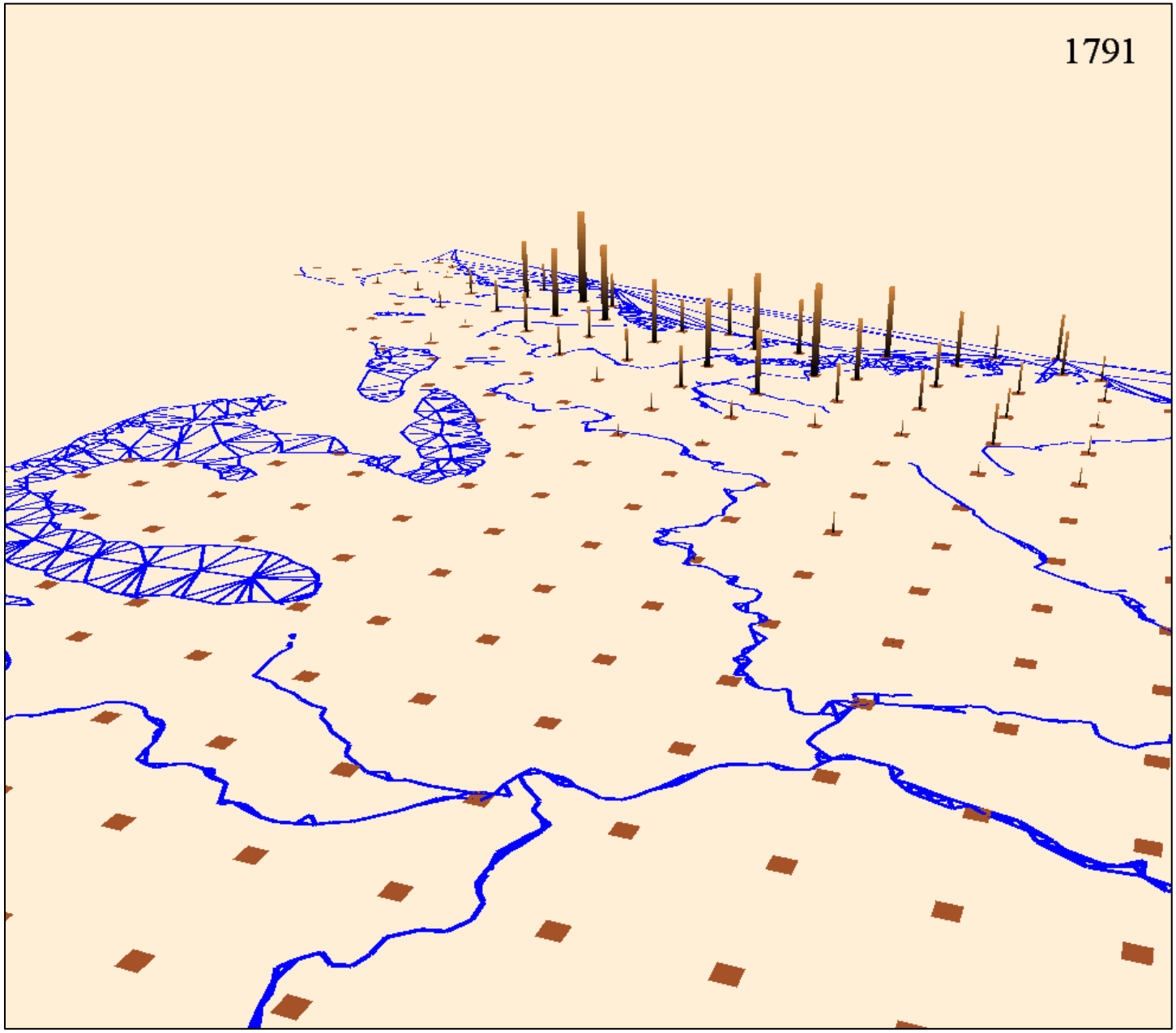




Results grid in [α, β] space

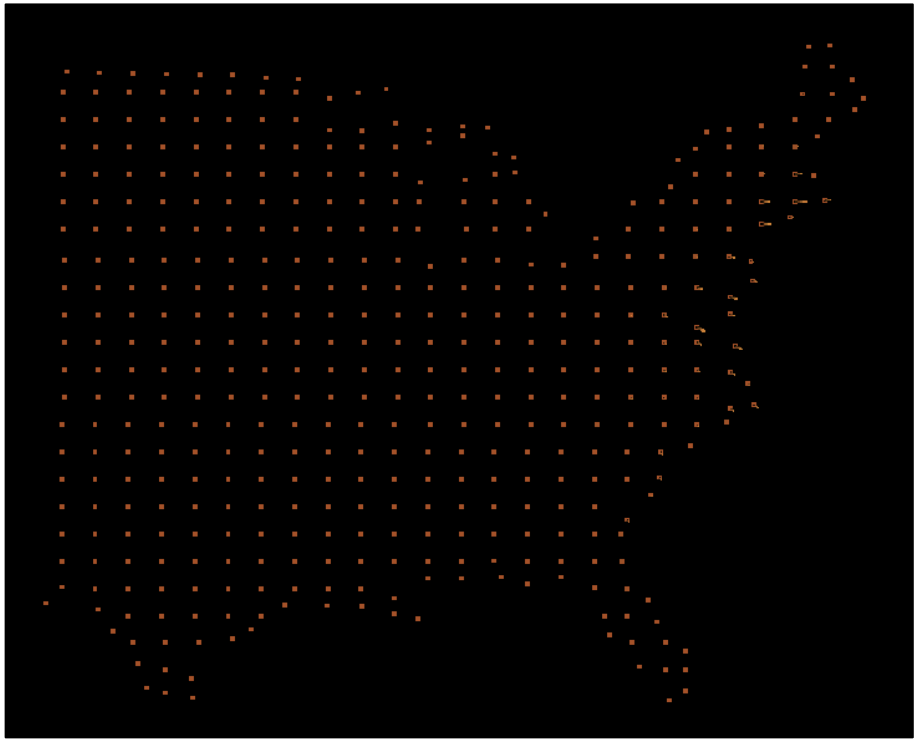



1791


1791

Best fit 1791 exports from Chicago

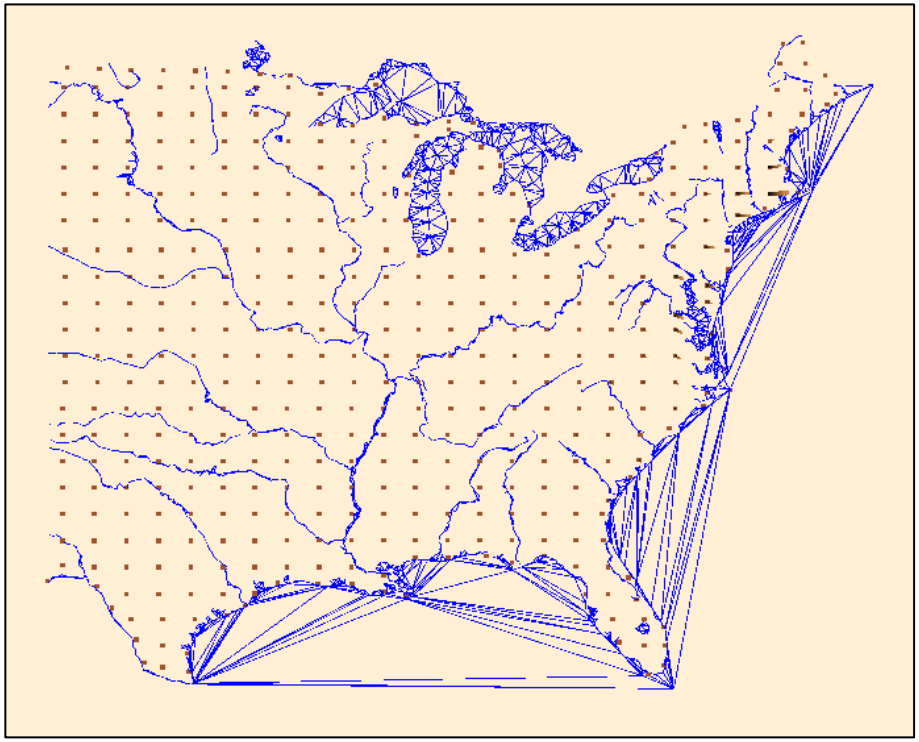
Exports



Value of exports ($)

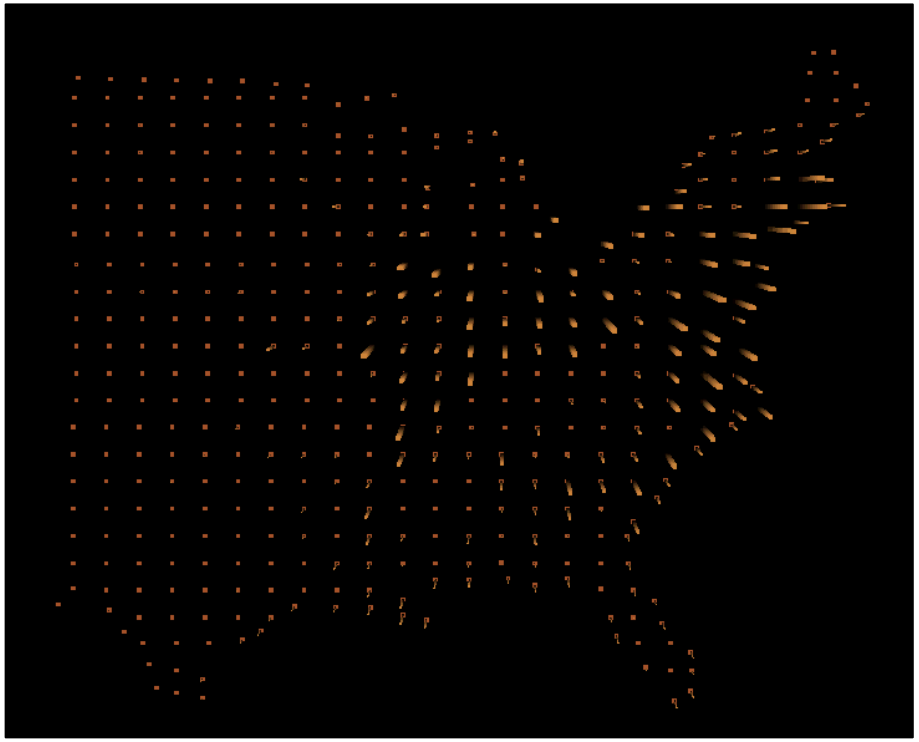
- 0 to 10
- 10 to 100
- 100 to 1,000
- 1,000 to 10,000
- 10,000 +

Transport network



Best fit 1870 exports from Chicago

Exports



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