Urban Simulation 5

b. Agent Based Models

Individuals Representing the Elements of Urban Systems

Michael Batty

http://www.spatialcomplexity.info/

5th February, 2024

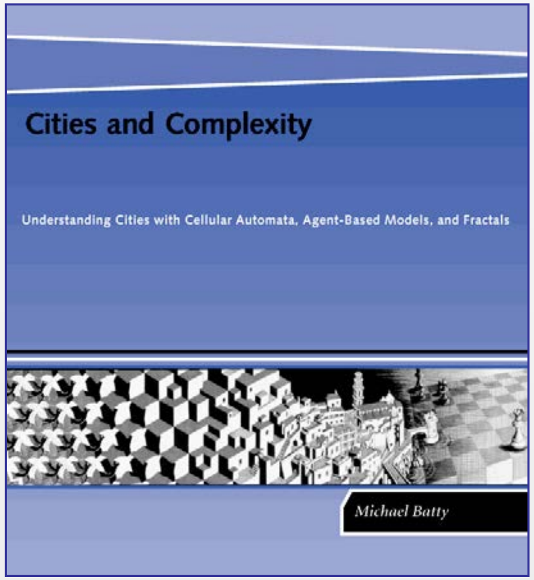
m.batty@ucl.ac.uk

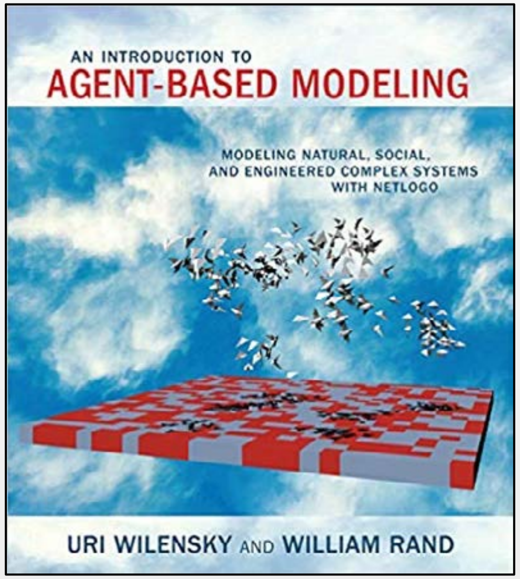
X @jmichaelbatty

We have had a good go at exploring complexity using cellular automata (**CA**) to illustrate many principles, particularly how complex systems like cities function and evolve from the bottom up. The essence of what we developed indicates how we can simulate 'emergence'

In this last week of my lectures, we will show how if we have a cellular or any spatial model, we can populate it with agents whose behaviour is largely mobile. We call these **ABM** – agent-based models or agent-based modelling

Reminding You of Reading on CA and ABM






geographical analysis

Geographical Analysis (2021) 53, 76–91

Special Issue

Future Developments in Geographical Agent-Based Models: Challenges and Opportunities

Alison Heppenstall[1,2], Andrew Crooks[3], Nick Malleson[1,2], Ed Manley[1,2], Jiaqi Ge[1], Michael Batty[4]

[1]School of Geography, University of Leeds, Leeds, U.K., [2]Alan Turing Institute, The British Library, London, U.K., [3]Department of Computational and Data Sciences and Department of Geography and Geoinformation Science, George Mason University, Fairfax, VA USA, [4]Centre for Advanced Spatial Analysis (CASA), University College London, London, U.K.

Despite reaching a point of acceptance as a research tool across the geographical and social sciences, there remain significant methodological challenges for agent-based models. These include recognizing and simulating emergent phenomena, agent representation, construction of behavioral rules, and calibration and validation. While advances in individual-level data and computing power have opened up new research avenues, they have also brought with them a new set of challenges. This article reviews some of the challenges that the field has faced, the opportunities available to advance the state-of-the-art, and the outlook for the field over the next decade. We argue that although agent-based models continue to have enormous promise as a means of developing dynamic spatial simulations, the field needs to fully embrace the potential offered by approaches from machine learning to allow us to fully broaden and deepen our understanding of geographical systems.

Introduction

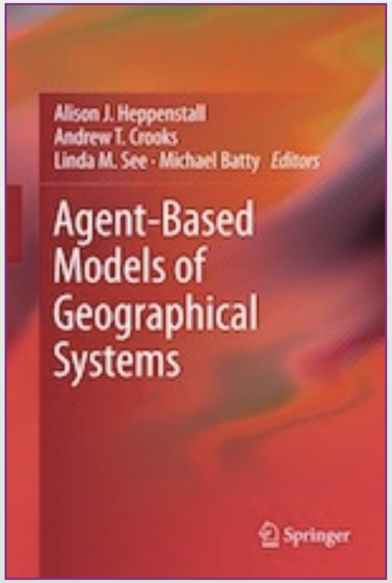
Individual-based methods, in particular agent-based models, have seen a rapid uptake by researchers across the social and geographical sciences in the past 20 years (Macal 2016). Agent-based models were first formally proposed in the early 1990s (e.g., Epstein and Axtell 1996) but their lineage goes back much further to the development of models of individual locational decision-making in the 1950s and 1960s in the influential work of Hagerstrand (1953), Donnelly et al. (1964), and Schelling (1969) among others. They are now reaching a point of acceptance as a research tool across the geographical and social sciences, exploring such phenomena as epidemiology (Shook and Wang 2015), invasive species (Anderson and Dragićević 2020), settlement patterns (Bura et al. 1996), and segregation (Benenson and Hatna 2011) (see Polhill et al. 2019 for further discussion on the applications of ABMs and their use in policy).

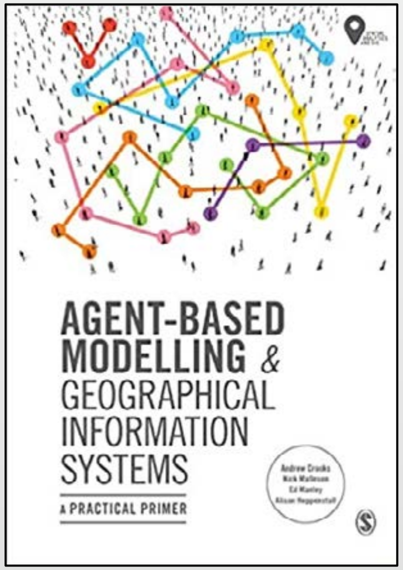
However, there remain significant methodological challenges, for example, in: recognizing and simulating emergent phenomena; agent representation; construction of behavioral rules;

Correspondence: Alison Heppenstall, School of Geography, University of Leeds, Leeds LS2 9JT, U.K. e-mail: a.j.heppenstall@leeds.ac.uk

Submitted: November 13, 2019; Revised version accepted: November 16, 2020

76 doi: 10.1111/gean.12267





Outline of Today's Lecture

- Agents – Behaviour – Randomness – Geometry
- Mobility and Random Walks –
- Constraining Randomness – Organic Growth
- Adding Intentions: Social Behaviour – Utility
- Models of Crowding – Buildings and Town Centres: Panic, Evacuation, Safety
- More on Swarming as a Basic Model of Movement
- Agents in a Cellular Landscape
- My Major Example: The Notting Hill Carnival
- The Model: Flocking and Crowding: Swarms
- Using Such Models in Policy

Agents – Behaviour – Randomness – Geometry

- I need to introduce a little bit of theory about defining agents and about behaviour – I also want to look at questions of randomness

- Essentially by randomness I don't mean chaos in any sense, mean random variation from some fairly basic structure – so as you see if you walk in a straight line then basically you can randomly deviate from the line as you correct your mechanisms for judging how to balance as you attempt to walk straight.

- Ok what does all this mean

- First this style of modelling is based on what we call '**agents**' – to an extent these are atomic units – indivisible, not like geographical areas as in spatial interaction

- And second, it is a style of modelling based on '**averages**' We basically model how a large number of agents respond to generic rules, not how each respond differently.

- The concept of the agent is most useful when it is **mobile**, in terms of dynamics and processes

- Behaviour is not simply a product of **intentions**. It is as much a product of **uncertainty**, hence **randomness** and physical constraints, of **geometry**

- Defining Agents – objects that have motion
- The concept is broad, hence confused – there are at least **four types** in various kinds of modelling
- Objects in the virtual world – software objects that move on networks – **bots**? Objects that define the physical world – **particles**? Objects in the natural world – **plants**? Objects that exist in the human world – **people**? perhaps **institutions** and **agencies**.
- Agents here are mainly people, literally individuals, but sometimes objects such as physical objects like streets, barriers and plots can be treated as agents
- Agents as people can have different kinds of behaviour from the routine to the strategic

Mobility and Random Walks

- I will begin with randomness which is at the basis of much movement in physical systems and then add some geometry
- A good model to begin with is the 'random walk' which we will look at in one- and then two- dimensions
- There is always some intentionality in a walk but the simplest least controversial is where we assume things are going forward in time

The classic one-dimensional walk

Here we simply generate a random deviation from the line which marks direction – time or space

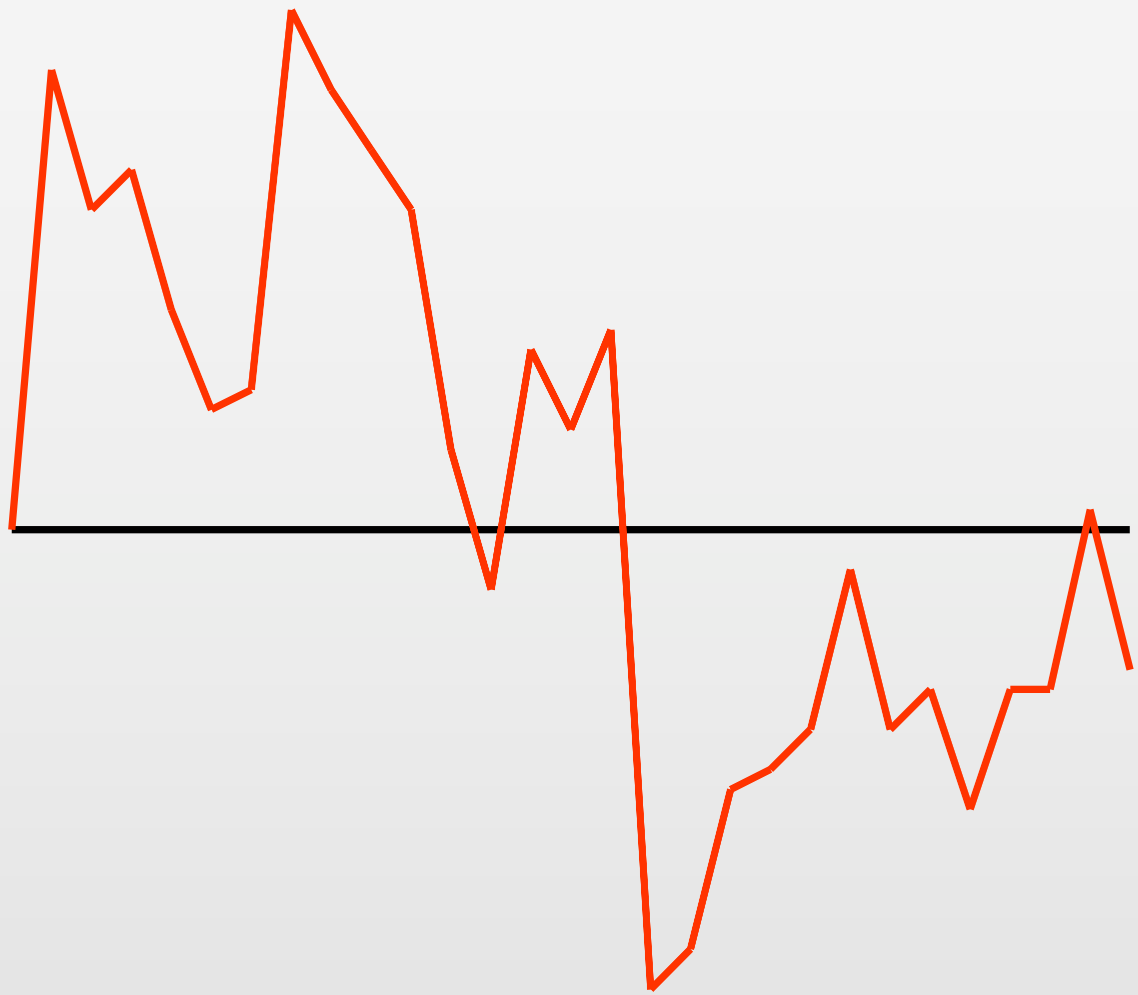
Good example is noise – as deviations from a pure signal –

There is no memory here – each deviation is independent of the previous one

The one-dimensional walk with memory

Here the random deviation is added to the position of the previous value – so there is memory – this is a first order Markov process

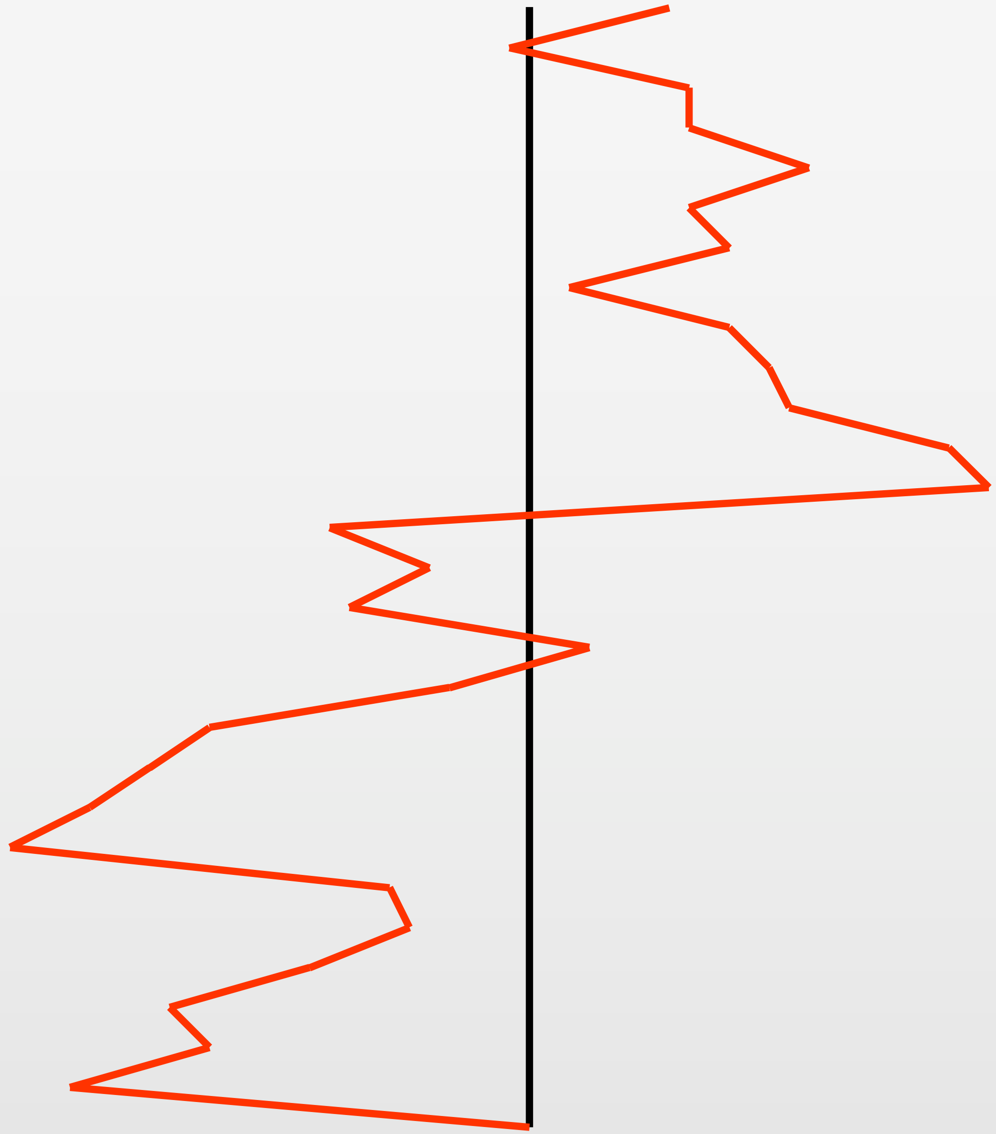
It is like a stock market, indeed this is what rocket scientists on Wall St try to model – they know they can't, but ……



Let's suppress time

This is exactly the same walk as the previous one but now think of it as a 'drunk' trying to go in one direction – in fact if we reduce the deviations this is what we all do when we walk in straight line

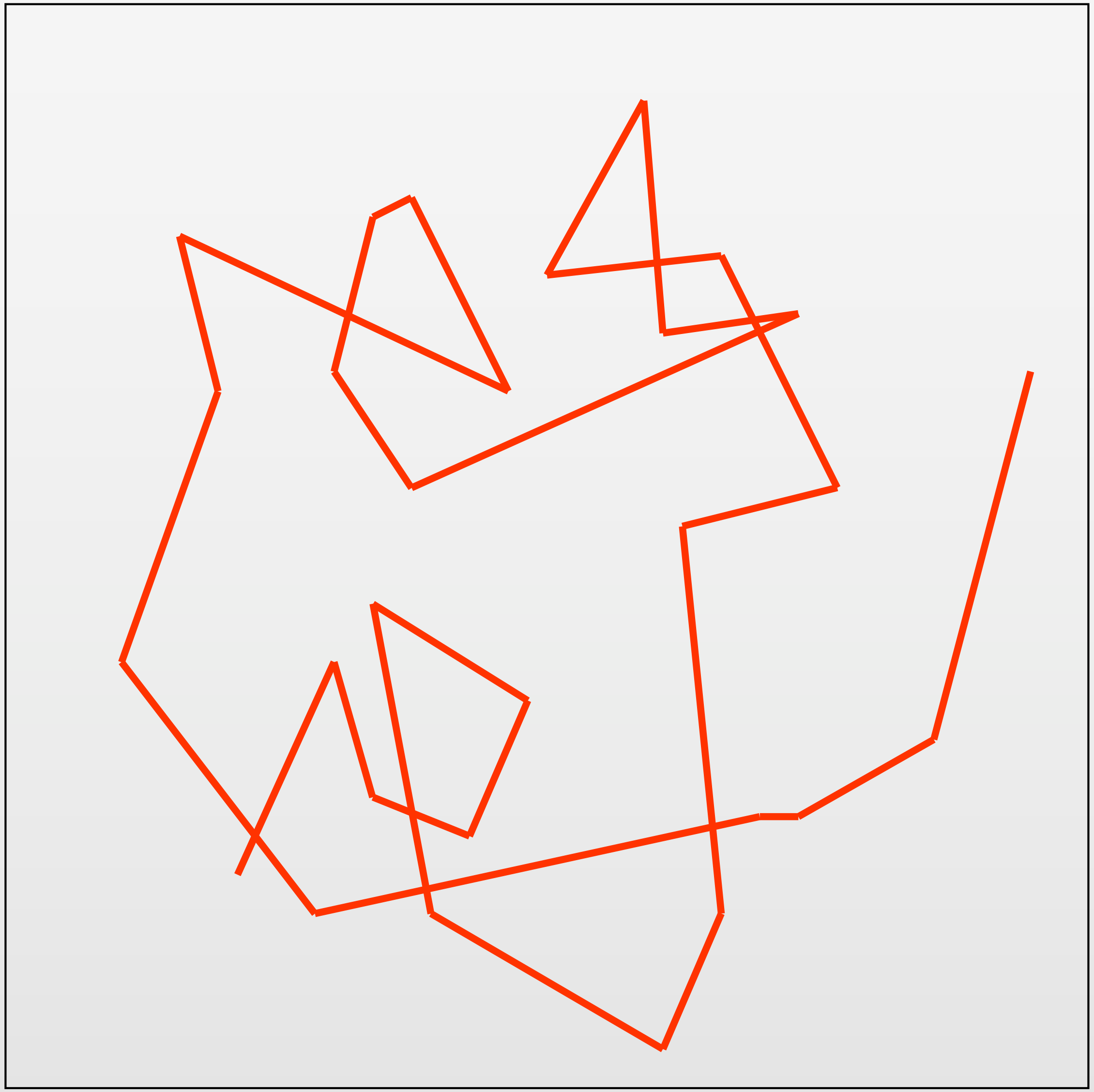
So it is as relevant to space as it is to time
Space and time are two sides of the same coin



Now think of the walk in two dimensions

This is a random walk which is the basis of an awful lot of physical behaviour.

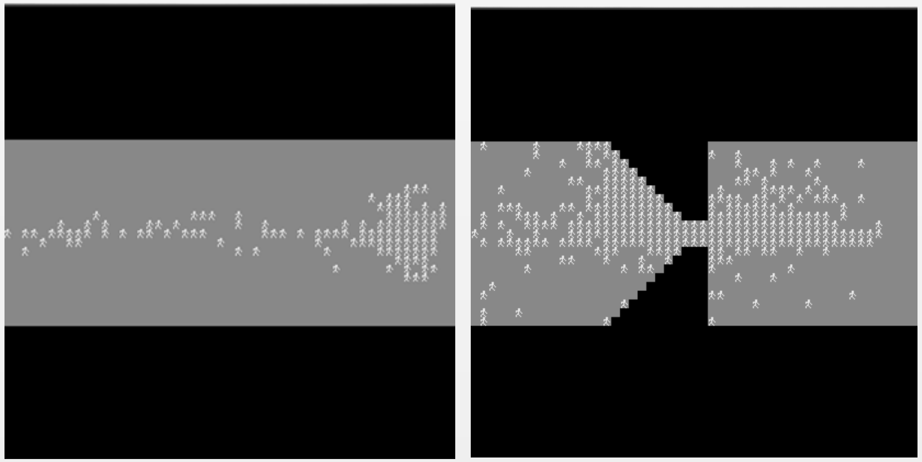
We are going add geometry and intentions to build models of how people move. But let's look at some examples of these models running



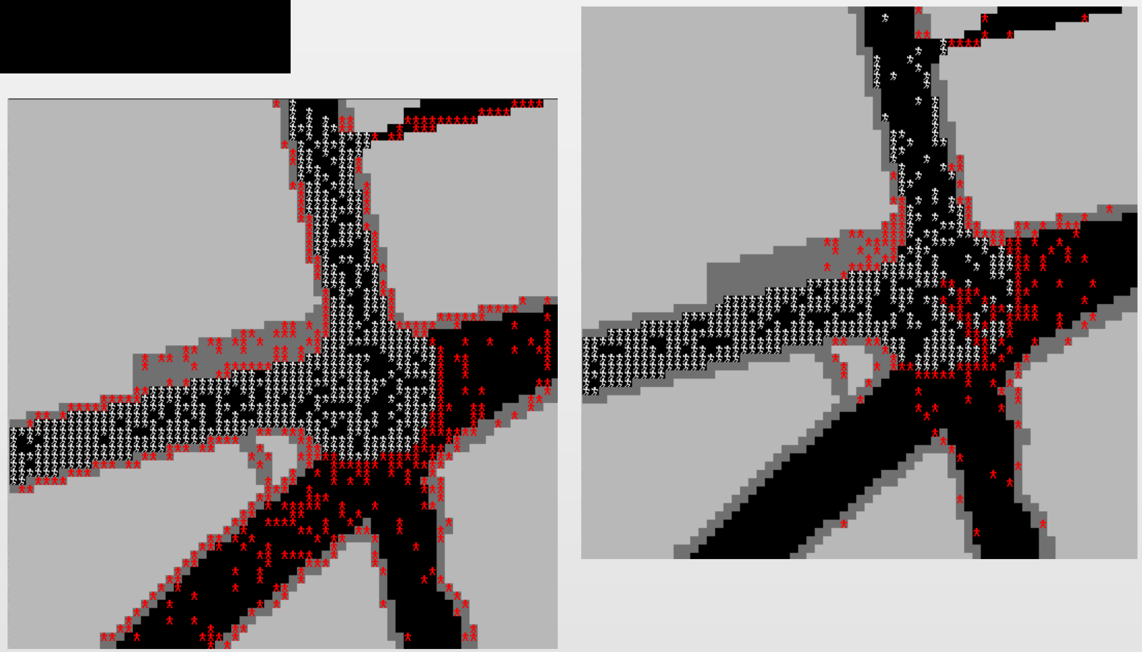
Adding Intentions: Social Behaviour – Utility

- Let us try to add some socio-economic logic to the random walk – we will assume that the walkers are moving to some specific destination – which we will encode into the spatial environment on which the walkers are moving.
- We will introduce a source of walkers and move them towards the destination with the walkers climbing a regular gradient surface to the destination. We will add various degrees of randomness to these walks and then constrain the geometry

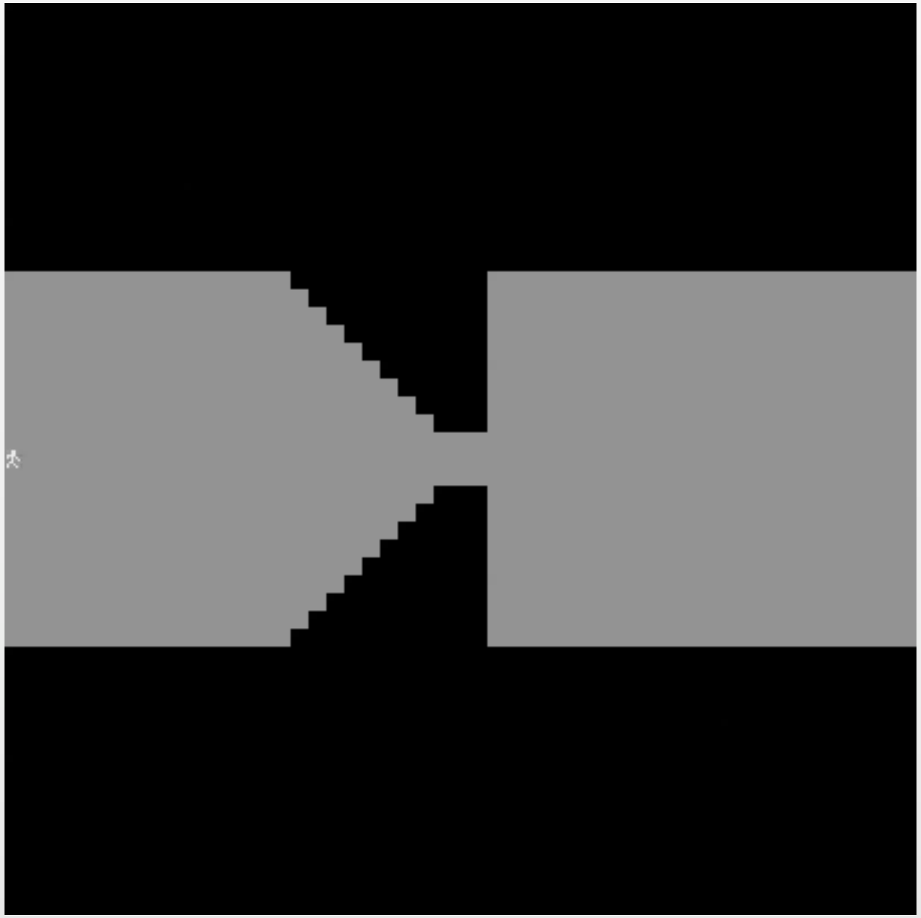
Here are some of our examples and we will run some movies to show what happens

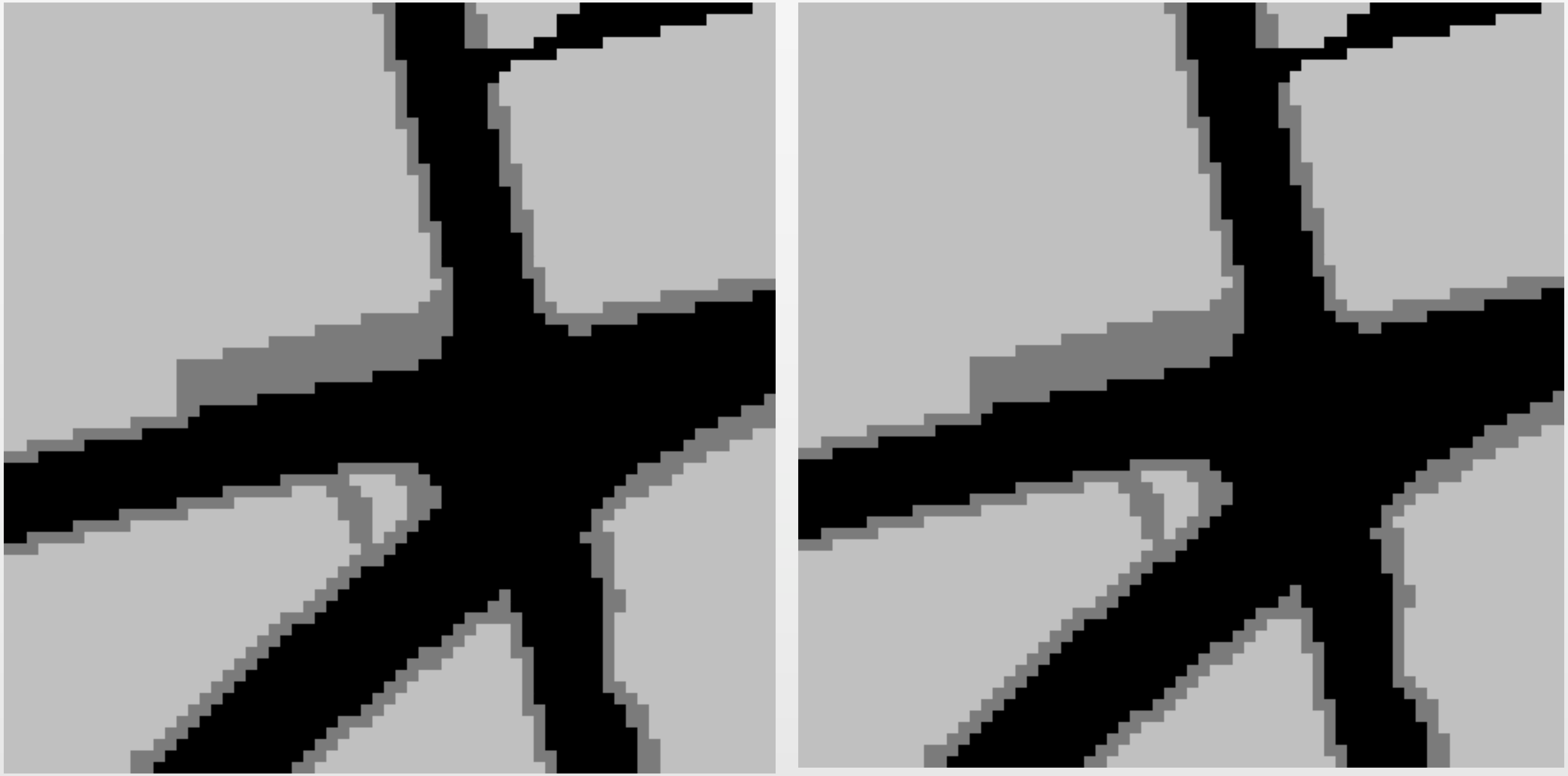


We start with a street, launch walkers and then narrow the street to see the effect of crowding



This is a street junction in Notting Hill where the parade – grey walkers – are surrounded by those watching the parade (red)then breaking through the parade in panic

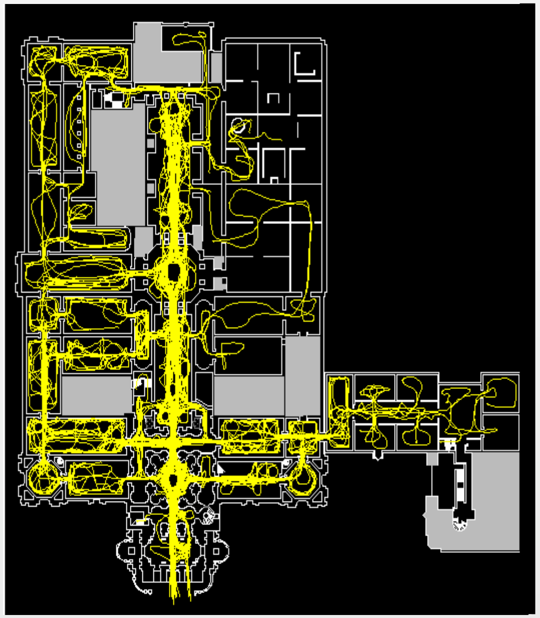


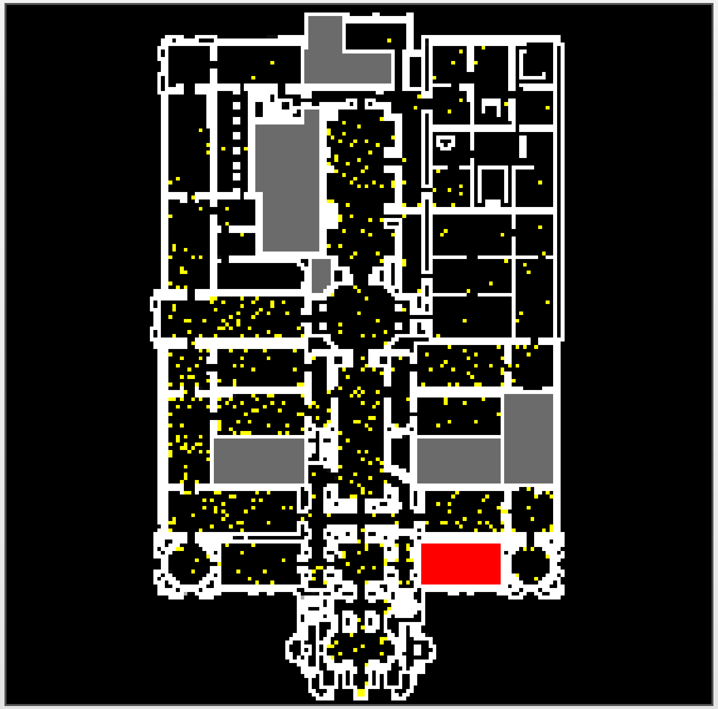


Models of Crowding – Buildings and Town Centres: Panic, Evacuation, Safety

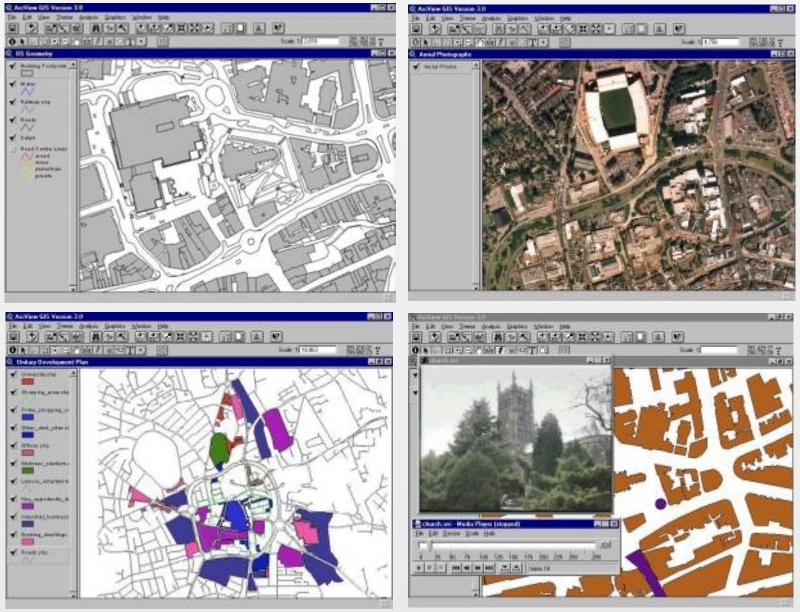
- We have developed a number of these models all with intention based on where people want to go, encoded into the spatial cells on which they walk
- We have geometry to which walkers react in term of obstacle avoidance
- We have randomness for any direction of walking – but constrained so that there is exploration to enable new directions to be chosen
- We have diffusion for dispersing congestion and flocking for copying what others do

Let us simply show what we can do
An art gallery: ***Tate Britain***:



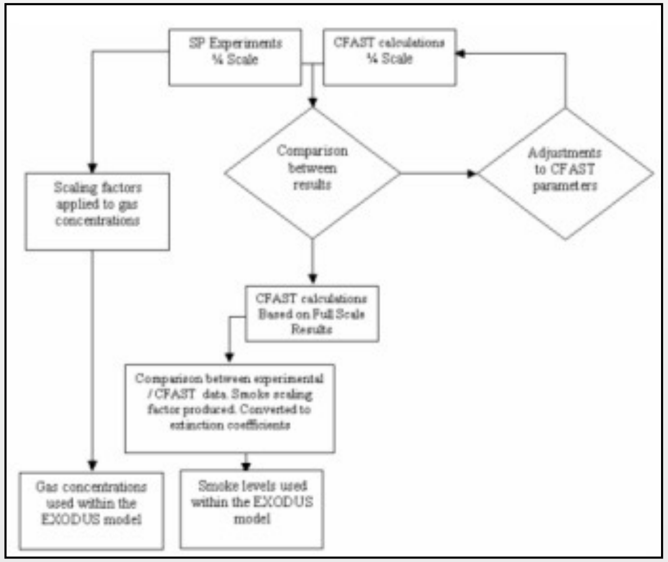


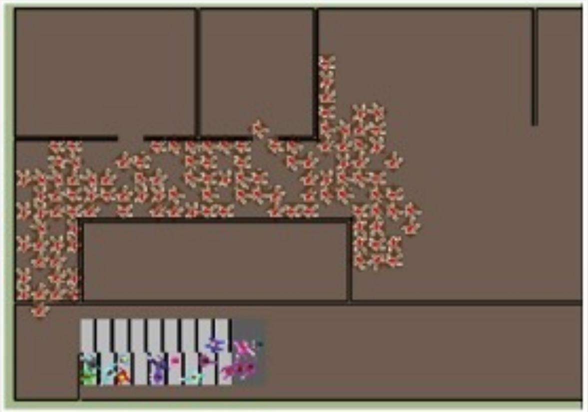
A Town Centre:
Movements from car parks and stations into the centre of a small English town: ***Wolverhampton***

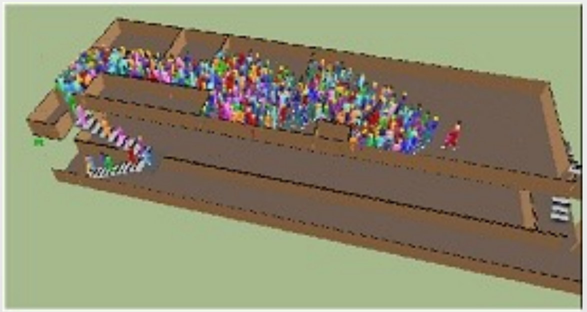


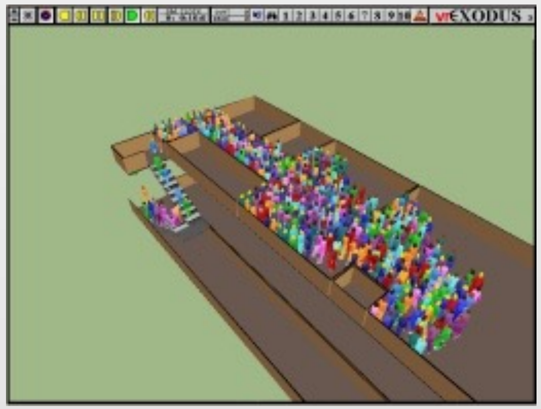
population ~ 250 000

A Fire Evacuation:
How fire spreads through a building and how people crowd and panic in evacuation





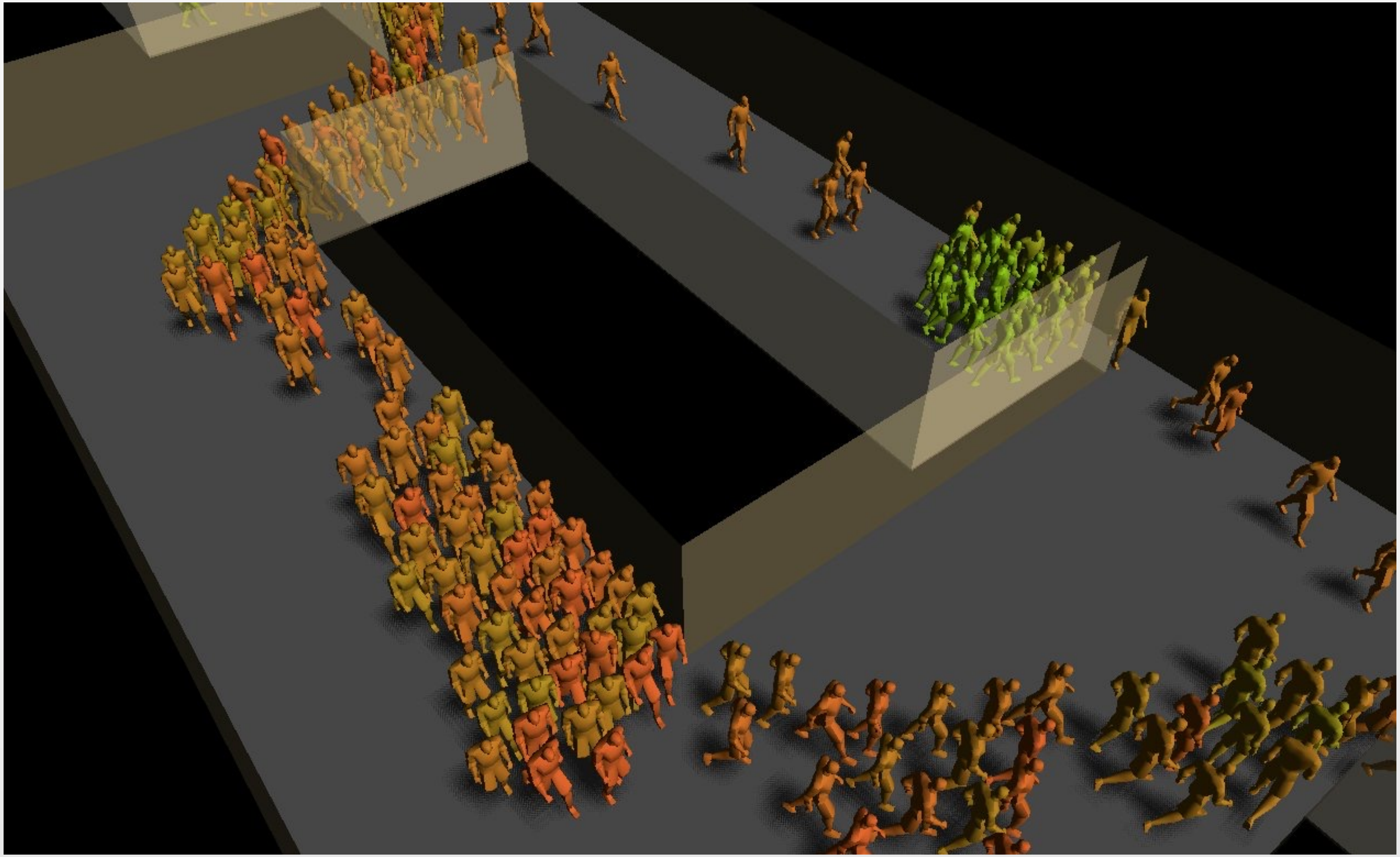




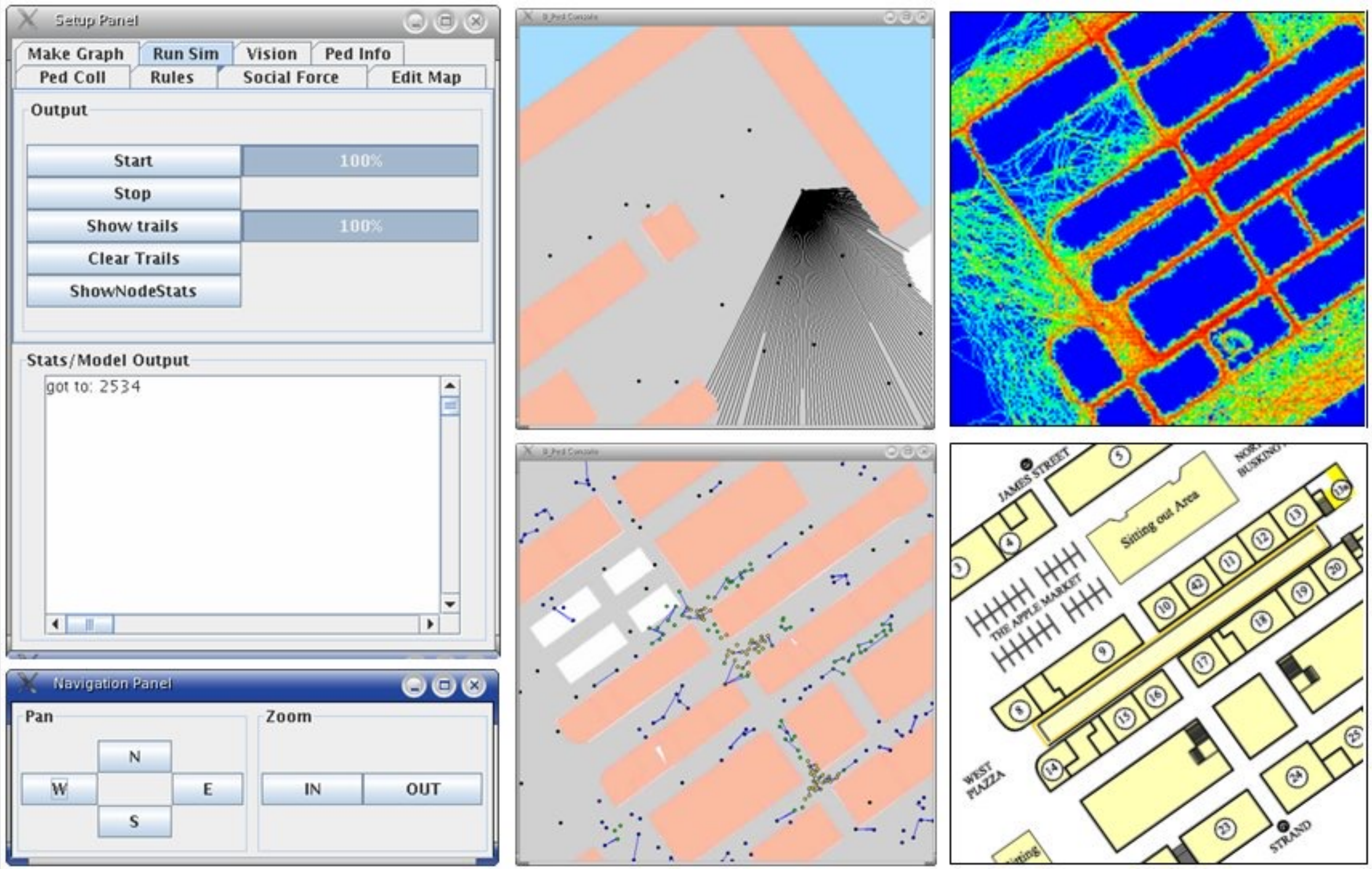
From the Greenwich Fire Safety Group

https://fseg.gre.ac.uk/fire/EXODUS_animations.asp

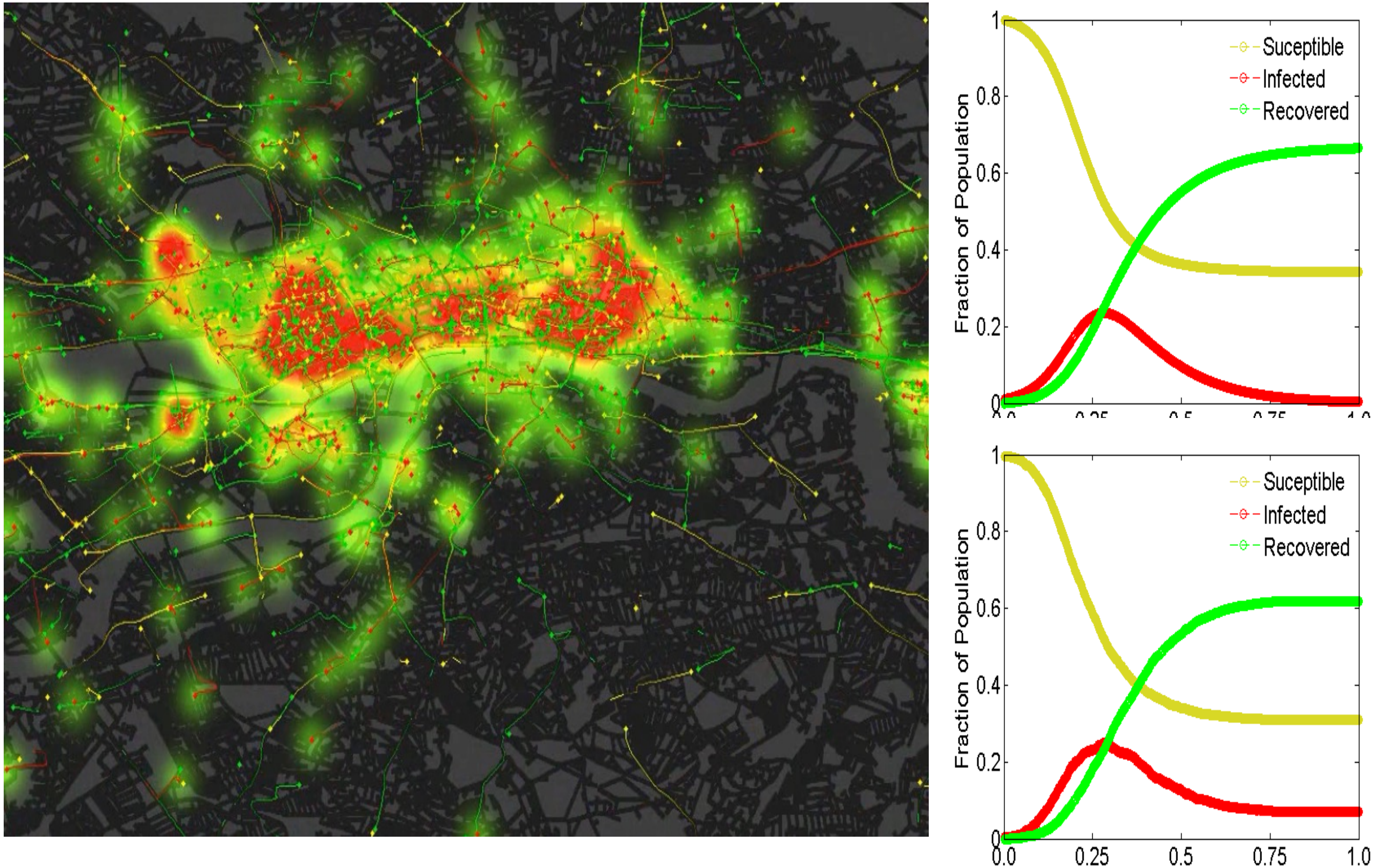
Modelling and Visualising Pedestrian Evacuation in a Large Building Complexes such as an Airport



Modelling and Visualising Pedestrian Congestion in Neighbourhoods and Large Building Complexes

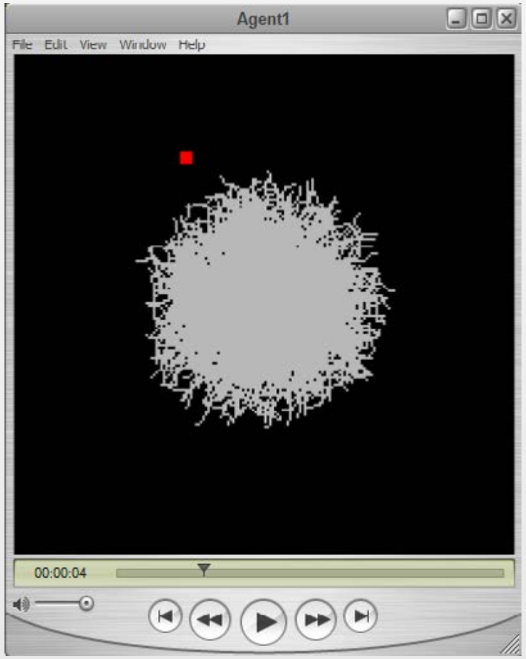


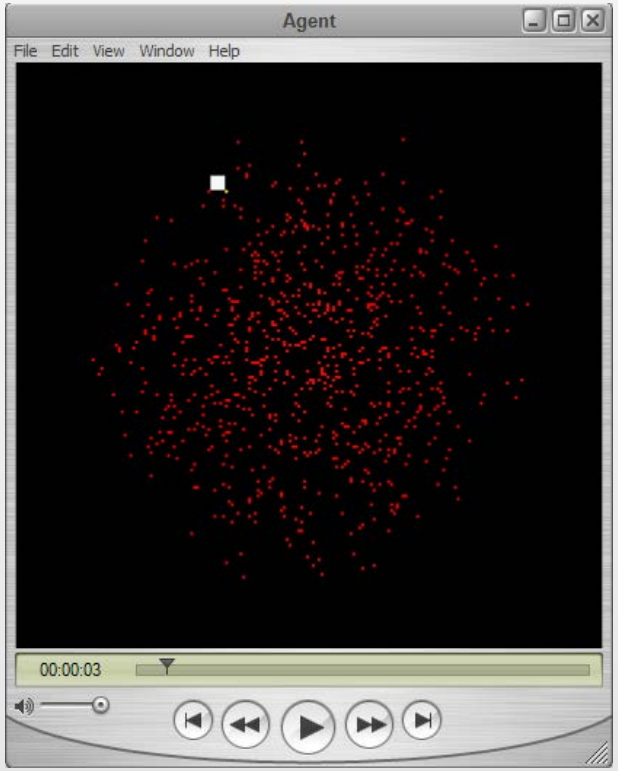
Ward's Model of Pedestrian Movement in Covent Garden

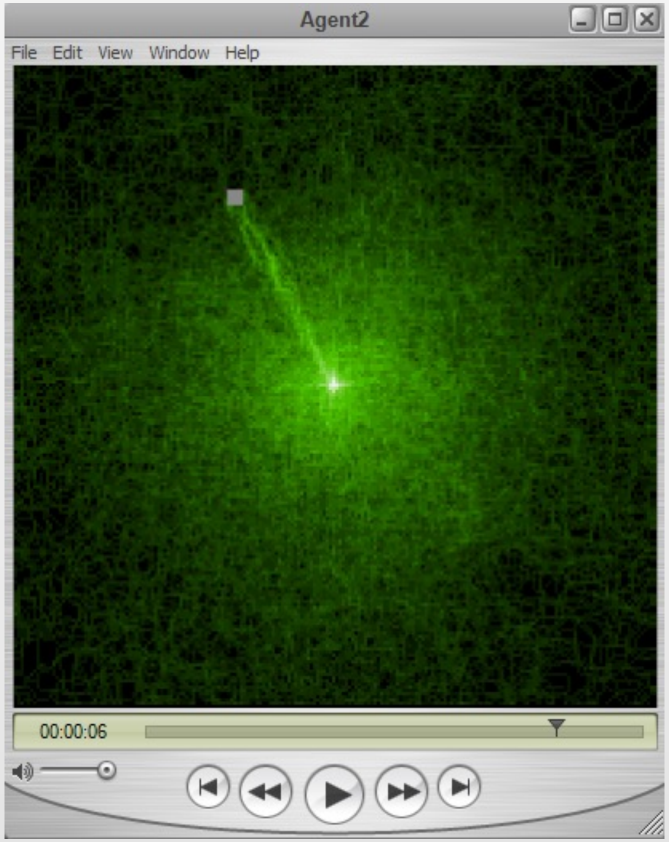


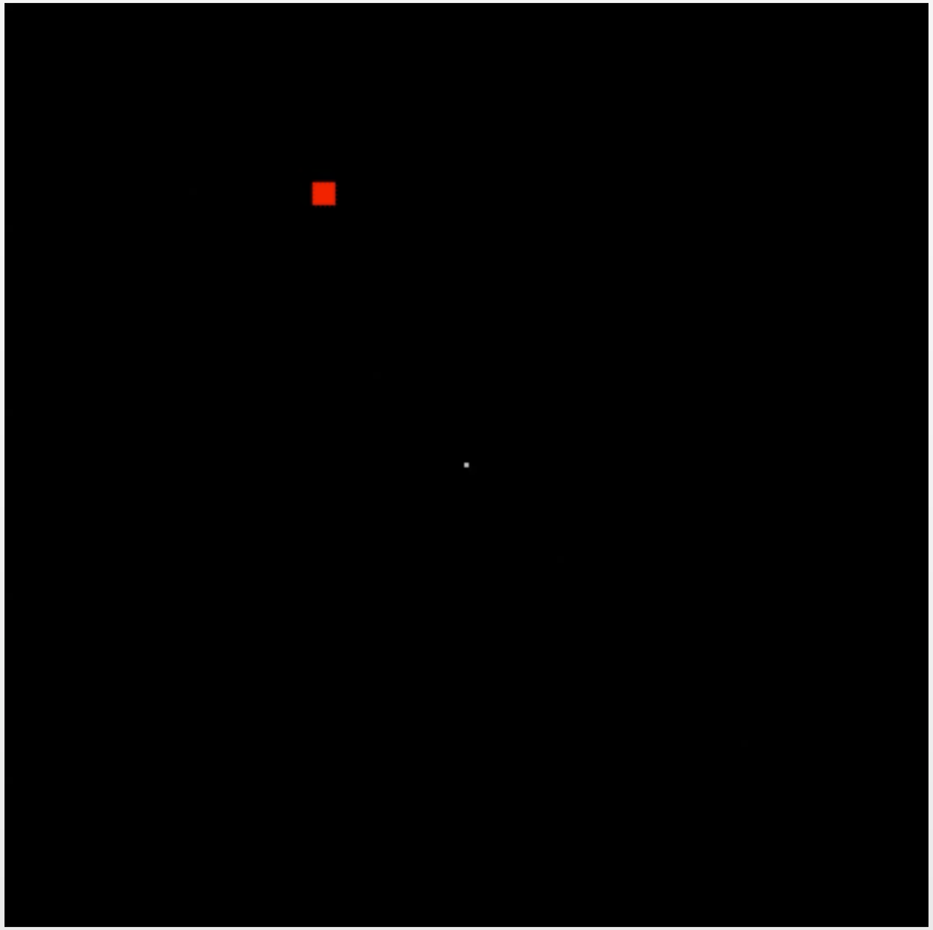
Epidemic Spread of Common Cold from GPS Traces in Taxis in Central London

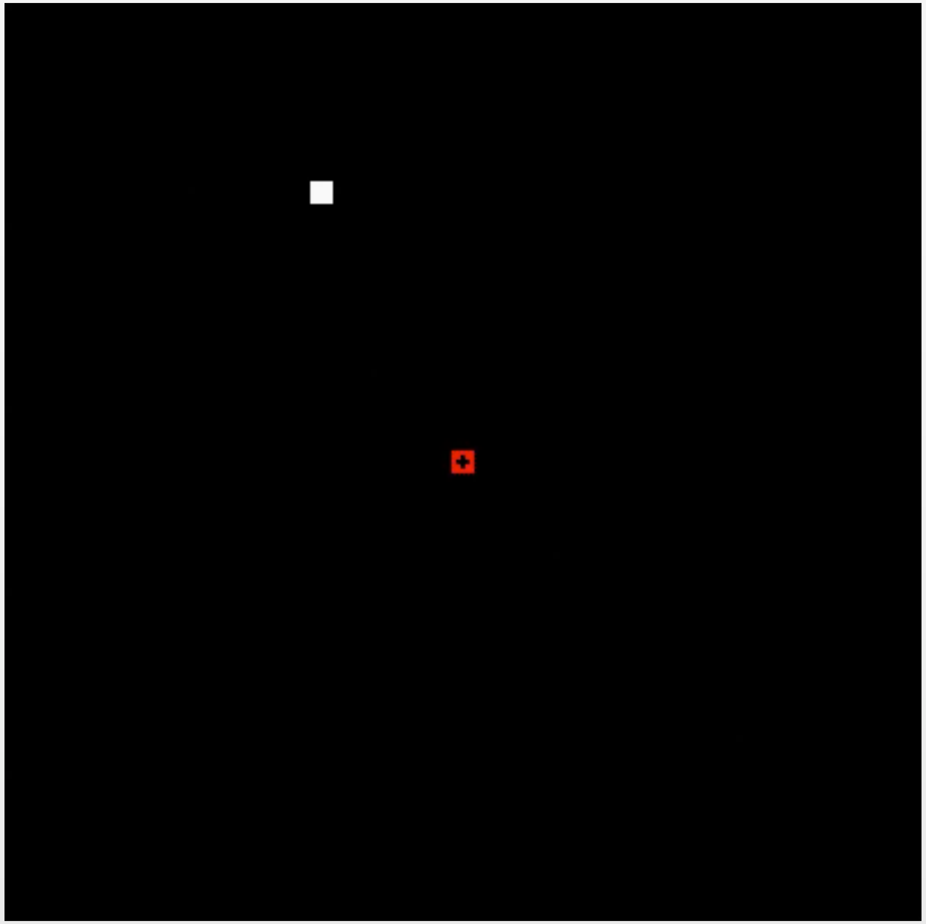
More on Swarming as a Basic Model of Movement



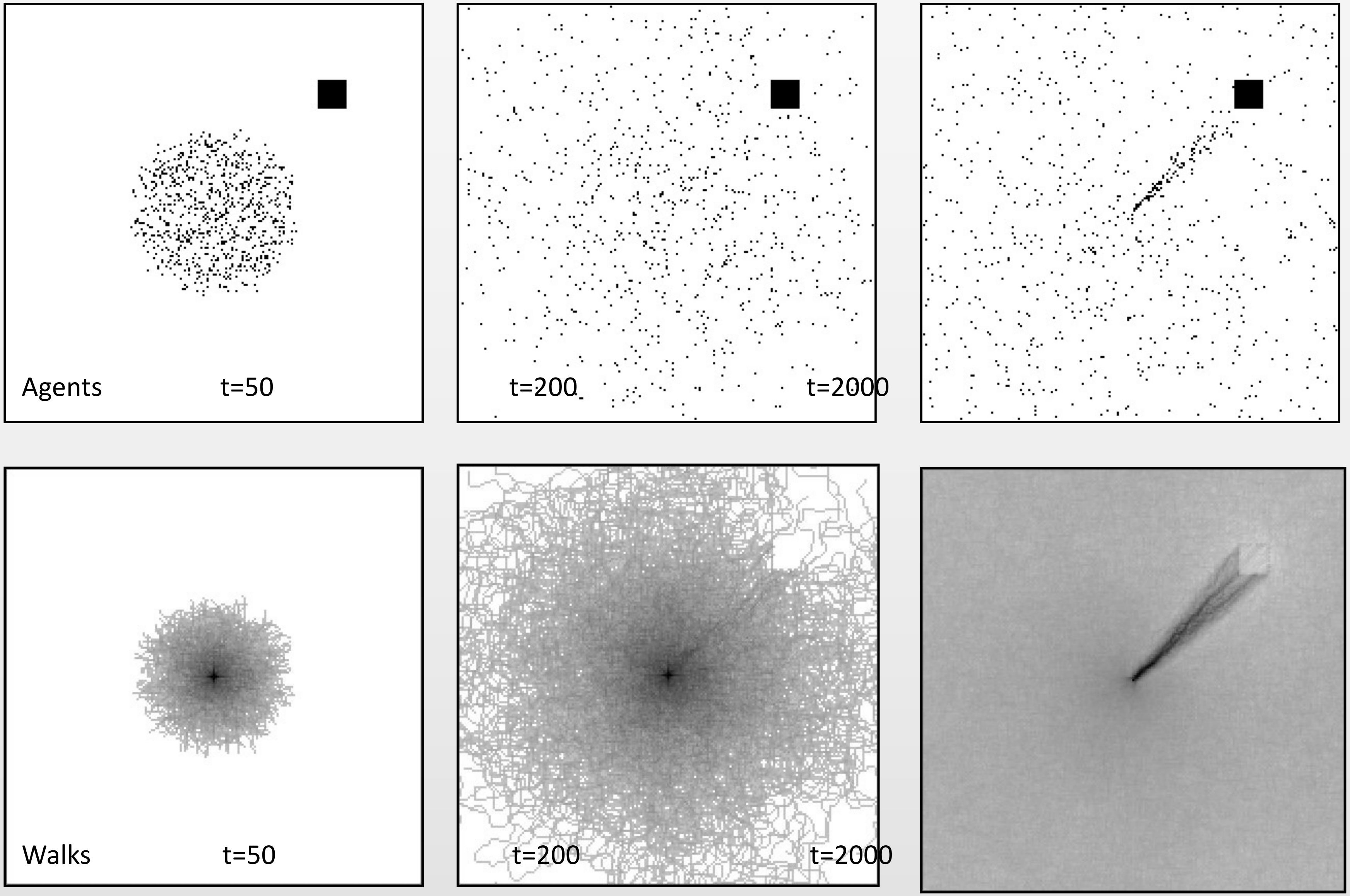








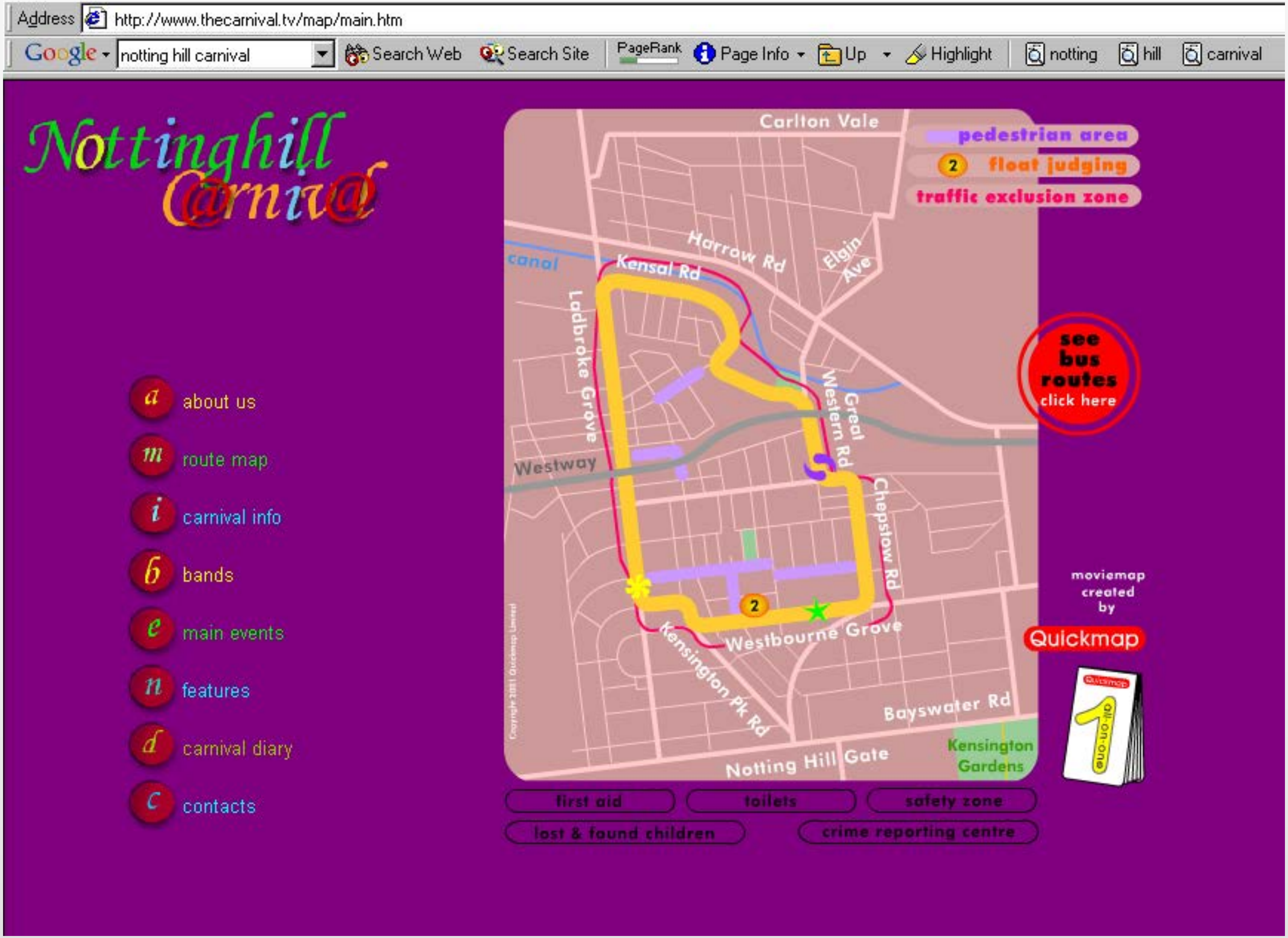
Moving to Agents in the Cellular Landscape



My Major Example: The Notting Hill Carnival

- A Two day Annual event based on a street parade and street concerts in inner London which is a celebration of West Indian ethnic culture. Started in 1964 as The Notting Hill Festival; attracting 150,000 people by 1974
- It celebrates diversity but also in memory of the first race riots in the UK in 1959
- It attracts up to 1 million visitors and spreads over an are of about 3.5 sq miles
- Its takes place at the August Bank Holiday
- Here are some pictures

Agent Based Models


Address
http://www.thecarnival.tv/map/main.htm
notting hill carnival
Search Web
Search Site
PageRank
Page Info
Up
Highlight
notting
hill
carnival
Nottinghill Carnival
about us
route map
carnival info
bands
main events
features
carnival diary
contacts
Carlton Vale
pedestrian area
float judging
traffic exclusion zone
Harrow Rd
Elgin Ave
canal
Kensal Rd
Ladbroke Grove
Great Western Rd
Westway
Chepstow Rd
see bus routes click here
Westbourne Grove
Kensington Pk Rd
Bayswater Rd
Notting Hill Gate
Kensington Gardens
moviemap created by
Quickmap
first aid
toilets
safety zone
lost & found children
crime reporting centre

The Project: Public Safety

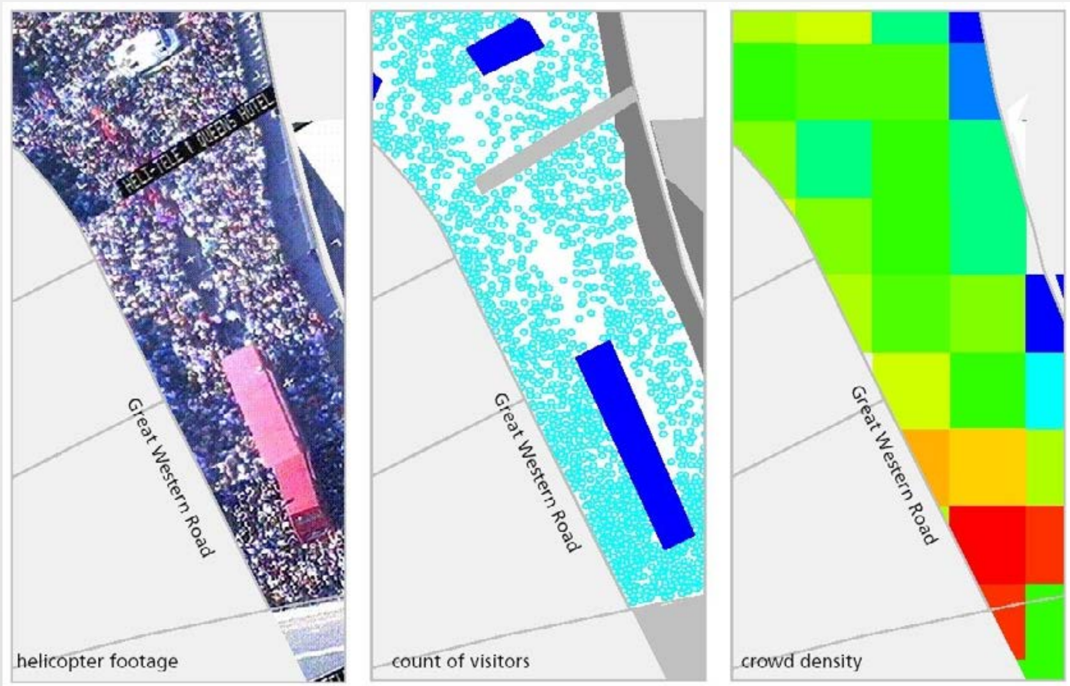
We have been involved in the problem of redesigning the route location for the parade which is judged to be ‘unsafe’ because of crowding and because of the crime and environmental hazards generated by concentration in a small area: for example crime has risen by about 15% annually for the last 10 years – 430 reported crimes committed in 2001. 3 murders in 2000.

- 710,000 visitors in 2001.
- continuous parade along a circular route of 3 miles
- 90 floats and 60 support vehicles move from noon until dusk each day.

- 40 static sound systems
- 250 street stalls selling food.
- peak crowds occur on the second day 4 and 5 pm
- 260,000 visitors in the area.
- 500 accidents, 100 requiring hospital treatment
- 30 percent related to wounding
- 430 crimes committed over the two days
- 130 arrests, 3500 police and stewards each day.

4 different methods to determine the number of people

- Intelligent Space Flow Survey : 38 streets, 80 people days
- Intelligent Space Crowd Density Survey : 1022 digital images, creating a composite image of carnival 2001
- LUL Tube Exit and Entrance Survey
- St Johns Ambulance Accident data



Agent Based Models

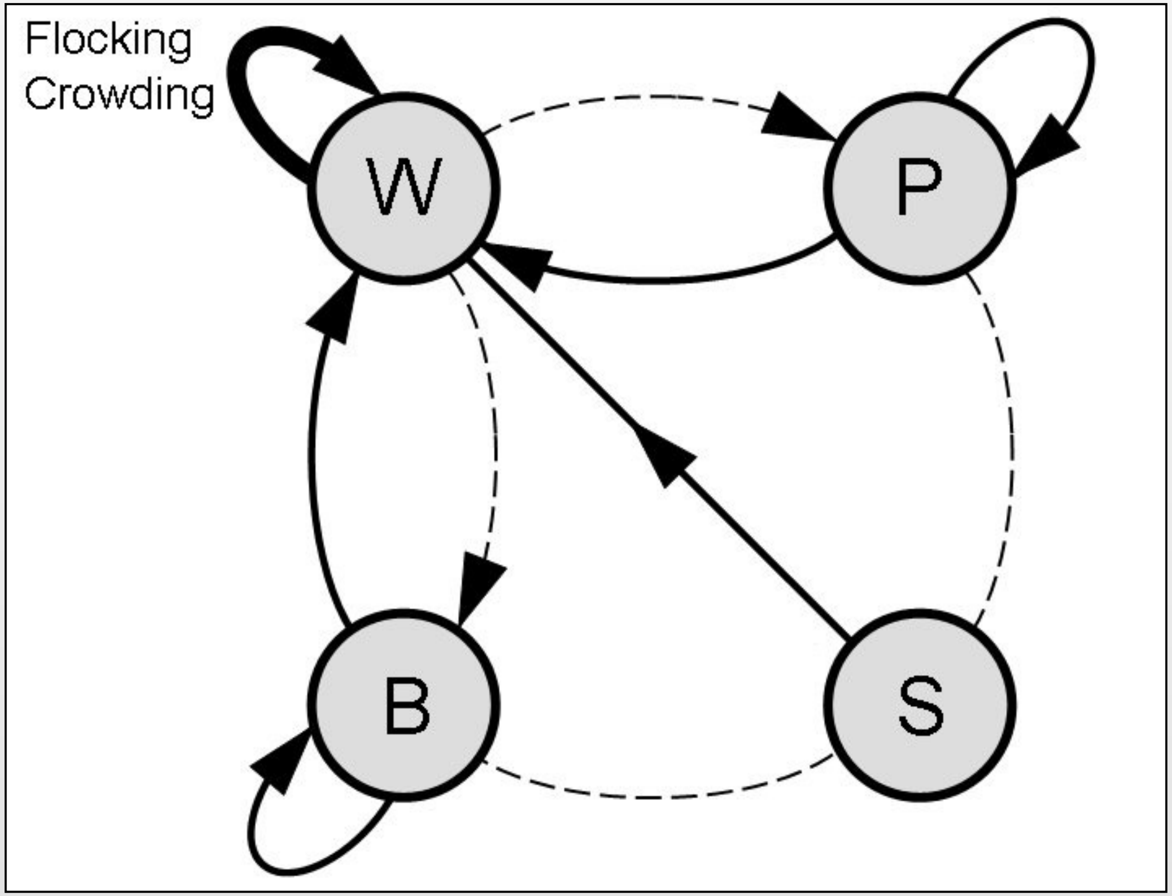
The Model: Flocking and Crowding: Swarms

- We need to simulate how visitors to the carnival move form their entry points to the events that comprise the carnival – the locations of the bands and the line of the parade

The problem is complicated by

- We do not know the actual (shortest) routes linking entry points to destinations
- Detailed control of the event by the police etc. is intrinsic to the event – we need to introduce this control slowly to assess its effect

- We define <u>agents</u> as walker/visitors (W) who move, the bands that can be moved (B), the paraders who move in a restricted sense (P), and the streets (S) that can be closed



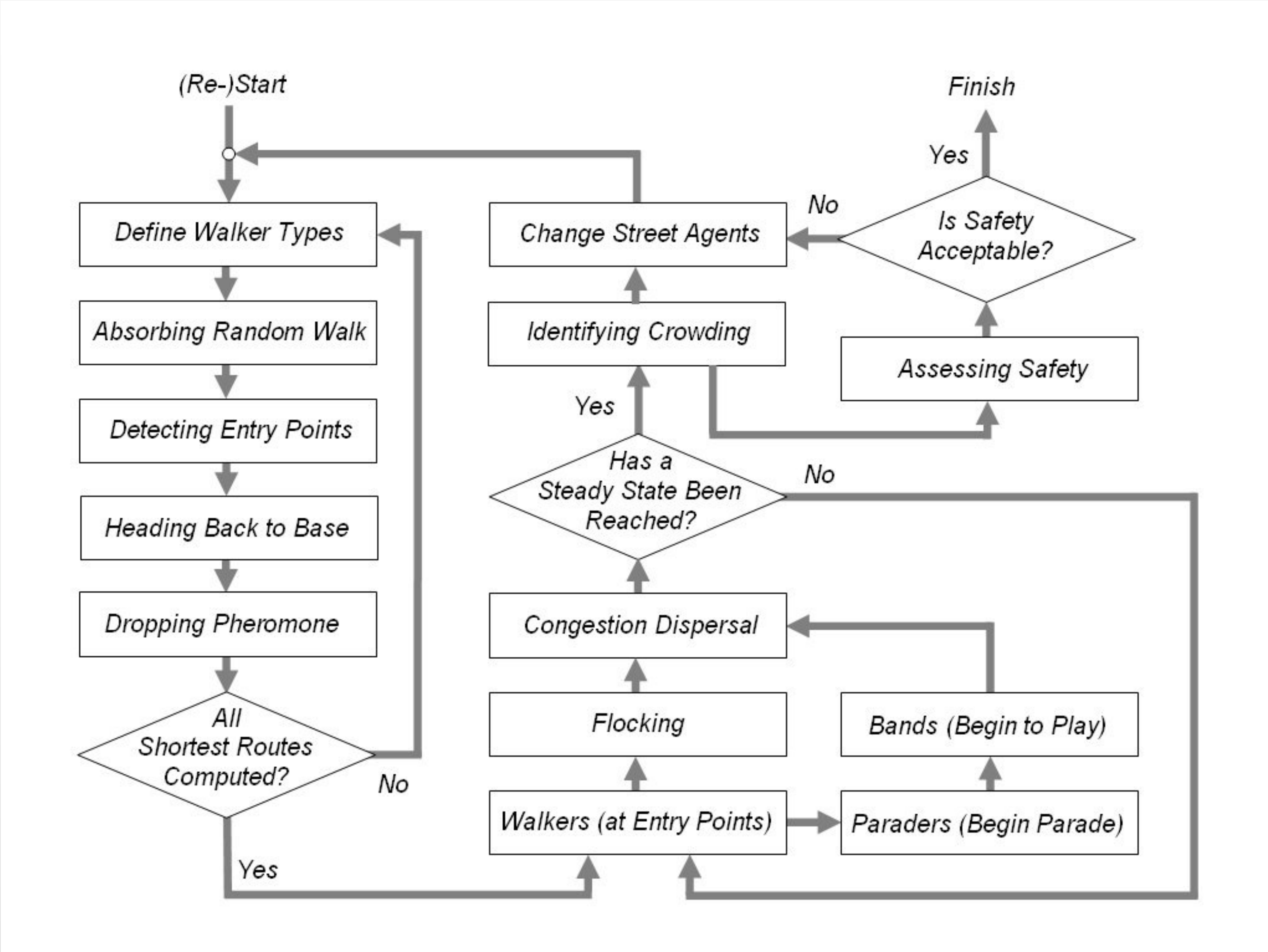
We run the model in three stages, slowly introducing more control to reduce congestion

- We first find the shortest routes from the ultimate destinations of the walkers to their entry points using a "SWARM" algorithm – this is our attraction surface

- This gives us the way walkers move to the carnival and in the second stage we simulate this and assess congestion

- We then reduce this congestion by closing streets etc and rerunning the model, repeating this stage, until a "safe" situation emerges

Here is a flow chart of how we structure the model

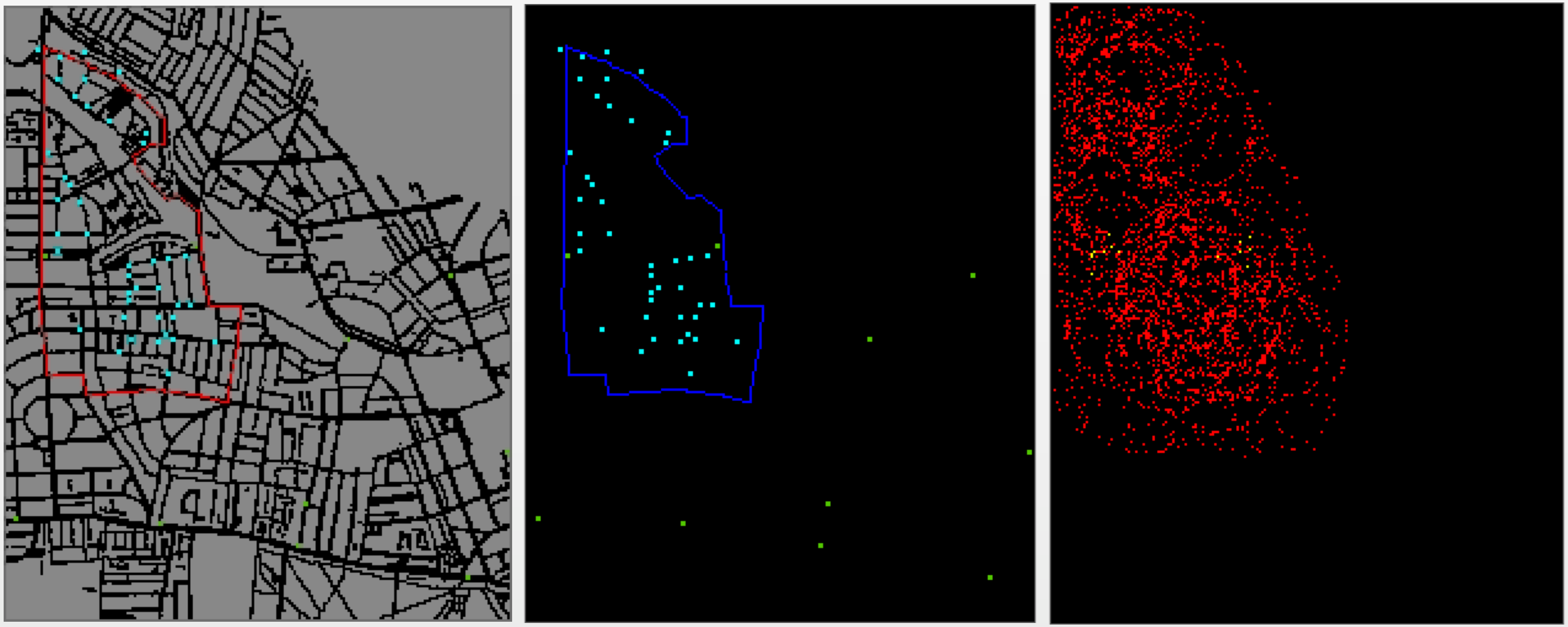


The First Stage: Computing the Attraction-Access Surface

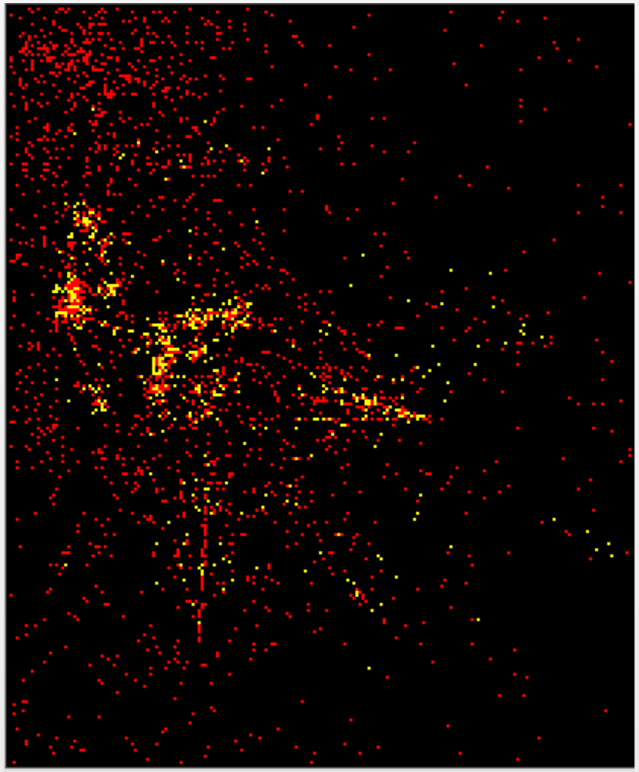
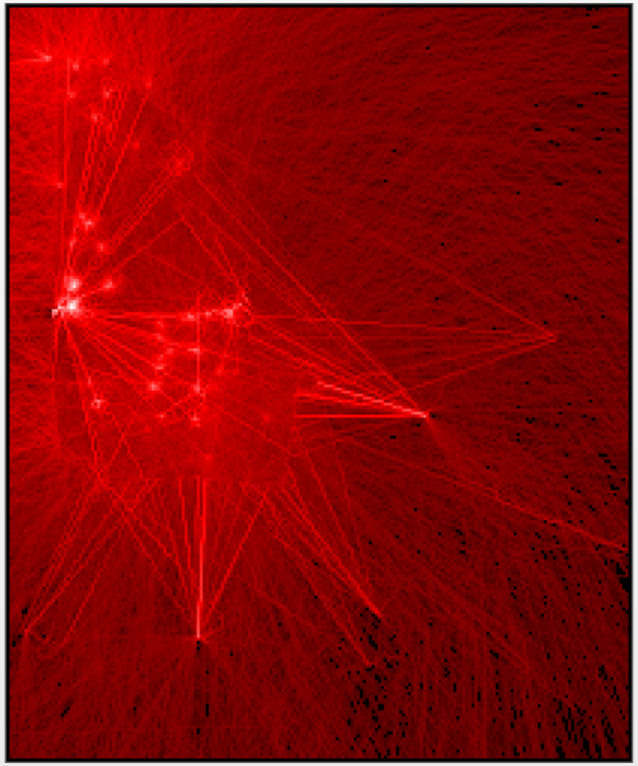
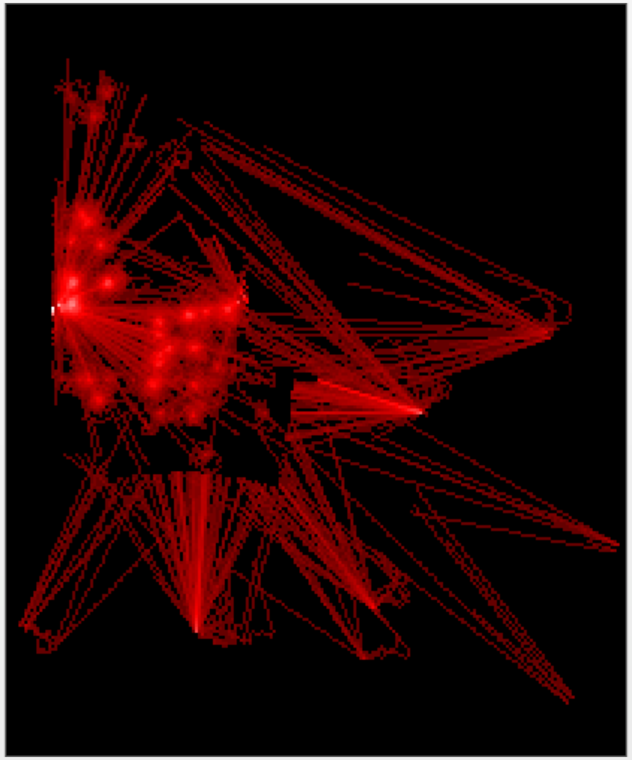
- We compute the access surface using the concept of swarm intelligence which essentially enables us to let agents search the space between origins and destinations to provide shortest routes, and these determine the access surface.

- This is an increasingly popular method of finding routes in networks and it is based on the idea that if you launch enough agents and let them wander <u>randomly</u> through the network, they will find the objects in question

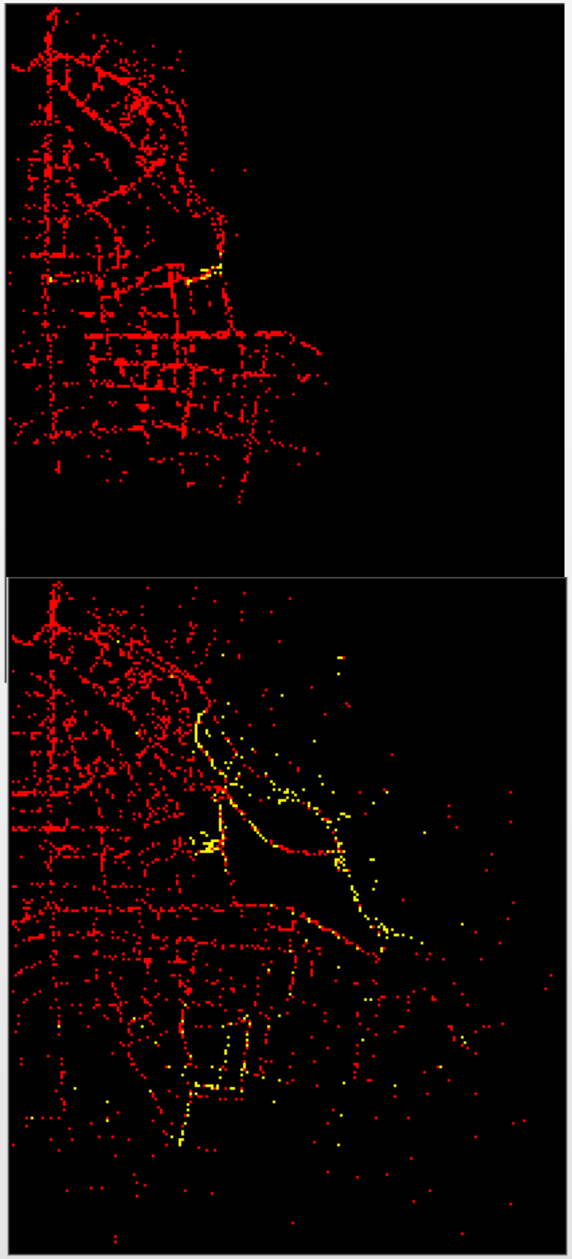
- Let me show you how this works – we will load in the agents onto the parade routes and the sound systems, then let them wander randomly without imposing a street network, and they will find a selected set of entry points – the subway stations in this case. Then the pattern is built up this way
- We show first the parade and the sound systems and the subway stations
- Then the random access map
- Then the shortest routes computed



Let me tell you how swarming works and show you some movies of this process.

Let's do this for the real street geometry and run the movie to see how this happens



Let me run the First Stage Swarm Movie

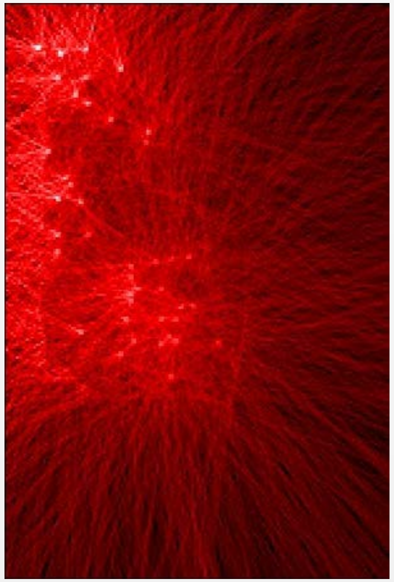
Agent Based Models

The Second and Subsequent Stages

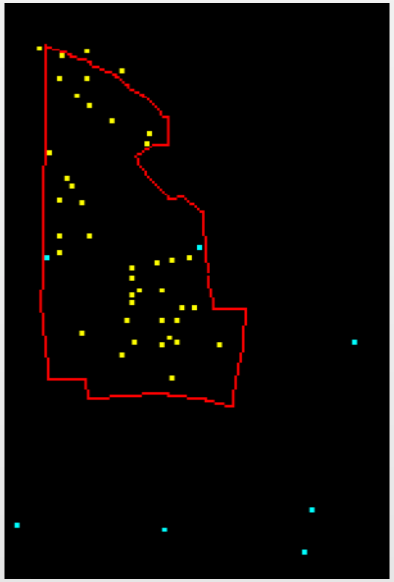
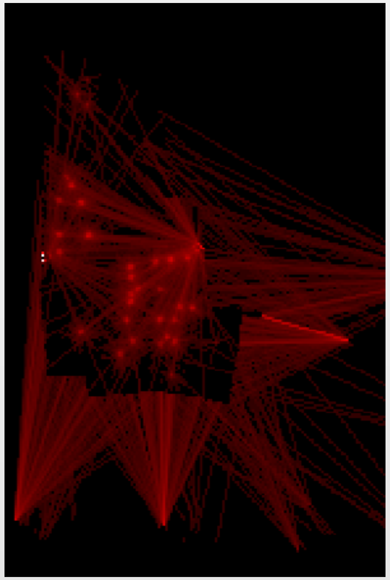
- In essence, once we have generated the access and shortest route surfaces, we use these or a combination of these – a linear/weighted combination – as the final surface and we then pass to a second stage

- We use a regression model to estimate entry point volumes and then let these walkers out at the entry points and then let them establish their steady state around the carnival – thus we run the model again

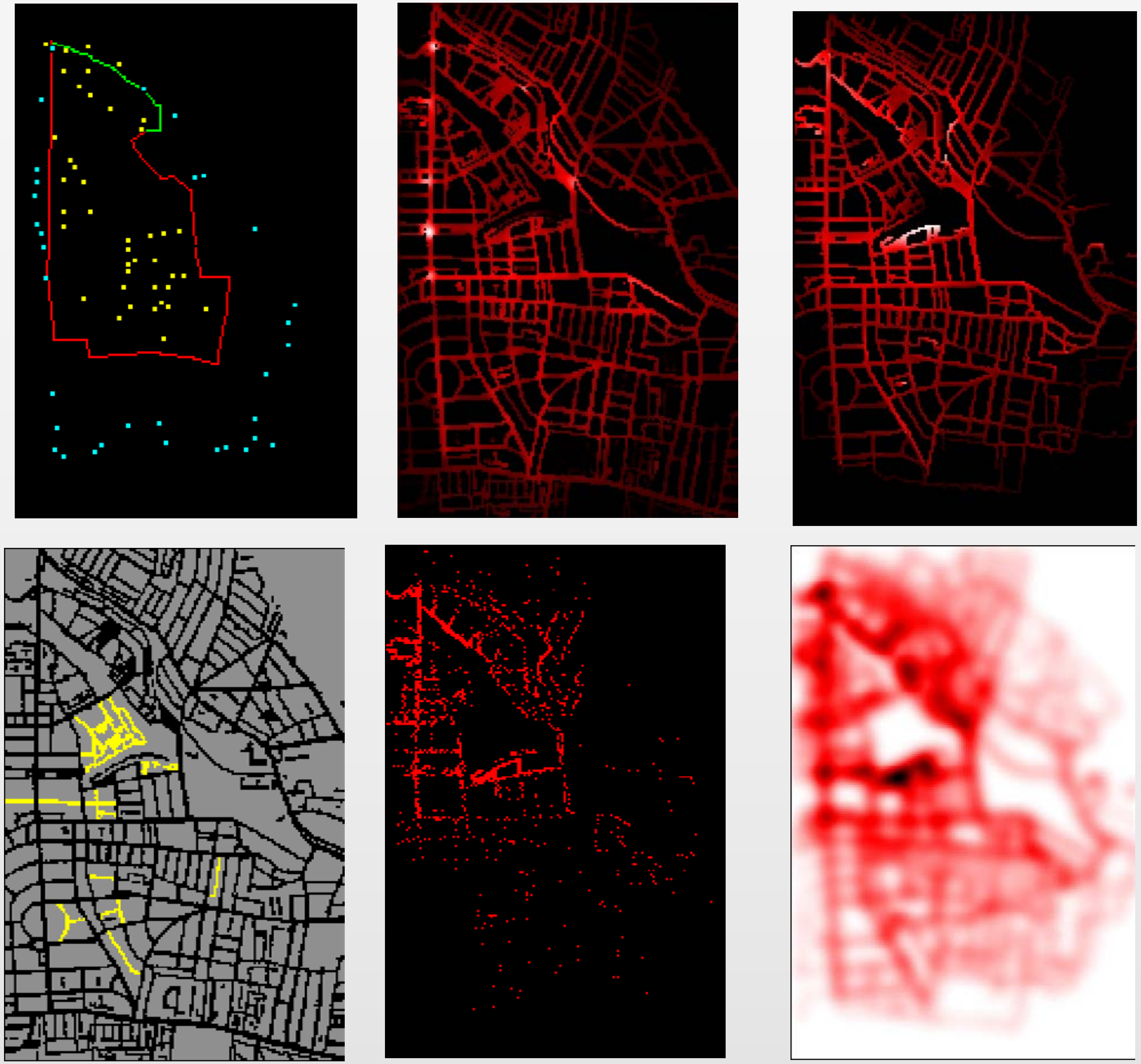
- We generate a new density surface and this then enables us to pass to a third stage


Let me run the Second Stage Unconstrained Simulation Movie


- In the third stage, we figure out where the crowding is worst and then introduce simple controls – close streets etc
- In fact in the existing simulation we already have several streets and subway stations controlled and we can test these alternatively
- Thus in the existing simulation, we can figure out if the existing controls are optimal



Agent Based Models

Using Such Models in Policy

- I am not going to prolong this but simply state some obvious things we can do
- Manipulate physical features – close roads, move groups around, control crowds, put in new routes
- Change temporal intervals over which people react
- Move attractions around
- Reduce densities in general
- Change behaviours – all of these are really part of the above
- Change hours of opening; change transportation to the events

Thanks for listening – I hope you have learnt something about models from these lectures

Michael Batty

http://www.spatialcomplexity.info/

4th February 2024

m.batty@ucl.ac.uk

X@jmichaelbatty