TEL AVIV UNIVERSITY
Faculty of the Arts - The Yolanda & David Katz
אוניברסיטת תל-אביב
הפקולטה לאמנויות על שם יולנדה ודוד כץ
David Azrieli School of Architecture
ביה"ס לאדריכלות ע"ש דוד עזריאלי

4 June 2013

Smart Cities

Digression 2: Into Modelling:

Session 3: Lecture 2:

Agent-Based Urban Models

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Outline of the Talk

First a digression about the history of the field

1. Agents – Behaviour – Randomness – Geometry
2. Mobility and Random Walks –
3. Constraining Randomness – Organic Growth
4. Adding Intentions: Social Behaviour – Utility
5. Models of Crowding – Buildings and Town Centres: Panic, Evacuation, Safety
6. My Major Example: The Notting Hill Carnival
7. The Model: Flocking and Crowding: Swarms
8. Using such Models in Policy

First a digression about the history of the field

A little bit of history. First came transport models, the land use transport interaction (LUTI) models (1950-1960s) and these were heavily developed in the 1970s. They were/are static and aggregate

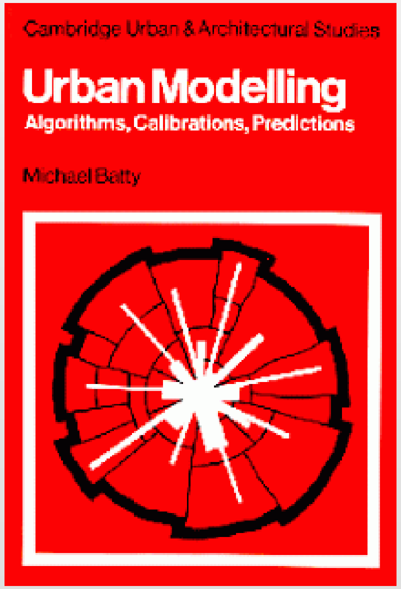
Then came a switch occasioned by complexity theory coming from systems theory

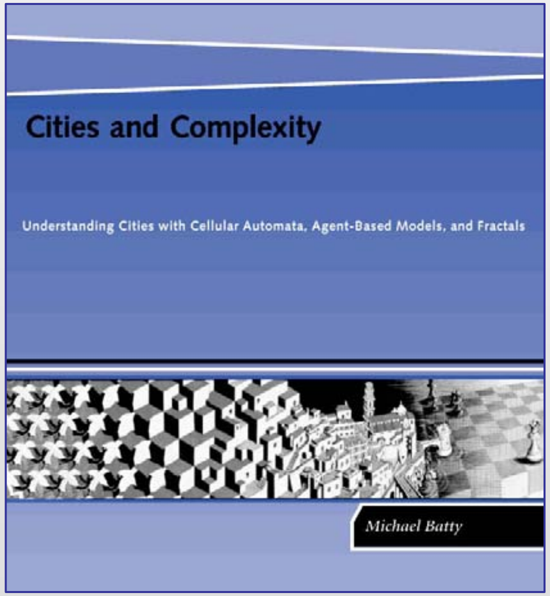
Cellular Automata (CA) (1980s and 1990s) came next and then Agent based Models (ABM in the 1990s/2000s). These tend to be dynamic and disaggregative.

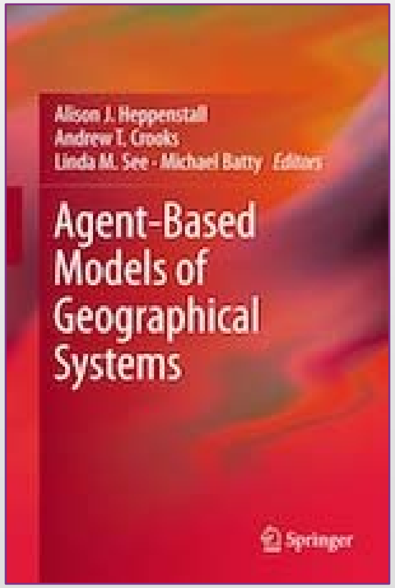
I think the next stage will be data-driven models

Couple of things to read on this – my urban modelling paper and my 50 years of urban modelling paper. I have just circulated these.

Also my own history of work in this field is relevant and my books really mirror these developments







LUTI >>>>>>>>>>>> CA >>>>>>>>>>>> ABM

1. Agents – Behavior – 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'

And second, it is a style of modelling based on 'averages' We basically model how a large number of agents respond, not how each respond

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 in this talk (and these models) are mainly people, literally individuals, but sometimes other objects such as physical objects like streets and barriers and plots of land can be treated as agents – this is often a matter of convenience in terms of the software used.

Agents as people can have different kinds of behaviour from the routine to the strategic

It is my contention that agent-based models are much better at simulating the routine rather than the strategic but this is a debating point

2. 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

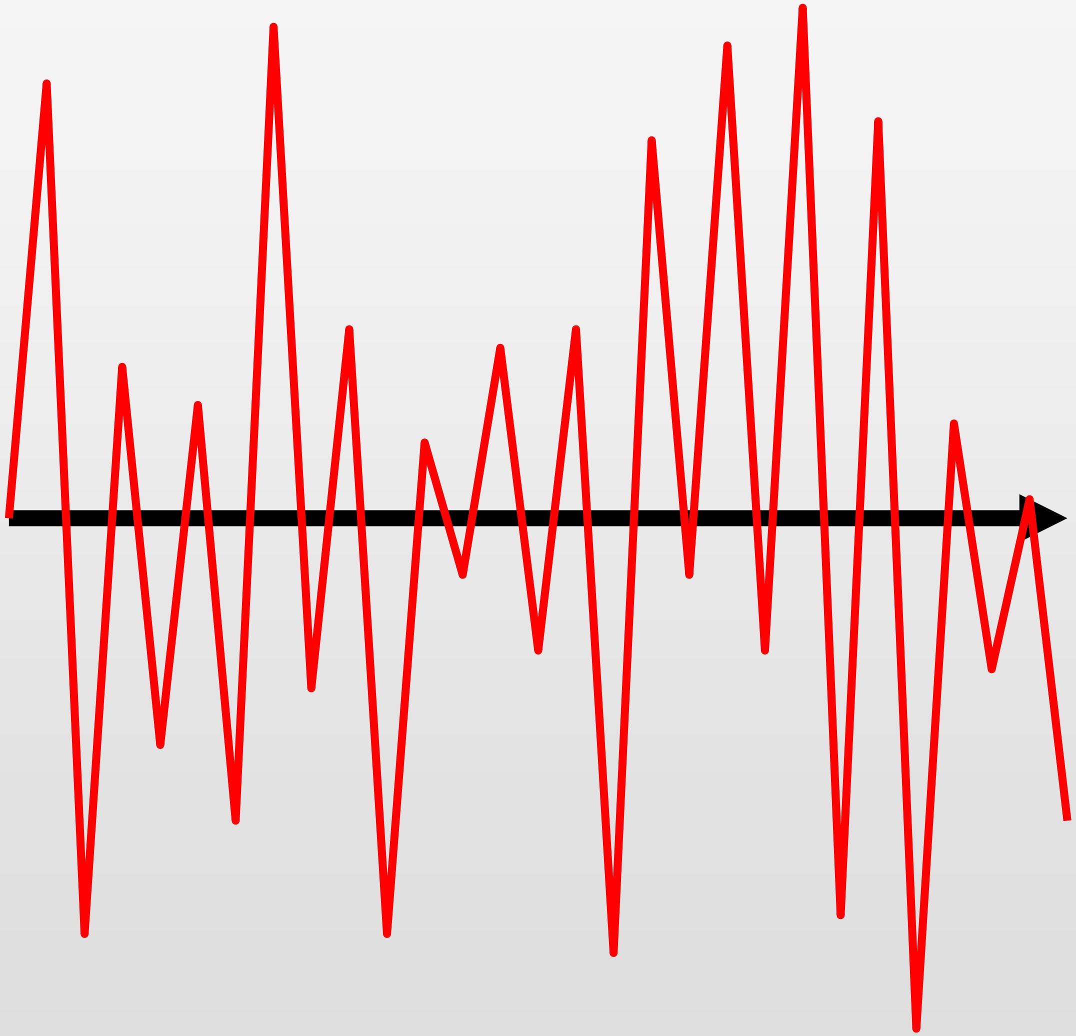
A good model to begin with is the ‘random walk’ which we will look at in one- and then two-dimensions

There is always some intentionality in any walk but the simplest is where we assume things are going forward – in time – which is uncontroversial

The classic one-dimensional walk ……..

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

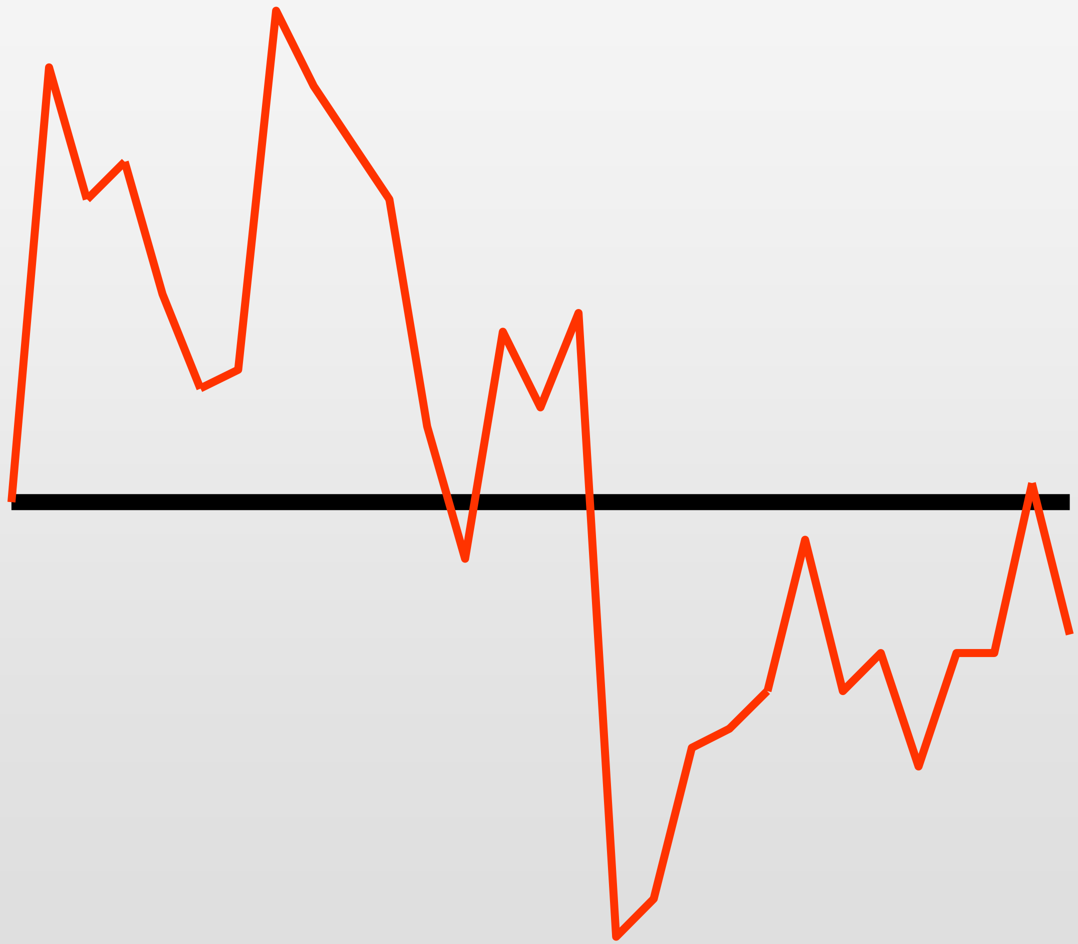
Good example is noise – as deviations from a pure signal – there is no memory here – each deviation is independent of the previous one



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

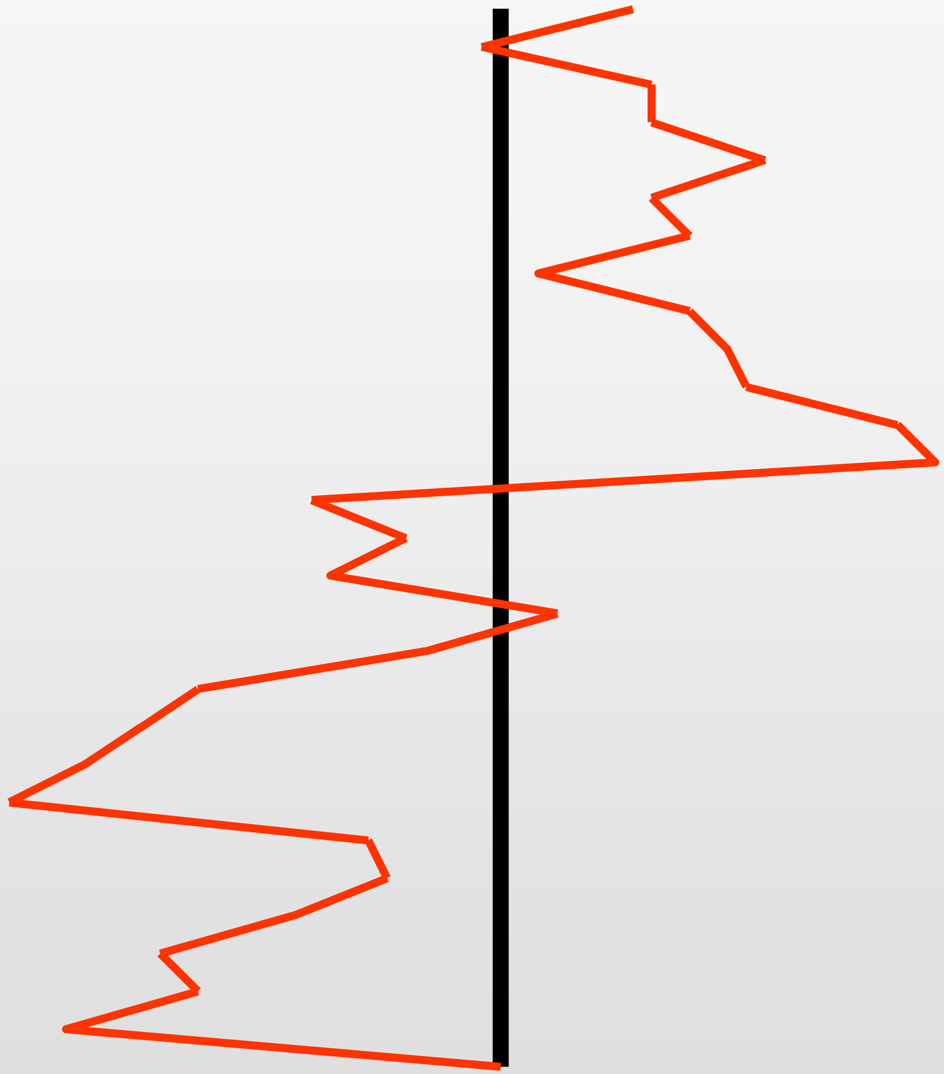
It is like a stock market, indeed this is what rocket scientists on Wall St try to model – they know they can't, but ……



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

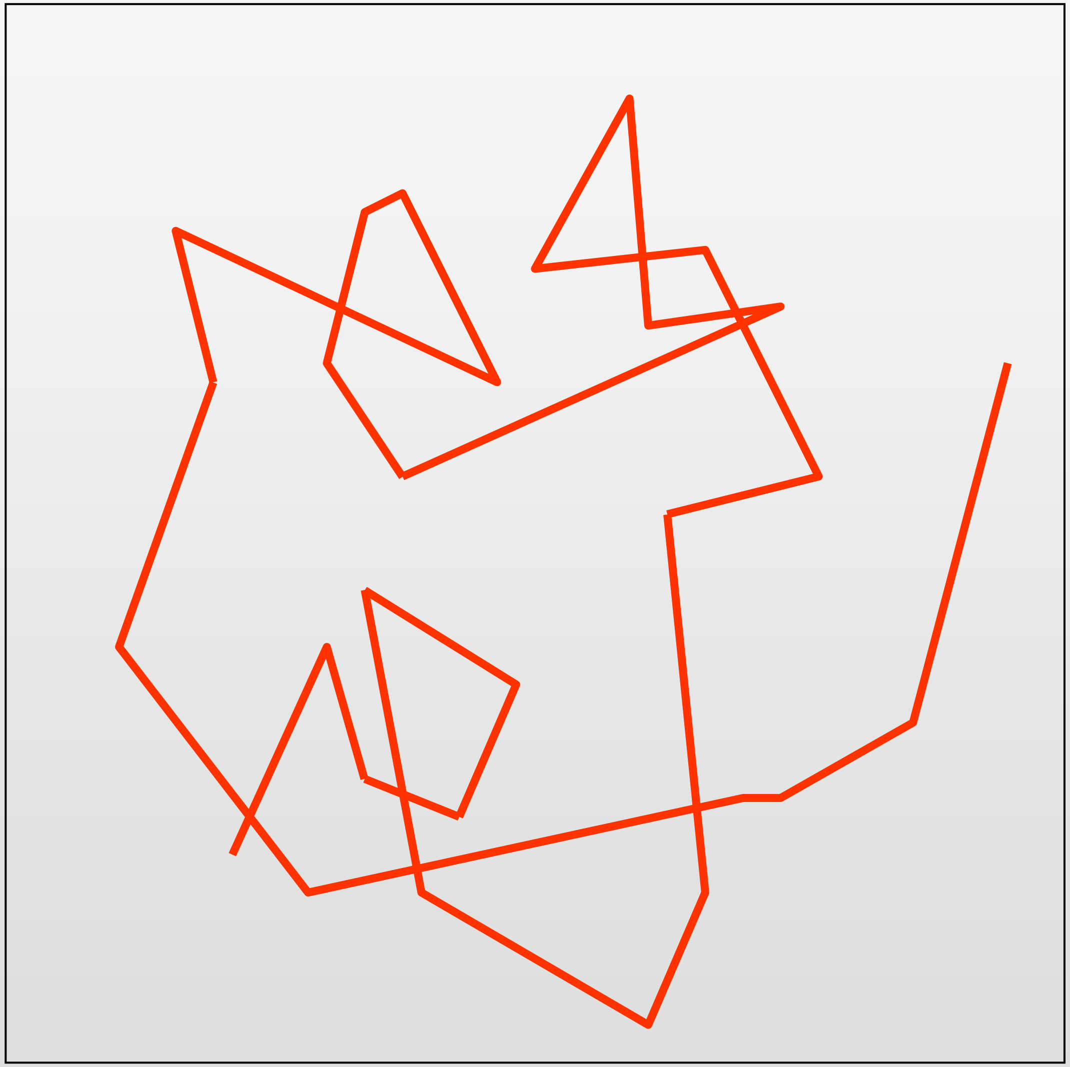


Now think of the walk in two dimensions …..

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



starlogo 1-d Random-walk-random-change

starlogo 1-d Random-walk-first-order-change

starlogo 2-d Random-walk-big-change

starlogo 2-d Random-walk-small-change

Note how these movements are independent of scale – not how they look the same at all scales – these are fractals – they are statistically self-similar across scales

Note how the 1d random walk and its trail in 2d space eventually fills the space – at the scale of the screen – this is a 1 d line which generates a kind of 2d area – it is a fractal with Euclidean dimension of 1 and a fractal dimension of 2

3. Constraining Randomness – Organic Growth

Let us constrain randomness – and add some geometry – we saw how we might do this by not letting the two-d random walk move outside the area

But a more sophisticated model is to let the random walk generate a growing structure

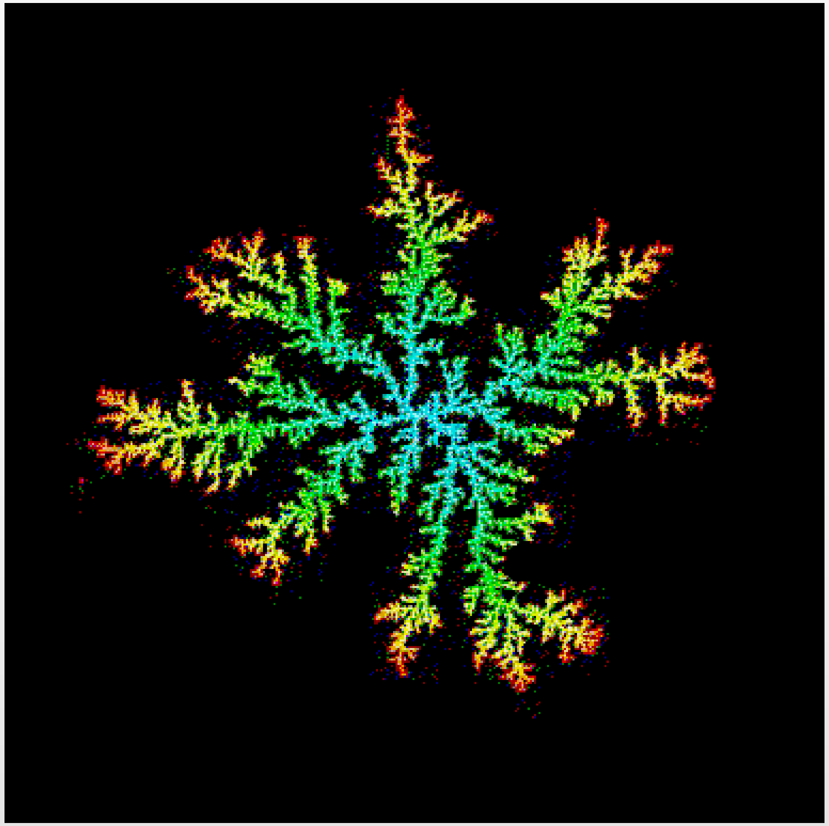
Plant a seed at the centre of the space – and then when a randomly moving particle touches the seed, develop the pixel – colour it red, say.

This then adds to the seed – there is now a connected structure – carry on with the process of bombarding the structure, and whenever the walker touches the structure, its grows a bit.

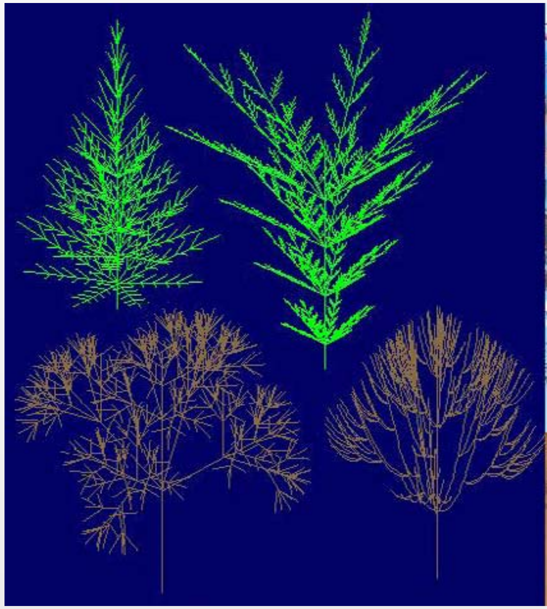
That's all there is to the model – what you do not get is a growing compact mass – let me illustrate because it is the best ever illustration of how the world around us is formed – from trees to cities, from crystals to the world wide web

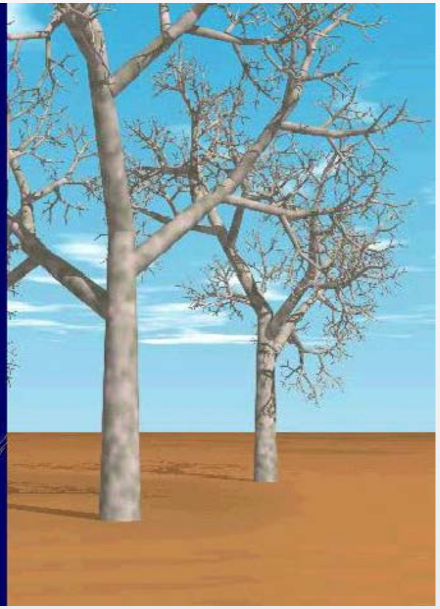
I will now run another Starlogo program to show this

Adding Geometry – the Diffusion Limited Aggregation Model



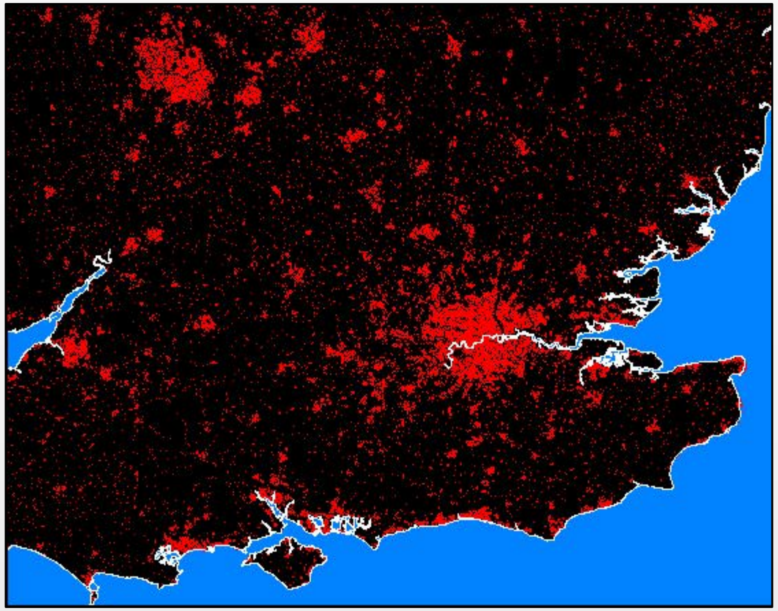
DLA – Diffusion Limited Aggregation

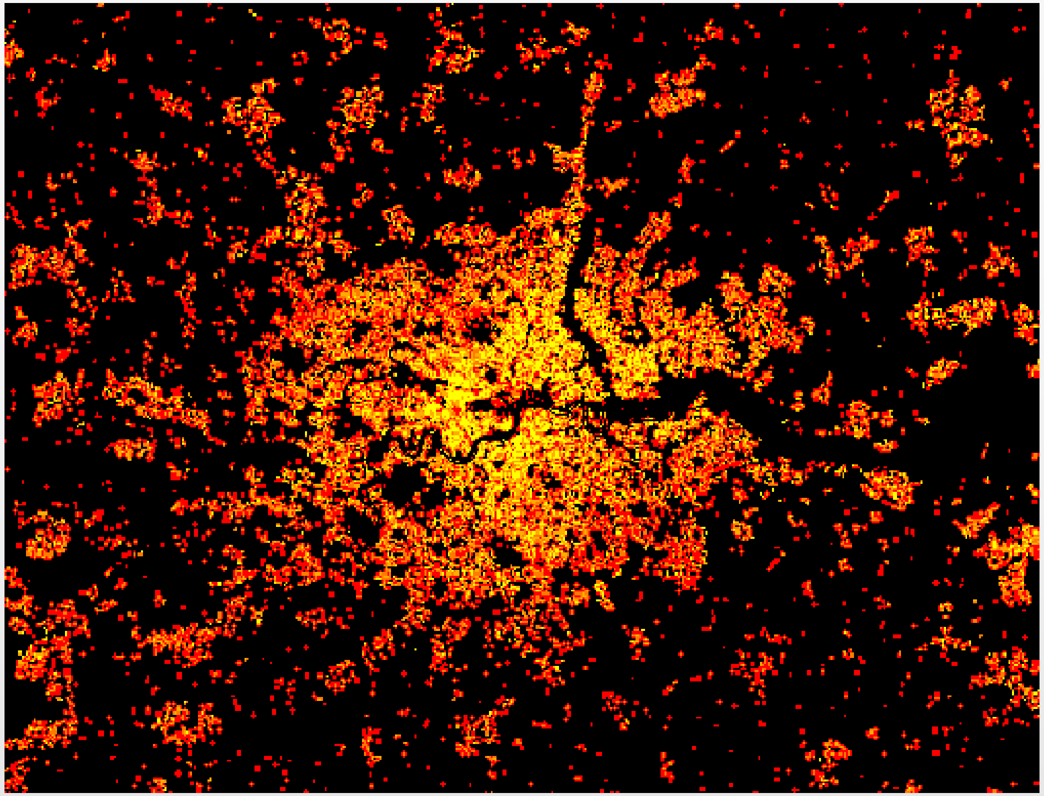


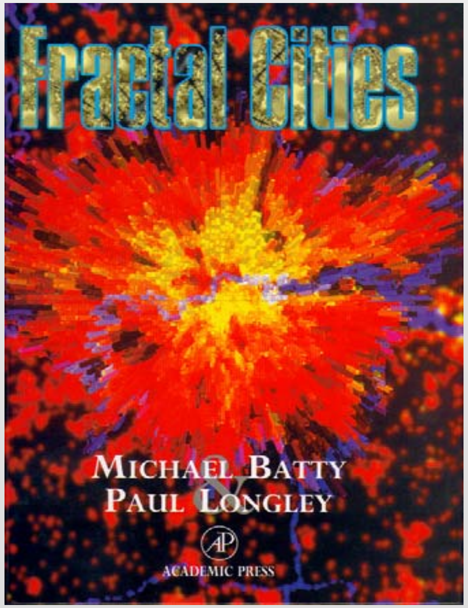


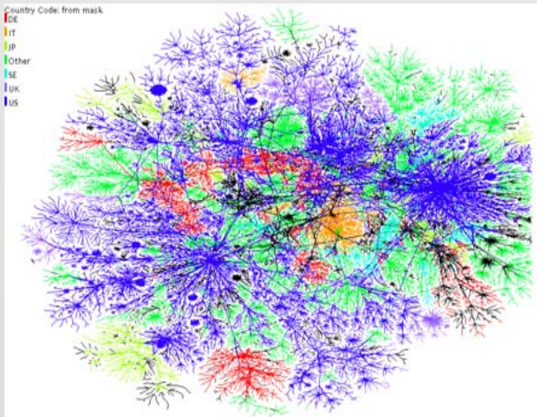
Fractal Trees

Barnsley's Fern





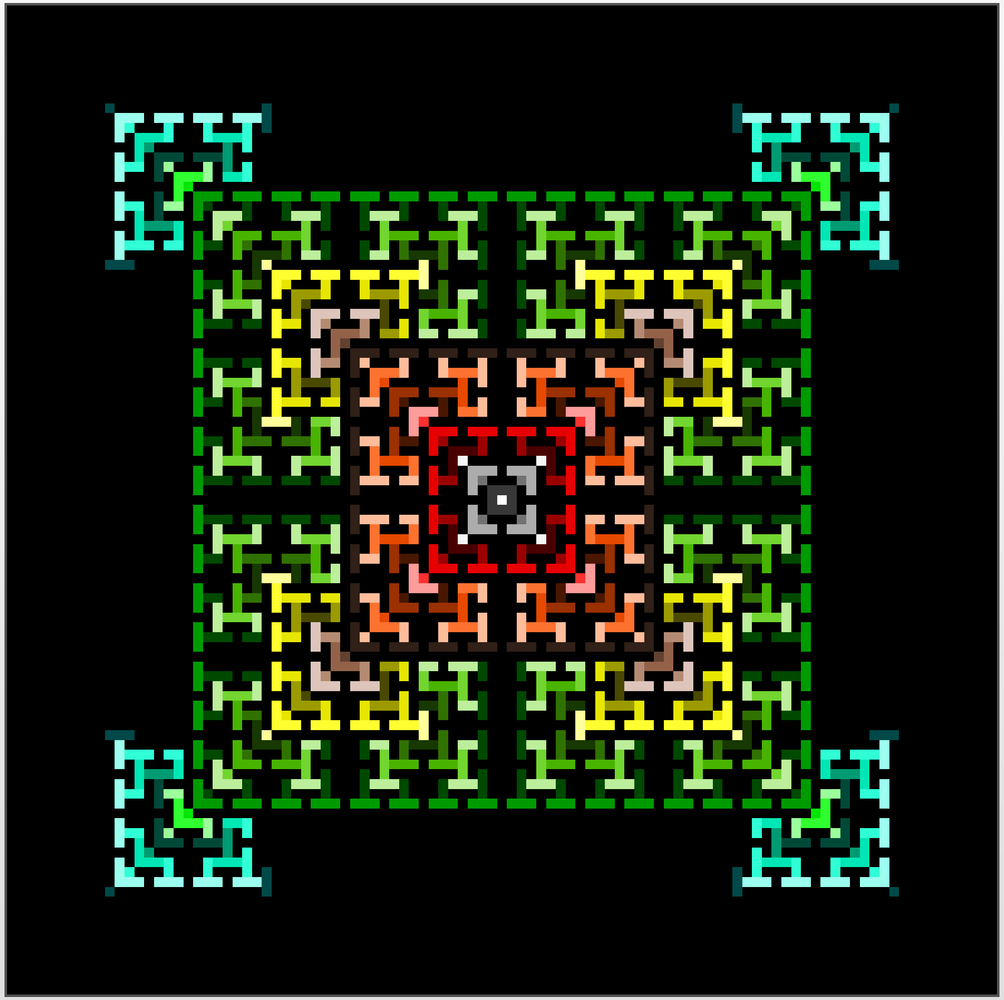




Population Density London

The World Wide Web

Now if we throw out the randomness and leave the geometry? We get
…….
That's a digression so let's move on to see what we can do with adding a little intentionality to these models

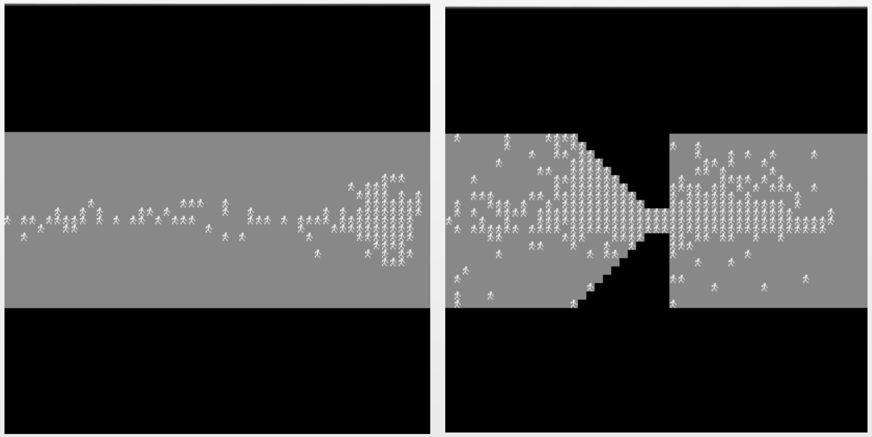


4. Adding Intentions: Social Behavior – Utility

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.

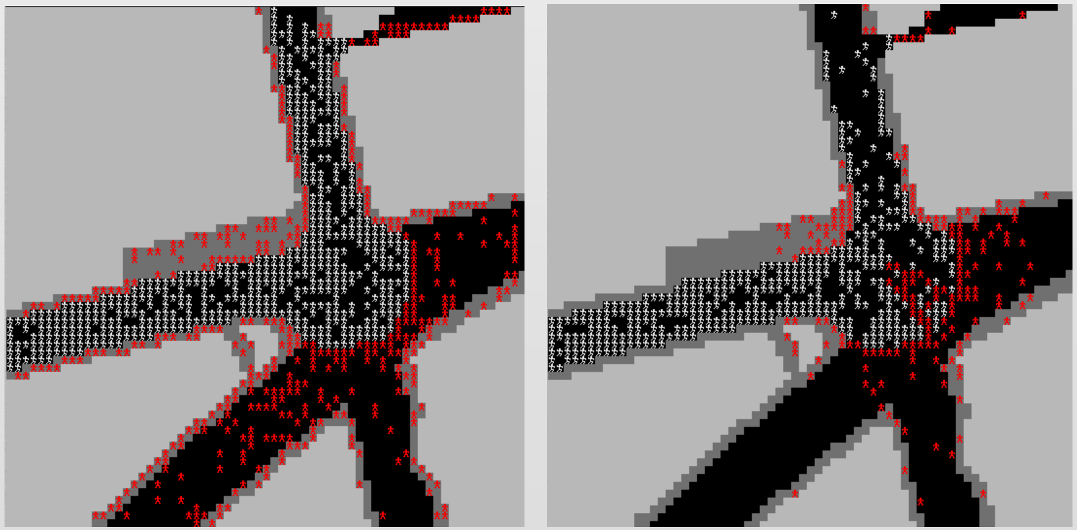
We will introduce a source of walkers and move then towards the destination with the walkers climbing a regular gradient surface to the destination. We will add various degrees of randomness to these walks and then constrain the geometry

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 in red with them breaking through the parade in panic



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

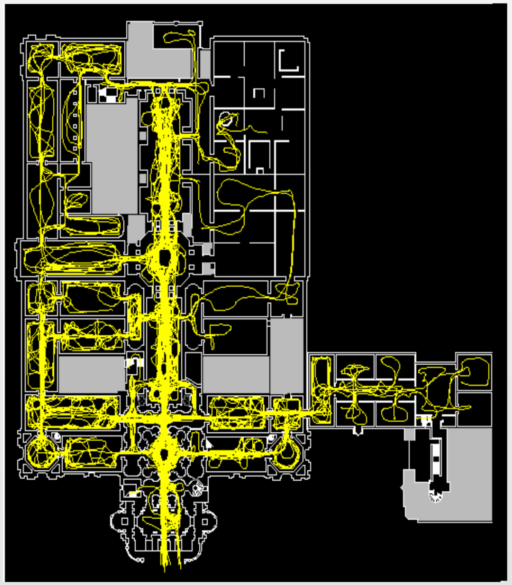
We have developed a number of these models all with intention based on where people want to go, encoded into the spatial cells on which they walk

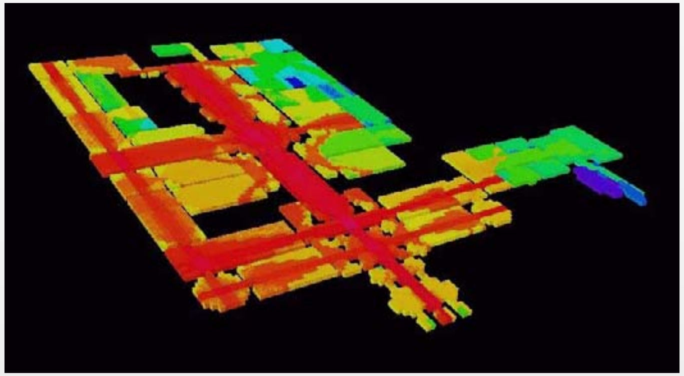
We have geometry to which walkers react in term of obstacle avoidance

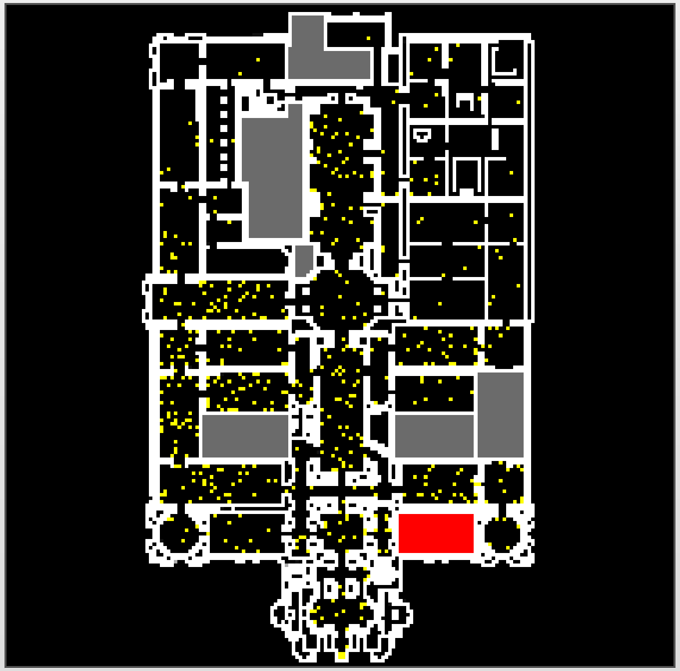
We have randomness for any direction of walking – but constrained so that there is exploration to enable new directions to be chosen

We have diffusion for dispersing congestion and flocking for copying what others do

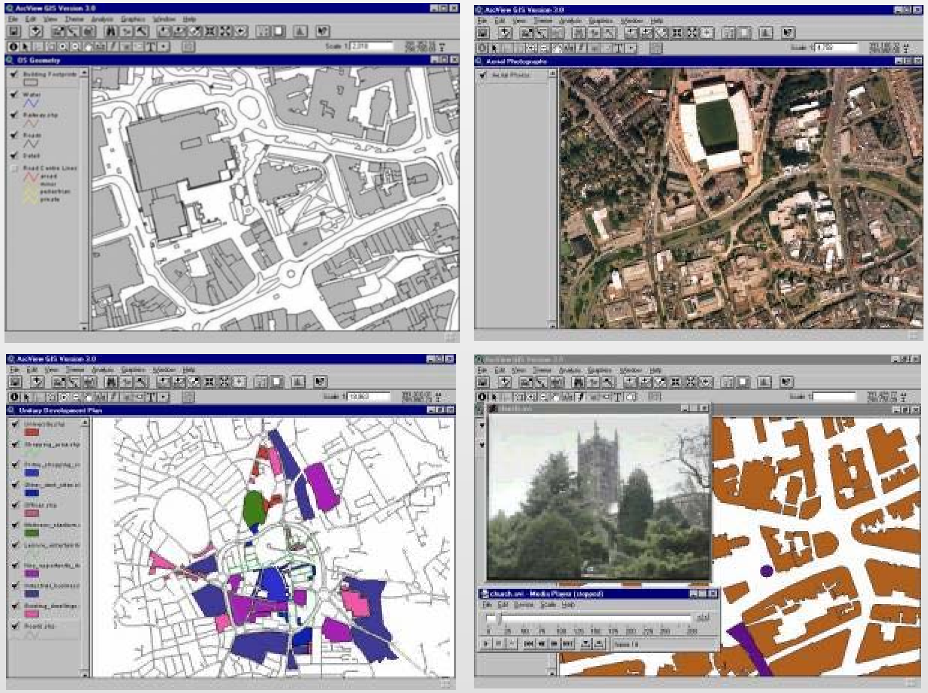
Let us simply show what we can do
An art gallery: Tate Britain:





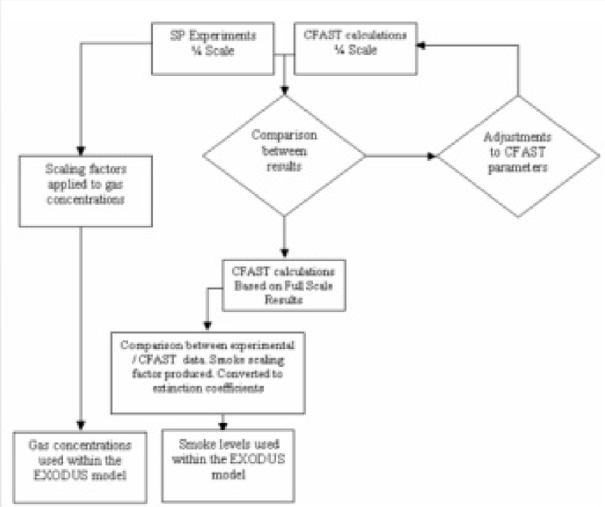


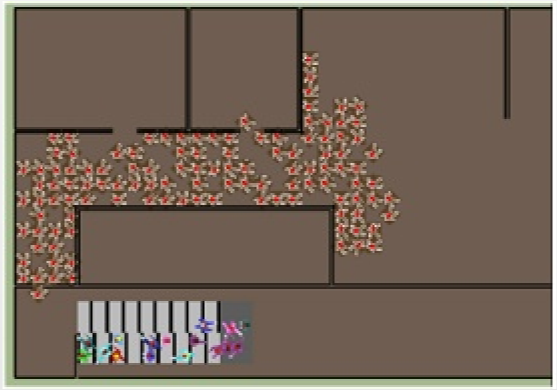
A Town Centre:
Movements from car parks and stations into the centre of a small English town: Wolverhampton

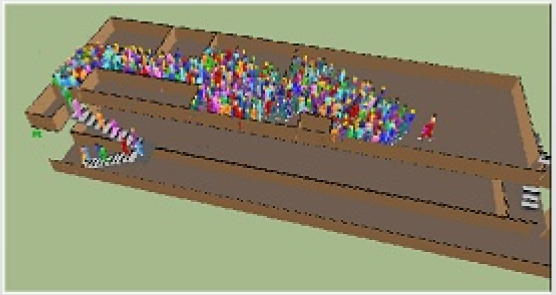


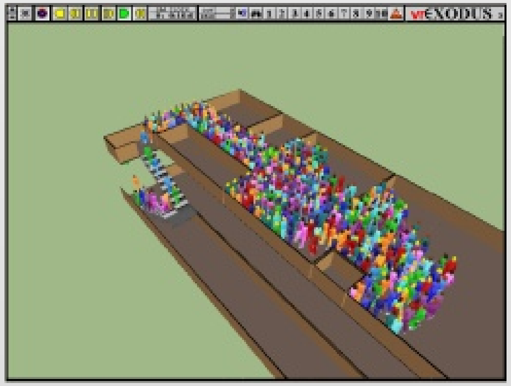
population ~ 250 000

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









From the Greenwich Fire Safety Group
http://fseg.gre.ac.uk/

6. My Major Example: The Notting Hill Carnival

How to solve problems of packing many people into small spaces and not letting them crush each other to death, and developing a quality environment which minimises crime.

We will look at the nature of the problem and then at the data needed to observe and understand the problem – this is an issue in its own right as it is complicated by lack of preference data and crude data on how people flock and disperse and track to the event itself

Intelligent Space were contracted by the GLA Carnival review group for the project and CASA was involved in the modeling

Intelligent Space is a spin off company from the Bartlett School of Planning and CASA

DR JAKE DESYLLAS

Project Manager

ELSPETH DUXBURY

Management of Crowd Observation

ZACHARAY AU

Risk Assessment Consultant

a.What is 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 attracts up to 1 million visitors and spreads over an are of about 3.5 sq miles

Here are some pictures

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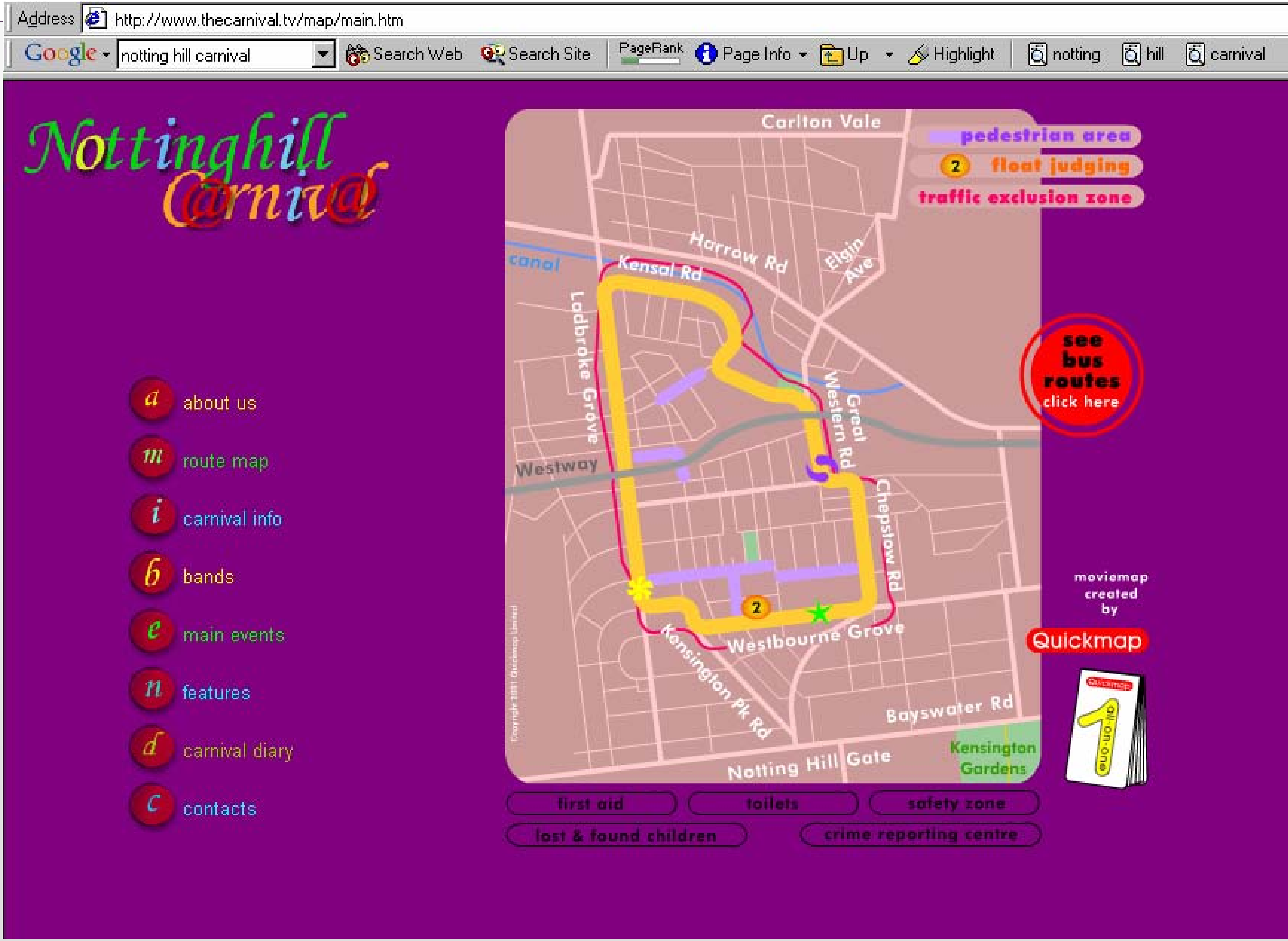
Address
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d carnival diary
c contacts
Carlton Vale
pedestrian area
2 float judging
traffic exclusion zone
canal
Kensal Rd
Harrow Rd
Elgin Ave
Ladbroke Grove
Great Western Rd
Westway
Chepstow Rd
Westbourne Grove
Kensington Pk Rd
Bayswater Rd
Notting Hill Gate
Kensington Gardens
see bus routes click here
moviemap created by
Quickmap
first aid
toilets
safety zone
lost & found children
crime reporting centre

b.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 last year. 3 murders in 2000.

- 710,000 visitors in 2001.
- continuous parade along a circular route of nearly 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 between 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.

c. Observing the Carnival: Data

We have used 4 different methods to determine the number of people at carnival 2001

1. Intelligent Space Flow Survey : 38 streets, 80 people days
2. Intelligent Space Crowd Density Survey : 1022 digital images, creating a composite image of carnival 2001
3. LUL Tube Exit and Entrance Survey

4. St Johns Ambulance Accident data


27/08/01 MON
HELI-TELE 1 QUEENS HOTEL


15:07:10
27/08/01 MON
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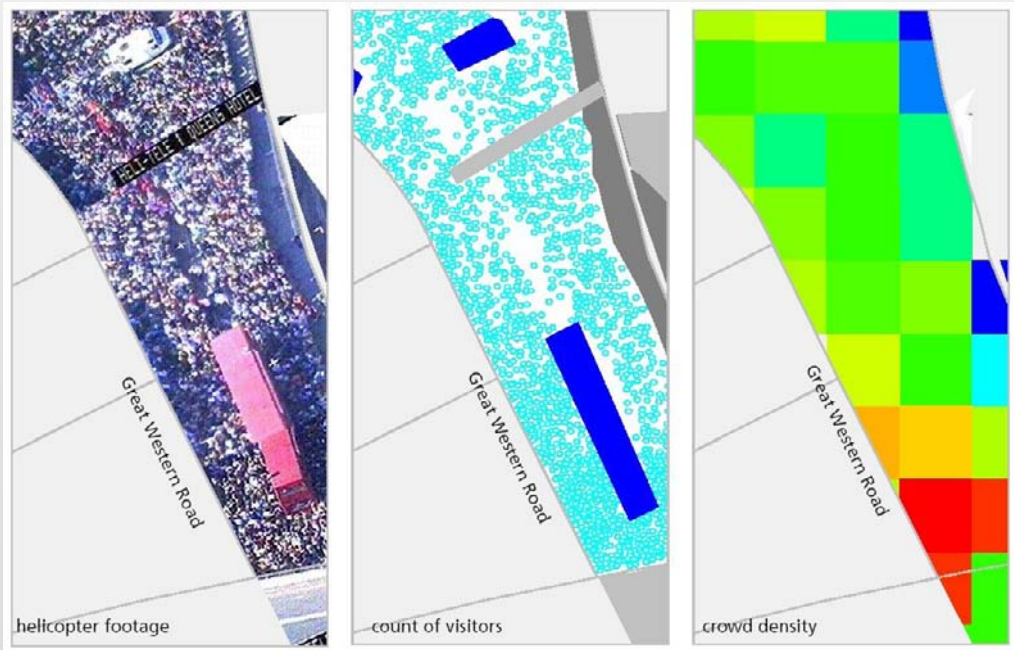
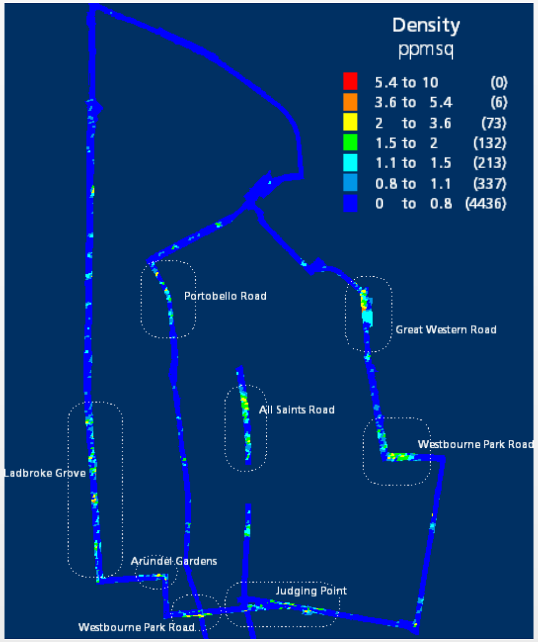
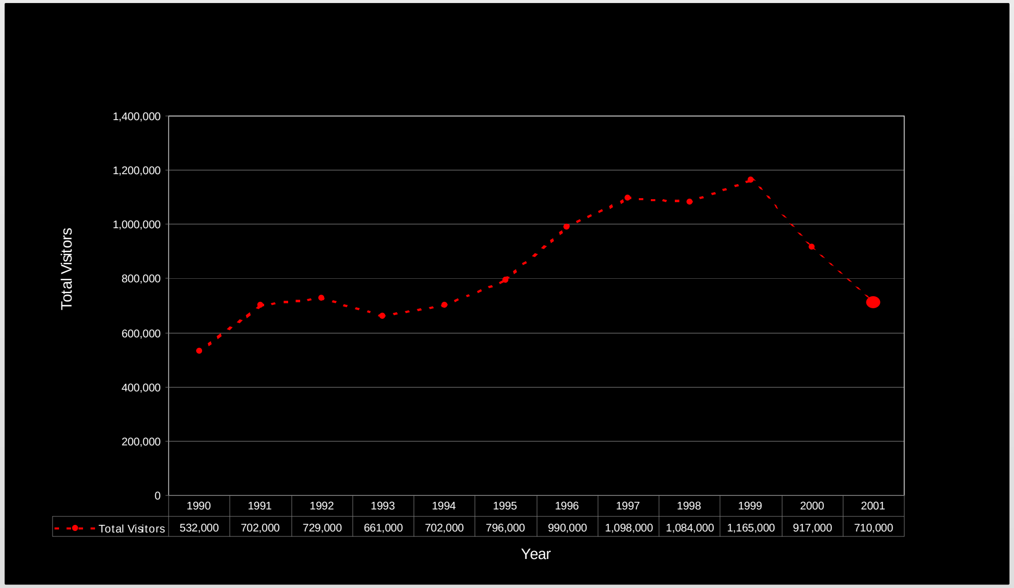
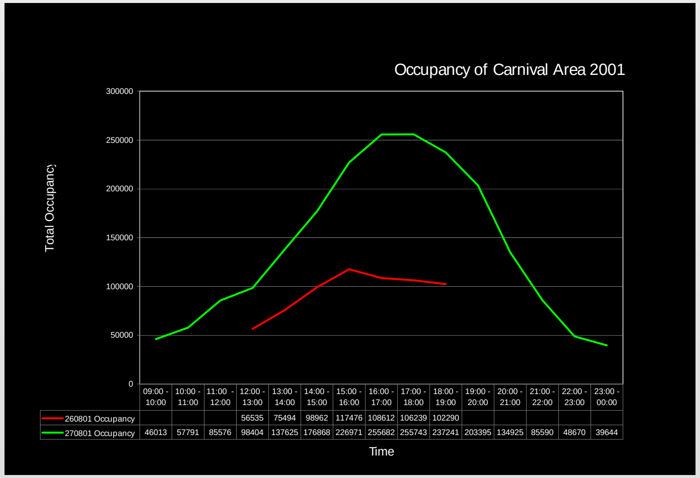

Great Western Road
helicopter footage
Great Western Road
count of visitors
Great Western Road
crowd density

Visitors to Carnival 2001

Source	Sunday	Monday	Total
ISP survey	172,344	366,636	538,980
Extrapolated Counts	39,217	48,222	87,439
Westbourne Park Tube	13,726	25,810	39,536
Residents	44,353	44,353	44,353
Total	269,600	485,000	710,300

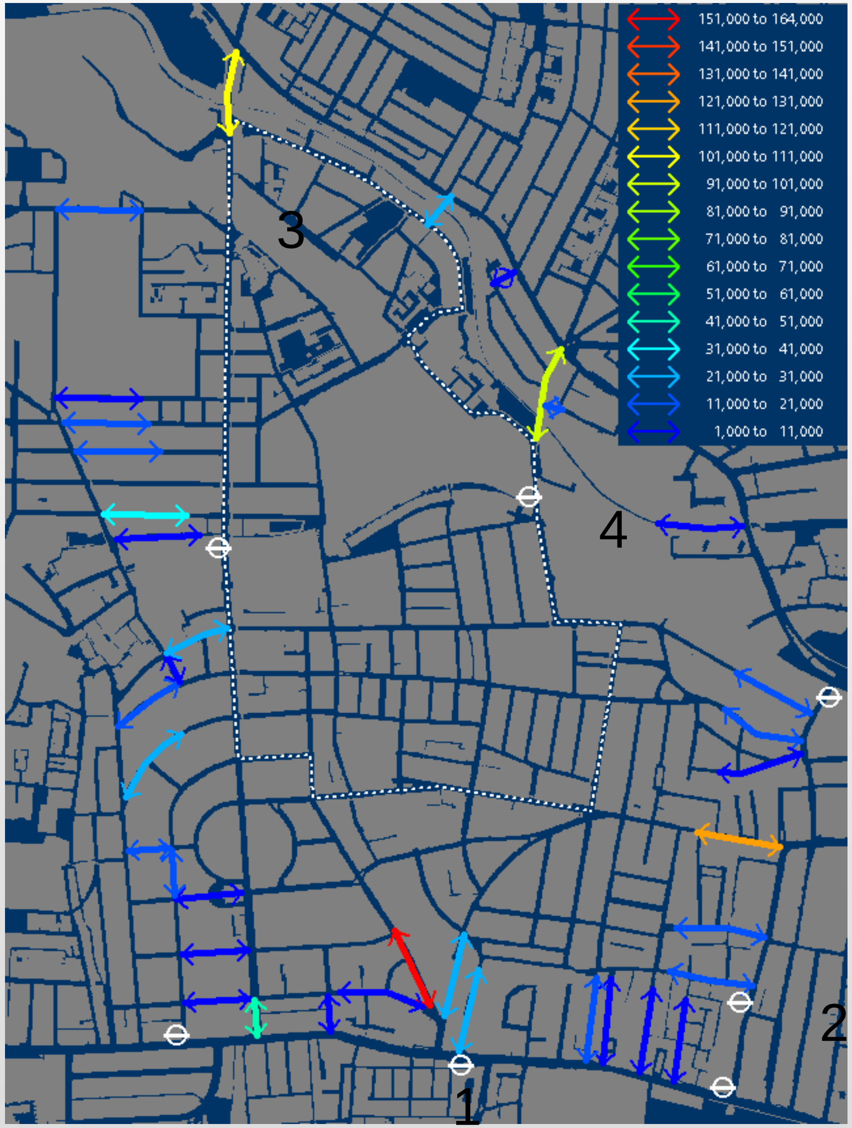






Access to Carnival is very unevenly distributed

Road Name	% of Total Flows In	% of Total Flows Out
1. Kensington Park Road	19%	14%
2. Westbourne Grove (East)	15%	10%
3. Ladbroke Grove (North)	10%	13%
4. Great Western Road	9%	12%
Sum Routes 1-4	54%	49%



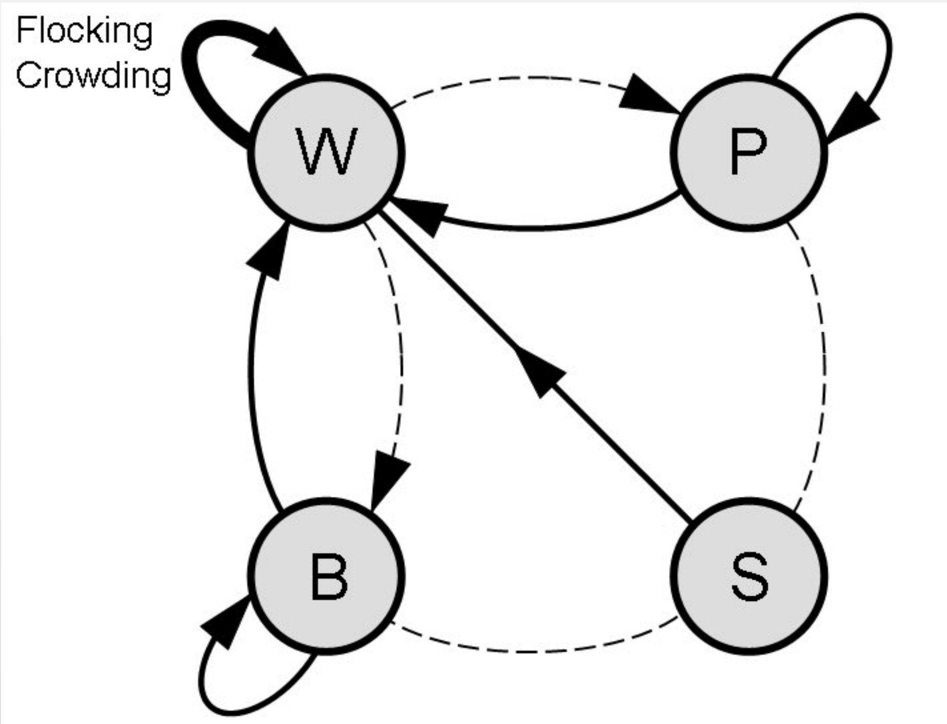
7. The Model: Flocking and Crowding: Swarms

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

1. We do not know the actual (shortest) routes linking entry points to destinations
2. 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

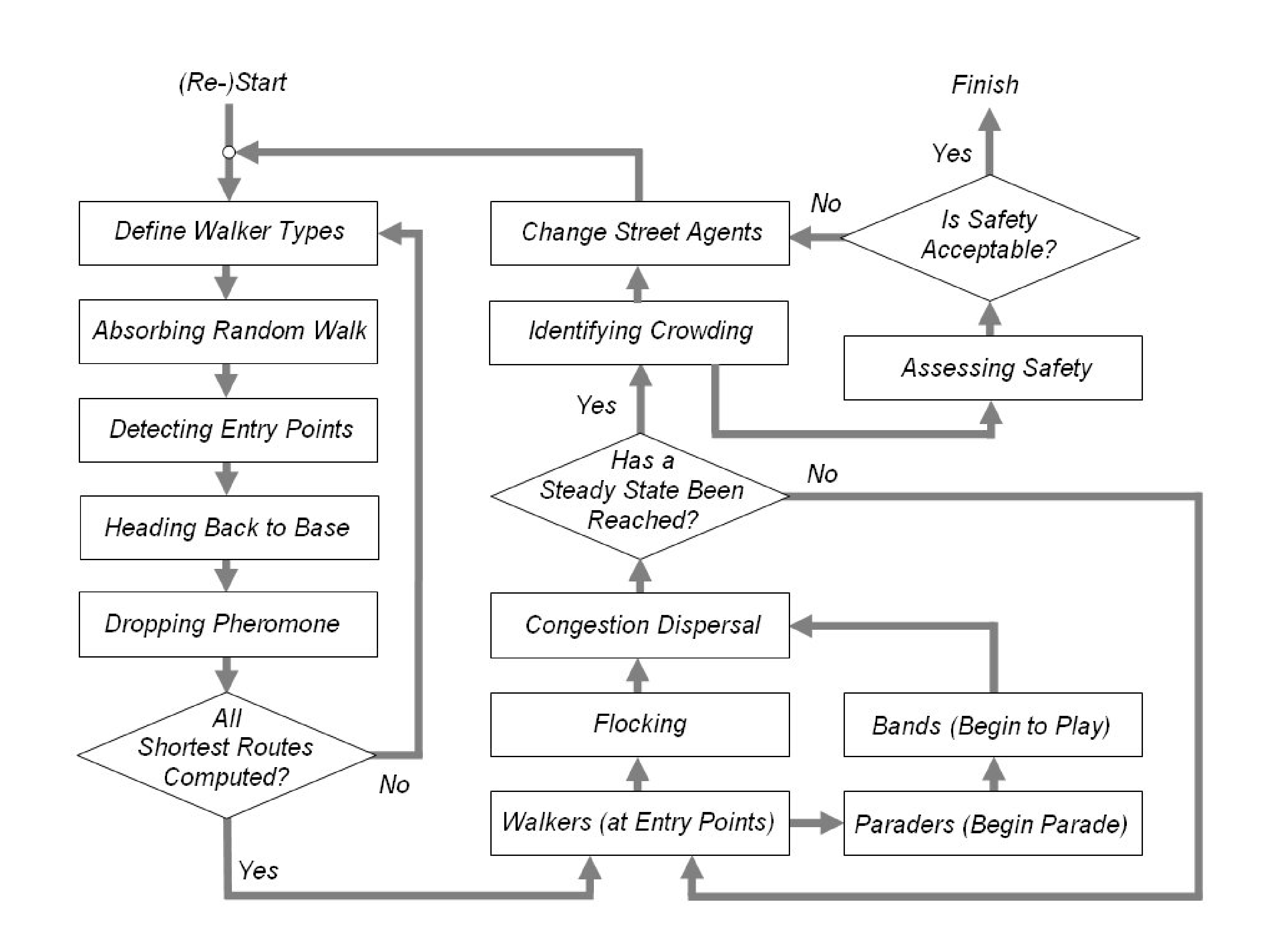
We define <u>agents</u> as walker/visitors (W) who move, the bands that can be moved (B), the paraders who move in a restricted sense (P), and the streets (S) that can be closed



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

1. 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
2. This gives us the way walkers move to the carnival and in the second stage we simulate this and assess congestion
3. 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.

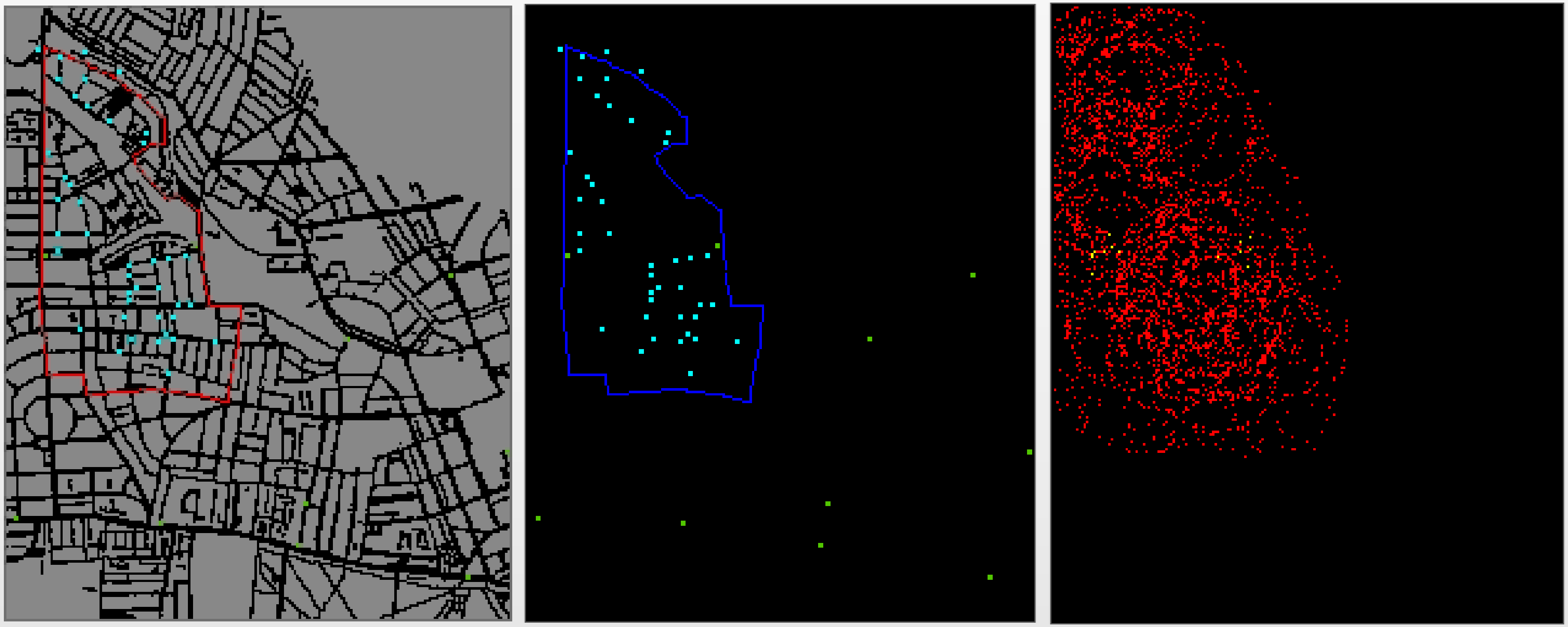
This is an increasingly popular method of finding routes in networks and it is based on the idea that if you launch enough agents and let them wander randomly through the network, they will find the objects in question

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

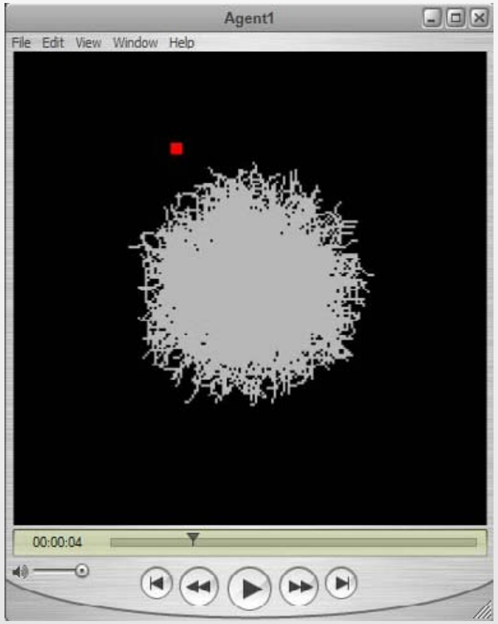
We show first the parade and the sound systems and the subway stations

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.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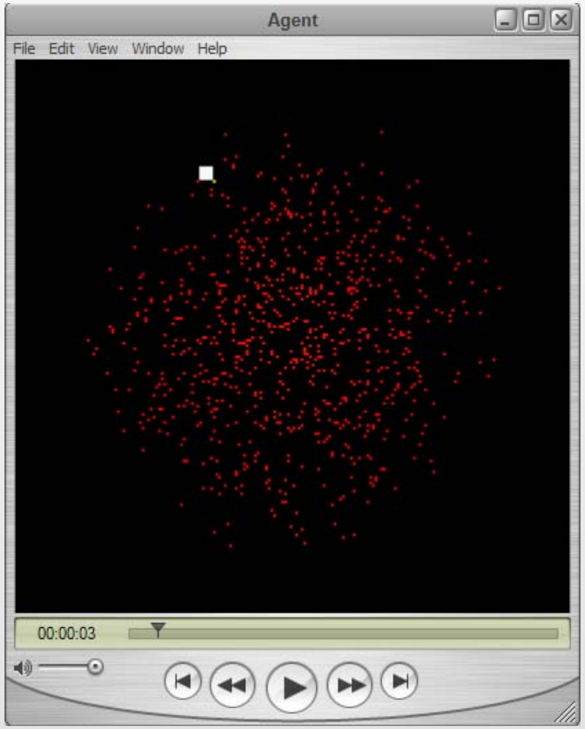
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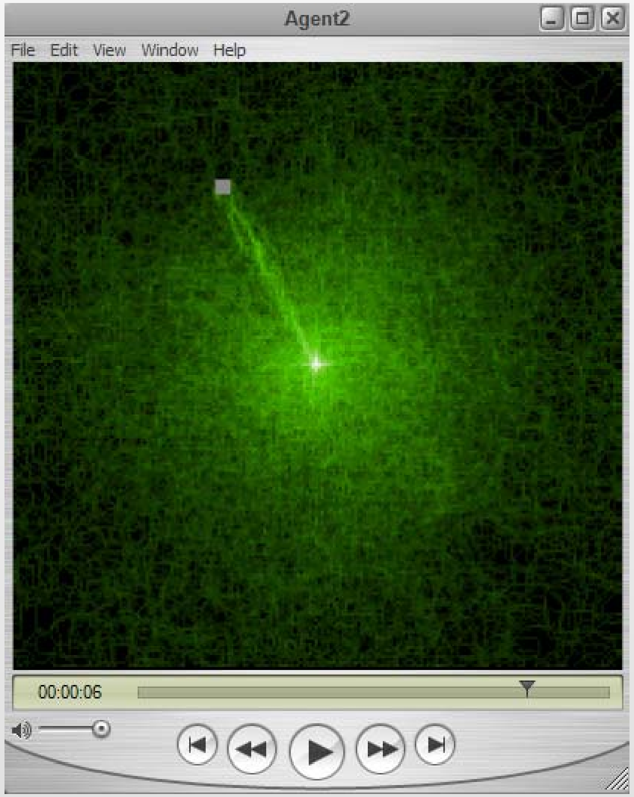
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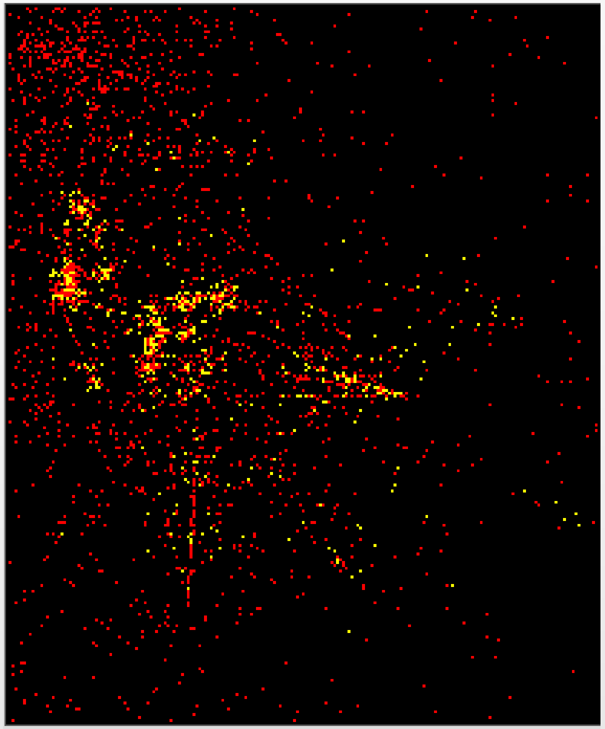
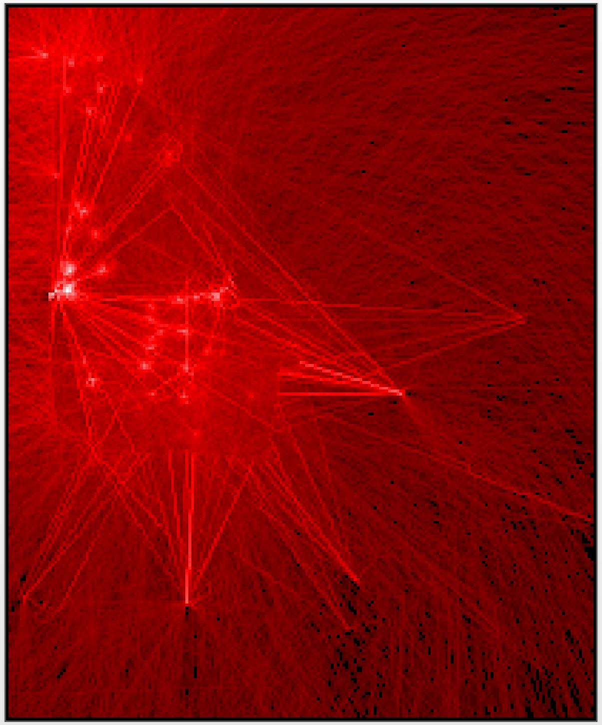
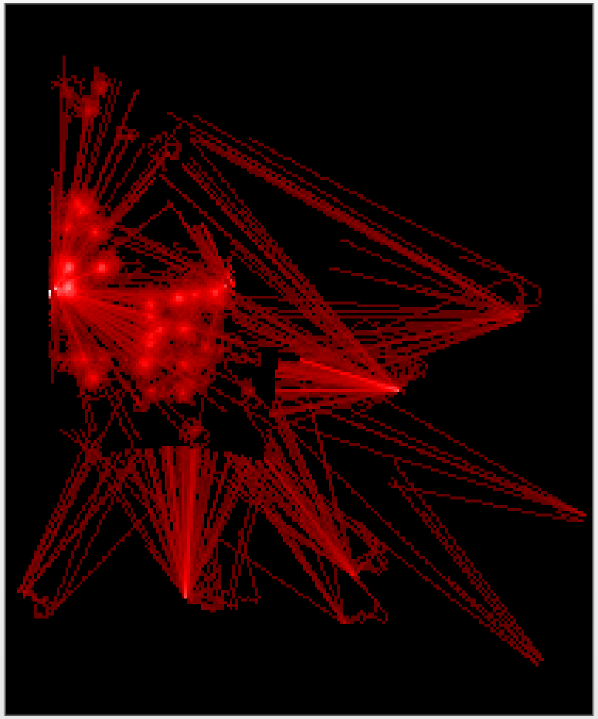
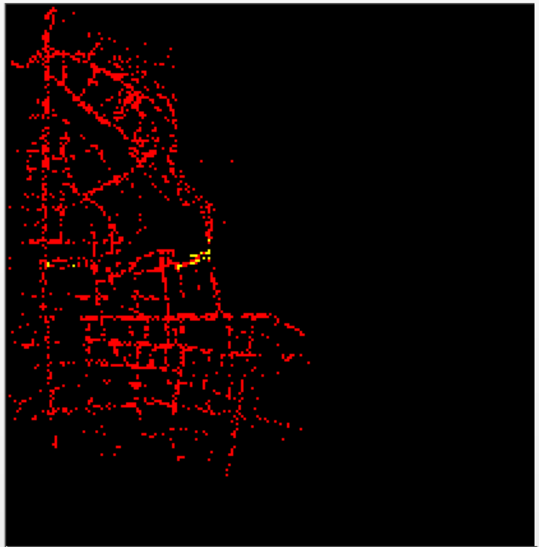
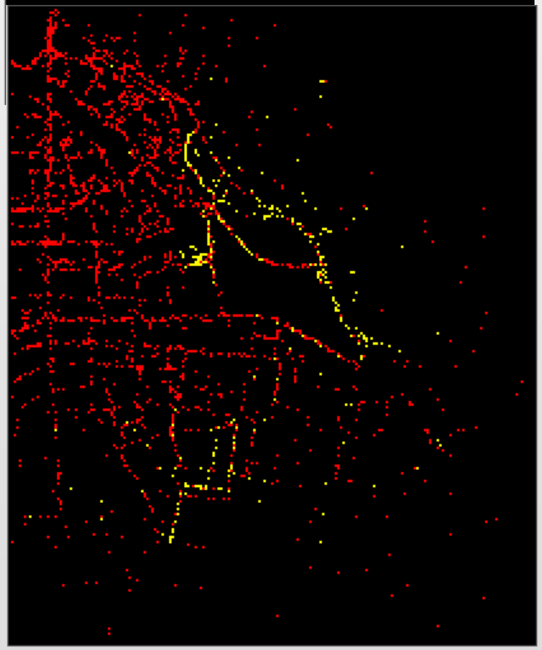




Let’s do this for the real street geometry and run the movie to see how this happens





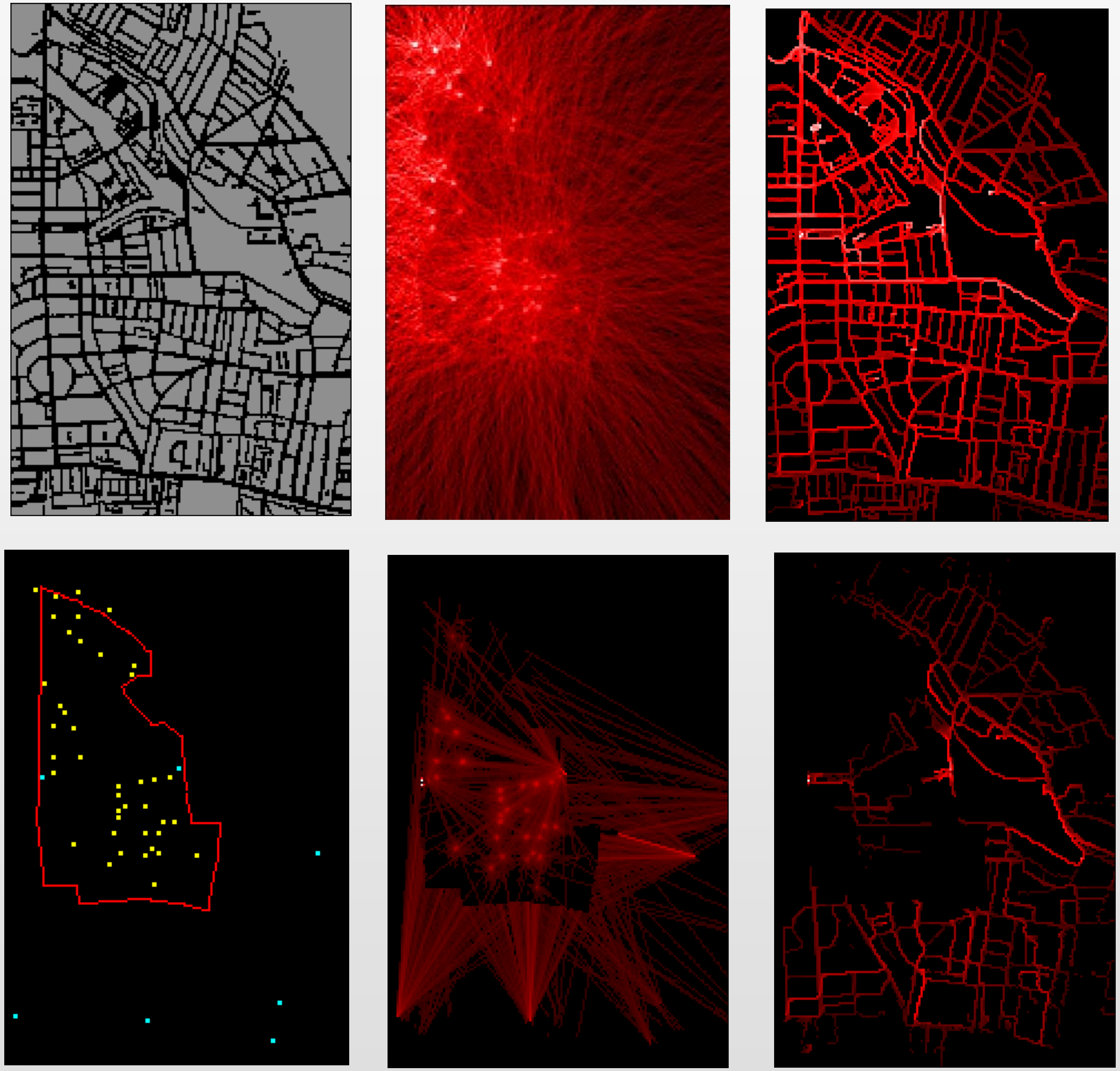
Let me run the First Stage Swarm Movie

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

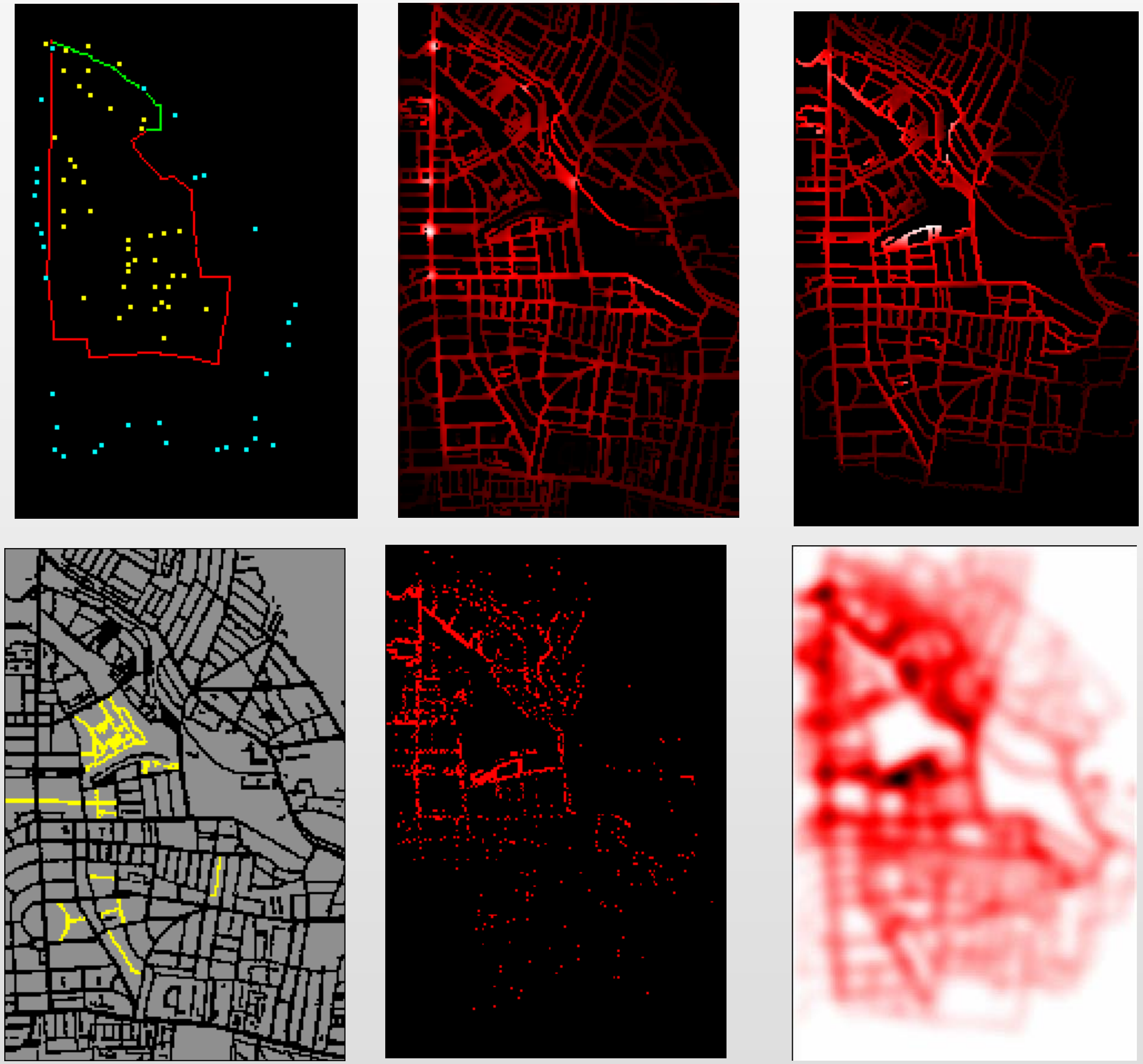


Let me run the Second Stage Unconstrained Simulation Movie

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

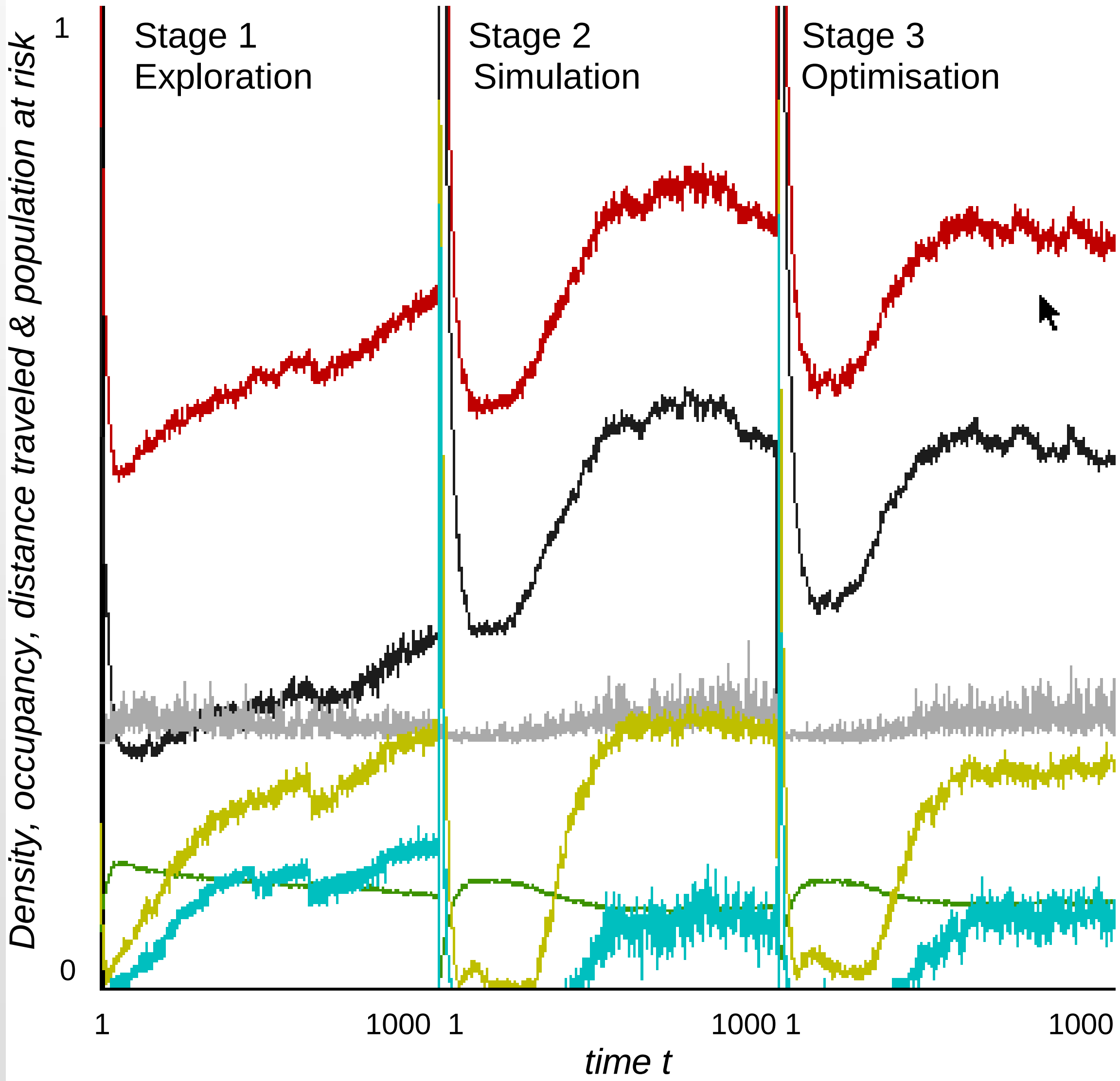
Thus in the existing simulation, we can figure out if the existing controls are optimal



Crowd Analysis

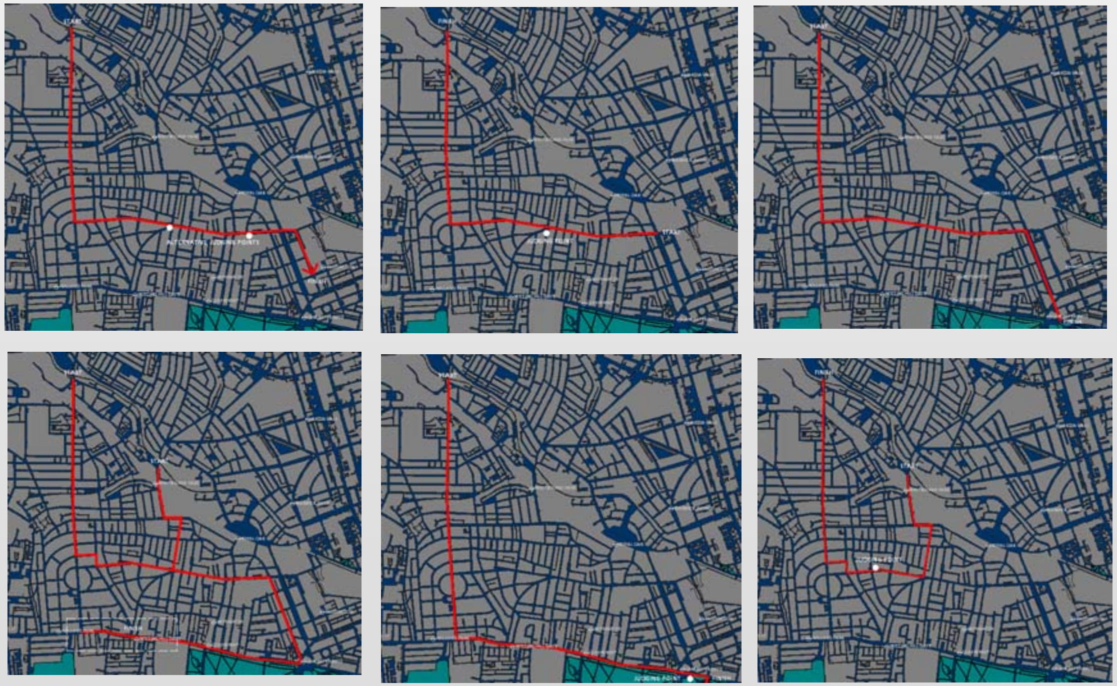
There is a substantial amount of analysis possible from this model with numerous additional graphics such as peak density analysis etc

Basically we can compute densities for each pixel and groups of pixels at any cross section of time and over any time period. We can also deal with distance moved and all related derivatives in terms of velocity with respect to each agent and cluster of agents as well as locations. Here's a typical example

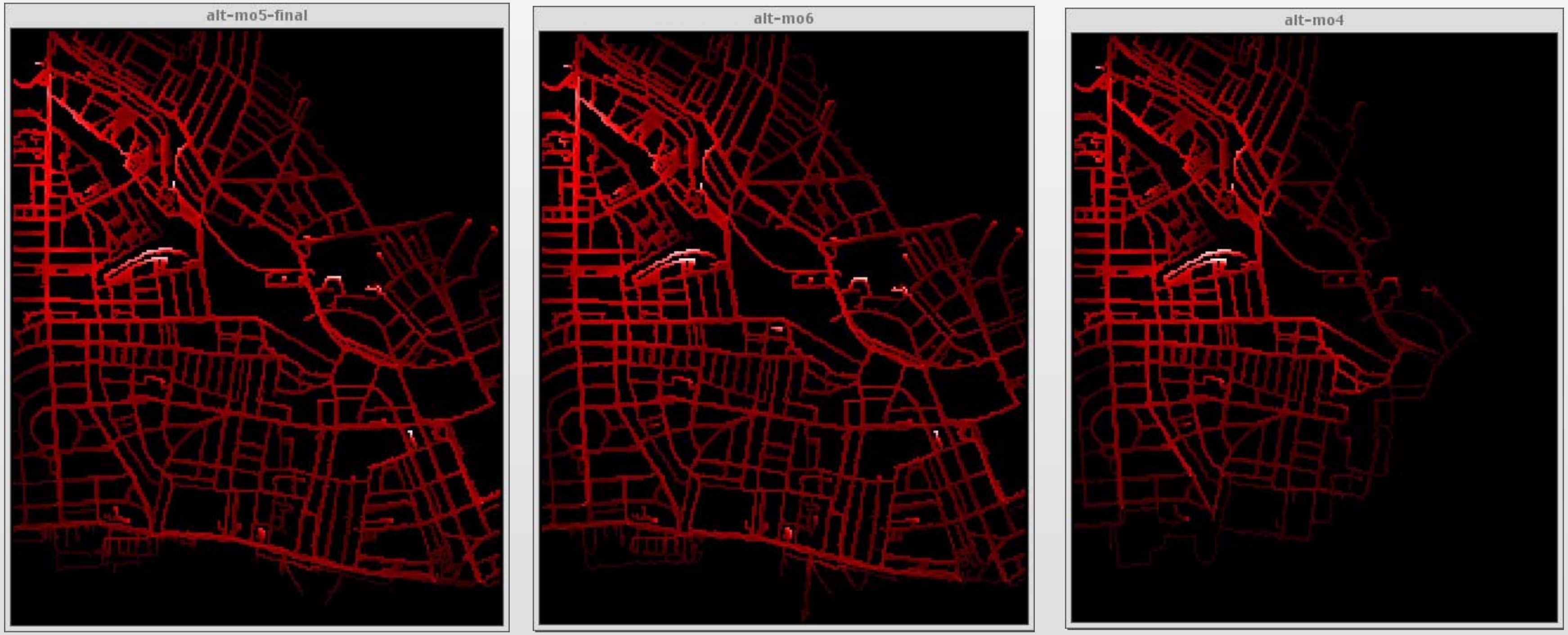

Density, occupancy, distance traveled & population at risk
1
0
Stage 1
Exploration
Stage 2
Simulation
Stage 3
Optimisation
1
1000
1
1000
1
1000
time t

3. Using such Models in Policy

There are six routes which were given to us by the GLA and Westminster – essentially we are engaged in ‘what if analysis’. The general principles is to break the loop of the carnival & reduce densities.



Here are the density maps for each scheme where the model has been run given new entry points and volumes from the regression model




alt1-mo7

alt1-mo9

alt1-mo8-final

Analysis of Crowding

Statistics	*Existing*	*Alt 1*	*Alt 2*	*Alt 3*	*Alt 4*	*Alt 5*	*Alt*
	Carnival	*MO8*	*MO5*	*MO7*	*MO6*	*MO4*	*MO9*
maximum density	116	47	64	75	77	88	50
max neighbor density	417	98	190	227	265	297	132
av density	2.5641	1.6402	2.05	2.331	2.2069	2.2099	2.2353
av distance in last iteration	1.0786	0.9999	1.0959	1.0916	1.0464	1.0578	1.0286
av distance from origin	74.3073	95.9656	71.9376	78.8635	77.5772	80.307	88.7344
		chair	W-E L	Park	E-W L	H	M-H

Questions?

You can get lots of info on all this in my book Cities and Complexity, various chapters