



The Ida Cordelia Beam Distinguished Visiting Professorships Program

Departments of Geography and Urban and Regional Planning
University of Iowa, April 12th, 2005

How People Walk:

*Modelling Crowds in Buildings, Shopping
Malls, Carnivals, and Streets*

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Why do we need to model how people walk ?

Some examples:

- *Complex places*
- *Crowds and panic*
- *Terrorist threats*
- *To make profit from where people walk -
shopping*
- *To develop walkable and enjoyable
environments*

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Outline of the Talk

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*
9. *Next Steps: The Covent Garden Model*
10. *Questions?*

1. Agents – Behavior – Randomness – Geometry

I appreciate that many of you here, in fact most, don't want to be lectured on theory – these are interesting problems and don't let's make them boring with theory.

But I do need to tell you why for the first time we can begin to model these kinds of problem.

I want to emphasise two key things.

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

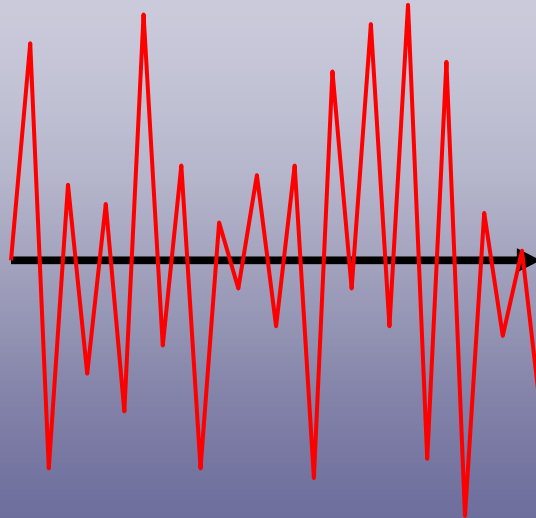
A good model to begin with is the 'random walk' which we will look at in one- and then two-dimensions

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



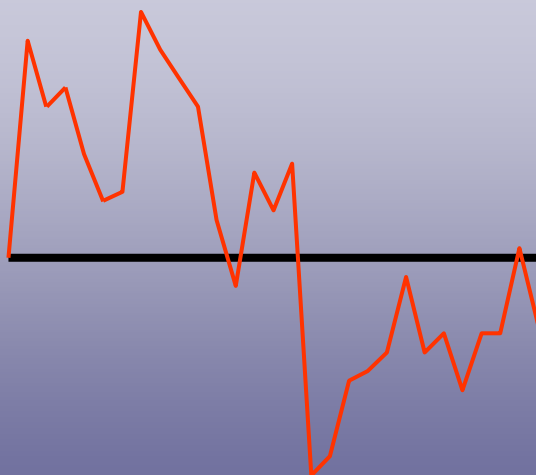
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The one-dimensional walk with memory ...

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



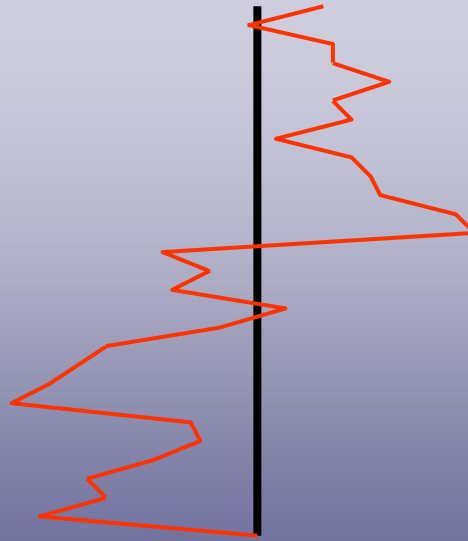
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Let's suppress time ...

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

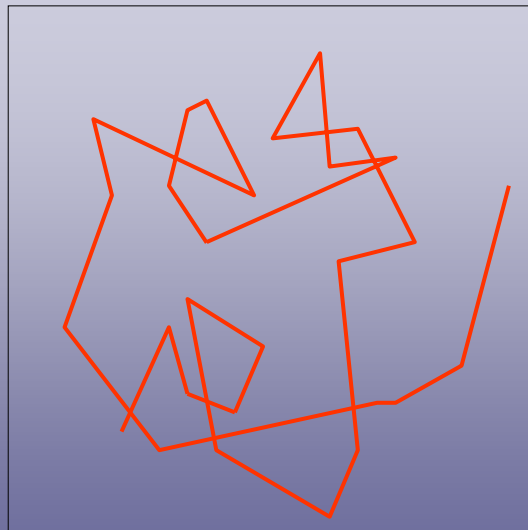


Now think of the walk in two dimensions

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

We are going to add geometry and intentions to build models of how people move

But let's look at some examples of these models running





1-d Random-walk-random-change



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



2-d Random-walk-big-change



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.

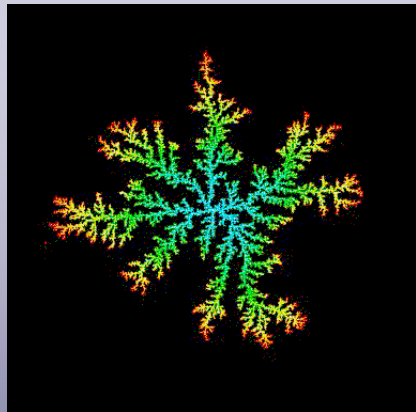
This then adds to the seed – there is now a connected structure – carry on with the process of bombarding the structure, and whenever the walker touches the structure, its grows a bit.

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

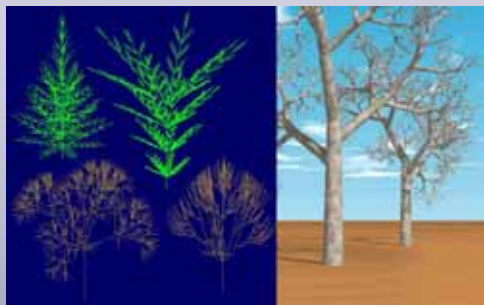
I will now run another Starlogo program to show this



Adding Geometry – the Diffusion Limited Aggregation Model



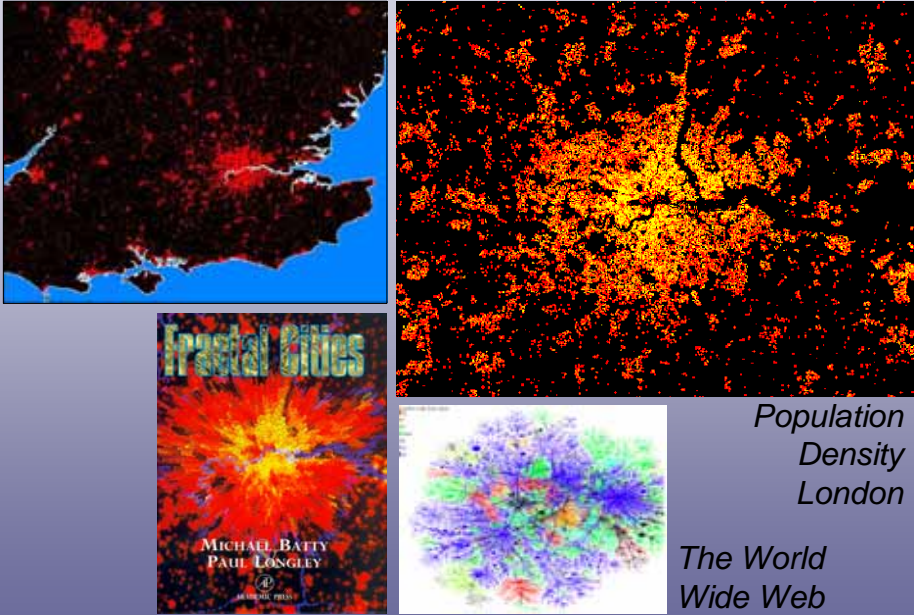
DLA – Diffusion Limited Aggregation



Fractal Trees




Barnsley's Fern



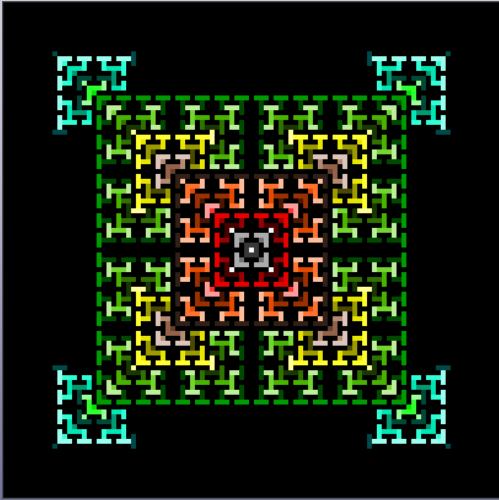
Fractal Cities
MICHAEL BATTY
PAUL LONGLEY


*Population
Density
London*

*The World
Wide Web*

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*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*



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4. Adding Intentions: Social Behavior – Utility

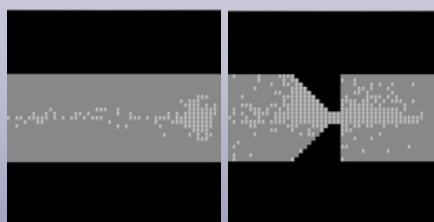
Let us try to add some socio-economic logic to the random walk – we will assume that the walkers are moving to some specific destination – which we will encode into the spatial environment on which the walkers are moving.

We will introduce a source of walkers and move them 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

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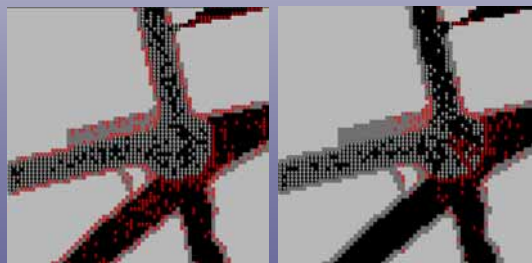


Here are some of our examples and we will run some movies to show what happens



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



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Narrow Street – no obstacles



Street with Obstacles



A Parade with Crowds pressing in an Panic

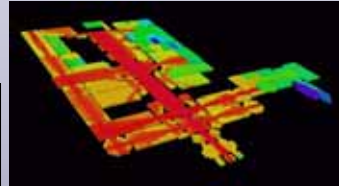
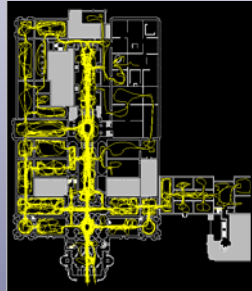
5. Models of Crowding – Buildings and Town Centres: Panic, Evacuation, Safety

*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:



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



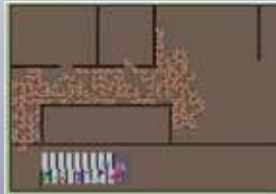
population ~ 250 000



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





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*Arrive in Makkah
Circle the Tawaf 7 Times*






Go to Mount Arafat





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Jamarat al Aqabah









*Return to Mekkah
Farewell*





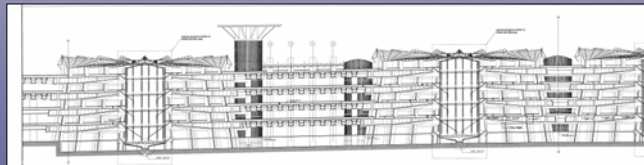
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YEAR H	Year	Date Hijrah	TIME	LOCATION	Number DEAD	Number INJURED
1414	1994	92	01:25	Southern North of Jamarah AI	266	88
1415	1995			No major accidents		
1416	1996			No major accidents		
1417	1997	12	15:10	North Side of the Eastern Entrance	22	43
1418	1998	12	13:30	North Side of the Eastern Entrance	118	414
1419	1999			No major accidents		
1420	2000			No major accidents		
1421	2001	10	08:12	Kubra-North of Jamarah AI	35	179
1422	2002			No major accidents		
1423	2003			No major accidents		
1424	2004	10	08:54	Kubra-North of Jamarah AI	240	252
1425	2005			No major accidents		



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

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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 area of about 3.5 sq miles

Here are some pictures

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bars & music
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services
football & sport
news & community
business zone
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My Village
NOTTING HILL

celebs & gossip
homes & property
kids & youth
personals
fashion & lifestyle
restaurants
health & beauty
message board

Name & Community




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Address: <http://www.thecarnival.tv/map/main.htm>

Google - notting hill carnival Search Site PageRank Page Info Up Highlight notting hill carnival

Nottinghill @nival

- a about us
- m route map
- i carnival info
- b bands
- e main events
- n features
- d carnival diary
- c contacts




pedestrian area
float judging
traffic exclusion zone

see bus routes click here

map created by Quickmap

first aid
toilets
safety zone
lost & found children
crime reporting centre

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b. The Project: Public Safety

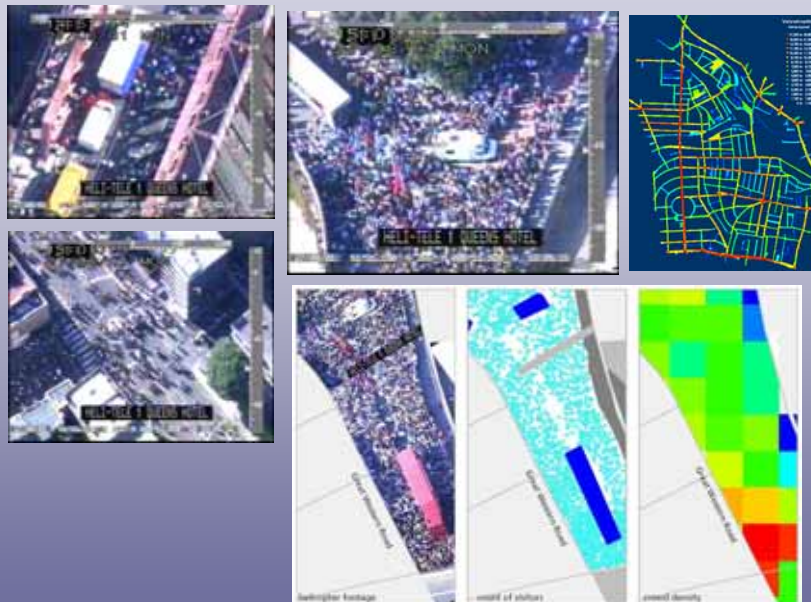
We have been involved in the problem of redesigning the route location for the parade which is judged to be 'unsafe' because of crowding and because of the crime and environmental hazards generated by concentration in a small area: for example crime has risen by about 15% annually for the last 10 years – 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

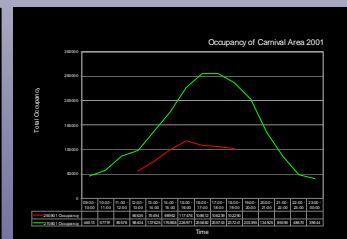
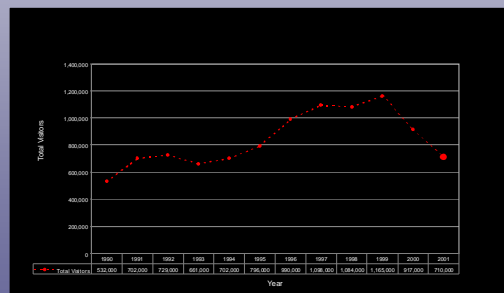
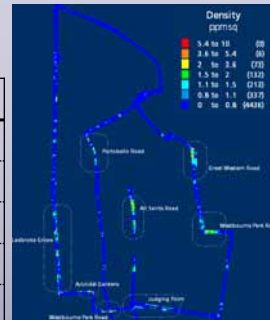
We have used 4 different methods to determine the number of people at carnival 2001

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*



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



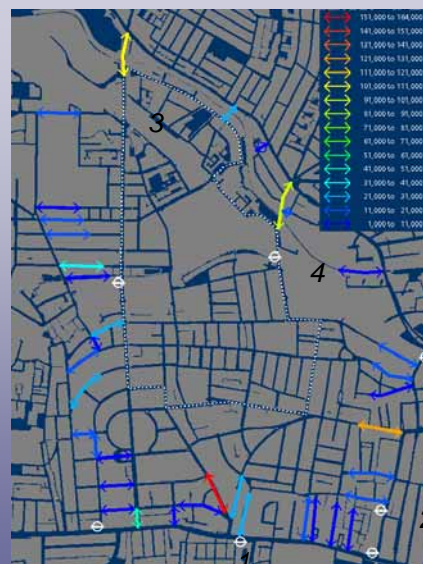
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Access to Carnival is very unevenly distributed

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%



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A Digression: our Tokyo Project – Measuring Pedestrian Volumes and Directions

We are hard at work with the Shibasaki Lab in the U of Tokyo who are experts in remote sensing of pedestrians and traffic. Here are some examples of our tests in London in our own Lab and also with London Transport outside their HQ in Victoria

Basically we are using small laser scanners which detect all motion with 50 metres radius. We need many of these to cover an area – they cost €3K per station

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Show the movie ? 

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

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

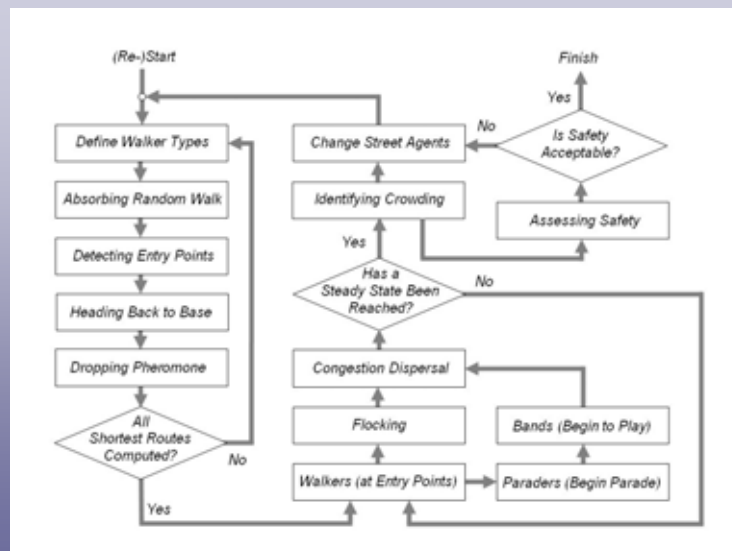
Flocking Crowding

The diagram shows four nodes labeled W, P, B, and S arranged in a square. Solid arrows represent flocking interactions: W to P, P to S, S to B, B to W, and a diagonal arrow from S to W. Dashed arrows represent crowding interactions: W to B, B to P, P to S, and S to W. Each node also has a self-loop arrow.

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.

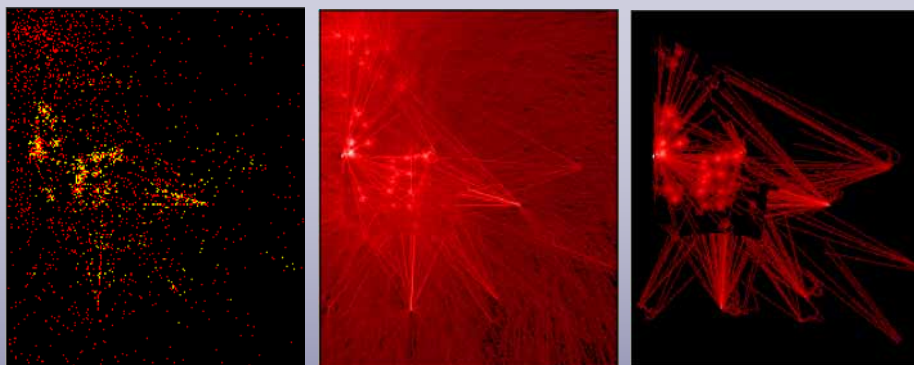
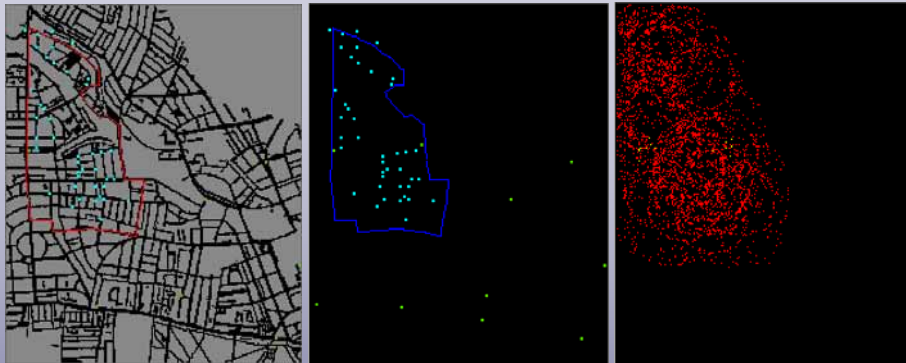
This is an increasingly popular method of finding routes in networks and it is based on the idea that if you launch enough agents and let them wander randomly through the network, they will find the objects in question

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

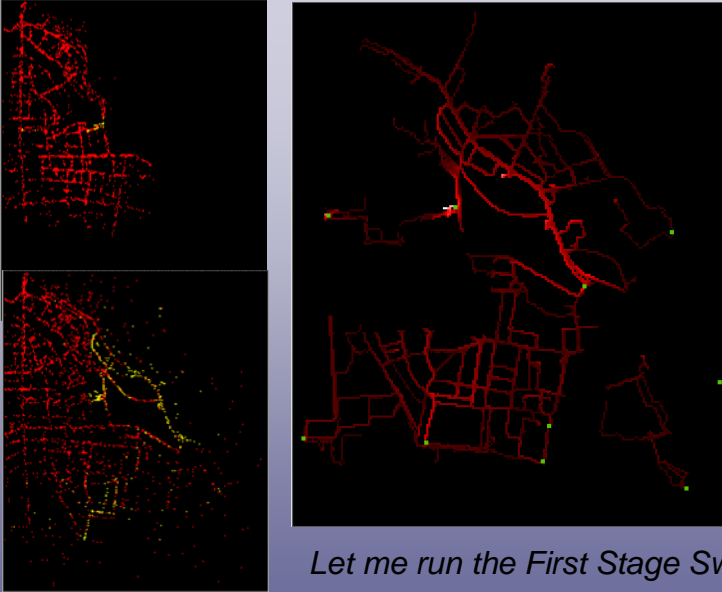
We show first the parade and the sound systems and the subway stations

Then the random access map


Then the shortest routes computed



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



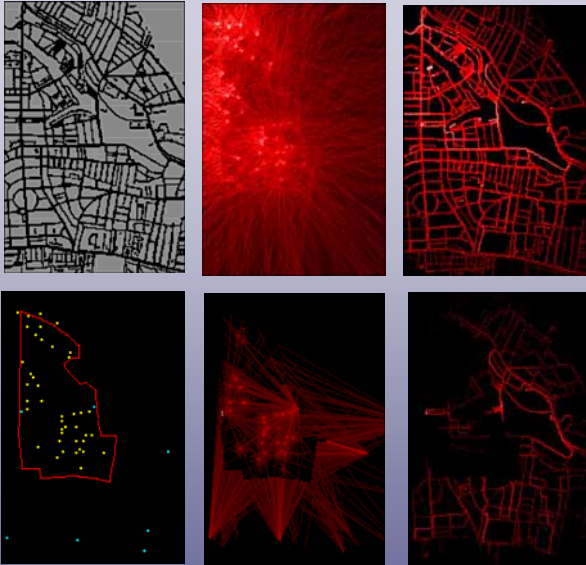
Let me run the First Stage Swarm Movie

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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*

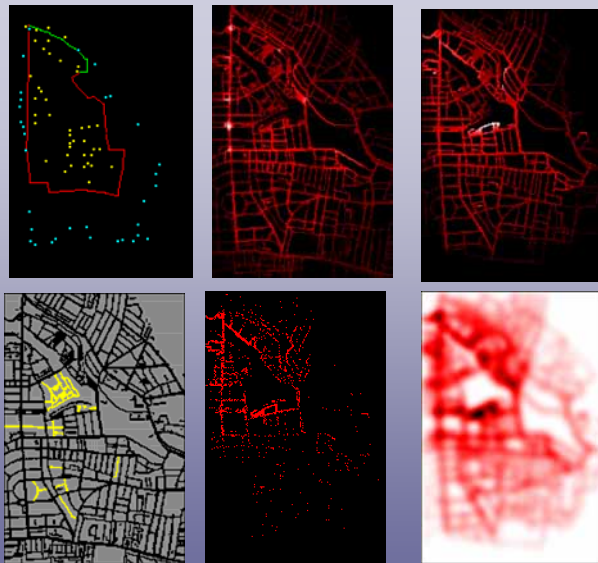


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In the third stage, we figure out where the crowding is worst and then introduce simple controls – close streets etc

In fact in the existing simulation we already have several streets and subway stations controlled and we can test these alternatively

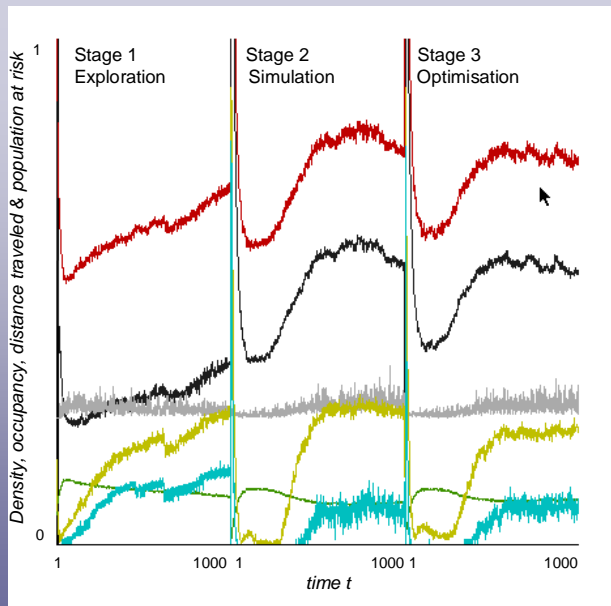
Thus in the existing simulation, we can figure out if the existing controls are optimal



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

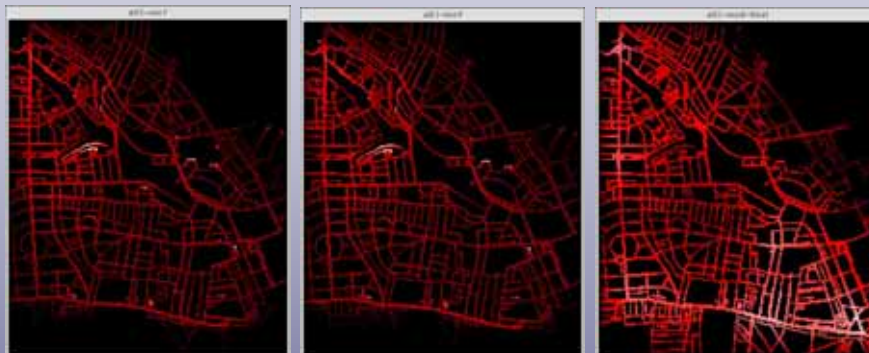
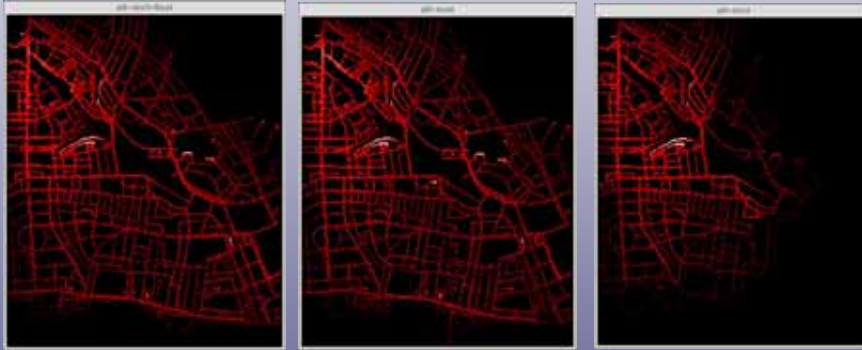


8. Using such Models in Policy

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



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	

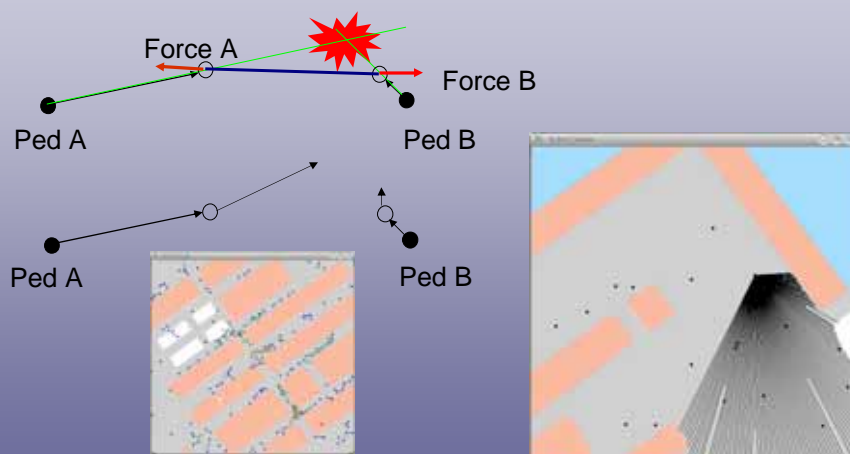
9. Next Steps: The Covent Garden Model

Designed by John Ward, Java based program called JPed which integrates Notting Hill like model equations with line of sight and agent preference structures

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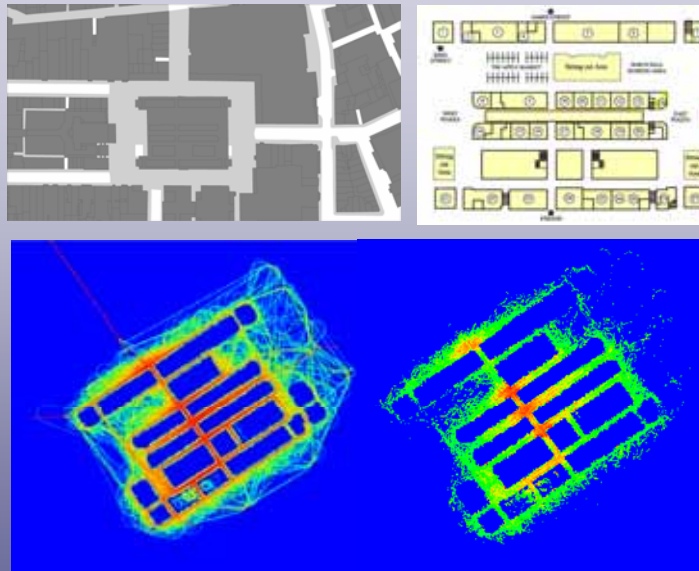


I will give you a quick visual tour of the model – three components – object forces, line of site, agent preferences



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10. Questions

Resources on these Kinds of Model

<http://www.casa.ucl.ac.uk/>

<http://www.geosimulation.com/>

http://www.csis.u-tokyo.ac.jp/english_2002/

<http://www.casa.ucl.ac.uk/~david/>

<http://www.casa.ucl.ac.uk/ijgis/>

<http://www.geog.psu.edu/faculty/davidO.html>

<http://education.mit.edu/starlogo/>

<http://www.natureonline.com/>

<http://www.envplan.com/>

Note that these were active in 2005, some 6 years ago ...