10 March, 2005

New Approaches to Urban Modelling: Agents, Cells, Representations and Visualizations

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Contents

Research at CASA

↓

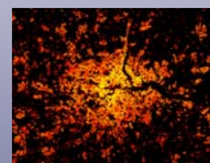
Pedestrian behaviour modelling

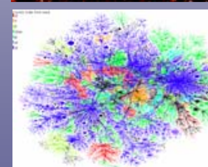
↓

An Integrated Simulation Model of Pedestrian Movements
-an application to retail behaviour-

Ongoing research projects at CASA

- *Urban and regional modelling: agent based and cellular automata models*
- *Virtual cities, including 3D-GIS and CAD*
- *Geodemographics*
- *Urban GIS: urban sprawl analysis*
- *Cybergeography: mapping the internet*
- Web-based GIS applications





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Urban modelling: agent based and CA models

- *Urban cellular automata models (cities in North America, Thai, Brazil)*
- *Agent-Based Models of Spatial Epidemics*
- *Pedestrian behaviour models*
  - ✓ *Crowding situations*
  - ✓ *Emergency evacuation*
  - ✓ *Retail movements*

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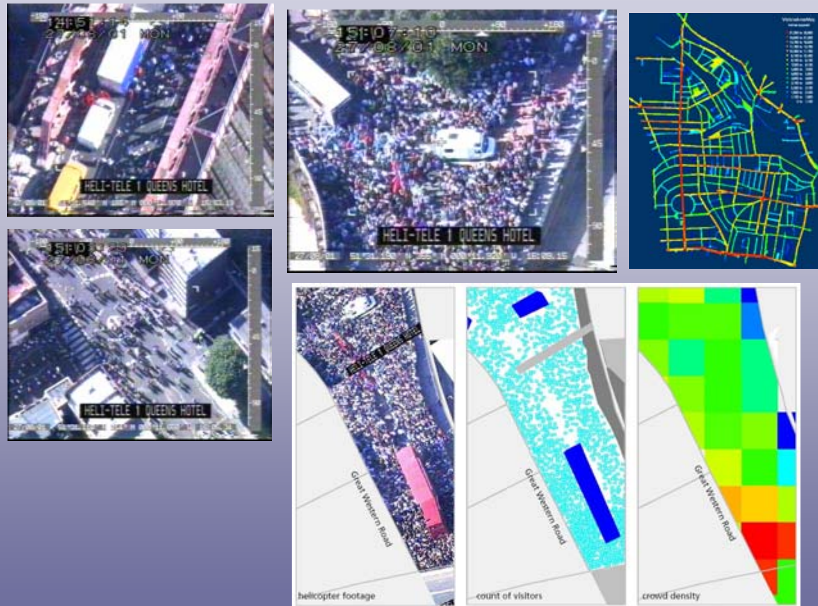
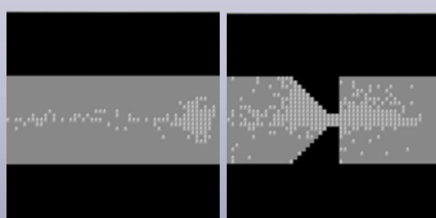
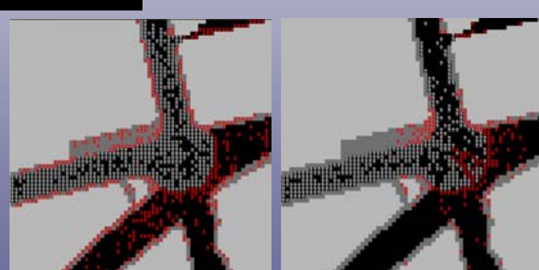


Crowd simulation

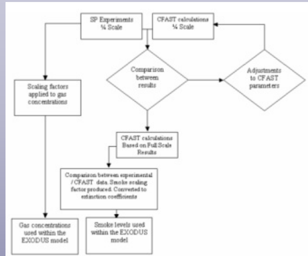


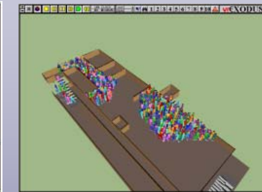
- launch walkers
- narrow the street to see the effect of crowding

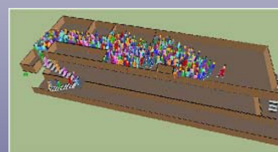
street junction where the parade (grey) collides the audience (red)

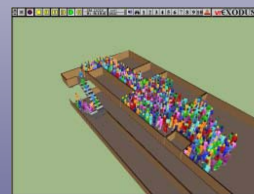


Emergency evacuation









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

Urban modelling: agent based and CA models

- *Urban cellular automata models*
  (cities in North America, Thai, Brazil)
- *Agent-Based Models of Spatial Epidemics*
- *Pedestrian behaviour models*
  - ✓ *Crowding situations*
  - ✓ *Emergency evacuation*
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An Integrated Simulation Model

Application to retail behaviour

Built environment agents

Geographic attributes
Attraction level

Knowledge
Needs

Pedestrian agents

Multi-agent-based model

Interaction between environment

- ✓**collision avoidance**
- ✓**walking speed**
- ✓**basic walking tendencies** (e.g.avoid rapid turn over)

Stimuli-Response

Calculation of the optimum route

- ✓**shortest path**
- ✓**cognitive process**
- ✓**spatial knowledge**

Route choice

Matching between people's preference/needs and attributes of places

- ✓**Which place to be chosen as a destination?**

Marketing

Background

- Spatial marketing
- Urban planning
- Location-based services (Digital City)

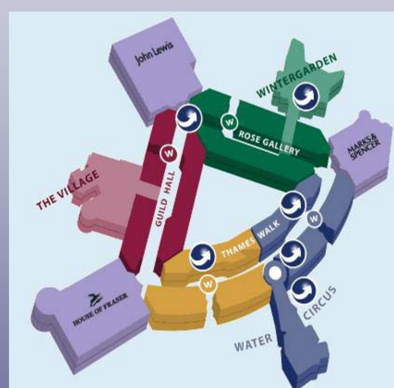
Background: Spatial marketing

- Marketing levels

Exit Surveys (counting, questionnaire)

1. Market penetration
2. Visitors
3. Passing trade
4. Peel-off rate
5. Browsing
6. Conversion

Observation by shop clerks
POS data



Background: Spatial marketing

- Passing trade
- Peel-off rate
- Route

✓Tenant strategy (leasing, fee)

✓Improvement of -floor plans
-signage system

Needs for Pedestrian behavior model

Background: Pedestrian-oriented urban planning

- Towards a fine City for People - London 2004

- Mayor Transport Strategy

  … a vision for London to become one of the world's most walking-friendly cities by 2015

(TfL report)

- Surveys on Public Space

Background: Pedestrian-oriented urban planning

- How people use space?
- What kind of problems are there?

Many pedestrians choose a very dangerous course, when insisting to cross St. Giles Circus at street level

Oxford Circus at Christmas time

Narrow footways

Evening: 96 metres of metal shutters

Background: Pedestrian-oriented urban planning

Further Analyses & Modeling are needed

✓Safety	less crime, fewer traffic accidents
✓Convenience	accessibility to transport, shops, services
✓Amenity	comfortable walking environment

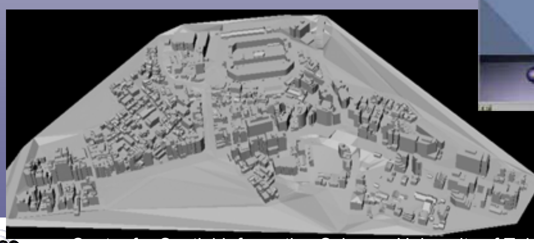
Actual movements
Necessary information
Influential factors

⇨ Needs for Pedestrian behavior model

Digital City

Planet9

Bath city

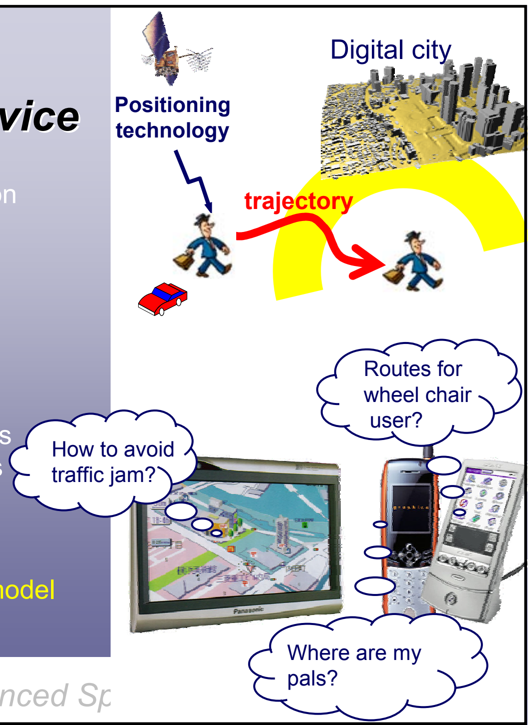


Background: Location-based service

Provide appropriate information according to user's location / needs

Patterns of users' routes/activities
Necessary Information - contexts

Needs for Pedestrian behavior model



Requirements of pedestrian behavior models

- There are several needs to develop pedestrian behaviour models

- Key issues

  ✓Understand and explain real pedestrian's movement

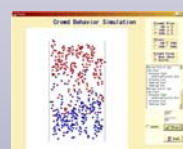
  ✓Represent dynamic interaction process between pedestrians and their environment

  (esp. Information which people obtain)

Review on current pedestrian behavior models

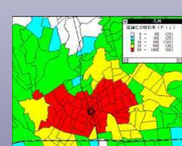
✓Crowd dynamics

Micro scale behaviour (e.g. obstacle avoidance)



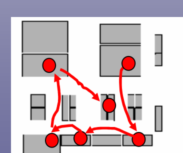
✓Transport model

Network analysis and OD/route estimation

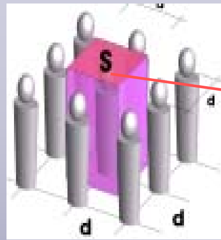


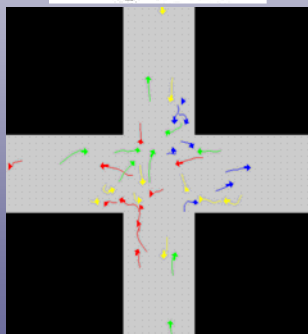
✓Stochastic model

Probability of state-to-state transition

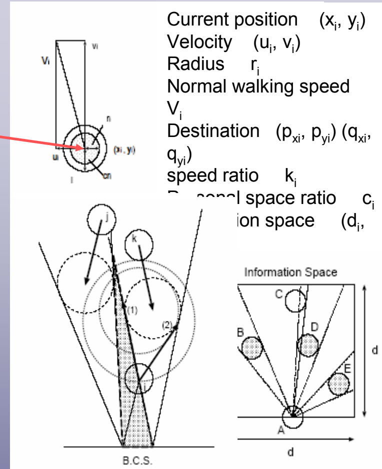


Crowd dynamics





(Kai Bolay)

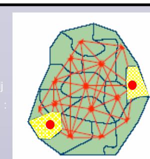


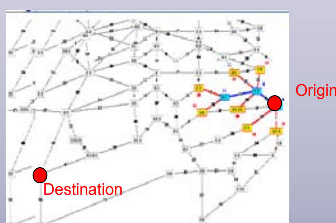
↑ Estimation of the next steps of other pedestrians

← Collision avoidance bahaviour

Transport model

Area: $S_1, S_2 \ldots S_n$
Trips between S_i to S_j : y_{ij}
Distance between S_i to S_j :

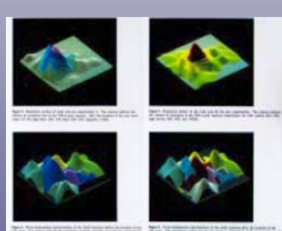




Shortest path between OD

(weights associated with each link can be distance, costs, condition of the road, etc)

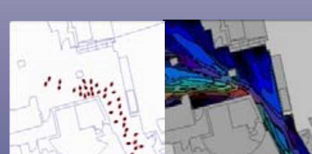
- Influence of other areas?
- Which area generates more trips than others?
- Why?



Gravity model

$$y_{ij} = \alpha_i^p \beta_j^q e^{\gamma d_{ij}}$$

α_i potential as origin
β_j potential as destination



Crowd dynamics Ltd

Most evacuation models adopt this concept

Logit model ---calculate probability of discrete choice

$$p_{ij} = \frac{\exp\left(-\alpha d_{ij} + \sum_k \beta_k A_{jk}\right)}{\sum_{k=1}^{n} \exp\left(-\alpha d_{ik} + \sum_l \beta_l A_{kl}\right)}$$

Consumer: $C_1, C_2, \ldots C_n$

Shop: $S_1, S_2, \ldots S_n$

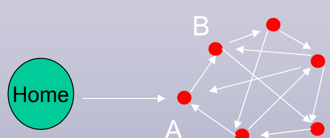
Attribute *k* of shop S_j: A_{jk}

Probability of C_i choosing S_j: p_{ij}

Distance between Ci and Sj: d_{ij}

parameter estimation by
maximum-likelihood method

Stochastic model



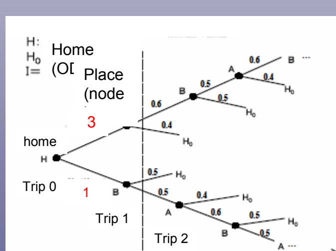
Marcov chain model

From \ To	A	B	H	total
A	0	0.6	0.4	1
B	0.5	0	0.5	1
H	3	1	0	

P_{II} Probability of visiting from one place to another

F_{HI} The observed number of people at their first destination

P_{IH} Probability of being the last destination



・Number of people who visit each place via another (Trip n : n>1)

$$RE = F_{HI}P_{II} + F_{HI}P_{II}^{2} + \cdots$$
$$= F_{HI}P_{II}(I - P_{II})^{-1}$$

Requirements of pedestrian behavior models

	advantage	disadvantage
✓Crowd dynamics	• Well represent micro-scale physical response • Dynamic	Not take it into account: • where they are going to and why • pre-fixed route = static model • geographical attributes
✓Transport model	•Suitable for description of selection behavior	Several things can't be represented: • interaction between others/environment •cognitive process of pedestrian
✓Stochastic model	•Useful for being briefed on how people move around •Capable of representing changeability of movements	•Inadequate to small scale movement •Not explain why they choose certain place

Understand and explain real pedestrian's movement

Represent dynamic interaction process between pedestrians and their environment

New pedestrian behaviour models are needed

Background

Requirements of pedestrian behaviour models

Review on current models

Research objective & Research Design

Framework of the model

Methodologies

project update

Research Aim and Objectives

To develop a new pedestrian behavior model

✓be capable of explaining real pedestrian's movement

Every factors should be determined based on observed data
It can deal with more complex behavior (e.g. shopping)

✓represents dynamic interaction between pedestrians and their environment

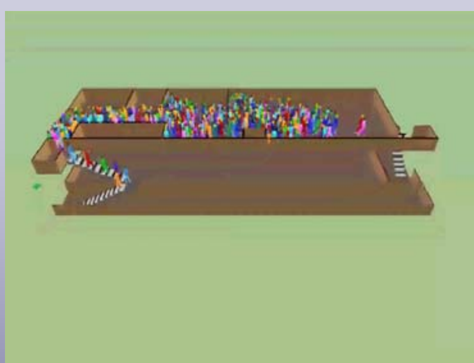
To deal with not only pre-determined route-choice
but also people's cognitive process or other changeable events

✓Easy-to-understand interface

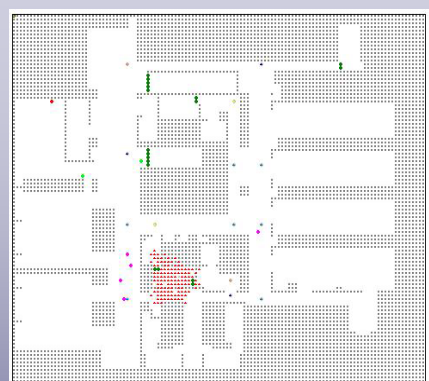
visualization, To make the model more transferable

✓be validated through comparison between actual trajectories

It should be different from playing with beautiful animation



EXODUS



Look different but follow same behaviour rules

Behavior model
(simulation)

+

Visualization

Research Aim and Objectives

Pedestrians' attributes

Space/Buildings' attributes

Behavior model
(simulation)

OUTPUT

Each pedestrian's trajectory

Visualization

(t, x, y, z)

Observed
trajectory

(Bandini)

An Integrated Simulation Model

Application to retail behaviour

Built environment agents

Geographic attributes
Attraction level

Knowledge
Needs

Pedestrian agents

Multi-agent-based model

Interaction between environment

- ✓collision avoidance
- ✓walking speed
- ✓basic walking tendencies (e.g.avoid rapid turn over)

Stimuli-Response

Calculation of the optimum route

- ✓shortest path
- ✓cognitive process
- ✓spatial knowledge

Route choice

Matching between people's preference/needs and attributes of places

- ✓Which place to be chosen as a destination?

Marketing

congestion

～m / min

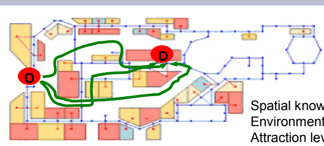
Obstacle avoidance

Stimuli-Response

How they walk around?

feedback

model



Spatial knowledge
Environmental info
Attraction level

Route choice

Which route to take?

collecting information

New info

Records of Optimization criteria

choose destinations

DB

Marketing Strategy of each shops

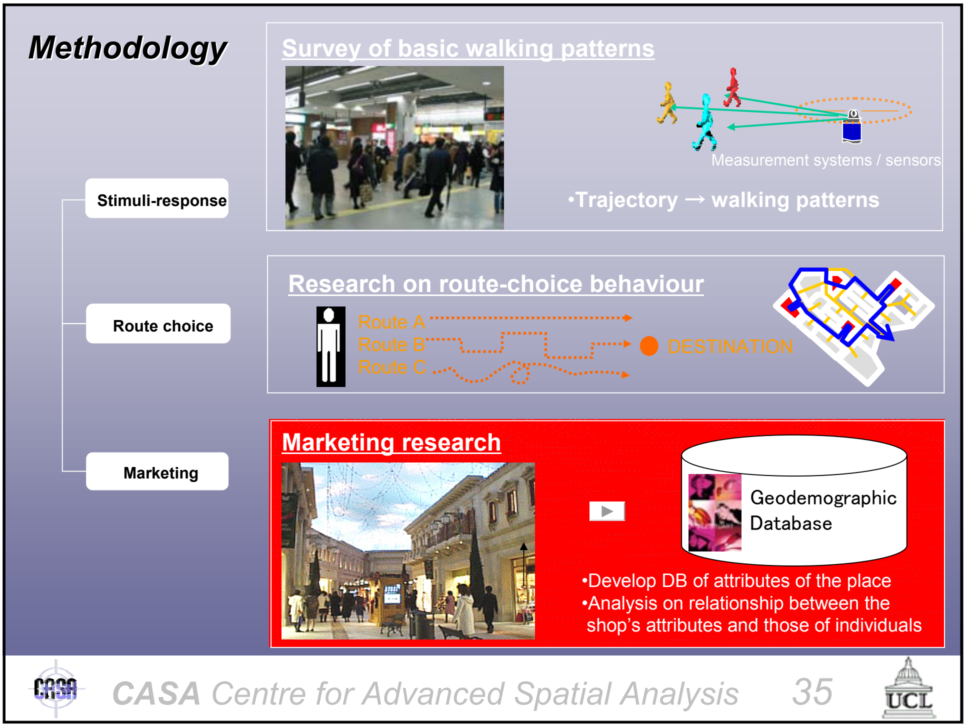
Attraction level
Cost
Distance

matching

User's

Attributes
Preference
Needs
Restriction

marketing


Methodology
Stimuli-response
Route choice
Marketing
Survey of basic walking patterns
Measurement systems / sensors
•Trajectory → walking patterns
Research on route-choice behaviour
Route A
Route B
Route C
DESTINATION
Marketing research
Geodemographic Database
•Develop DB of attributes of the place
•Analysis on relationship between the shop's attributes and those of individuals
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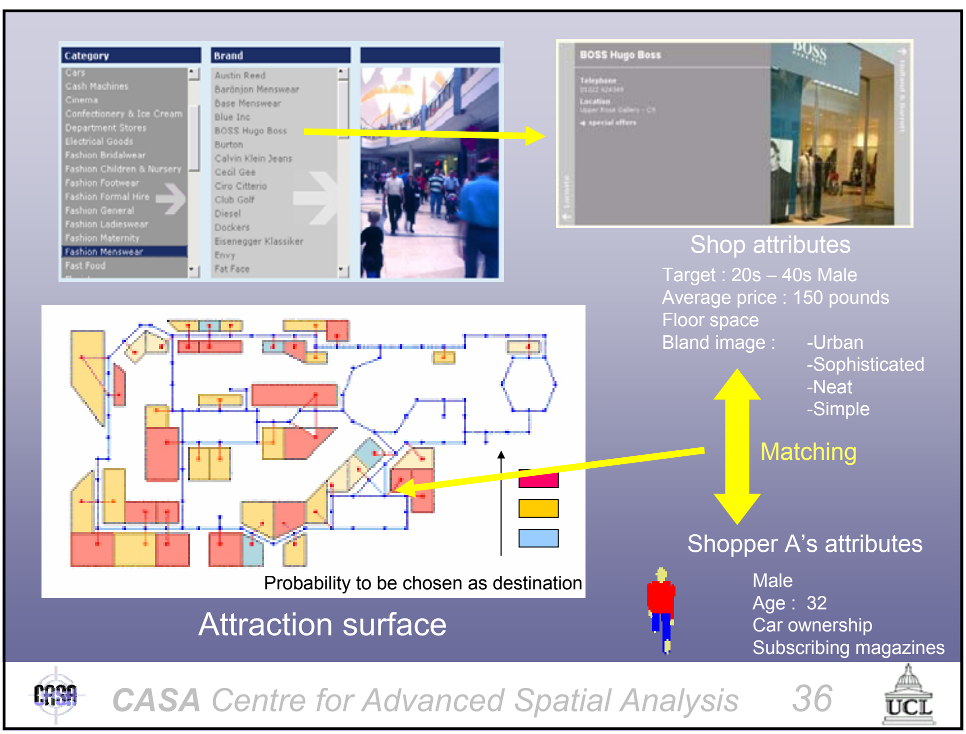
Category
Brand
BOSS Hugo Boss
Shop attributes
Target : 20s – 40s Male
Average price : 150 pounds
Floor space
Bland image : -Urban
-Sophisticated
-Neat
-Simple
Matching
Shopper A's attributes
Male
Age : 32
Car ownership
Subscribing magazines
Probability to be chosen as destination
Attraction surface
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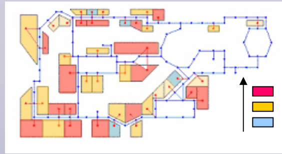
Attraction surface (matrix) for each shopper

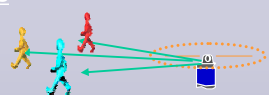


	Shopper A	Shopper B	Shopper C	Shopper D	Shopper E
Marks & Spencer	90%	43%	57%	70%	9%
Joseph	30%	1%	22%	20%	39%
Boots	95%	14%	89%	15%	94%
Monsoon	60%	0%	23%	50%	22%
HMV	12%	90%	31%	82%	11%
Dickson	4%	82%	40%	14%	42%
Sony store	2%	70%	5%	23%	25%
⋮					

Methodology

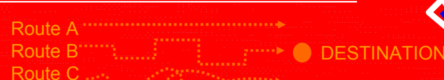
- Stimuli-response
- Route choice
- Marketing

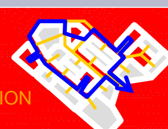
Survey of basic walking patterns



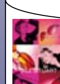
•Trajectory → walking patterns

Research on route-choice behaviour





Marketing research



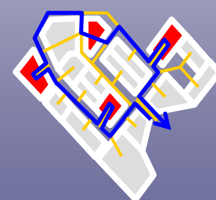
Geodemographic Database

•Develop DB of attributes of the place
•Analysis on relationship between the shop's attributes and those of individuals

Research on route-choice behaviour

Retail movement in a large shopping centre

- Visitors have the same objective = Shopping
- Survey area has distinct boundary
- Shoppers “walk around”



Surveys of route choice behaviour

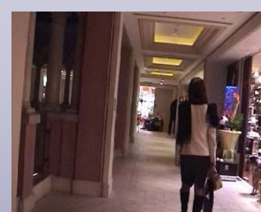
- Tracking retail movement

  18 samples (female, 20 year-old)
  2 hours shopping * 3 times

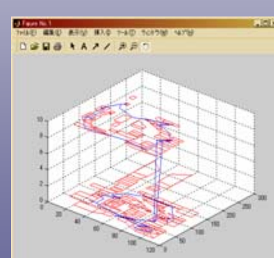
- Analysis on influential factors on shopper’s route choice

  ✓Knowledge about the place
  ✓Time constraints
  ✓Preferences

  Shop-till-you-drop consumer?
  People who doesn’t like to shop?

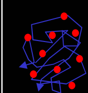
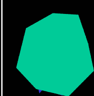
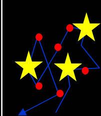
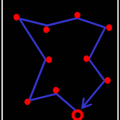
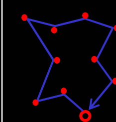


Retail movement

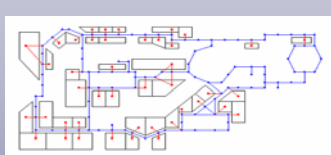


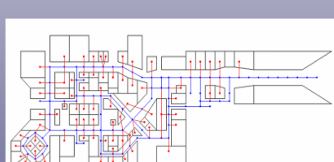
Sample trajectory

Typology of shoppers

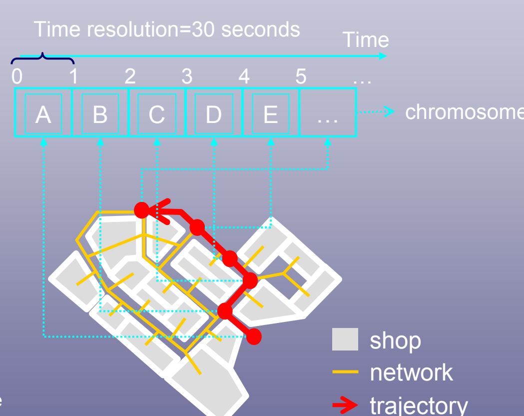
Type	Shop-till-you-drop consumer				middle	People who doesn't like to shop	
Category 1	Shop explorer			Repeat guest (Regular customer)		Buying motives YES	Buying motives NO
Category 2	Buying motives YES	Buying motives NO	Buying motives POTENTIAL		Shopping opportunity (Time)		
Proposed critical factor	Satisfactio n	informatio n	Visibility of potential purchases	Fixed route	Visibility of potential purchases	Spatial knowledge	
Route							
Behaviour pattern	Complex Time: long	Try to see whole area	Shortest path & Other factors	Shortest path Time: long	Deviate from prefixed route by visual stimulus	Shortest path Time: short	not go shopping

Test simulation using GA



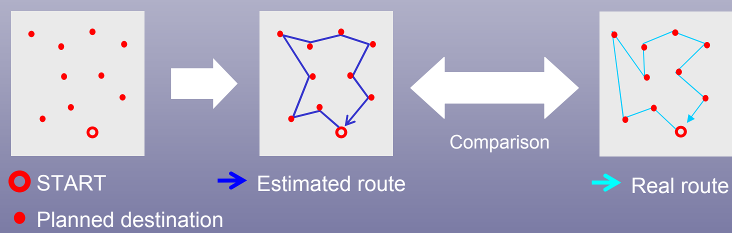


Floor plans/ networks of the shopping centre



326 nodes (shops, centre points of corridor-every 10m)
364 links (corridor)

Check the validity of the shortest path model



Test simulation using GA

Evaluation criteria

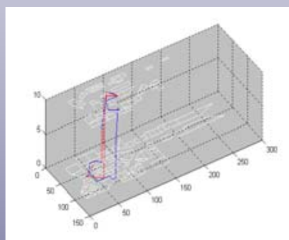
$$\max V = \sum_{i=1}^{N} a_i \cdot x_i$$

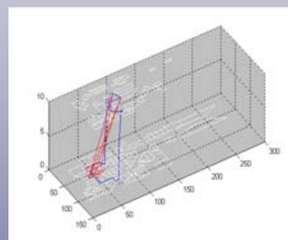
α Parameter
X Evaluation function for criterion *i*

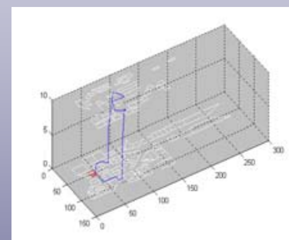
- Travel distances (shortest-path model)
- Does it include the ID of nodes which were scheduled to visit?
- Prefixed Start point and Goal point
- Physical restriction
  - walking speed (average 60 metres per minute)
  - rotation angle (less than 150 degree)
  - limited vertical movements

Calibration

Estimated route
Observed route


Test simulation

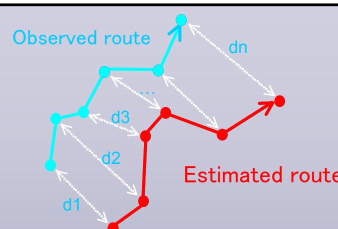

without restriction on distance


with severe restriction on distance

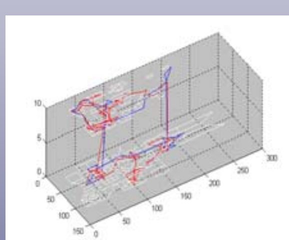
Evaluated value
Estimated route 7.62
Observed route 7.69

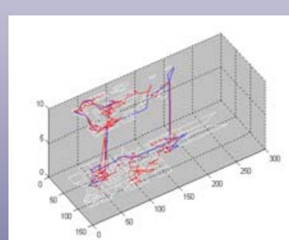
Set weighted parameters' values

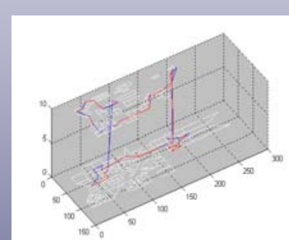
Results



Estimated route
Observed route (real route)


Simulation 1


Simulation 2


Given the real route
as one of initial chromosomes

	Simulation 1	Simulation 2	Given the real route as one of initial chromosomes
Evaluated value	Estimated route 100 Observed route 107	Estimated route 99.5 Observed route 107	Estimated route 108.8 Observed route 107
Distance between 2 routes	68.8m	52.4m	1.25m

Findings

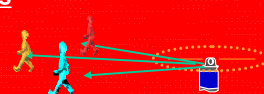
Shortest path model

– capable of predicting outlines of the routes
– evaluation criteria and parameter values tested
– other influential factors

Methodology

- Stimuli-response
- Route choice
- Marketing

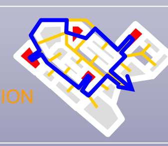
Survey of basic walking patterns



•Trajectory → walking patterns

Research on route-choice behaviour

Route A
Route B
Route C
DESTINATION

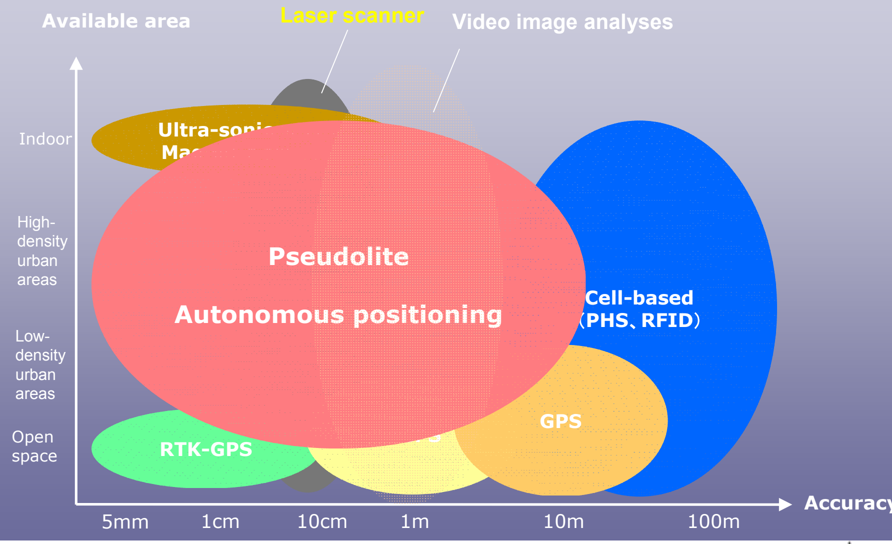


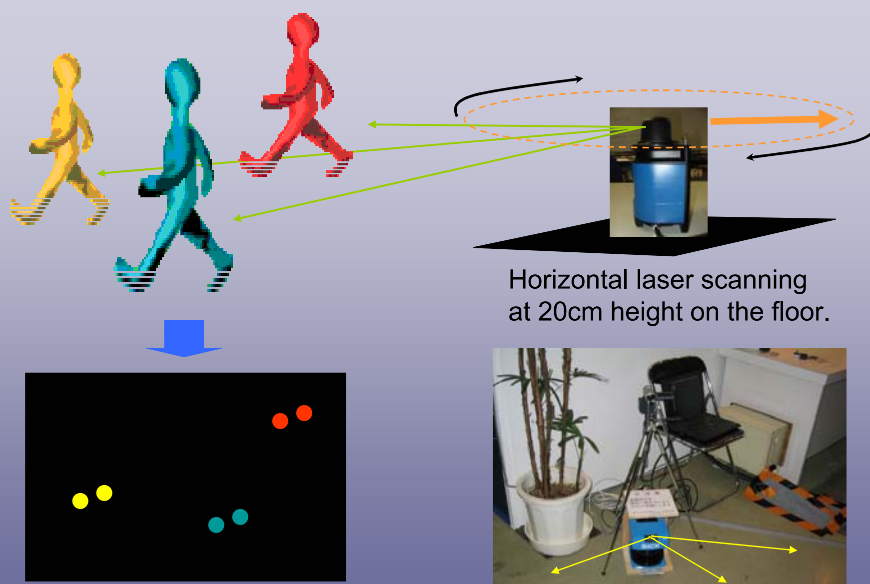
Marketing research

Geodemographic Database

•Develop DB of attributes of the place
•Analysis on relationship between the shop's attributes and those of individuals

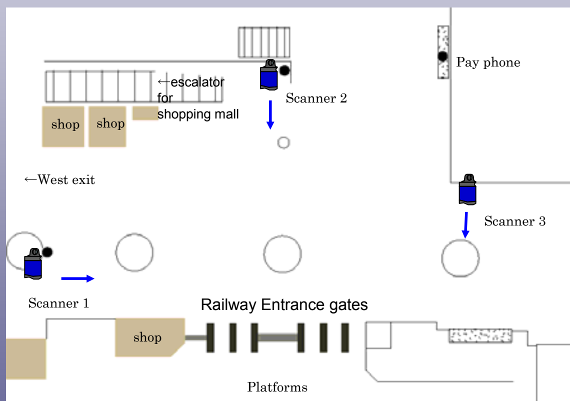
Measurement systems





Survey on pedestrian movement in a railway station

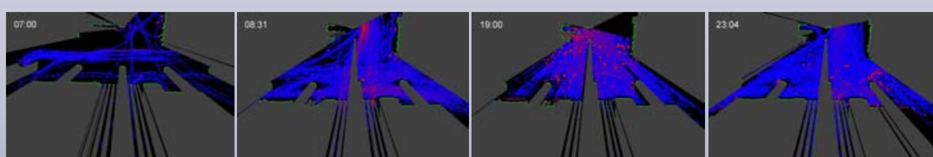
■Time　　2003/02/21(fri) 5:00 - 2003/02/22(Sat) 25:00



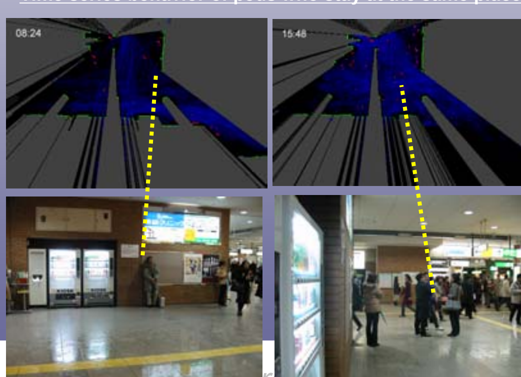
Laser scanner
LD-A *Maker:* IBEO Lasertechnik、SICK 291
（10Hz、1080 points/270°、maximum reach 70m）

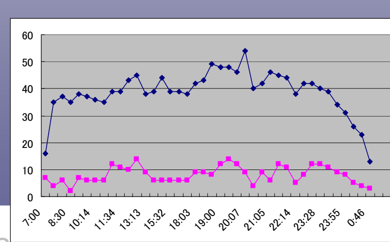
Routes = consecutive series of coordinates(ID,t,x,y)

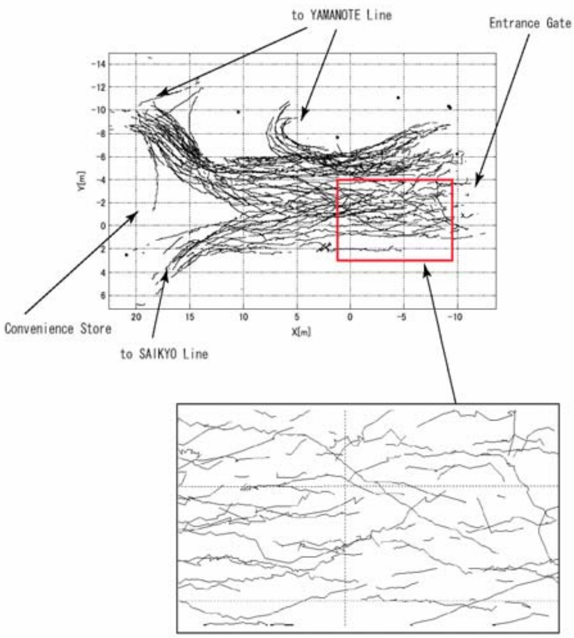
Analysis on basic walking patterns



Time series behavior of peds who stay at the same place more than 5 minutes







Trajectory 0

32622213	x1=-1.120	y1=1.478
32622313	x1=-1.095	y1=1.492
32622403	x1=-1.053	y1=1.499
32622503	x1=-1.056	y1=1.502
32622603	x1=-1.058	y1=1.547
32622693	x1=-0.952	y1=1.574
32622794	x1=-0.656	y1=1.513
32623274	x1=-0.255	y1=1.620
32623475	x1=-0.279	y1=1.555
32623565	x1=-0.220	y1=1.568
32623765	x1=-0.101	y1=1.692
32623855	x1=-0.100	y1=1.774
32624045	x1=0.520	y1=1.612
32624336	x1=0.492	y1=1.608
32624436	x1=0.601	y1=1.615
32624536	x1=0.764	y1=1.639
32624626	x1=0.962	y1=1.818
32624726	x1=0.982	y1=1.789
32624917	x1=1.109	y1=1.762

Trajectory 1

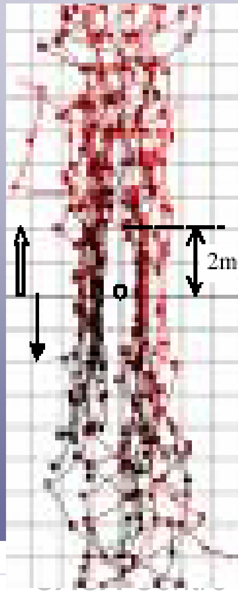
32625017	x1=-0.279	y1=1.555
32625207	x1=-0.220	y1=1.568
32625307	x1=-0.101	y1=1.692

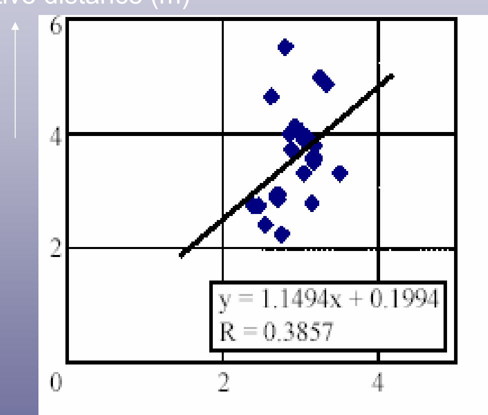
Walking speed

(m/sec)	Tanaboriboon			Fruin	Navin and Wheeler	Laser data
Walking speed	Male	Female	General	General	General	General
Average	1.32	1.15	1.23	1.33	1.31	1.27
SD	0.20	0.18	0.20	–	–	0.36
Max	2.05	1.68	2.05	–	–	2.98
Min	0.73	0.63	0.63	–	–	0.10

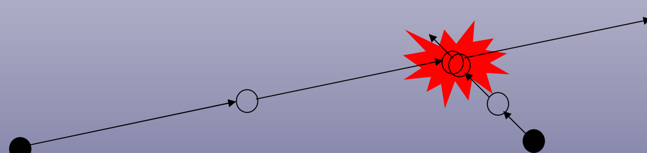
0.75[m/sec] < free walk < 2.33[m/sec] < running

Obstacle avoidance behaviour

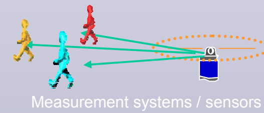




Obstacle avoidance behaviour



Survey of basic walking patterns



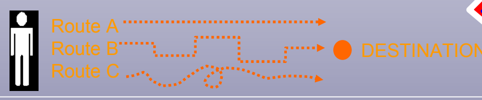
•Trajectory → walking patterns

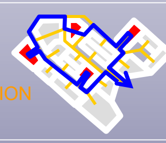
Stimuli-response

Route choice

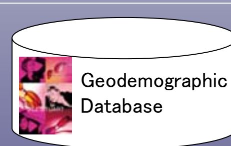
Marketing

Research on route-choice behaviour





Marketing research

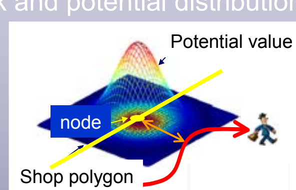


•Develop DB of attributes of the place
•Analysis on relationship between the shop's attributes and those of individuals

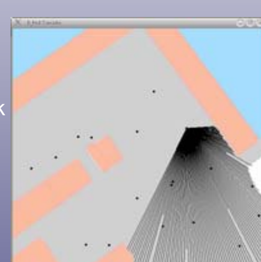
Future research

✓Improving the simulation system

- Combining network and potential distribution (walkability)

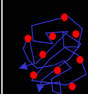
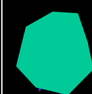
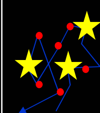
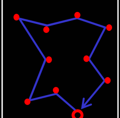
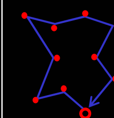
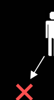


- Network analysis
  - •width of corridor, visibility, connection to other network



- Improve GA algorithm
- Implement "marketing" unit

Typology of shoppers

Type	Shop-till-you-drop consumer				middle	People who doesn't like to shop	
Category 1	Shop explorer			Repeat guest (Regular customer)		Buying motives YES	Buying motives NO
Category 2	Buying motives YES	Buying motives NO	Buying motives POTENTIAL		Shopping opportunity (Time)		
Proposed critical factor	Satisfaction	information	Visibility of potential purchases	Fixed route	Visibility of potential purchases	Spatial knowledge	
Route							
Behaviour pattern	Complex Time: long	Try to see whole area	Shortest path & Other factors	Shortest path Time: long	Deviate from prefixed route by visual stimulus	Shortest path Time: short	not go shopping

Thank you!

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http://www.casa.ucl.ac.uk/kay