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

http://www.casa.ucl.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
  - Retail movements
Contents

Research at CASA

Pedestrian behaviour modelling

An Integrated Simulation Model of Pedestrian Movements
-an application to retail behaviour-
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
  ✓ Retail movements
Contents

Research at CASA

Pedestrian behaviour modelling

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

An Integrated Simulation 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

Application to retail behaviour

Built environment agents

Geographic attributes
• Attraction level

Knowledge Needs

Pedestrian agents

Multi-agent-based model
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
- Surveys on Public Space
**Background: Pedestrian-oriented urban planning**

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

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
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)

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**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**

- Current position \((x, y)\)
- Velocity \((u, v)\)
- Radius \(r\)
- Normal walking speed \(V\)
- Destination \((p_x, p_y)\)
- Speed ratio \(k_i\)
- Space ratio \(c_i\)
- Information space \(d_i\)

↑ Estimation of the next steps of other pedestrians

← Collision avoidance behaviour

---

**Transport model**

- Area: \(S_1, S_2, \ldots, S_n\)
- Trips between \(S_i\) to \(S_j\): \(y_{ij}\)
- Distance between \(S_i\) to \(S_j\): \(d_{ij}\)

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

\[ y_i = \alpha \beta_i j \]

\(\alpha\) potential as origin
\(\beta_i\) potential as destination

Most evacuation models adopt this concept
Logit model  ---calculate probability of discrete choice

Consumer: C_1, C_2, ..., C_n
Shop: S_1, S_2, ..., S_n
Attribute k of shop S_j: A_{jk}
Probability of C_i choosing S_j: p_{ij}
Distance between C_i and S_j: d_{ij}

Parameter estimation by maximum-likelihood method

Stochastic model

Marcov chain model

<table>
<thead>
<tr>
<th>Home</th>
<th>A</th>
<th>B</th>
<th>H</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0.6</td>
<td>0.4</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>0</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>H</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

- Probability of visiting from one place to another
- The observed number of people at their first destination
- Probability of being the last destination

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

\[ RE = F_{t1}P_{t1} + F_{t2}P_{t2}^2 + \cdots = F_{t1}P_{t1}(I - P_{t1})^{-1} \]
### Requirements of pedestrian behavior models

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔ Crowd dynamics</td>
<td>• Well represent micro-scale physical response</td>
</tr>
<tr>
<td>• Dynamic</td>
<td>• Dynamic</td>
</tr>
<tr>
<td>• Not take it into account:</td>
<td>• Where they are going to and why</td>
</tr>
<tr>
<td>• Pre-fixed route = static model</td>
<td>• Geographical attributes</td>
</tr>
<tr>
<td>✔ Transport model</td>
<td>• Suitable for description of selection behavior</td>
</tr>
<tr>
<td>• Several things can’t be represented:</td>
<td>• Interaction between others/environment</td>
</tr>
<tr>
<td>• Cognitive process of pedestrian</td>
<td>• Inadequate to small scale movement</td>
</tr>
<tr>
<td>✔ Stochastic model</td>
<td>• Useless for being briefed on how people move around</td>
</tr>
<tr>
<td>• Capability of representing changeability of movements</td>
<td>• Not explain why they choose certain place</td>
</tr>
</tbody>
</table>

#### New pedestrian behaviour models are needed

- Understand and explain real pedestrian’s movement
- Represent dynamic interaction process between pedestrians and their environment

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### Background

- Requirements of pedestrian behavior 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

(t, x, y, z)

Visualization

Observed trajectory
An Integrated Simulation Model

Application to retail behaviour

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

Multi-agent-based model

Built environment agents
- Geographic attributes
- Attraction level

Knowledge Needs

Pedestrian agents

Interaction between environment

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Calculation of the optimum route

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Marketing
Methodology

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

Marketing

Route choice

Stimuli-response

Probability to be chosen as destination

Attraction surface

Shop attributes
- Target: 20s – 40s Male
- Average price: 150 pounds
- Floor space
- Bland image:
  - Urban
  - Sophisticated
  - Neat
  - Simple

Shopper A’s attributes
- Male
- Age: 32
- Car ownership
- Subscribing magazines
### Attraction surface (matrix) for each shopper

<table>
<thead>
<tr>
<th>Shopper</th>
<th>Marks &amp; Spencer</th>
<th>Joseph</th>
<th>Boots</th>
<th>Monsoon</th>
<th>HMV</th>
<th>Dickson</th>
<th>Sony store</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopper A</td>
<td>90%</td>
<td>43%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shopper B</td>
<td>30%</td>
<td>1%</td>
<td>22%</td>
<td>69%</td>
<td>0%</td>
<td>31%</td>
<td>5%</td>
</tr>
<tr>
<td>Shopper C</td>
<td>60%</td>
<td>90%</td>
<td>14%</td>
<td>0%</td>
<td>12%</td>
<td>82%</td>
<td>70%</td>
</tr>
<tr>
<td>Shopper D</td>
<td>12%</td>
<td>90%</td>
<td>69%</td>
<td>0%</td>
<td>12%</td>
<td>82%</td>
<td>70%</td>
</tr>
<tr>
<td>Shopper E</td>
<td>4%</td>
<td>82%</td>
<td>40%</td>
<td>14%</td>
<td>90%</td>
<td>82%</td>
<td>14%</td>
</tr>
</tbody>
</table>

### Methodology

#### Survey of basic walking patterns

- **Stimuli-response**
- **Route choice**
- **Marketing**

#### Research on route-choice behaviour

- **DESTINATION**
- **Route A**
- **Route B**
- **Route C**

#### 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?
## Typology of shoppers

<table>
<thead>
<tr>
<th>Type</th>
<th>Shop-till-you-drop consumer</th>
<th>middle</th>
<th>People who doesn’t like to shop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Shop explorer</td>
<td>Repeat guest (Regular customer)</td>
<td>Buying motives YES</td>
</tr>
<tr>
<td>Category 2</td>
<td></td>
<td>Fixed route</td>
<td>Shopping opportunity (Time)</td>
</tr>
<tr>
<td>Proposed critical factor</td>
<td></td>
<td>Deviate from prefixed route by visual stimulus</td>
<td>Spatial knowledge</td>
</tr>
<tr>
<td>Route</td>
<td></td>
<td>Shortest path</td>
<td>Potential knowledge</td>
</tr>
<tr>
<td>Behaviour pattern</td>
<td></td>
<td>Shortest path</td>
<td>Shortest path</td>
</tr>
<tr>
<td></td>
<td>Complex</td>
<td>Time: long</td>
<td>Time: short</td>
</tr>
<tr>
<td></td>
<td>Time: long</td>
<td>Try to see whole area</td>
<td>not go shopping</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shortest path &amp; Other factors</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Time: long</td>
<td></td>
</tr>
</tbody>
</table>

### Test simulation using GA

**Floor plans/ networks of the shopping centre**
- 326 nodes (shops, centre points of corridor-every 10m)
- 364 links (corridor)

**Time resolution=30 seconds**

- Time
  - 0 1 2 3 4 5 ...
  - chromosome
- shop
- network
- trajectory
Check the validity of the shortest path model

Test simulation using GA

Evaluation criteria

- 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

\[ \max V = \sum_{i=1}^{N} \alpha_i X_i \]

\( \alpha \) Parameter
\( X \) Evaluation function for criterion
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

Evaluated value:
- Simulation 1: Estimated route 100 Observed route 107
- Simulation 2: Estimated route 99.5 Observed route 107
- Given the real route: Estimated route 108.8 Observed route 107

Distance between 2 routes:
- Simulation 1: 68.8m
- Simulation 2: 52.4m
- Given the real route: 1.25m
Findings

Shortest path model

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

Methodology

Survey of basic walking patterns

• Trajectory → walking patterns

Research on route-choice behaviour

Route A
Route B
Route C

Marketing research

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

- Laser scanner
- Video image analyses
- Cell-based (PHS, RFID)
- Pseudolite
- Autonomous positioning

Available area:
- Indoor
- High-density urban areas
- Low-density urban areas
- Open space

Accuracy:
5mm 1cm 10cm 1m 10m 100m

Indoor

RTK-GPS

GPS

Horizontal laser scanning at 20cm height on the floor.
Survey on pedestrian movement in a railway station

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

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
Walking speed

<table>
<thead>
<tr>
<th>Walking speed (m/sec)</th>
<th>Tanaboriboon</th>
<th>Fruin</th>
<th>Navin and Wheeler</th>
<th>Laser data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>Male</td>
<td>Female</td>
<td>General</td>
<td>General</td>
</tr>
<tr>
<td></td>
<td>1.32</td>
<td>1.15</td>
<td>1.23</td>
<td>1.33</td>
</tr>
<tr>
<td>SD</td>
<td>0.20</td>
<td>0.18</td>
<td>0.20</td>
<td>–</td>
</tr>
<tr>
<td>Max</td>
<td>2.05</td>
<td>1.68</td>
<td>2.05</td>
<td>–</td>
</tr>
<tr>
<td>Min</td>
<td>0.73</td>
<td>0.63</td>
<td>0.63</td>
<td>–</td>
</tr>
</tbody>
</table>

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

Trajectory 0

<table>
<thead>
<tr>
<th>x1</th>
<th>y1</th>
</tr>
</thead>
</table>
| 32622213 | 1.120
| 32622313 | 1.095
| 32622403 | 1.053
| 32622503 | 1.096
| 32622603 | 1.053
| 32622693 | 0.952
| 32622794 | 0.656
| 32623274 | 0.255
| 32624755 | 0.273
| 32623655 | 0.220
| 32623765 | 0.101
| 32624855 | 0.110
| 32624945 | 0.520
| 32624338 | 0.492
| 32624446 | 0.601
| 32624536 | 0.764
| 32624628 | 0.962
| 32624728 | 0.982
| 32624917 | 1.109

Trajectory 1

<table>
<thead>
<tr>
<th>x1</th>
<th>y1</th>
</tr>
</thead>
</table>
| 32625017 | 0.279
| 32625207 | 0.220
| 32625307 | 0.101

CASA Centre for Advanced Spatial Analysis
Obstacle avoidance behaviour

Relative distance (m)

Relative speed (m/s)

Obstacle avoidance behaviour

Ped A

Ped B
Survey of basic walking patterns

- Trajectory → walking patterns

Research on route-choice behaviour

Route A → Route B → Route C → DESTINATION

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
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</tr>
<tr>
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<td>Shopping opportunity (Time)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visibility of potential purchases</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spatial knowledge</td>
<td></td>
<td></td>
</tr>
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<td>shortest path</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
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<td></td>
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