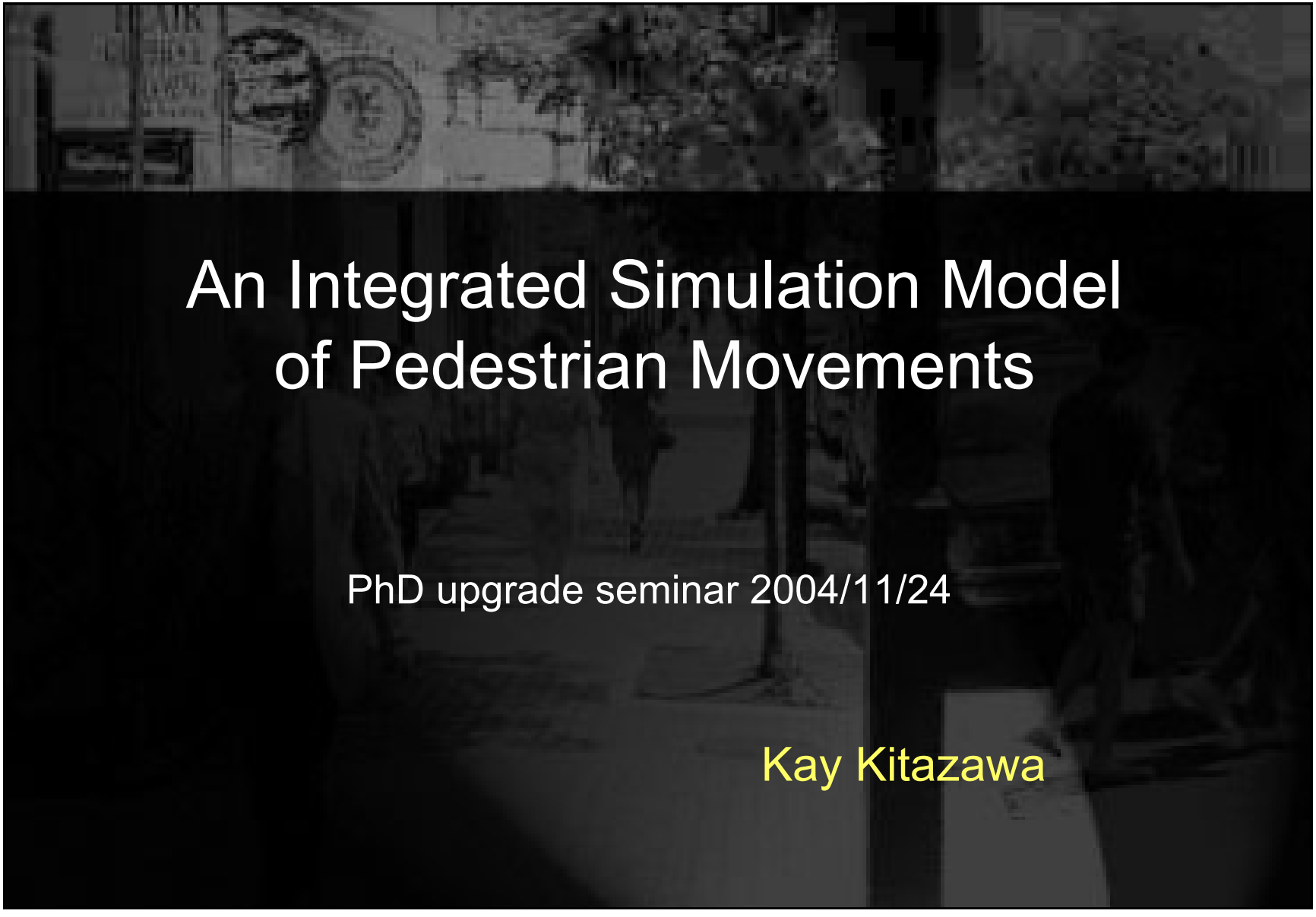

An Integrated Simulation Model of Pedestrian Movements

PhD upgrade seminar 2004/11/24

Kay Kitazawa

Contents

Background

Requirements of pedestrian behaviour models

Review on current models

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Framework of the model

Methodologies

project progress

future plan

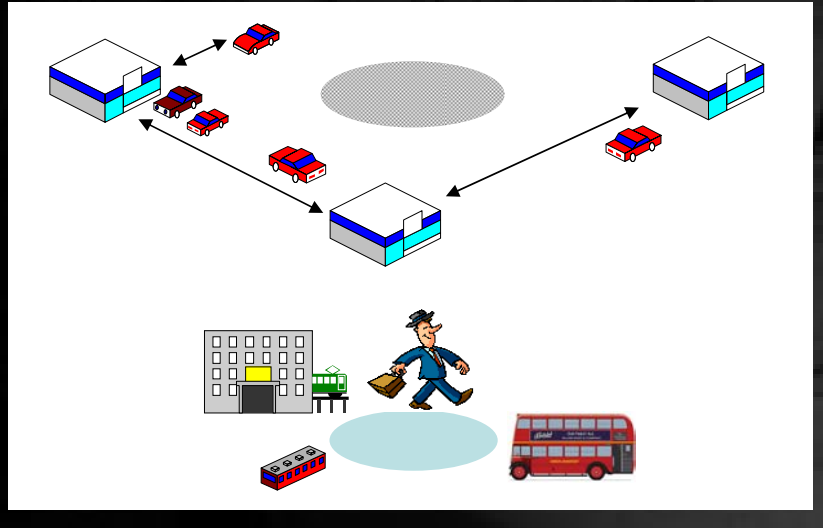
Background

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

Background

- Urban planning

Not-compact city



Compact city

Lively town centres

Pedestrian-oriented planning

Pedestrian-Oriented 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

(TfL report)

Pedestrian-Oriented Planning

- How is the space used?
- 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

(TfL report)

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

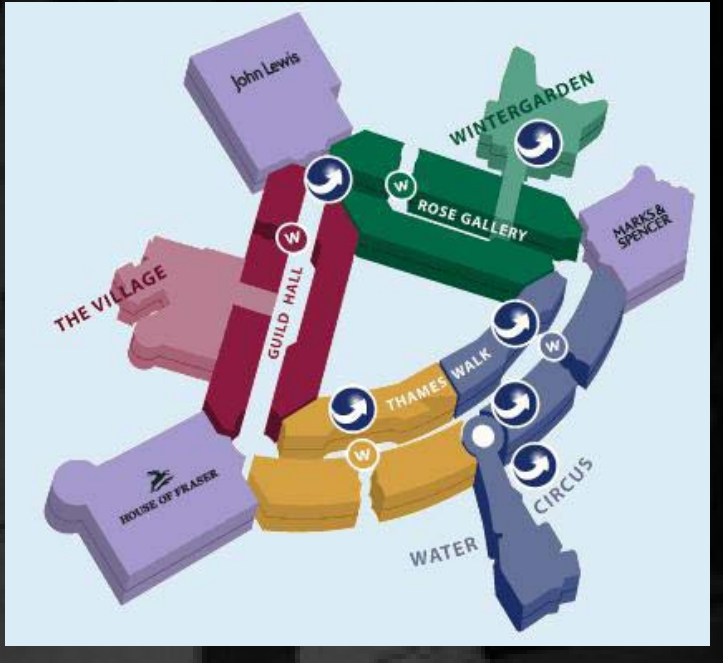
Spatial Marketing

- Marketing levels

Exit Surveys (counting, questionnaire)

3.Passing trade
4.Peel-off rate
5.Browsing
6.Conversion

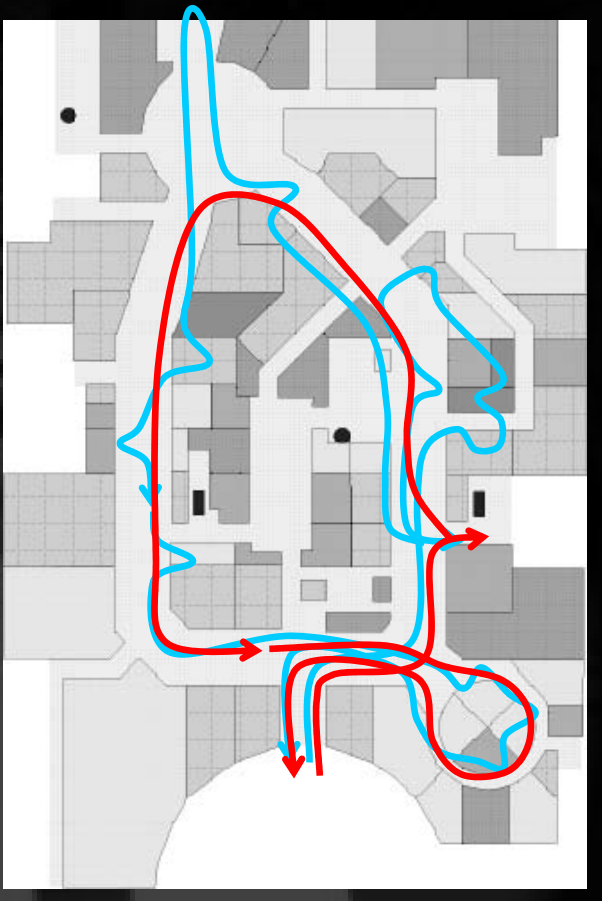
Observation by shop clerks
POS data



Bluewater shopping mall

Spatial Marketing

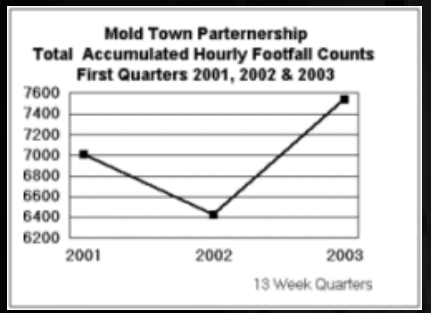
- Passing trade
- Peel-off rate
- Route



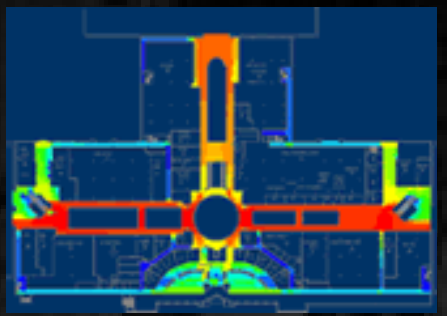
✓Tenant strategy (leasing, fee)

✓Improvement of -floor plans
-signage system

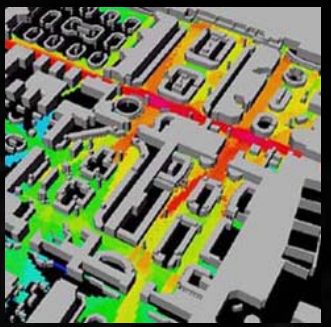
Spatial Marketing



FootFall



Intelligent Space



Space Syntax

CCTV

Manual counting

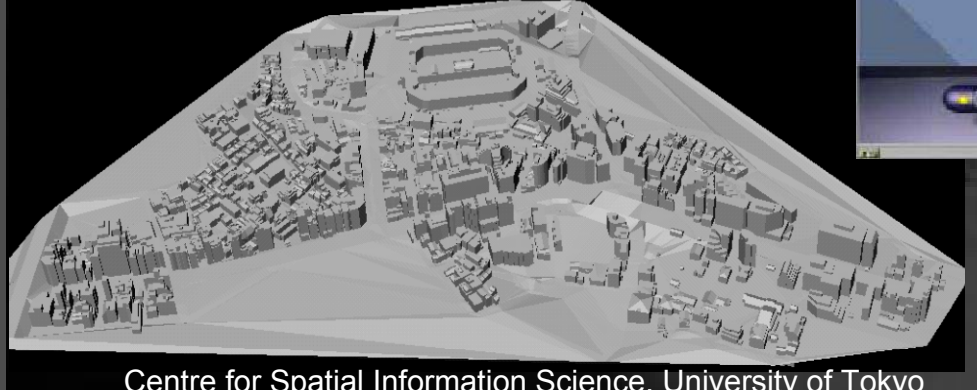
Individual level
Trajectory (route)

Needs for Pedestrian behaviour model

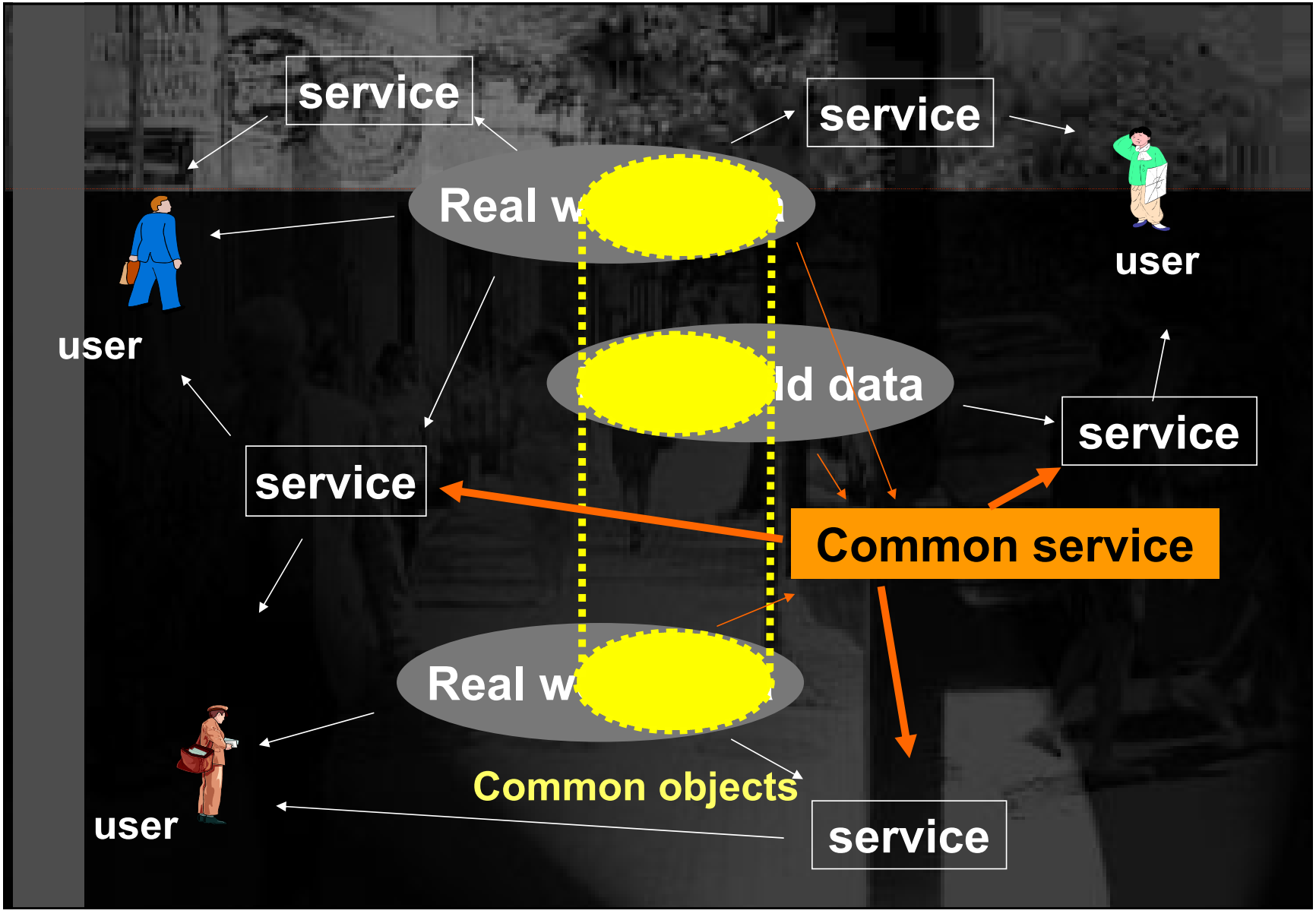
Digital City

Planet9

Bath city



Centre for Spatial Information Science, University of Tokyo


service
service
Real w
user
user
ld data
service
service
Common service
Real w
Common objects
user
service

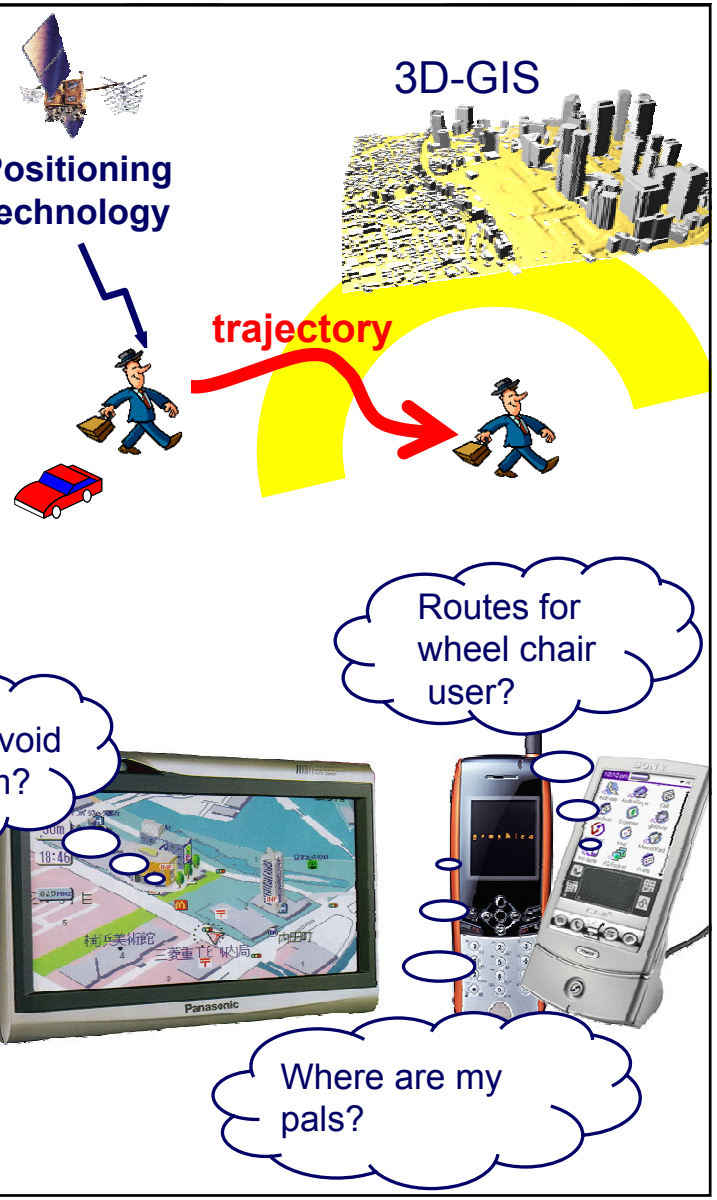
Background

- Location-based services

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)

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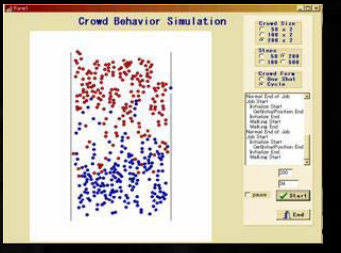
Review on current pedestrian behavior models

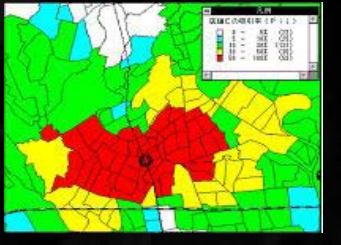
✓Crowd dynamics

Micro scale behaviour (e.g. obstacle avoidance)



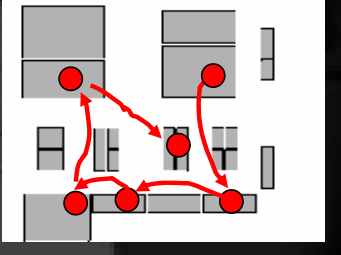
✓Transport model

Network analysis and OD/route estimation

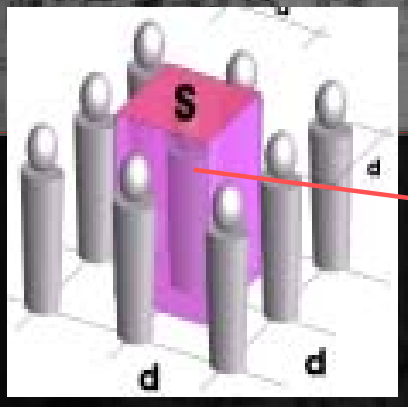


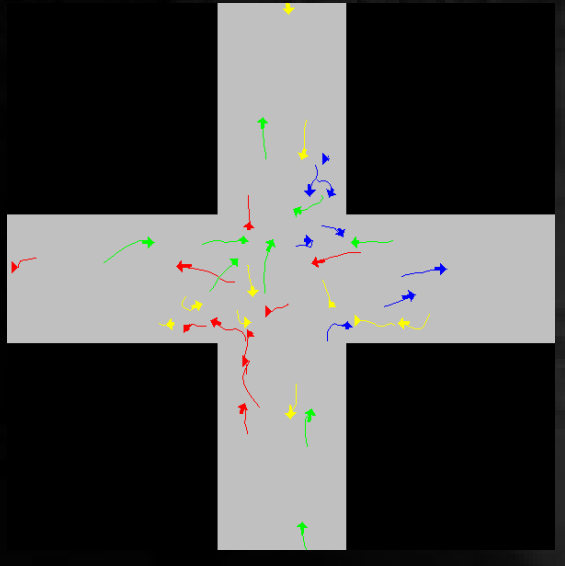
✓Stochastic model

Probability of state-to-state transition

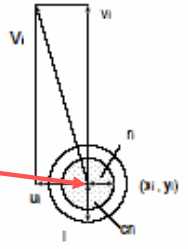


Crowd dynamics

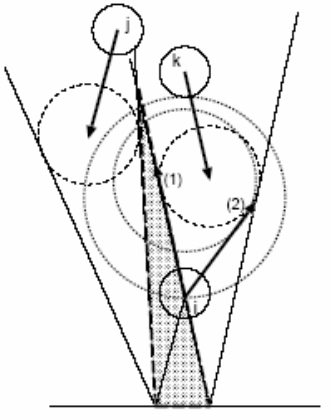


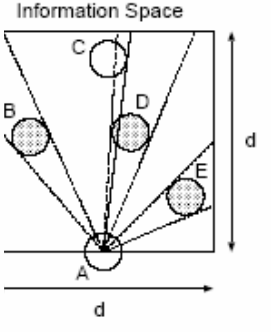


(Kai Bolay)



Current position (x_i, y_i)
Velocity (u_i, v_i)
Radius r_i
Normal walking speed V_i
Destination (p_{xi}, p_{yi}) (q_{xi}, q_{yi})
speed ratio k_i
Personal space ratio c_i
Information space (d_i, d_i^t)



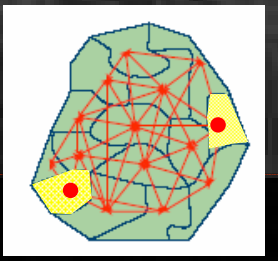


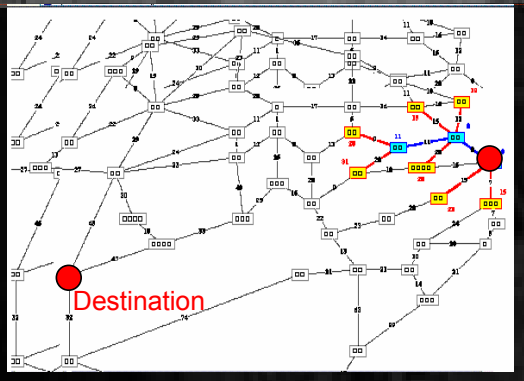
↑ Estimation of the next steps of other pedestrians

← Collision avoidance bahaviour

Transport model

Area: S_1, S_2…S_n
Trips between S_i to S_j : y_{ij}
Distance between S_i to S_j : d_{ij}

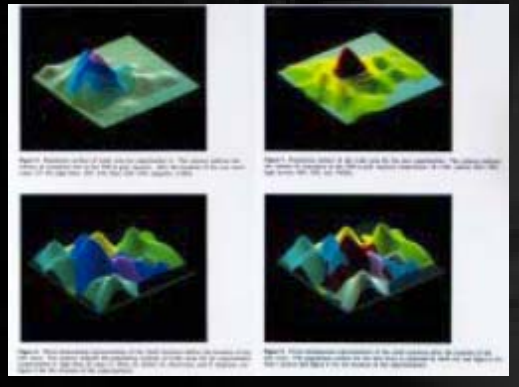




Shortest path between OD

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

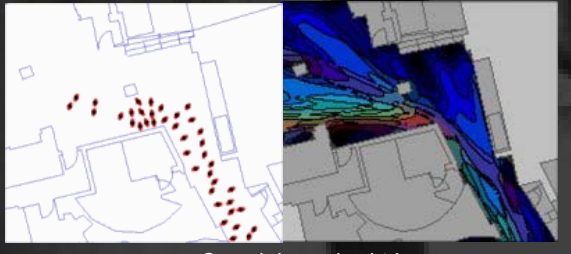
- Influence of other areas?
- Which area generates more trips than others?
- Why?



Gravity model

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

α_i potential as origin
β_j potential as destination



Most evacuation models adopt this concept

Crowd dynamics Ltd

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,….C_n

Shop: S_1, S_2,….S_n

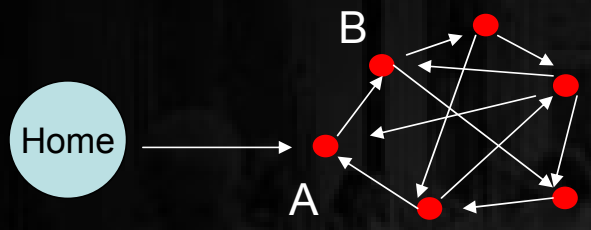
Attribute *k* of shop S_j: A_{jk}

Probability of C_i choosing S_j: p_{ij}

Distance between Ci and Sj: d_{ij}

parameter estimation by
maximum-likelihood method

Stochastic model



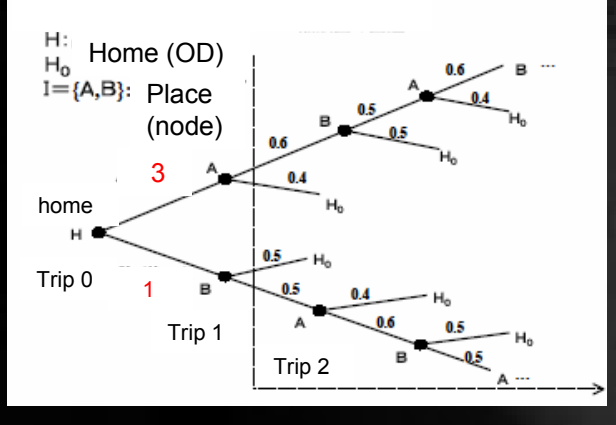
Marcov chain model

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

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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

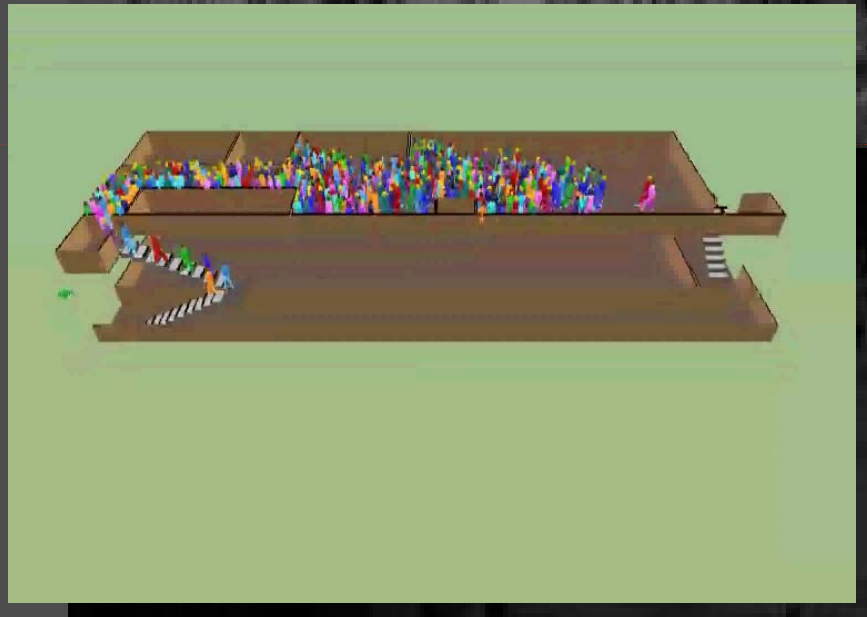
  To deal with not only pre-determined route-choice
  but also people's cognitive process or other changeable events

- ✓Easy-to-understand interface

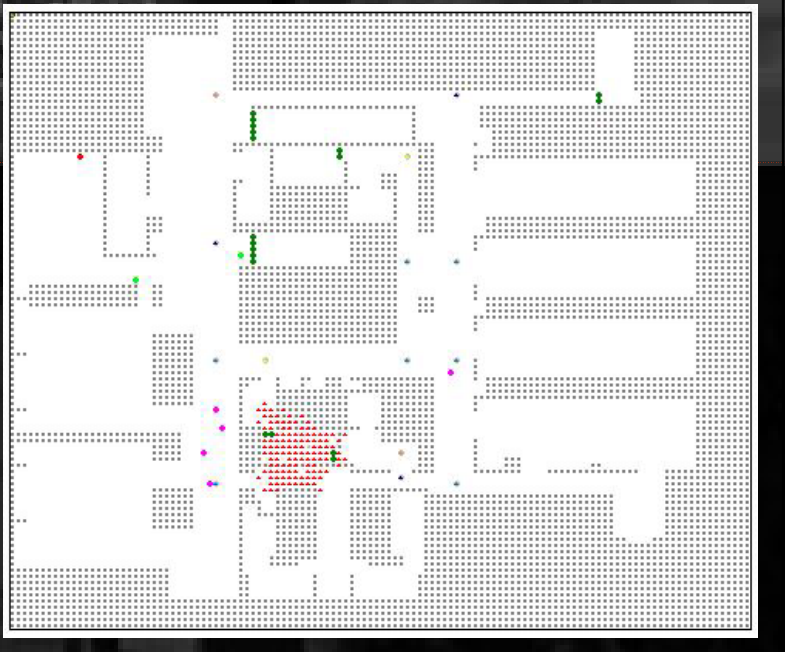
  visualization, To make the model more transferable

- ✓be validated through comparison between actual trajectories

  It should be different from playing with beautiful animation



EXODUS



Both are using same behaviour rules


Behavior model
(simulation)
+
Visualization

Research Aim and Objectives

Pedestrians' attributes

Space/Buildings' attributes

Behavior model (simulation)

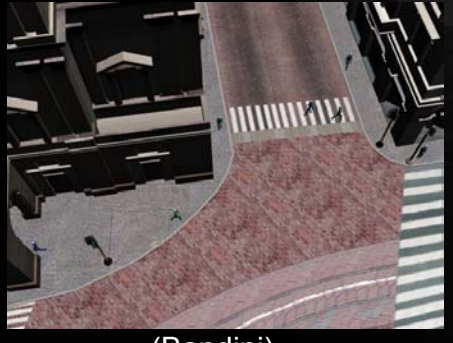
OUTPUT

Each pedestrian's trajectory

(t, x, y, z)

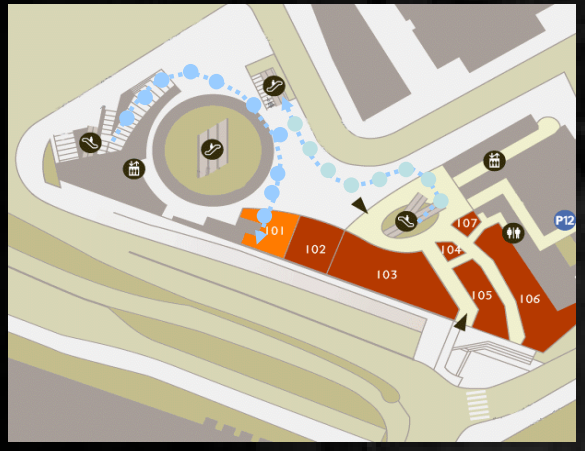
Observed trajectory

Visualization



(Bandini)

Framework of the model

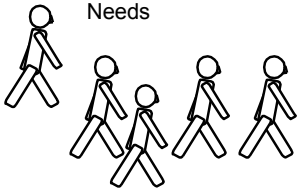


Integrated Simulation Model
of Pedestrian Movements

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

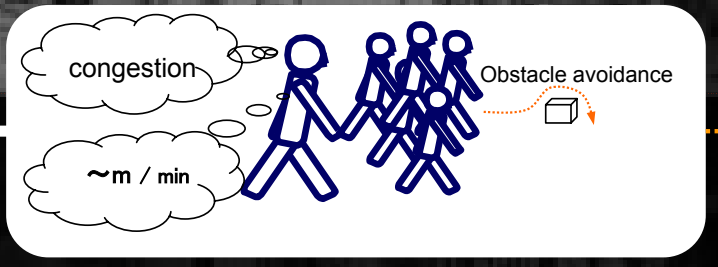
Matching between people's preference/needs and attributes of places

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

Marketing

Framework of the model

3 levels of pedestrian's behavior

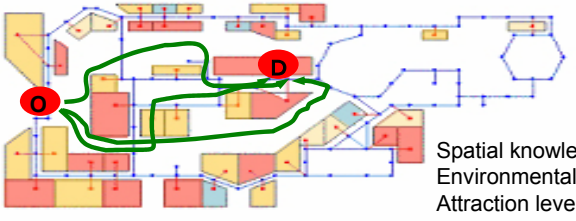


Stimuli-Response

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

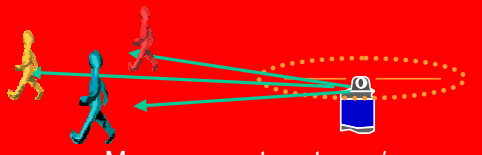
Attributes
Preference
Needs
Restriction

marketing

Methodology

Stimuli-response

Survey of basic walking patterns



Measurement systems / sensors

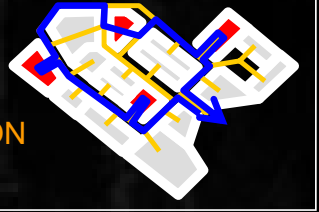
•**Trajectory → walking patterns**

Route choice

Research on route-choice behaviour

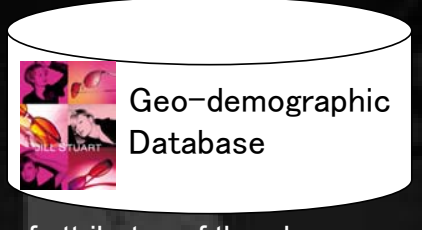
Route A
Route B
Route C

DESTINATION



Marketing

Marketing research



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

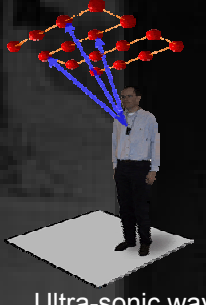
Current positioning technologies

- ✓GPS-based technology
- ✓Cell-based technology
- ✓Image processing
- ✓Autonomous-positioning
- ✓Laser scanning
- ✓Ultra-sonic wave
- ✓Traffic counter

GPS

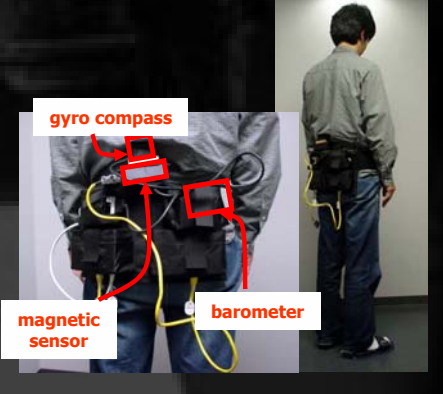
RFID tag

Thermal infrared



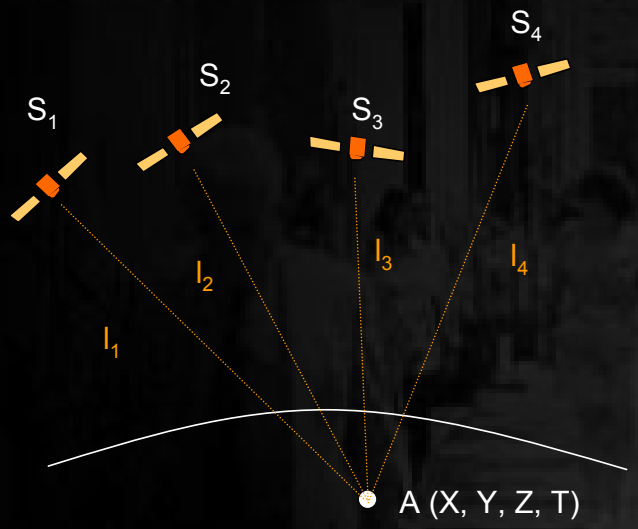
Ultra-sonic wave

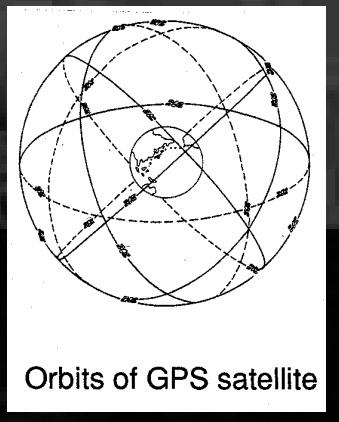
Laser scanning



Autonomous positioning system

GPS-based technology




Orbits of GPS satellite

GPS satellite positions

$(x_i, y_i, z_i. t_i)$ i =1..4

$(X-x_i)^2 + (Y- y_i)^2 + (Z-z_i)^2 = l_i^2$

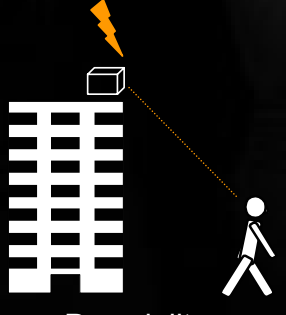
$= C^2 * (T- ti)^2$ → (X, Y, Z, T)

✓Requirement

Signals from at least 4 different satellites

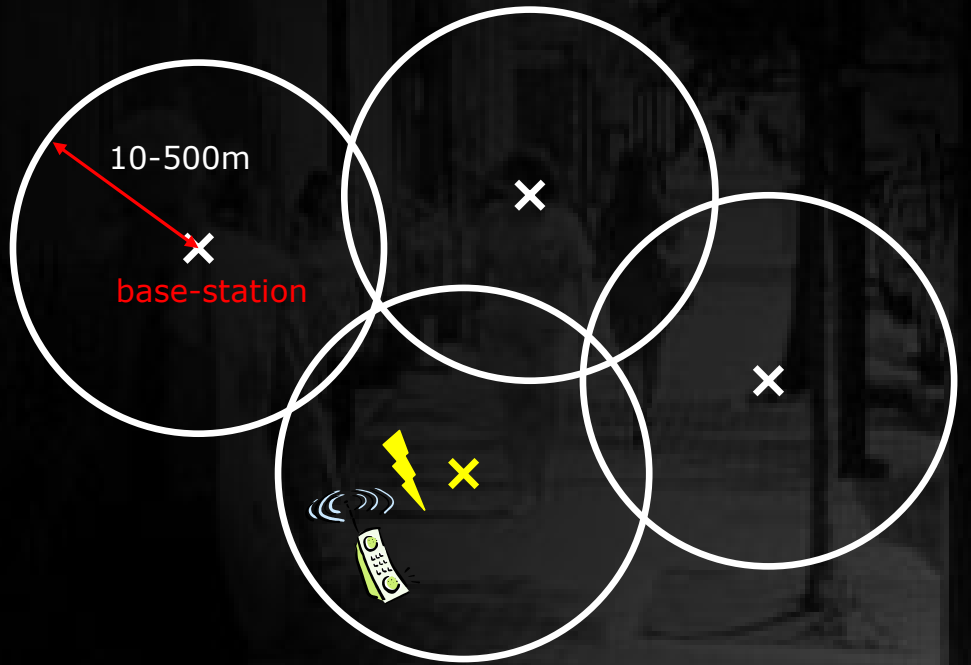
✓Lots of complementary technologies

DGPS	Improve the accuracy by FM radio wave	0.3m-10m
RTK-GPS	Receive the same GPS signal at a reference points & mobile receiver	1-10cm
Pseudolite	Set transmitters which emit signal similar to that of GPS	6-30cm
SnapTrack	Mobile GPS receiver and server	10-100m
Indoor GPS	High-reception receiver	10-100m
GPS one	Combination of GPS and cellular system	10-500m


Pseudolite

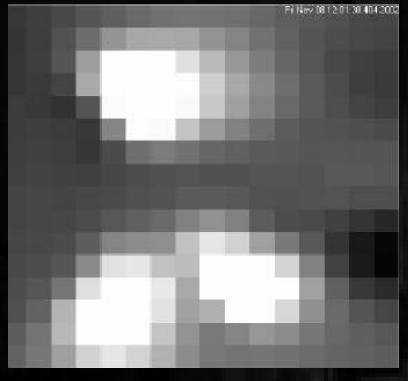
GPS receiver

Cell-based positioning



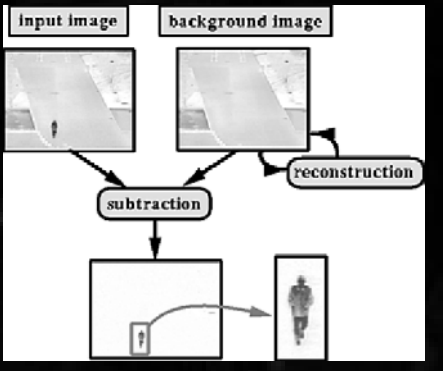
- ✓Cellular phone
- ✓PHS
- ✓RFID Tag
- ✓Beacon (GI Stone)

Image processing



Infra-red image
Thermal infrared image

Video image



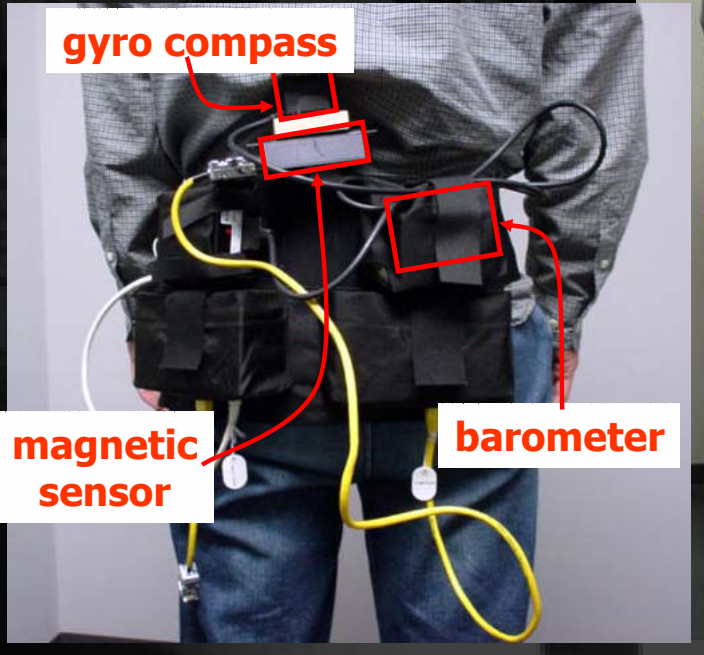
Detect and track characteristic points

sensors

Gyro compass

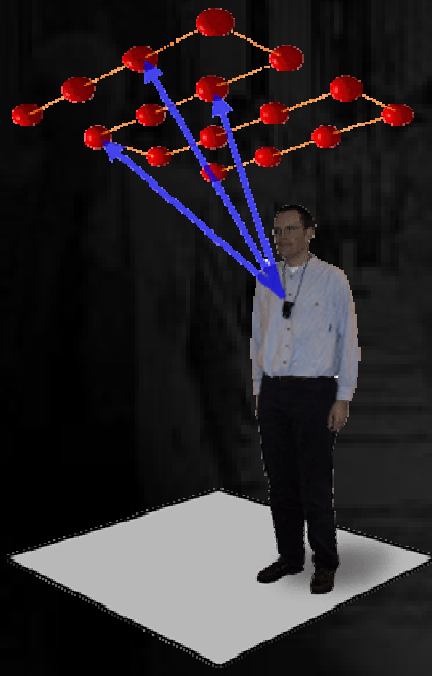
Magnetic sensor

barometer

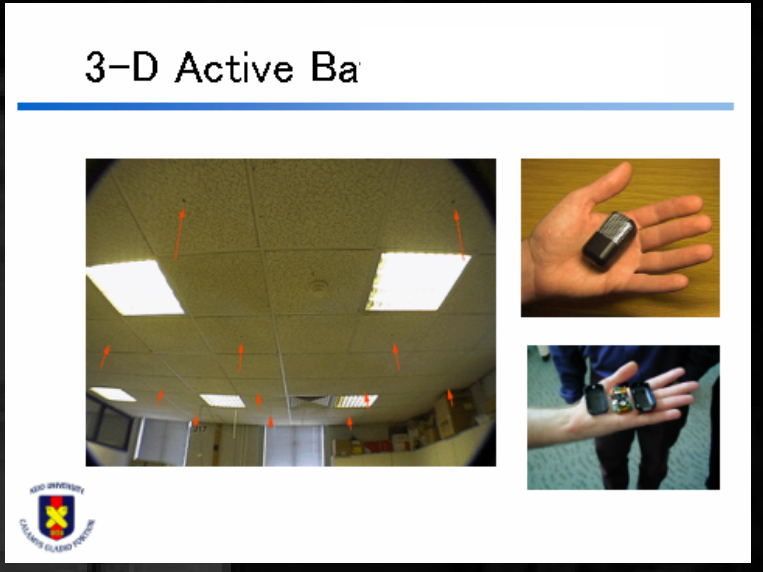


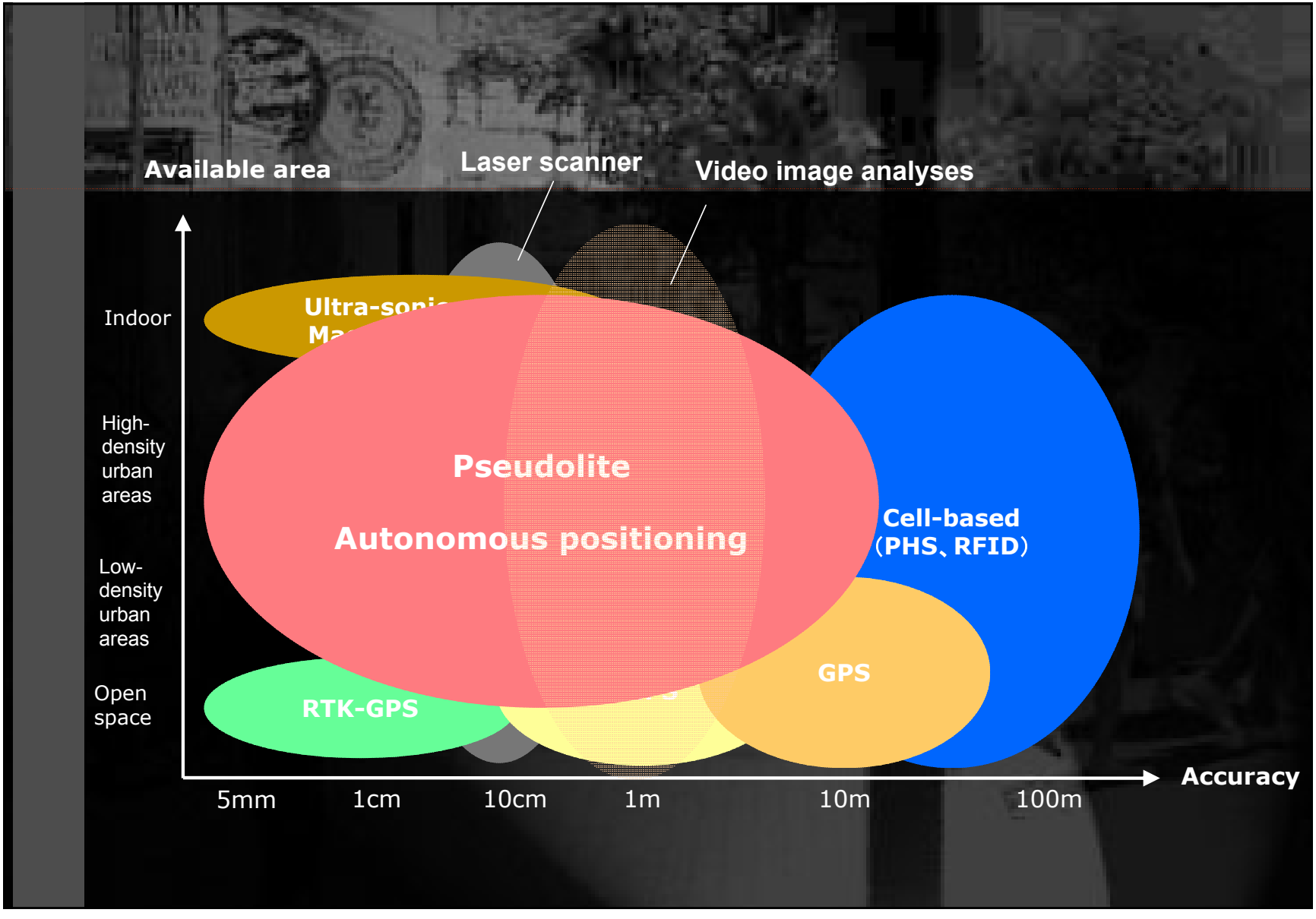
Ultra-sonic wave

trilateration measurement of distances from 3 points



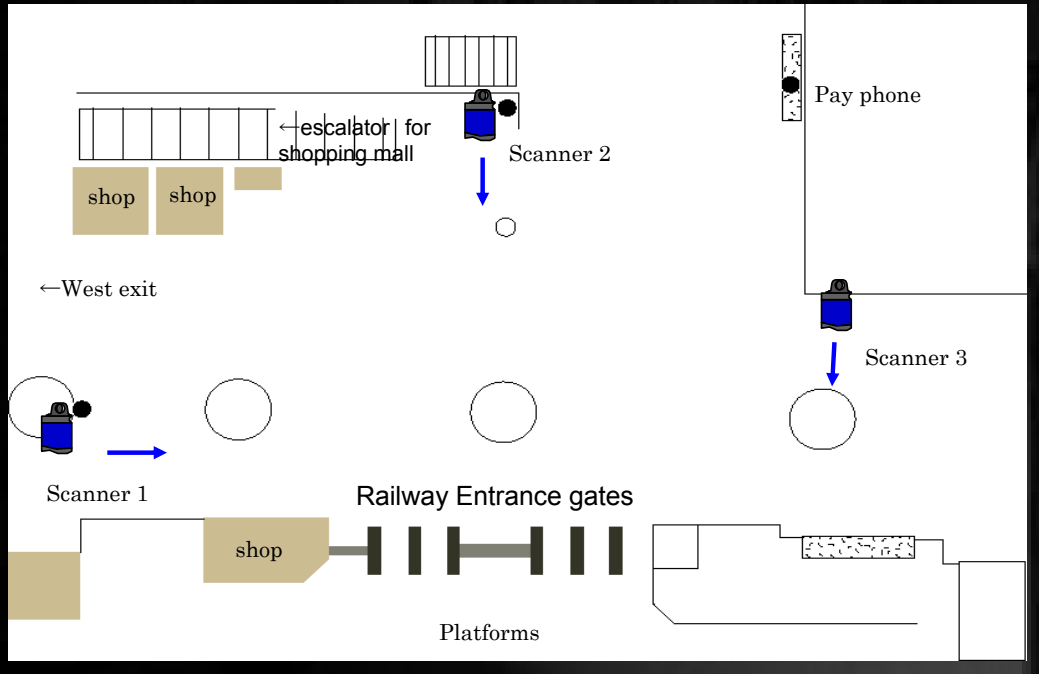
AT&T Laboratories Cambridge



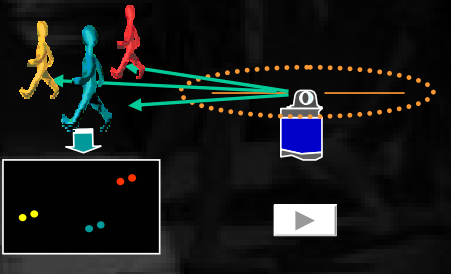

Available area
Laser scanner
Video image analyses
Indoor
High-density urban areas
Low-density urban areas
Open space
Ultra-soni
Ma
Pseudolite
Autonomous positioning
Cell-based
(PHS、RFID)
GPS
RTK-GPS
Accuracy
5mm
1cm
10cm
1m
10m
100m

Survey on pedestrian movement in a railway station

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

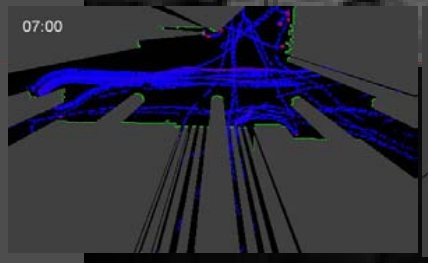


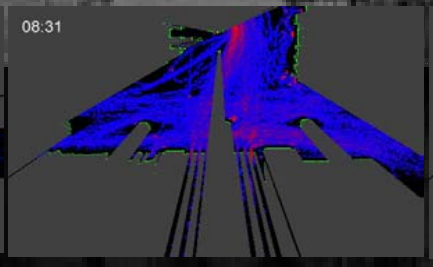
Laser scanner
LD-A *Maker:* IBEO Lasertechnik、SICK 291
（10Hz、1080 points/270°、maximum reach 70m）

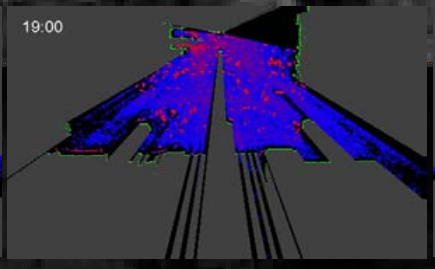


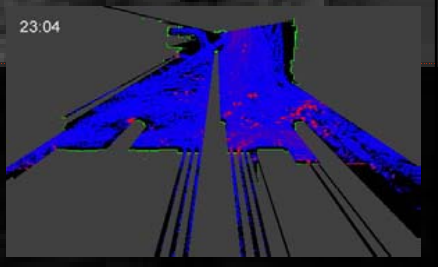
Routes = consecutive series of coordinates(ID,t,x,y)

Analysis on basic walking patterns

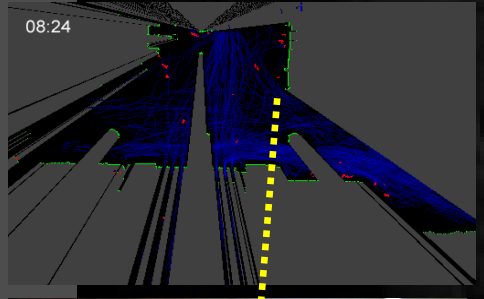


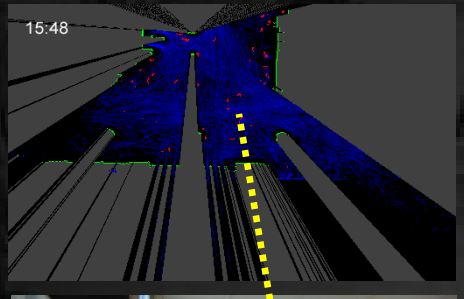


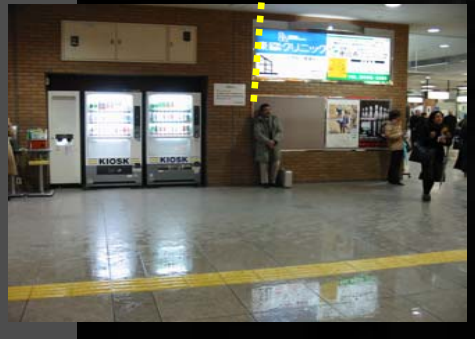


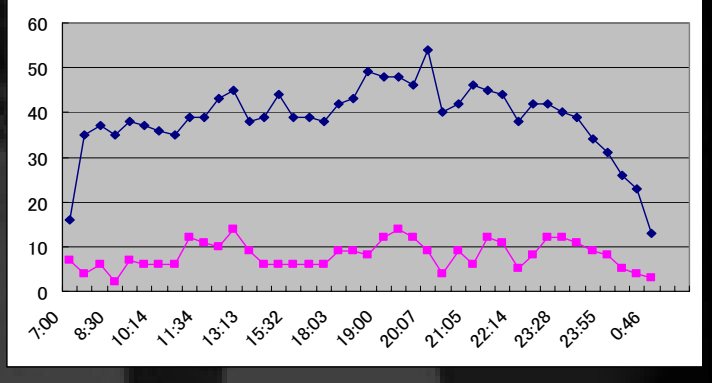


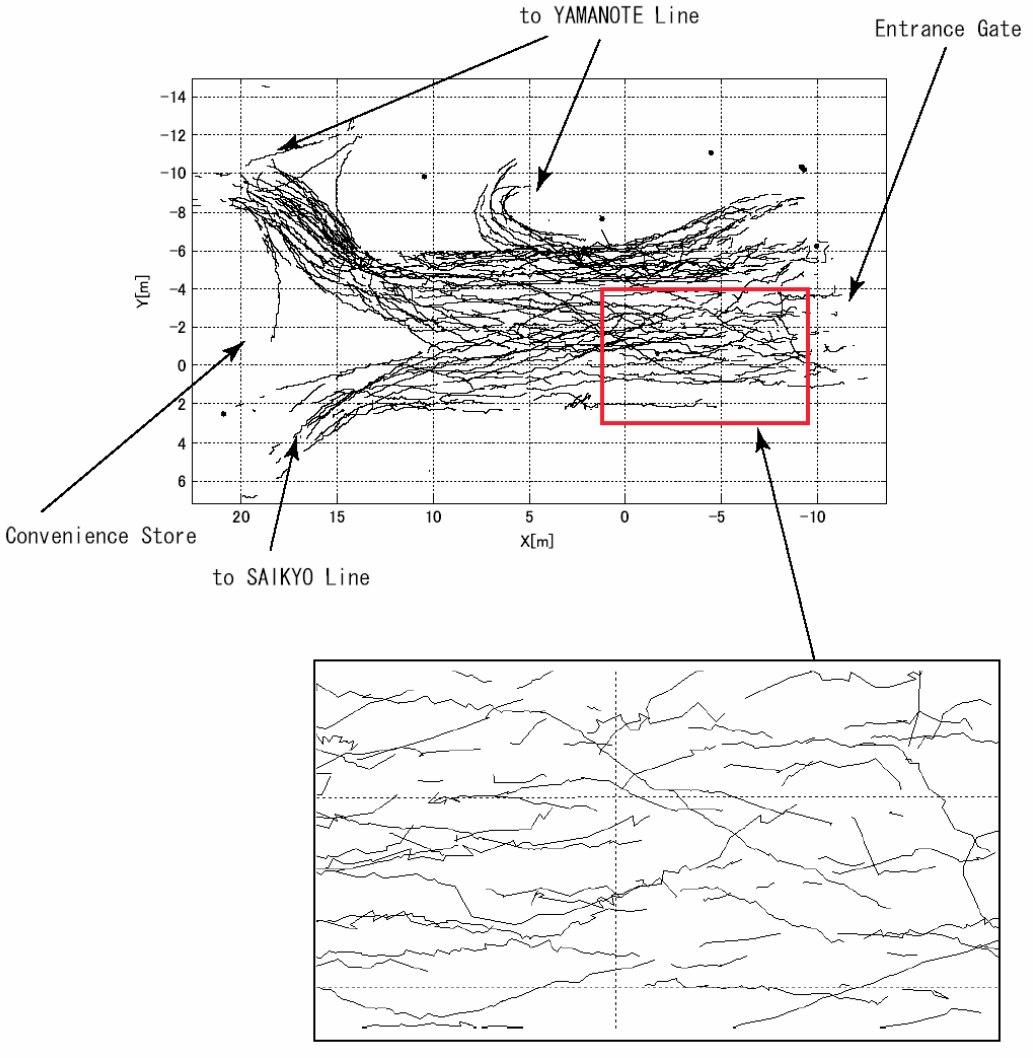
Time series behavior of peds who stay at the same place more than 5 minutes









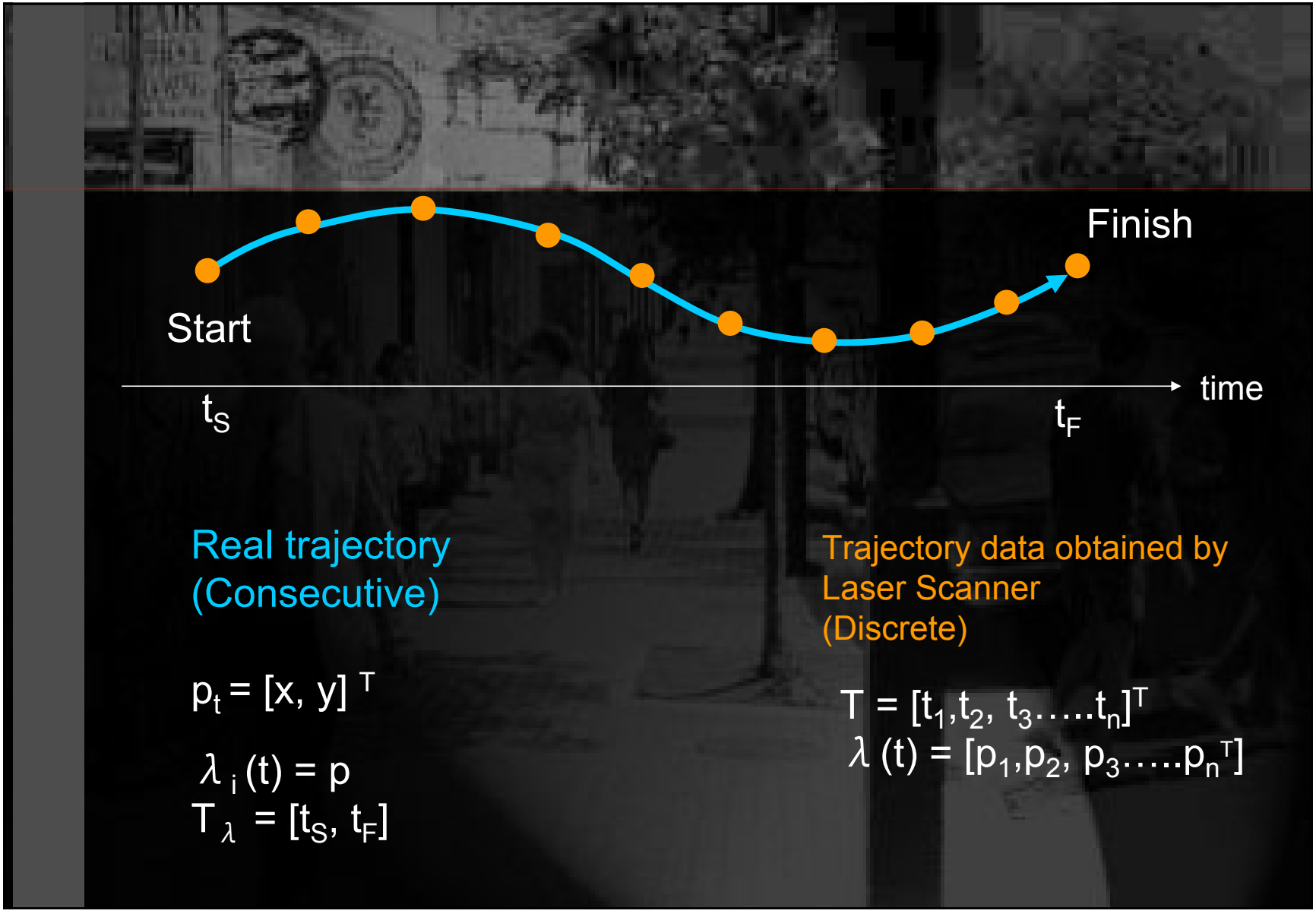


Trajectory 0

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
32625498	x1=-0.100	y1=1.774
32625688	x1=0.520	y1=1.612



Real trajectory
(Consecutive)

$p_t = [x, y]^T$

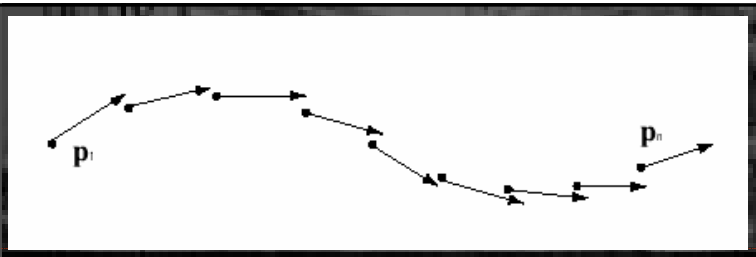
$\lambda_i(t) = p$

$T_\lambda = [t_S, t_F]$

Trajectory data obtained by
Laser Scanner
(Discrete)

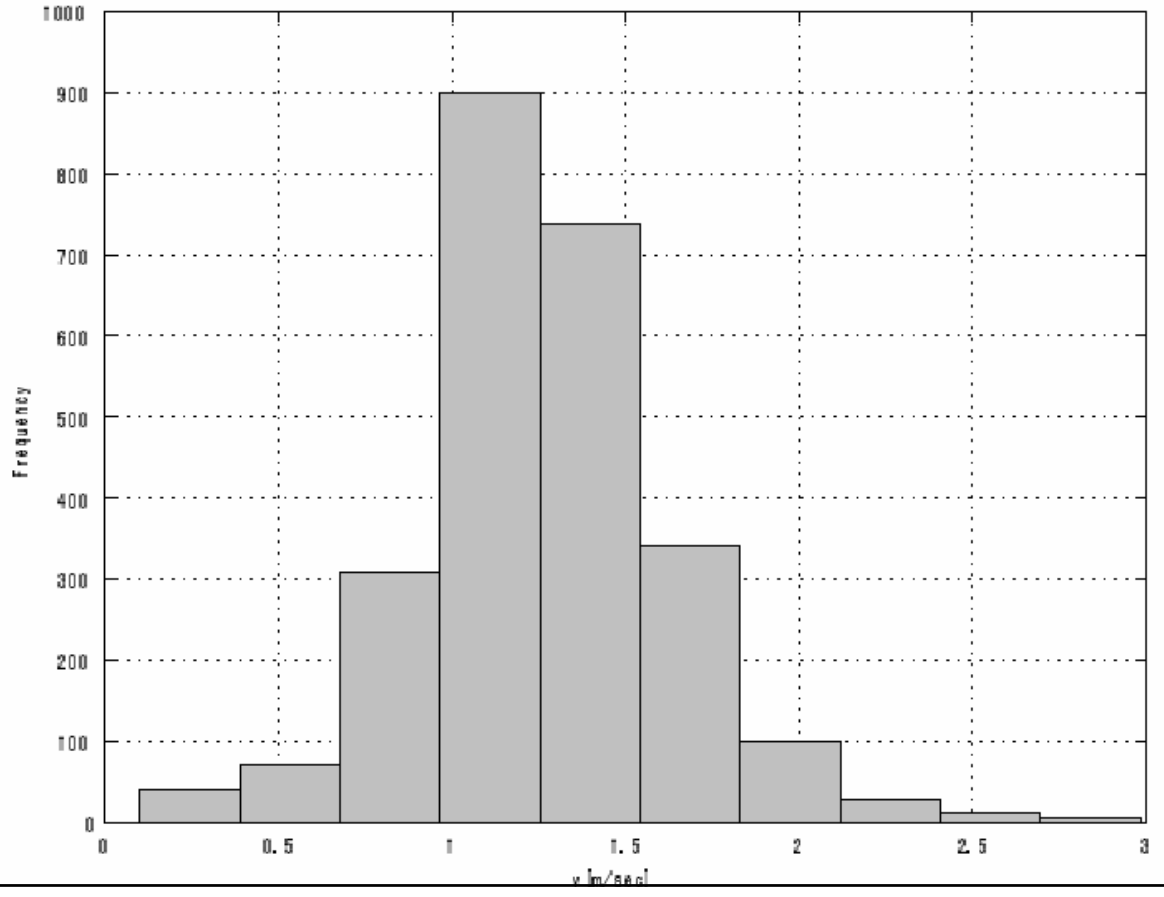
$T = [t_1, t_2, t_3 \ldots . t_n]^T$

$\lambda(t) = [p_1, p_2, p_3 \ldots . p_n{}^T]$



Around 17:20 (30 seconds)
Density < 0.2 person/m^2

Walking speed

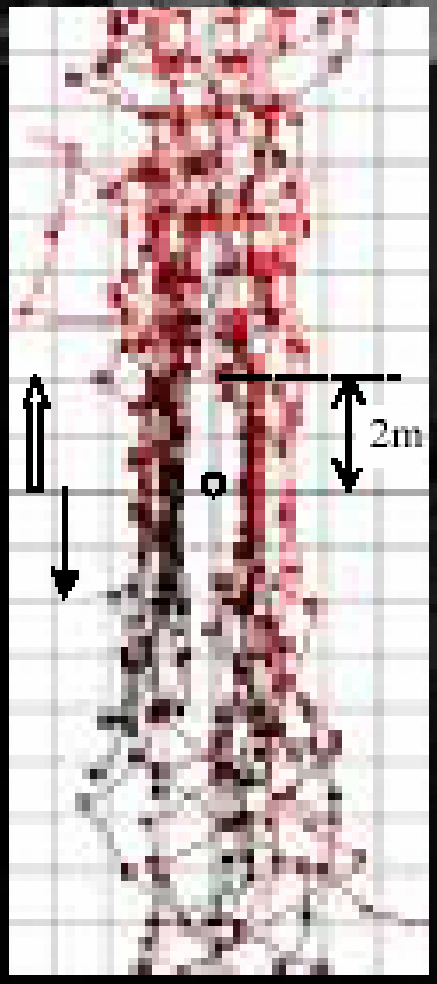


Walking speed

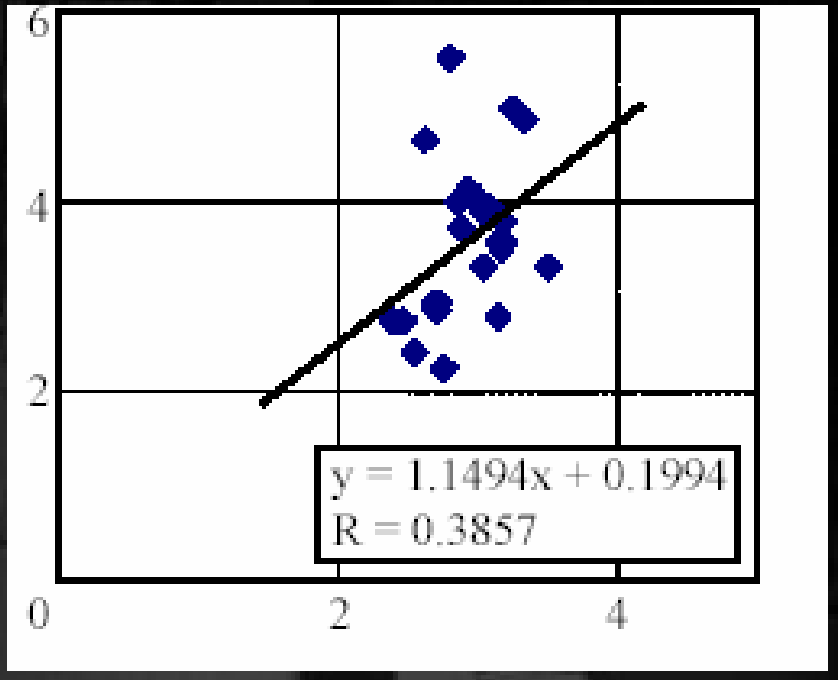
(m/sec)	Tanaboriboon			Fruin	Navin and Wheeler	Laser data
Walking speed	Male	Female	General	General	General	General
Average	1.32	1.15	1.23	1.33	1.31	1.27
SD	0.20	0.18	0.20	–	–	0.36
Max	2.05	1.68	2.05	–	–	2.98
Min	0.73	0.63	0.63	–	–	0.10

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

Obstacle avoidance behaviour



Relative distance (m)



Relative speed (m/s)

Methodology

Stimuli-response

Survey of basic walking patterns

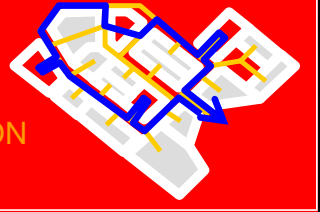
Measurement systems / sensors

•**Trajectory → walking patterns**

Route choice

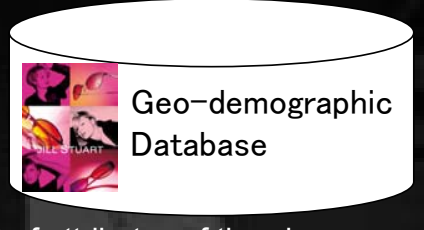
Research on route-choice behaviour

Route A
Route B
Route C
DESTINATION



Marketing

Marketing research



•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

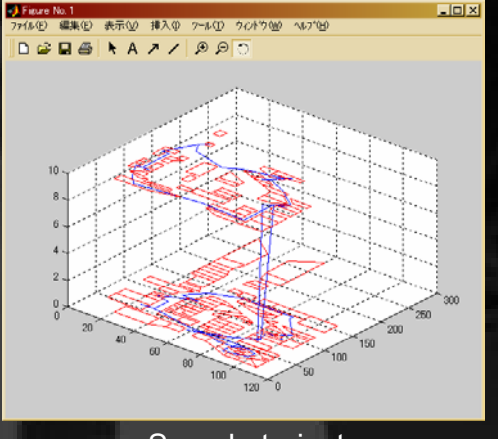
  18 samples (female, 20 year-old)
  2 hours shopping * 3 times

- Analysis on influential factors on shopper's route choice

  - ✓Knowledge about the place
  - ✓Time constraints
  - ✓Preferences

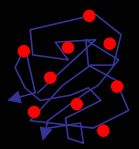
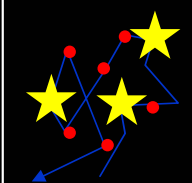
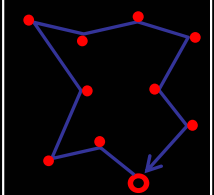
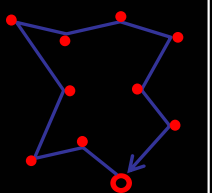
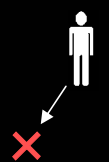
  Shop-till-you-drop consumer?
  People who doesn't like to shop?

Retail movement

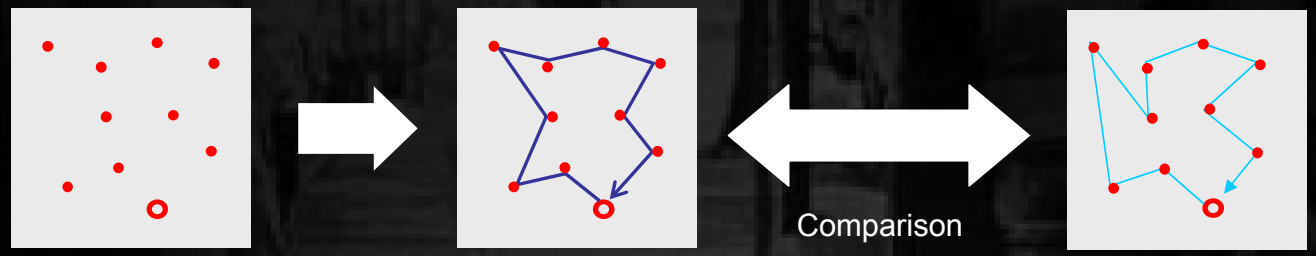


Sample trajectory

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	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

Check the validity of the shortest path model



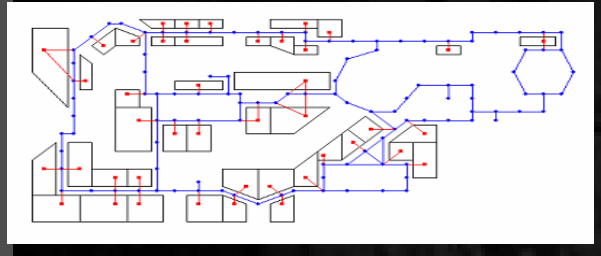
START

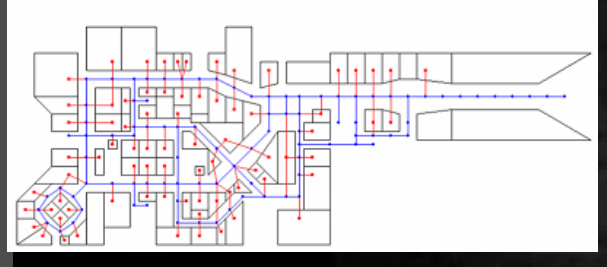
Planned destination

Estimated route

Real route

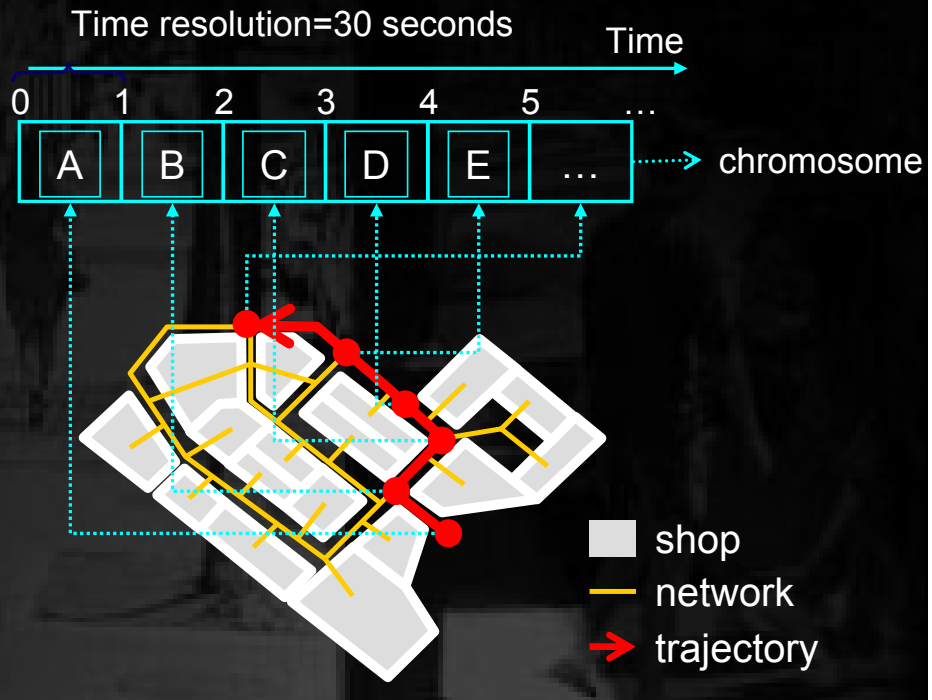
Test simulation using GA





Floor plans/ networks of the shopping centre

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



Test simulation using GA

Evaluation criteria

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

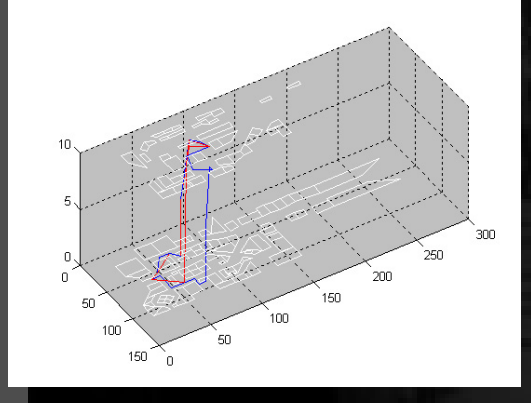
α Parameter
X Evaluation function for criterion *i*

- Travel distances (the 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

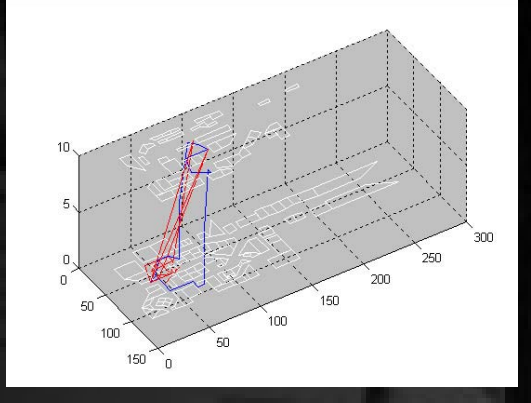
Results

- calibration

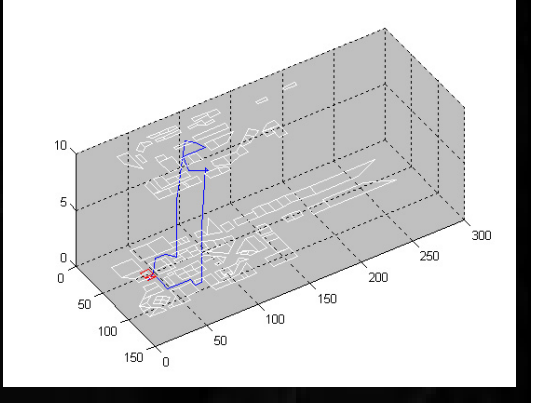
Estimated route
Observed route



Test simulation



without restriction on distance



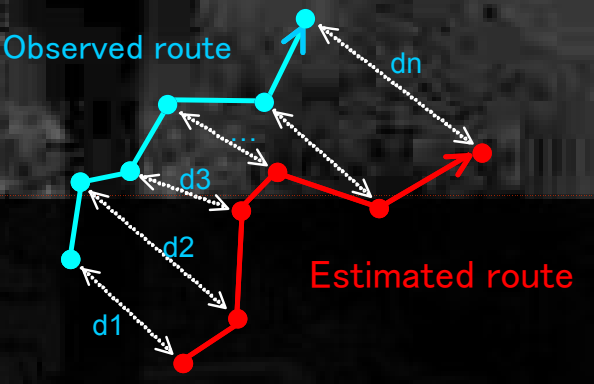
with severe restriction on distance

Evaluated value

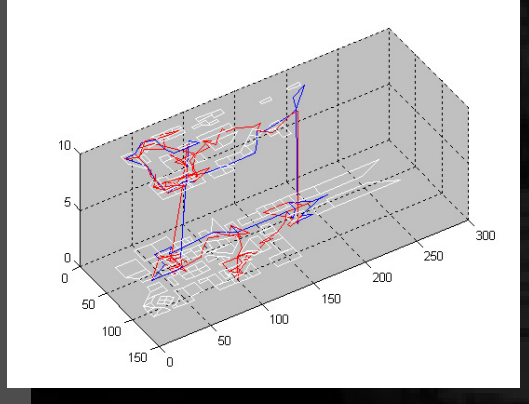
Estimated route	7.62
Observed route	7.69

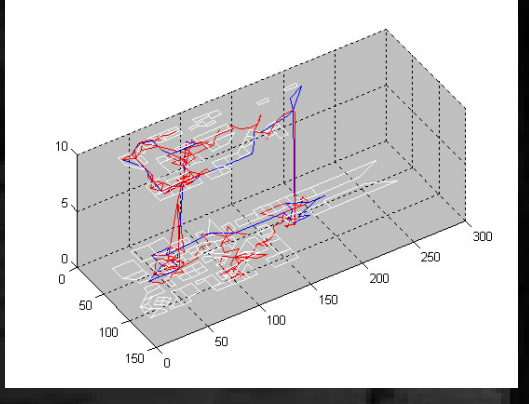
Set weighted parameters' values

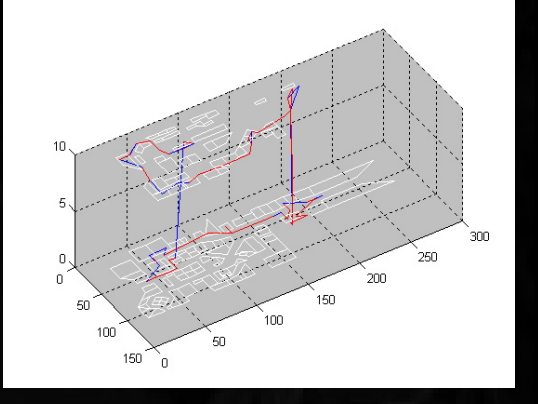
Results



Estimated route
Observed route (real route)







Simulation 1

Evaluated value
Estimated route 100
Observed route 107
Distance between 2 routes 68.8m

Simulation 2

Estimated route 99.5
Observed route 107
52.4m

Given the real route
as one of initial chromosomes

Estimated route 108.8
Observed route 107
1.25m

Findings

- Problems of GA
- Shortest path model
  - capable of predicting outlines of the routes
  - evaluation criteria and parameter values tested
  - other influential factors

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)		
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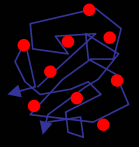
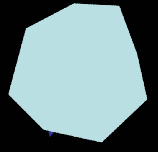
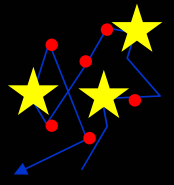
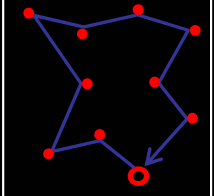
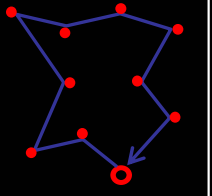
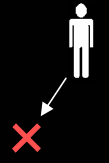
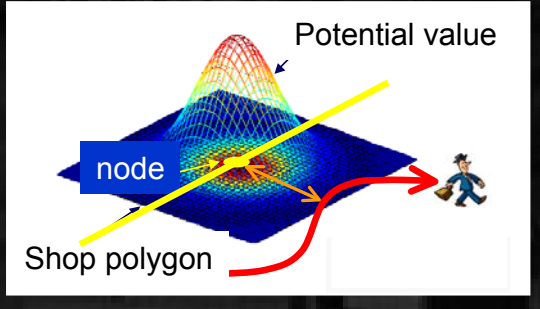
Route							
Behaviour pattern	Complex Time: long	Try to see whole area	Shortest path & Other factors	Shortest path Time: long	Deviate from prefixed route by visual stimulus	Shortest path Time: short	not go shopping

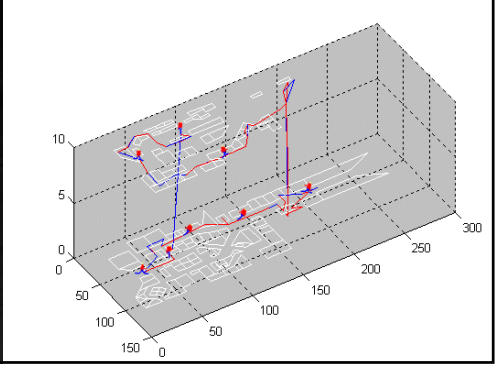
Future research

✓**Improving the simulation system**

- Combining network and potential distribution



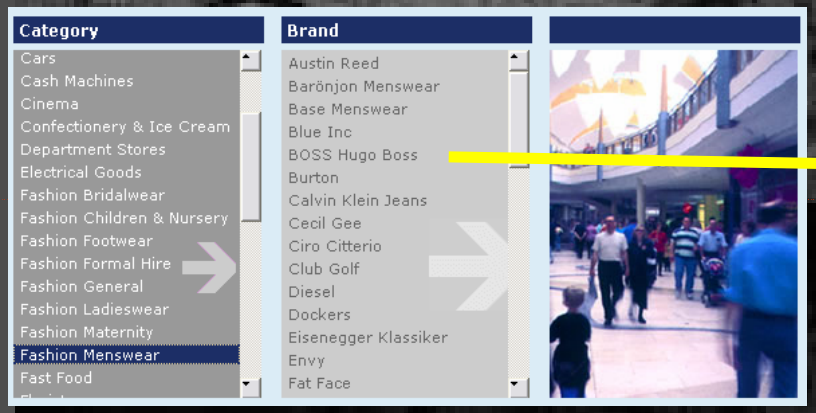
- Network analysis
  - •width of corridor, visibility, connection to other network
- Improve GA algorithm
  (resource-consuming)
- Analyses on factors in route selection



Future research

✓**Marketing research**

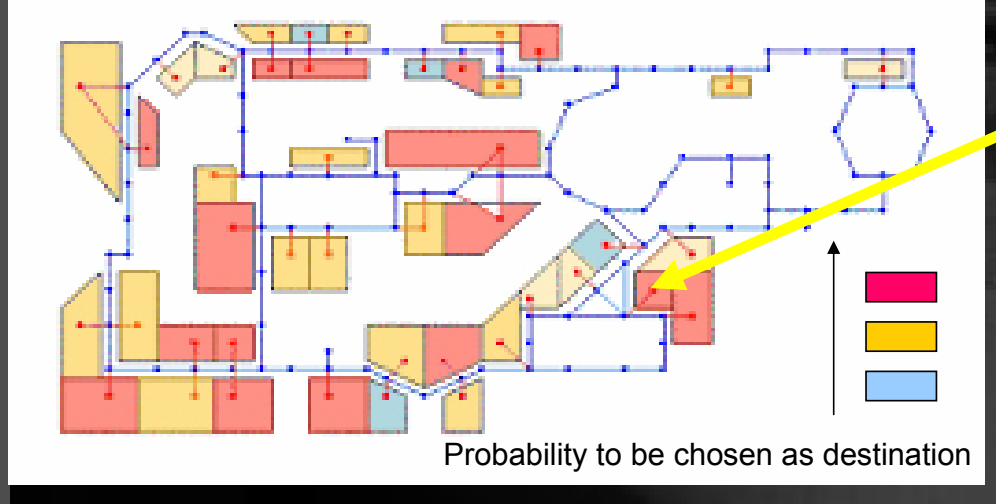
- Develop DB (Shops' attributes)
- Analysis on relationship between the place's attributes and those of shoppers



Shop attributes

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

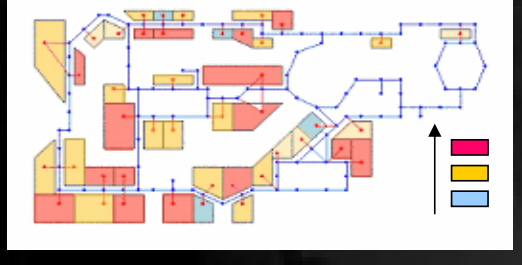
Matching



Shopper A's attributes

Male
Age : 32
Car ownership
Subscribing magazines
Preferences

	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%



Data availability problem

OPTION 1: Questionnaire survey on shoppers

OPTION 2: Substitute these data with MOSAIC type

OPTION 3: Implement simulation system with dummy data

How to validate the model

It is necessary to carry out measurement survey

1. Passing trade
2. Peel-off rate

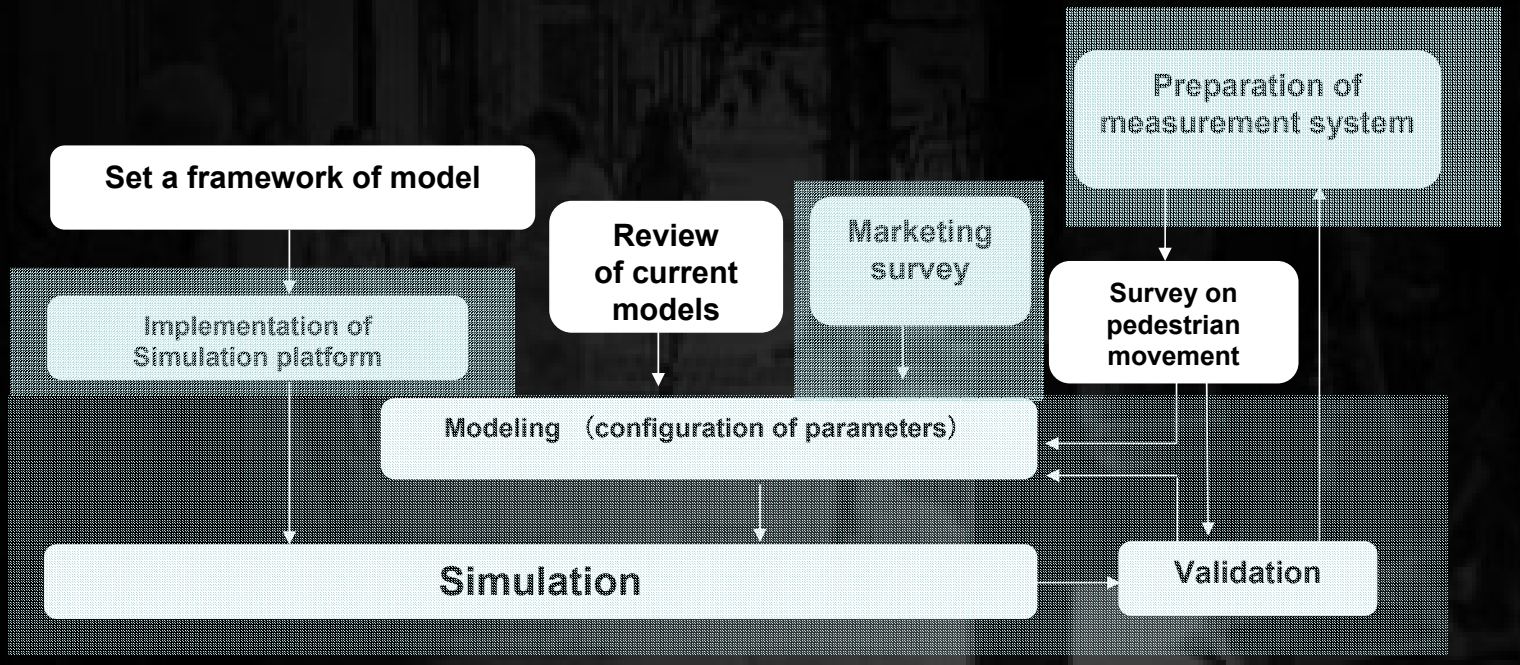
↔ Shopper's attributes

Extract pedestrian by image analysis

- Laser scanner?
- Video camera?
- Manual counting / following?

Need to get a permission!

Work Plan



Next Step: - a permission to carry out surveys from some shopping centers
- marketing data

Thank you!

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