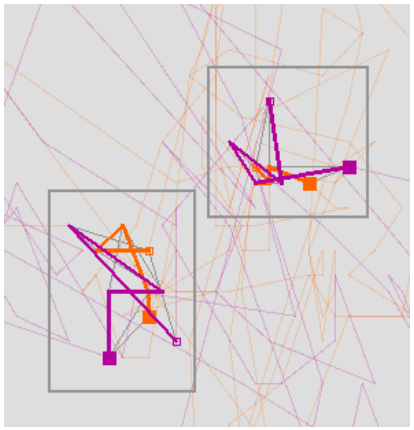
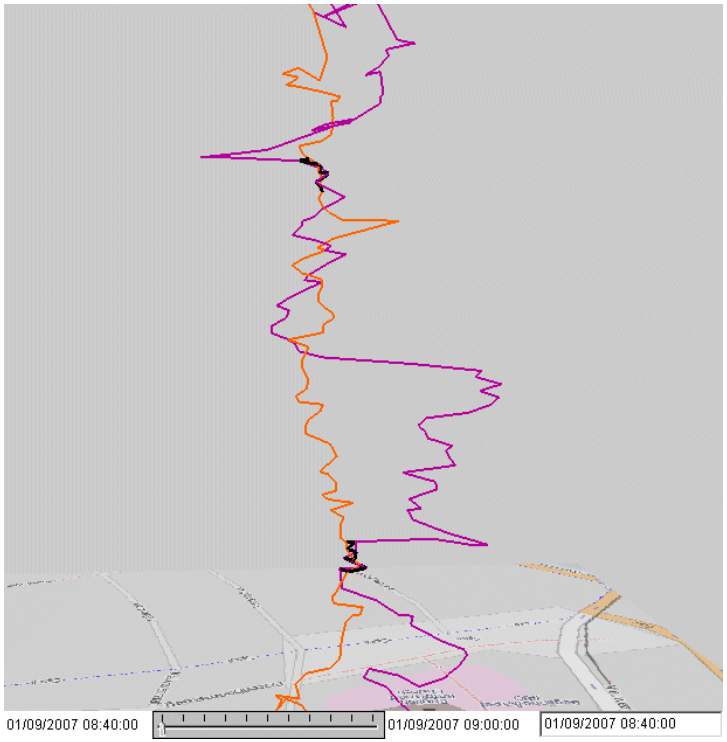
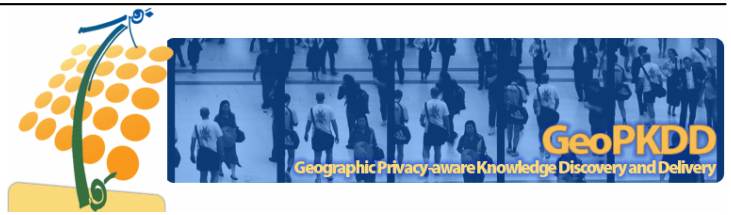
Uncovering Interactions Between Moving Objects







Gennady Andrienko & Natalia Andrienko

http://geoanalytics.net

IAIS

Fraunhofer Institut Intelligente Analyse- und Informationssysteme

Monica Wachowicz & Daniel Orellana

UPM
UNIVERSIDAD POLITÉCNICA DE MADRID

Research Topic

Research focus: **interactions** (between individuals) occurring during **movement**

Definitions

A **movement** is a motion, a change in position.
In physics, **motion** means a constant change in the location of a body.

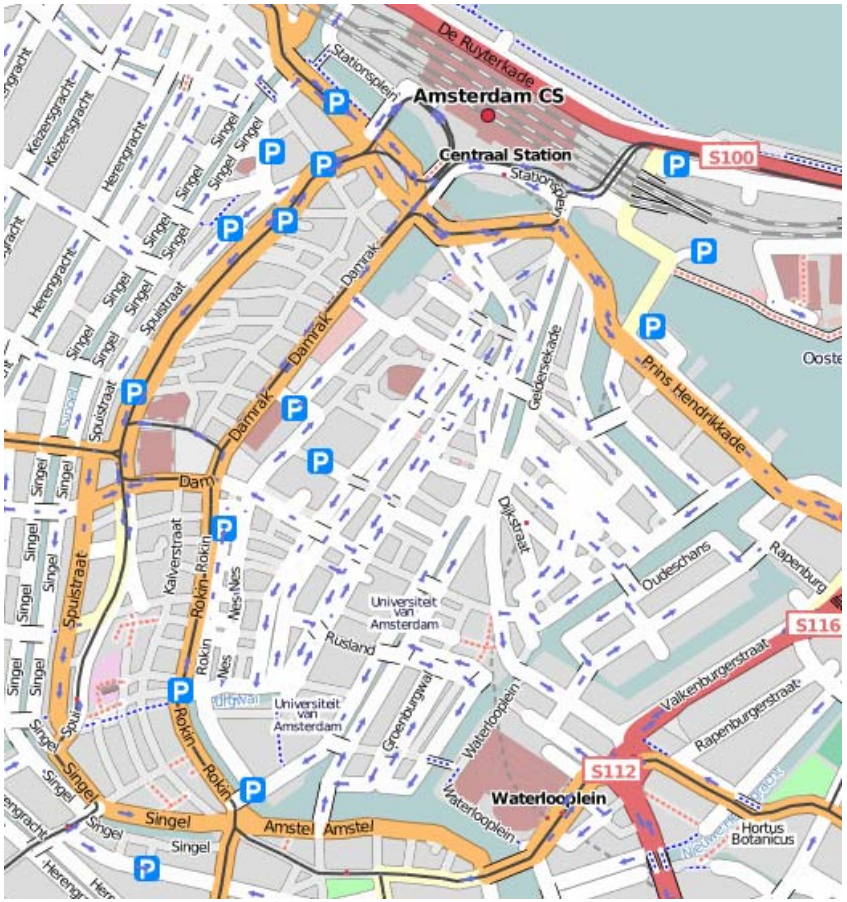
Interaction is a kind of action that occurs as two or more objects have an effect upon one another. The idea of a two-way effect is essential in the concept of interaction <…>

Research problem:

How to **find** and **understand**
(indications of possible) **interactions**
in **movement data**?

An Example

- Schoolchildren playing an outdoor mobile game in Amsterdam (303 players)
- Equipped with mobile positioning devices
- Goal: find specified historical places and answer place-related riddles
- 6 competing teams
- Questions:
  - Did the players cooperate within the teams?
  - Were there conflicts between players from different teams?



GeoPKDD
Geographic Privacy-aware Knowledge Discovery and Delivery

Movement Data

ID	Longitude	Latitude	time
1	4.90091	52.37476	01-09-07 07:50:00
1	4.90112	52.37489	01-09-07 07:50:10
1	4.90102	52.37502	01-09-07 07:50:20
1	4.90103	52.37513	01-09-07 07:50:30
1	4.90113	52.37524	01-09-07 07:50:40
1	4.90113	52.37536	01-09-07 07:50:50
1	4.90107	52.37539	01-09-07 07:51:00
...			

and nothing else!

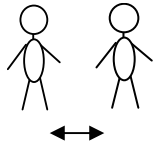
Research problem:

How to **find** and **understand**
(indications of possible) **interactions**
in **movement data**?

e.g. cooperation, conflict, …

An indication of a possible interaction:

spatial proximity

IDx  IDy

distance ≤ Dmax (threshold)

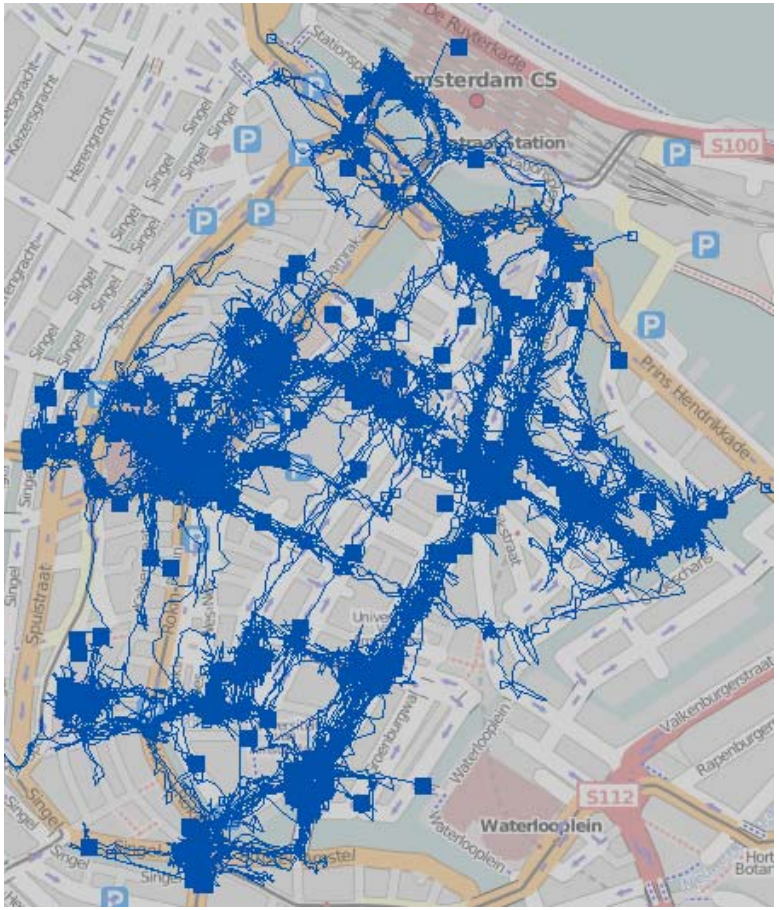
Dmax depends on

Type and characteristics of moving objects	human (adult, child), animal (bird, snail, …), car, ship, …
Type of movement	walking, cycling, driving, playing, …
Type of relation in focus (analysis task)	possibility to observe, possibility to talk, possibility to touch, …
Place	city center, shopping mall, nature park, highway, …
Time	early morning, rush hours, late evening, night, …

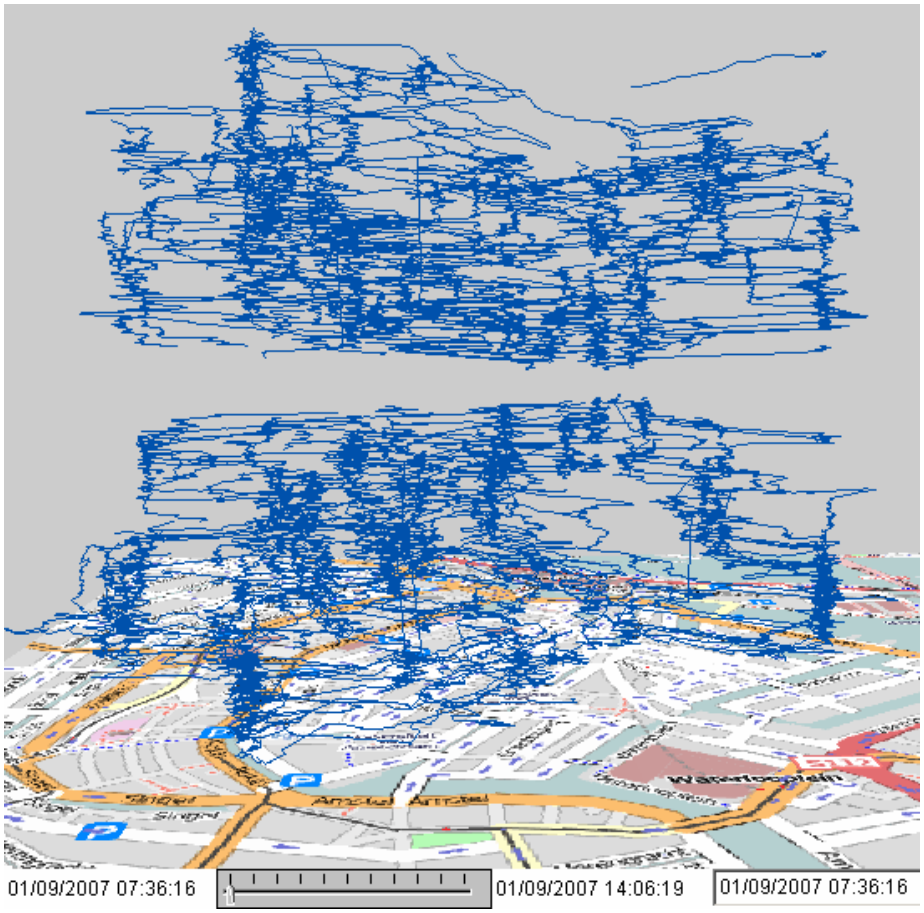
GeoPKDD
Geographic Privacy-aware Knowledge Discovery and Delivery

Visualisations of Movement Data

Occurrences of spatial proximity are very hard to find by visual inspection



Map



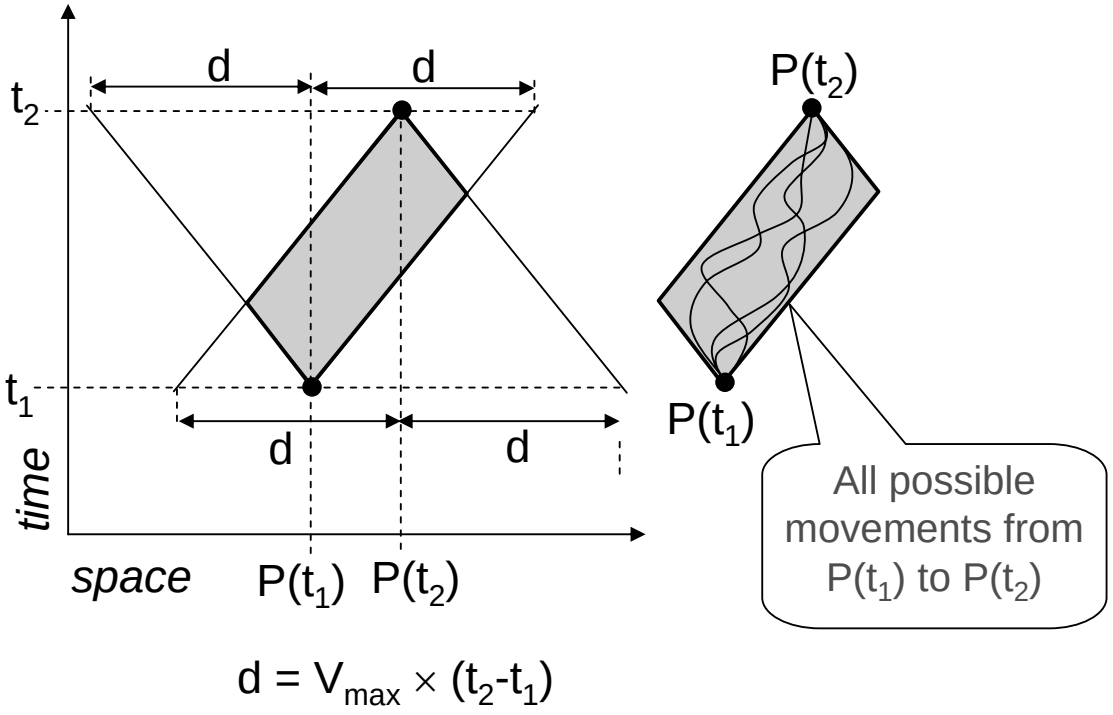
Space-Time Cube

GeoPKDD
Geographic Privacy-aware Knowledge Discovery and Delivery

Computational Detection of Possible Interactions

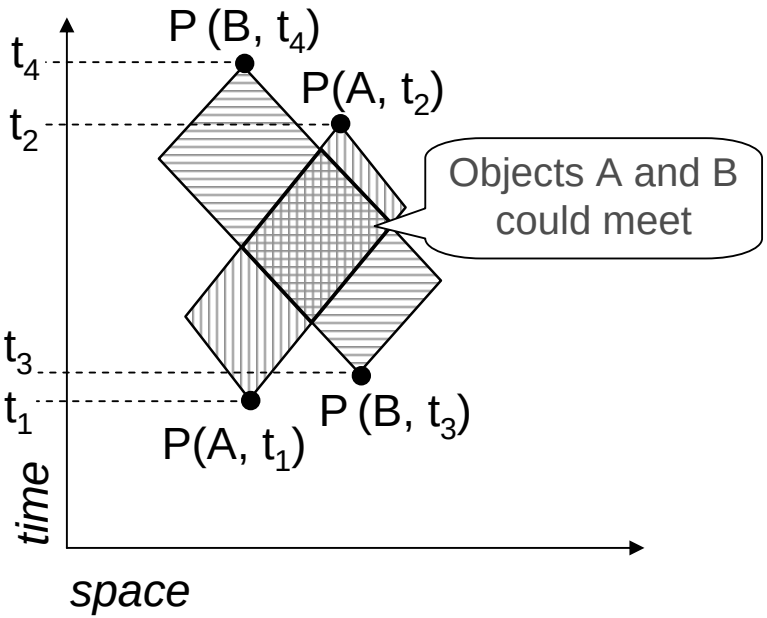
Uncertainty problem:
positions of moving objects are known only for some time moments

Space-Time Prism (Hägerstrand 1970)

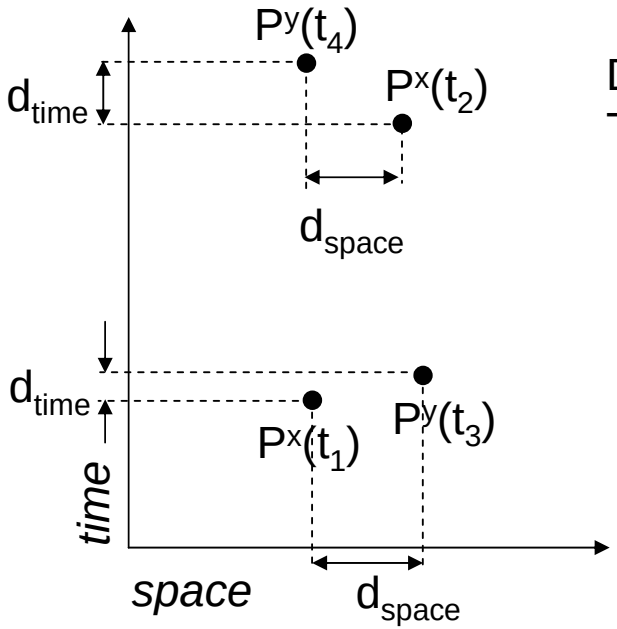


$$d = V_{max} \times (t_2 - t_1)$$

Intersection of two prisms



Computational Detection of Possible Interactions: a simplistic approach



Near $(P^x(t'),P^y(t'')) == d_{space} \leq Dmax$ *and* $d_{time} \leq Tmax$

Dmax – spatial distance threshold
Tmax – temporal distance threshold

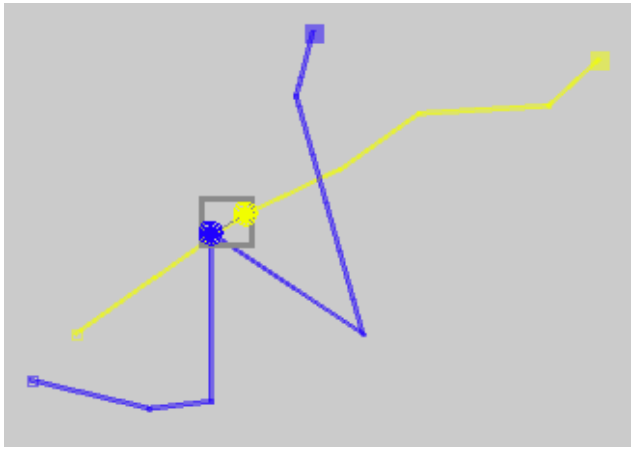
Interaction (working definition):

$\{<P(A, t_{k1}),P(B, t_{n1})>, <P(A, t_{k2}),P(B, t_{n2})>, \ldots \}$

where for each i:

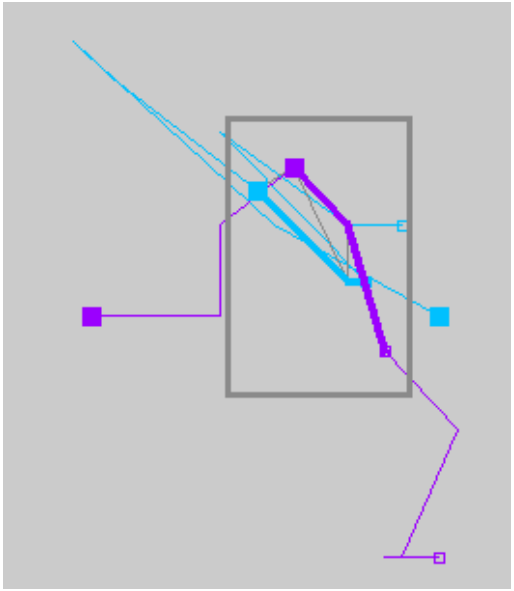
- ***Near*** $(P(A, t_{ki}), P(B, t_{ni}))$
- No known positions between $P(A, t_{ki})$ and $P(B, t_{ki+1})$
- No known positions between $P(A, t_{ni})$ and $P(B, t_{ni+1})$

Detected Interactions (Examples)



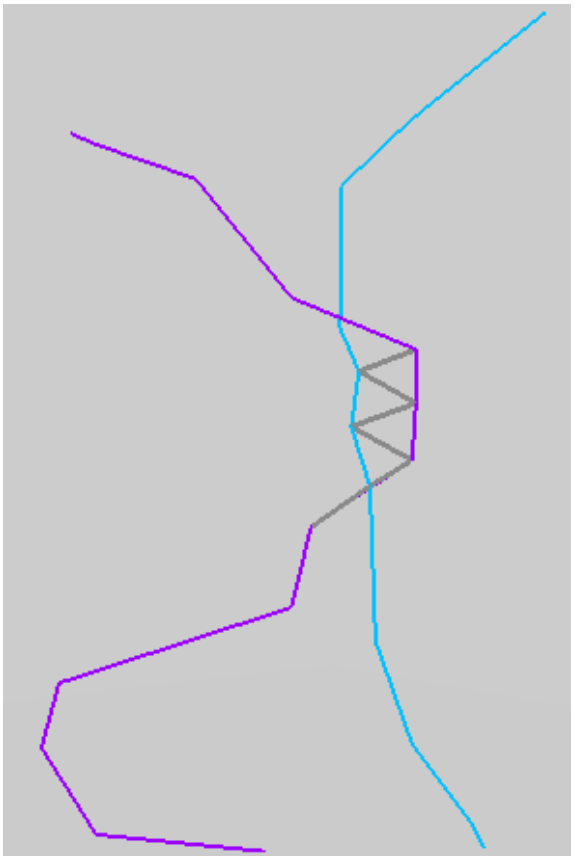
760: [01/09/2007 12:45:10 - 01/09/2007 12:45:20]

Id	Name	Earliest time	Latest time
12	12	01/09/2007 12:45:10	01/09/2007 12:45:10
168	168	01/09/2007 12:45:20	01/09/2007 12:45:20



670: [01/09/2007 12:07:14 - 01/09/2007 12:07:44]

Id	Name	Earliest time	Latest time
105	105	01/09/2007 12:07:20	01/09/2007 12:07:40
203	203	01/09/2007 12:07:14	01/09/2007 12:07:44

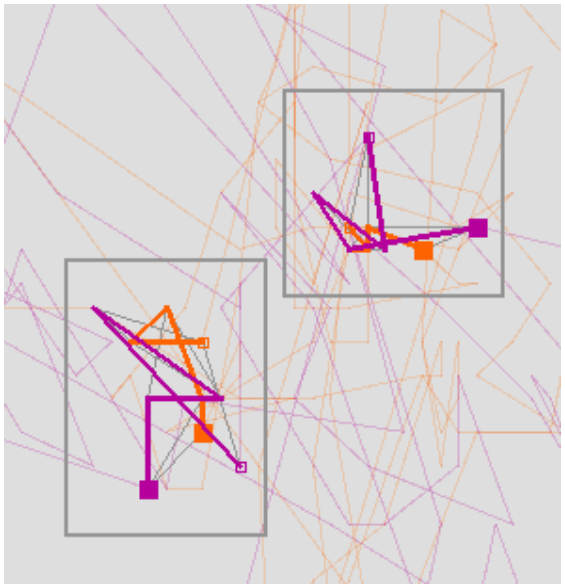


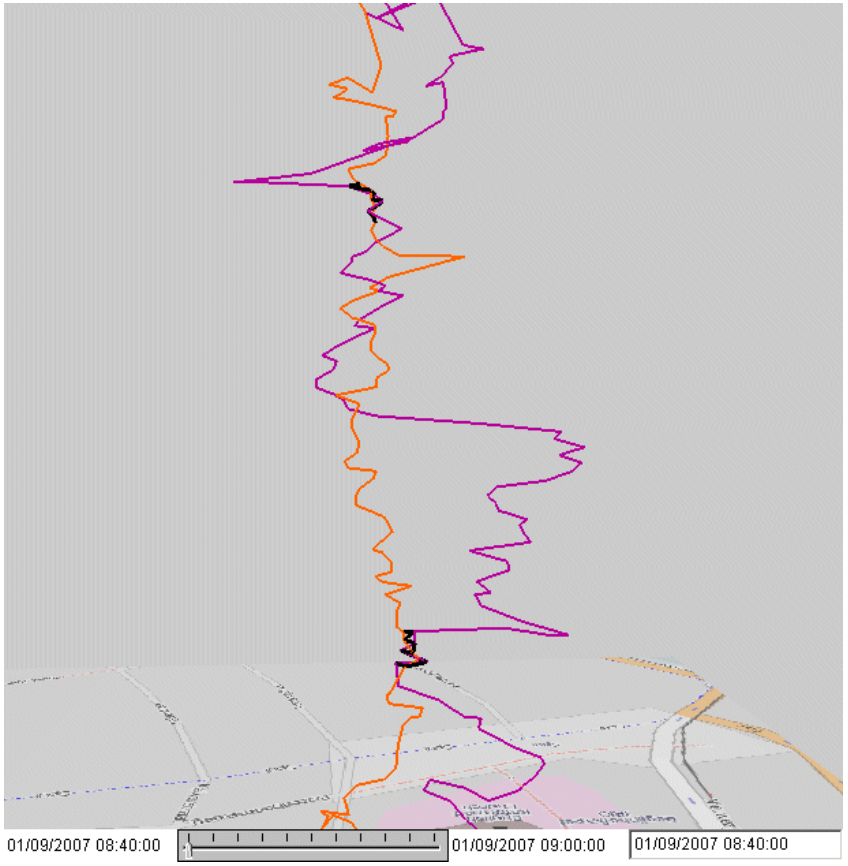
Dmax = 5 meters
Tmax = 12 seconds

Visualization Helps to Understand

Research problem:

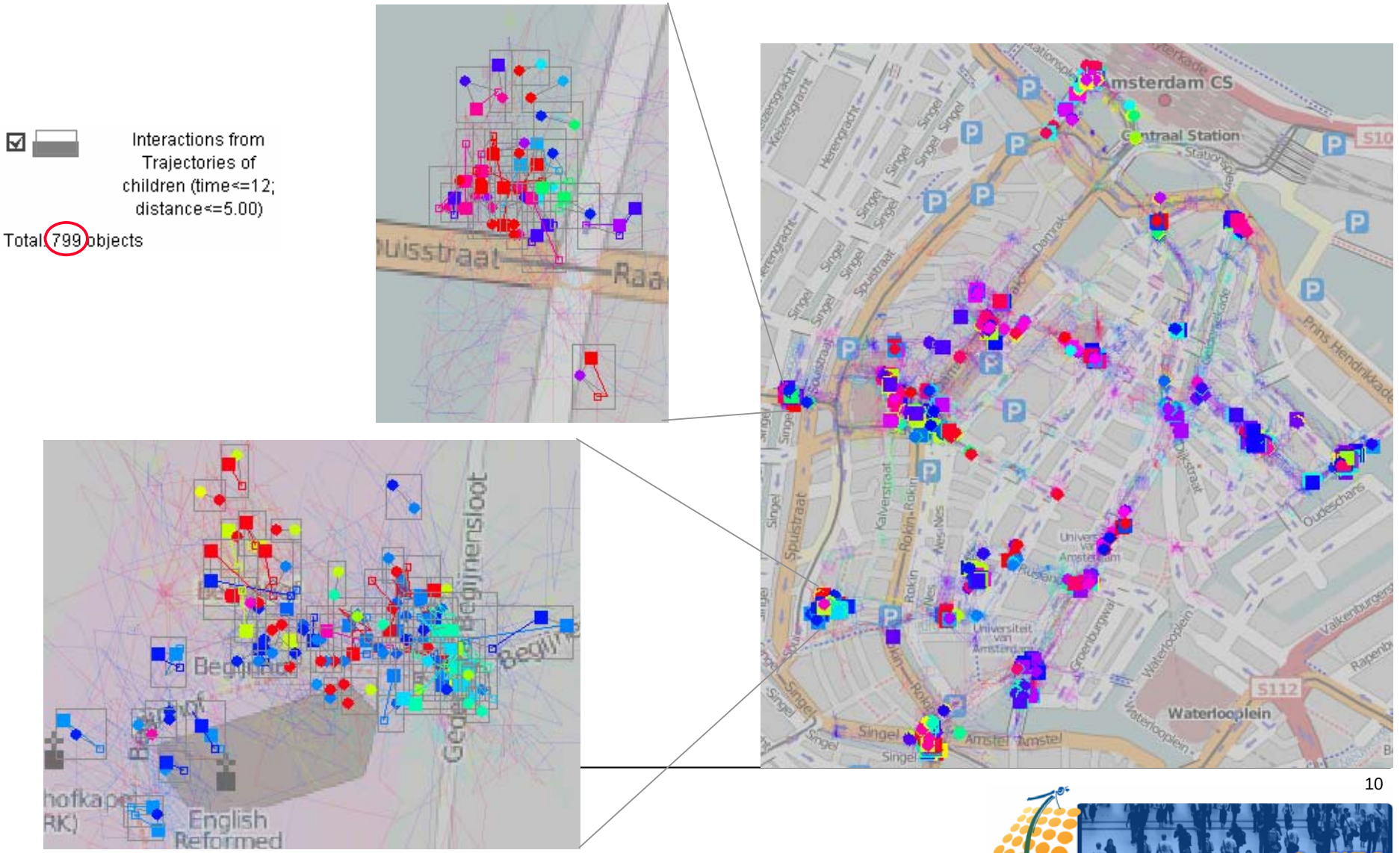
How to **find** and **understand**
(indications of possible) **interactions**
in **movement data**?



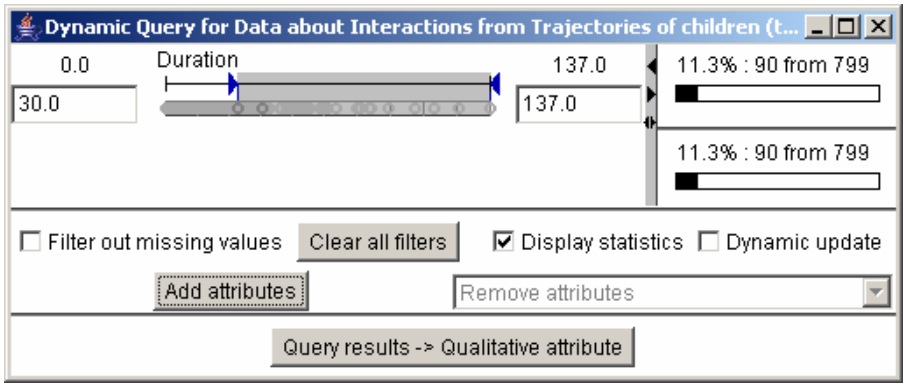


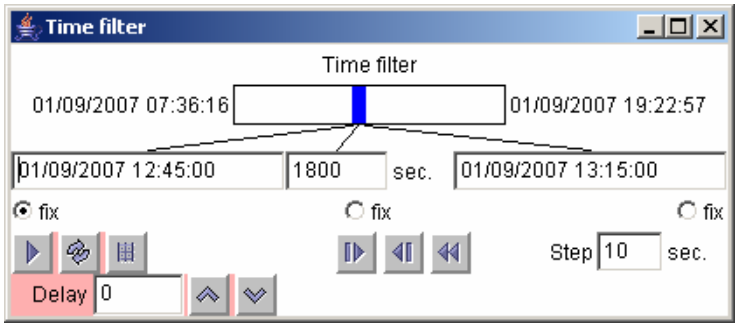
These patterns may indicate a conflict
between two players from different teams

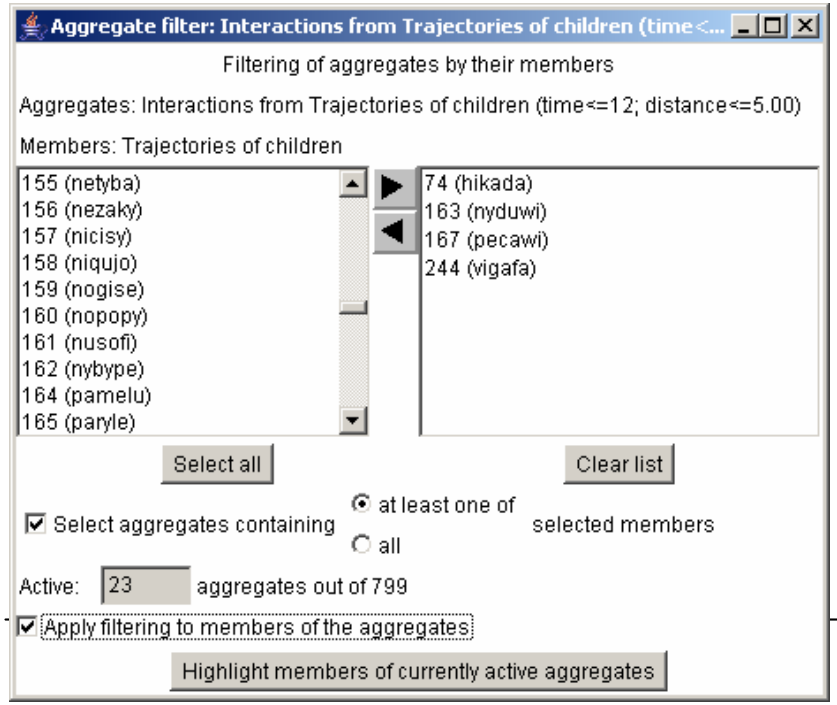
A Typical Result of Computational Detection of Interactions

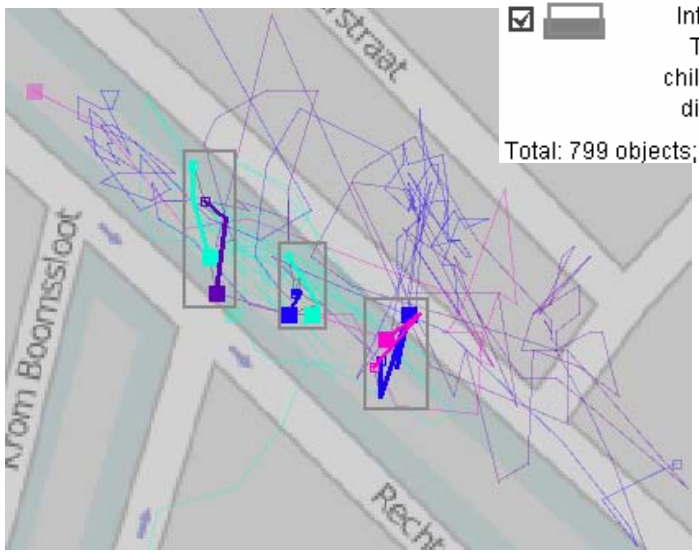


An Approach: Filtering









Limitation: very few interactions can be considered

Demand: Automated Classification

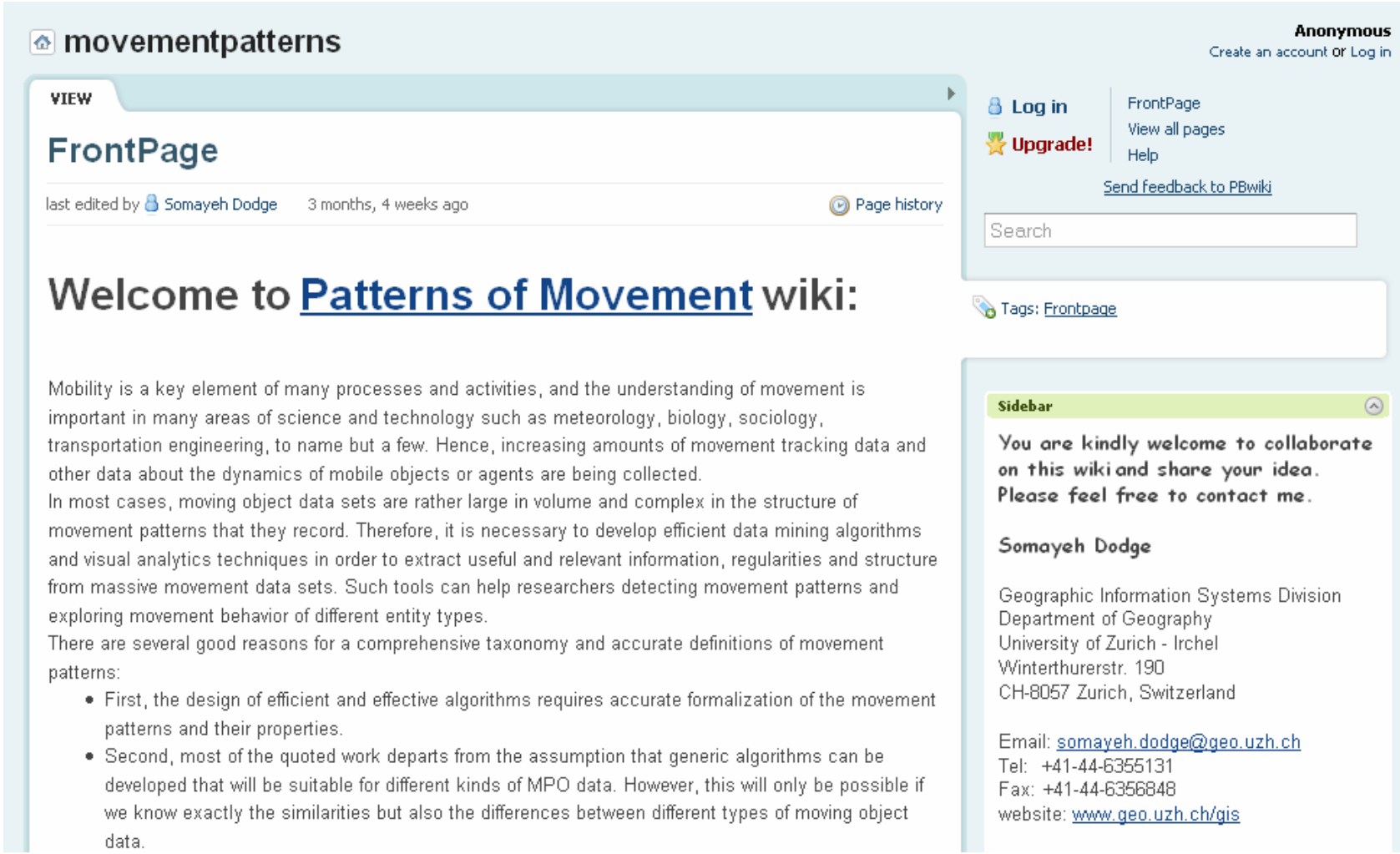
- Approach 1:
  - **Formally define** potentially interesting types of interactions in terms of suitable characteristics *derivable from movement data*
  - Develop a method which derives the characteristics and classifies interactions according to the definitions
- Approach 2:
  - Collect representative **examples** of potentially interesting types of interactions
  - Develop a method capable of learning from the examples
    - ➢ The method must compare new interactions with the examples in terms of suitable characteristics *derivable from movement data*

⇒ Nearest research task:

- Define a “vocabulary” of characteristics to describe various types of interactions

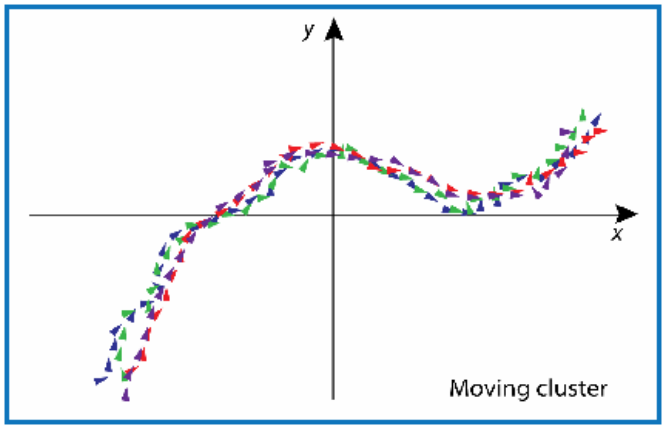
What Exists

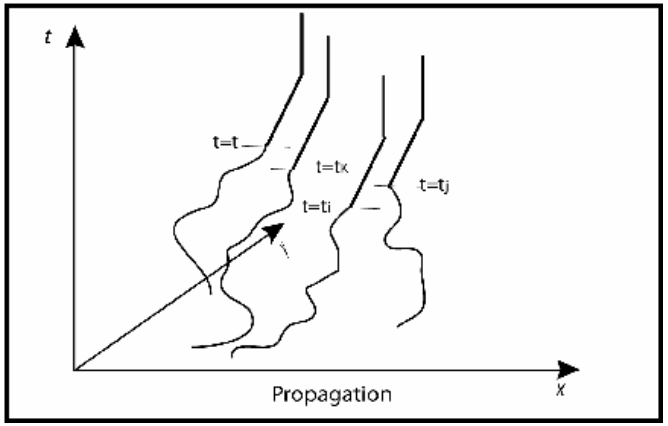
http://movementpatterns.pbwiki.com/FrontPage

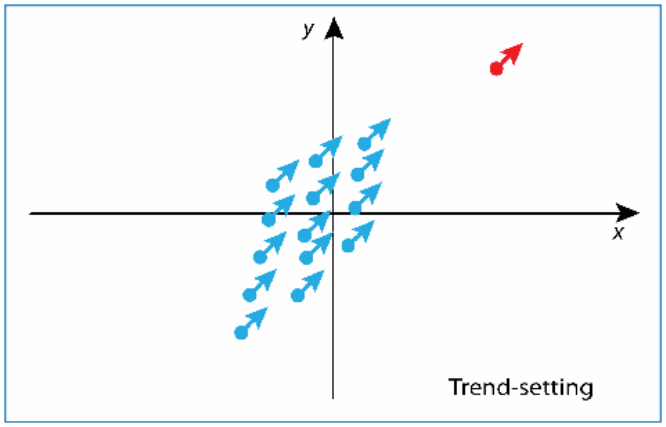


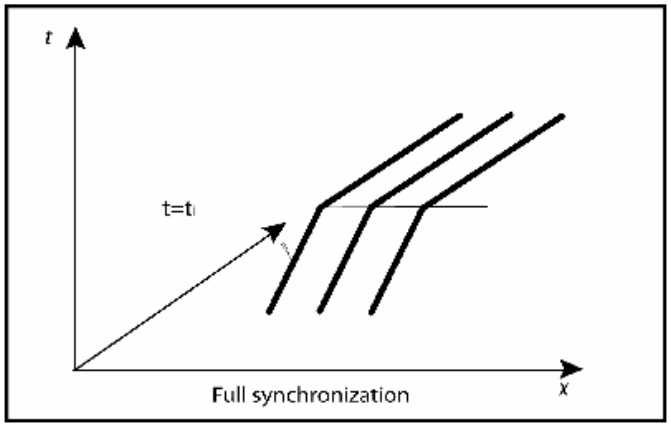
http://movementpatterns.pbwiki.com/FrontPage

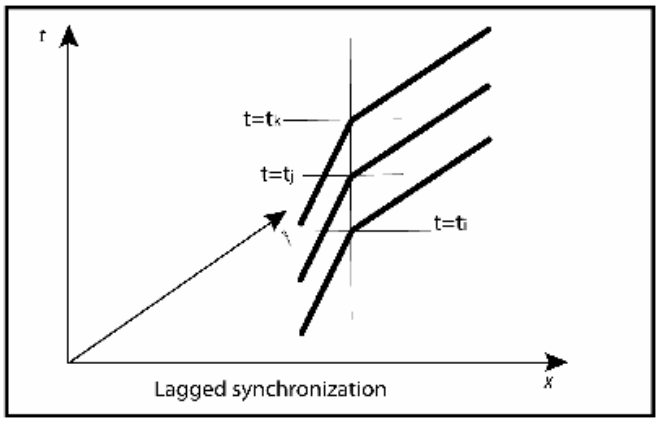
Some movement patterns can be treated as interactions











- Most patterns are only informally defined
- No “common language”, i.e. uniform way to describe different patterns

GeoPKDD
Geographic Privacy-aware Knowledge Discovery and Delivery

Movement Parameters

Table 1 Movement parameters

Parameters/Dimension	*Primitive*	*Primary derivatives*	*Secondary derivatives*
Spatial	Position *(x,y)*	Distance *f(posn)* Direction *f(posn)* Spatial extent *f(posn)*	Spatial distribution *f(distance)* Change of direction *f(direction)* Sinuosity *f(distance)*
Temporal	Instance *(t)* Interval *(t)*	Duration *f(t)* Travel time *f(t)*	Temporal distribution Change of duration *f(duration)*
Spatio-temporal *(x, y,t)*	—	Speed *f(x,y,t)* Velocity *f(x,y,t)*	Acceleration *f(speed)* Approaching rate

Defined in:

Towards a taxonomy of movement patterns

Somayeh Dodge
Robert Weibel
Anna-Katharina Lautenschütz

Department of Geography, University of Zurich, Switzerland

Information Visualization (2008), 1 – 13
© 2008 Palgrave Macmillan Ltd. All rights reserved 1473-8716
www.palgrave-journals.com/ivs

Use of the Movement Parameters *(same source)*

	Primitive param.		*Primary derivatives*				*Secondary derivatives*	
Generic patterns	*Position*	*Instance*	*Distance* $f(x, y)$	*Direction* $f(x, y)$	*Speed* $f(x, y, t)$	*Duration*	*Curvature*	*Acceleration*
Primitive patterns								
Co-location in space	x		x					
Concentration	x		x					
Concurrence	x	x	x	x	x	x	x	x
Co-incidence in space and time	x	x	x					
Opposition	x	x	x	x	x	x	x	x
Dispersion	x	x	x	x	x	x	x	x
Constancy	x	x	x	x	x	x	x	x
Sequence	x	x				x		
Periodicity	x	x	x	x	x	x	x	x
Meet	x	x	x			x		
Moving cluster	x	x	x	x	x	x	x	x
Temporal relations		x				x		
Synchronization	x	x	x	x	x	x	x	x
Compound patterns								
Isolated object	x	x	x	x	x	x	x	x
Symmetry	x	x	x	x	x	x	x	x
Repetition	x	x	x	x	x	x	x	x
Propagation	x	x	x	x	x	x	x	x
Convergence/divergence	x	x		x		x		
Encounter/breakup	x	x	x	x				
Trend/fluctuation	x	x	x	x	x	x	x	x
Trend-setting	x	x	x	x	x	x	x	x

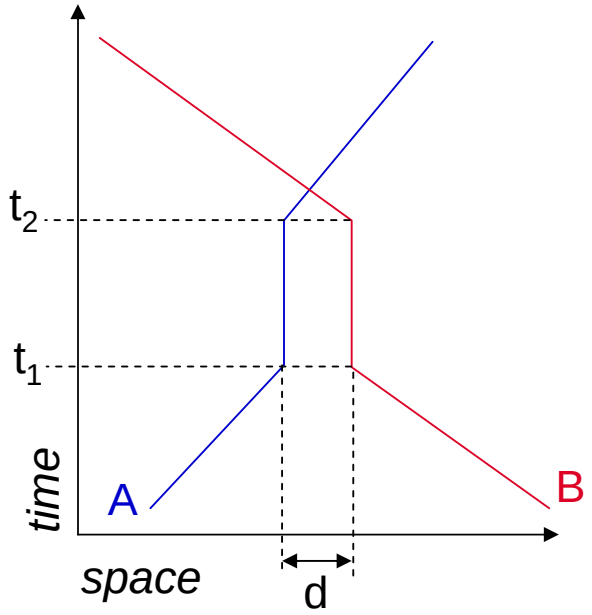
- The parameters are not consistently used in describing the patterns

Exercise

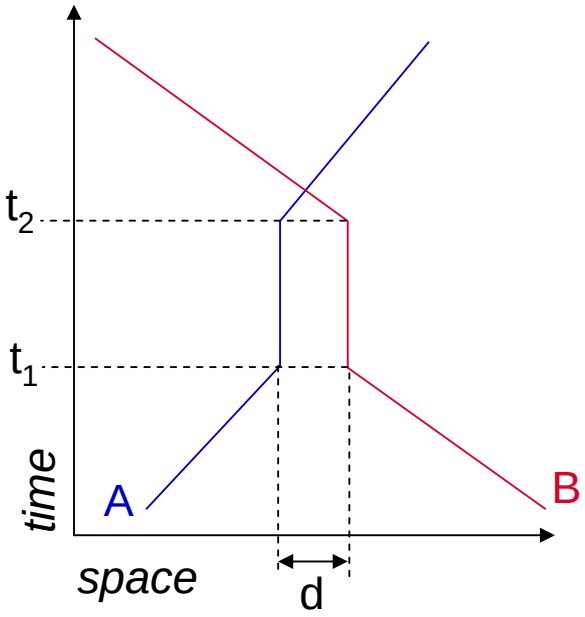
- We try to describe some types of interactions
  - Begin with an informal description
  - Then try to turn it into formal
  - Note what characteristics (parameters) we need for this
- We try to find examples of these types of interactions in real data
- We check whether our formal descriptions are suitable and sufficient for classifying these examples

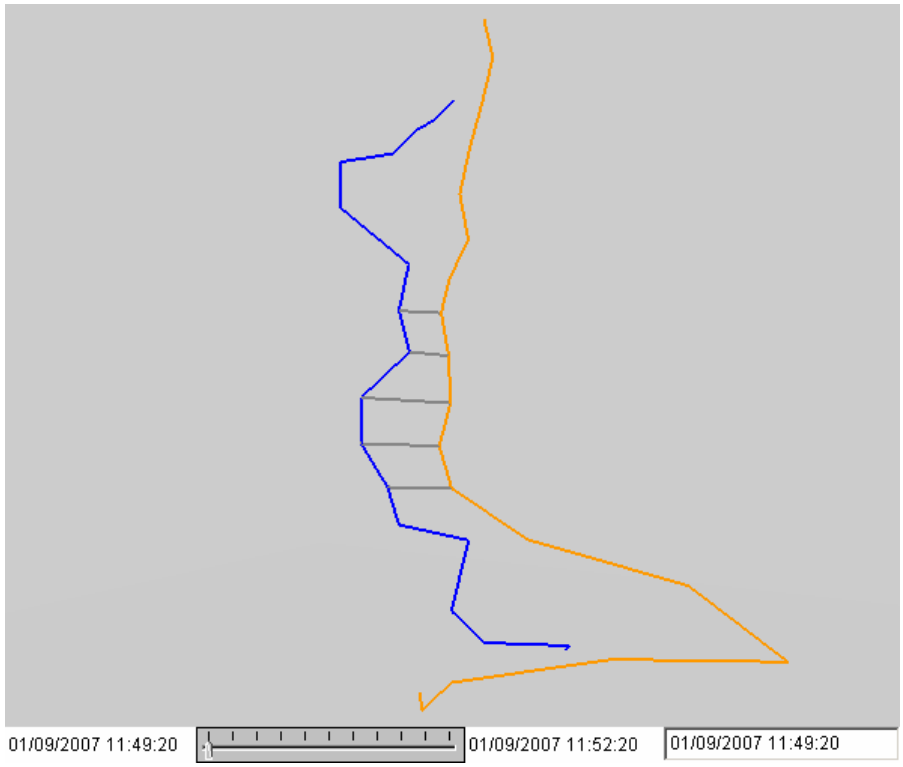
"Meet → Stop → Diverge"

- A and B come close to each other and stop (possibly, for a conversation), then move in different directions
- $\exists\ t_1, t_2$:
  $\forall t, t_1 \le t \le t_2$: distance (A, B, t) ≤ dMax
  (A and B are close to each other during $[t_1, t_2]$)
  $\exists t_0 < t_1$: $\forall t, t_0 \le t < t_1$: distance (A, B, t) > dMax
  (A and B are not close before t_1)
  $\exists t_3 > t_2$: $\forall t, t_2 < t < t_3$: distance (A, B, t) > dMax
  (A and B are no more close after t_2)
  $t_2 - t_1 \ge$ Tmin
  (A and B spend sufficient time together)
  $\forall t, t_1 < t \le t_2$: position (A, t) = position (A, t_1) & position (B, t) = position (B, t_1)
  (A and B stay in the same place during $[t_1, t_2]$)



"Meet → Stop → Diverge": Theory vs. Reality





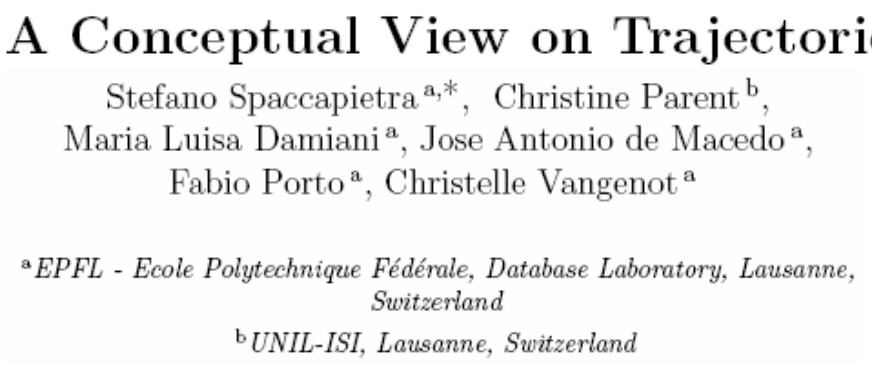
Difference: A and B do not keep exactly constant positions (due to small movements and/or measurement errors)
⇒ "stop" has to be defined in a different way

"Stop"

- $\exists\ t_1, t_2$:
  $t_2 - t_1 \geq$ Tmin (minimum duration for being in some place to be treated as a stop)
  $\forall t, t_1 < t \leq t_2$:
  - distance $(A, t_1, t) \leq$ Dmax (all measured positions are close to the original position, i.e. the measured position at moment t_1)
  - distance $(A, t_{previous}, t) \leq$ Dmax (each measured position is close to the previous measured position)

  $\exists\ t_x, t_y; t_1 < t_x < t_y \leq t_2$:
  - distance $(A, t_1, t_y) <$ distance (A, t_1, t_x) (the distance to the original position does not monotonously increase)

“Stop” and “Move”: the Primitives to Describe Movement



A Conceptual View on Trajectories

Stefano Spaccapietra [a,*], Christine Parent [b],
Maria Luisa Damiani [a], Jose Antonio de Macedo [a],
Fabio Porto [a], Christelle Vangenot [a]

[a] *EPFL - Ecole Polytechnique Fédérale, Database Laboratory, Lausanne, Switzerland*

[b] *UNIL-ISI, Lausanne, Switzerland*

Data & Knowledge Engineering

Volume 65 , Issue 1 (April 2008)
Pages 126-146

- Movement of an individual is a temporal sequence of **stops** and **moves**
- “**Stop**” is defined in an application-dependent way *(e.g. our definition)*
- “**Move**” is anything which is not “**stop**”
- “**Stop**” and “**move**” may be suitable primitives to describe interactions and define types of interactions

Characteristics of Stops and Moves

Stop

- Temporal position T: $[t_1, t_2]$
- Duration $\Delta t = t_2 - t_1$
- Spatial position P
  - In our case, the area enclosing all measured positions

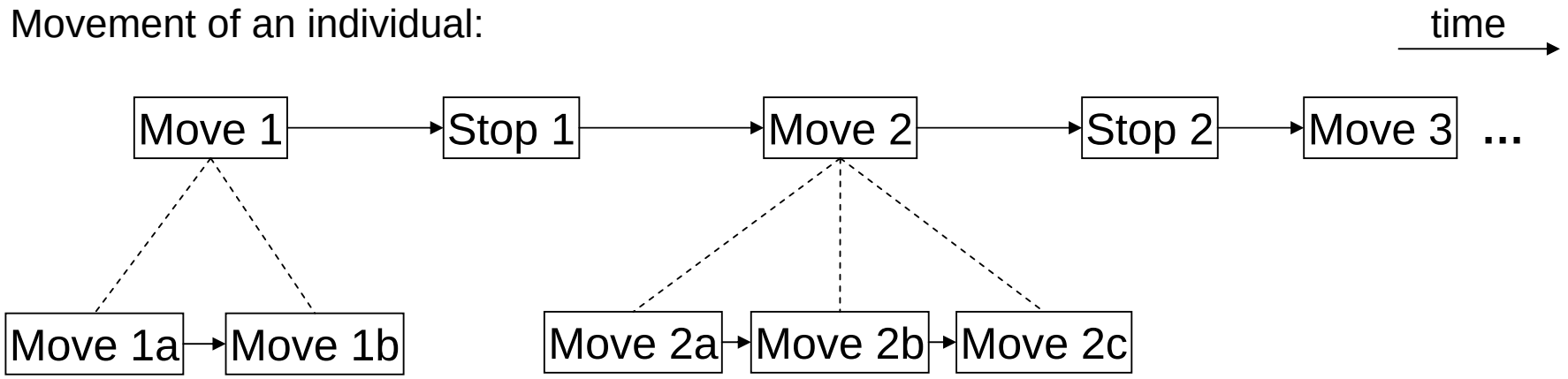
Move

- Temporal position T: $[t_1, t_2]$
- Duration $\Delta t = t_2 - t_1$
- Original spatial position $P_0 = P(t_1)$
- Final spatial position $P_{end} = P(t_2)$
- Path: P(t); $t_1 \leq t \leq t_2$
- Travelled distance
- Movement vector (from $P(t_1)$ to $P(t_2)$)
  - Direction and length
- (Average) speed
- Curvature
- Sinuosity

** May significantly vary*

Sub-division of Moves *(when necessary)*

Movement of an individual:



- Move 1a, Move 1b, …: “episodes of homogenous spatio-temporal behaviour”
  - J. A. Dykes and D. M. Mountain: Seeking structure in records of spatio-temporal behaviour: visualization issues, efforts and applications.
    Computational Statistics & Data Analysis, Volume 43, Issue 4, 28 August 2003, Pages 581-603

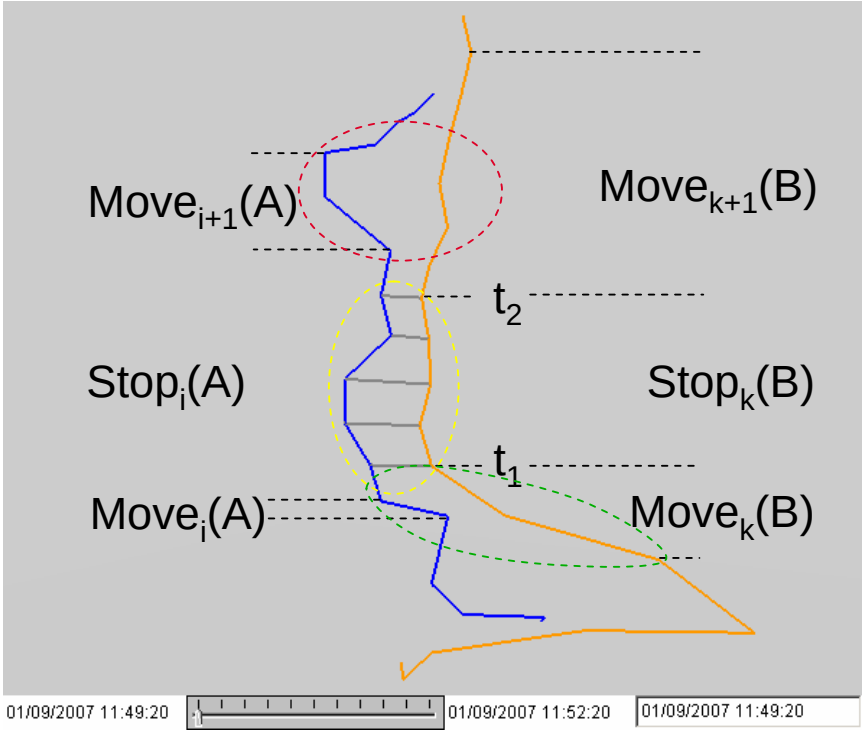
⇒ Low variation in direction, speed, curvature, and sinuosity

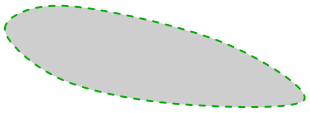
An Extension for Interactions: Relative Moves

- Approaching:
  $\exists$ $Move_i(A)$, $\exists$ $Move_k(B)$:
  - $T(Move_i(A)) \cap T(Move_k(B)) = [t_1, t_2] \neq \varnothing$ - *T(x) is the temporal position of x*
  - $distance(P_0(Move_i(A)), P_0(Move_k(B))) < distance(P_{end}(Move_i(A)), P_{end}(Move_k(B)))$
- Overtaking: approaching where $direction(Move_i(A)) \approx direction(Move_k(B))$
- Diverging:
  $\exists$ $Move_i(A)$, $\exists$ $Move_k(B)$:
  - $T(Move_i(A)) \cap T(Move_k(B)) = [t_1, t_2] \neq \varnothing$ - *T(x) is the temporal position of x*
  - $distance(P_0(Move_i(A)), P_0(Move_k(B))) > distance(P_{end}(Move_i(A)), P_{end}(Move_k(B)))$
  - $direction(Move_i(A)) \neq direction(Move_k(B))$
    - Practically, the difference between the directions exceeds a certain threshold
- … and so on

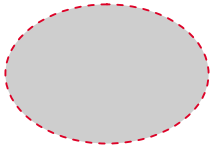
"Meet → Stop → Diverge": a definition in terms of relative moves and stops

- Approaching → Joint stop → Diverging
- Joint stop:
  ∃ $Stop_i(A)$, ∃ $Stop_k(B)$:
  - $T(Stop_i(A)) \cap T(Stop_k(B)) = [t_1, t_2]$; $t_2 - t_1 \geq Tmin$
  - distance $(P(Stop_i(A)), P(Stop_k(B))) \leq Dmax$
    - Practically, this may be the minimum / maximum / average distance between the measured positions belonging to $Stop_i(A)$ and $Stop_k(B)$




Approaching

Joint stop


Diverging

Conclusion: a Promising Approach

- Take “stop” and “move” and their characteristics as basic primitives (level 0)
- In terms of stops and moves, define primitives of *relative movement* (level 1): joint stop, joint moving, approaching, overtaking, escaping, diverging, crossing, …
- Use the relative movement primitives
  - to describe observed *instances of interactions* and
  - to define various potentially interesting *types of interactions*
- The primitives may be used for developing methods for automated detection and classification of possible interactions between individuals
- The research to be continued:
  - Consider more types of interactions and more instances from real data
  - Consider more complex interaction patterns: cooperation, conflict, …
- This will also promote the research on visualization of movement