
Geospatial Visual Analytics:

Visual analysis of spatio-temporal data

Part 4: collective movement of multiple objects



Fraunhofer Institut
Intelligente Analyse- und
Informationssysteme

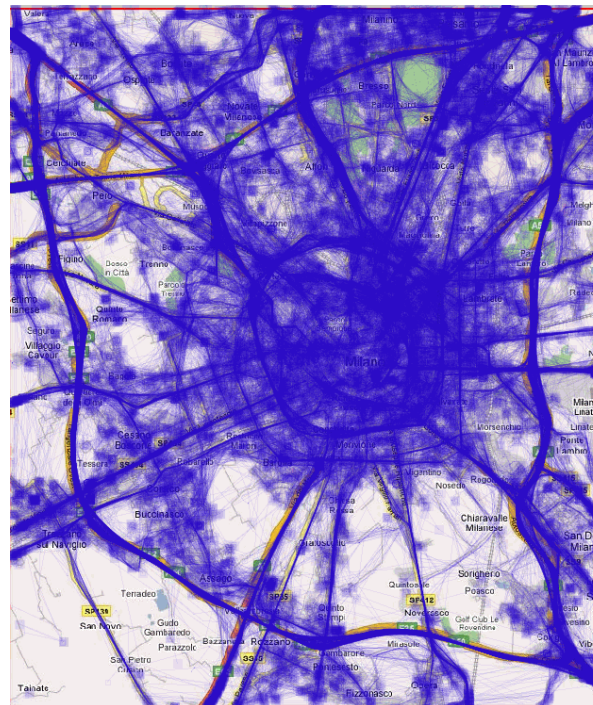
Gennady Andrienko & Natalia Andrienko

<http://geoanalytics.net>

Data example: movement of 17,241 cars in Milan during one week

ID	X	Y	time	SPEED
141	9.178838	45.47985	04-04-07 17:12	0
141	9.178838	45.47984	04-04-07 17:13	0
600	9.170161	45.43414	02-04-07 13:47	0
600	9.158362	45.43737	02-04-07 13:52	16
600	9.152749	45.43947	02-04-07 13:57	0
600	9.152749	45.43947	02-04-07 14:00	0
600	9.152736	45.43967	02-04-07 14:01	0
600	9.152835	45.43945	02-04-07 14:07	0
600	9.14287	45.4489	02-04-07 14:16	24
600	9.129485	45.44251	02-04-07 14:21	0
1165	9.266666	45.431	03-04-07 03:47	88
1165	9.251568	45.43143	03-04-07 03:49	80
1165	9.232685	45.4361	03-04-07 03:52	48
1165	9.211592	45.4466	03-04-07 03:55	42
1165	9.210249	45.45635	03-04-07 04:00	0
1330	9.263878	45.55659	02-04-07 08:32	64
1330	9.258997	45.54192	02-04-07 08:35	68
1330	9.259572	45.525	02-04-07 08:37	74
1330	9.260412	45.50731	02-04-07 08:38	98
1330	9.251644	45.48974	02-04-07 08:40	86
1330	9.252272	45.47198	02-04-07 08:41	62
1330	9.254257	45.45447	02-04-07 08:43	74
1330	9.255733	45.43661	02-04-07 08:44	76
1330	9.245868	45.42104	02-04-07 08:46	80
1330	9.26125	45.4063	02-04-07 08:48	78
1330	9.260258	45.39222	02-04-07 08:50	54
1330	9.262255	45.39502	02-04-07 08:52	0
1330	9.262254	45.39502	02-04-07 08:54	0

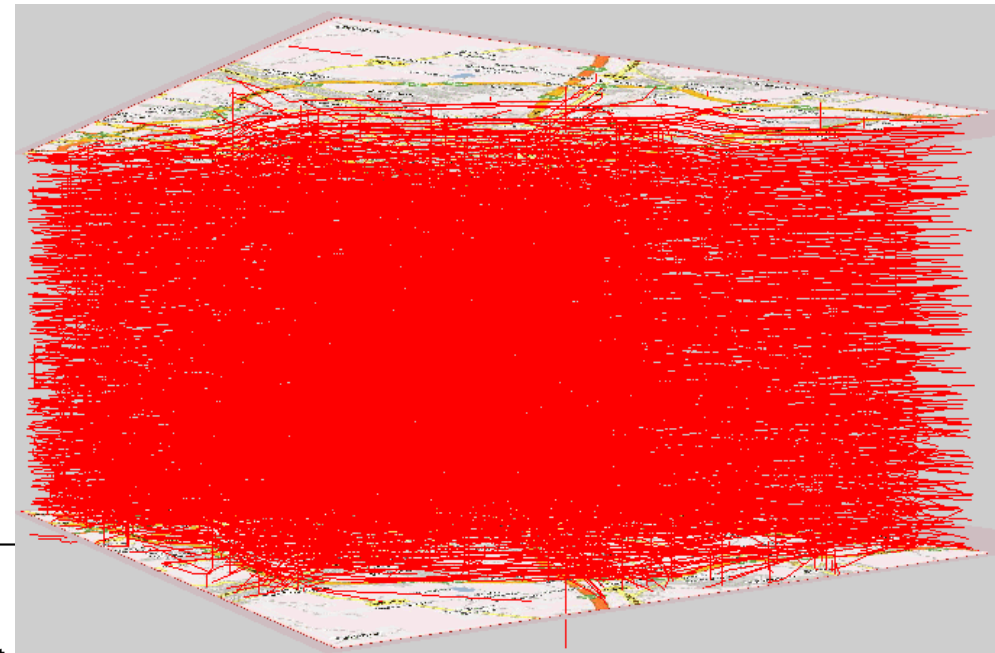
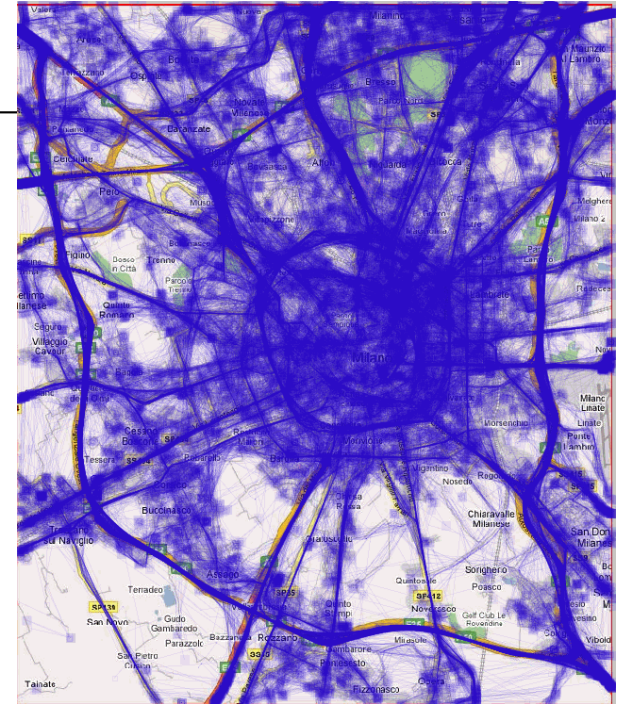
2,075,216 position records



Typical challenges

Movement data by themselves lack semantics.
It may be supplied by a human (relating to
geography and background knowledge, reasoning)
⇒ visualization is required

Movement data are collected in large amounts ⇒
traditional visualizations fail



Data collection technologies: GPS,
GSM, RFID, WLAN, motion sensors...

General approach

- Aggregate: put together what is close and similar
- Summarize: characteristics of elementary items → characteristics of aggregates

A formal model of collective movement

- Movement of multiple entities can be modeled as a function

$$\mu: E \times T \rightarrow S \quad \text{or} \quad \mu(e,t) = s$$

E : the set of entities (*discrete; unordered*)

T (time): the set of all time moments (*continuous, linearly ordered, cyclically ordered*)

S (space): the set of all positions (*continuous; partially ordered*)

- May be viewed in 2 complementary ways:

- Trajectory-oriented view: $\{ \mu_e: T \rightarrow S \mid e \in E \}$ or $\{ \mu_e(t) \mid e \in E \}$

$\mu_e(t)$ – the temporal behavior of entity e : **trajectory**

$\{ \mu_e(t) \mid e \in E \}$ - the set of trajectories of all entities

- Traffic-oriented view: $\{ \mu_t: E \rightarrow S \mid t \in T \}$ or $\{ \mu_t(e) \mid t \in T \}$

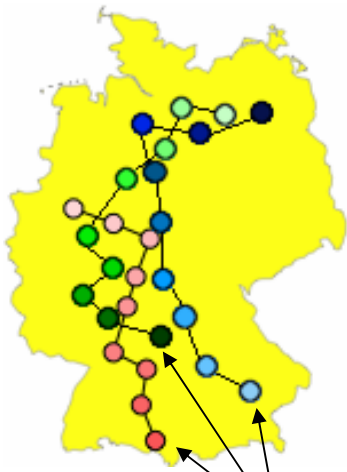
$\mu_t(e)$ – positions and movement characteristics of the entities at time t :
traffic situation (*in an abstract sense*)

$\{ \mu_t(e) \mid t \in T \}$ – variation of traffic situation over time

2 views: graphical illustration

Trajectory-oriented view

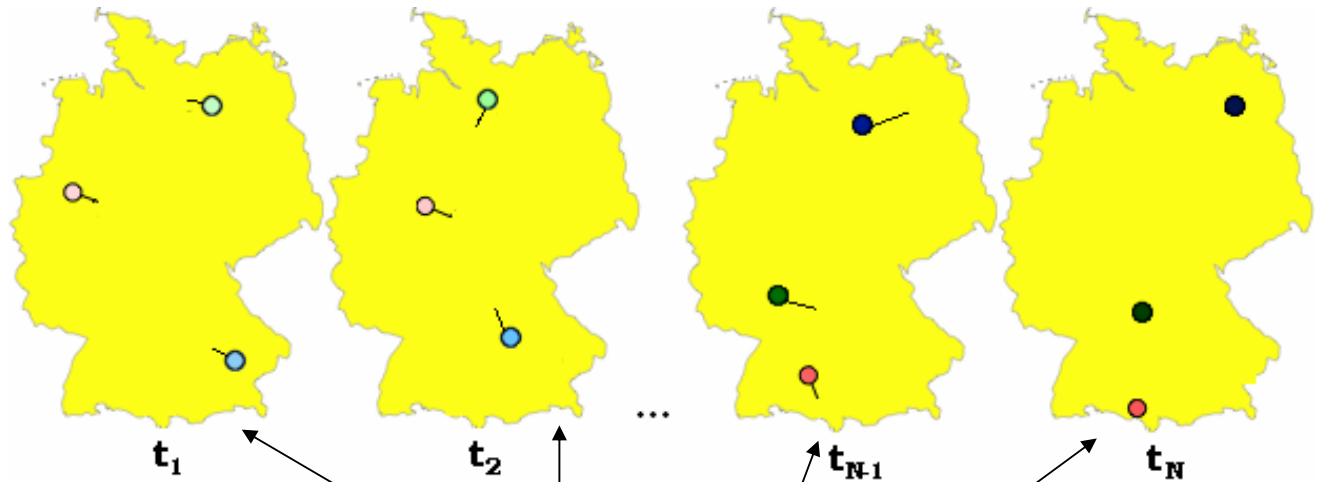
$$\{\mu_e(t) \mid e \in E\}$$



Trajectories

Traffic-oriented view

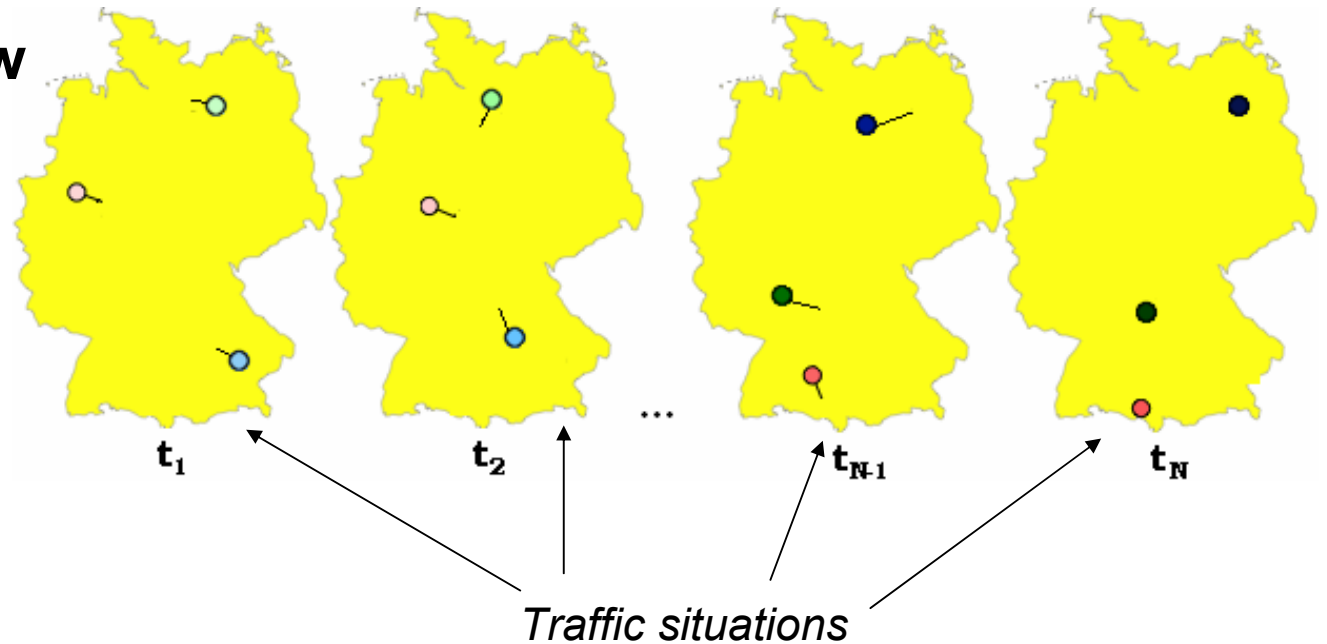
$$\{\mu_t(e) \mid t \in T\}$$



Traffic situations

Traffic-oriented view

$$\{\mu_t(e) \mid t \in T\}$$



Needed: aggregation and summarization of traffic situations, i.e. multiple entities distributed in space and their movement characteristics

Spatial aggregation: positions in space \rightarrow areas (e.g. regular grid)

Temporal aggregation: moments in time \rightarrow intervals on time line or in time cycles

Attributive aggregation: individual values \rightarrow intervals (numeric) or subsets (qualitative)

\rightarrow compute various statistical summaries for the divisions (*use DB queries*) \rightarrow visualize

S×T-aggregation

Spatial aggregation: by cells of a regular rectangular grid

Temporal aggregation: by days of the week + by hours of the day

Resulting data structure: spatial time series

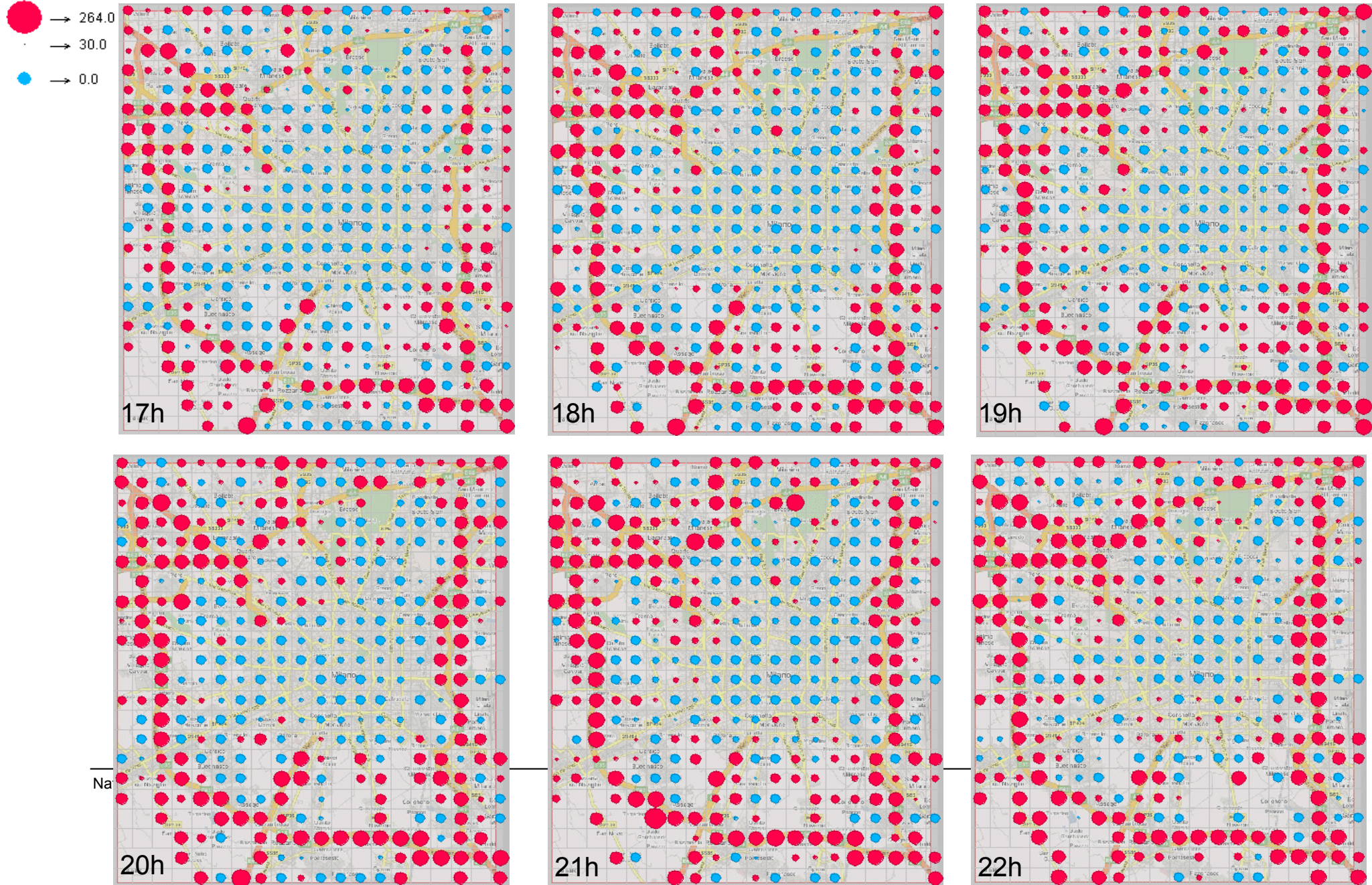
Various visualization techniques

(any techniques suitable for spatial time series data)

Car data aggregated by grid
median speed (Day of week=1)

Animated map with graduated symbols

Circle area is proportional to value: Attribute: median speed; day: **Monday**; hour: from 17 to 22 (states of the animated map); blue: <30; red: >30

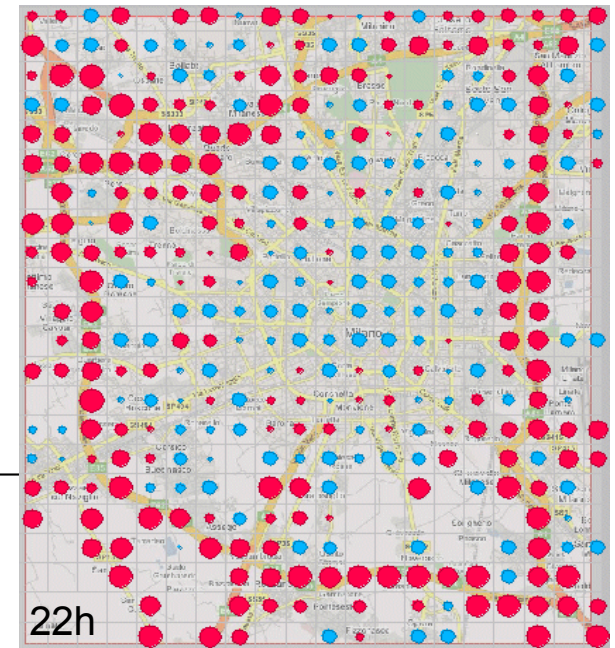
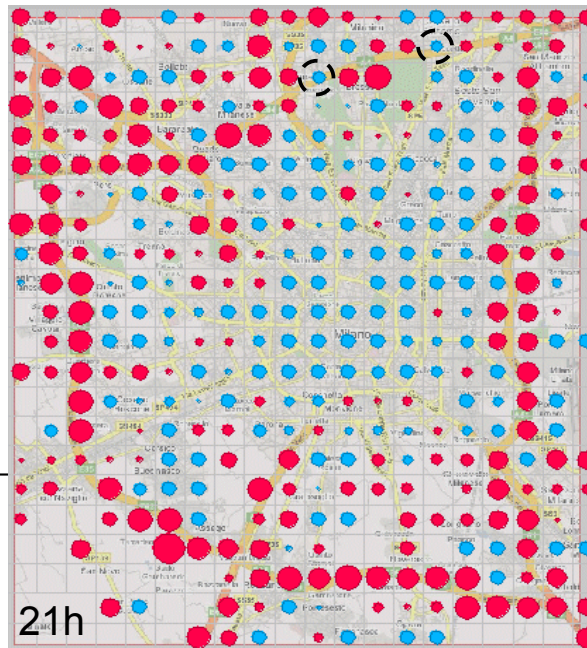
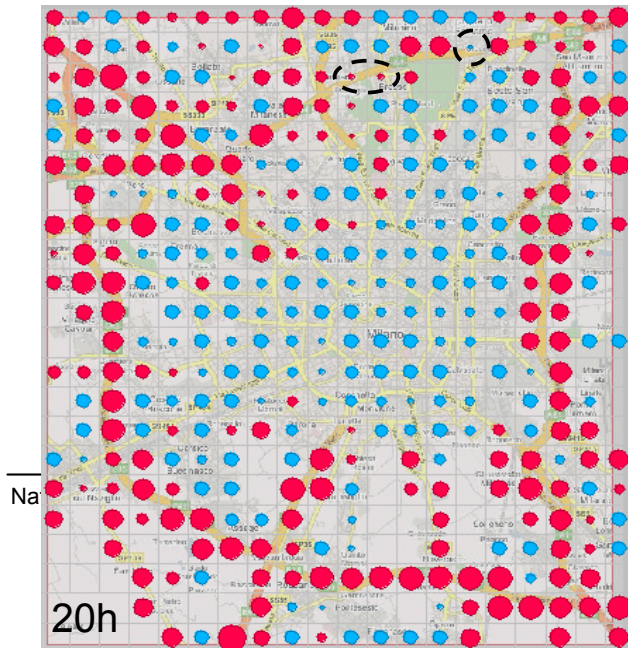
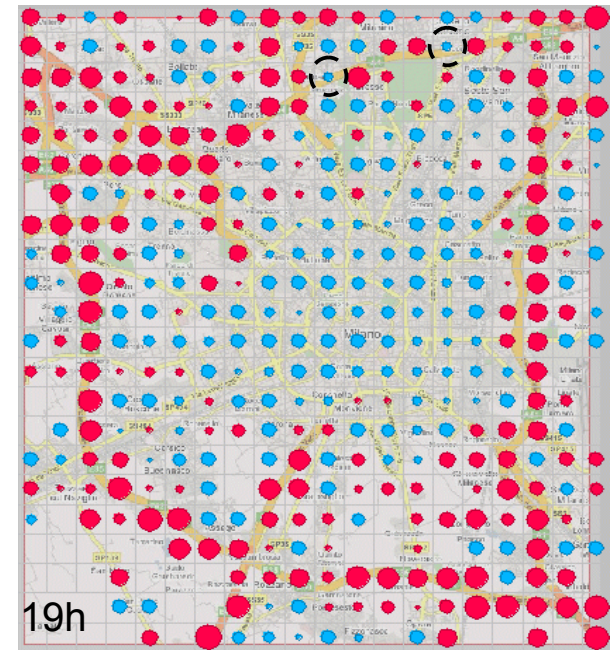
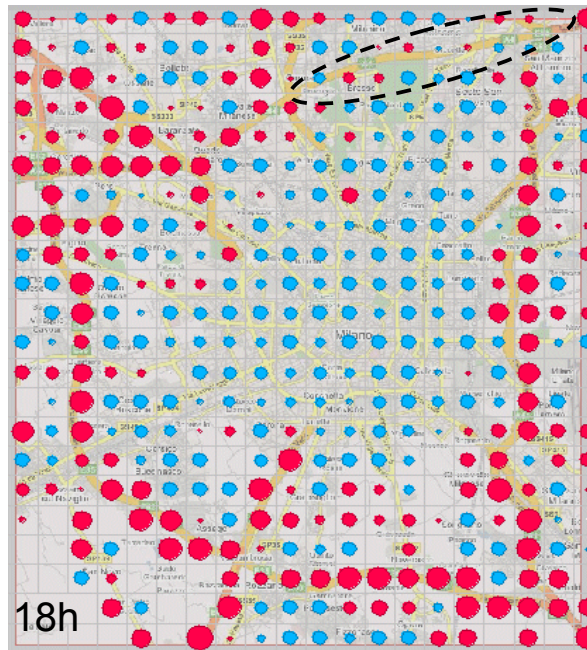
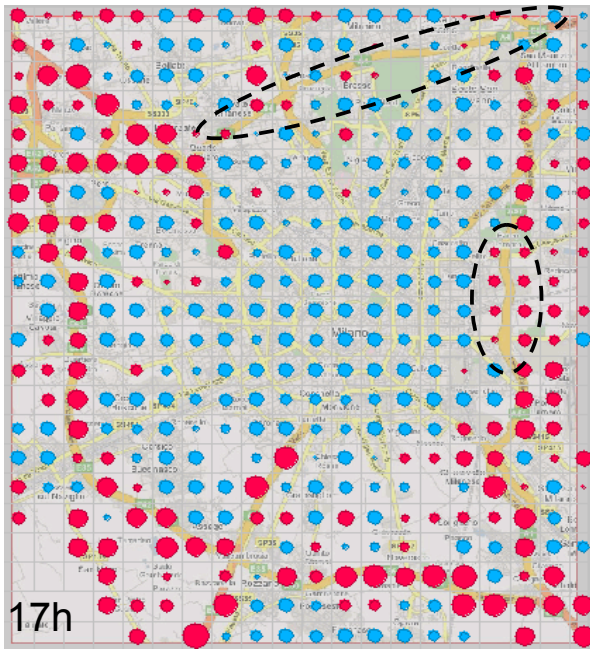
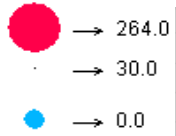


Na

Car data aggregated by grid
median speed (Day of week=1)

Too low speeds on the major belt roads

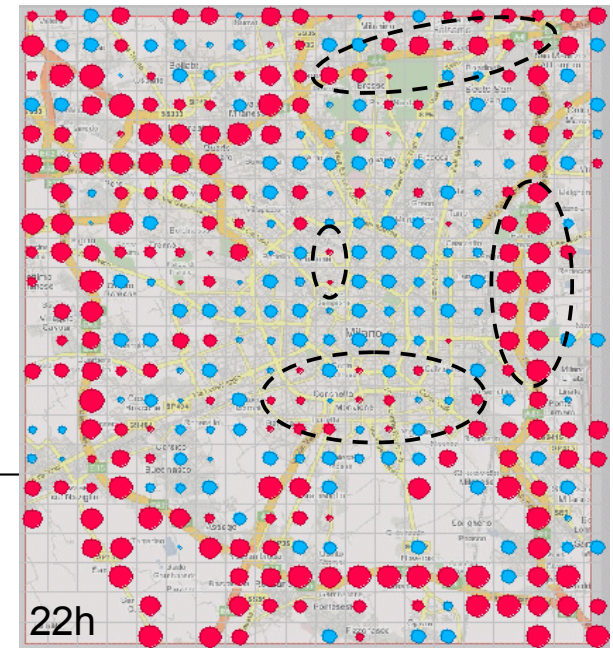
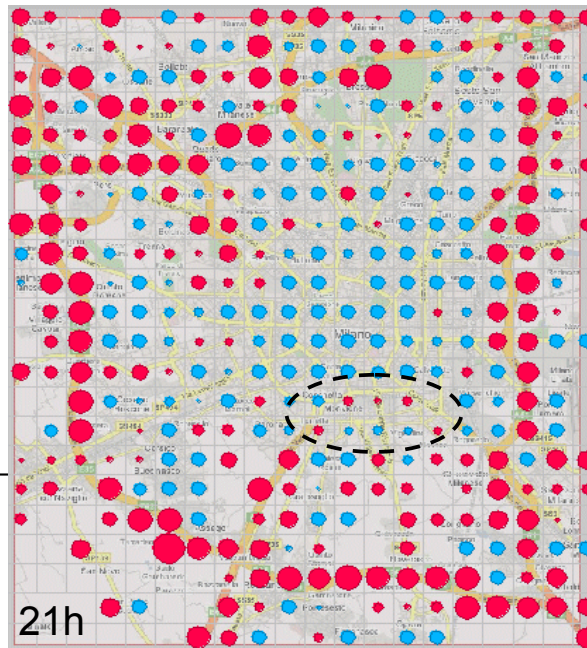
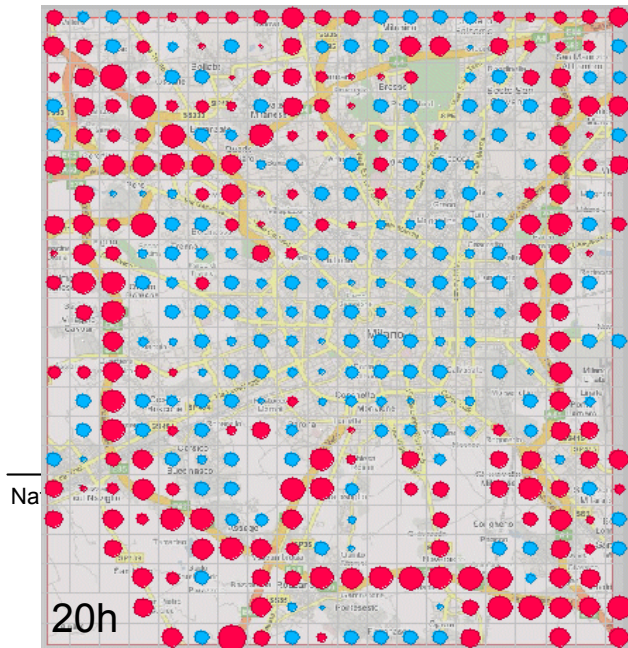
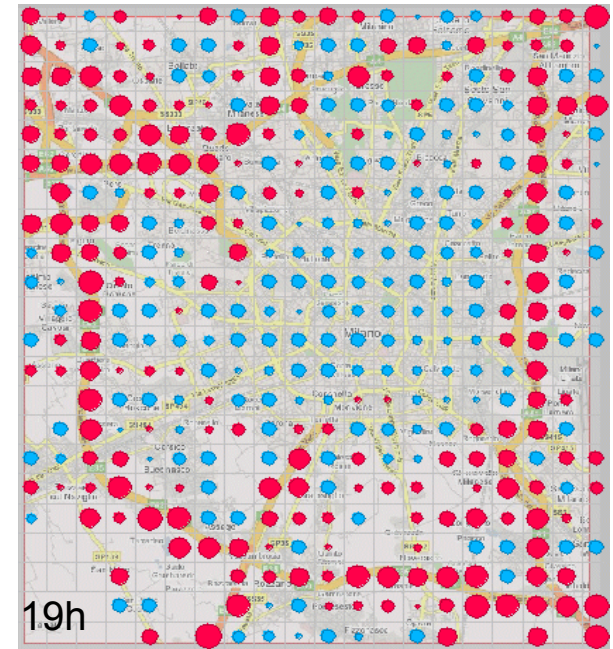
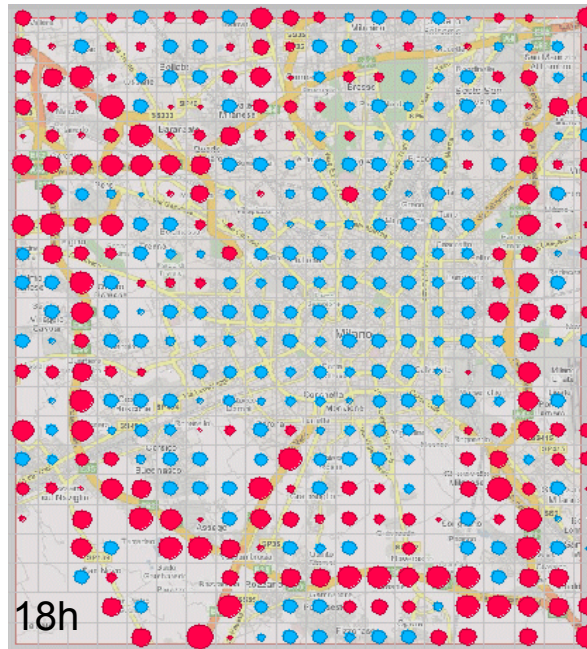
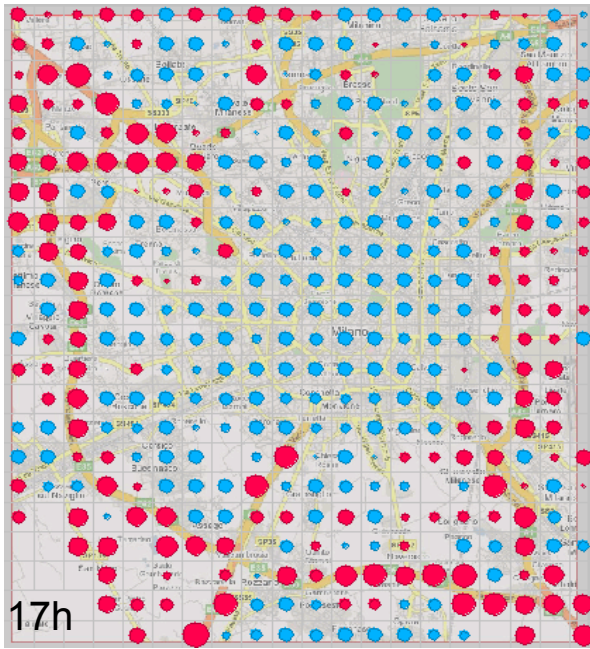
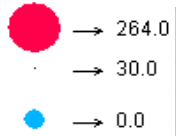
Circle area is proportional to value:



Car data aggregated by grid
median speed (Day of week=1)

Increase of speeds in late evening

Circle area is proportional to value:

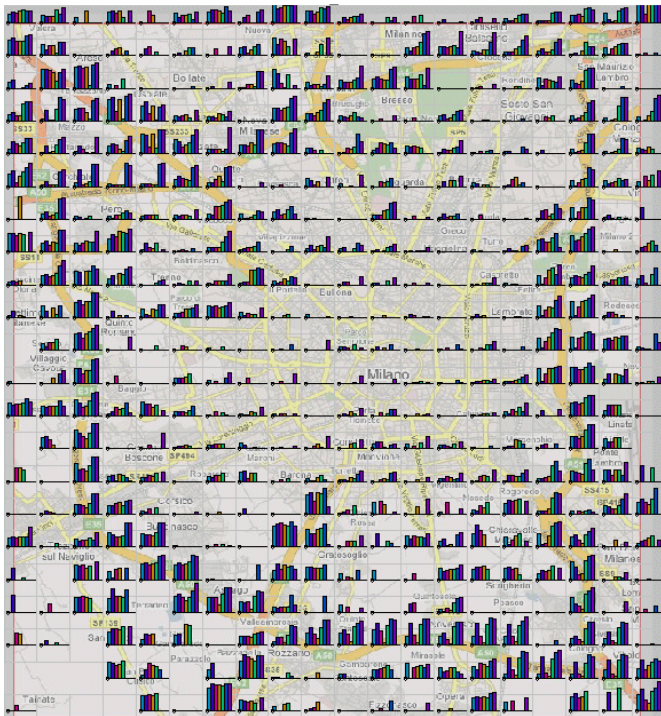


Na

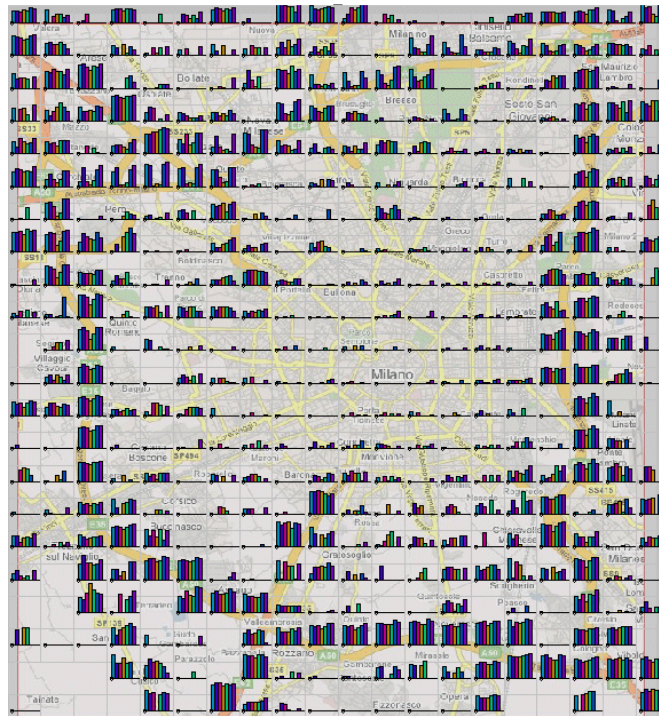
Animated map with bar diagrams

Attribute: median speed; days: **Monday to Sunday** (bars of the diagrams); hour: 7, 11, 20 (states of the animated map)

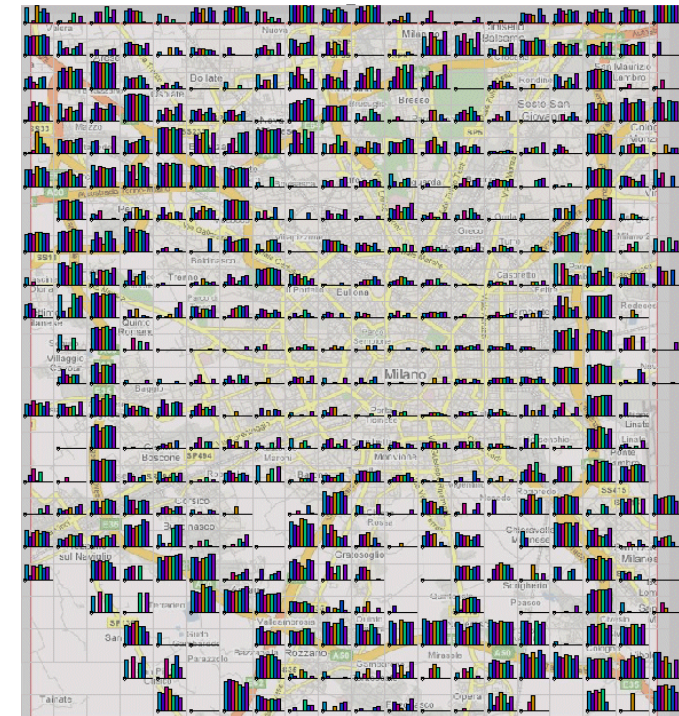
7h



11h

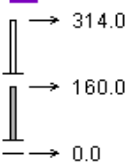


20h



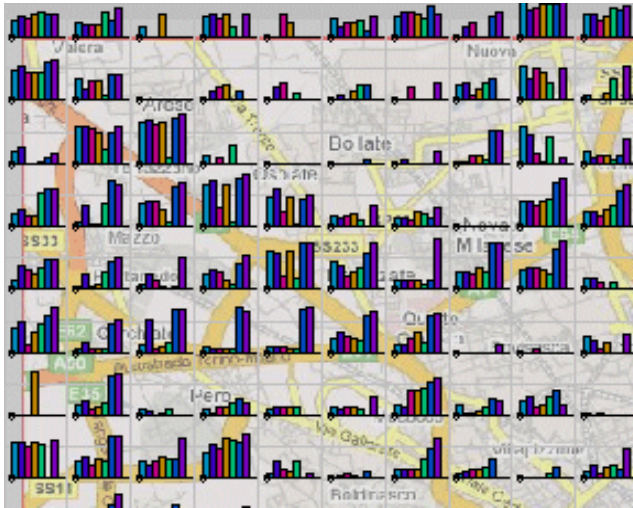
Car data aggregated by grid

- median speed (Day of week=1)
- median speed (Day of week=2)
- median speed (Day of week=3)
- median speed (Day of week=4)
- median speed (Day of week=5)
- median speed (Day of week=6)
- median speed (Day of week=7)

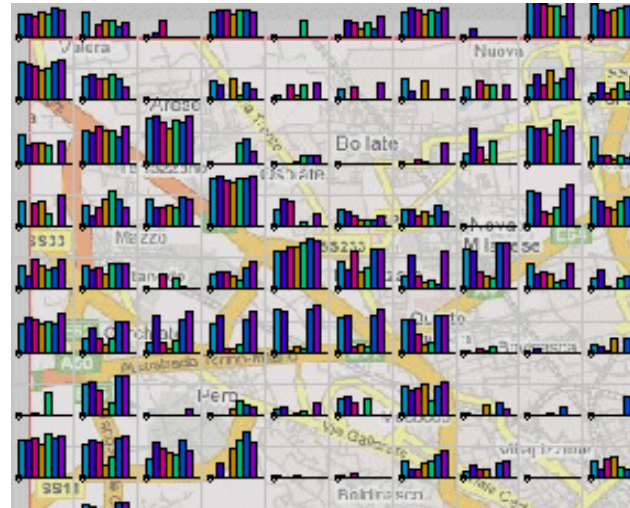


Same as previous; map fragment

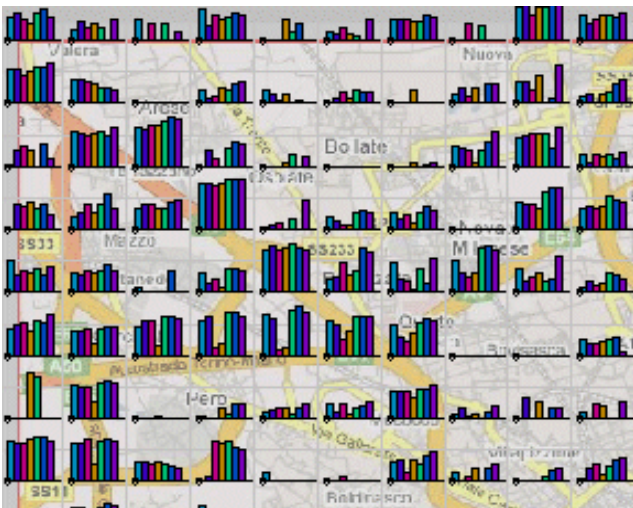
7h



11h



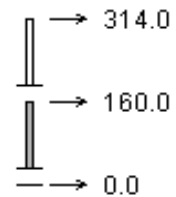
15h



20h



- Car data aggregated by grid
- median speed (Day of week=1)
 - median speed (Day of week=2)
 - median speed (Day of week=3)
 - median speed (Day of week=4)
 - median speed (Day of week=5)
 - median speed (Day of week=6)
 - median speed (Day of week=7)

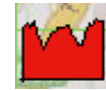
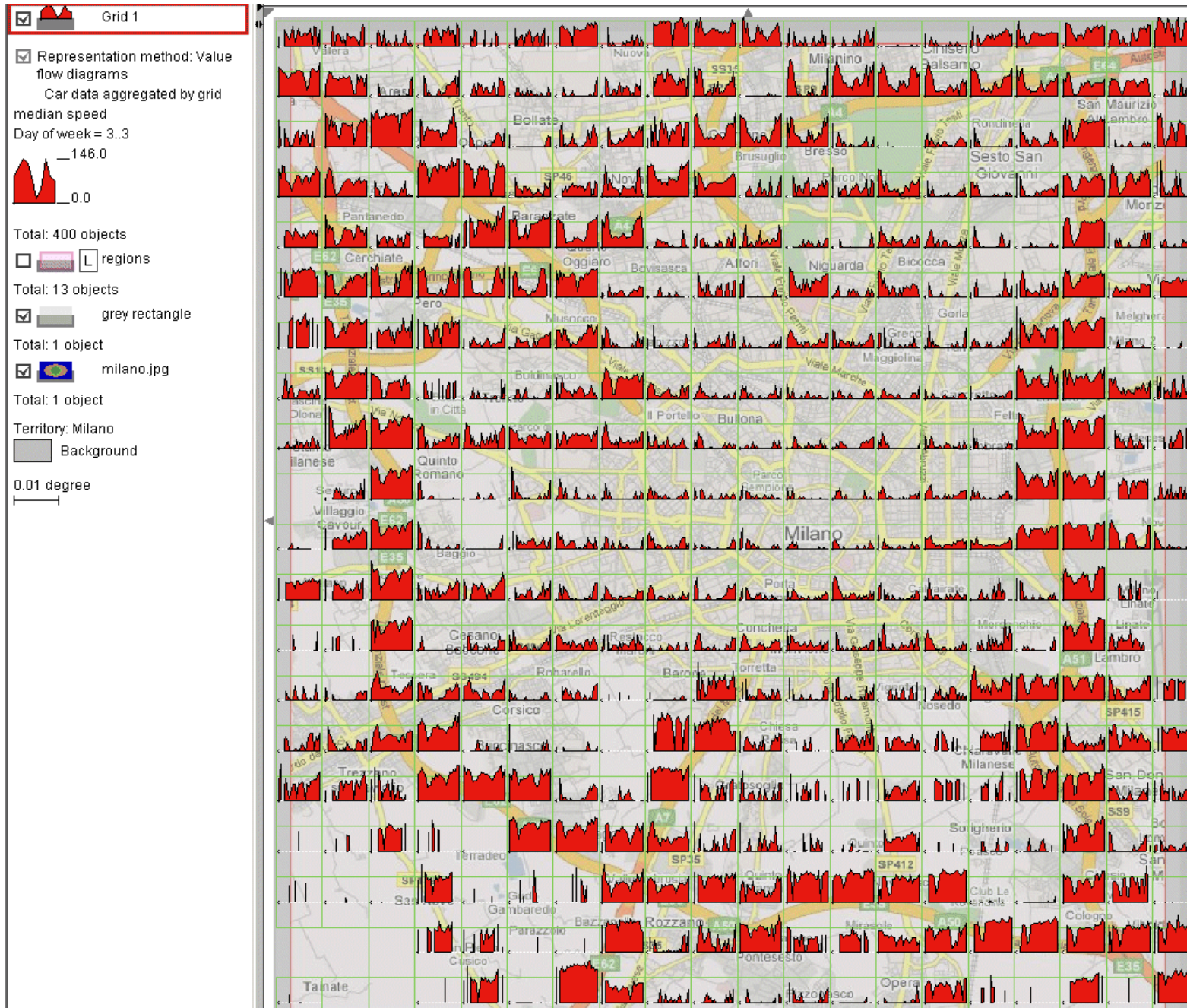


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Map with value flow diagrams

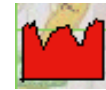
Attribute: median speed; day: **Wednesday**; hour: from 0 to 23



A frequent temporal pattern: significant drop of the speed in the morning and afternoon rush hours

Map with value flow diagrams

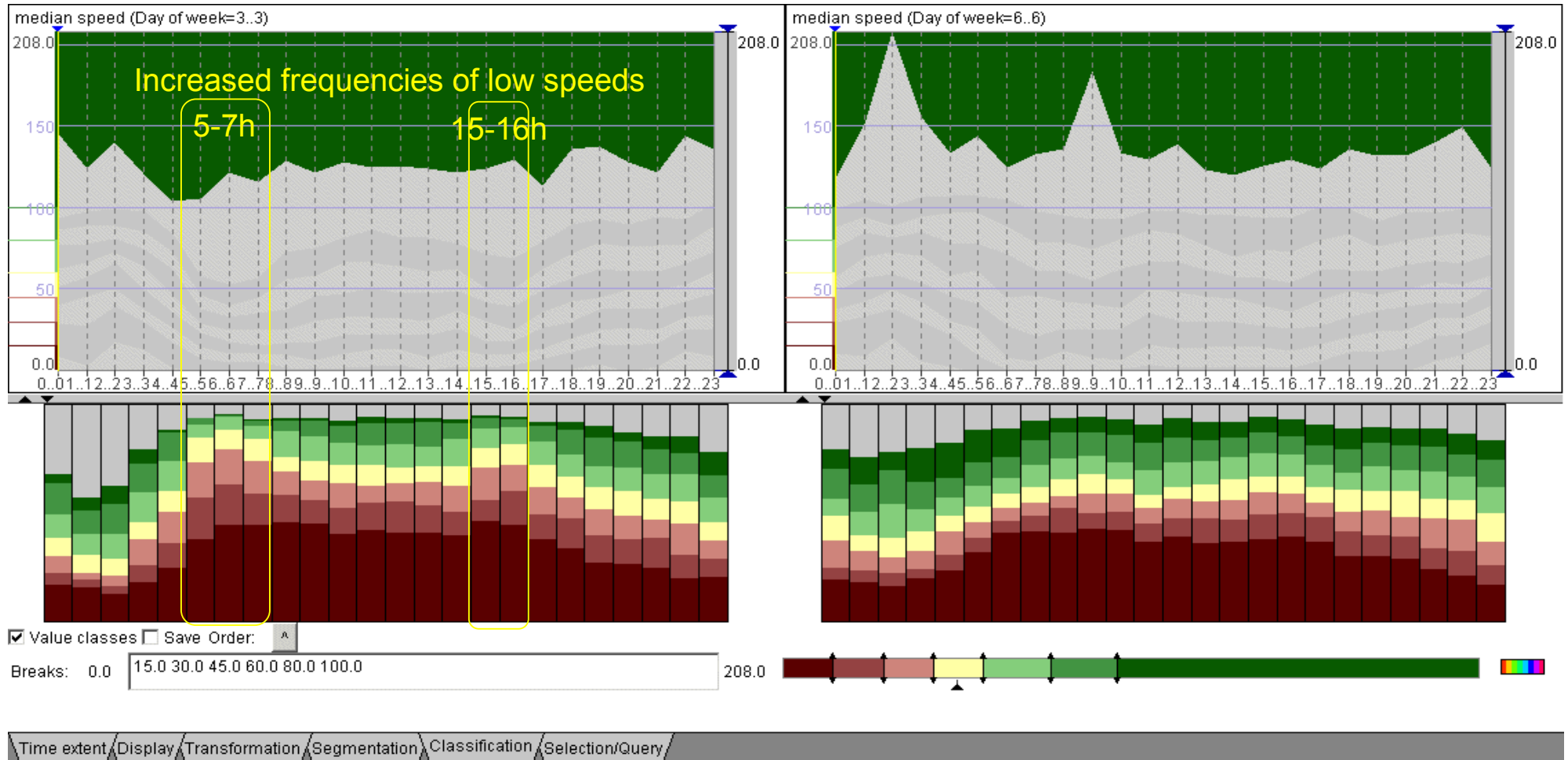
Attribute: median speed; day: Saturday; hour: from 0 to 23



This temporal pattern does not occur on Saturday

Variation of value frequencies over time

Attribute: median speed; days: **Wednesday** and **Saturday**; hour: from 0 to 23; space: all compartments (grid cells)

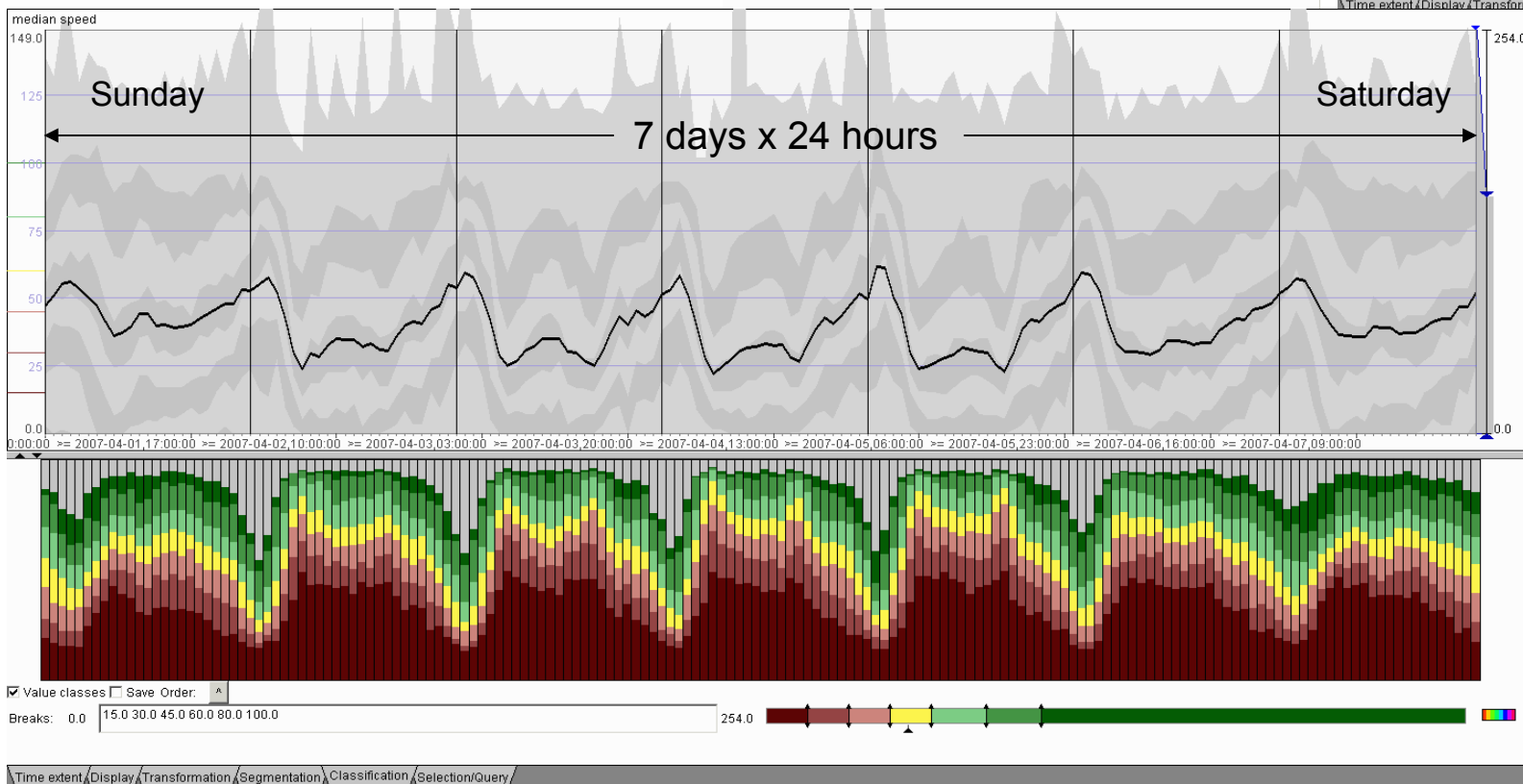
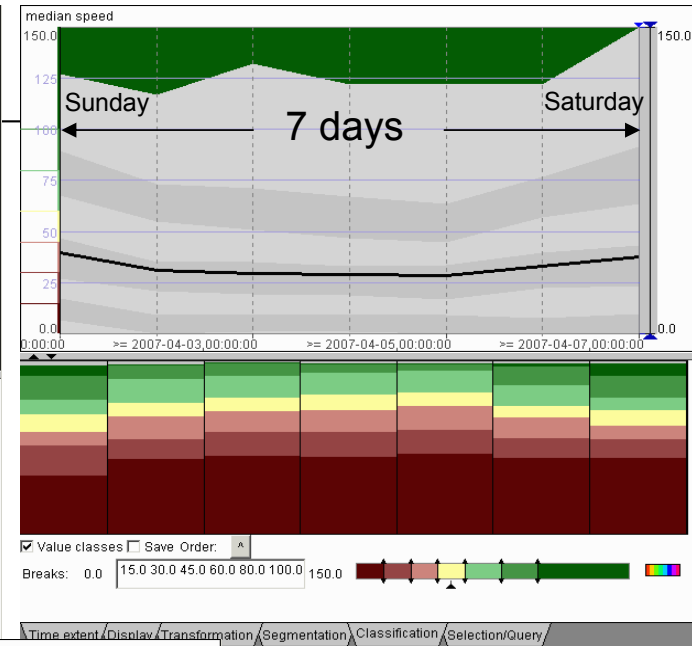
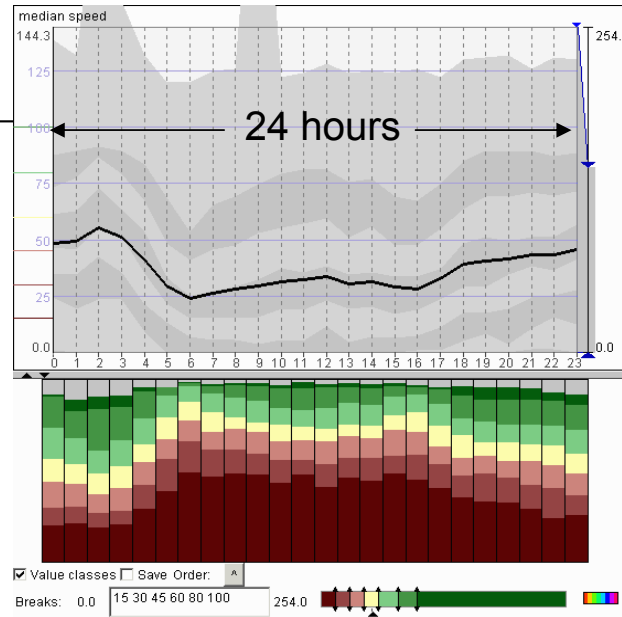


Variation of the median speeds in the spatial compartments:

24 hours (all days);

7 days (all times of the day);

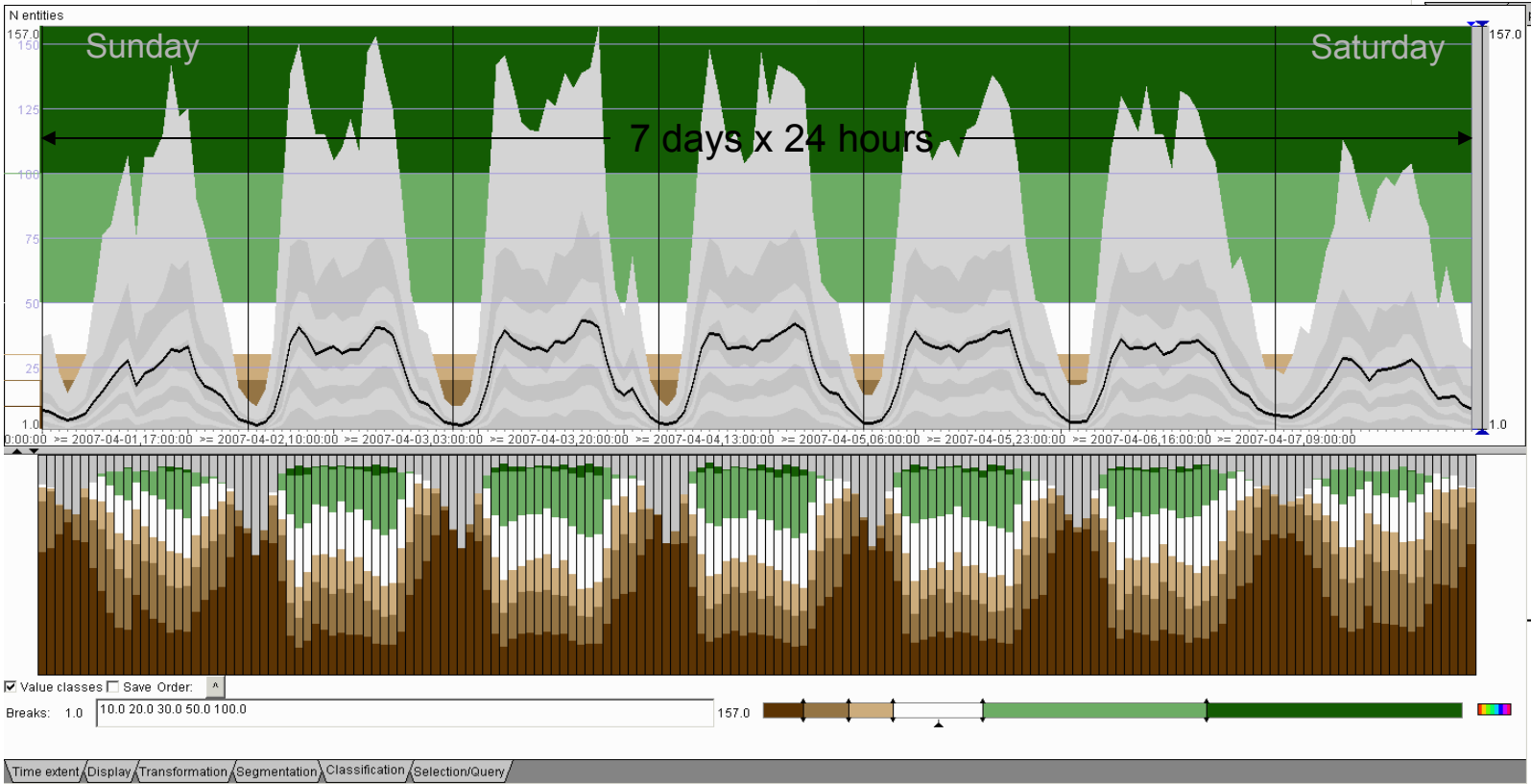
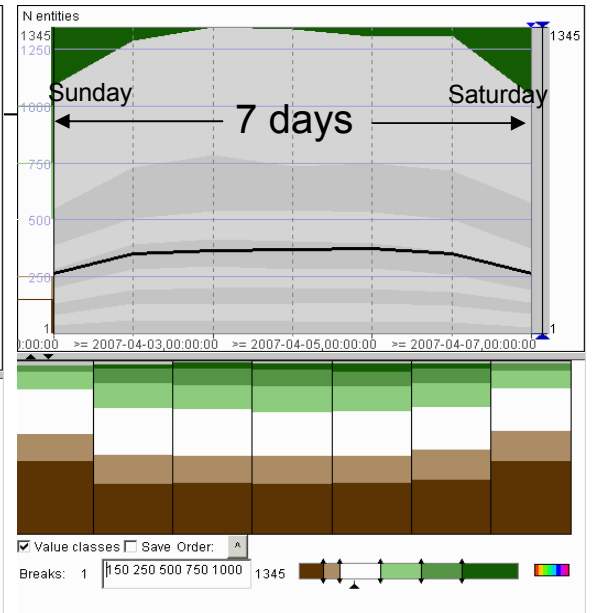
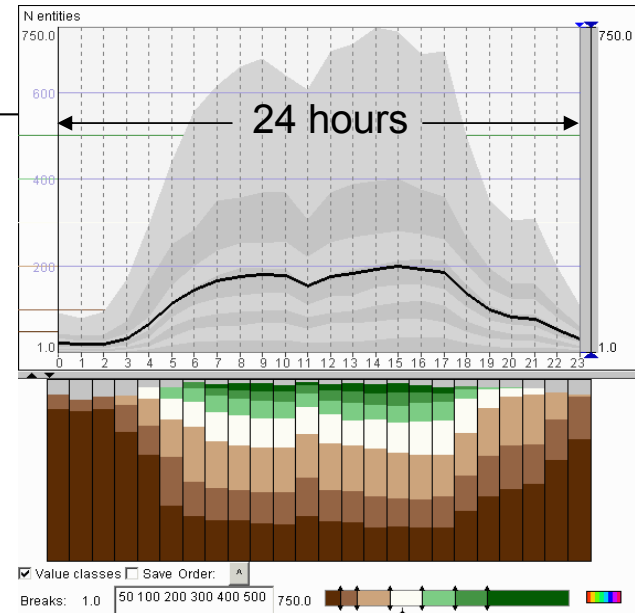
7 days x 24 hours



Note the similarity of the daily patterns from Monday to Thursday and the difference of the Friday pattern

Variation of the numbers of cars in the spatial compartments:

- 24 hours;
- 7 days;
- 7 days x 24 hours

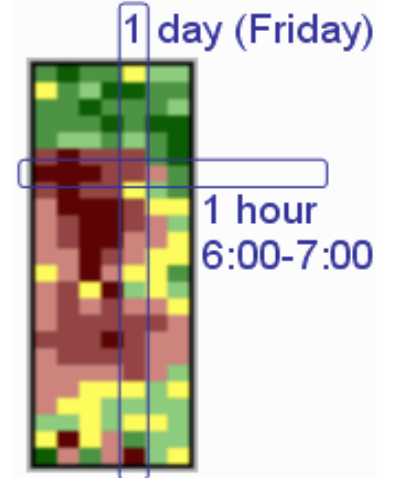
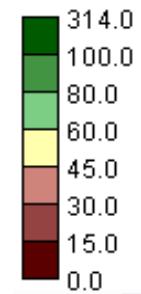


Map with mosaic diagrams

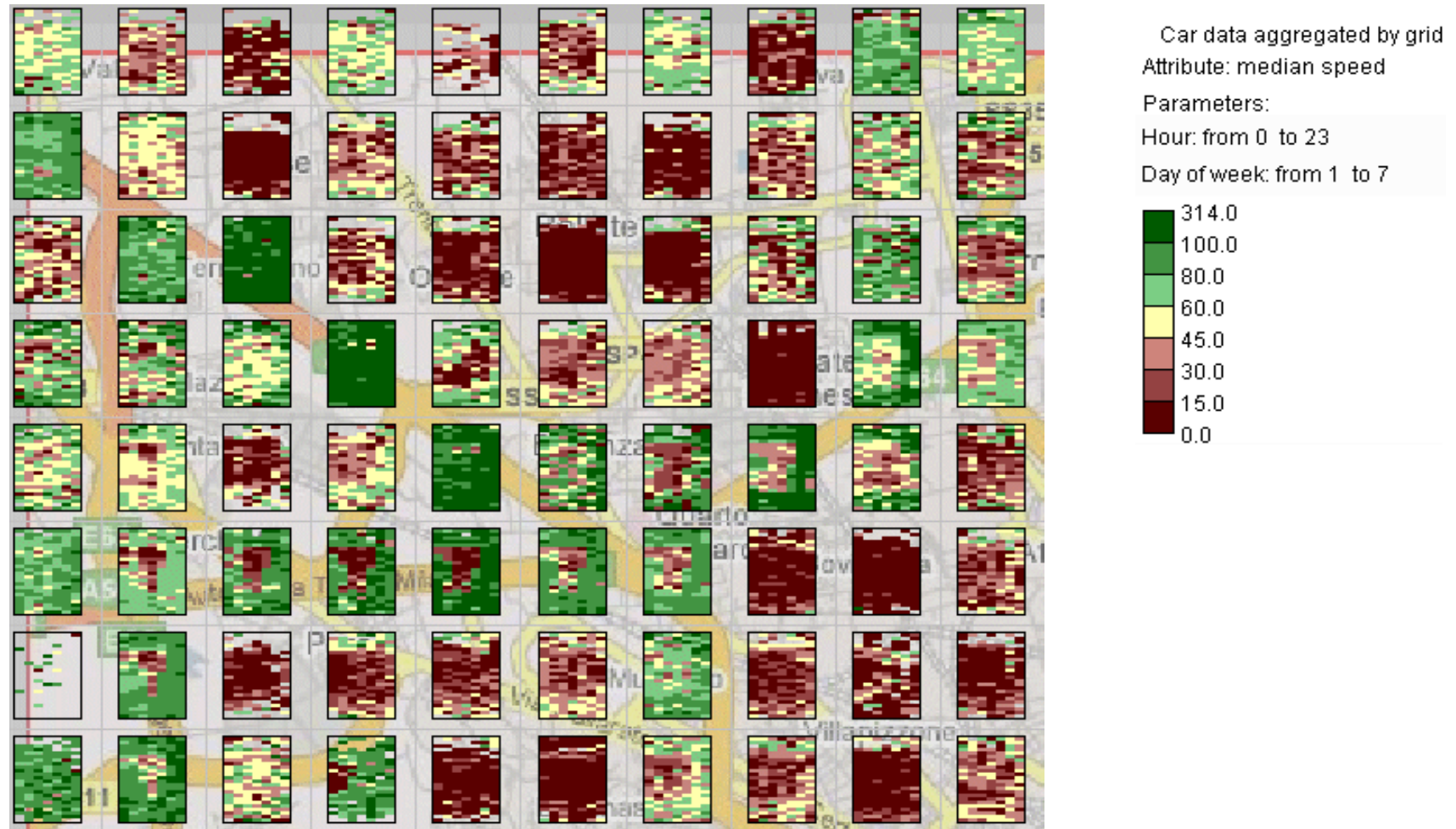
Attribute: median speed; columns of the mosaic diagrams: days of the week; rows: hours of the day



Car data aggregated by grid
Attribute: median speed
Parameters:
Hour: from 0 to 23
Day of week: from 1 to 7

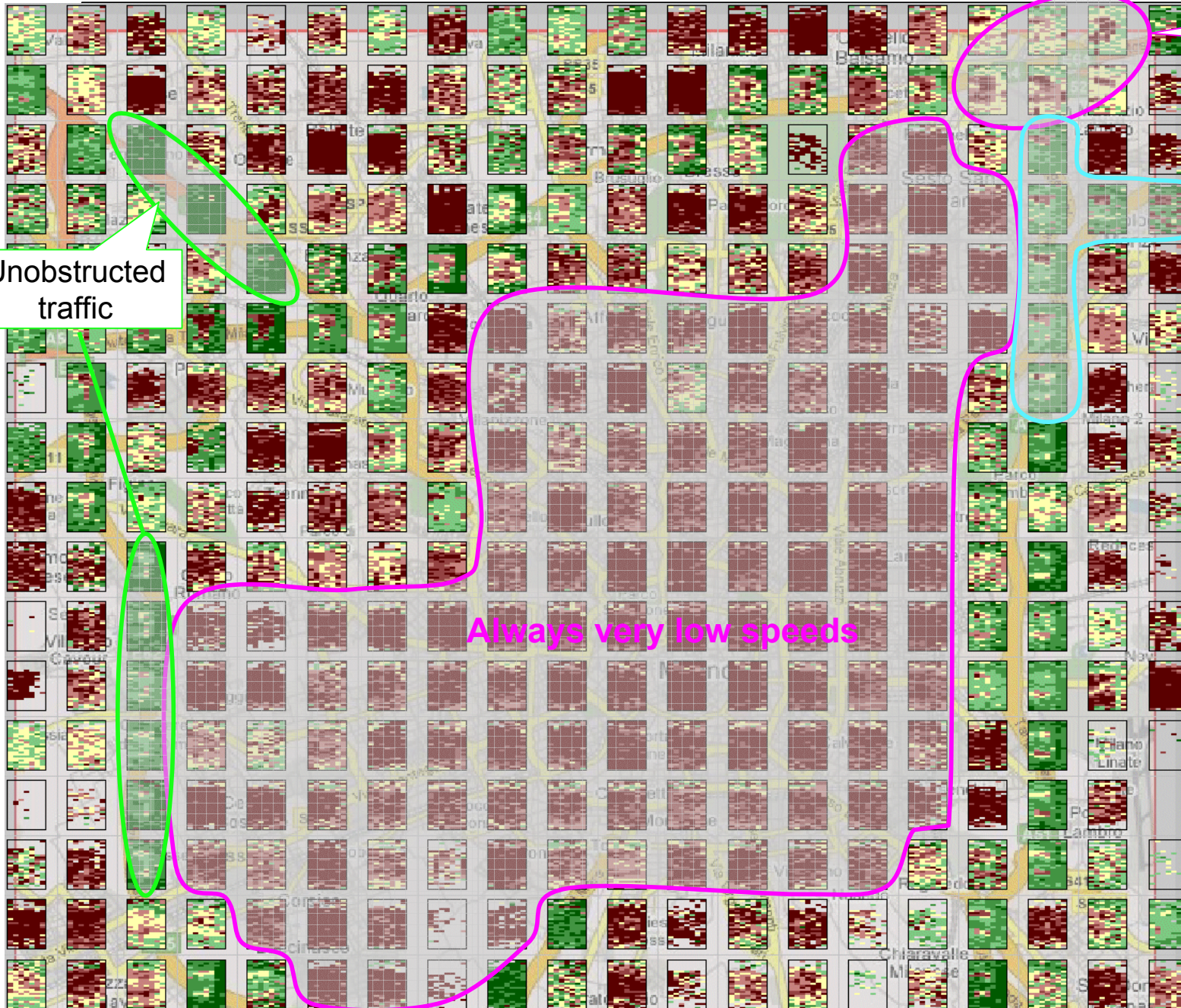


A fragment of the map from the previous slide: northwest of Milan



Map with mosaic diagrams

Attribute: median speed; columns of the mosaic diagrams: days of the week; rows: hours of the day



Normal driving only in the night

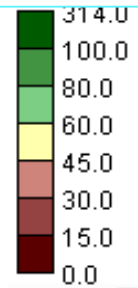
Unobstructed traffic

Slow traffic in the workday mornings

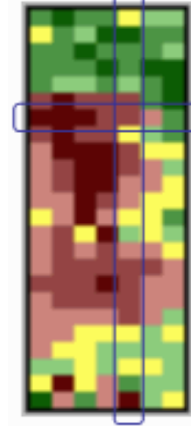
Always very low speeds

Car data aggregated by grid
Attribute: median speed

Slow traffic in the workday mornings

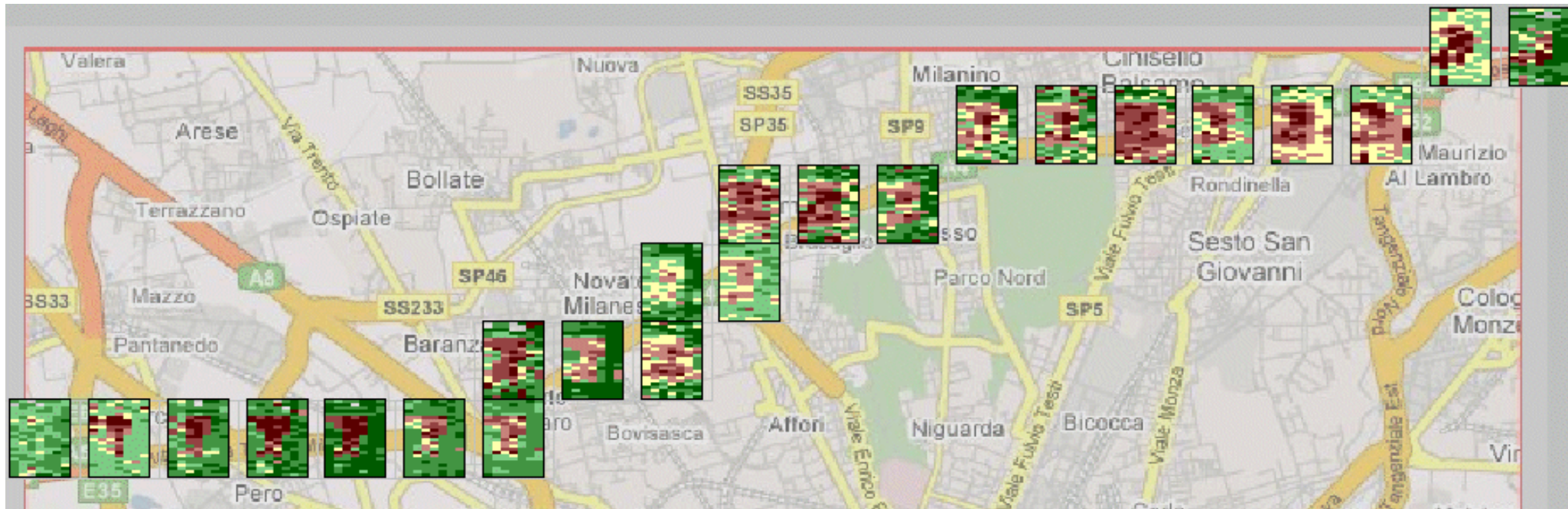


1 day (Friday)

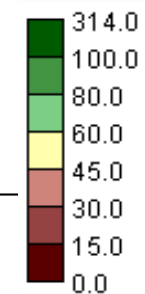


1 hour
6:00-7:00

Exploration of the traffic on a particular road (selected spatial compartments)



Car data aggregated by grid
Attribute: median speed
Parameters:
Hour: from 0 to 23
Day of week: from 1 to 7



S×T×A-aggregation

Spatial aggregation: by cells of a regular rectangular grid

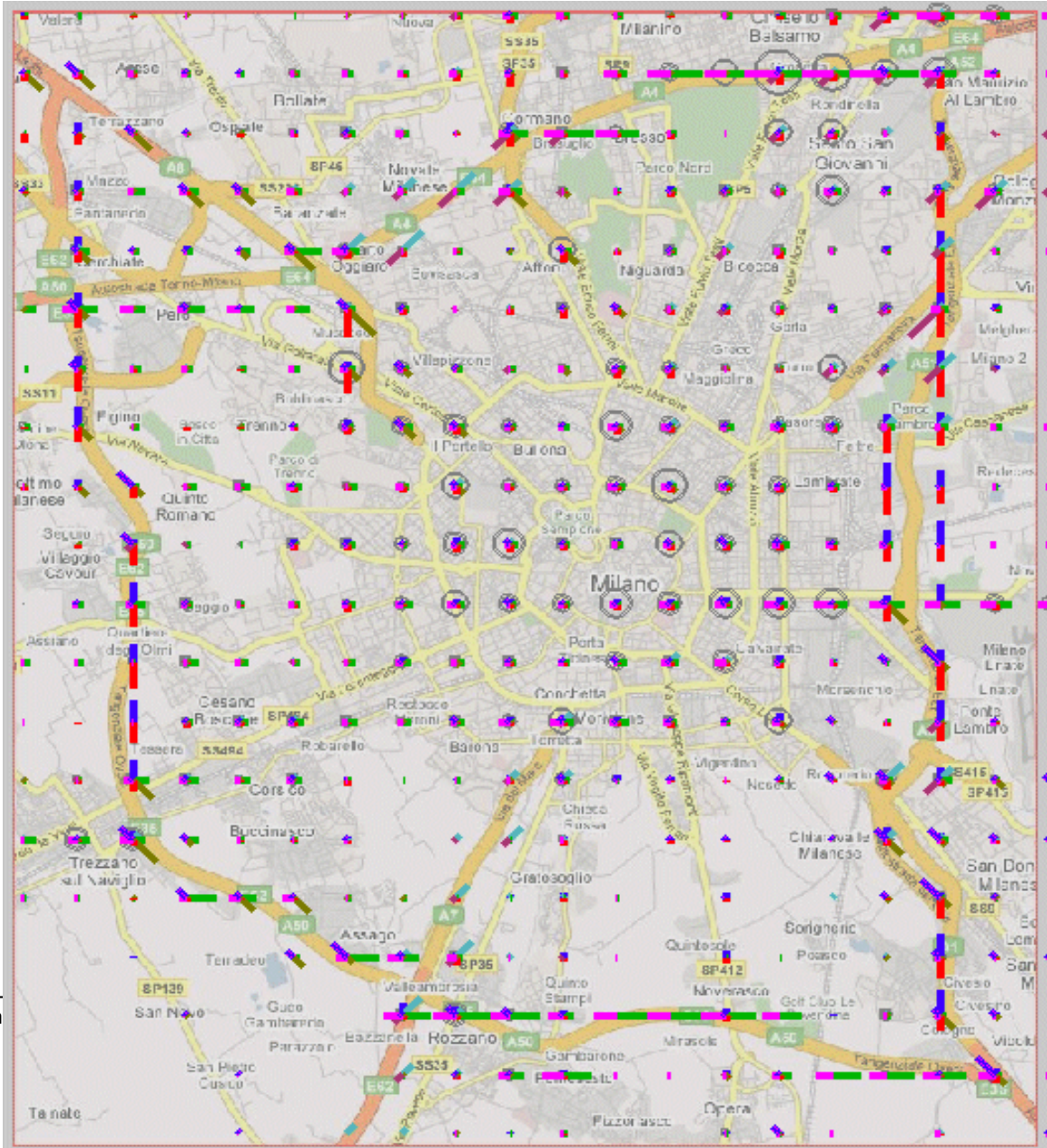
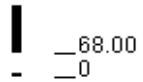
Temporal aggregation: by days of the week + by hours of the day

Attributive (directional) aggregation: 8 movement directions
(N, NE, E, SE, S, SW, W, NW)

Visualization: map with directional bar diagrams

The bar lengths are proportional to the numbers of the cars moving in the respective directions.
 The radii of the circles are proportional to the numbers of the cars having the speed below the specified threshold (5km/h).
 Selected day: Monday; selected hour: 7h

Car data aggregated by grid
 N of cars
 Hour = 7..7
 Day of week = 1..1
 No move (speed < 5.0, shown by circles) + 9 directions; all are shown



Attribute: N of cars

- N of cars
- N of visits
- median speed

Hour: 7..7

Day of week: 1..1

- 1..1
- 2..2
- 3..3
- 4..4
- 5..5
- 6..6
- 7..7

0.00 Focus: 68.00

0.00 68.00

<input checked="" type="checkbox"/> 0	<input checked="" type="checkbox"/> N	<input checked="" type="checkbox"/> NE	<input checked="" type="checkbox"/> E	<input checked="" type="checkbox"/> SE
<input checked="" type="checkbox"/> S	<input checked="" type="checkbox"/> SW	<input checked="" type="checkbox"/> W	<input checked="" type="checkbox"/> NW	

Dominant directions only, threshold:

- ratio(%) to next: 0
- difference to next: 0.00

Display manipulator:

- Select aggregate attribute
- Select day of the week
- Select hour of the day
- Select directions
- Focus on a value interval
- Switch to showing only dominant directions and specify parameters

Effect of focusing on a value interval (selected interval: from 10 to 40)

Grid 1

Visualization method:
Direction & speed diagrams
Car data aggregated by grid

N of cars
Hour = 7..7
Day of week = 1..1
No move (speed < 5.0, shown by circles) + 9 directions; all are shown

Legend:
 — 68.00
 — 40.00
 - - 10.00
 - - 0

The maximum bar length corresponds to the value 40

milano.jpg

Total: 1 object
Territory: Milano
Background

0.02 degree

Value >40

Attribute: N of cars

N of cars
 N of visits
 median speed

Hour: 7..7

Day of week: 1..1

1..1
 2..2
 3..3
 4..4
 5..5
 6..6
 7..7

10.00 Focus: 40.00
0.00 68.00

0 N NE E SE
 S SW W NW

Dominant directions only, threshold:
 ratio(%) to next: 0
 difference to next: 0.00

Show only selected objects

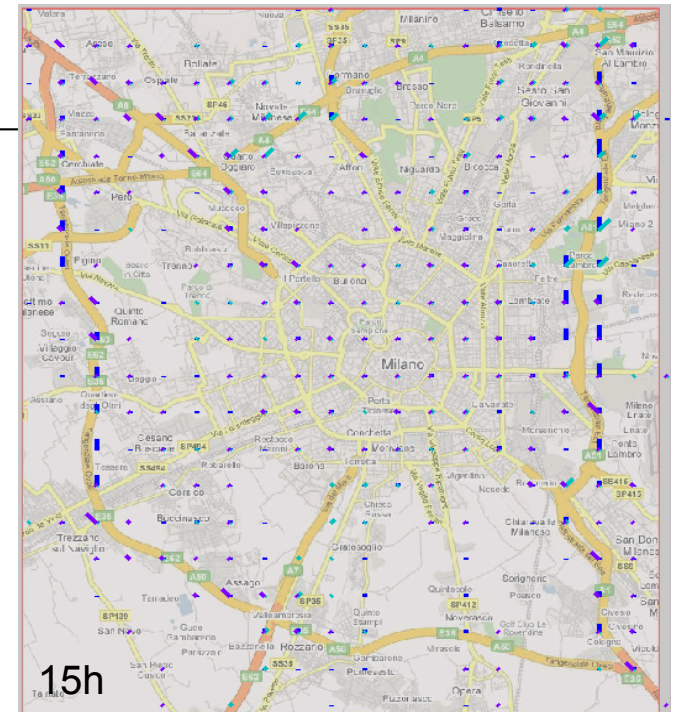
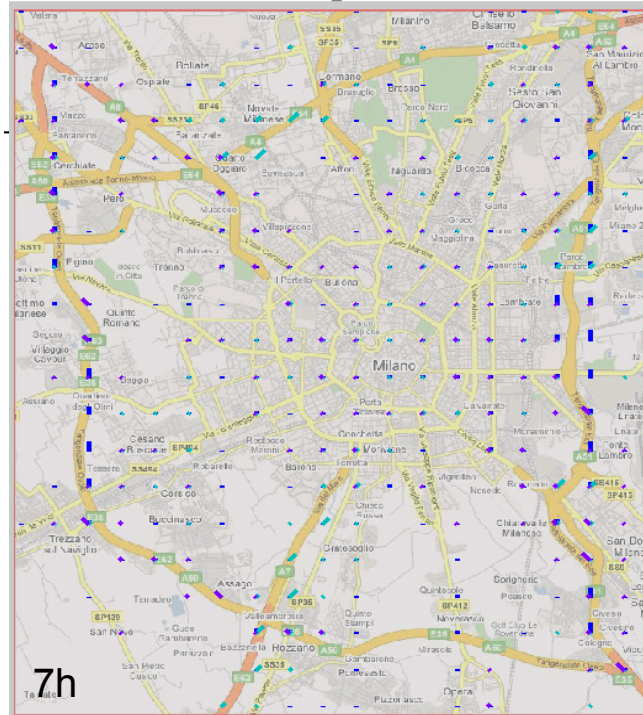
Setup diagrams

Manipulate

Table Car data aggregated by grid has been attached to layer Grid 1

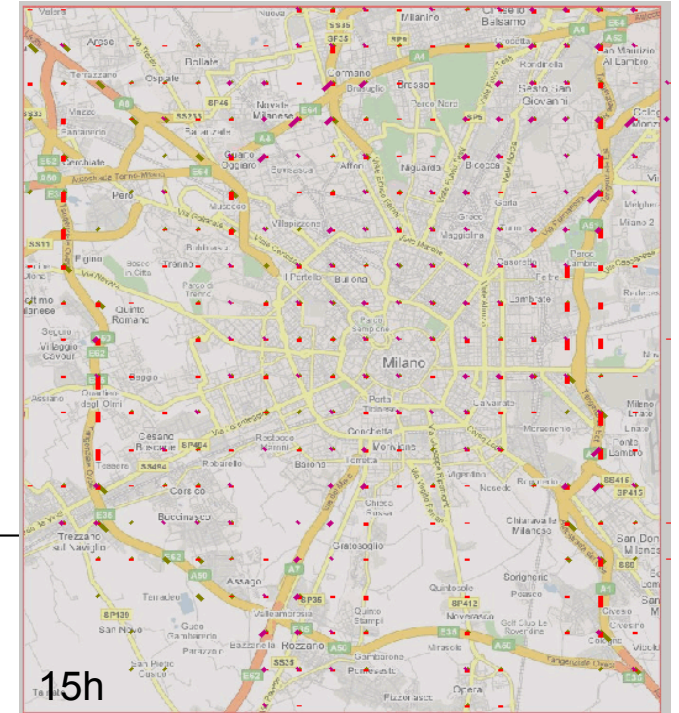
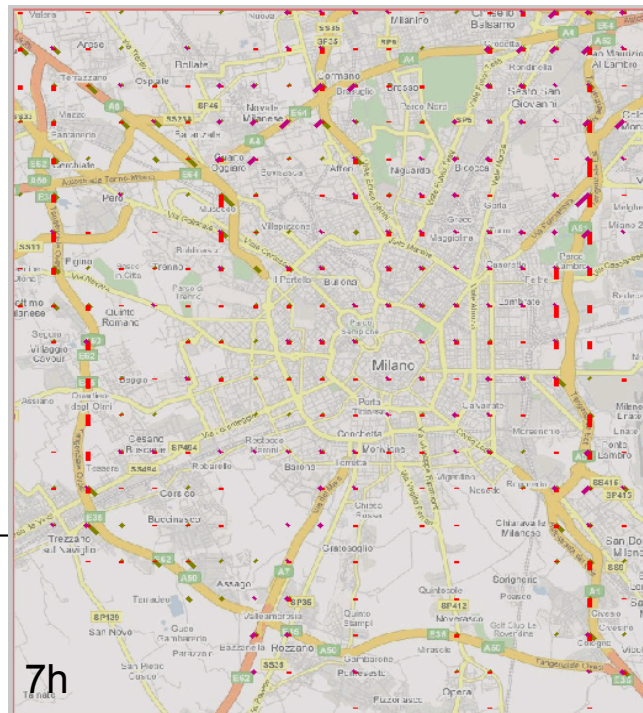
North,
northwest,
northeast

Focusing on
particular directions



South,
southwest,
southeast

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Dominant movement directions (+ focusing)

The user specifies when a direction must be treated as dominant (see the lower right corner)

Here: attribute value must be at least 25% higher than the next value

Grid 1

- Visualization method:
Direction & speed diagrams
Car data aggregated by grid
- N of cars
- Hour = 7..7
- Day of week = 1..1
- No move (speed < 5.0, shown by circles) + 9 directions; all are shown
- Only segments with maximal value (or less by 25.0 %) are shown in each sign

Legend:

- 68.00
- 55.00
- 5.00
- 0

Total: 400 objects

- regions
- grey rectangle
- milano.jpg
- Background

0.02 degree

Attribute: N of cars

- N of cars
- N of visits
- median speed

Hour: 7..7

Day of week: 1..1

- 1.1
- 2.2
- 3.3
- 4.4
- 5.5
- 6.6
- 7.7

5.00 Focus: 55.00

0.00 68.00

- 0
- N
- NE
- E
- SE
- S
- SW
- W
- NW

Dominant directions only, threshold:

ratio(%) to next: 25.0

0 100.0

difference to next: 0.00

Show only selected objects

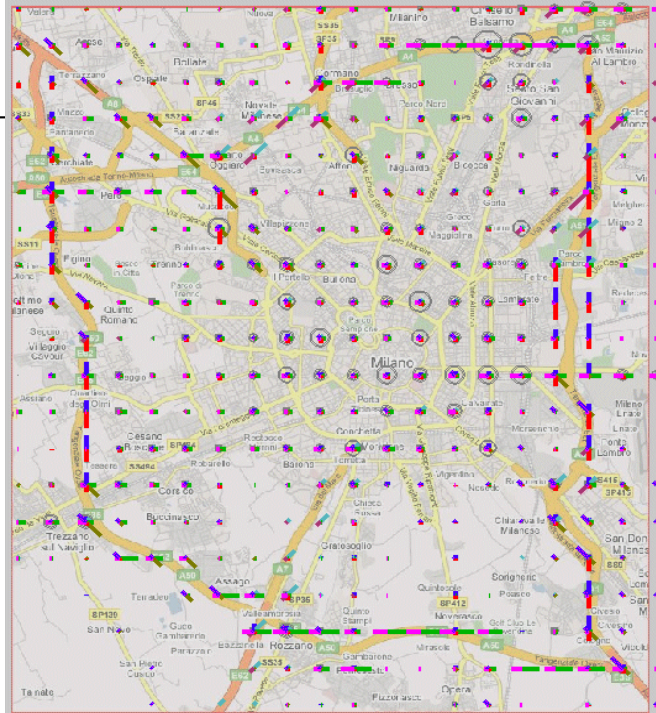
Setup diagrams

Manipulate

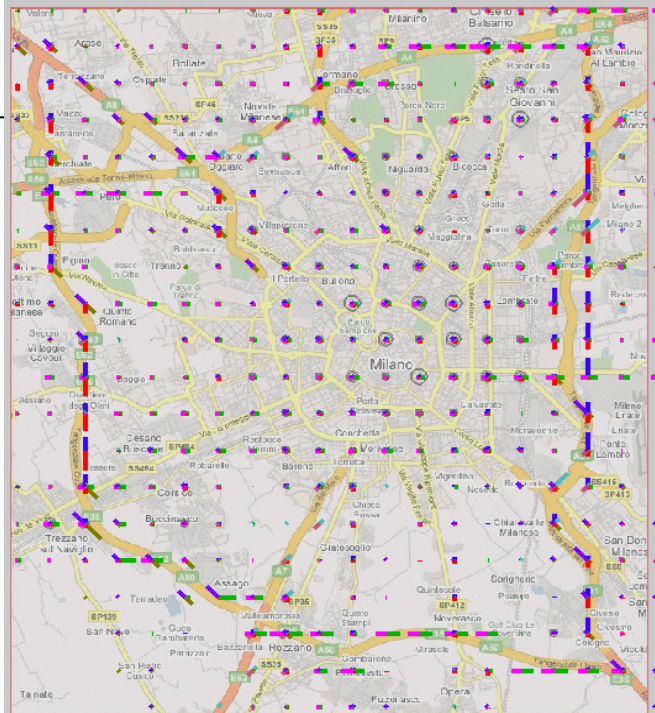
Table Car data aggregated by grid has been attached to layer Grid 1

Traffic in different directions by hours of a day
Attribute: N of cars
Day of week: Monday

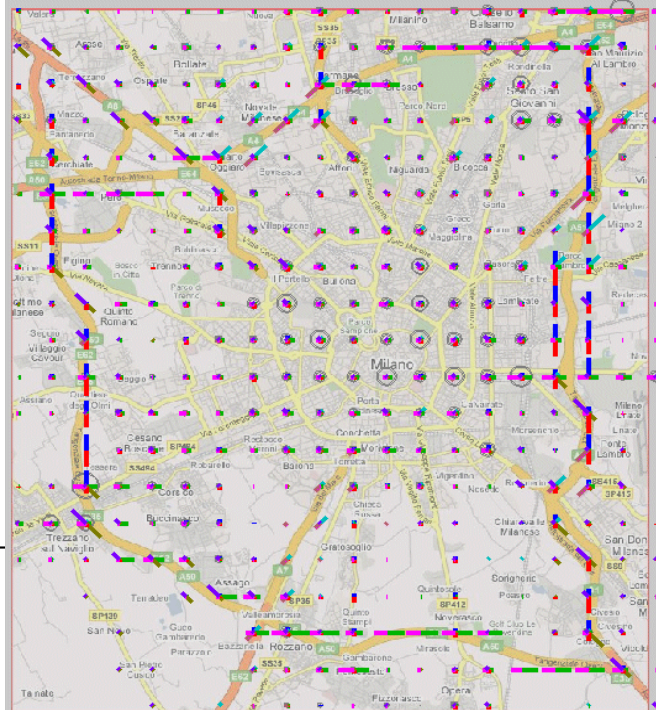
7h



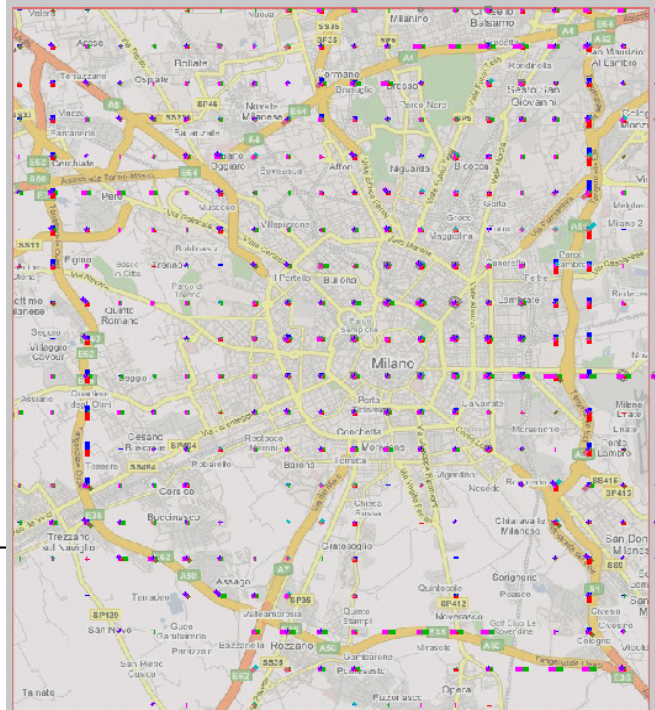
11h



15h

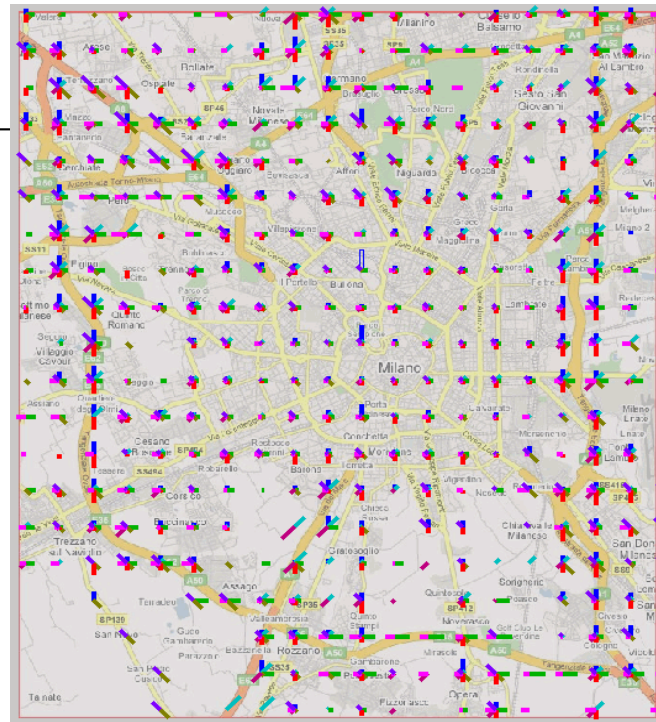


19h

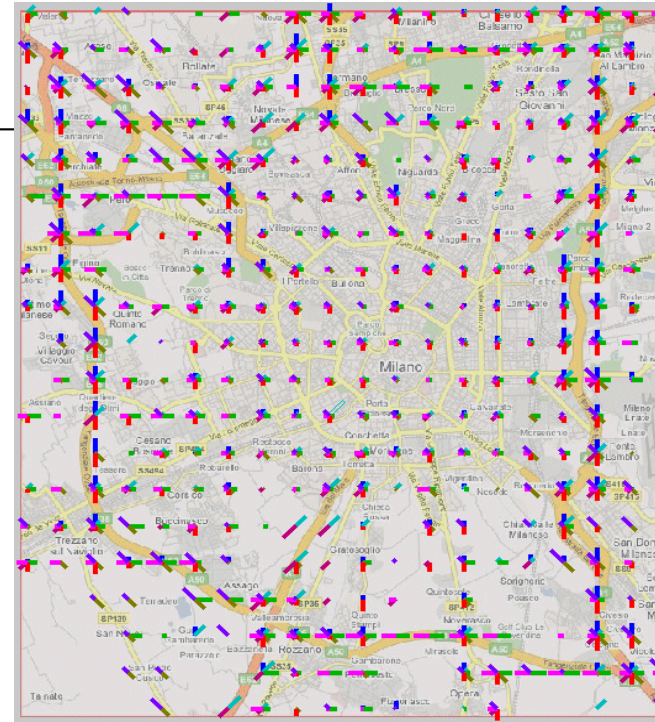


Traffic in different directions by hours of a day
Attribute: median speed
Day of week: **Monday**

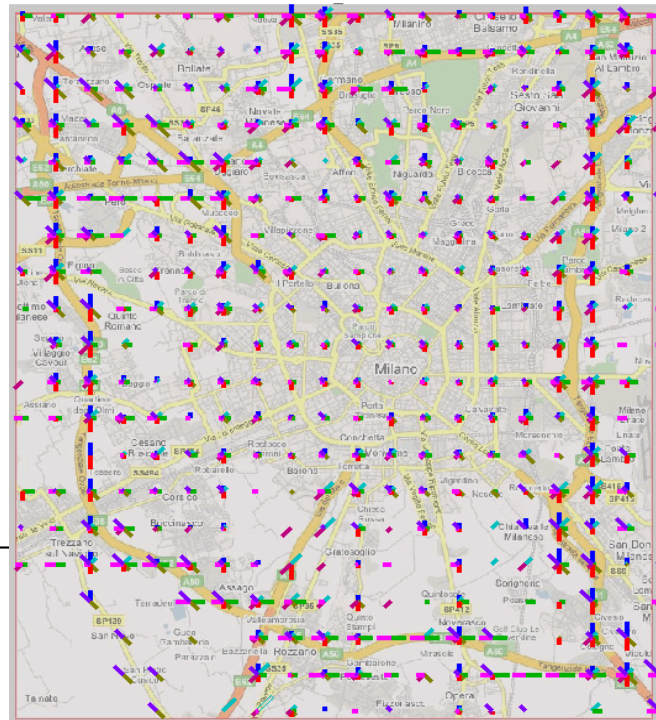
7h



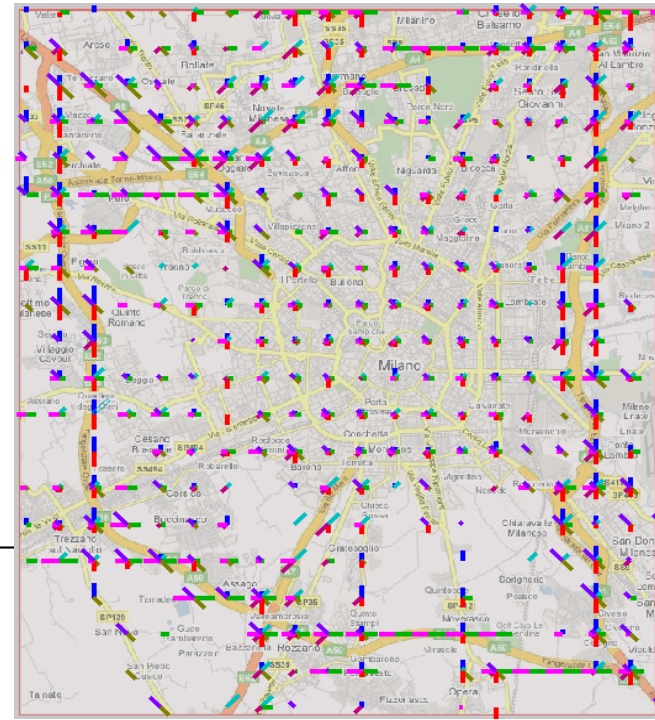
11h



15h



19h



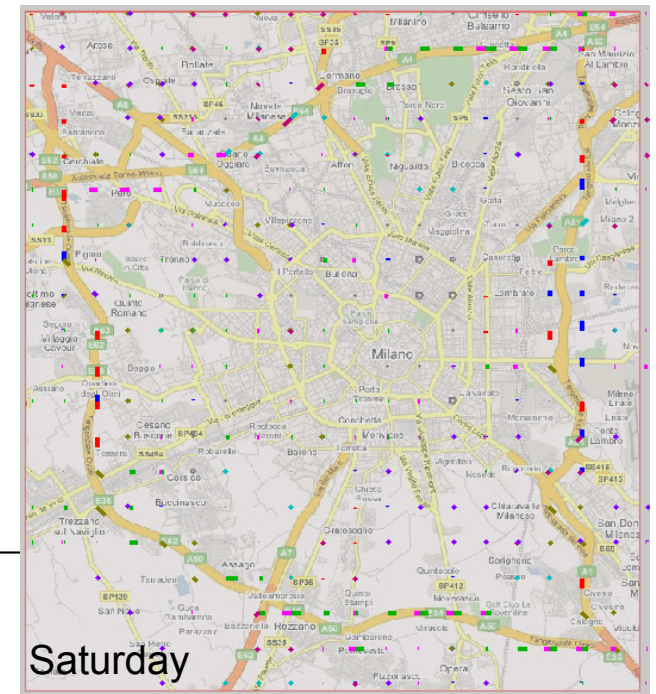
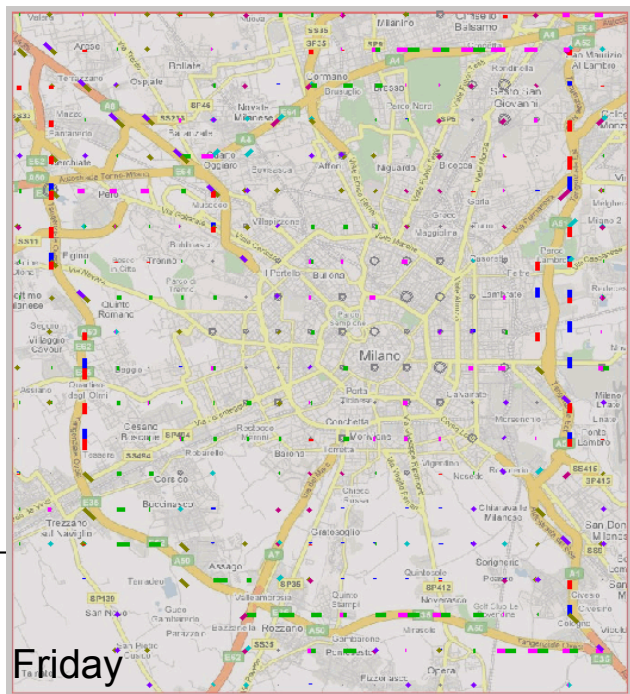
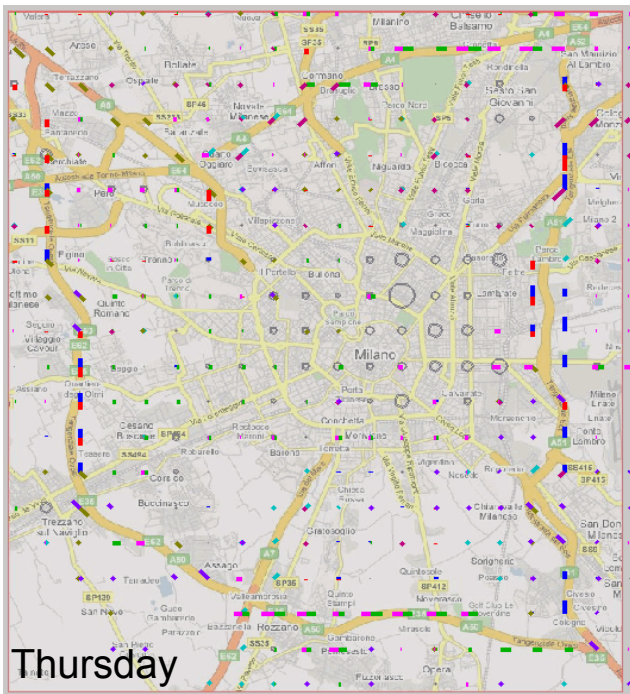
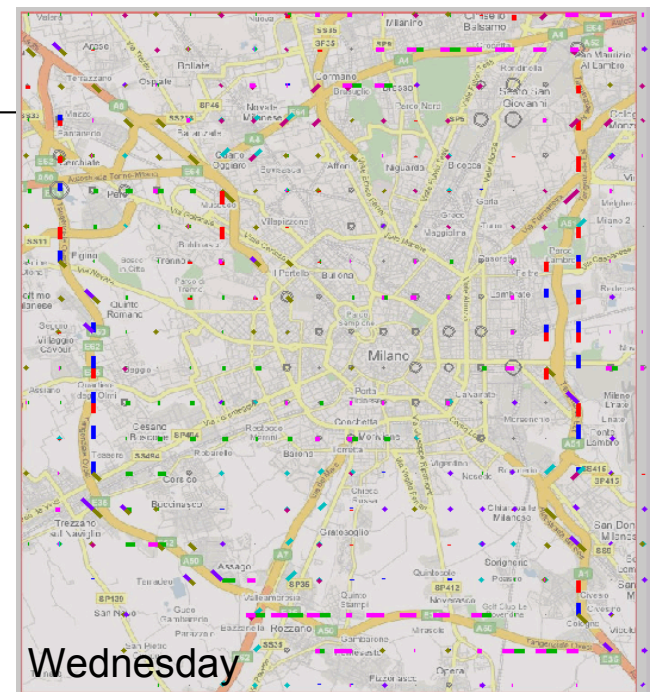
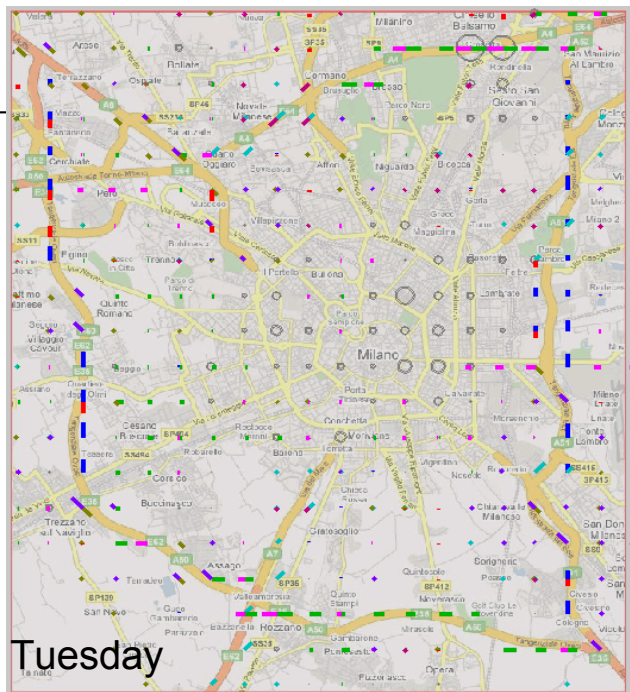
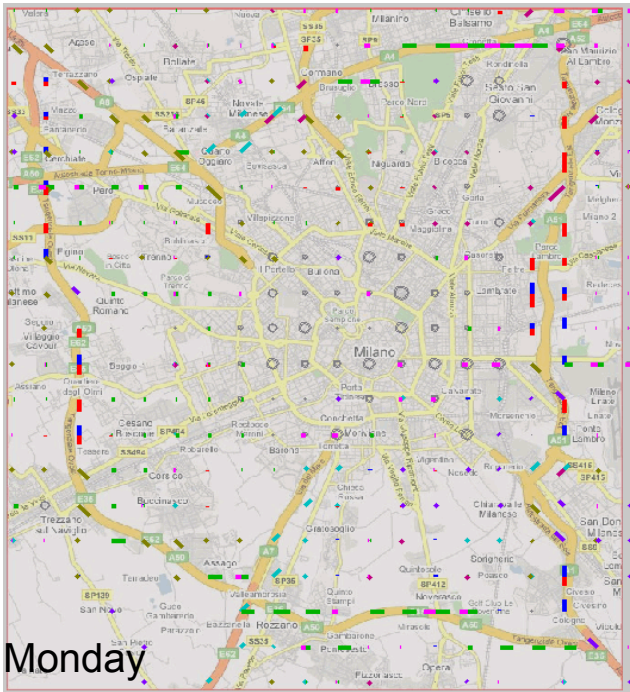
Next slide: traffic in different directions by days of a week, **from Monday to Saturday**

Attribute: N of cars

Hour of a day: 7h

Dominant directions: value of the attribute is at least 25% higher than next value

Focusing: from 5 (N of cars ≥ 5)



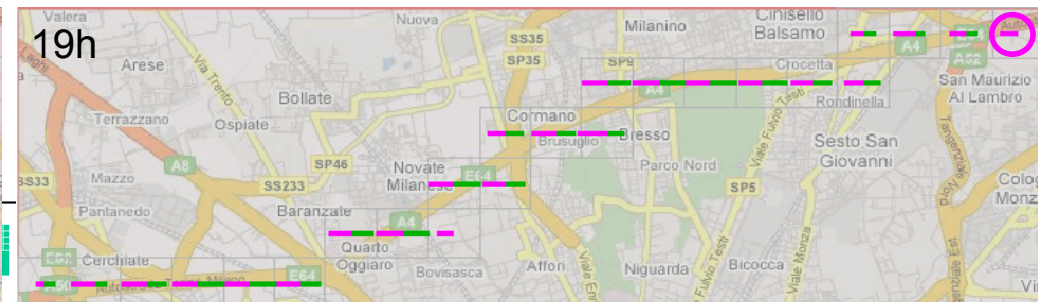
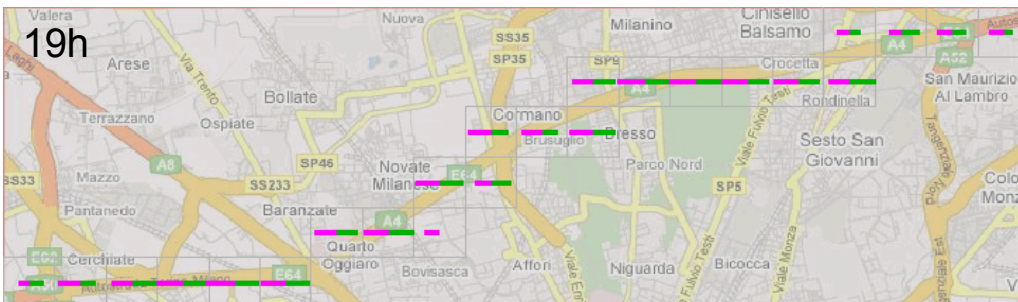
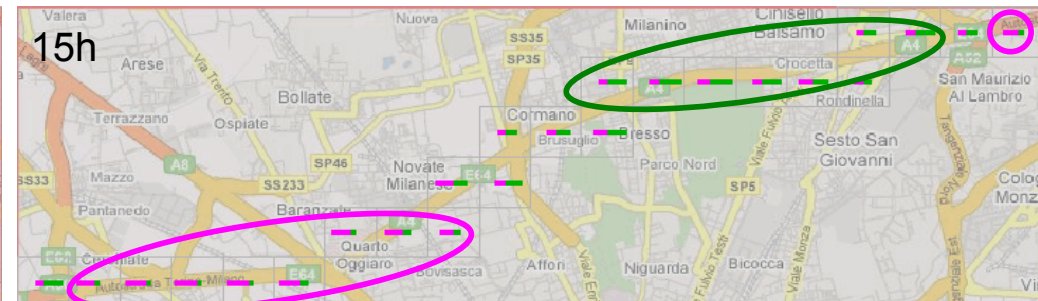
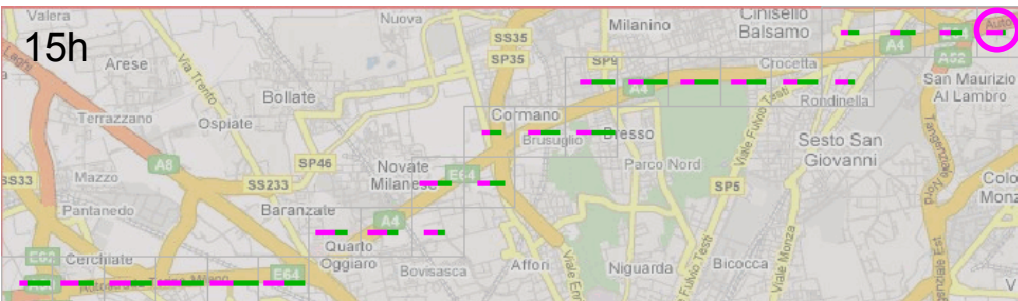
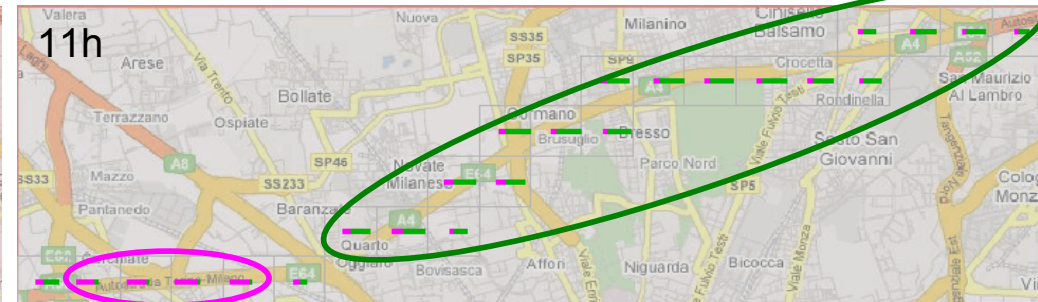
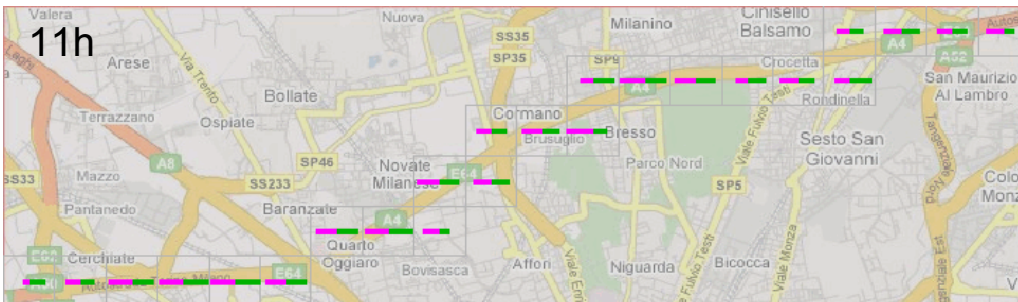
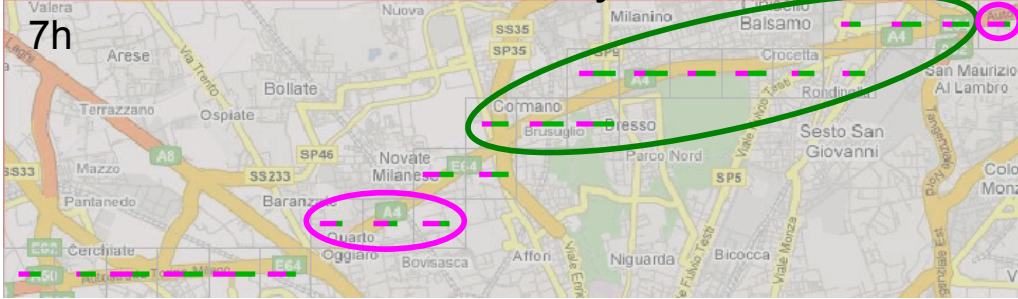
Exploration of the impedance of a particular road
in different directions
Spatial aggregation: regular grid
Temporal aggregation: days of the week; hours of the day
Directional aggregation: 4 movement directions (N, E, S, W)

Visualization: map with directional bar diagrams
Focusing on directions E and W
Attribute: median speed

The bar lengths are proportional to the **median speeds** of the cars moving in the respective directions.

Monday

Wednesday



Note the asymmetry of some diagrams signifying different load of the street in two directions

Trajectory-oriented view

$$\{\mu_e(t) \mid e \in E\}$$

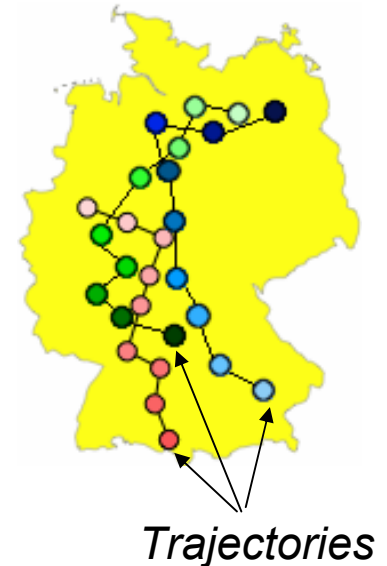
Needed: aggregation and summarization of trajectories,
i.e. individual movement behaviors of different entities

Attribute aggregation: by general characteristics of trajectories,
e.g. duration, traveled distance, average speed, ...

Temporal aggregation: trajectories or fragments made during time intervals

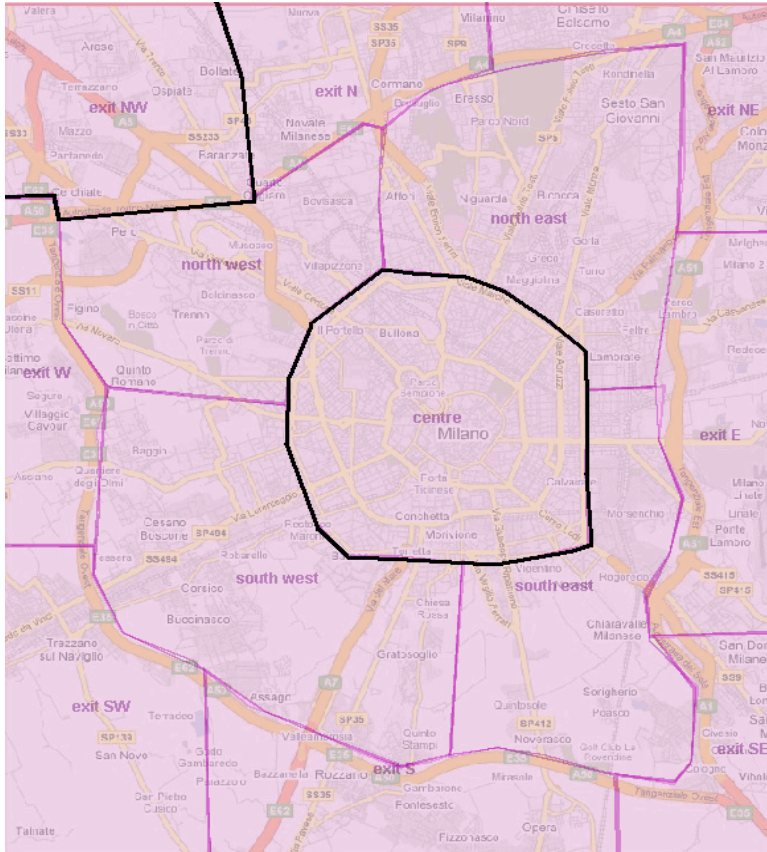
Spatial aggregation: ?
(trajectories have complex spatial configuration)

Let's disregard for a while the whole configuration and look only at the starts and ends...

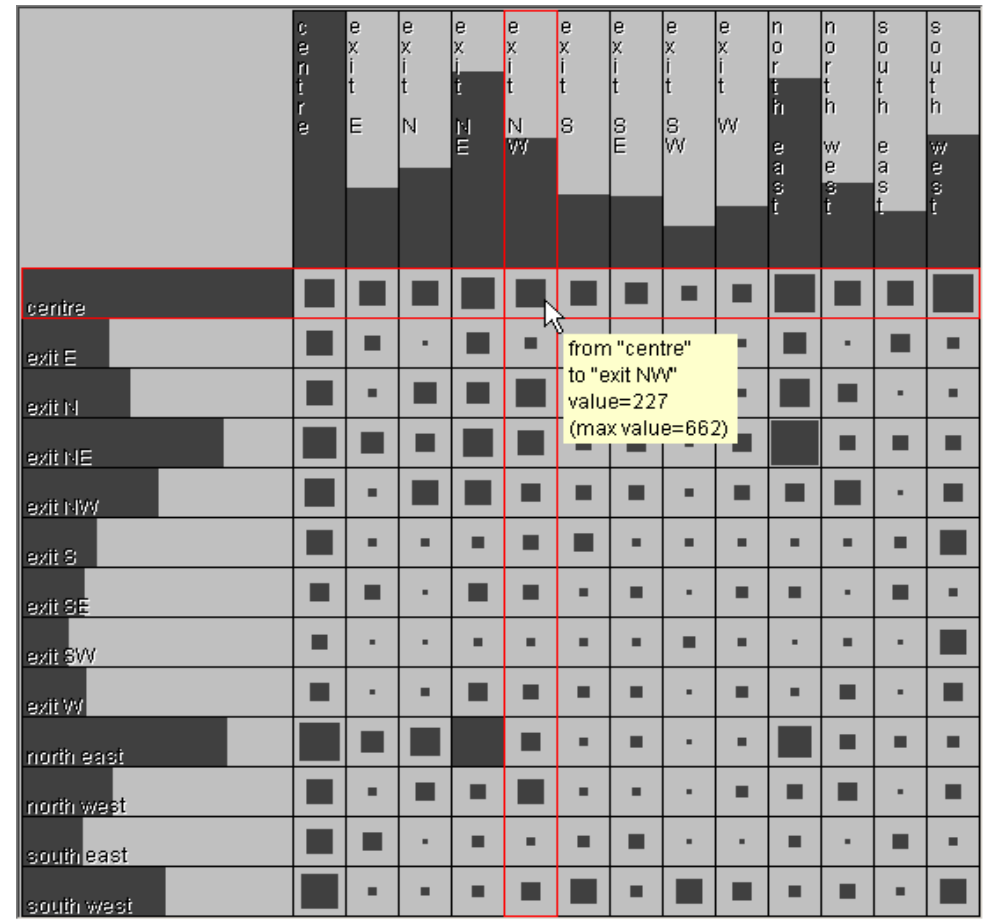


S×S-aggregation: trajectories are grouped by the origins and destinations

1. The start and end points of the trajectories are referred to areas in space



2. For each pair of areas, the number of trajectories and statistics of their numeric properties (duration, distance) are computed



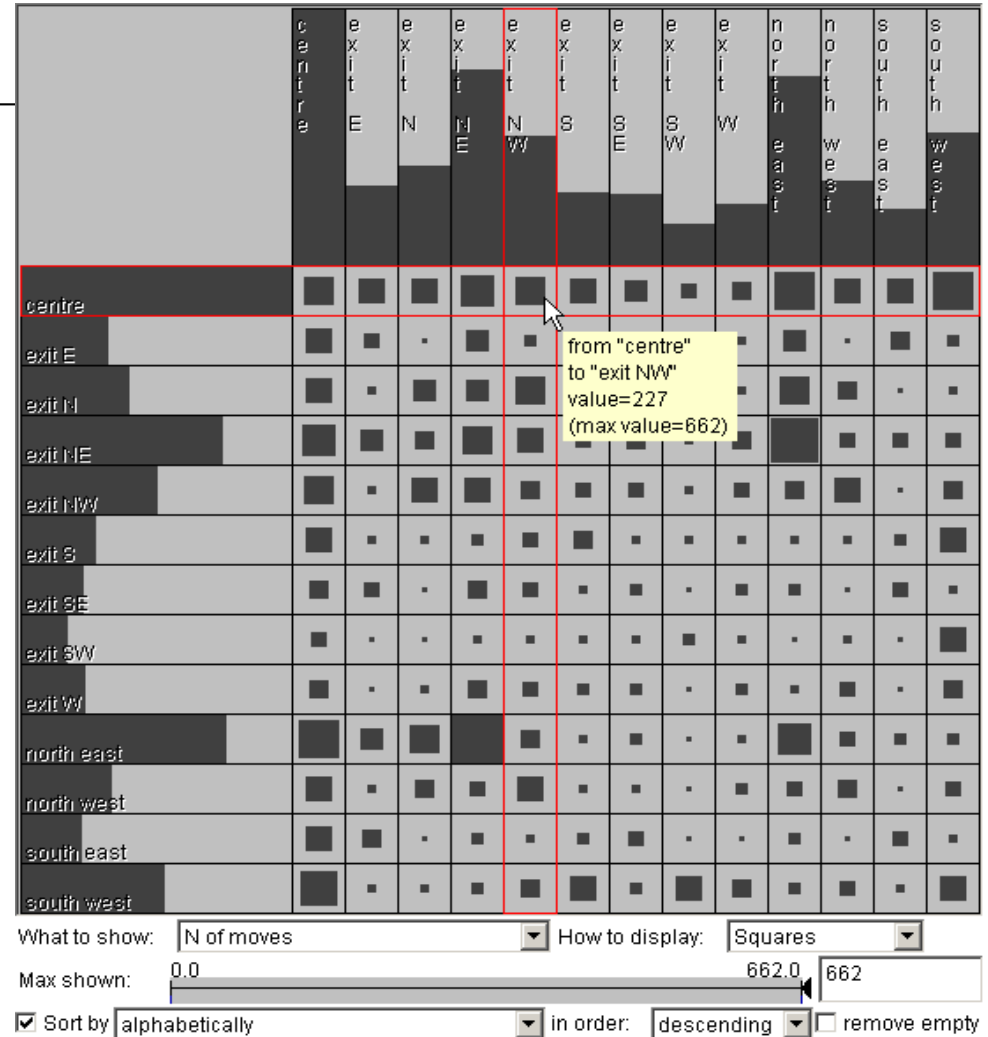
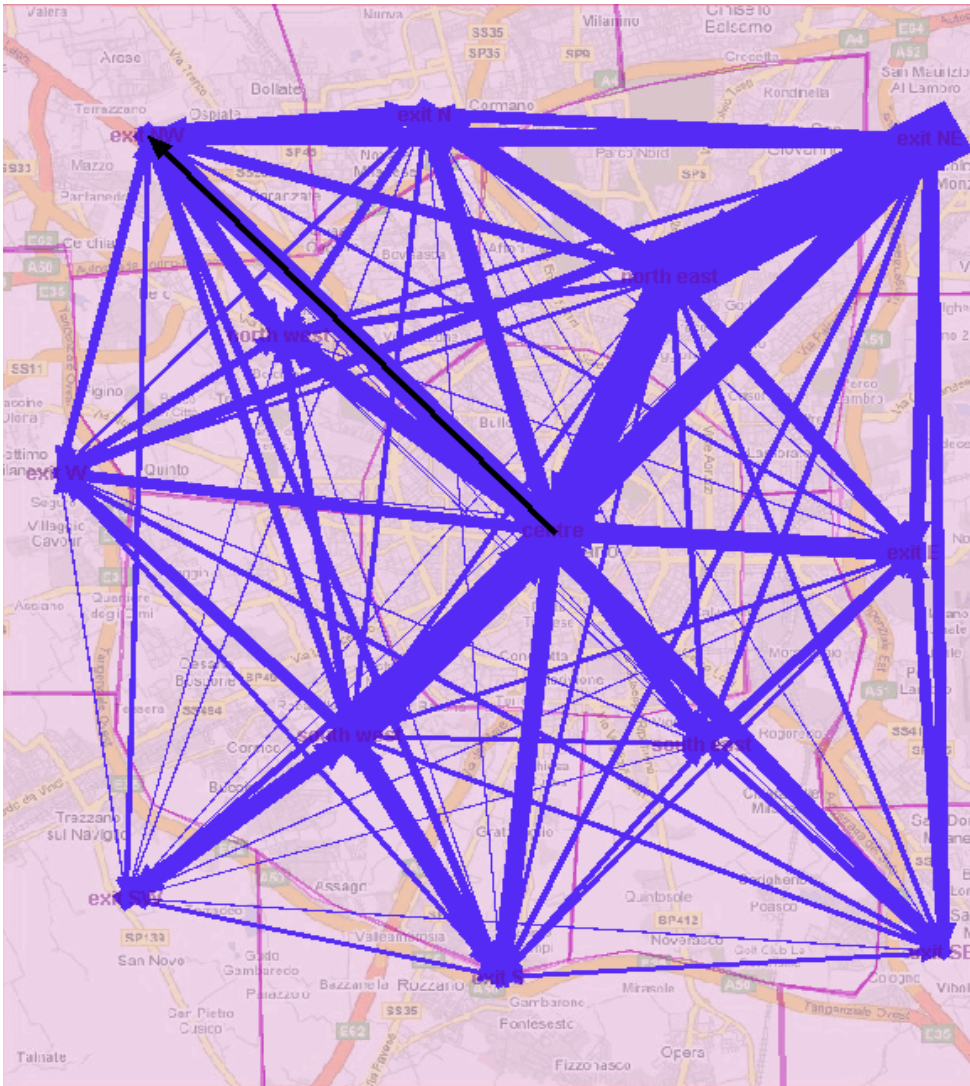
What to show: How to display:

Max shown:

Sort by in order: remove empty

Natalia & Gennady Andrienko

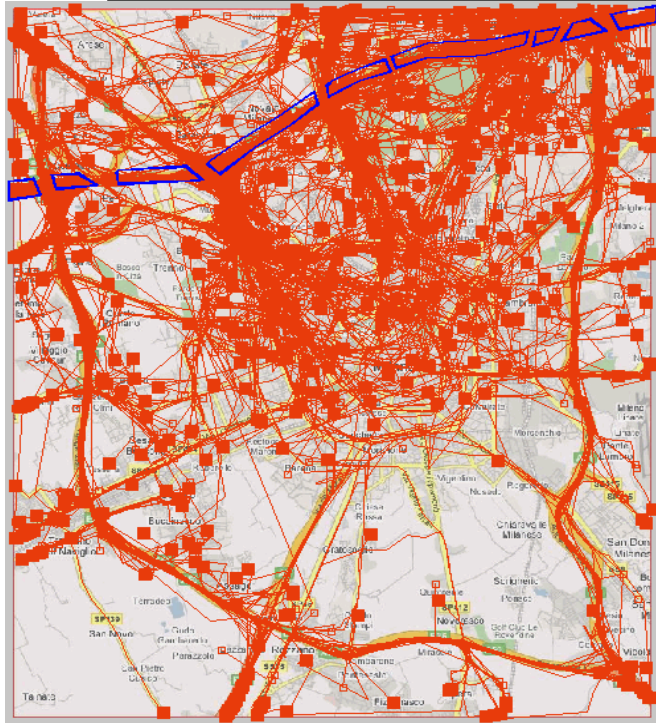




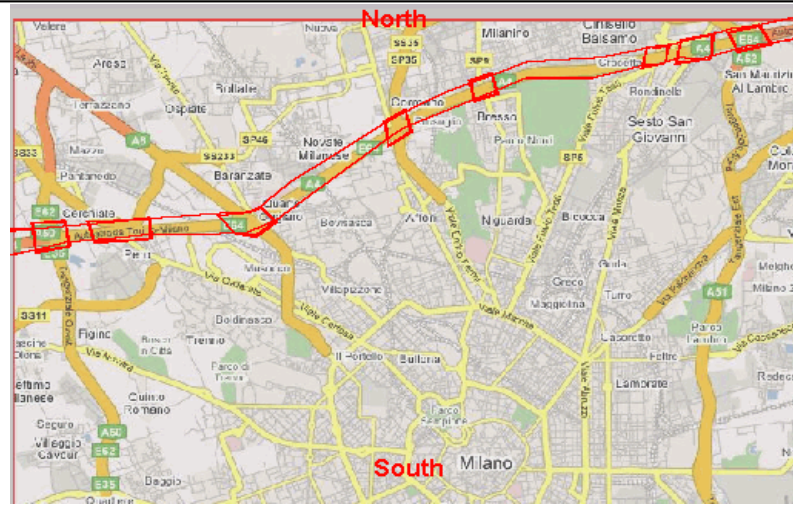
The aggregated data can also be represented on a map by directed lines (vectors) with the thicknesses proportional to the numbers of the trajectories or to the values of another aggregate attribute.

Investigation of the movement through a particular road

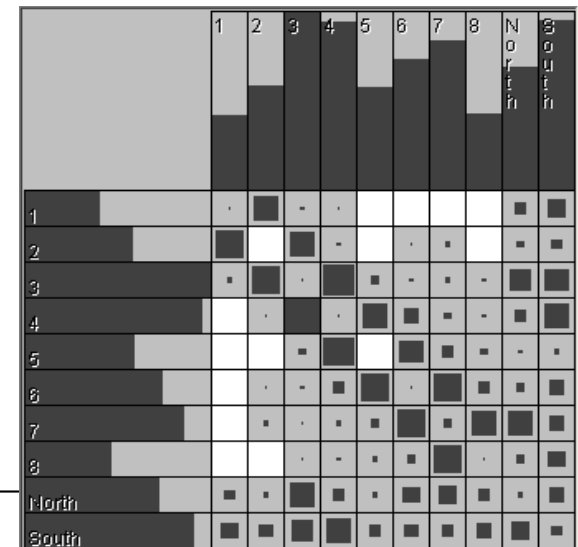
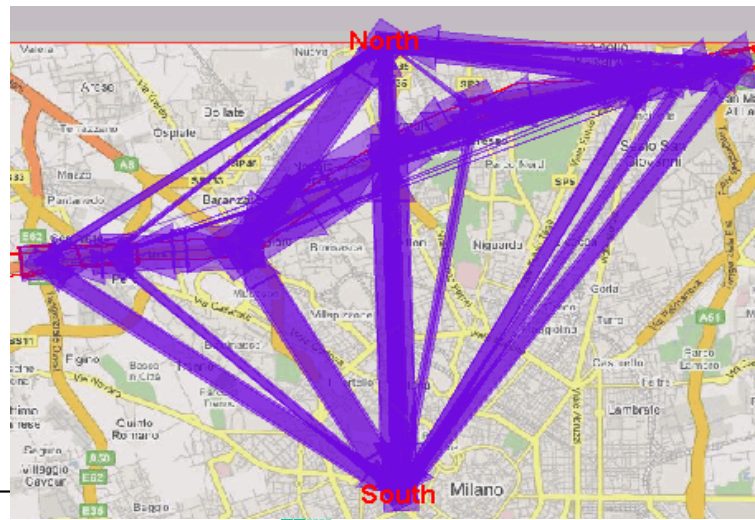
1. Select the trajectories going through the road under analysis



2. Build appropriate regions: crossings + two sides of the road (here North and South)

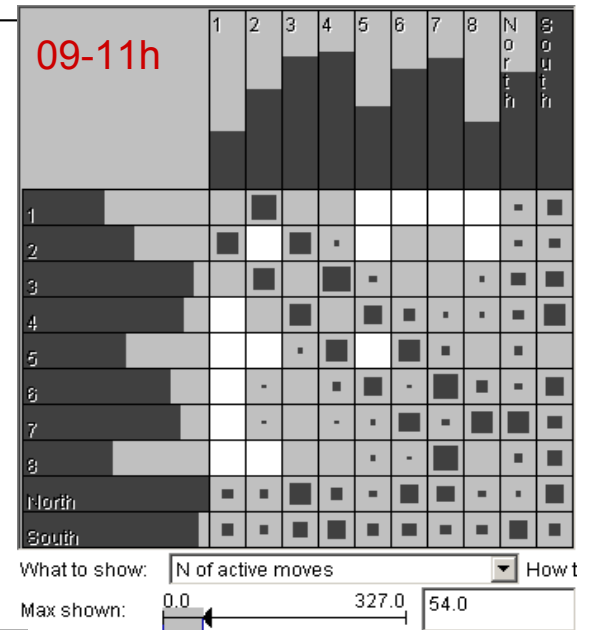
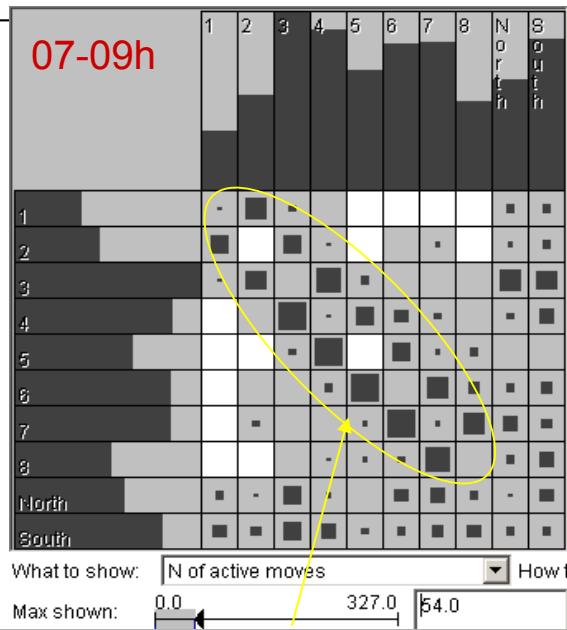
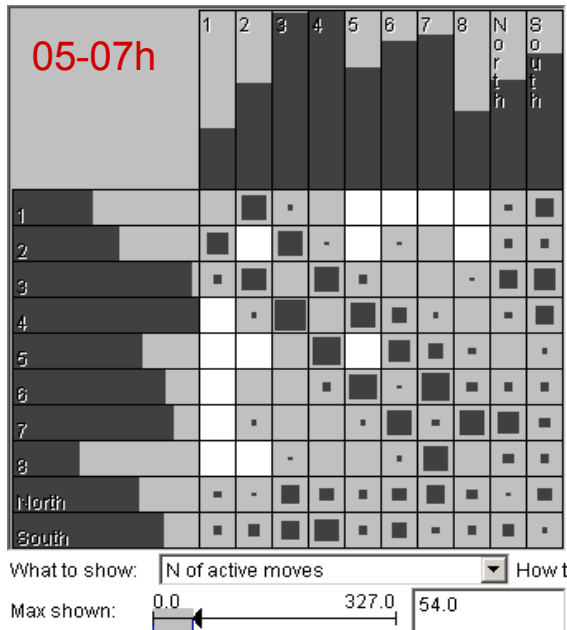


3. Transform the trajectories into sequences of moves between the regions and aggregate the moves by common origins and destinations

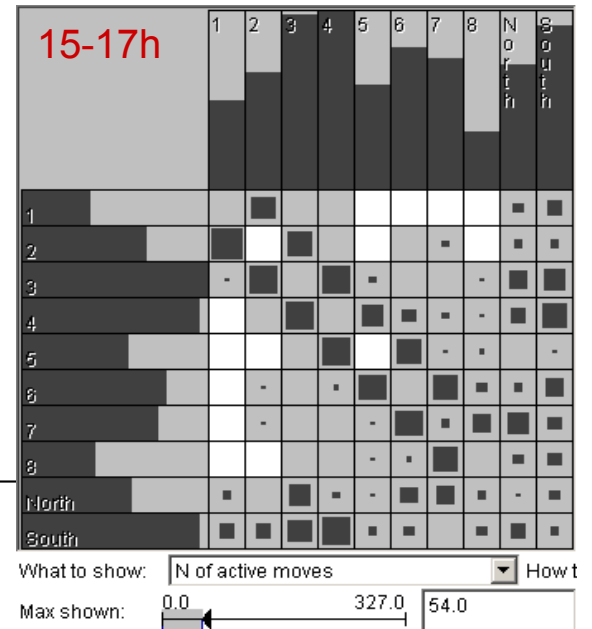
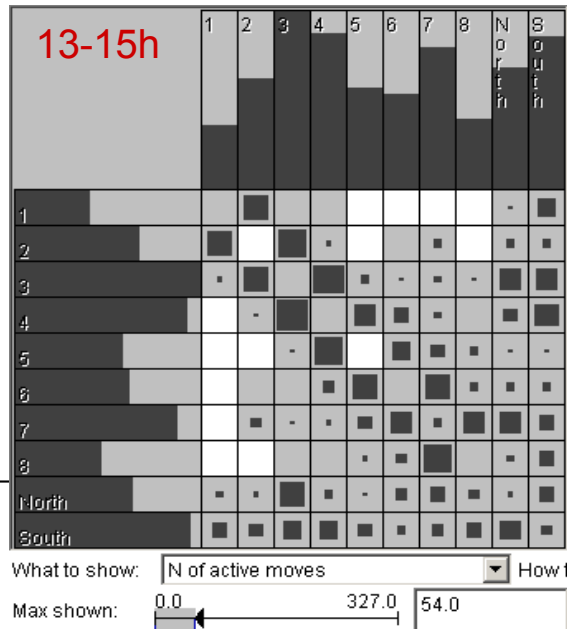
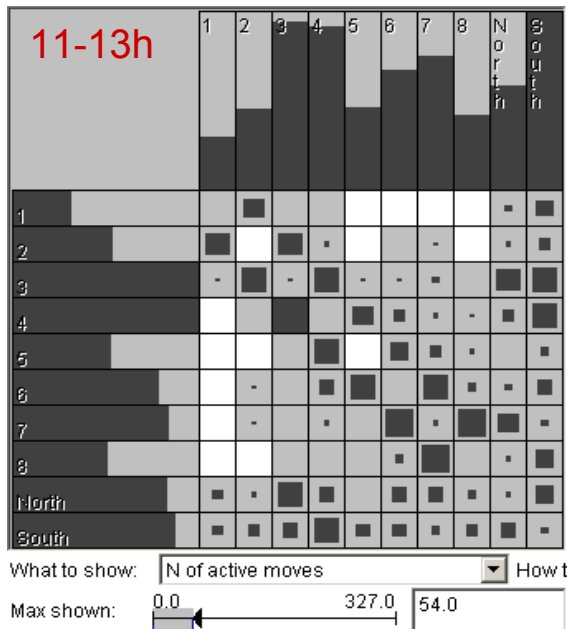


What to show: How to
 Max shown:

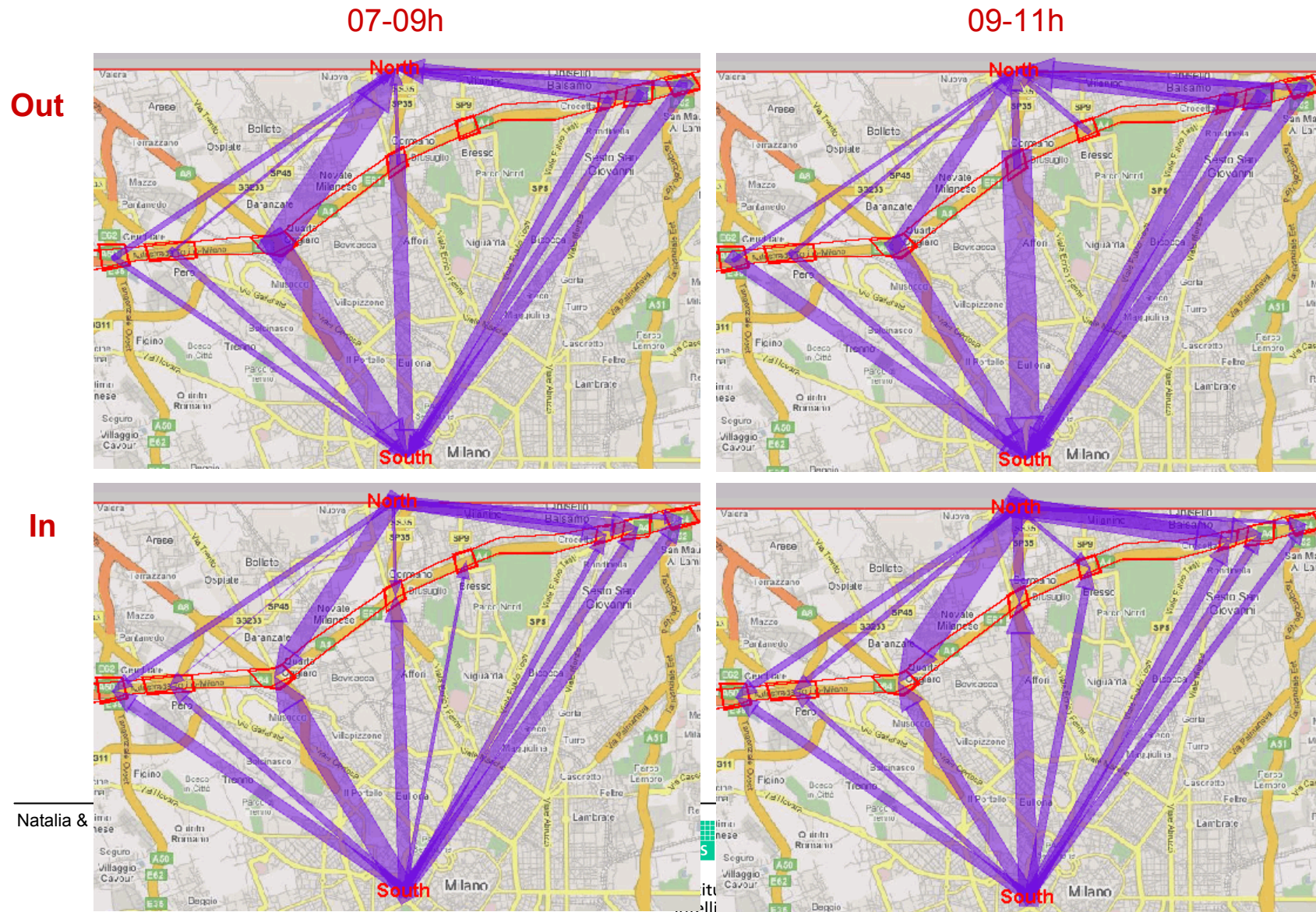
Exploration of the temporal dependency of the flows via the road



Note the asymmetric movement in two directions



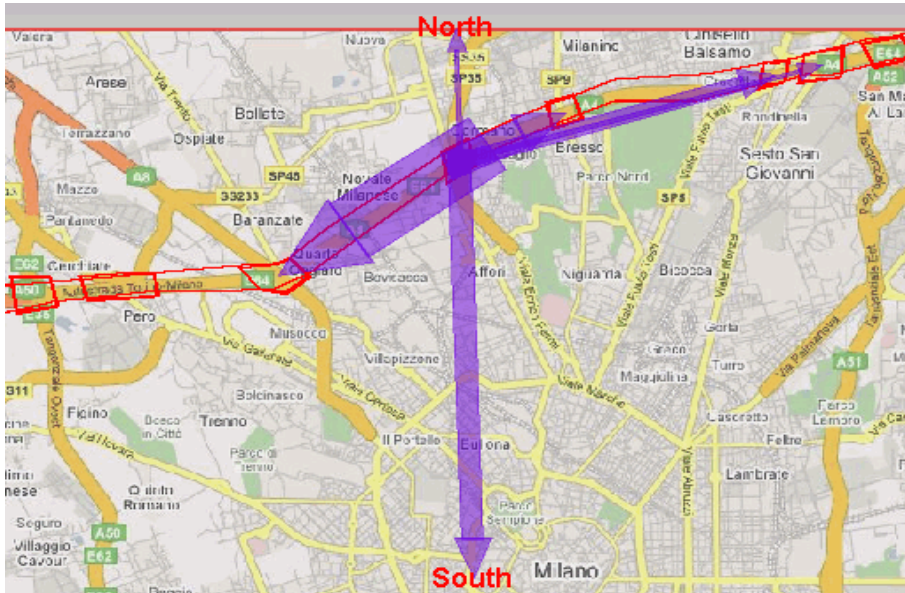
Focusing on the cars leaving the road or entering the road



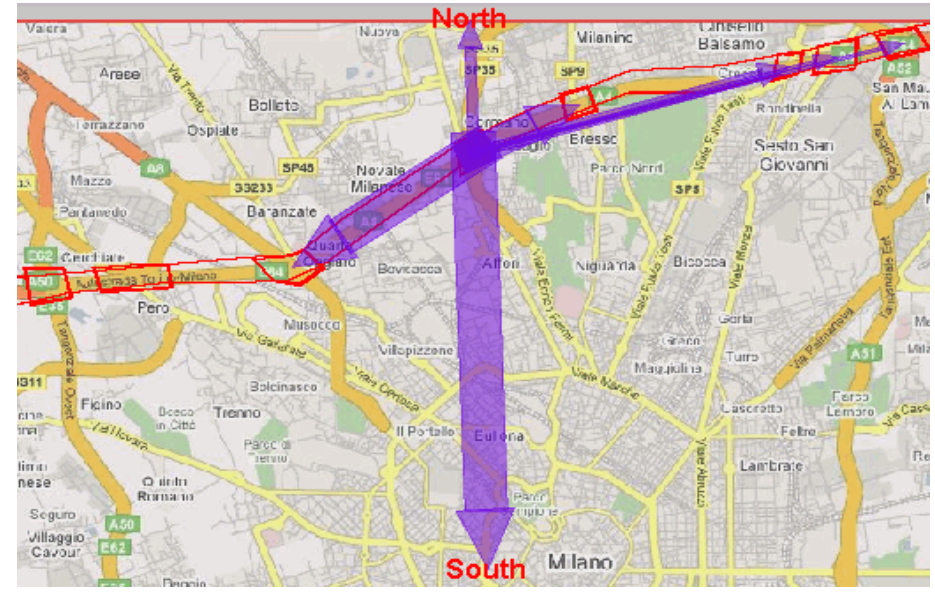
Natalia &

Focusing on the movements through a selected crossing

07-09h



09-11h



A more complex task: not only starts and ends but also the intermediate positions

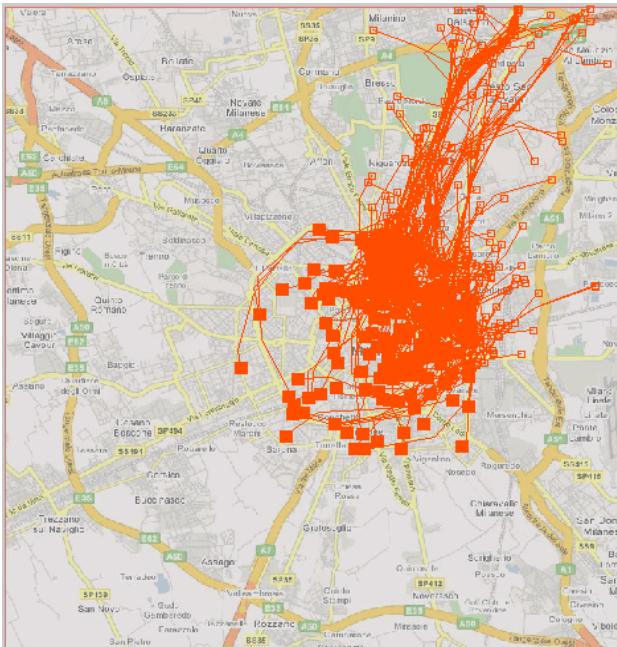
- Approach: **clustering** of the trajectories by shape (route) similarity and spatial proximity
 - using appropriate similarity measures (distance functions)

$R \times S \times S$ - and $R \times S \times S \times T \times T$ aggregation

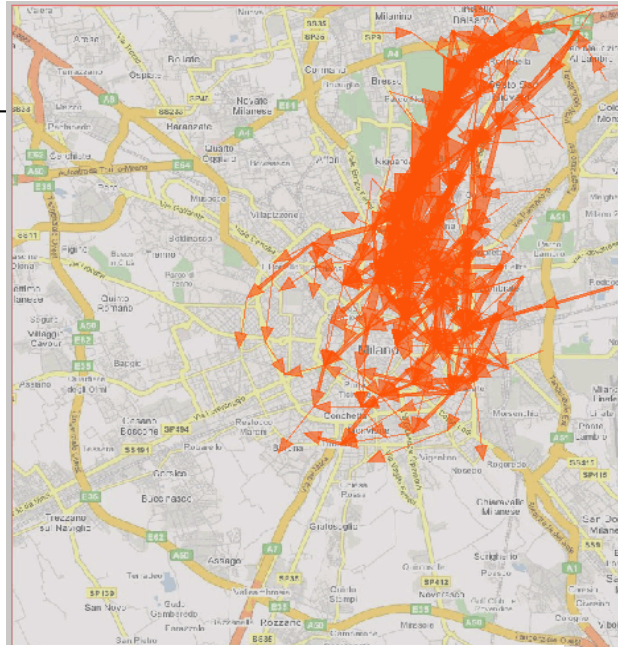
Routes: trajectories are clustered by the similarity of the routes
(similar geometry and spatial closeness)

Space: generalized places (small areas) defined as circles around
characteristic points of the trajectories

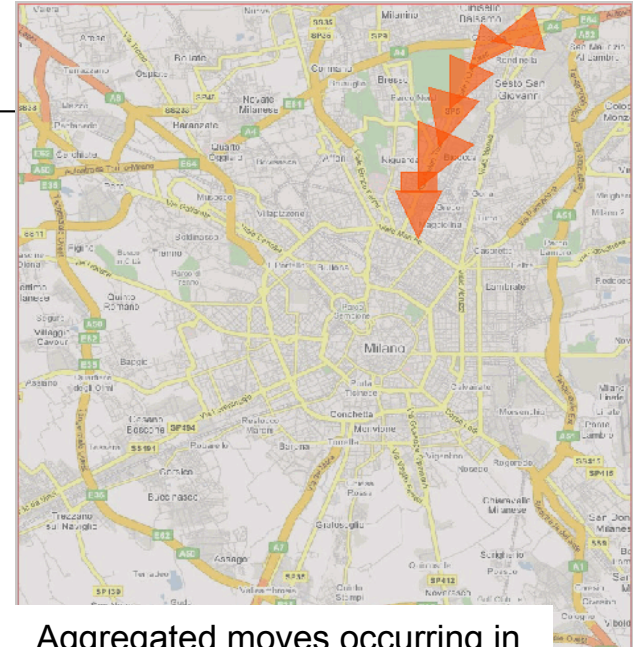
Time: arbitrary intervals



An example of a cluster of trajectories



Aggregated moves; all are visible



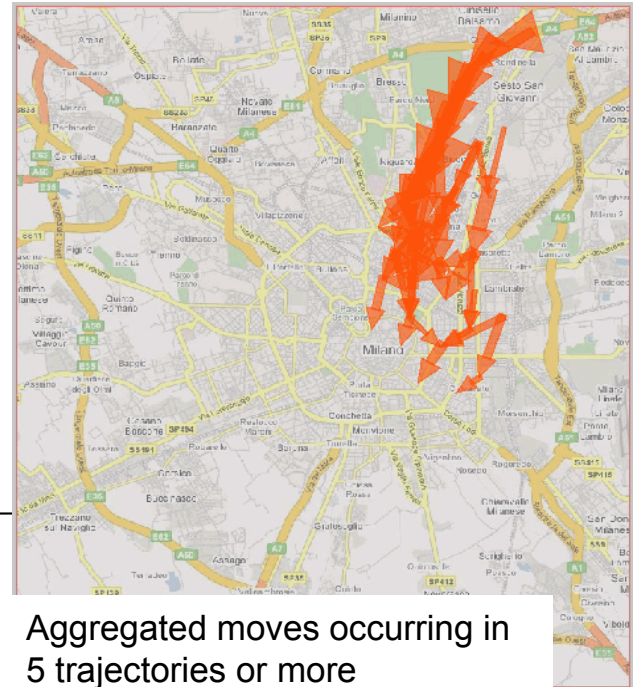
Aggregated moves occurring in 20 trajectories or more



Aggregated moves occurring in 15 trajectories or more



Aggregated moves occurring in 10 trajectories or more



Aggregated moves occurring in 5 trajectories or more

Selection of clusters

Map showing aggregated moves in Milan. Legend:

- cluster 4 (239)
- cluster 3 (129)
- cluster 7 (111)
- cluster 11 (107)
- cluster 17 (86)
- cluster 2 (50)
- cluster 19 (50)
- cluster 21 (49)
- cluster 13 (39)
- cluster 5 (28)
- cluster 8 (28)
- cluster 34 (26)
- cluster 6 (25)
- cluster 12 (23)
- cluster 23 (19)
- cluster 31 (19)
- cluster 37 (18)
- cluster 26 (15)
- cluster 29 (15)
- cluster 14 (10)
- cluster 15 (9)
- cluster 25 (9)
- cluster 27 (9)
- cluster 28 (9)
- cluster 43 (9)

Selection of aggregated moves

Dynamic Query for Aggregated moves from Trajectories on 04/04/2007; 30 min break (an...)

0.0 N of different active trajectories 43.0 0.8% : 52 from 6796

5.00 43.00 0.8% : 52 from 6796

Filter out missing values Display statistics Dynamic update

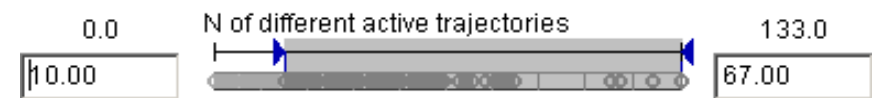
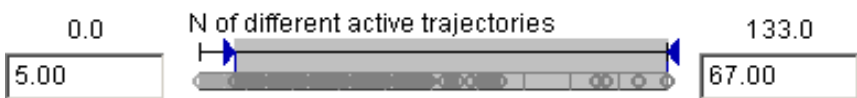
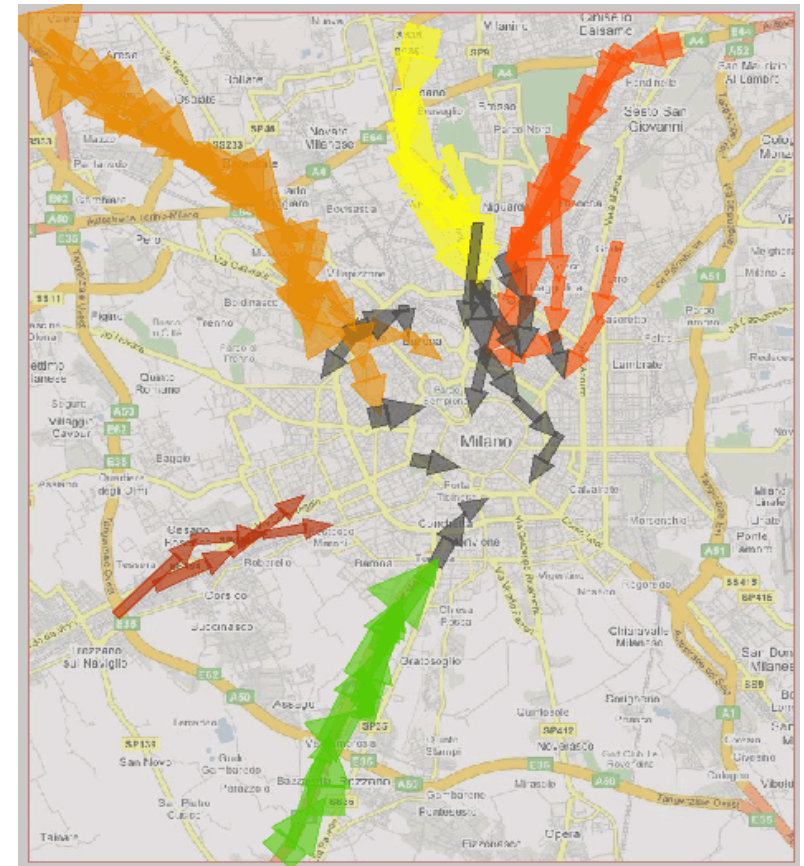
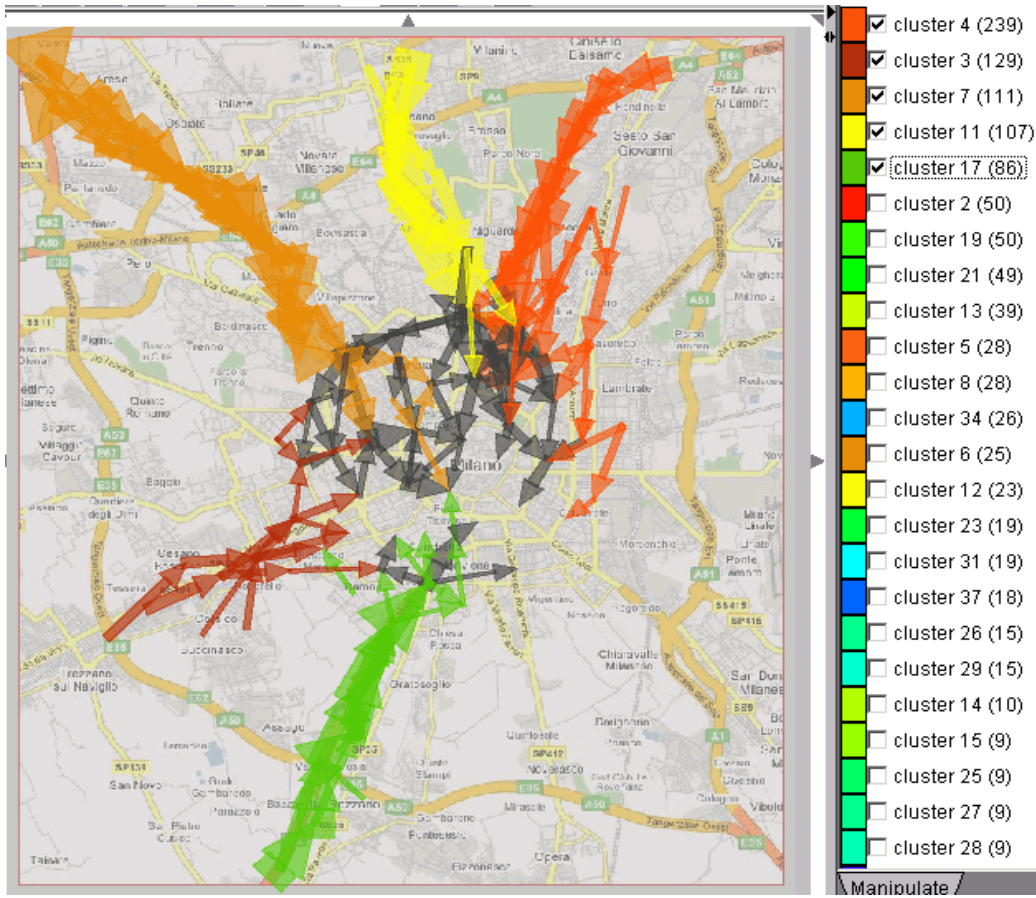
...

- cluster 47 (2)
- cluster 51 (2)
- cluster 54 (2)
- cluster 55 (2)
- noise (1285)

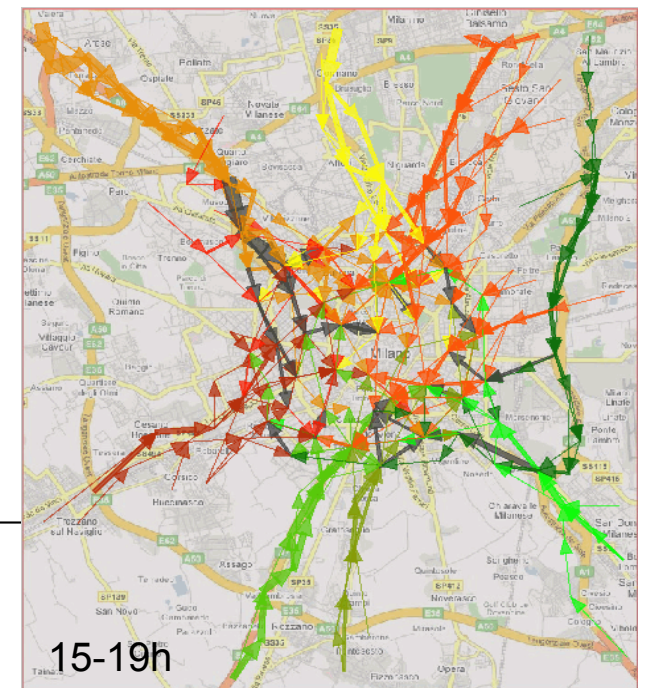
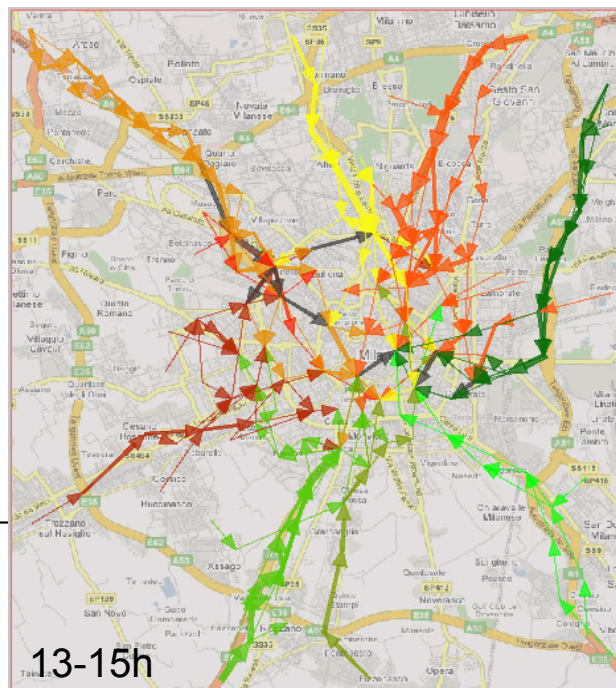
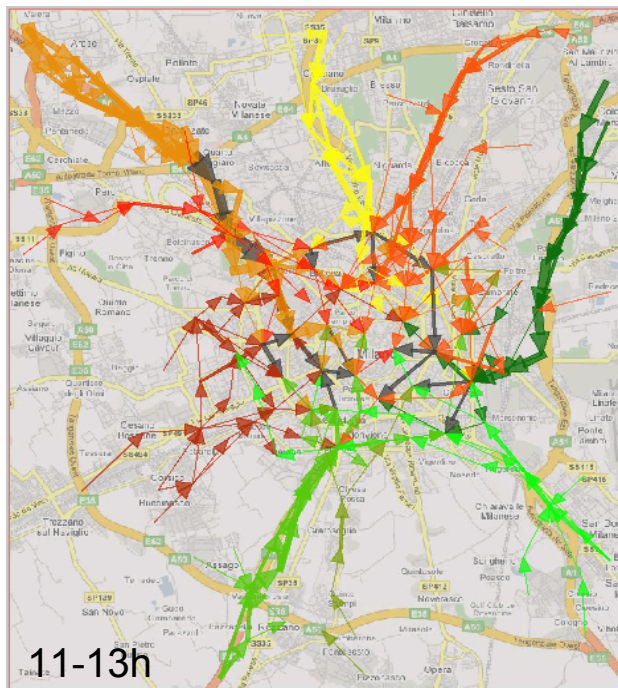
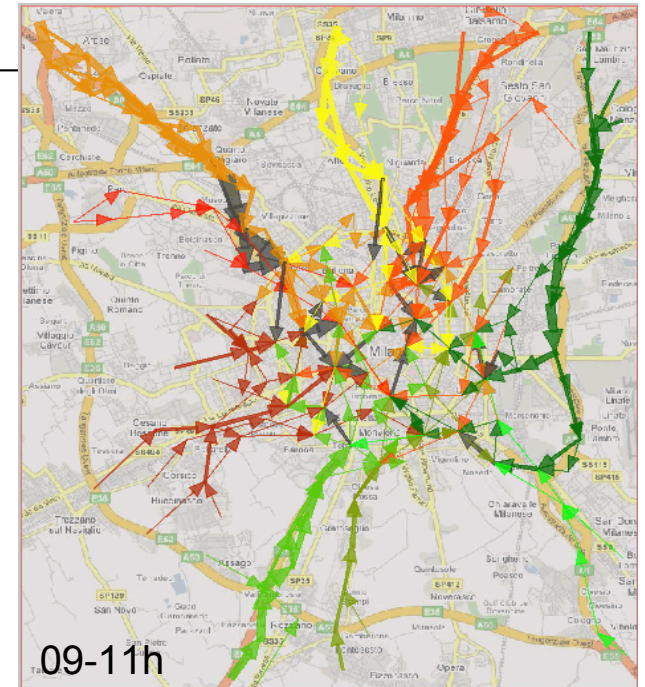
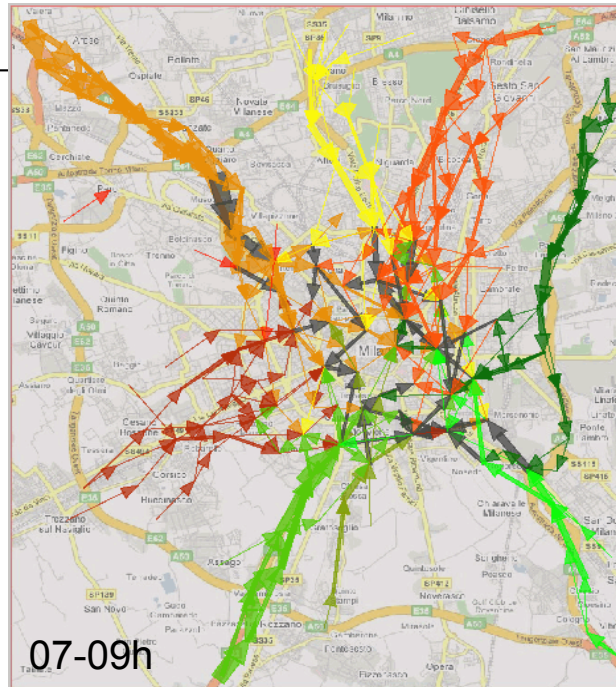
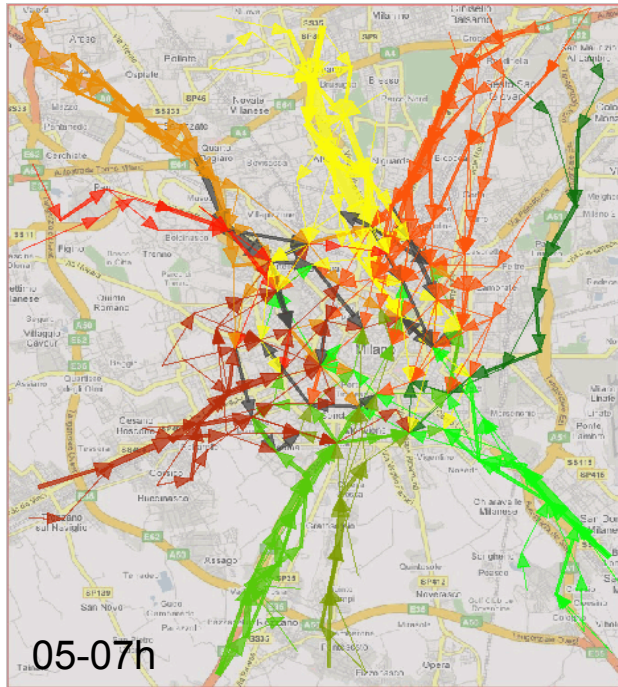
Broadcast classification

5 biggest clusters of trajectories towards the city centre

Dark grey: moves occurring in trajectories from several clusters



Exploration of the use of the most popular routes towards the centre by times of the day



Summary

- Analysis of collective movements of multiple objects
 - Major complexity: huge data size
- 2 possible views of collective movements: traffic-oriented and trajectory-oriented
- Aggregation:
 - Traffic-oriented view: by time intervals; by space compartments; by movement direction; by other point-related movement attributes → spatial time series
 - Trajectory-oriented view: by time intervals; by general (trajectory-related) attributes; by starts and ends; by route similarity (through clustering) → groups of trajectories
- Summarization:
 - Numeric: count, mean, median, ...
 - Spatial: aggregated moves
- Visualization and interaction:
 - Multiple coordinated views: animated and static maps, non-cartographic displays
 - Interactive filtering: by time, space, cluster membership, attribute values
 - Dynamic aggregates reacting to the filtering

See also

- Gennady Andrienko, Natalia Andrienko
Spatio-temporal aggregation for visual analysis of movements
IEEE Visual Analytics Science and Technology (VAST 2008)
Proceedings, IEEE Computer Society Press, 2008
- Salvatore Rinzivillo, Dino Pedreschi, Mirco Nanni, Fosca Giannotti,
Natalia Andrienko, Gennady Andrienko
Visually-driven analysis of movement data by progressive clustering
Information Visualization,
2008, v.7 (3/4)