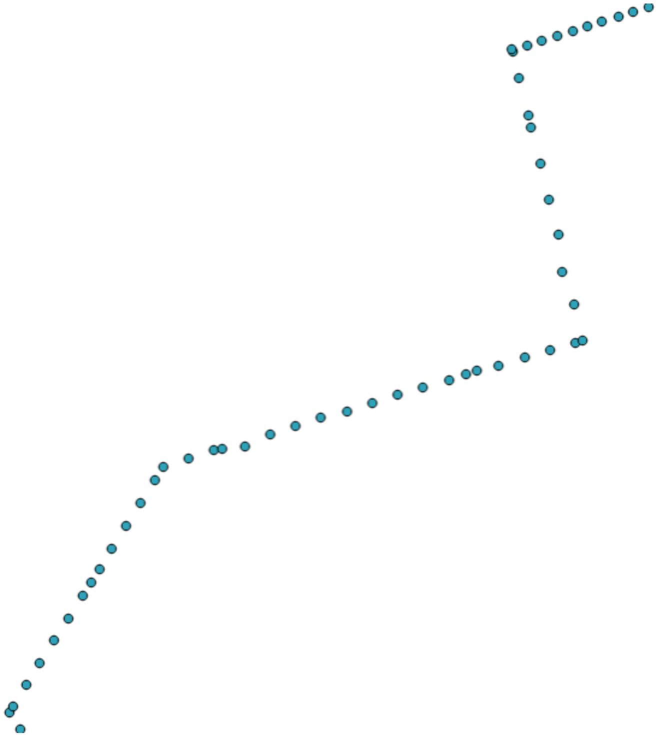
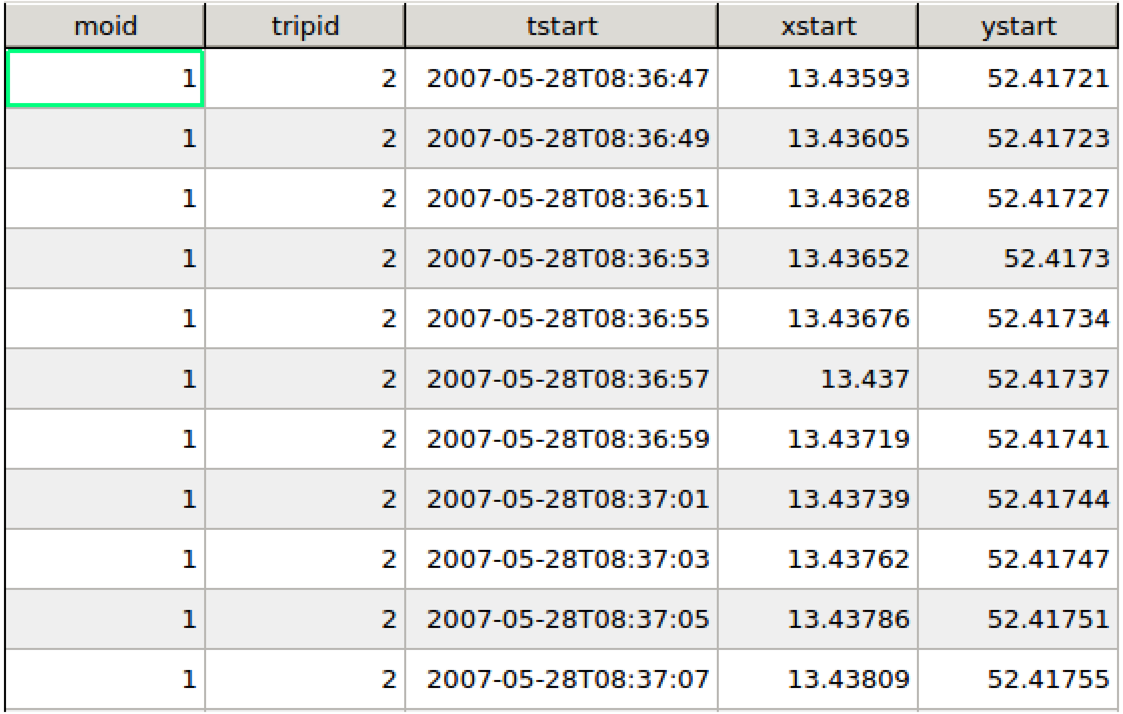
MobilityDB

A PostgreSQL-PostGIS Extension for Mobility Data Management

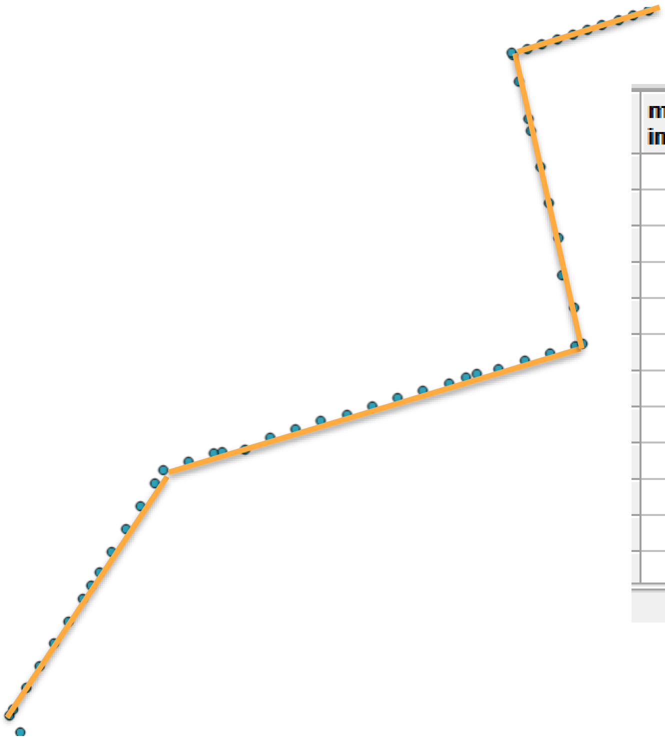
What is Mobility Data ?

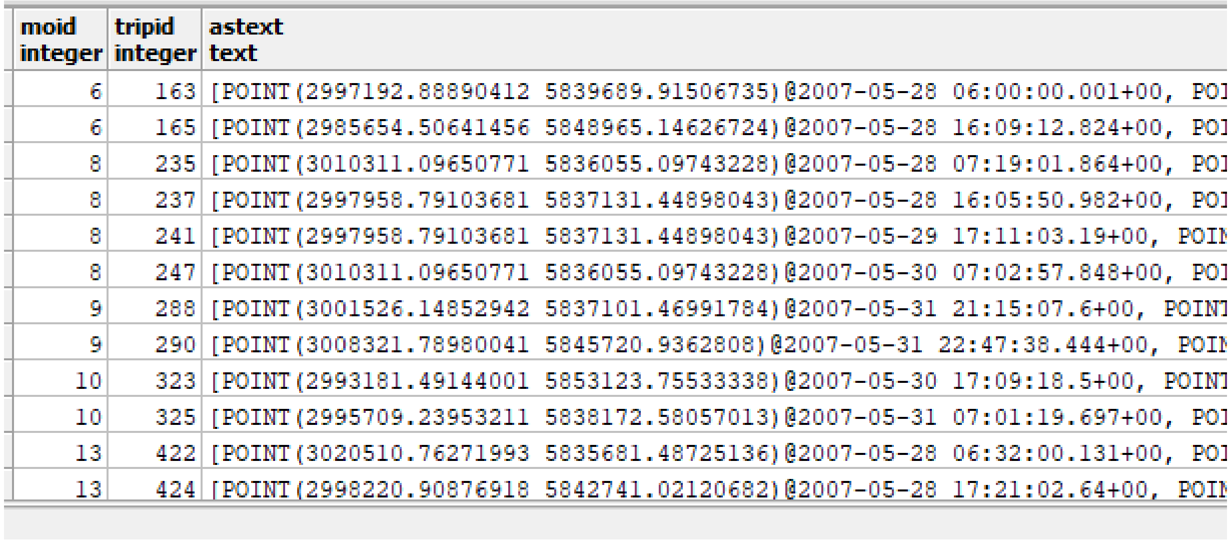




moid	tripid	tstart	xstart	ystart
1	2	2007-05-28T08:36:47	13.43593	52.41721
1	2	2007-05-28T08:36:49	13.43605	52.41723
1	2	2007-05-28T08:36:51	13.43628	52.41727
1	2	2007-05-28T08:36:53	13.43652	52.4173
1	2	2007-05-28T08:36:55	13.43676	52.41734
1	2	2007-05-28T08:36:57	13.437	52.41737
1	2	2007-05-28T08:36:59	13.43719	52.41741
1	2	2007-05-28T08:37:01	13.43739	52.41744
1	2	2007-05-28T08:37:03	13.43762	52.41747
1	2	2007-05-28T08:37:05	13.43786	52.41751
1	2	2007-05-28T08:37:07	13.43809	52.41755

Mobility Data: Constructing Trajectories

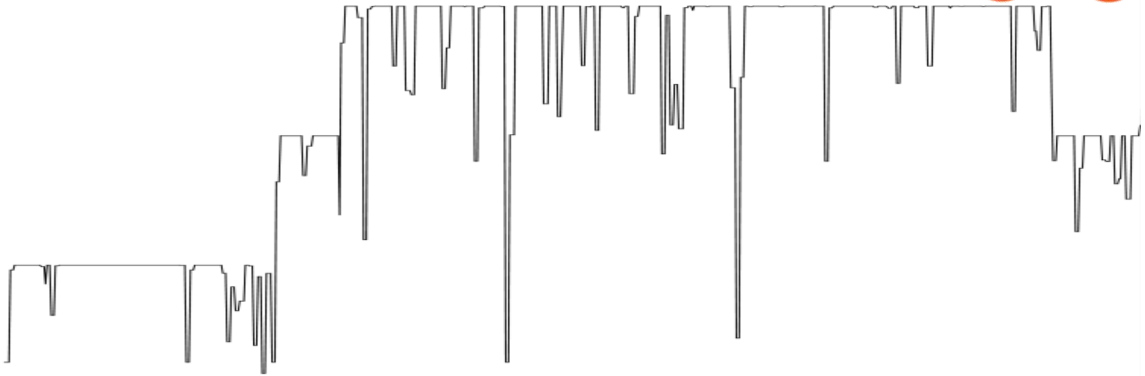




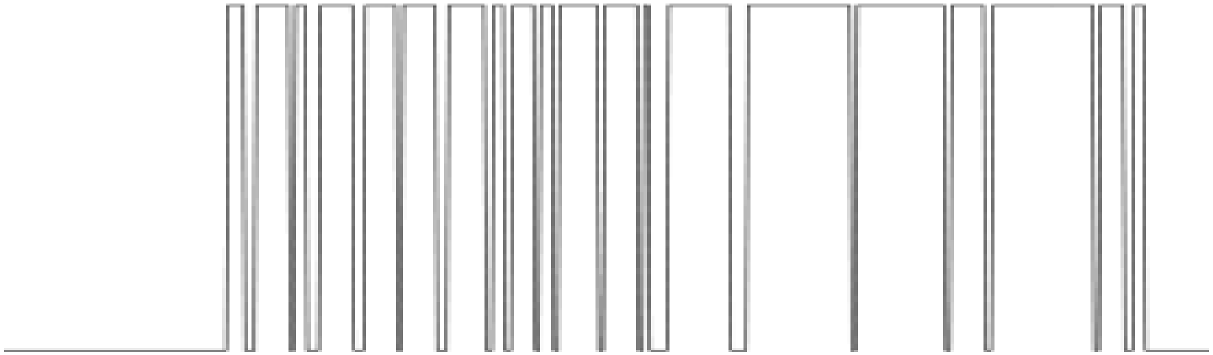
moid integer	tripid integer	astext text
6	163	[POINT(2997192.88890412 5839689.91506735)@2007-05-28 06:00:00.001+00, POI
6	165	[POINT(2985654.50641456 5848965.14626724)@2007-05-28 16:09:12.824+00, POI
8	235	[POINT(3010311.09650771 5836055.09743228)@2007-05-28 07:19:01.864+00, POI
8	237	[POINT(2997958.79103681 5837131.44898043)@2007-05-28 16:05:50.982+00, POI
8	241	[POINT(2997958.79103681 5837131.44898043)@2007-05-29 17:11:03.19+00, POIN
8	247	[POINT(3010311.09650771 5836055.09743228)@2007-05-30 07:02:57.848+00, POI
9	288	[POINT(3001526.14852942 5837101.46991784)@2007-05-31 21:15:07.6+00, POINT
9	290	[POINT(3008321.78980041 5845720.9362808)@2007-05-31 22:47:38.444+00, POIN
10	323	[POINT(2993181.49144001 5853123.75533338)@2007-05-30 17:09:18.5+00, POINT
10	325	[POINT(2995709.23953211 5838172.58057013)@2007-05-31 07:01:19.697+00, POI
13	422	[POINT(3020510.76271993 5835681.48725136)@2007-05-28 06:32:00.131+00, POI
13	424	[POINT(2998220.90876918 5842741.02120682)@2007-05-28 17:21:02.64+00, POIN

But also Temporal Alphanumeric Types

tfloat: speed(Trip)



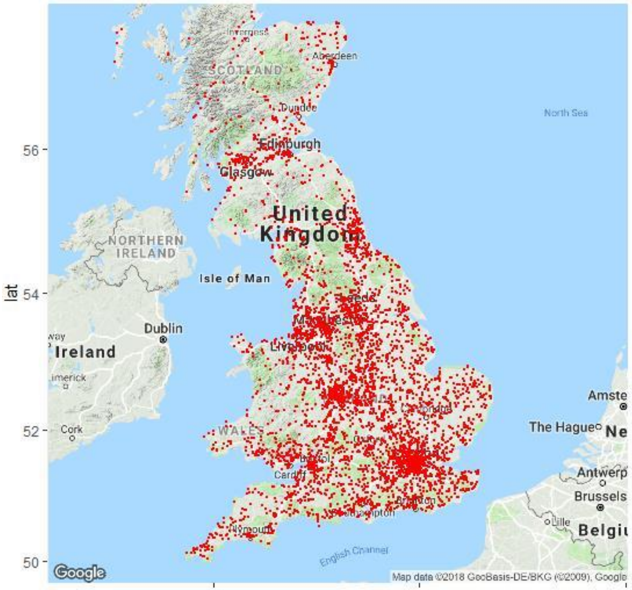
tbool: speed(Trip) > 90

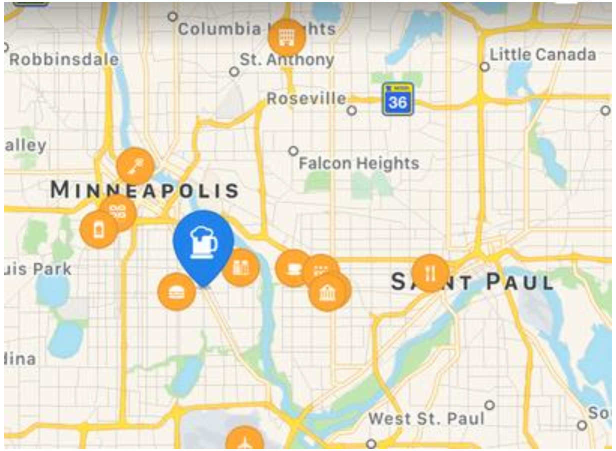


Also Instantaneous Events

Instant: UK road accidents 2012-14

https://www.kaggle.com/daveianhickey/2000-16-traffic-flow-england-scotland-wales





InstantSet: foursquare check-ins

https://support.foursquare.com/

MobilityDB

- A mainstream moving object database (MOD)
- Builds on PostgreSQL and PostGIS
- Developed by a team in Université Libre de Bruxelles
- Meant to be OPEN SOURCE
- Compliant with Open Geospatial Consortium (OGC) standards, in particular the OGC Moving Features Access

Quick Example: Spatial Projection

```
TABLE Bus ( LineNo integer, TripNo integer, Trip tgeompoint(Sequence, Point, 3812) );

TABLE POI ( POINo integer, Name text, Geo GEOMETRY(3812) );
```

List the bus lines that traverse Place Louise

```
SELECT TripNo

FROM Bus B, (SELECT P.Geo FROM POI P WHERE P.Name = ‘Place Louise' LIMIT 1) T

WHERE intersects(B.Trip, T.Geo)
```

The intersects function is index supported, i.e., it is defined as follows

```
    'SELECT $1 OPERATOR(@extschema@.&&) $2 AND @extschema@._intersects($1,$2)'
```

The && operator performs a bounding box overlaps index filtering

Quick Example: Spatial Filtering

```
TABLE Bus ( LineNo integer, TripNo integer, Trip tgeompoint(Sequence, Point, 3812) );

TABLE Network ( LineNo integer, Route GEOMETRY(LINESTRING, 3812) );
```

Find all the trips that deviated from their line routes

```
SELECT TripNo

FROM Bus B, Network N

WHERE B.LineNo = N.LineNo AND NOT contains(st_buffer(N.Route, 20), B.Trip)
```

Quick Example: Traditional Aggregation

```
TABLE Bus ( LineNo integer, TripNo integer, Trip tgeompoint(Sequence, Point, 3812) );
```

Total distance per week travelled by the buses

```
SELECT SUM( length(Trip) ) travelled, date_part('week', startTimestamp(Trip)) AS week

FROM Bus

GROUP BY week;
```

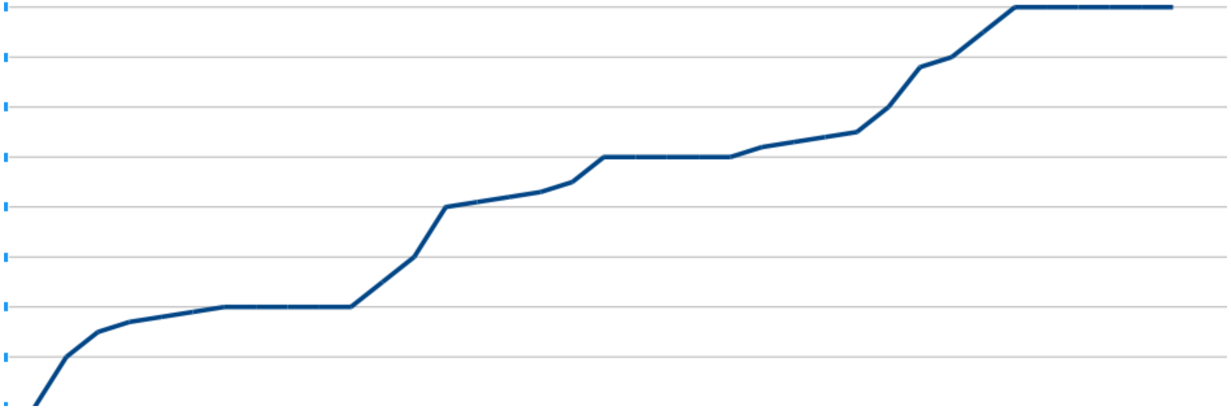
Quick Example: Temporal Aggregation

```
TABLE Bus ( LineNo integer, TripNo integer, Trip tgeompoint(Sequence, Point, 3812) );
```

Cumulative distance travelled by the buses at each instant during one week

```
SELECT tsum( cumulativeLength(Trip) ) travelled, date_part('week', startTimestamp(Trip))
AS week

FROM Bus

GROUP BY week;
```

Partial output for 3 days



Quick Example: Spatio-temporal Join

```
TABLE Bus ( LineNo integer, TripNo integer, Trip tgeompoint(Sequence, Point, 3812) );
TABLE Stops ( StopNo integer, Geo GEOMETRY(POLYGON, 3812) );
```

List all transit possibilities, i.e., when two buses from different lines meet at a station, so the passenger have the opportunity to change the line

```
WITH AllStops AS ( SELECT ST_Union(S.Geo) AS Geo FROM Stops S ),
     BusStops AS (SELECT TripNo, atGeometry(B.Trip, S.Geo) RestrictedRoute
          FROM Bus B, AllStops S )
SELECT A.TripNo, B.TripNo FROM BusStops A, BusStops B
WHERE A.LineNo < B.LineNo AND A.TripNo < B.TripNo AND
     toverlaps(A.RestrictedRoute, B.RestrictedRoute) &= TRUE
```

The &= (ever equals) operator tests whether a temporal type ever has a given value and results in a Boolean value

MobilityDB Components

- Time types
- Temporal types
- Query functions
- GiST and SP-GiST indexes
- Aggregation functions

Time Types

- In addition to TimestampTz we needed 3 additional time types
- Period is a specialized version of tstzrange

```
SELECT period '[2012-01-01 08:00:00, 2012-01-03 09:30:00)';
```

- Similar functionality, more efficient implementation
  - fixed length while tstzrange is of variable length
  - empty periods and infinite bounds not allowed
- TimestampSet represents a set of distinct and ordered timestamptz values

```
SELECT timestampset '{2012-01-01 08:00:00, 2012-01-03 09:30:00}';
```

- PeriodSet represents a set of disjoint and ordered period values

```
SELECT periodset '{[2012-01-01 08:00:00, 2012-01-01 08:10:00],
                   [2012-01-01 08:20:00, 2012-01-01 08:40:00]}';
```

Time Types

- Accessor Functions: lower, upper, duration, startTimestamp, …

```
SELECT timestampN(periodset ’{[2012-01-01, 2012-01-03),
            (2012-01-03, 2012-01-05)}’, 3);
-- "2012-01-04"
```

- Operators: =, <, …, @>, &&, …, <<#, &<#, …, -|-, +, -, *

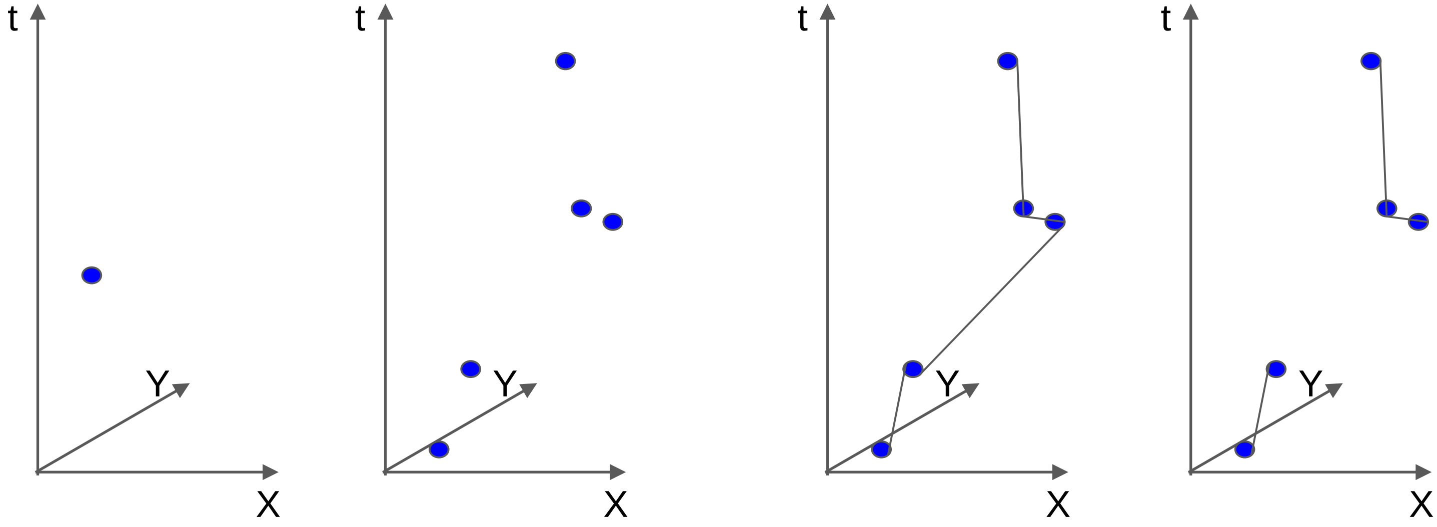
```
SELECT period ’[2011-01-01, 2011-01-05]’ - period ’[2011-01-03, 2011-01-04]’
-- "{[2011-01-01,2011-01-03), (2011-01-04,2011-01-05]}"
```

- Indexing: GiST and SP-GiST indexes are supported

```
CREATE CREATE TABLE reservation (ResID integer, RoomID integer, During period);
CREATE INDEX reservation_during_idx ON reservation USING GIST (during);
```

Temporal Types

- Currently tint, tfloat, tbool, ttext, tgeompoint, tgeogpoint
- Come in four durations



Instant InstantSet Sequence SequenceSet

Temporal Types

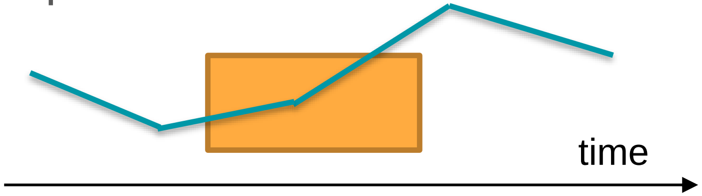
```
CREATE TABLE Department ( DeptNo integer, DeptName varchar(25), NoEmps tint(Sequence) );

CREATE TABLE Flight ( FlightNo integer, Route tgeogpoint(Sequence,PointZ,4326) );

CREATE TABLE Trips ( CarId integer, TripId integer, Trip tgeompoint );

INSERT INTO Trips VALUES

     (10, 1, tgeompoint ’{[Point(0 0)@2012-01-01 08:00:00, Point(2 0)@2012-01-01 08:10:00,

     Point(2 1)@2012-01-01 08:15:00)}’),

     (20, 1, tgeompoint ’{[Point(0 0)@2012-01-01 08:05:00, Point(1 1)@2012-01-01 08:10:00,

     Point(3 3)@2012-01-01 08:20:00)}’);
```

Why not PostGIS Trajectories

- Moving objects represented using LinestringM
- Measure M is not designed to specifically represent time, so total ordering cannot be assumed
- This prevents efficient implementation
  - e.g., binary search cannot be used on general LinestringM values
- Besides temporal point, we also need temporal numbers, temporal Booleans, temporal strings, etc.

From Static to Temporal Types: Lifting

- Lifted functions: functions that have static counterparts, but because some of the arguments are temporal, the return is also temporal
  - Static: st_intersects: geometry × geometry → bool
  - Lifted: tintersects: tgeompoint × geometry → tbool
    tintersects: tgeompoint × tgeompoint → tbool
- Semantics: result of a lifted function obtained by applying static function to each instant of a temporal value



- Spatial support delegated to PostGIS
- We developed a novel generic method for lifting static functions

Temporal Types: Functions

Constructor Functions: easier than input literals

```
SELECT tgeompointinst(’Point(0 0)’, ’2001-01-01 08:00:00’);
SELECT tintseq(ARRAY[tintinst(2,’2001-01-01 08:00:00’),
      tintinst(2,’2001-01-01 08:10:00’)], true, false);
```

Accessor Functions: startValue, startTimestamp, Instants, …

```
SELECT instantN(tfloat ’{[1@2012-01-01, 2@2012-01-02),
      [3@2012-01-03, 3@2012-01-04 , 5@2012-01-05)}’, 3);
-- "3@2012-01-03"
```

Temporal Types: Functions

Spatiotemporal functions: twCentroid, nearestApproachInstant, …

```
SELECT nearestApproachDistance( tgeompoint ’[Point(0 0)@2012-01-
02, Point(1 1)@2012-01-04, Point(0 0)@2012-01-06)’,
geometry ’Linestring(2 2,2 1,3 1)’);
-- "1"
```

Projection functions: atValue, atRange, atMax, atTimestamp, …

```
SELECT astext(atGeometry(
tgeompoint ’[Point(0 0)@2012-01-01, Point(3 3)@2012-01-04)’,
geometry ’Polygon((1 1,1 2,2 2,2 1,1 1))’));
-- "{"[POINT(1 1)@2012-01-02, POINT(2 2)@2012-01-03]"}"
```

Temporal Types: Functions

- Difference Functions: minusValue, minusMax, minusPeriod, …
- Comparison Operators: =, <, …, (B-Tree), #=, #<, … (temporal comparison), &=, @= (temporal type to Boolean)
- Temporal Operators: +, -, *, / for temporal integers and floats
- Bounding Box Operators
    - <<, >>, &<, &>: value dimension for tint and tfloat, x-dimension for temporal points
    - <<|, |>>, &<|, and |&>, y-dimension
    - <</, />>, &</, and /&> z-dimension
    - <<#, #>>, #&<, and #&> time dimension
- Distance Operators: |=|, <->
- Casting: tfloat::tint, tgeogpoint::tgeompoint
- Spatial Relationships: intersects, relate, …, tintersects, trelate, …

GiST and SP-GiST Indexes

Temporal types support both GiST and SP-GiST indexes

```
CREATE CREATE INDEX Department_NoEmps_Gist_Idx ON Department USING Gist(NoEmps);
CREATE INDEX Trips_Trip_SPGist_Idx ON Trips USING SPGist(Trip);
```

Indexes store the bounding box for the temporal types

- period for tbool and ttext (1D)
- box for tint and tfloat (2D)
- gbox for tgeompoint and tgeogpoint (4D)

Indexes can accelerate queries involving the following operators

- <<, &<, …, <<|, &<|, …, &</, <</, …, for the value/spatial dimension
- &<#, <<#, .., for the time dimension
- &&, @>, <@, ~=, consider as many shared dimensions

SP-GiST Indexes

- To implement SP-GiST, the bounding box is transformed into a higher dimensional point
    - 2D point to represent a period
    - 4D point to represent a box
    - 8D point to represent a gbox
- We reused approach from SP-GiST indexes for BOX type in PostgreSQL
- After that we proposed patches for SP-GiST indexes for 2D/3D Geometry (PostGIS V2.5) and ND Geometry (PostGIS V3.0)

Aggregation Functions

Three types of aggregations

- Regular aggregation functions

```
SELECT COUNT(Trip) FROM Bus;
```

- Temporal aggregation functions: result in a temporal type

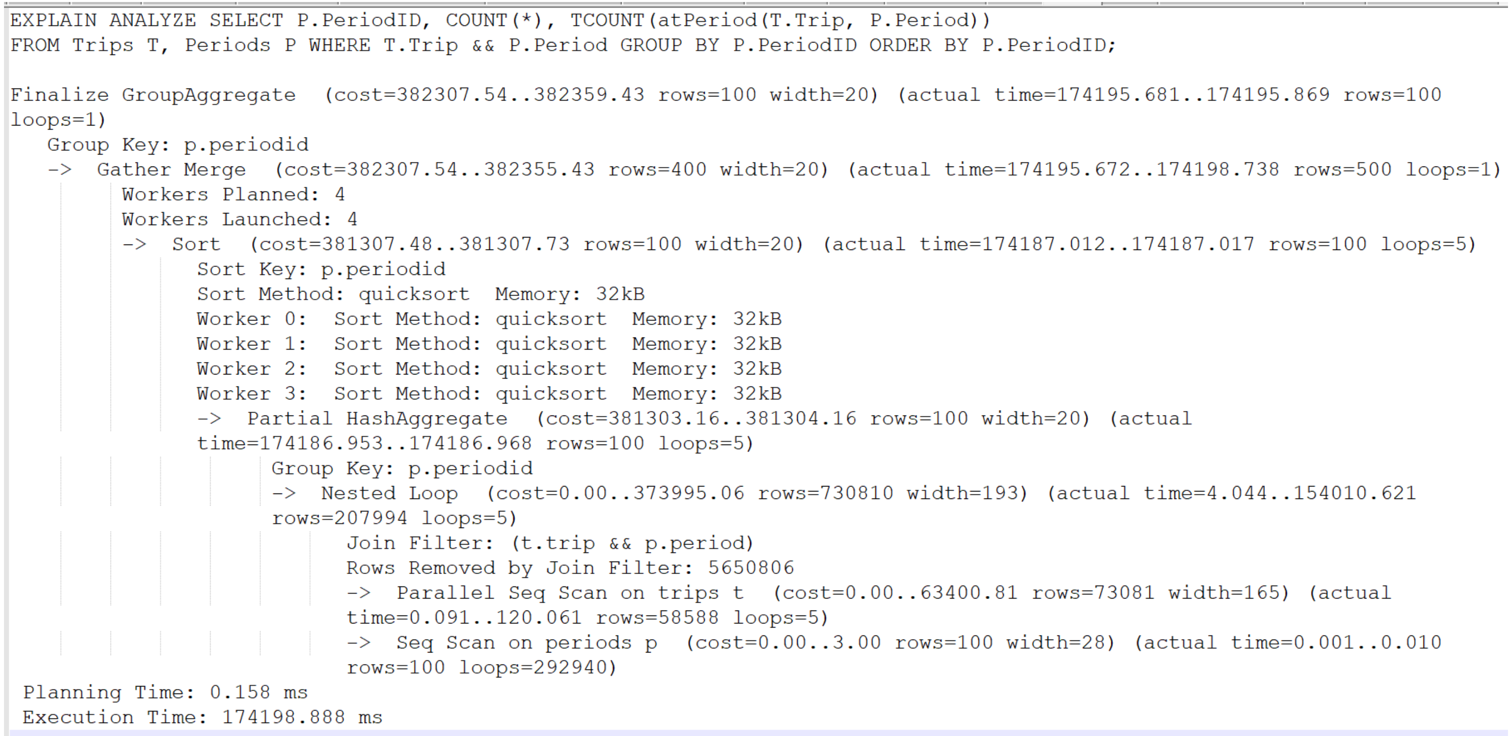
```
SELECT TCOUNT(Trip) FROM Bus;
```

- Sliding window aggregation functions : interval parameter, result in a temporal type

```
SELECT WMAX(speed(Trip), interval ’10 minutes’) FROM Bus;
```

Temporal Aggregation: Parallel Execution

Compute how many cars were active at each period in table Periods

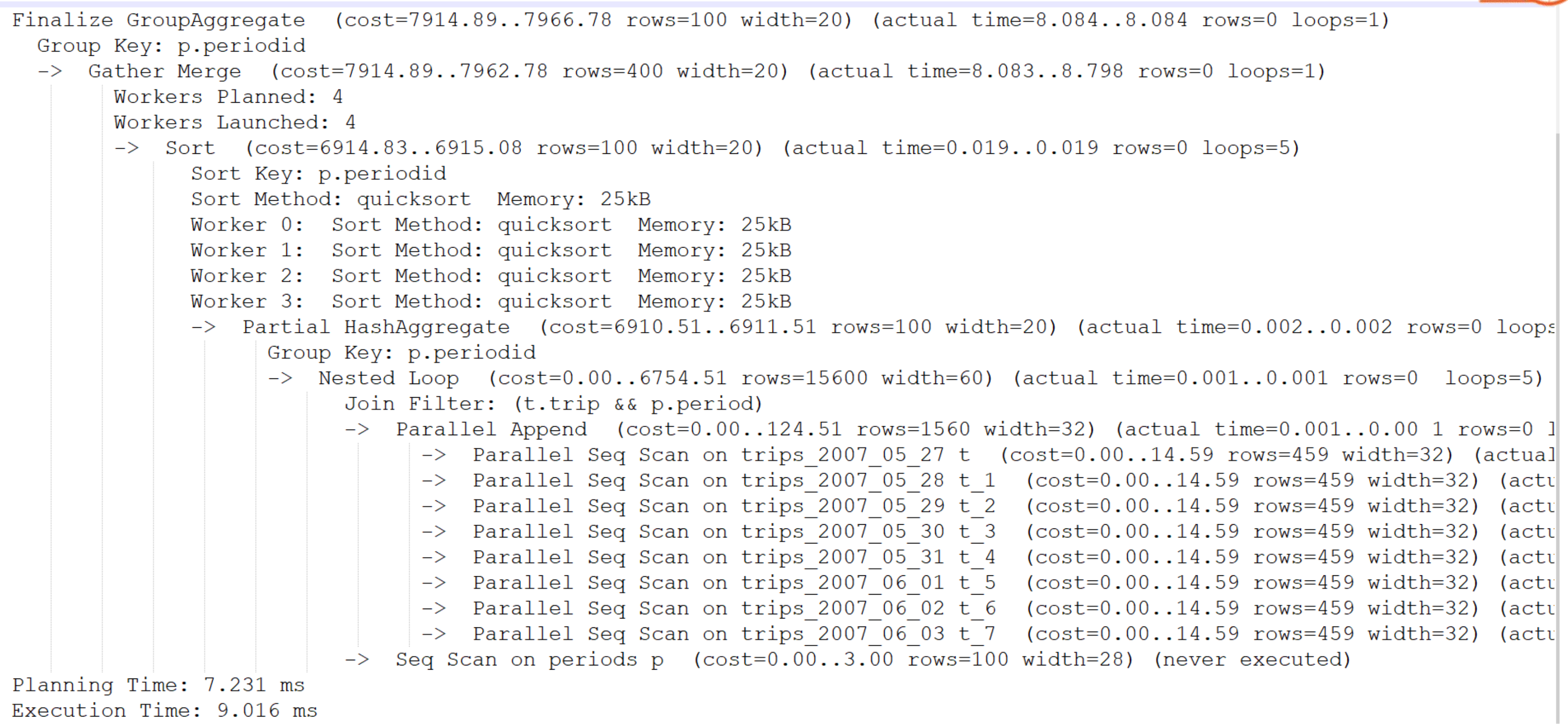


```
EXPLAIN ANALYZE SELECT P.PeriodID, COUNT(*), TCOUNT(atPeriod(T.Trip, P.Period))
FROM Trips T, Periods P WHERE T.Trip && P.Period GROUP BY P.PeriodID ORDER BY P.PeriodID;

Finalize GroupAggregate  (cost=382307.54..382359.43 rows=100 width=20) (actual time=174195.681..174195.869 rows=100
loops=1)
   Group Key: p.periodid
   ->  Gather Merge  (cost=382307.54..382355.43 rows=400 width=20) (actual time=174195.672..174198.738 rows=500 loops=1)
         Workers Planned: 4
         Workers Launched: 4
         ->  Sort  (cost=381307.48..381307.73 rows=100 width=20) (actual time=174187.012..174187.017 rows=100 loops=5)
               Sort Key: p.periodid
               Sort Method: quicksort  Memory: 32kB
               Worker 0:  Sort Method: quicksort  Memory: 32kB
               Worker 1:  Sort Method: quicksort  Memory: 32kB
               Worker 2:  Sort Method: quicksort  Memory: 32kB
               Worker 3:  Sort Method: quicksort  Memory: 32kB
               ->  Partial HashAggregate  (cost=381303.16..381304.16 rows=100 width=20) (actual
               time=174186.953..174186.968 rows=100 loops=5)
                     Group Key: p.periodid
                     ->  Nested Loop  (cost=0.00..373995.06 rows=730810 width=193) (actual time=4.044..154010.621
                     rows=207994 loops=5)
                           Join Filter: (t.trip && p.period)
                           Rows Removed by Join Filter: 5650806
                           ->  Parallel Seq Scan on trips t  (cost=0.00..63400.81 rows=73081 width=165) (actual
                           time=0.091..120.061 rows=58588 loops=5)
                           ->  Seq Scan on periods p  (cost=0.00..3.00 rows=100 width=28) (actual time=0.001..0.010
                           rows=100 loops=292940)
 Planning Time: 0.158 ms
 Execution Time: 174198.888 ms
```

Temporal Aggregation: Partitioning

```
CREATE TABLE Trips
(
          CarId integer NOT NULL,
          TripId integer NOT NULL,
          TripDate date,
          Trip tgeompoint,
          Traj geometry,
          PRIMARY KEY (CarId, TripId, TripDate),
          FOREIGN KEY (CarId) REFERENCES Cars (CarId)
) PARTITION BY LIST(TripDate);

CREATE TABLE Trips_2007_05_27 PARTITION OF Trips FOR VALUES IN ('2007-05-27');
CREATE TABLE Trips_2007_05_28 PARTITION OF Trips FOR VALUES IN ('2007-05-28');
CREATE TABLE Trips_2007_05_29 PARTITION OF Trips FOR VALUES IN ('2007-05-29');
CREATE TABLE Trips_2007_05_30 PARTITION OF Trips FOR VALUES IN ('2007-05-30');
...
```

Temporal Aggregation: Partitioning



```
Finalize GroupAggregate  (cost=7914.89..7966.78 rows=100 width=20) (actual time=8.084..8.084 rows=0 loops=1)
 Group Key: p.periodid
 ->  Gather Merge  (cost=7914.89..7962.78 rows=400 width=20) (actual time=8.083..8.798 rows=0 loops=1)
    Workers Planned: 4
    Workers Launched: 4
    ->  Sort  (cost=6914.83..6915.08 rows=100 width=20) (actual time=0.019..0.019 rows=0 loops=5)
       Sort Key: p.periodid
       Sort Method: quicksort  Memory: 25kB
       Worker 0:  Sort Method: quicksort  Memory: 25kB
       Worker 1:  Sort Method: quicksort  Memory: 25kB
       Worker 2:  Sort Method: quicksort  Memory: 25kB
       Worker 3:  Sort Method: quicksort  Memory: 25kB
       ->  Partial HashAggregate  (cost=6910.51..6911.51 rows=100 width=20) (actual time=0.002..0.002 rows=0 loops
          Group Key: p.periodid
          ->  Nested Loop  (cost=0.00..6754.51 rows=15600 width=60) (actual time=0.001..0.001 rows=0  loops=5)
             Join Filter: (t.trip && p.period)
             ->  Parallel Append  (cost=0.00..124.51 rows=1560 width=32) (actual time=0.001..0.00 1 rows=0 l
                ->  Parallel Seq Scan on trips_2007_05_27 t  (cost=0.00..14.59 rows=459 width=32) (actual
                ->  Parallel Seq Scan on trips_2007_05_28 t_1  (cost=0.00..14.59 rows=459 width=32) (actu
                ->  Parallel Seq Scan on trips_2007_05_29 t_2  (cost=0.00..14.59 rows=459 width=32) (actu
                ->  Parallel Seq Scan on trips_2007_05_30 t_3  (cost=0.00..14.59 rows=459 width=32) (actu
                ->  Parallel Seq Scan on trips_2007_05_31 t_4  (cost=0.00..14.59 rows=459 width=32) (actu
                ->  Parallel Seq Scan on trips_2007_06_01 t_5  (cost=0.00..14.59 rows=459 width=32) (actu
                ->  Parallel Seq Scan on trips_2007_06_02 t_6  (cost=0.00..14.59 rows=459 width=32) (actu
                ->  Parallel Seq Scan on trips_2007_06_03 t_7  (cost=0.00..14.59 rows=459 width=32) (actu
             ->  Seq Scan on periods p  (cost=0.00..3.00 rows=100 width=28) (never executed)
Planning Time: 7.231 ms
Execution Time: 9.016 ms
```

3D Temporal Points

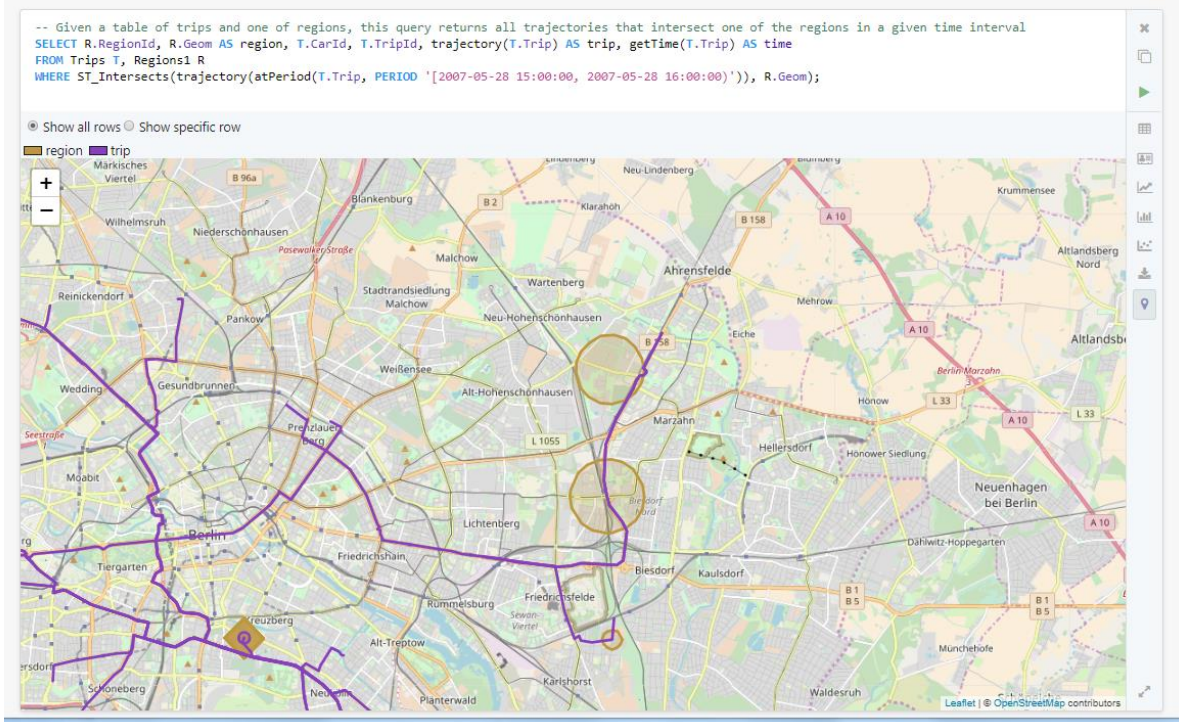
- Builds upon PostGIS 3D Geometry and Geography
- Many functions: length, cumulativeLength, speed, expandSpatial, expandTemporal, twCentroid, azimuth, tintersects, …
- gbox is used for representing the bounding box
- Supported in both GiST and SP-GiST

MobilityDB Roadmap

- Development started locally at ULB
  - 2,374 functions, 62,825 lines of C, 19,070 lines of SQL, 19,939 lines of regression tests
- Promising results from robustness tests, performance tests, benchmarking wrt PostGIS trajectories and Secondo
- Currently finalizing planner statistics and selectivity functions
- Development planned to move to github soon
- Stable release delivered open source as soon as it is ready
- Several extensions are being explored
  - Network-constrained trajectories with pgRouting
  - Visualization with QGIS
  - Big mobility data with Postgres-XL
  - Split lists for optimized temporal aggregation

MobilityDB Roadmap

- Demo at http://demo.mobilitydb.com/ using BerlinMOD benchmark data



```
-- Given a table of trips and one of regions, this query returns all trajectories that intersect one of the regions in a given time interval
SELECT R.RegionId, R.Geom AS region, T.CarId, T.TripId, trajectory(T.Trip) AS trip, getTime(T.Trip) AS time
FROM Trips T, Regions1 R
WHERE ST_Intersects(trajectory(atPeriod(T.Trip, PERIOD '[2007-05-28 15:00:00, 2007-05-28 16:00:00)')), R.Geom);
```

● Show all rows ○ Show specific row

▨ region ▨ trip

Thanks for listening !

Questions ?

ULB