Spatial trajectories in Boost Geometry

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FOSDEM 2020

Boost.Geometry

- Part of Boost C++ Libraries
- Header-only
- C++03 (conditionally C++11, C++14)
- Metaprogramming, Tags dispatching
- Primitives, Algorithms, Spatial Index
- Standards: OGC SFA
- used by MySQL for GIS

How to Get Started?

- Documentation: `www.boost.org/libs/geometry`
- Mailing list: `lists.boost.org/geometry`
- GitHub: `github.com/boostorg/geometry`

Who is Boost.Geometry?

- Boost.Geometry is an open source project (as any other Boost library)
- Anybody can, and is welcome, to contribute
- Core development team:
  - Barend Gehrels
  - Bruno Lalande
  - Mateusz Loskot
  - Adam Wulkiewicz
  - Menelaos Karavelas
  - Vissarion Fysikopoulos
- Contributions from about a dozen of other developers
- See Boost.Geometry website for credits and GitHub repositorys history

Boost.Geometry & MySQL

- MySQL (since 5.7) relies on Boost geometry for GIS support (geographic support since 8)
- no homegrown set of GIS functions for MySQL
- both aim in OGC standard compliance
- compatible licences
- MySQL benefit from BG open source community (maintenance, bug fixing, gsoc)
- BG is C++/header only $\rightarrow$ no problems with versions of a shared library on different platforms for MySQL

Hello, world!

```
#include <boost/geometry.hpp>
#include <boost/geometry/geometries/geometries.hpp>
#include <iostream>
namespace bg = boost::geometry;
int main() {
  using point = bg::model::point
                  <double, 2, bg::cs::geographic<bg::degree>>;

  std::cout << bg::distance(
                 point(23.725750, 37.971536),   //Athens, Acropolis
                 point(4.3826169, 50.8119483)); //Brussels, ULB
}
```

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result=2088.389 km

Hello strategies!

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```

Hello strategies!

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```

result=2088389 m

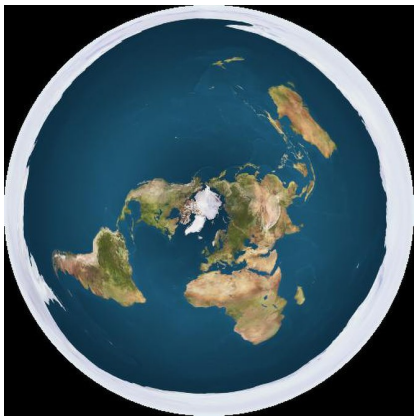
result with strategy=2088384 m

Boost Geometry Algorithms= CS-independent part + CS-specific part (strategies)

Models of the earth and coordinate systems

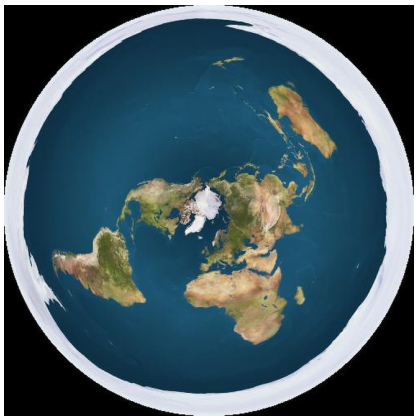
- Flat

  `boost::geometry::cs::cartesian`



Models of the earth and coordinate systems

- Flat
  `boost::geometry::cs::cartesian`
- Sphere (*Widely used e.g.* `google.maps`)
  `boost::geometry::cs::spherical_equatorial<bg::degree>`
  `boost::geometry::cs::spherical_equatorial<bg::radian>`



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- Ellipsoid of revolution (*geographic GIS state-of-the-art*)
  `boost::geometry::cs::geogrphic<bg::degree>`
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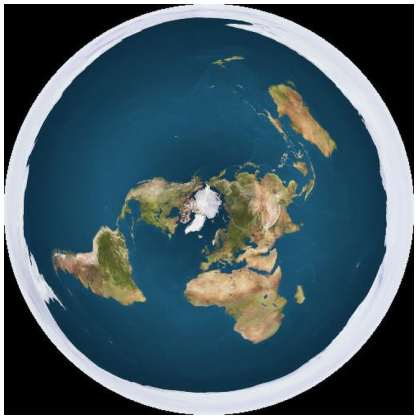

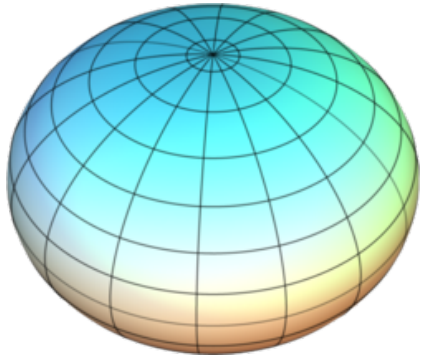

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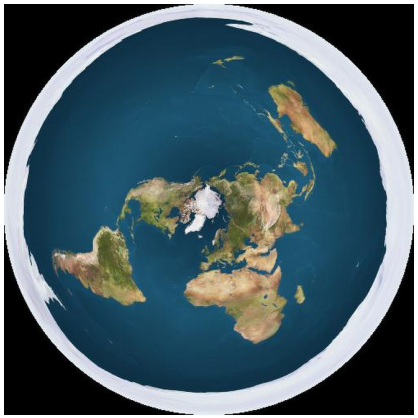
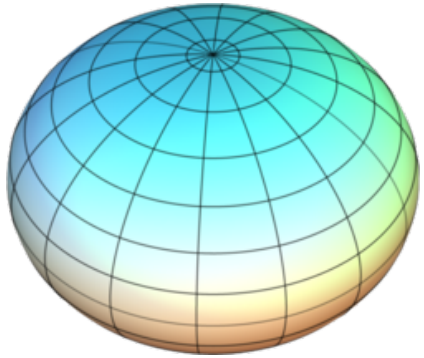
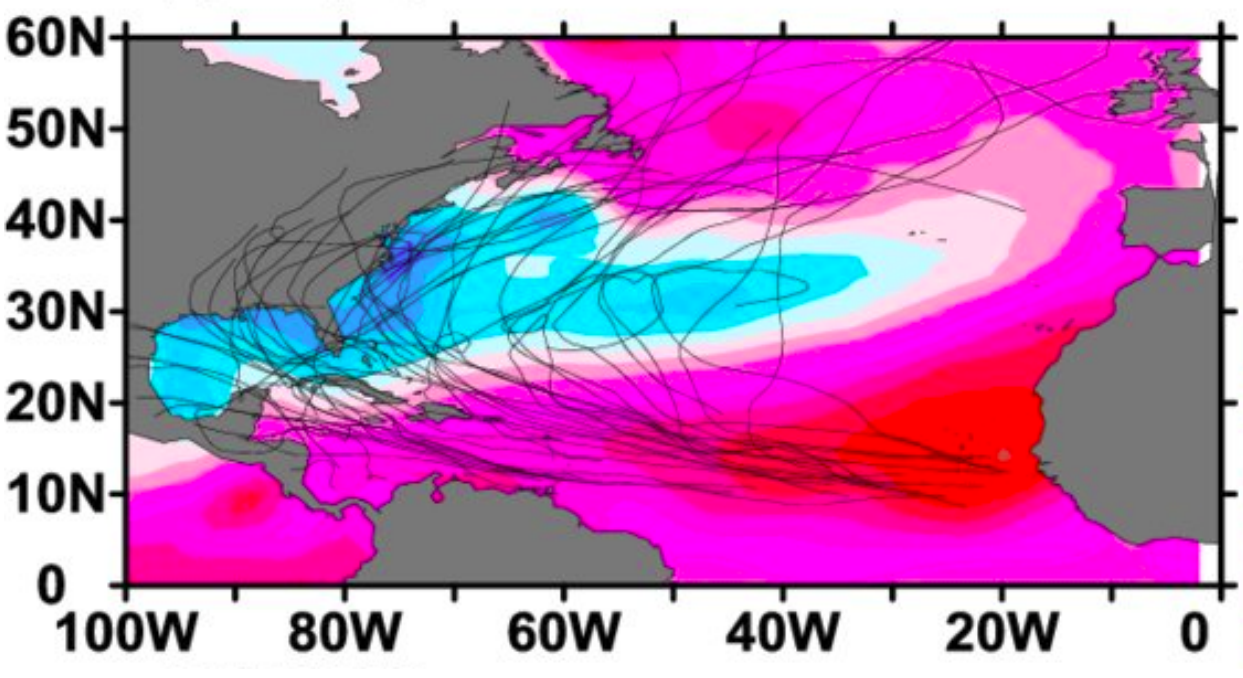
  `boost::geometry::cs::geogrphic<bg::degree>`
  `boost::geometry::cs::geogrphic<bg::radian>`
- Geoid (*Special applications, geophysics etc*)





Spatial trajectories

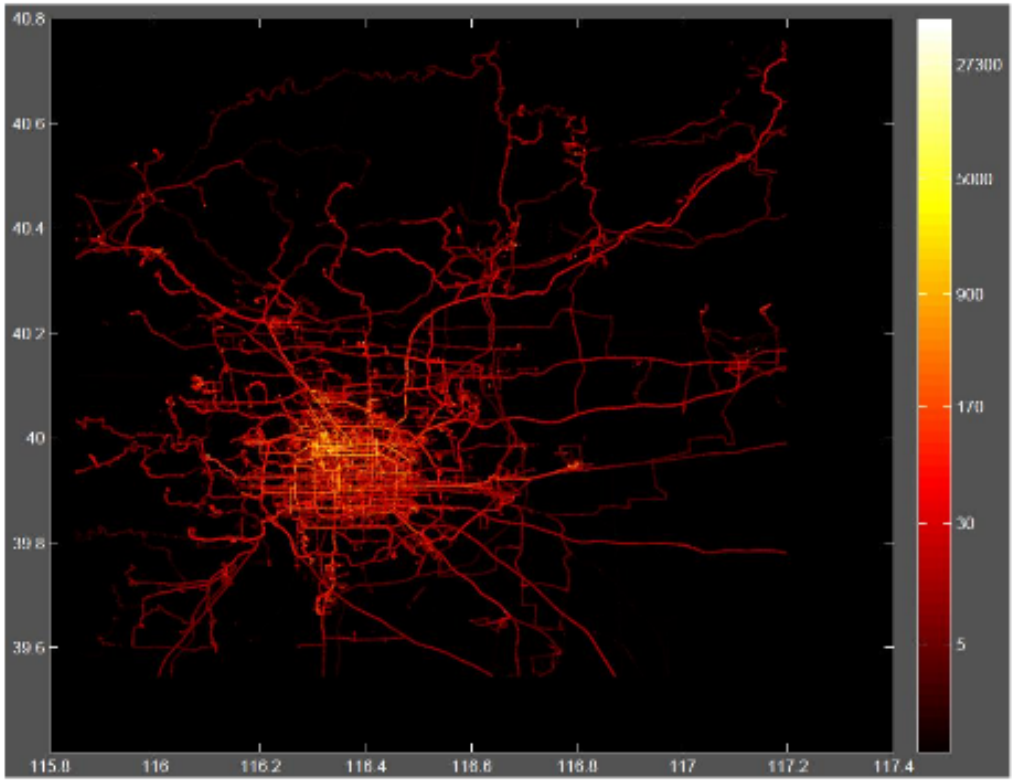
- trajectories are sequencies of time-stamped locations
- generated by GPS, smartphones, infrastructure, computer games, natural phenomena, etc
- here we study only the spatial and not the temporal information, i.e. trajectories are modelled as `linestrings`



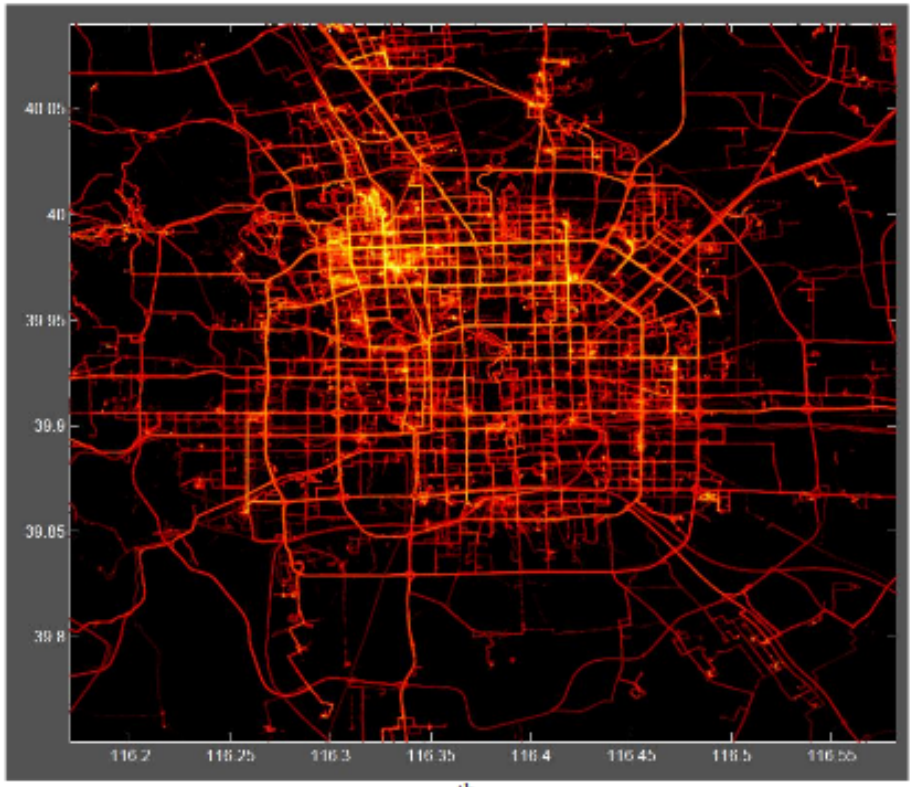
Trajetories of major huricanes in Atlantic [Wang et al.'17]

Trajectories data-set

GeoLife GPS Trajectories dataset [download]



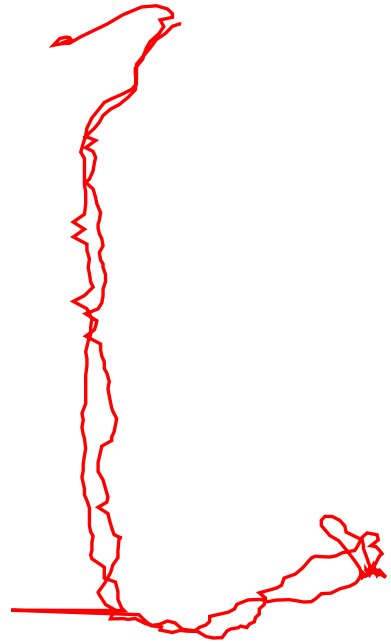
A) Data overview in Beijing

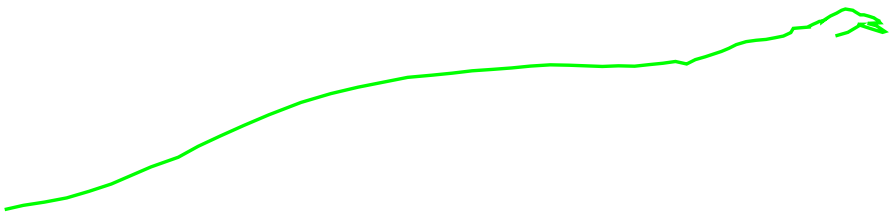


B) Within the 5th Ring Road of Beijing

https://www.microsoft.com/en-us/research/wp-content/uploads/2016/02/User20Guide-1.2.pdf

Two trajectories





Simple operations: size, length, distance

```
using point = bg::model::point
                    <double, 2, bg::cs::geographic<bg::degree>>;
bg::model::linestring<point> ls1, ls2;

std::ifstream myfile1 ("Geolife_Trajectories_1.3/Data/000/
                        Trajectory/20090516091038.plt");
std::ifstream myfile2 ("Geolife_Trajectories_1.3/Data/010/
                        Trajectory/20081224011945.plt");
read_linestring(myfile1, ls1);
read_linestring(myfile2, ls2);

std::cout << boost::size(ls1) << std::endl;
std::cout << boost::size(ls2) << std::endl;

std::cout << bg::length(ls1) << std::endl;
std::cout << bg::length(ls2) << std::endl;

std::cout << bg::distance(ls1, ls2) << std::endl;
```

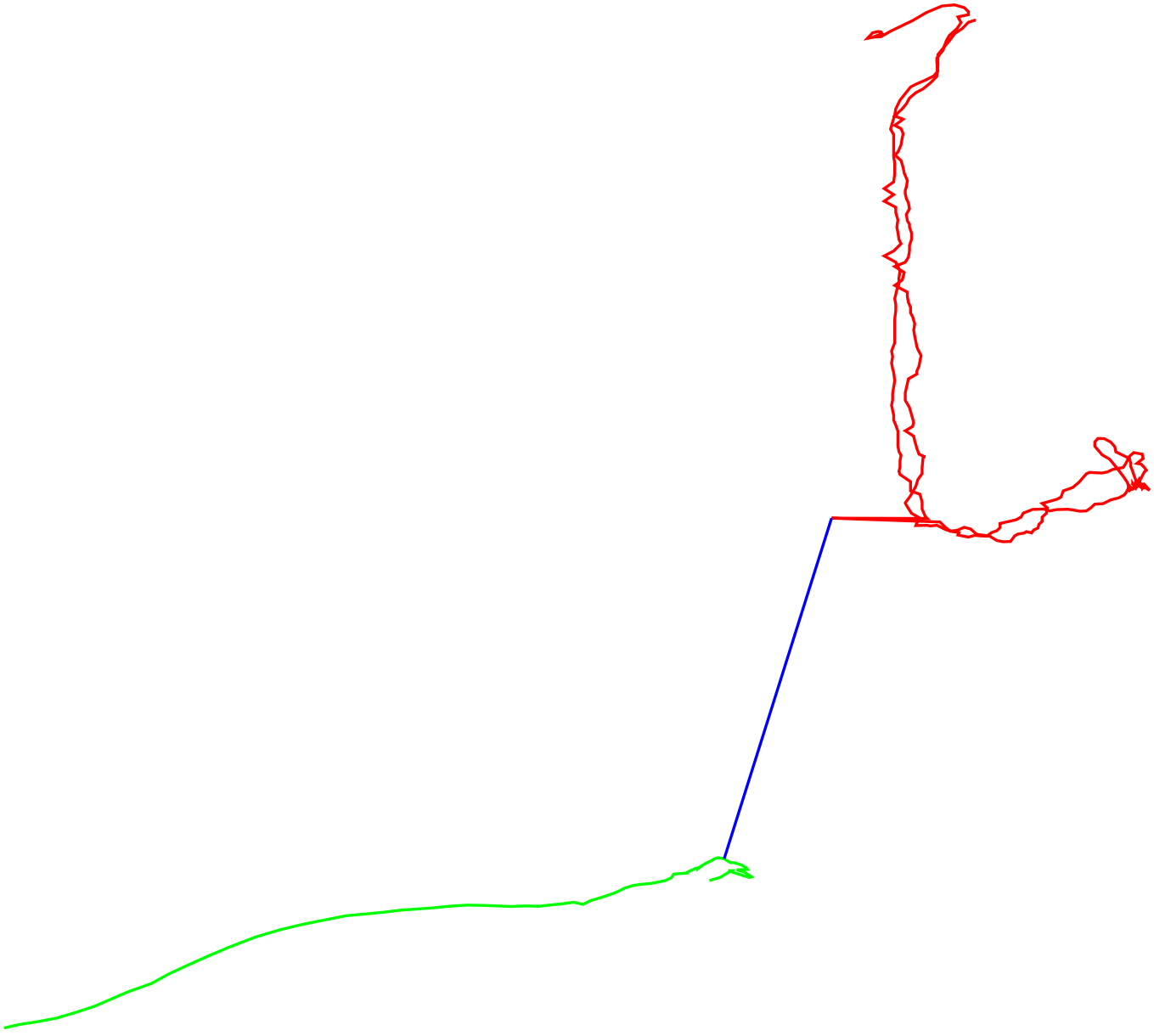
```
317
75
2196.14
718.456
369.504
```

Note: distances in meters, result by use of non default strategies neglectable

Closest points

```
using point = bg::model::point
                  <double, 2, bg::cs::geographic<bg::degree>>;

using linestring = bg::model::linestring<point>;

linestring ls1, ls2;

std::ifstream myfile1 ("Geolife_Trajectories_1.3/Data/000/
                        Trajectory/20090516091038.plt");
std::ifstream myfile2 ("Geolife_Trajectories_1.3/Data/010/
                        Trajectory/20081224011945.plt");

read_linestring(myfile1, ls1);
read_linestring(myfile2, ls2);

bg::model::segment<point> sout;
bg::closest_points(ls1, ls2, sout);
```

Closest points



Simplification of trajectories

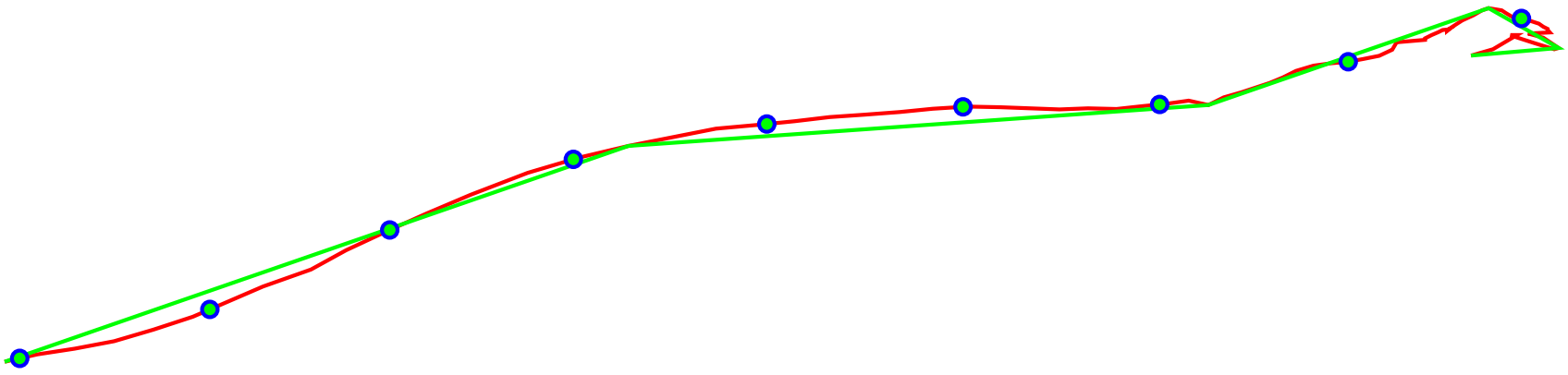
- simplification using Douglas-Peucker algorithm
- quadratic worst case complexity [Hershberger et.al'92]
- line_interpolate: interpolate points on linestring at a fixed distance
- sampling points on linestrings (https://github.com/boostorg/geometry/pull/618)

Simplify and line_interpolate

```
using point = bg::model::point
                    <double, 2, bg::cs::geographic<bg::degree>>;
using linestring = bg::model::linestring<point>;
linestring ls;

std::ifstream myfile2 ("Geolife_Trajectories_1.3/Data/010/
                        Trajectory/20081224011945.plt");
read_linestring(myfile2, ls);

std::cout << "#points in ls = " << boost::size(ls2) << std::endl;
std::cout << "ls length (m) = " << bg::length(ls2) << std::endl;

linestring ls_simplified;
bg::simplify(ls2, ls_simplified, 20);
std::cout << "#points in  simplified = " << boost::size(ls_simplif

using multipoint_type = bg::model::multi_point<point>;
multipoint_type mp;
bg::line_interpolate(ls2, 70, mp);
std::cout << "#points interpolated = " << boost::size(mp) << std::
```

#points in ls = 75
ls length (m) = 718.456
#points in simplified = 6
#points interpolated = 9

Simplification and line_interpolate



Measuring similarity of trajectories

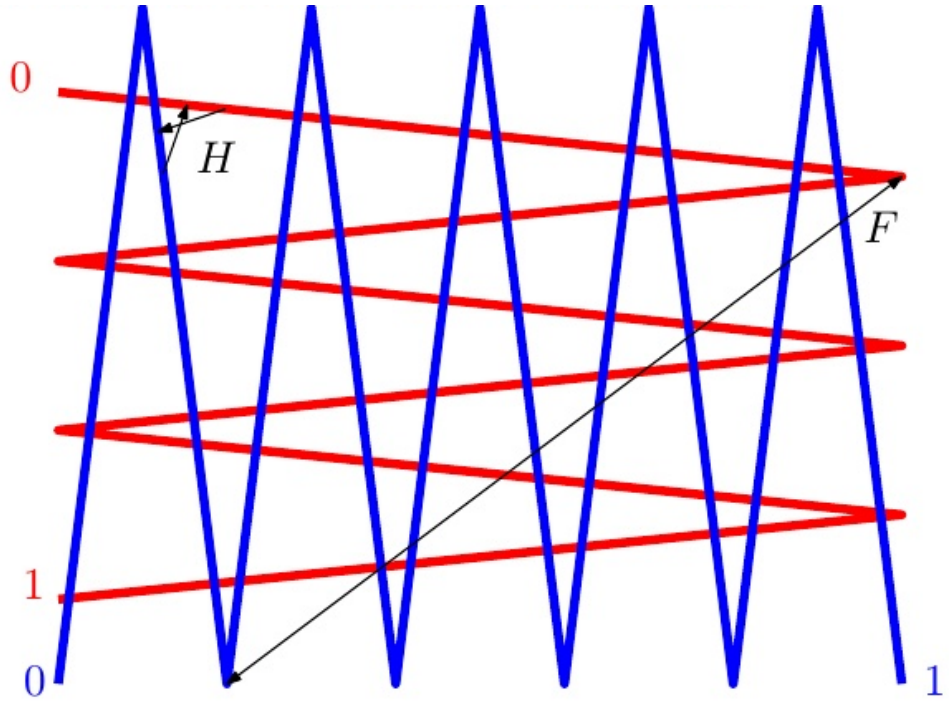
- Hausdorff distance

$$H(f,g) = \max_{a \in f} \{ \min_{b \in g} \{ dist(a,b) \} \}$$

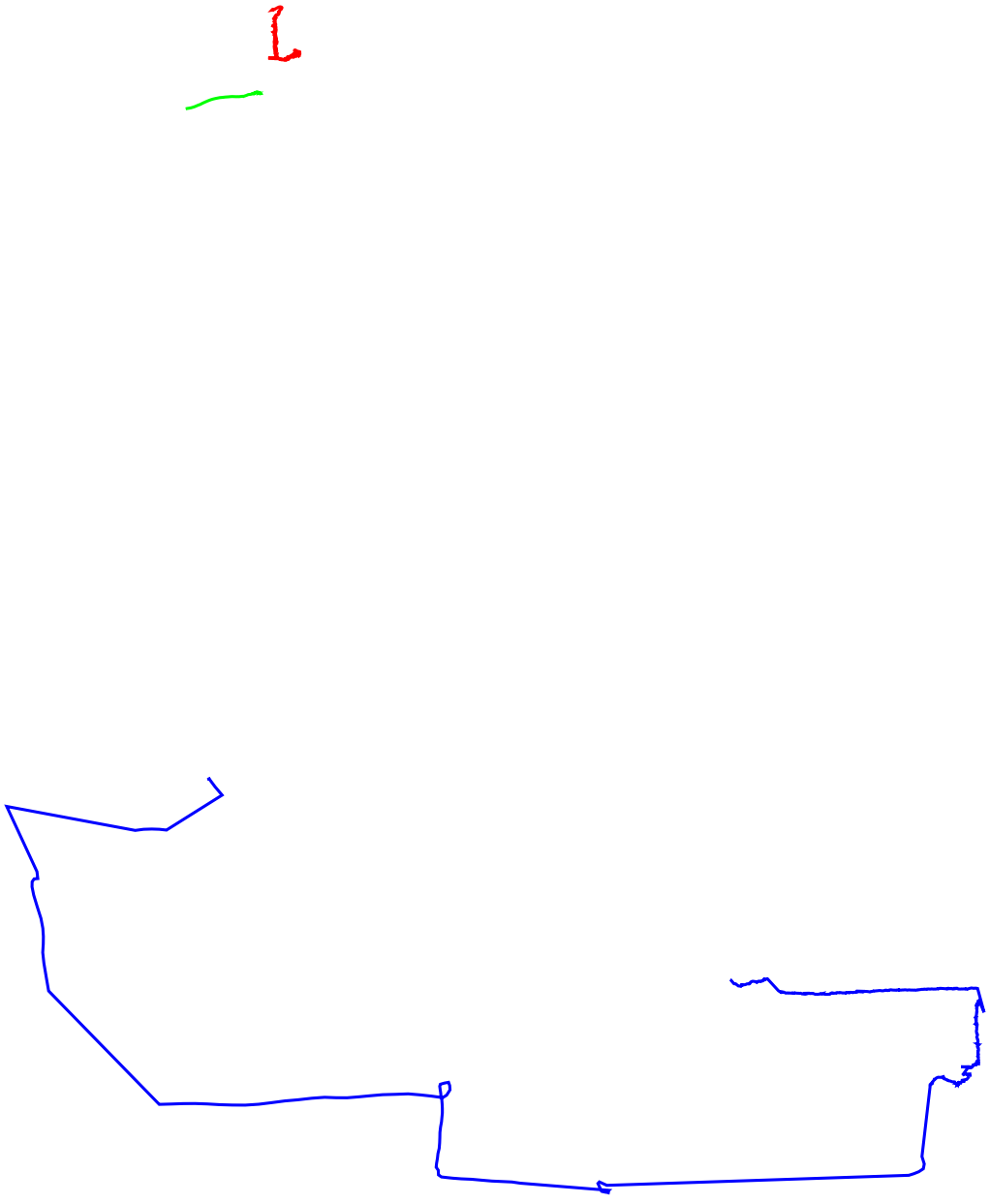
- Fréchet distance

$$F(f,g) = \min \{ ||L|| \; L \text{ is a coupling between } f \text{ and } g \}$$

coupling is a sequence of pairs from f, g that respect the order



Three trajectories



l_1: red, l_2: green, l_3: blue

Hausdorff & Fréchet distance

```
using point = bg::model::point
              <double, 2, bg::cs::geographic<bg::degree>>;
bg::model::linestring<point> ls1, ls2, ls3;
std::ifstream myfile1 ("Geolife_Trajectories_1.3/Data/000/
                        Trajectory/20090516091038.plt");
std::ifstream myfile2 ("Geolife_Trajectories_1.3/Data/010/
                        Trajectory/20081224011945.plt");
std::ifstream myfile3 ("Geolife_Trajectories_1.3/Data/000/
                           Trajectory/20081026134407.plt");
read_linestring(myfile1, ls1);
read_linestring(myfile2, ls2);
read_linestring(myfile3, ls3);
std::cout << bg::discrete_hausdorff_distance(ls1, ls2) << ","
          << bg::discrete_hausdorff_distance(ls2, ls3) << ","
          << bg::discrete_hausdorff_distance(ls1, ls3)
          << std::endl;
std::cout << bg::discrete_frechet_distance(ls1, ls2) << ","
          << bg::discrete_frechet_distance(ls2, ls3) << ","
          << bg::discrete_frechet_distance(ls1, ls3)
          << std::endl;
```

919.467, 7266.3, 8175.84

1260.76, 12601.7, 12837.9

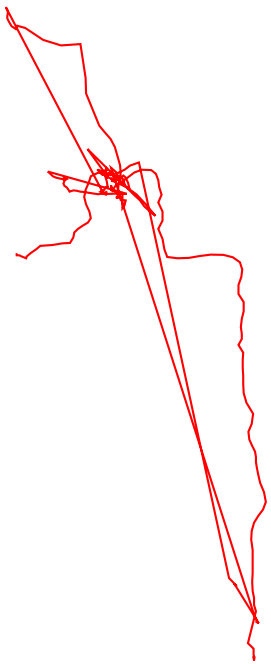
Hausdorff & Fréchet distance

Comparing similarity of 160 pairs of trajectories

```
namespace bf = boost::filesystem;
using point = bg::model::point
                    <double, 2, bg::cs::geographic<bg::degree>>;
linestring = bg::model::linestring<point> ls1, ls2;

bf::path p{"Geolife_Trajectories_1.3/Data/000/Trajectory/"};
bf::directory_iterator it1{p};
double min_frechet = 10000000;

bf::directory_iterator it2{bf::path{"Geolife_Trajectories_1.3/
                                    Data/010/Trajectory/"}};
for (; it2 != bf::directory_iterator{}; it2++)
{
    std::ifstream myfile1((*it1).path().string());
    std::ifstream myfile2((*it2).path().string());
    read_linestring(myfile1, ls1);
    read_linestring(myfile2, ls2);
    double frechet = bg::discrete_frechet_distance(ls1, ls2);
    min_frechet = frechet < min_frechet ? frechet : min_frechet;
}
```

cartesian: 9.97[sec]
spherical: 28.47[sec]
geographic: 52.30[sec]

Most similar trajectories



Same result for cartesian, spherical, geographic

Thank you!

Questions?