

RoutingWatch

Visual Exploration and Analysis of Routing Events

Davide Ceneda
Marco Di Bartolomeo
Valentino Di Donato

Maurizio Patrignani
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Massimo Rimondini

RoutingWatch



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Visual Exploration and
Analysis of **Routing Events**



State of the Art



Management &
Monitoring Tools

Inference
Algorithms

Visualization
Systems

State of the Art



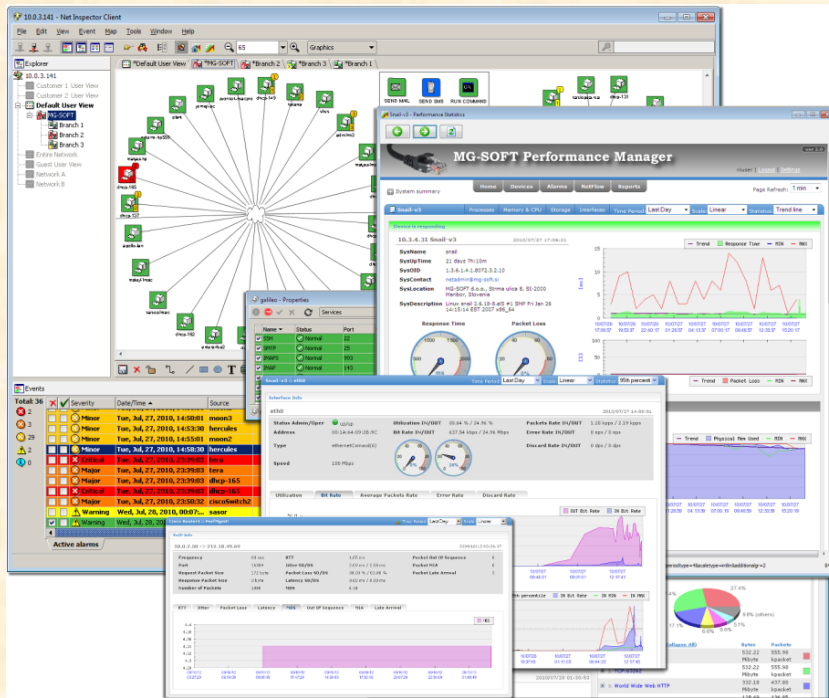
Management & Monitoring Tools

Inference Algorithms

Visualization Systems



Net Inspector



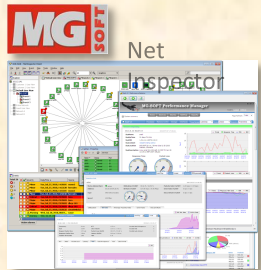
State of the Art



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Embedded CISCO™ Event Manager

```
event manager applet interface_shutdown
event syslog pattern "Interface FastEthernet1/0, changed
state to administratively down"
action 1.0 cli command "enable"
action 1.5 cli command "config t"
action 2.0 cli command "interface fa1/0"
action 2.5 cli command "no shutdown"
action 3.0 cli command "end"
action 3.5 cli command "who"
action 4.0 mail server "192.168.1.1" to
".engineer@cisco.com." from ".EEM@cisco.com."
subject ".ISP1_Interface_fa1/0_SHUT." body "Current
users $_cli_result"
```

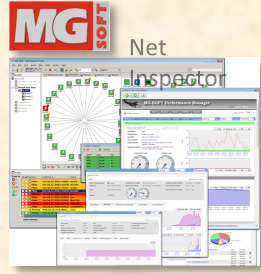
State of the Art



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Visualization Systems



```

Cisco Embedded Event Manager
event manager applet Interface_Shutdown
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"Current users $_cli_result"
    
```

Nagios® Monitoring System

Nagios®

Home
Documentation

Current Status

Tactical Overview
Map
Hosts
Services
Host Groups
Summary
Grid
Service Groups
Summary
Grid
Problems
Services (Unhandled)
Hosts (Unhandled)
Network Outages

Quick Search:

Reports

Availability
Trends
Alerts
History
Summary
Histogram
Notifications
Event Log

System

Comments
Downtime
Process Info
Performance Info
Scheduling Queue
Configuration

Current Network Status
Last Updated: Fri Oct 17 18:51:18 UTC 2014
Updated every 90 seconds
Nagios® Core™ 4.0.8 - www.nagios.org
Logged in as nagiosadmin

View History For all hosts
View Notifications For All Hosts
View Host Status Detail For All Hosts

Host Status Totals

Up	Down	Unreachable	Pending
11	0	0	0

All Problems All Types

0	11
---	----

Service Status Totals

Ok	Warning	Unknown	Critical	Pending
33	1	1	4	0

All Problems All Types

6	39
---	----

Service Status Details For All Hosts

Limit Results: 100

Host	Service	Status	Last Check	Duration	Attempt	Status Information	
NOAA	Auroral Activity	OK	10-17-2014 18:51:09	535d 4h 28m 6s	1/3	Aurora OK: Activity level is 2	
	Weather Carteret North Carolina	WARNING	10-17-2014 18:43:15	0d 0h 46m 57s	3/3	Weather Warning: Beach Hazards	
	Weather King Washington	OK	10-17-2014 18:45:25	737d 1h 52m 46s	1/3	Weather OK: No watches or warni area.	
	Weather Ramsey Minnesota	OK	10-17-2014 18:46:45	59d 20h 47m 12s	1/3	Weather OK: No watches or warni area.	
	Weather San Bernardino California	OK	10-17-2014 18:41:45	0d 0h 48m 40s	1/3	Weather OK: No watches or warni area.	
	Weather Stafford New Hampshire	OK	10-17-2014 18:43:45	0d 0h 46m 51s	1/3	Weather OK: No watches or warni area.	
	Weather Tulsa Oklahoma	OK	10-17-2014 18:45:53	737d 1h 53m 51s	1/3	Weather OK: No watches or warni area.	
	localhost	Current Load	OK	10-17-2014 18:49:08	0d 0h 46m 9s	1/4	OK - load average: 0.29, 0.49, 0.56
		Current Users	OK	10-17-2014 18:51:02	1710d 15h 36m 24s	1/4	USERS OK - 0 users currently logg
		HTTP	OK	10-17-2014 18:48:25	1019d 2h 7m 58s	1/4	HTTP OK: HTTP/1.1 200 OK - 218 response time
PING		OK	10-17-2014 18:50:20	1710d 15h 35m 9s	1/4	PING OK - Packet loss = 0%, RTA	

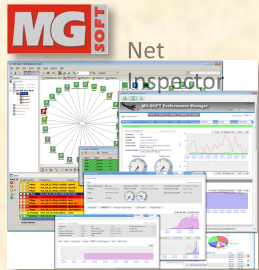
State of the Art



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```



- Raise alarms based on unexpected changes in:
 - performance levels (bandwidth)
 - health flags (interface status)
 - configurations

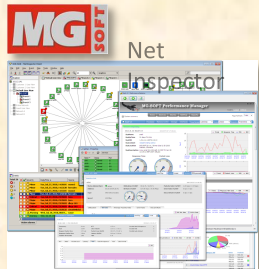
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- Raise alarms based on unexpected changes in:
 - performance levels (bandwidth)
 - health flags (interface status)
 - configurations
- Require polling and/or agents
- Must support many technologies

State of the Art



Management &
Monitoring Tools

**Inference
Algorithms**

Visualization
Systems

- J. Wu, Z. M. Mao, J. Rexford, and J. Wang, “Finding a Needle in a Haystack: Pinpointing Significant BGP Routing Changes in an IP Network”. Proc. NSDI, 2005
 - Online BGP route analysis to find and correlate events
- G. Comarela, G. Gürsun, and M. Crovella, “Studying Interdomain Routing over Long Timescales”. Proc. IMC, 2013
 - Evolution of the Routing State Distance
- G. Comarela and M. Crovella, “Identifying and Analyzing High Impact Routing Events with PathMiner”. Proc. IMC, 2014
 - Next-hop tensor factorization

State of the Art



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- Focus on BGP
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- Limited information about each event (typically, cause AS)

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 - Evolution of the Routing State Distance
 - Future work envisions combined investigation of space and time, assessment of the type of routing change, event inference
- G. Comarela and M. Crovella, “Identifying and Analyzing High Impact Routing Events with PathMiner”. Proc. IMC, 2014
 - Next-hop tensor factorization
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- M. Di Bartolomeo, V. Di Donato, M. Pizzonia, C. Squarcella, and M. Rimondini, “Discovering High-impact Routing Events using Traceroutes”. Proc. ISCC, 2015
- M. Di Bartolomeo, V. Di Donato, M. Pizzonia, C. Squarcella, and M. Rimondini, “Mining Network Events using Traceroute Empathy”. Tech. Rep., 2015 <http://arxiv.org/abs/1412.4074v2.pdf>
 - Event inference

State of the Art



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 - Event inference
- Lots of inferred events

State of the Art



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State of the Art

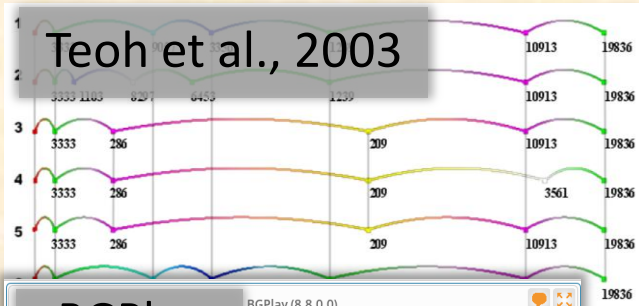


Management & Monitoring Tools

Inference Algorithms

Visualization Systems

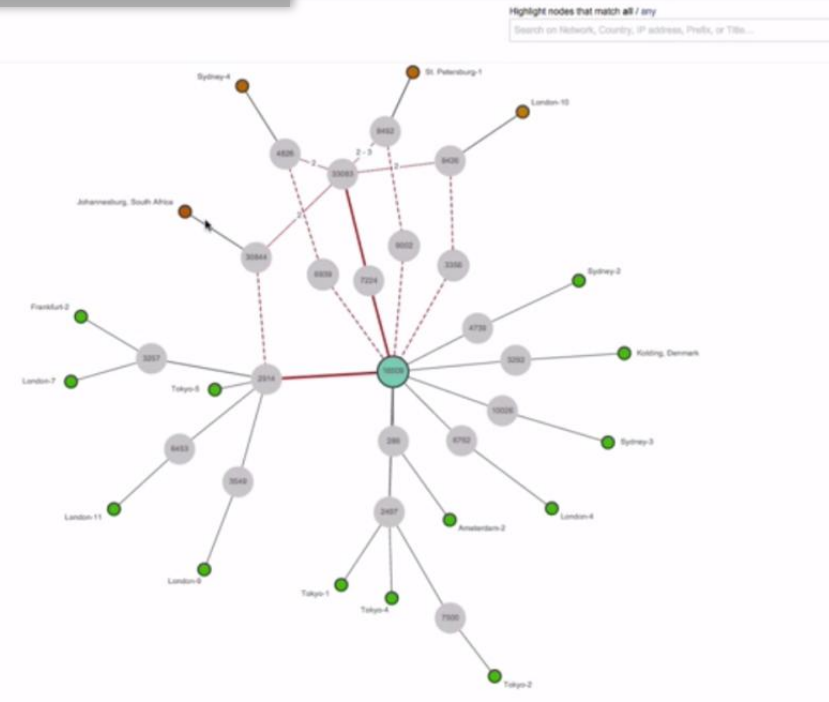
Teoh et al., 2003



Radian/(TPlay)

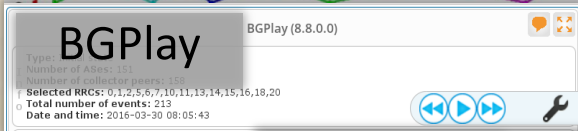


ThousandEyes

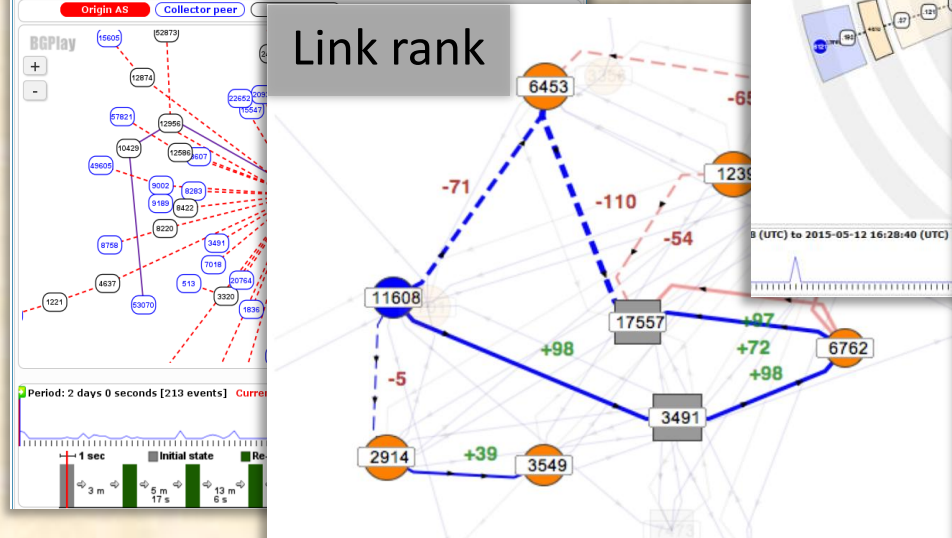


BGPlay

BGPlay (8.8.0.0)



Link rank



RoutingWatch



- Visual exploration tool for a large number of routing events

RoutingWatch



- Visual exploration tool for a large number of routing events
- **Target users:** high-level administrators in a NOC, interested in highly informative aggregate reports



RoutingWatch



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- **Target users:** high-level administrators in a NOC, interested in highly informative aggregate reports
- Does not require **agents** running on devices



RoutingWatch



- Visual exploration tool for a large number of routing events
- **Target users:** high-level administrators in a NOC, interested in highly informative aggregate reports
- Does not require **agents** running on devices
- (Partial) **visibility** of events in external networks



RoutingWatch



- Visual exploration tool for a large number of routing events
- **Target users:** high-level administrators in a NOC, interested in highly informative aggregate reports
- Does not require **agents** running on devices
- (Partial) **visibility** of events in external networks



Traceroutes → Events

Traceroutes → Events



RIPE NCC
RIPE NETWORK COORDINATION CENTRE
RIPE Atlas



ARCHIPELAGO

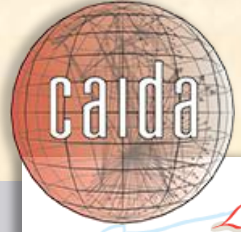


Traceroutes → Events



RIPE NCC
RIPE NETWORK COORDINATION CENTRE
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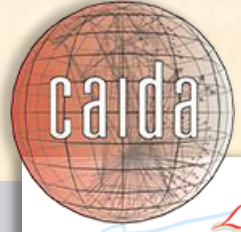
**Sam
Knows**



Traceroutes → Events



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RIPE NETWORK COORDINATION CENTRE
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Traceroutes → Events

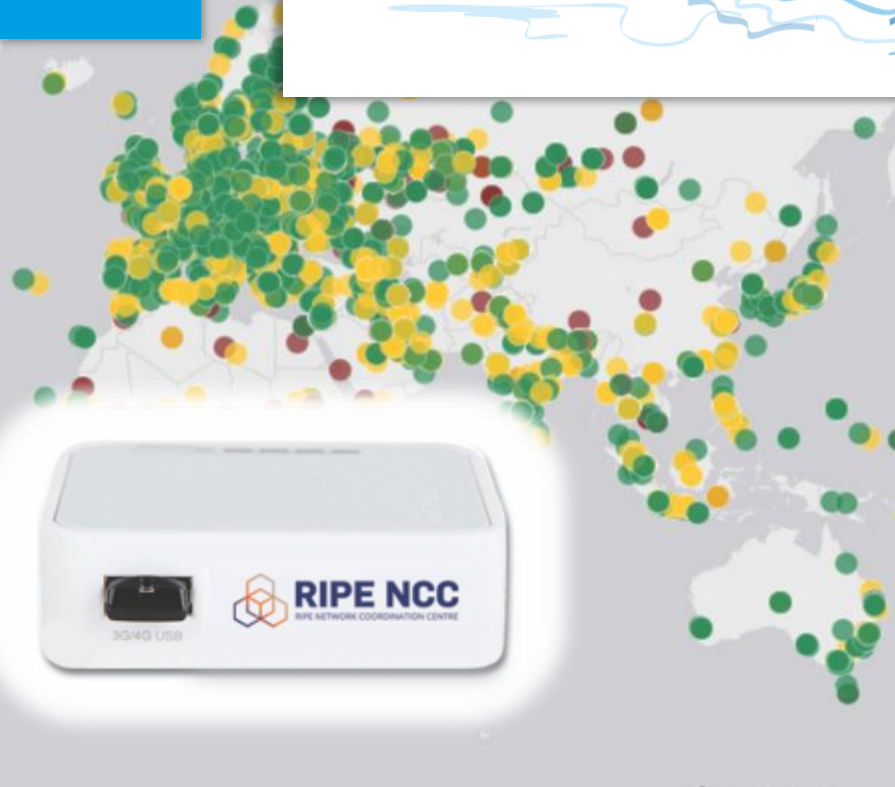


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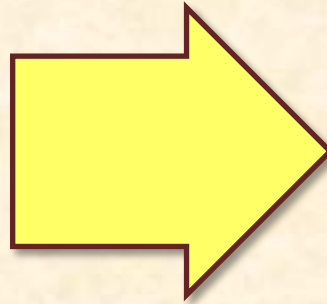
ARCHIPELAGO

```
$ traceroute 193.0.14.129
traceroute to
193.0.14.129, 30 hops max,
60 byte packets
 1 193.204.161.1
(193.204.161.1) 3.277 ms
3.282 ms 3.397 ms
...
```

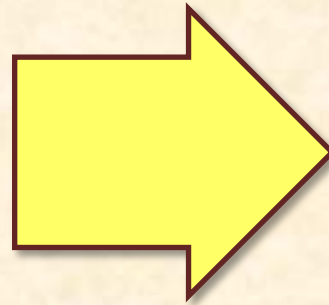
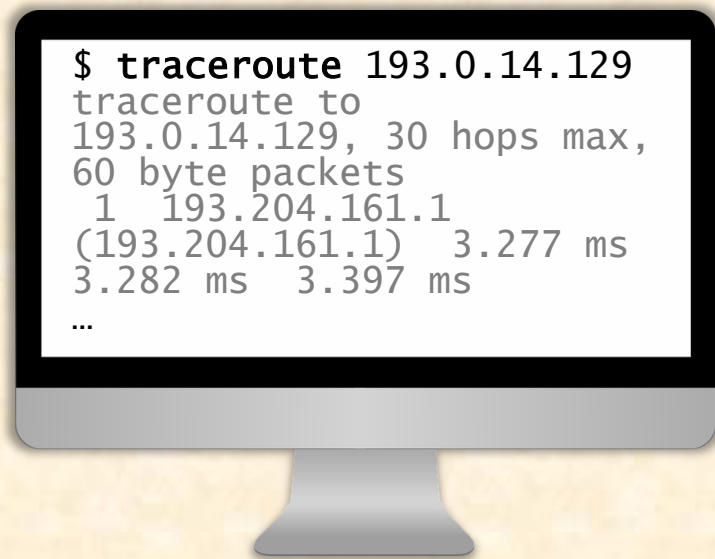


Traceroutes → Events

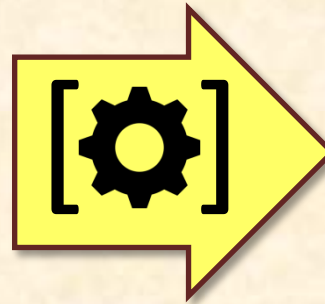
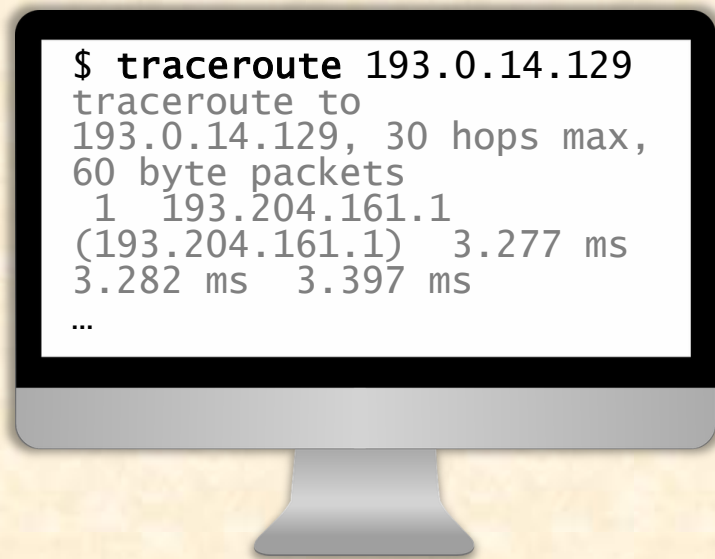
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Traceroutes → Events



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Event nt

Traceroutes → Events

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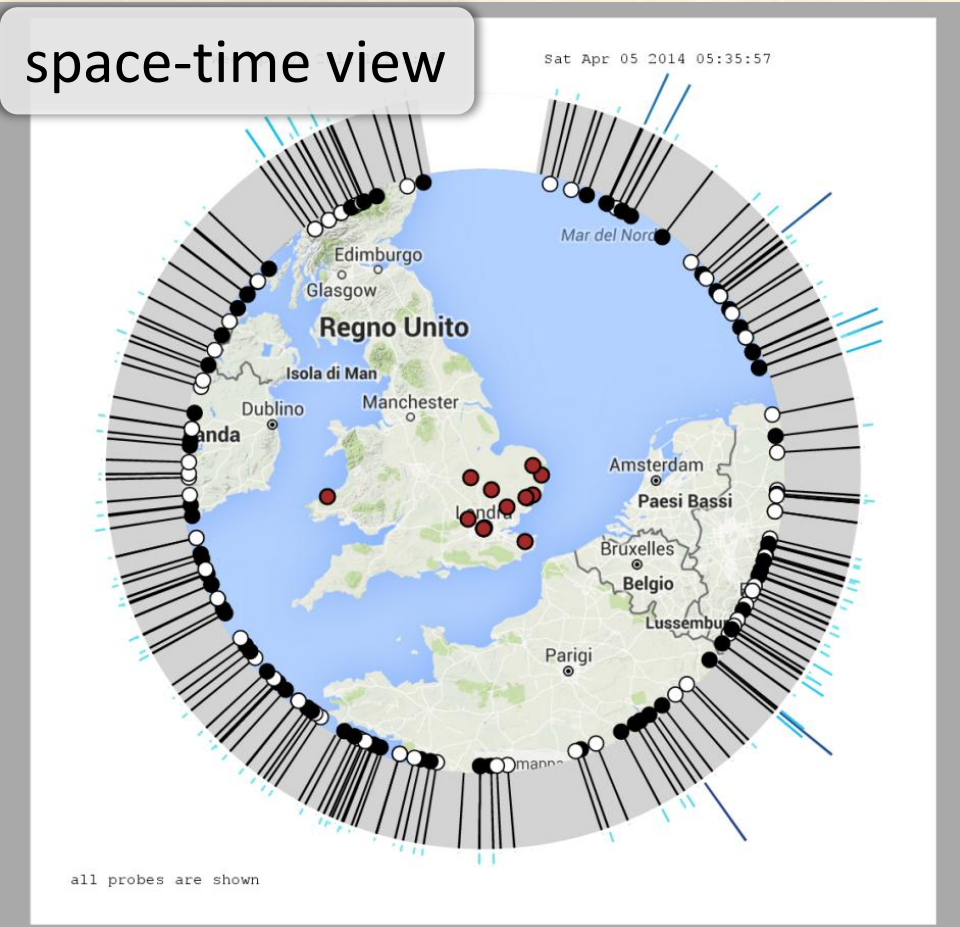
Event



User interface



User interface



User interface



space-time view

Sat Apr 05 2014 05:35:57

all probes are shown

Display events that satisfy the following conditions:

Min impact 5 10 15 20 AND

Impacted AS is:

Target is:

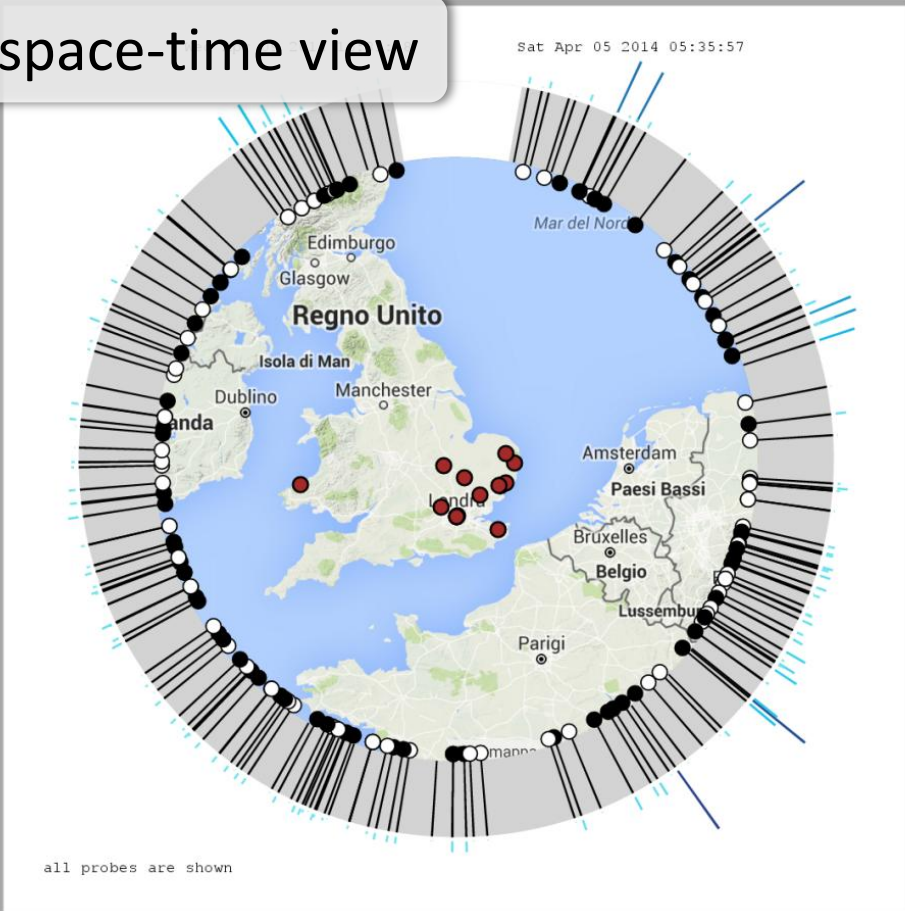
Cause AS is:

filtering panel

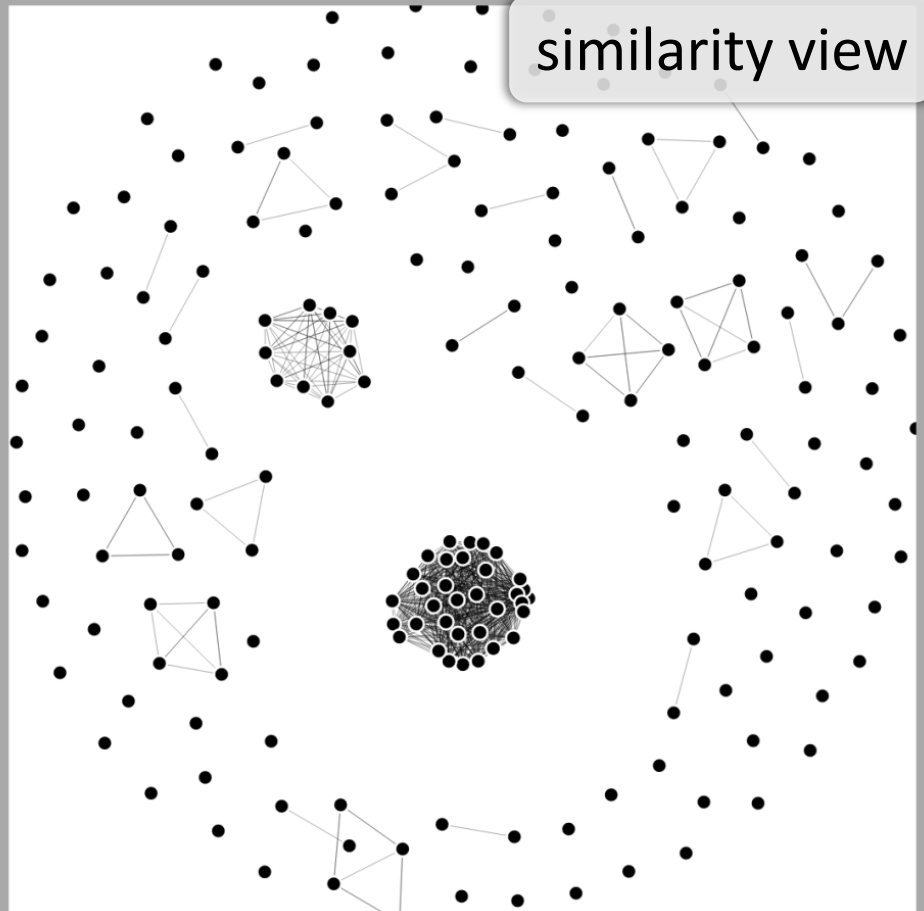
User interface



space-time view



similarity view



Display events that satisfy the following conditions:

Min impact 5 10 15 20 **AND**

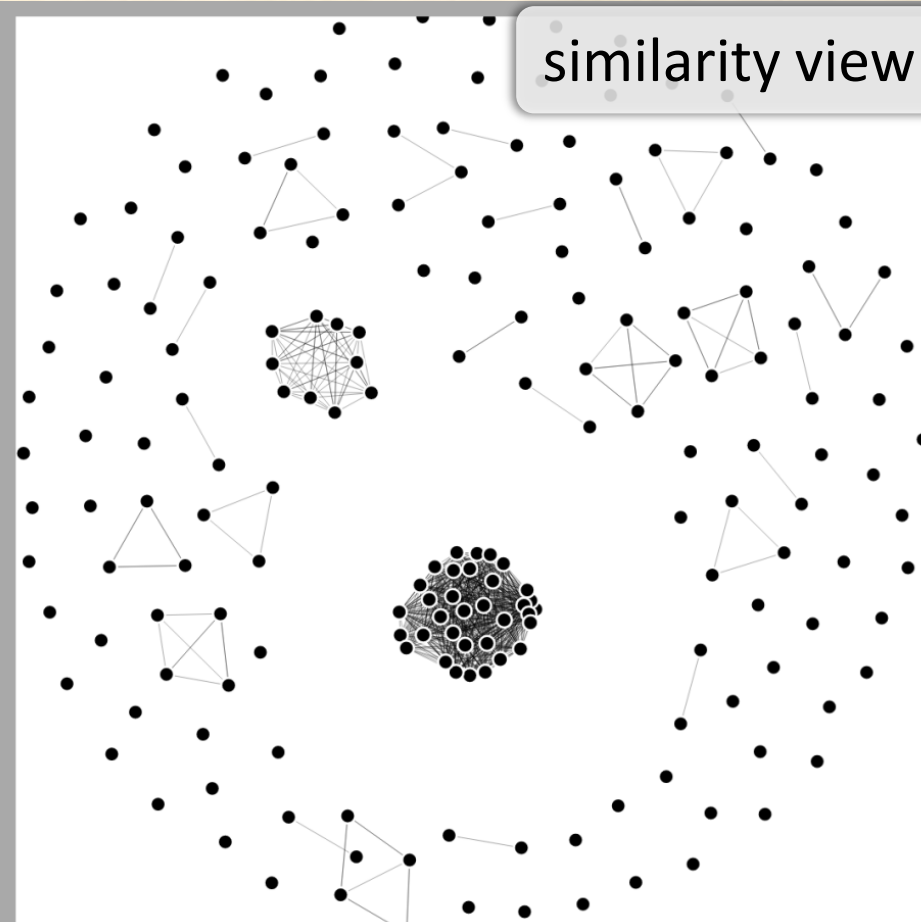
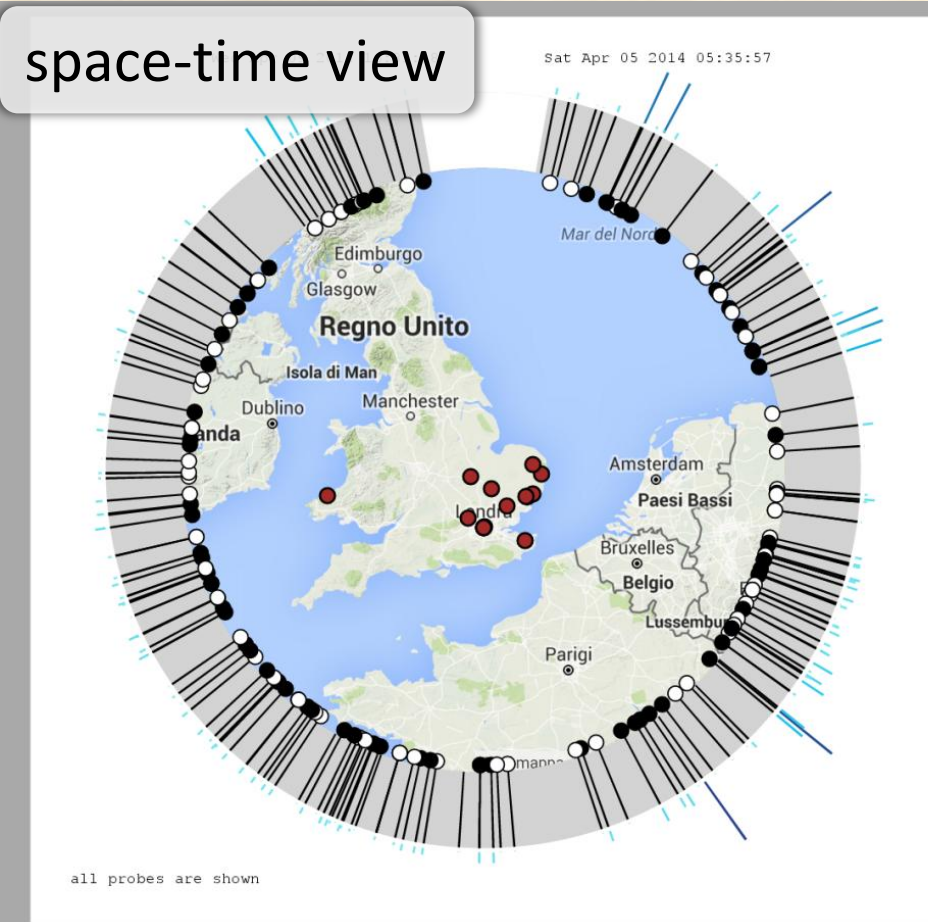
Impacted AS is:

Target is:

Cause AS is:

filtering panel

User interface



Display events that satisfy the following conditions:

Min impact 5 10 15 20 **AND**

Impacted AS is:

Target is:

Cause AS is:

filtering panel

Edge count cap (max:35532) 0 2000 4000

Compute similarity between events considering:

Sets of probes 0 50 100

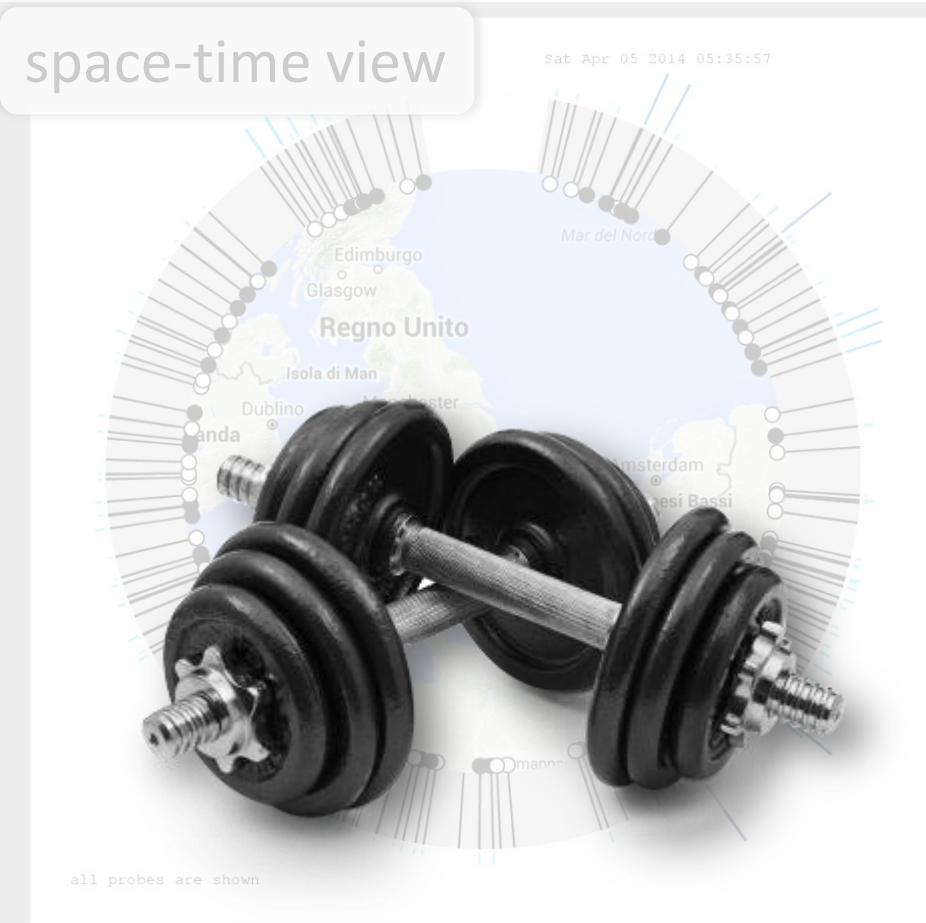
Time: 0 50 100

Recurrence:

Sets of causes 0 50 100

similarity panel

User interface



Display events that satisfy the following conditions:

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filtering panel

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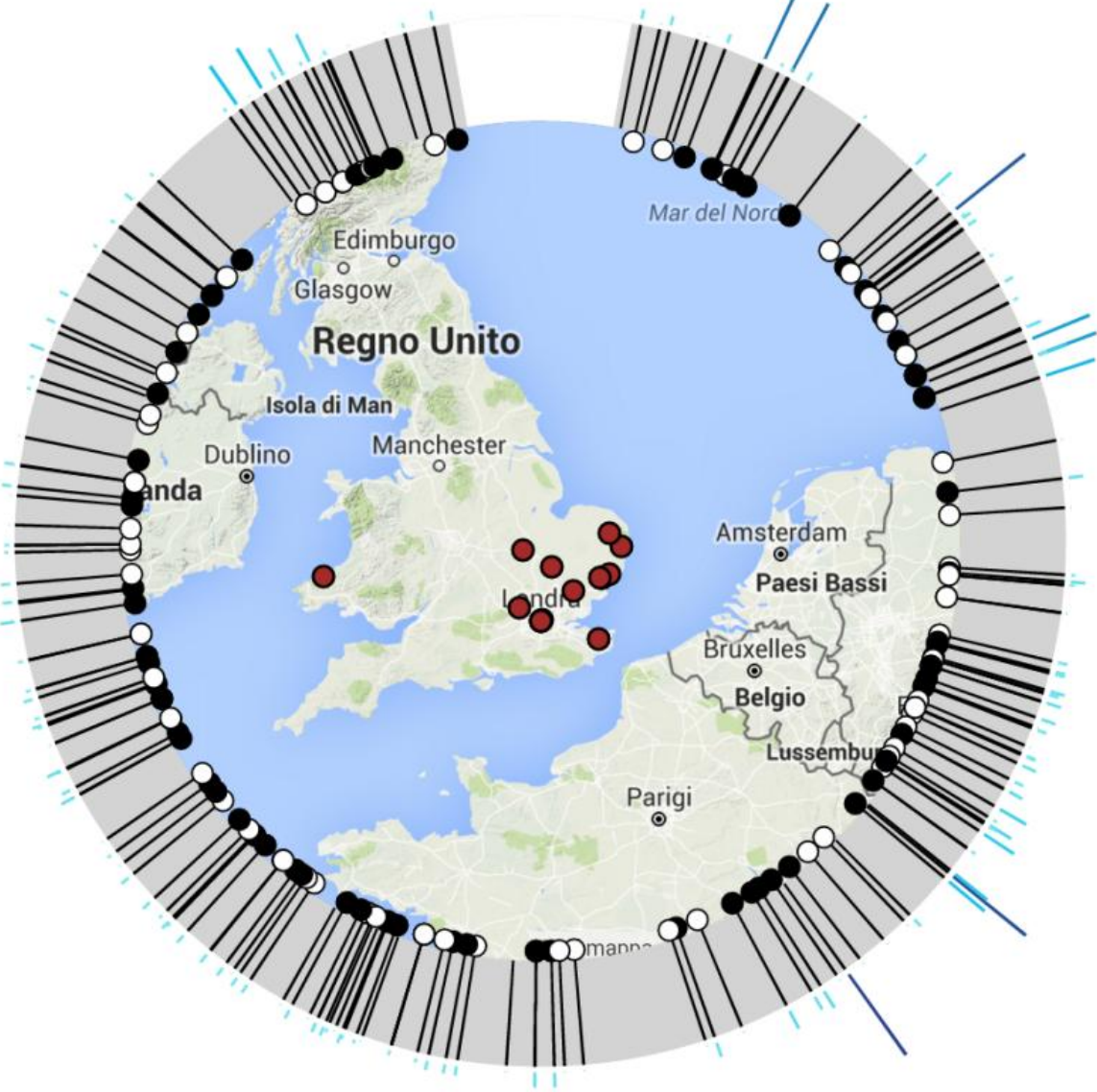
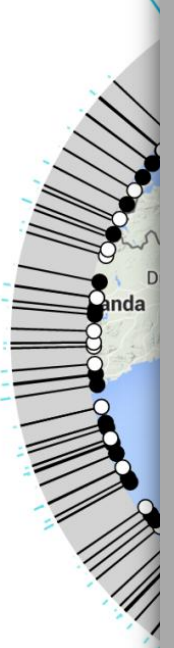
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similarity panel

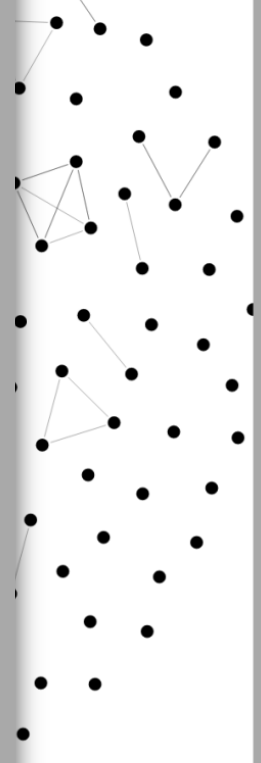
Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57

space-time



priority view



all probes are shown

Display events that

Min impact

5 10

filtering

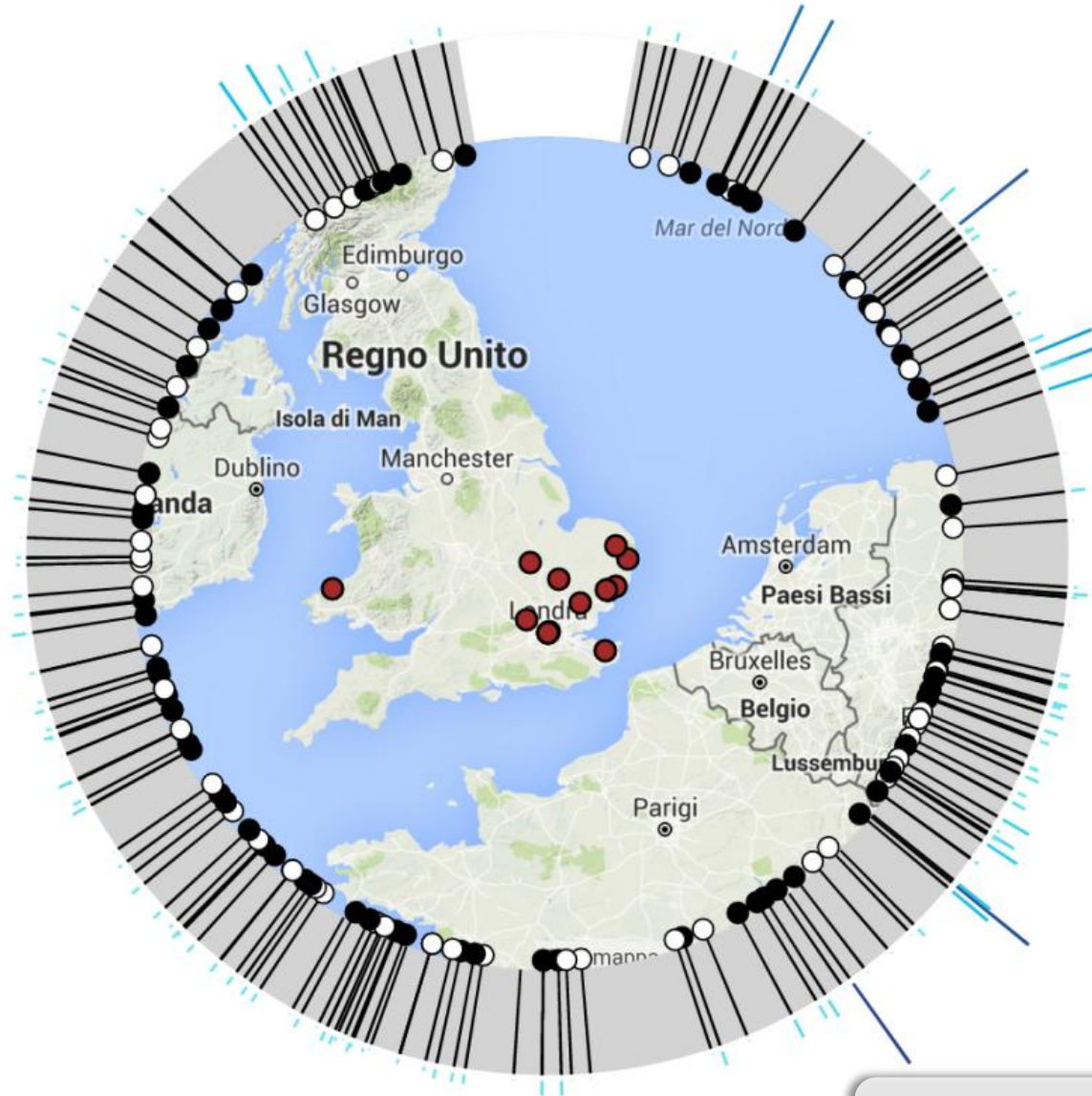
all probes are shown

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Sat Apr 05 2014 05:35:57

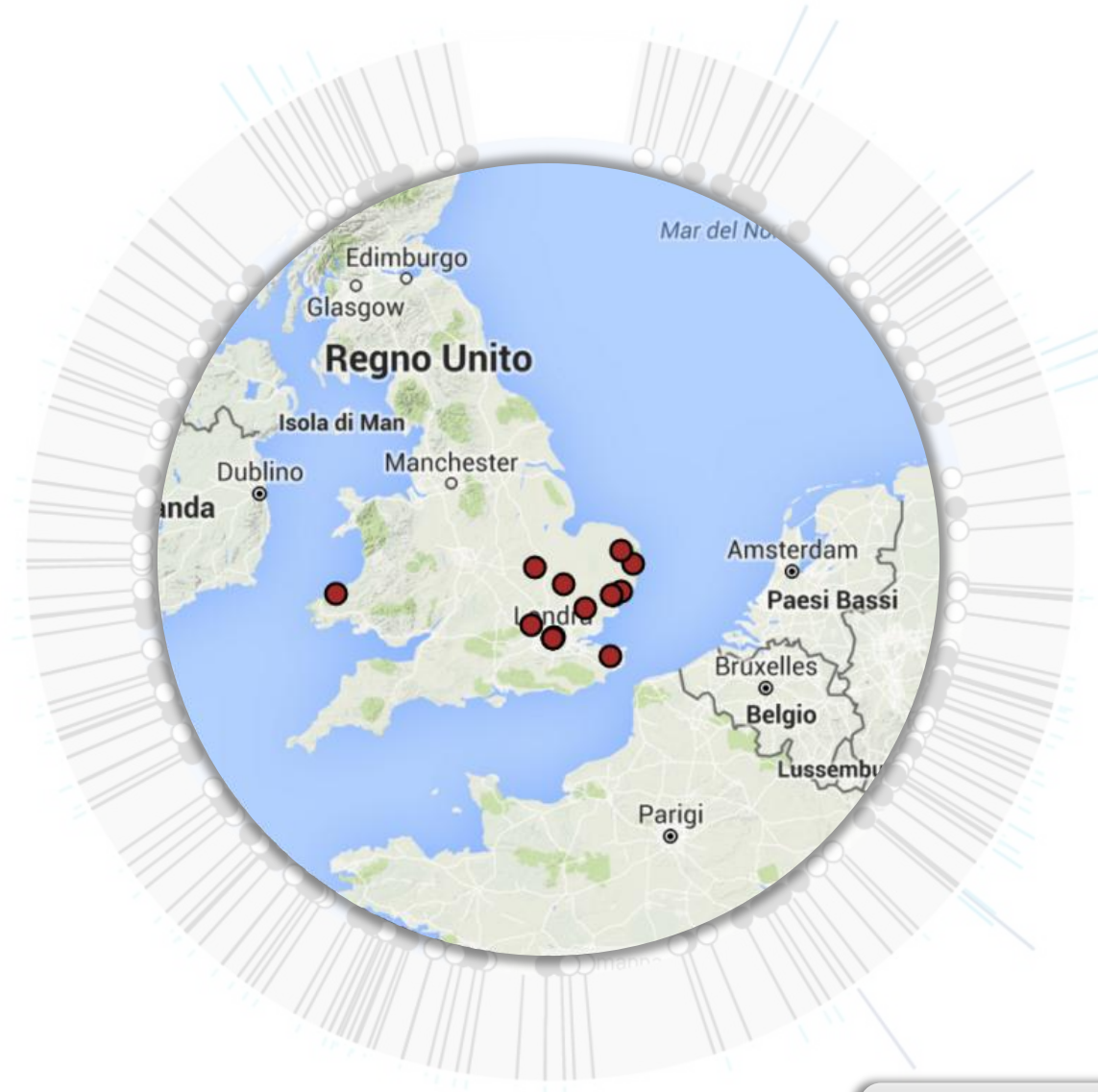


all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57

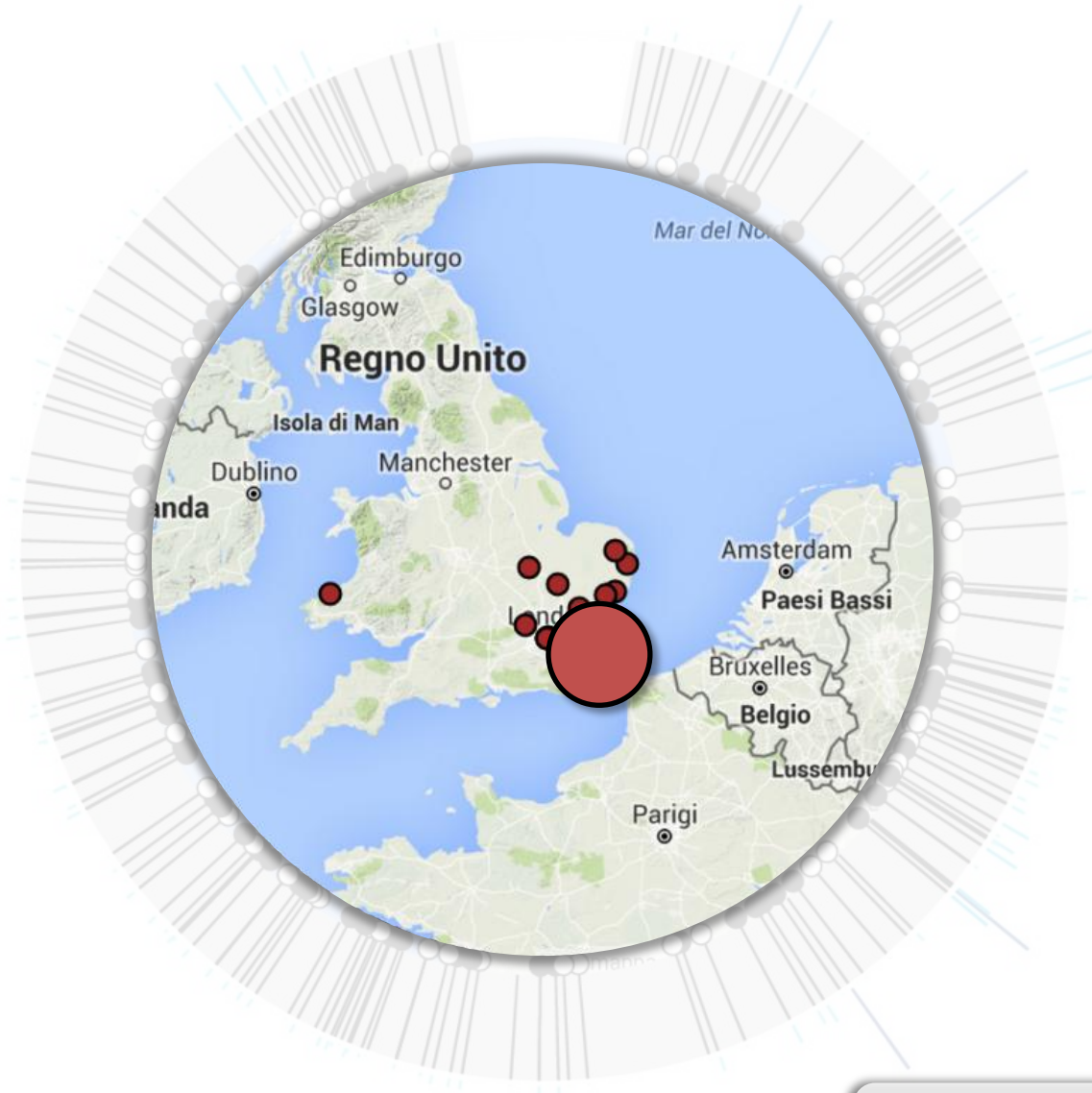


all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57

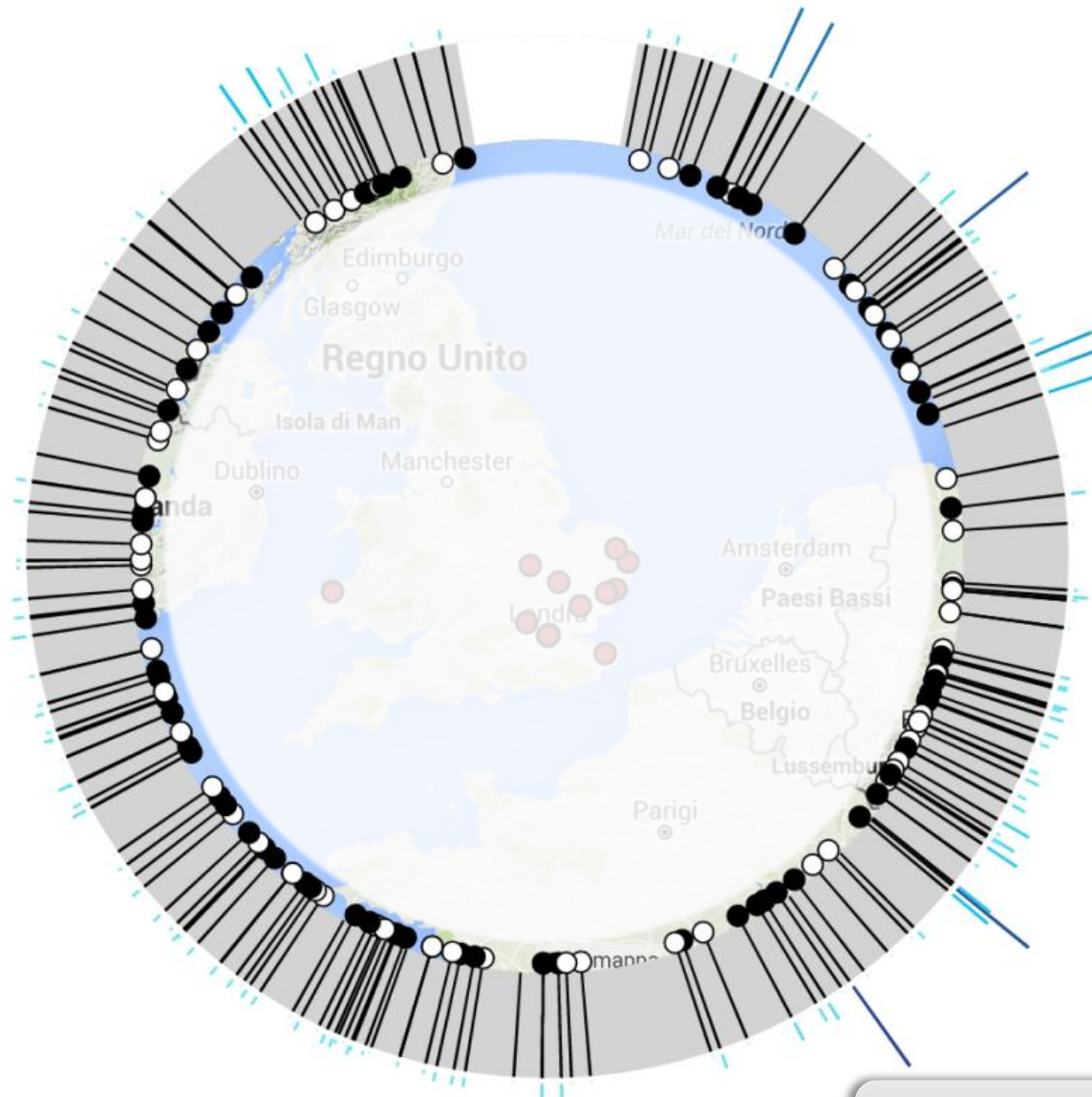


all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57



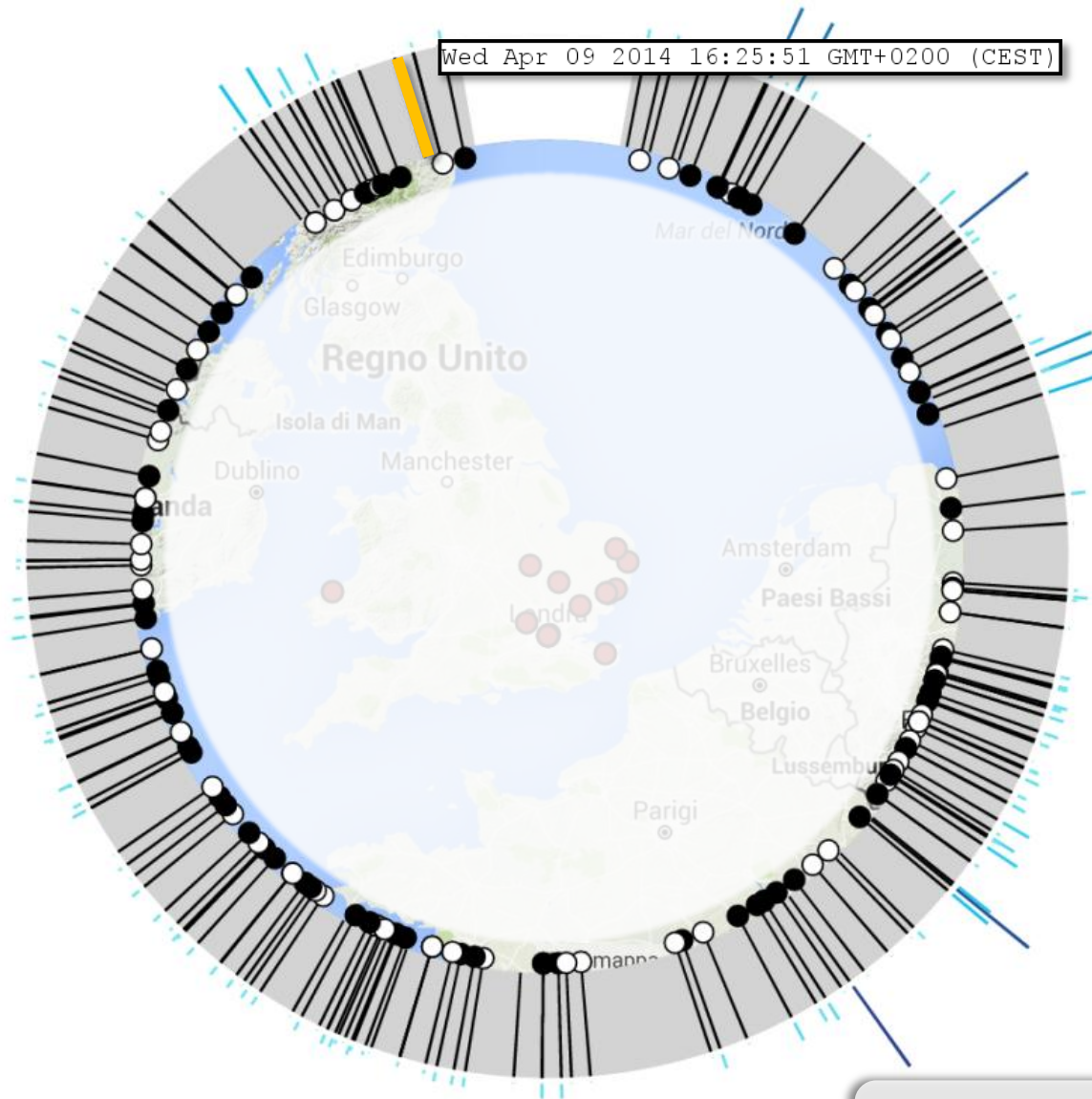
all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57

Wed Apr 09 2014 16:25:51 GMT+0200 (CEST)



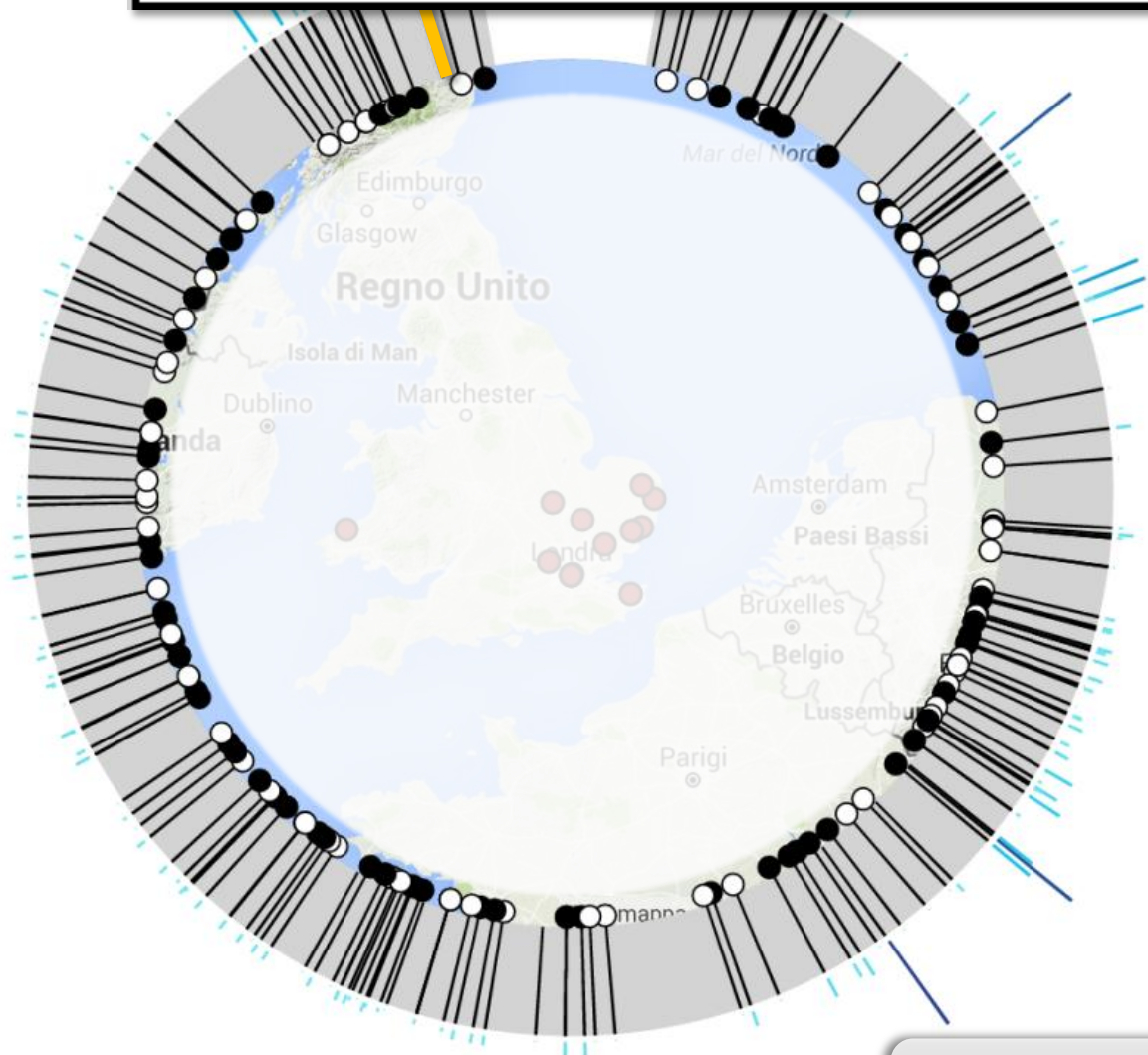
all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57

Wed Apr 09 2014 16:25:51 GMT+0200 (CEST)



all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57



all probes are shown

space-time view

Wed Apr 09 2014 16:31:18

Sat Apr 05 2014 05:35:57



all probes are shown

space-time view

Tue Apr 08 2014 15:23:00

Sat Apr 05 2014 18:17:15

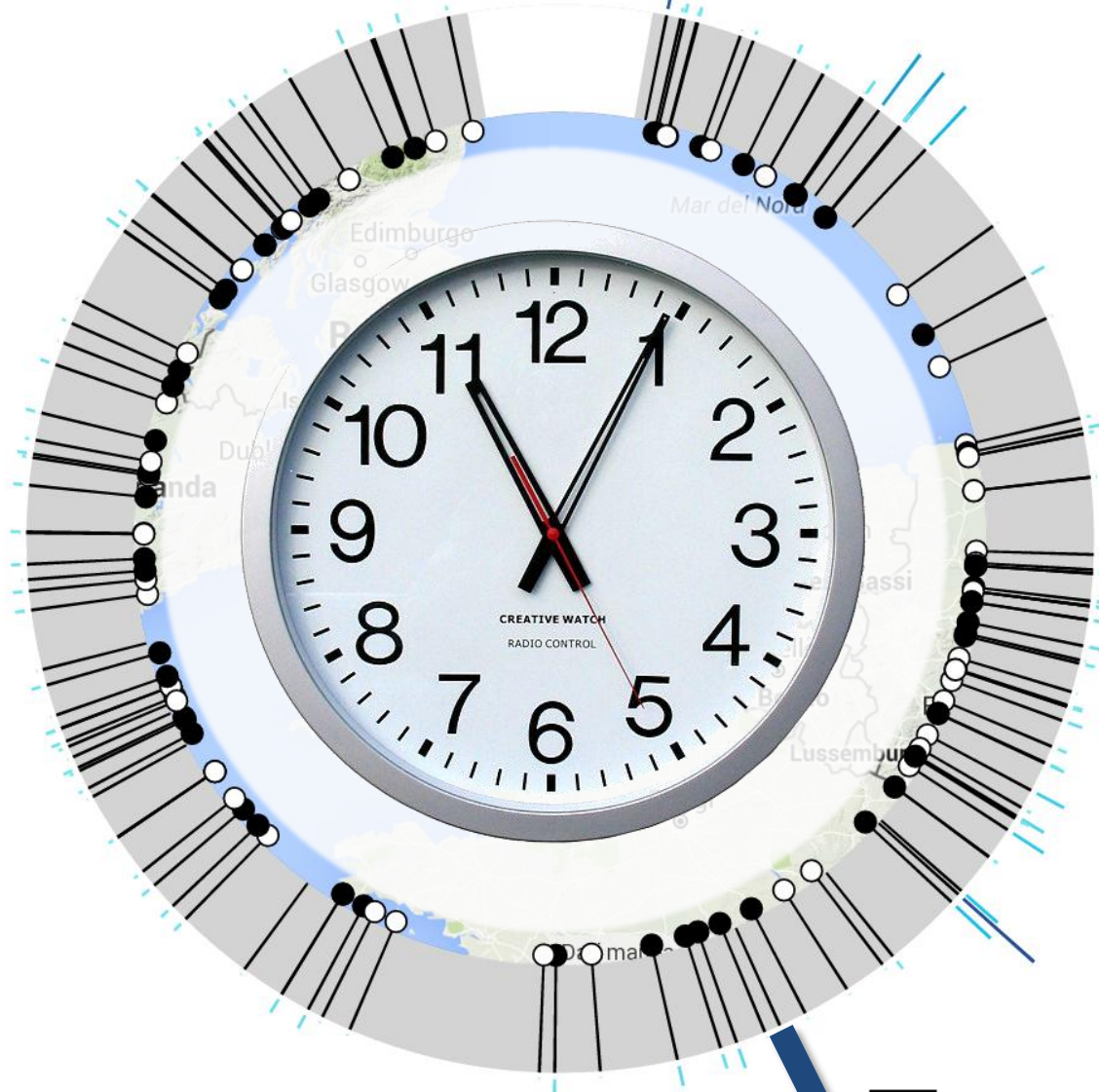


all probes are shown

space-time view

Tue Apr 08 2014 15:23:00

Sat Apr 05 2014 18:17:15



all probes are shown

20

Tue Apr 08 2014 15:23:00

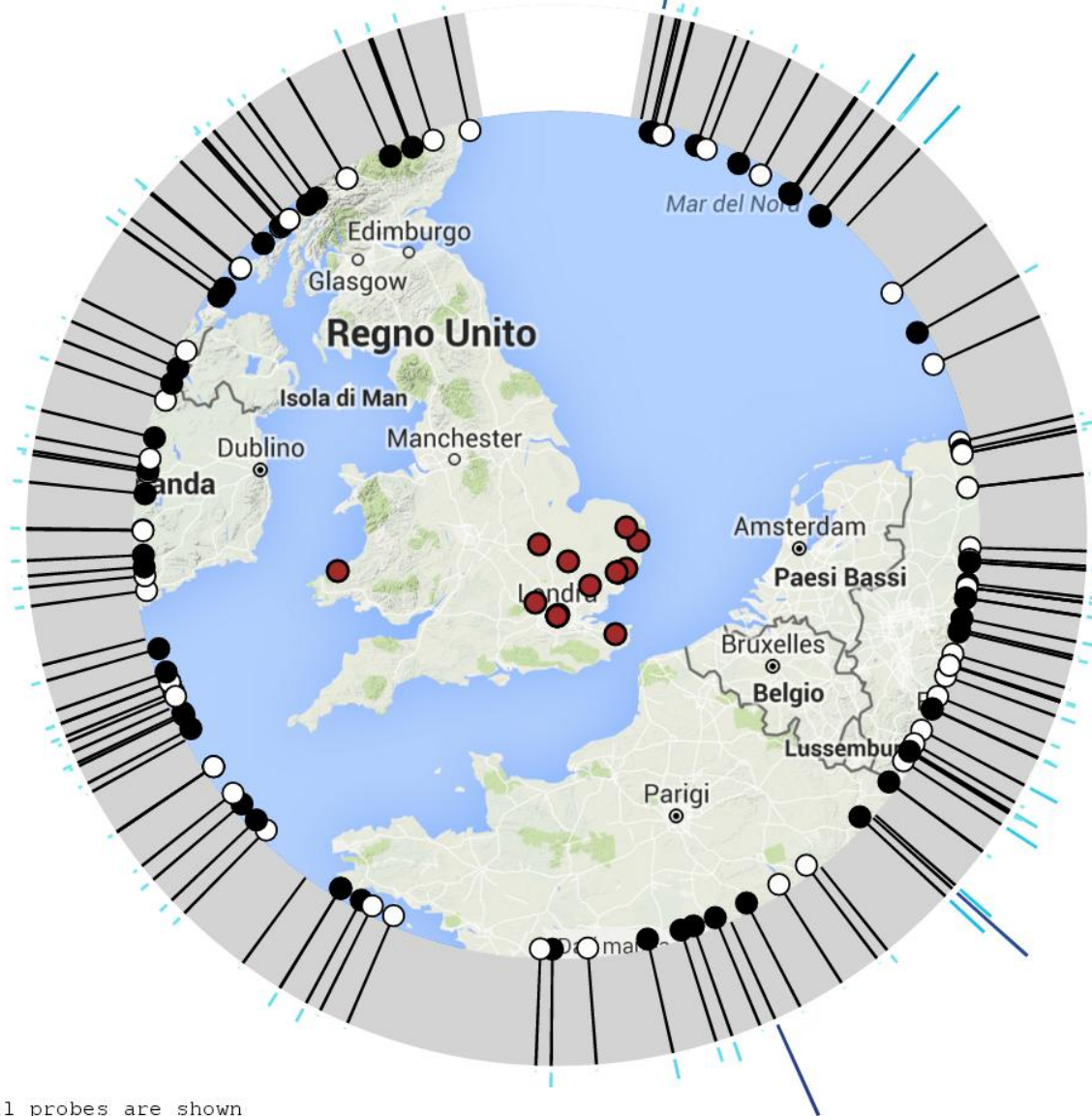
Sat Apr 05 2014 18:17:15



all probes are shown

Tue Apr 08 2014 15:23:00

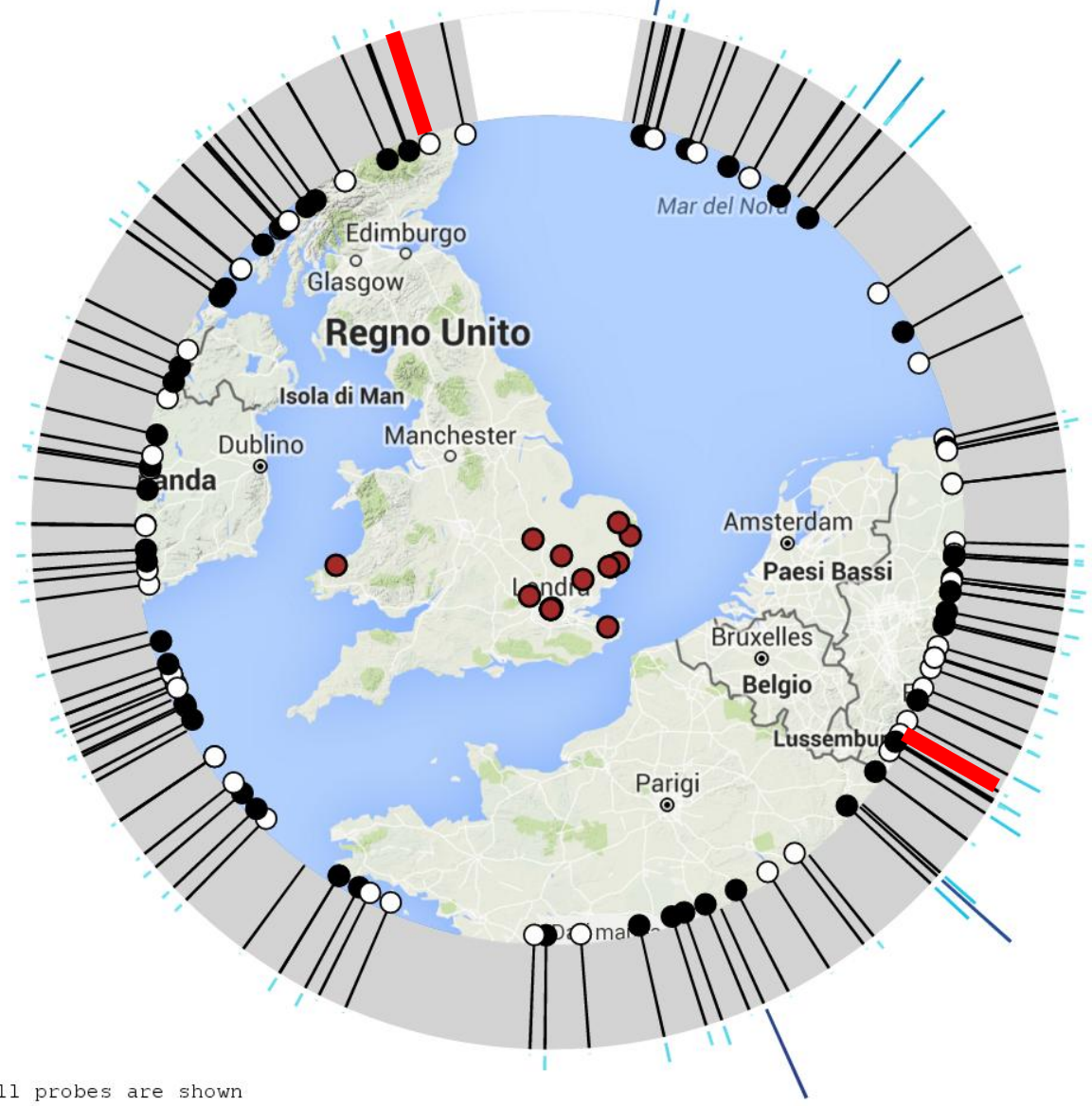
Sat Apr 05 2014 18:17:15



all probes are shown

Tue Apr 08 2014 15:23:00

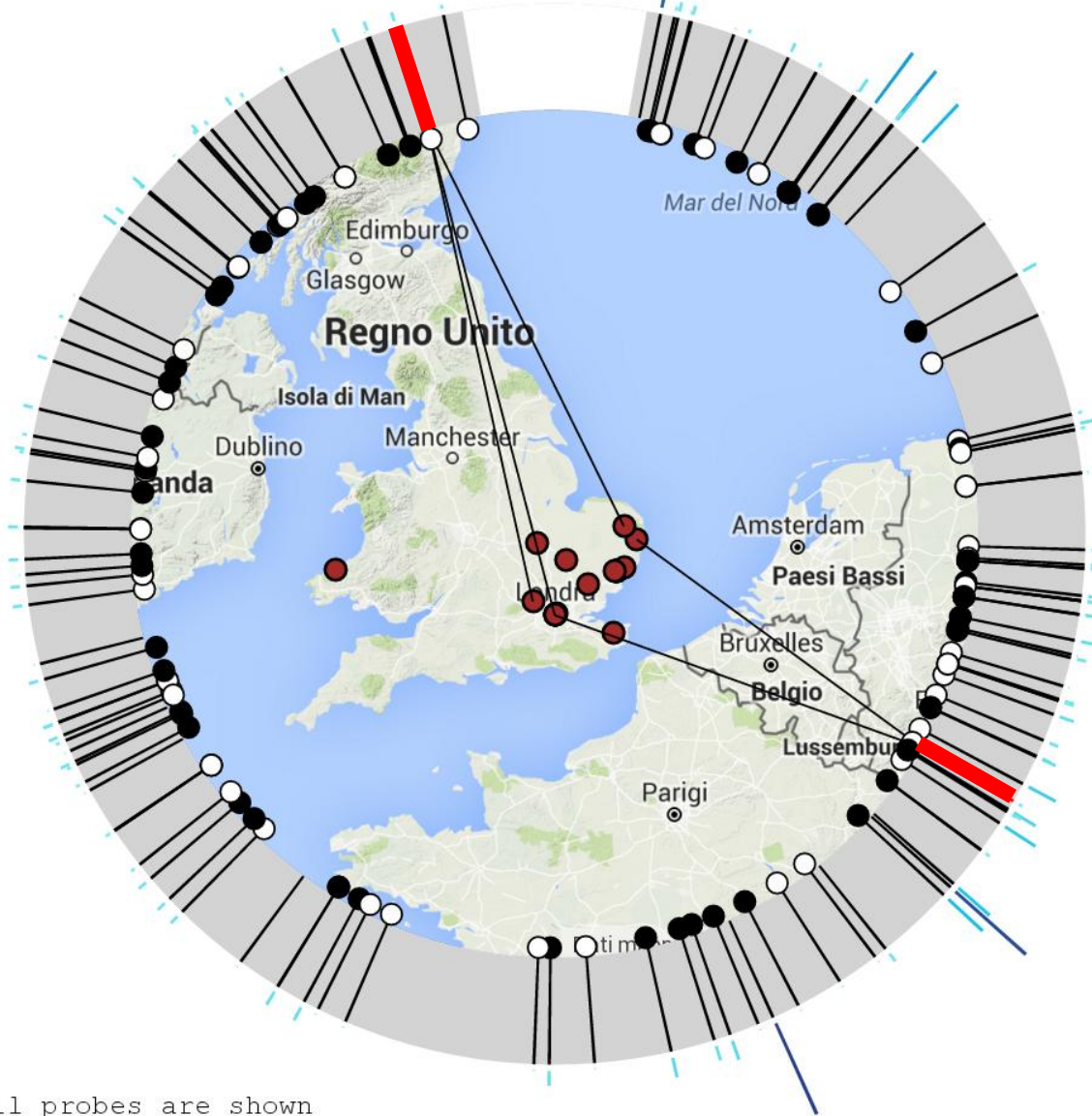
Sat Apr 05 2014 18:17:15



all probes are shown

Tue Apr 08 2014 15:23:00

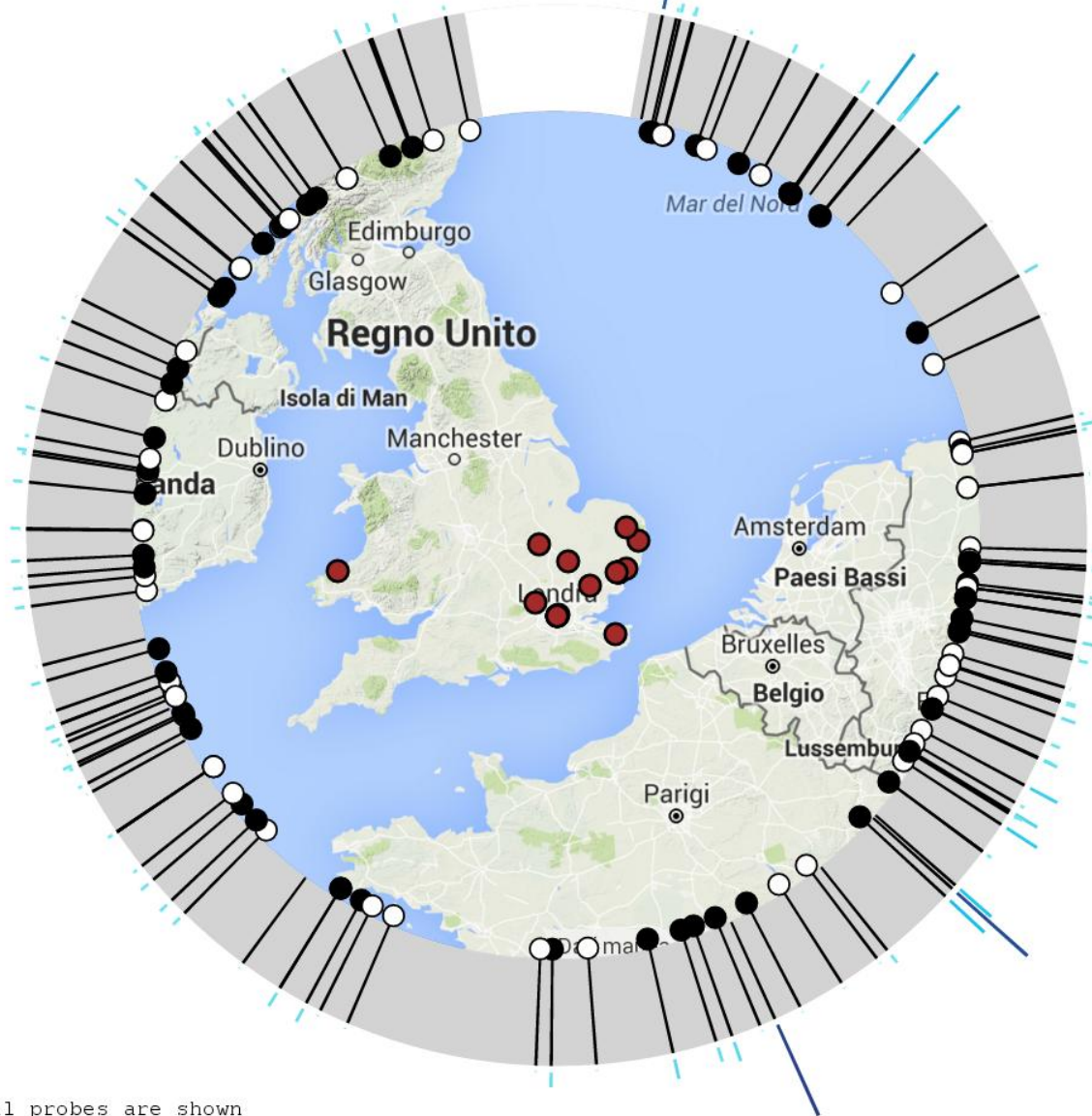
Sat Apr 05 2014 18:17:15



all probes are shown

Tue Apr 08 2014 15:23:00

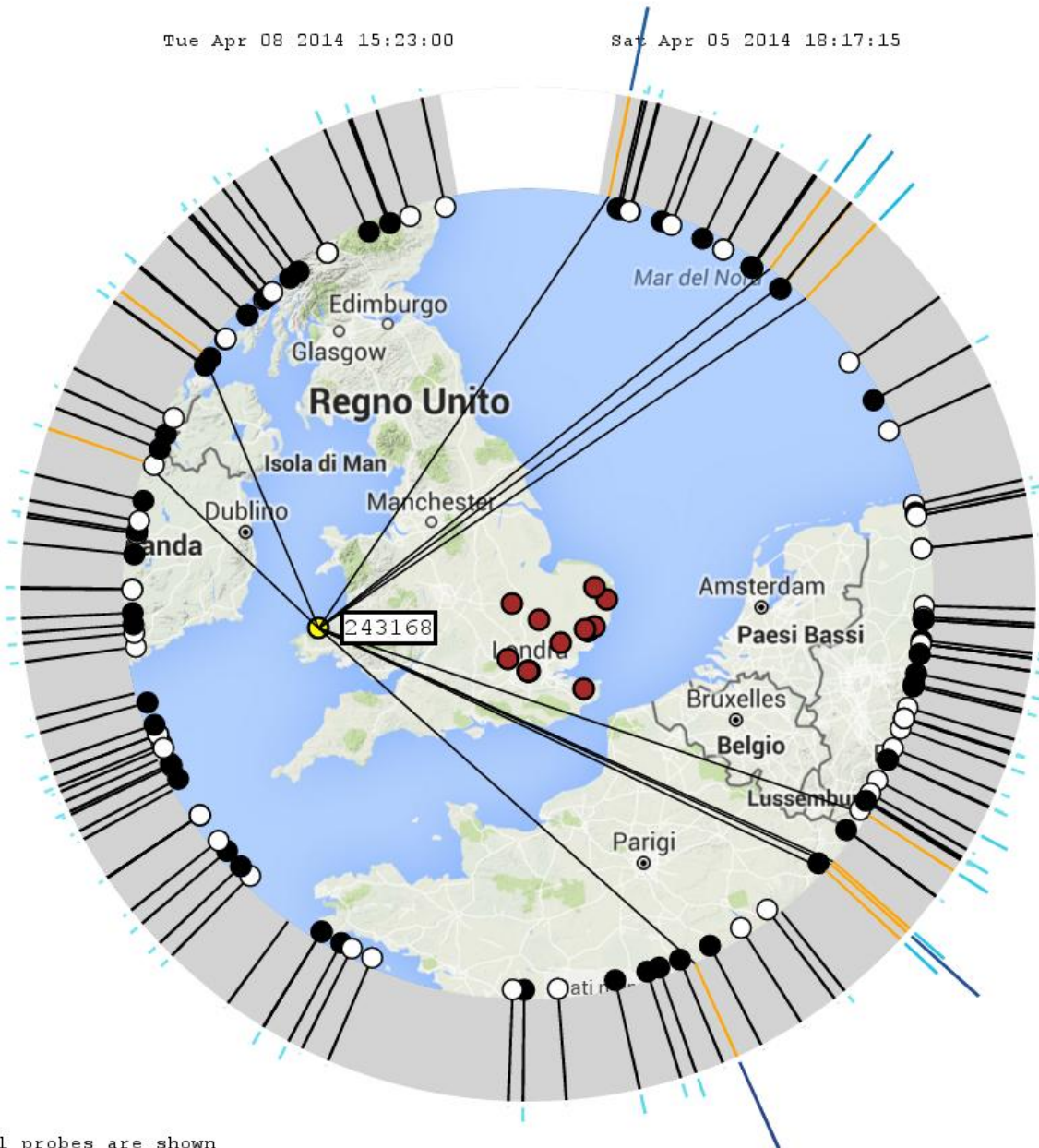
Sat Apr 05 2014 18:17:15



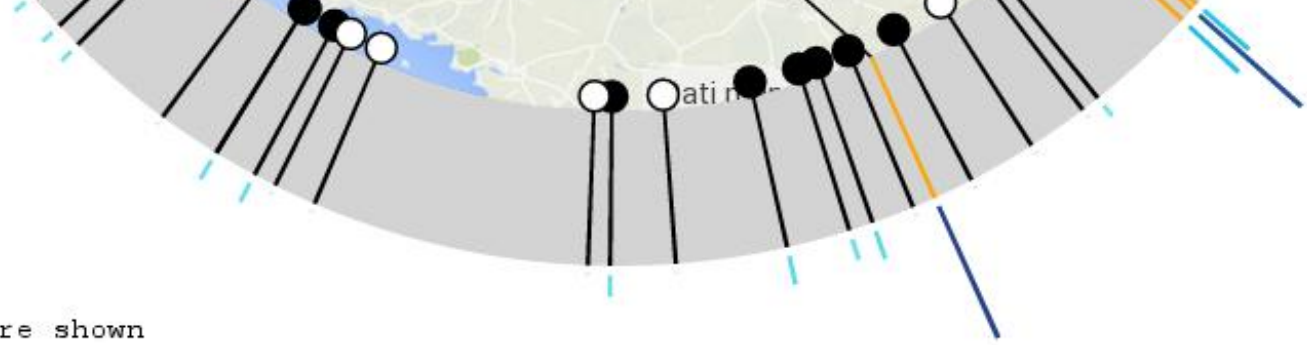
all probes are shown

Tue Apr 08 2014 15:23:00

Sat Apr 05 2014 18:17:15



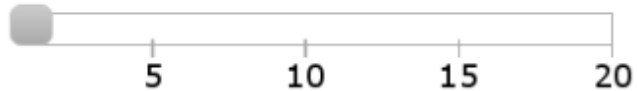
all probes are shown



all probes are shown

Display events that satisfy the following conditions:

Min impact



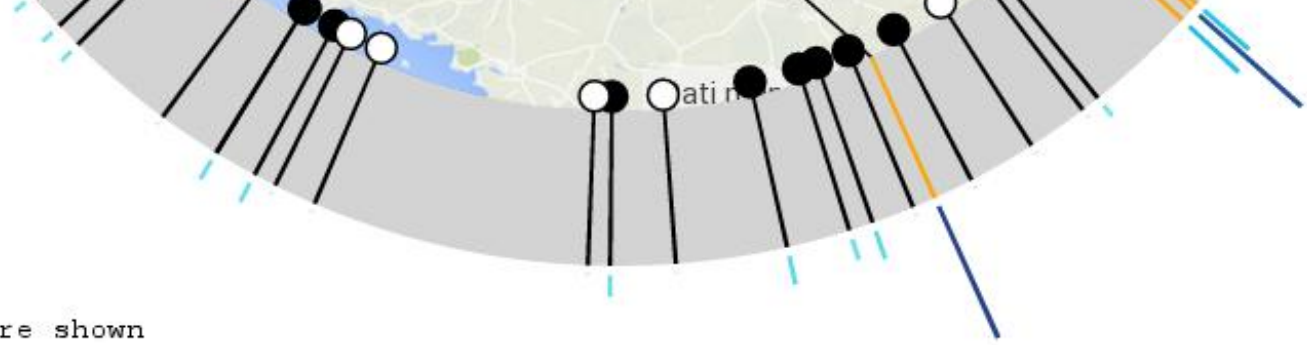
AND

Impacted AS is:

Target is:

Cause AS is:

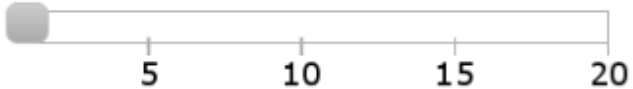
filtering panel



all probes are shown

Display events that satisfy the following conditions:

Min impact



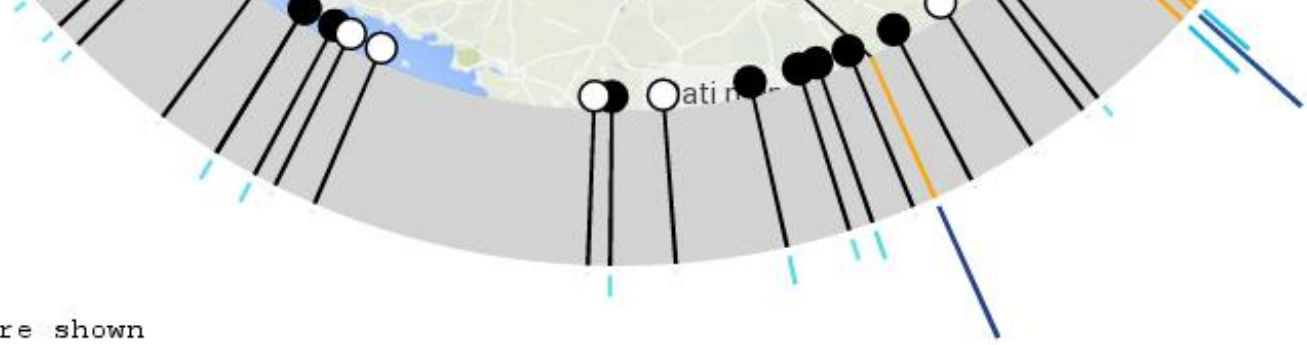
AND

Impacted AS is:

Target is:

Cause AS is:

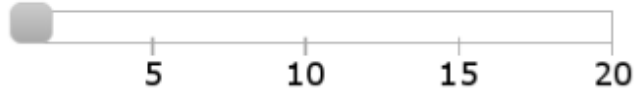
filtering panel



all probes are shown

Display events that satisfy the following conditions:

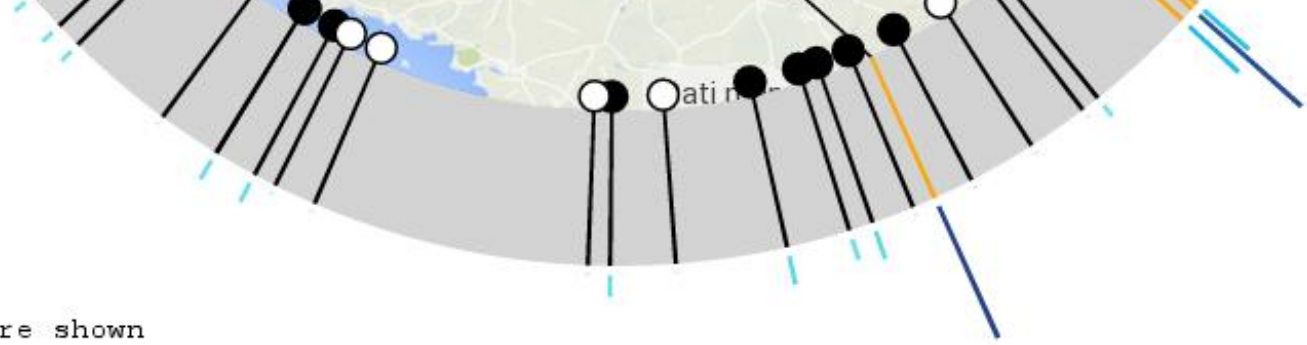
Min impact



AND

Impacted AS is:	<input type="text" value="<None>"/>
Target is:	<input type="text" value="<None>"/>
Cause AS is:	<input type="text" value="<None>"/>

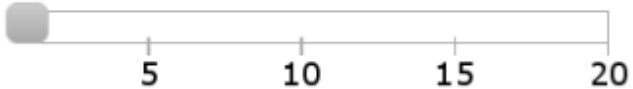
filtering panel



all probes are shown

Display events that satisfy the following conditions:

Min impact



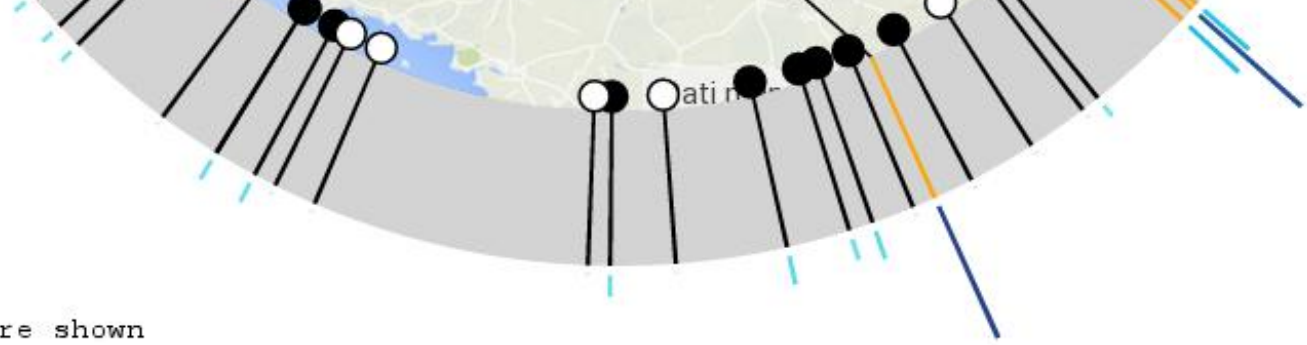
AND

Impacted AS is:

Target is:

Cause AS is:

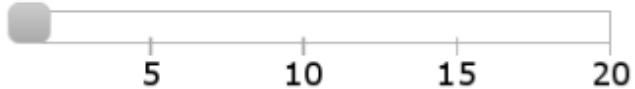
filtering panel



all probes are shown

Display events that satisfy the following conditions:

Min impact



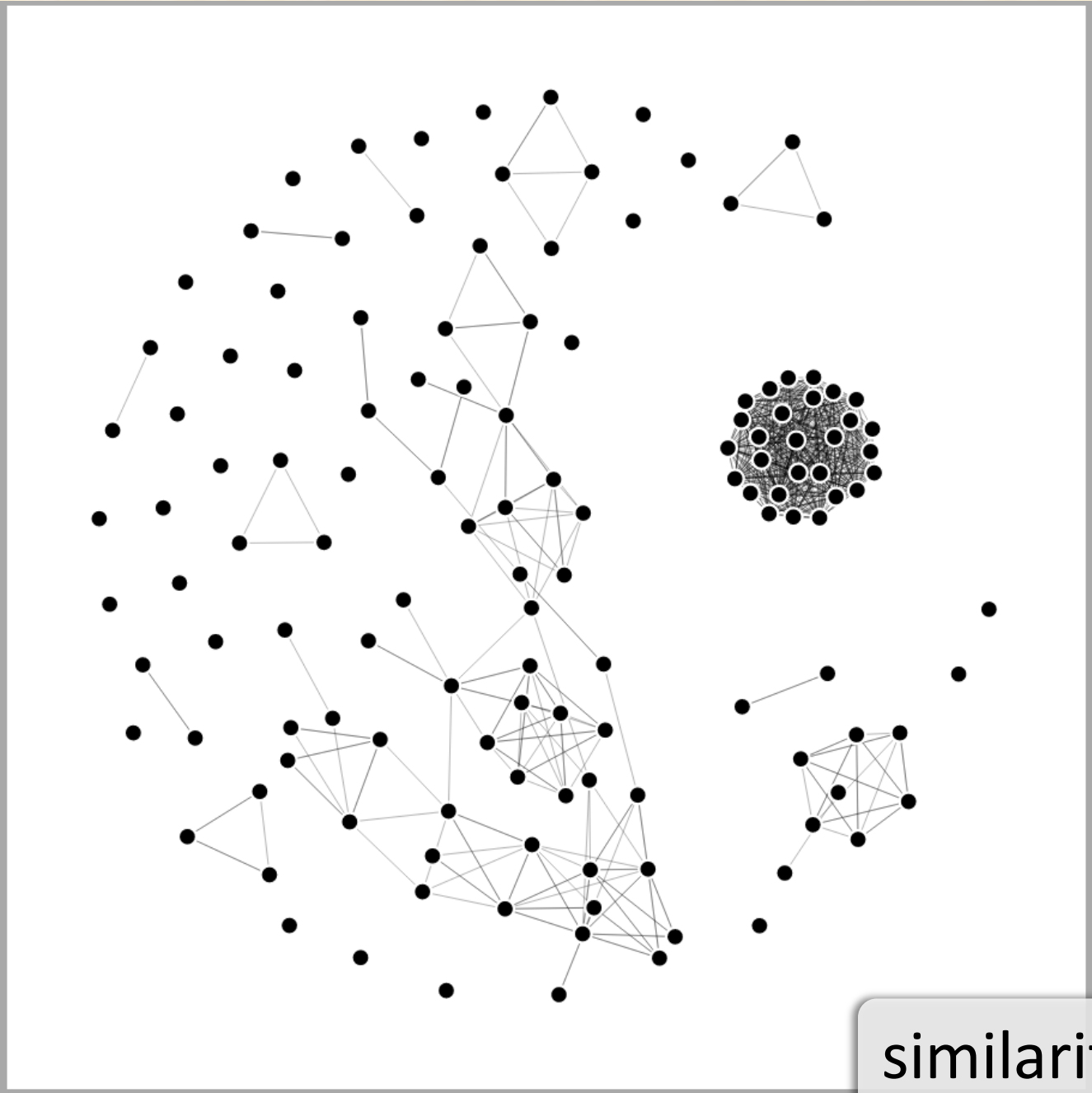
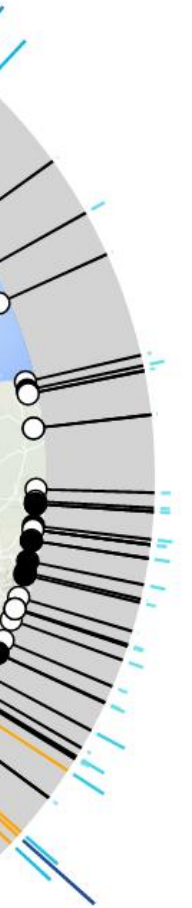
AND

Impacted AS is:

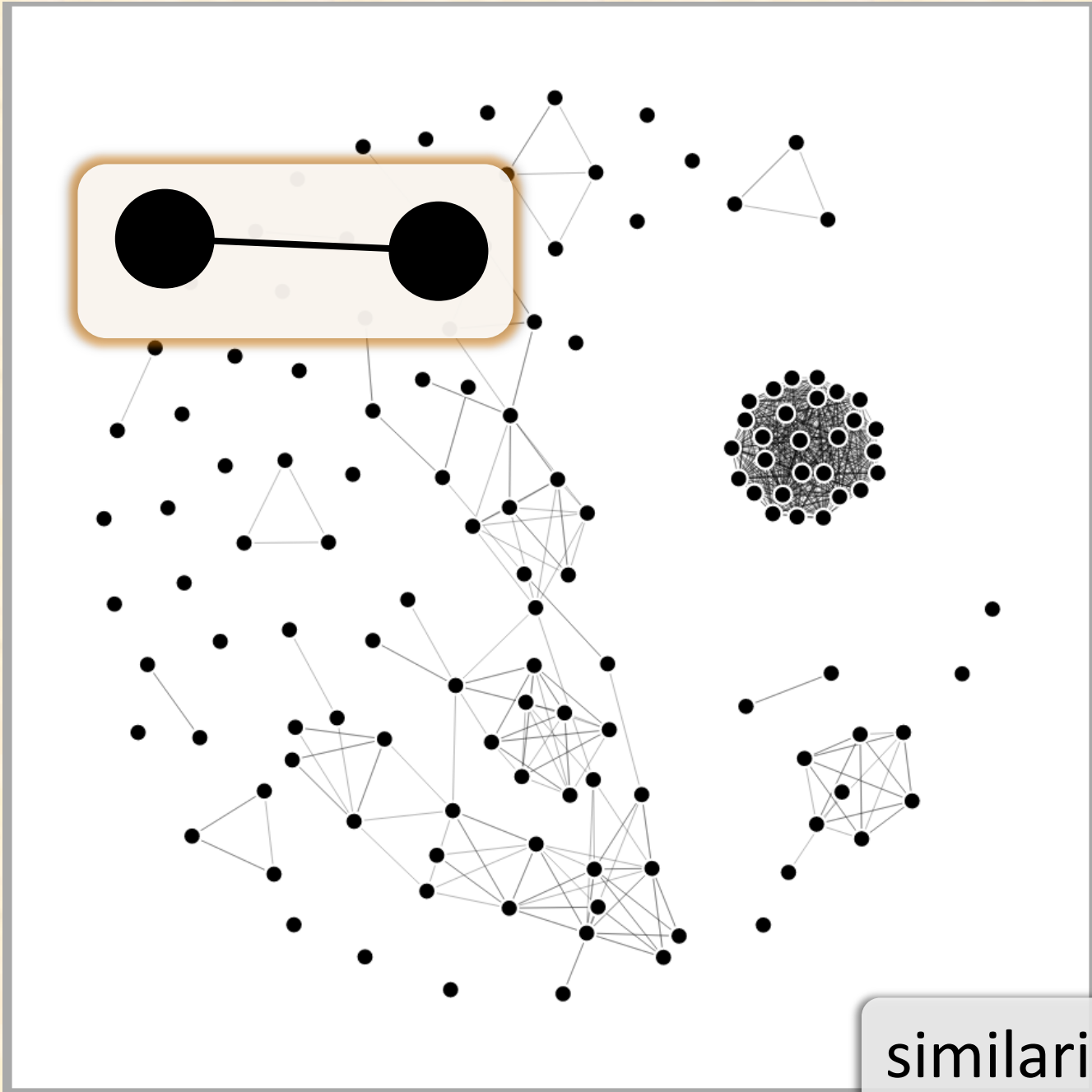
Target is:

Cause AS is:

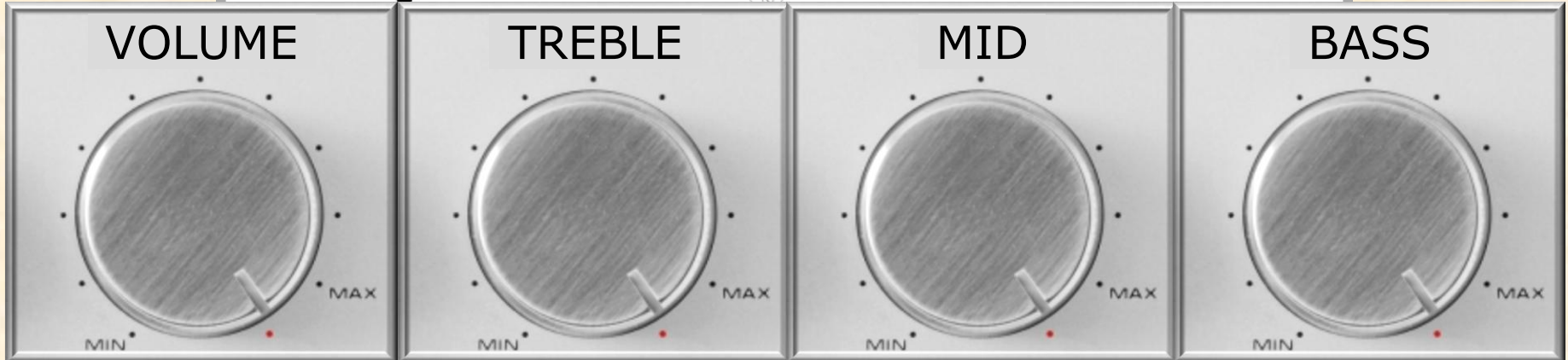
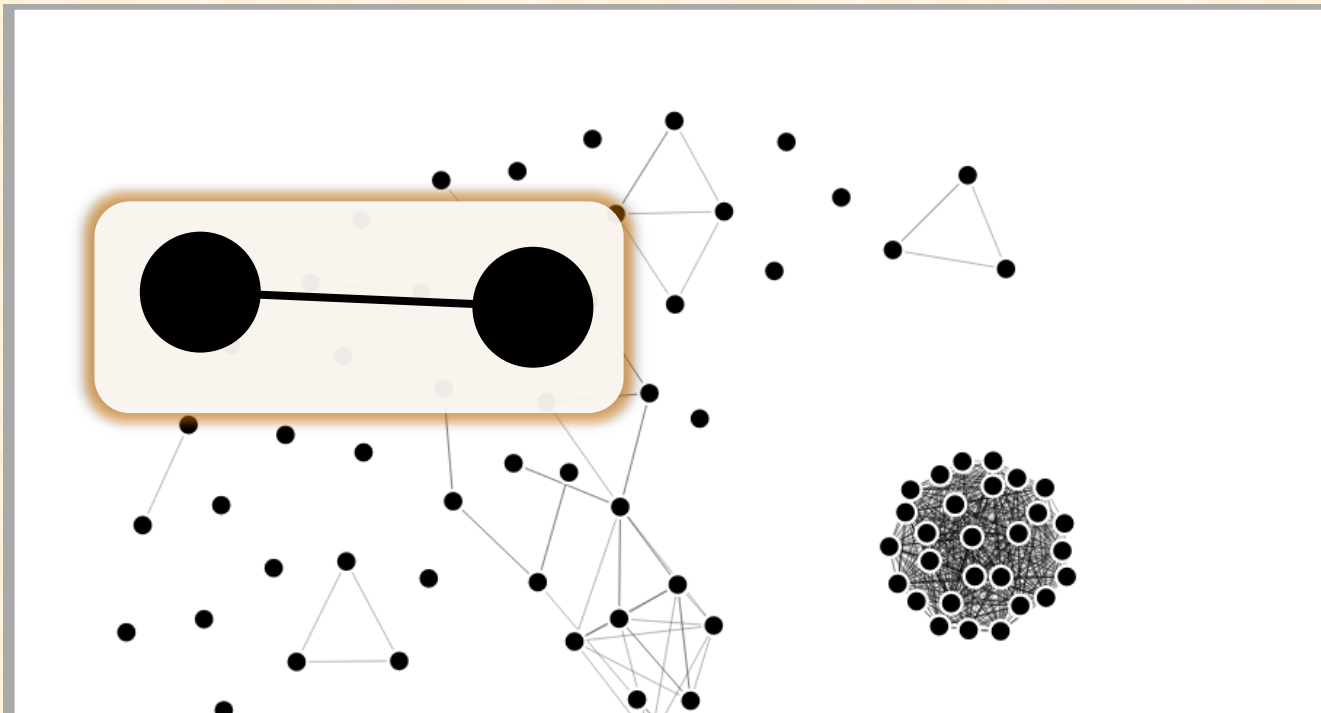
filtering panel



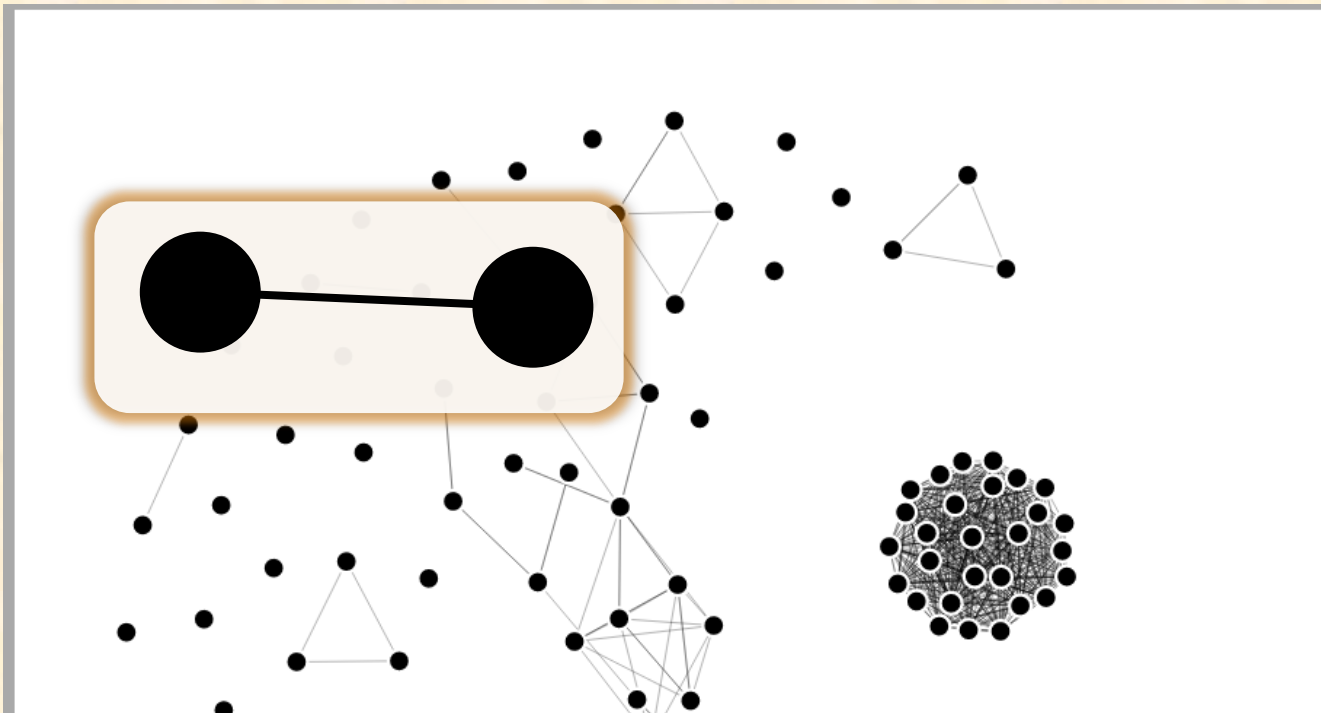
similarity view



similarity view



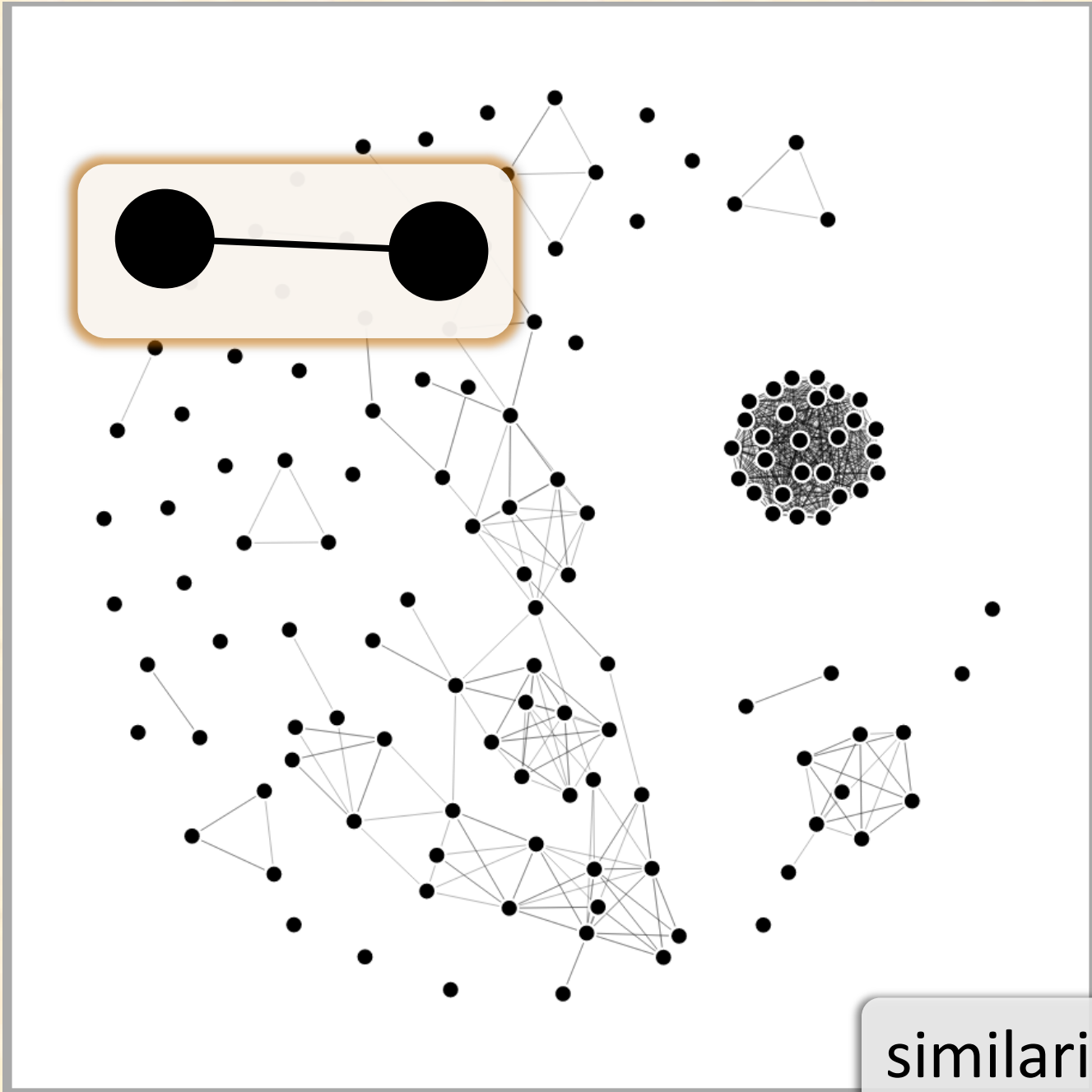
similarity view



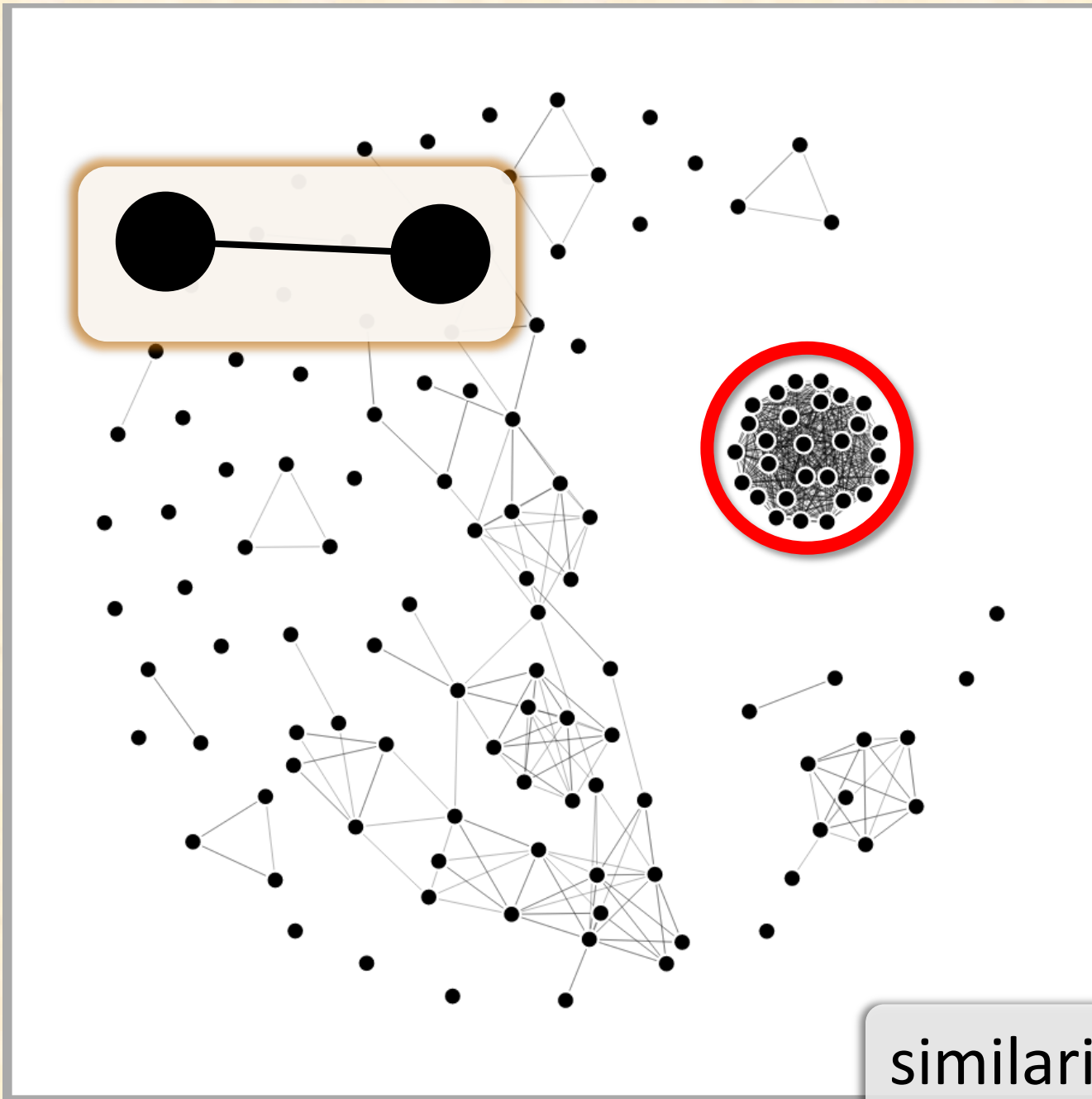
# EDGES	PROBES	CAUSES	TIME
			

Four slider controls are shown, each with a circular dial and a vertical indicator. The dials are labeled with 'MIN' and 'MAX' at the bottom. The sliders are currently positioned at approximately 25% of the range.

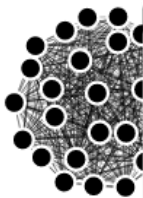
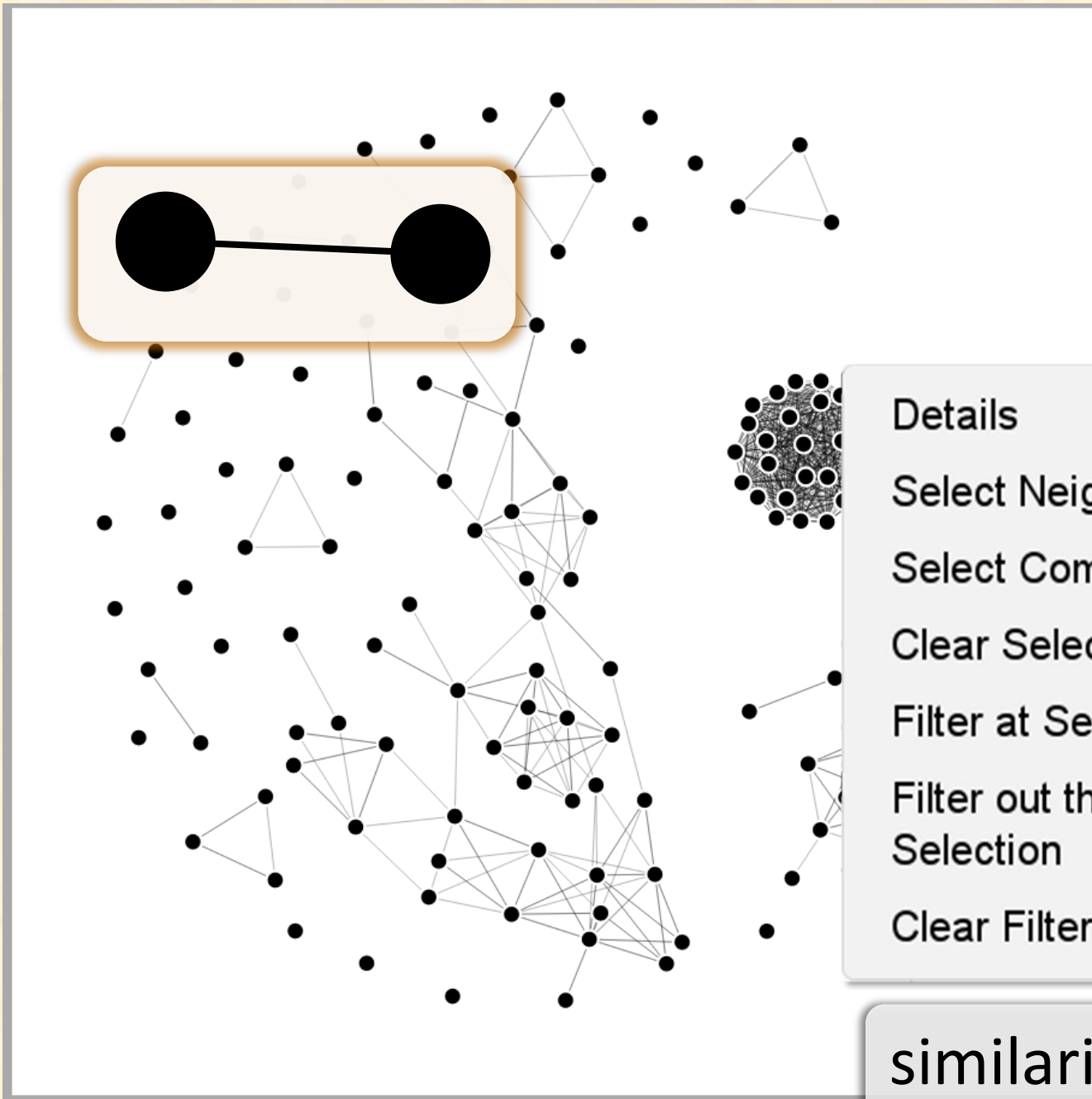
similarity view



similarity view

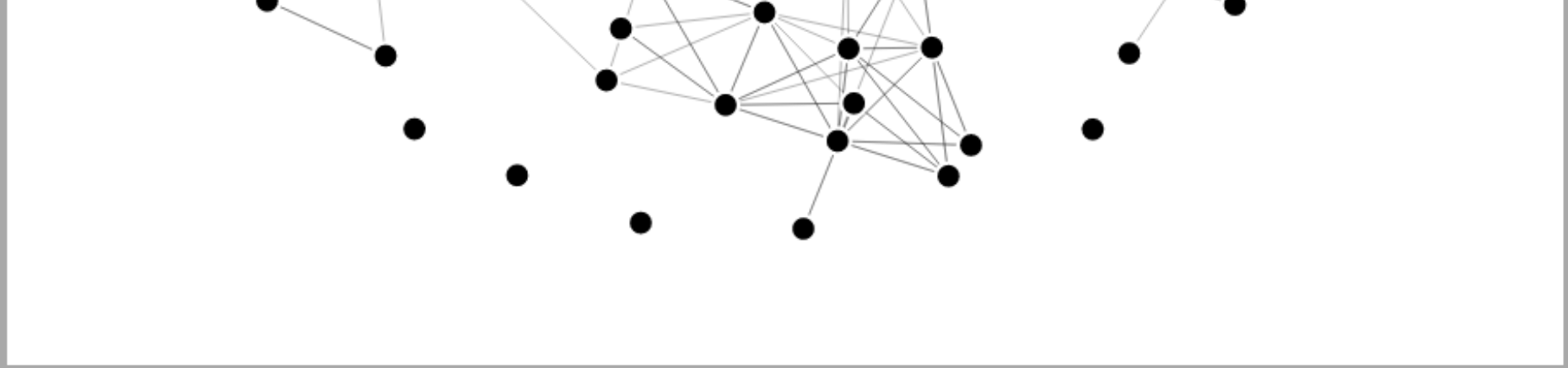


similarity view



- Details
- Select Neighbors
- Select Component
- Clear Selection
- Filter at Selection
- Filter out the Selection
- Clear Filtering

similarity view

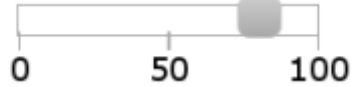


Edge count cap (max:35532)

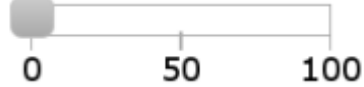


Compute similarity between events considering:

Sets of probes



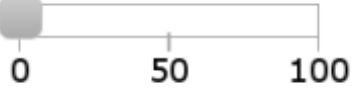
Time:



Recurrence:

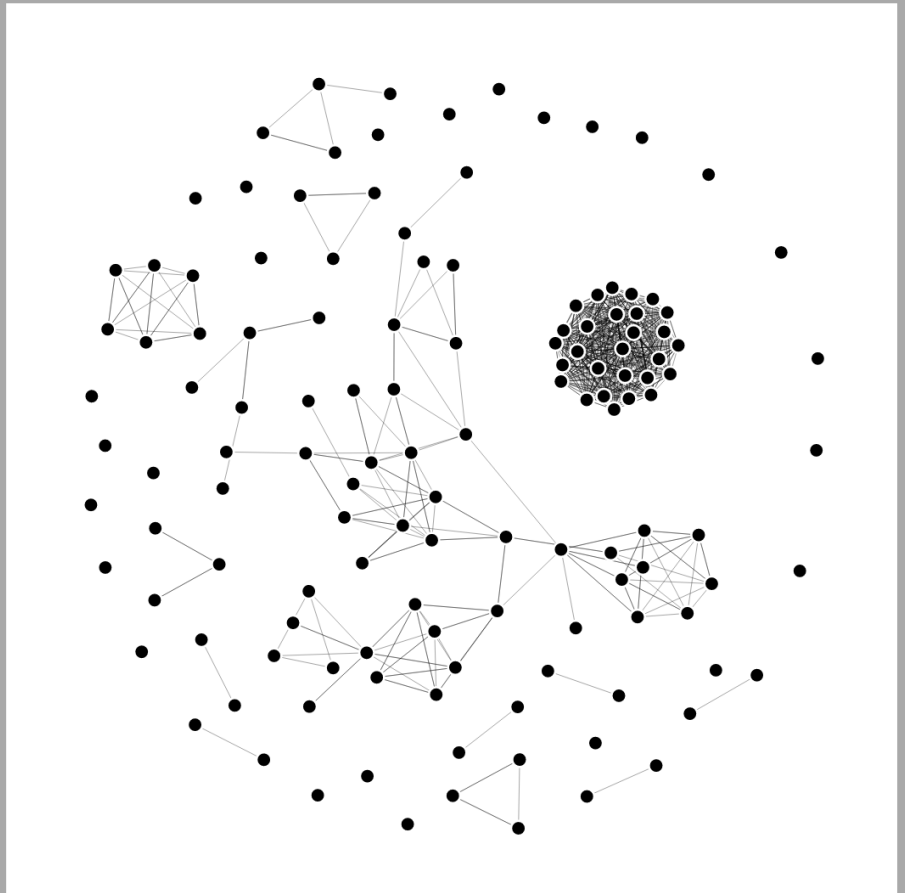
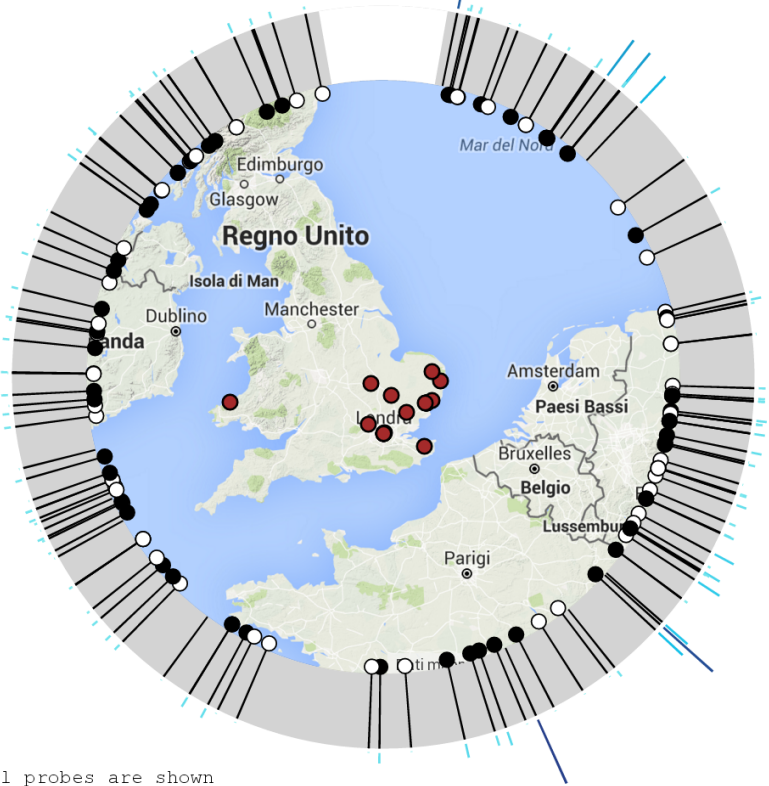
None ▼

Sets of causes



similarity panel

Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



Display events that satisfy the following conditions:

Min impact: 5 10 15 20 AND Target is:

Impacted AS is:

Cause AS is:

Edge count cap (max:17292) 0 2000 4000

Compute similarity between events considering:

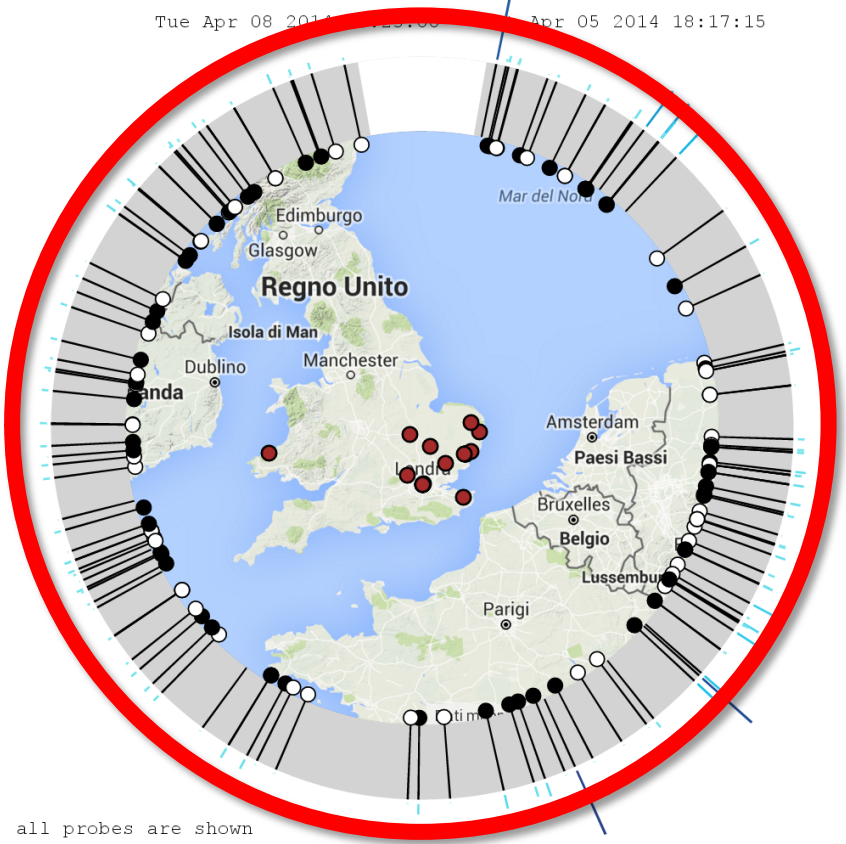
Sets of probes: 0 50 100

Time: 0 50 100

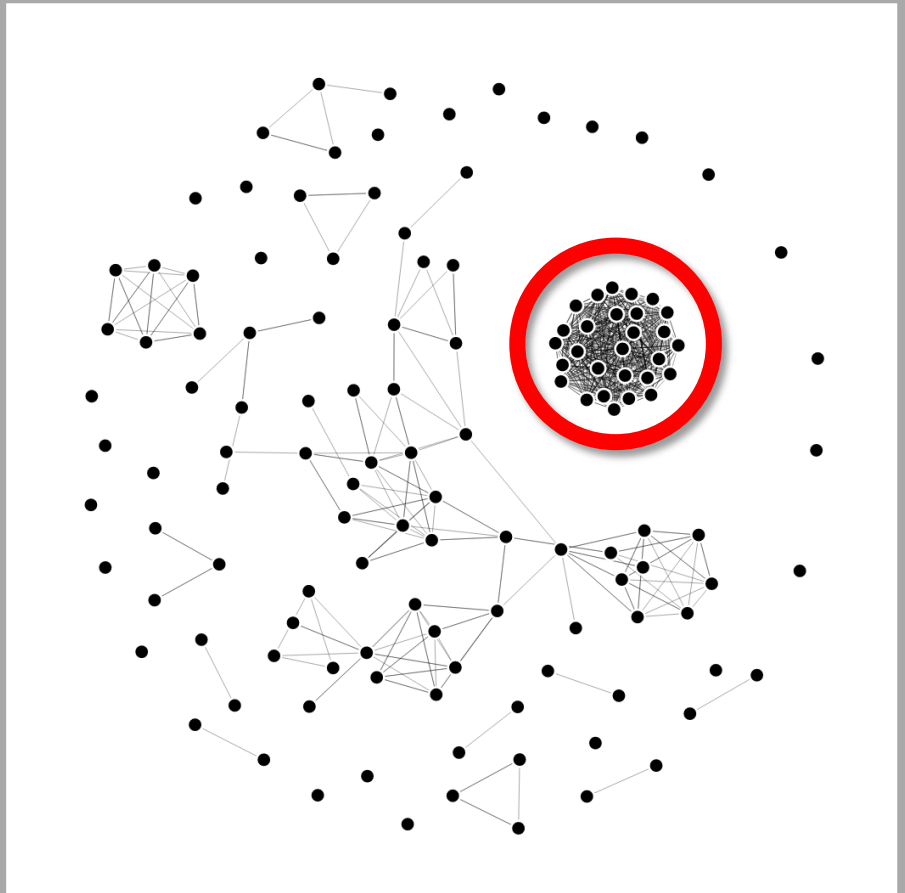
Recurrence:

Sets of causes: 0 50 100

Tue Apr 08 2014 12:51:00 - Apr 05 2014 18:17:15



all probes are shown



Display events that satisfy the following conditions:

Min impact 5 10 15 20 AND Target is:

Impacted AS is:

Cause AS is:

Edge count cap (max:17292)

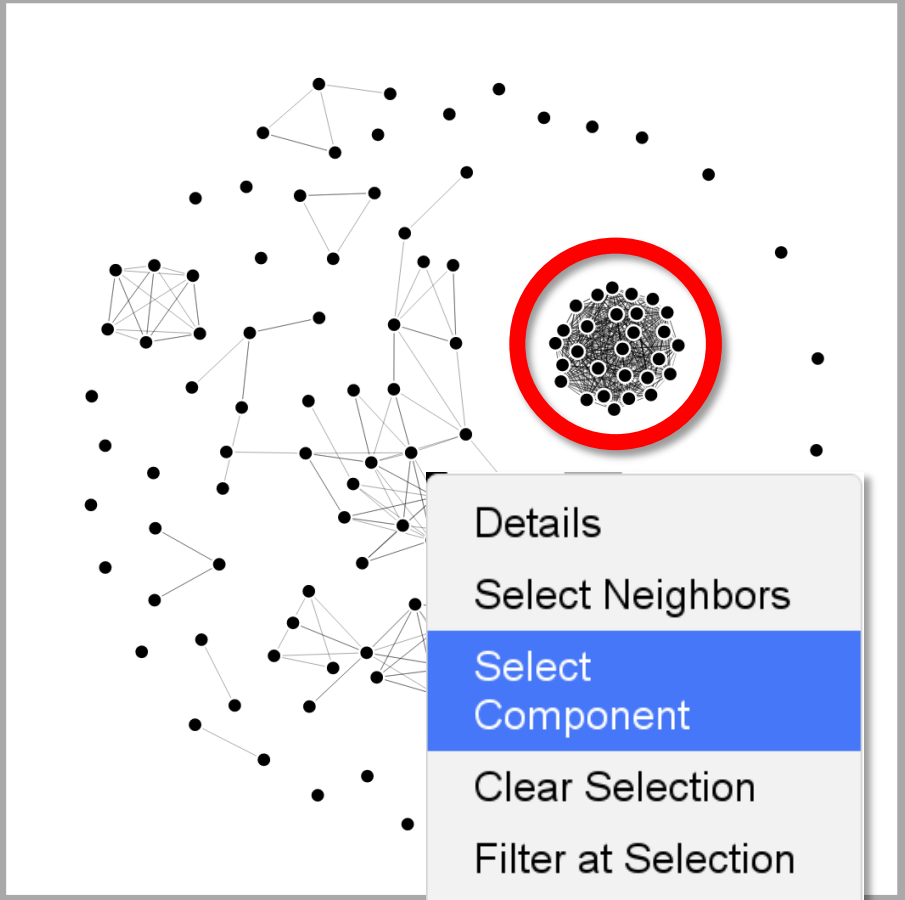
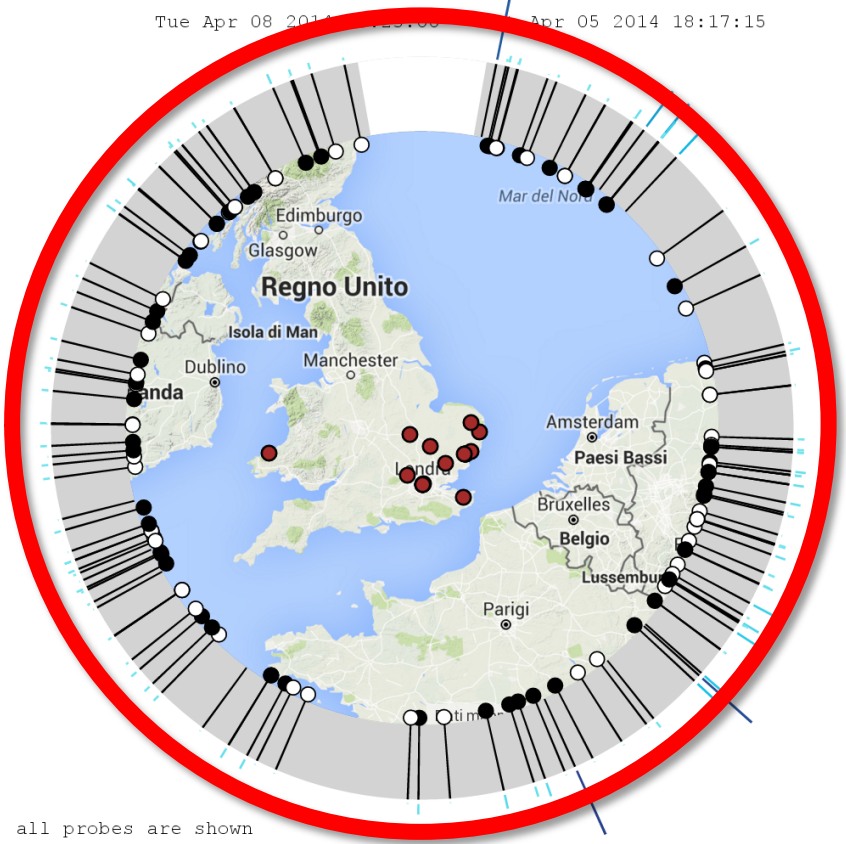
0 2000 4000

Compute similarity between events considering:

Sets of probes 0 50 100 Time: 0 50 100 Recurrence:

Sets of causes 0 50 100

Tue Apr 08 2014 12:51:00 - Apr 05 2014 18:17:15



Display events that satisfy the following conditions:

Min impact: 5 10 15 20 AND Impacted AS is:

Target is:

Cause AS is:

Edge count: 0 2

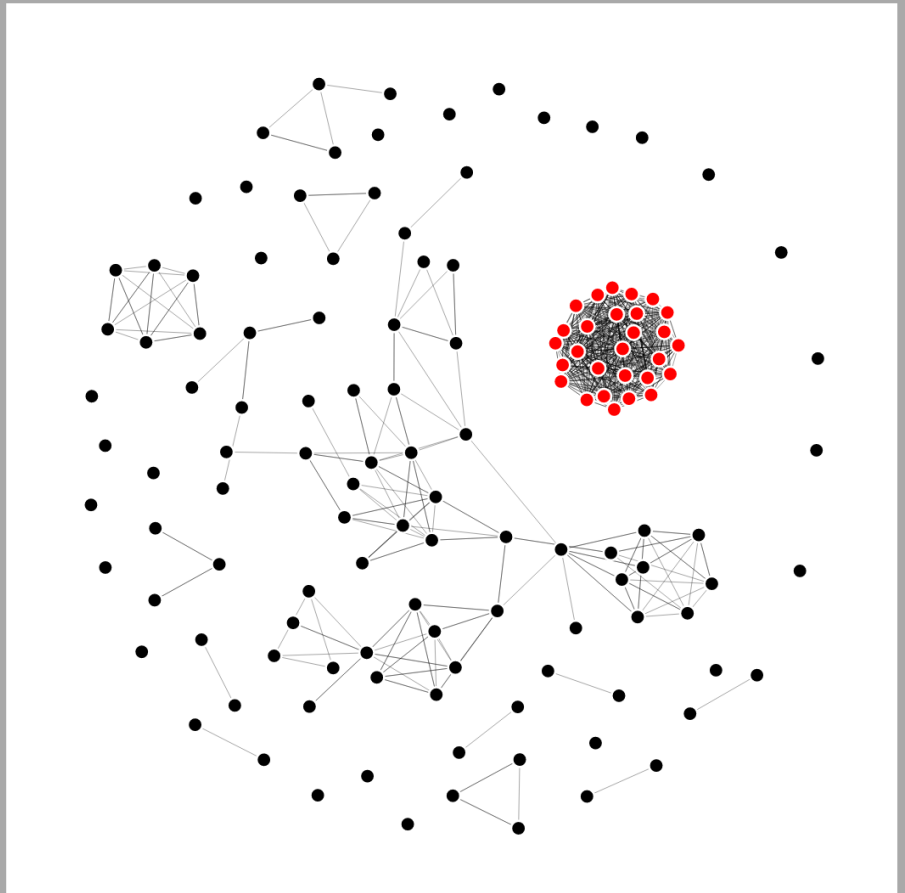
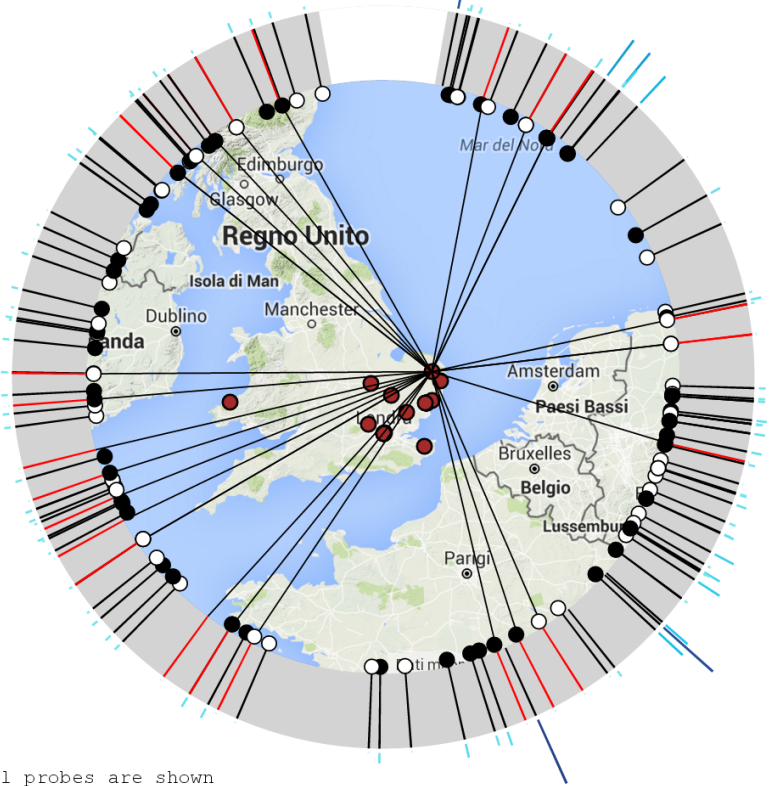
Compute similarity between events con

Sets of probes: 0 50 100

Sets of causes: 0 50 100

Time: 0 50

Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



Display events that satisfy the following conditions:

Min impact: 5 10 15 20 AND Target is:

Impacted AS is:

Cause AS is:

Edge count cap (max:17292): 0 2000 4000

Compute similarity between events considering:

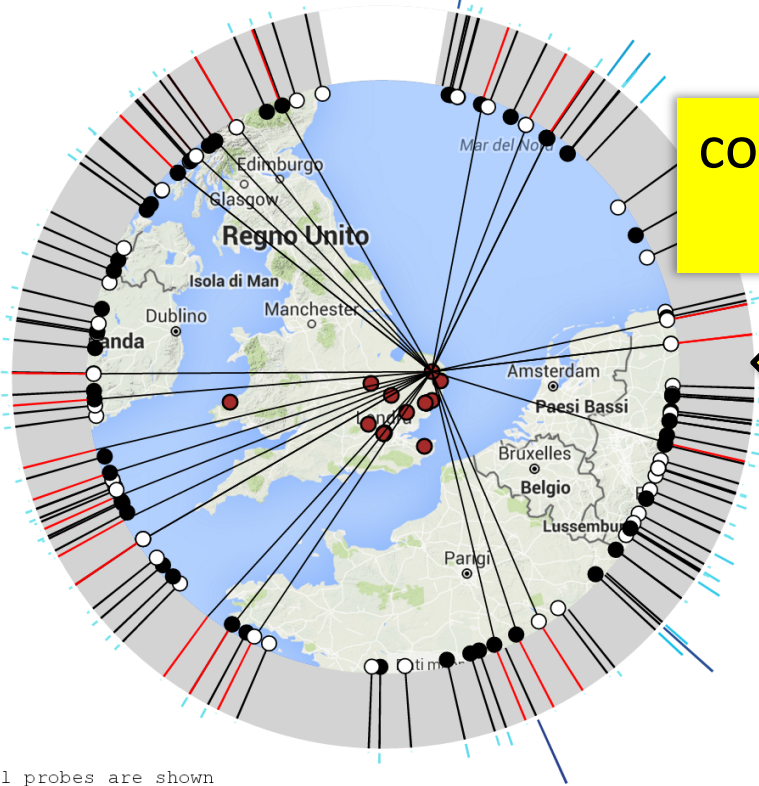
Sets of probes: 0 50 100

Time: 0 50 100

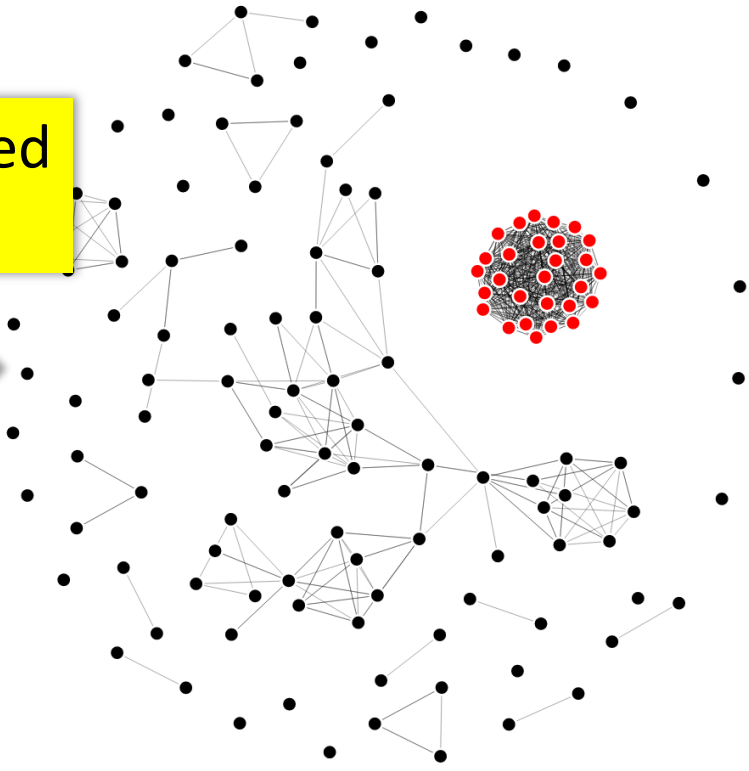
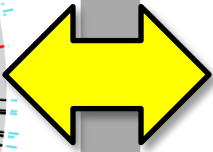
Sets of causes: 0 50 100

Recurrence:

Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



coordinated views



all probes are shown

Display events that satisfy the following conditions:

Min impact: 5 10 15 20 AND Target is:

Impacted AS is:

Cause AS is:

Edge count cap (max:17292): 0 2000 4000

Compute similarity between events considering:

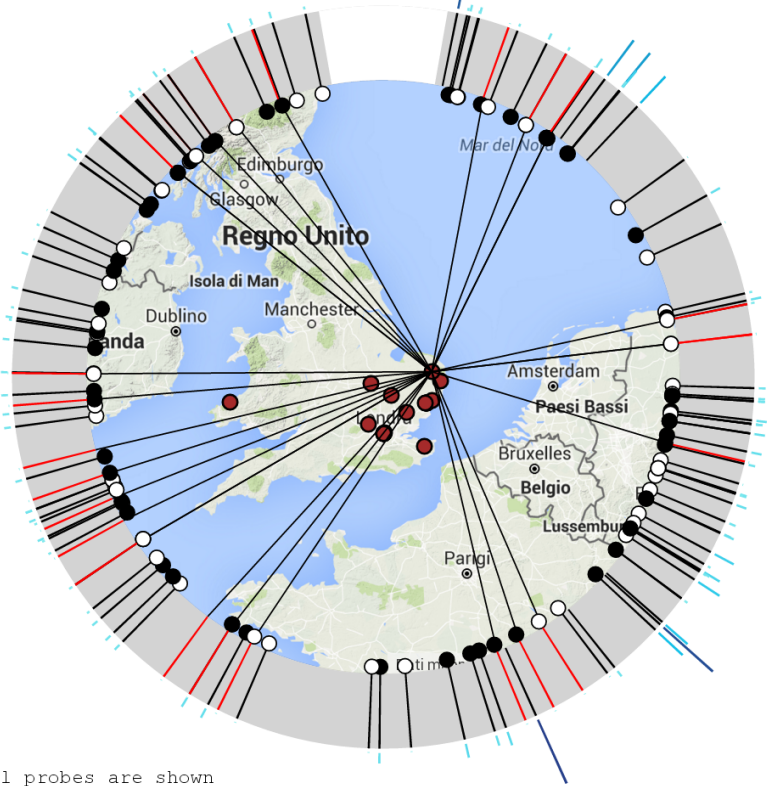
Sets of probes: 0 50 100

Sets of causes: 0 50 100

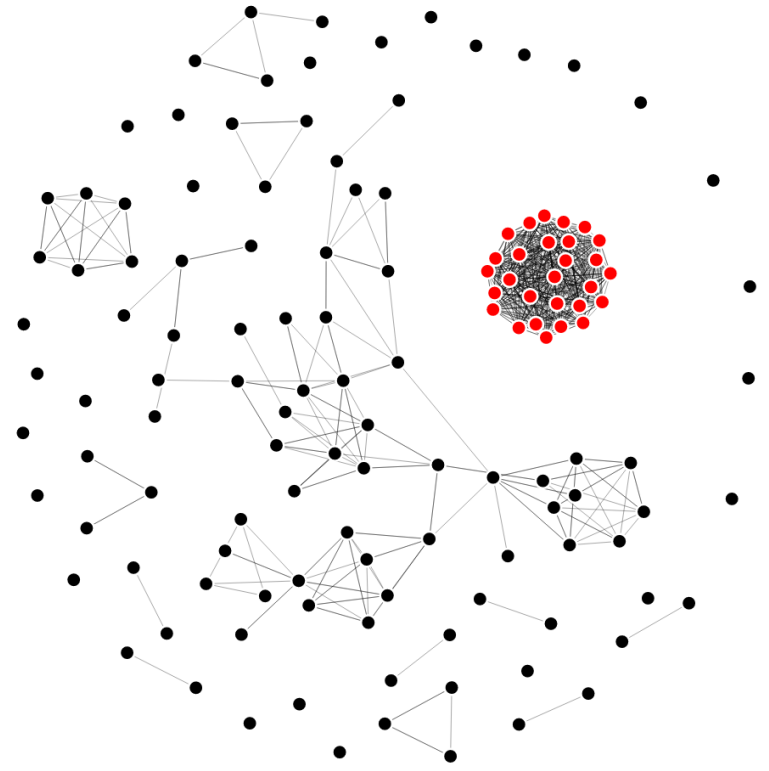
Time: 0 50 100

Recurrence:

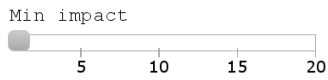
Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



all probes are shown



Display events that satisfy the following conditions:



AND

Impacted AS is:

Target is:

Cause AS is:

Sets of probes



Time:



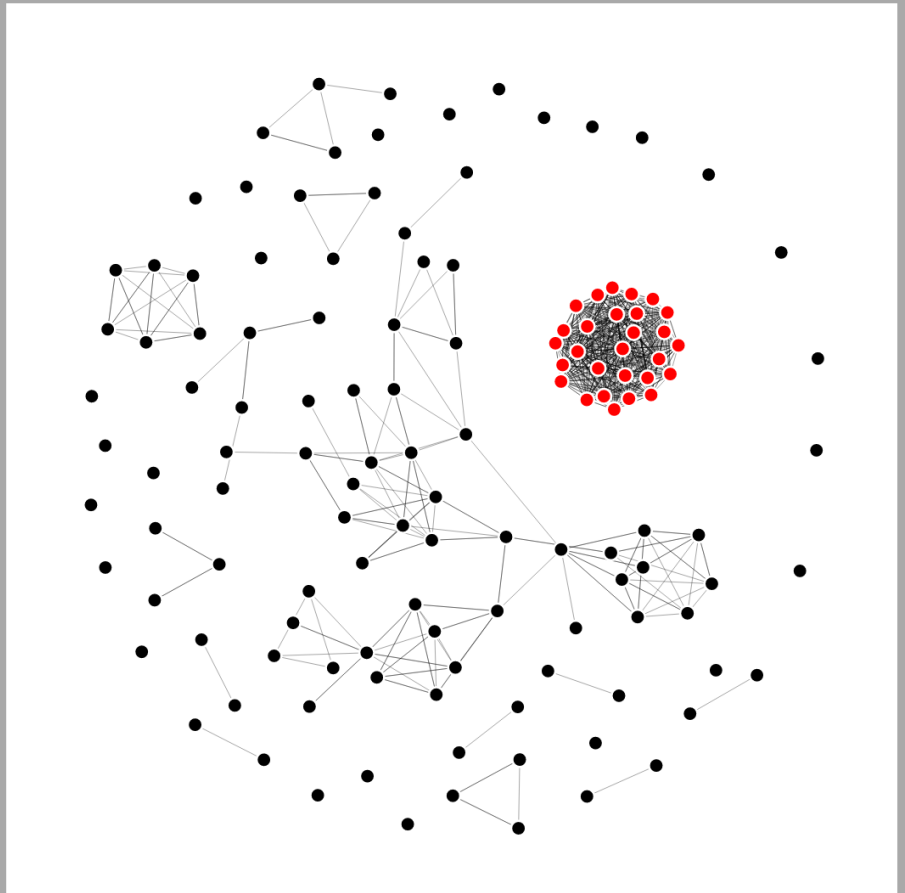
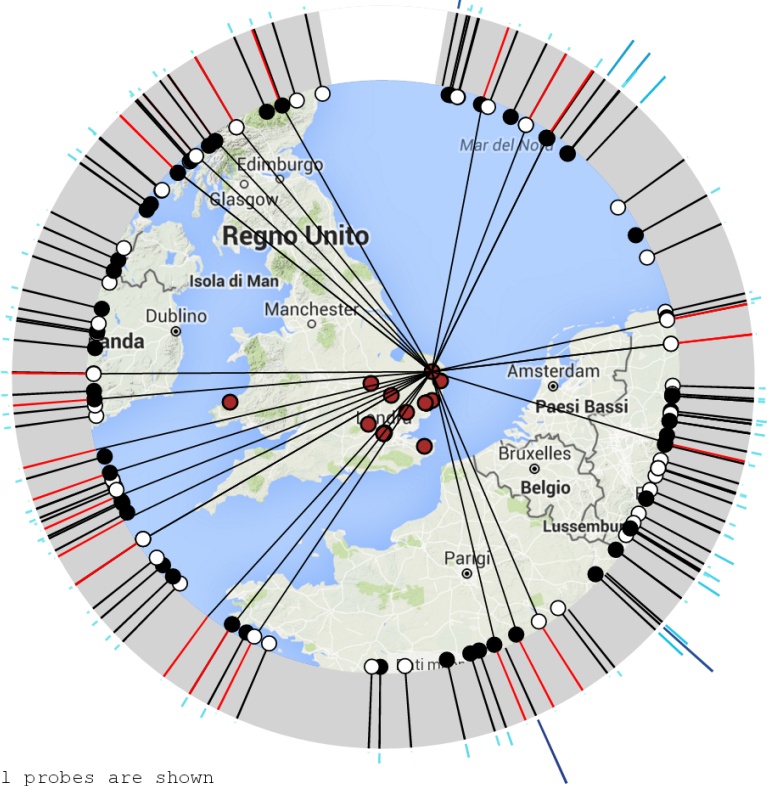
Recurrence:

Edge count cap (max:17292)



0 50 100

Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



Display events that satisfy the following conditions:

Min impact: 5 10 15 20 AND Impacted AS is:

Target is:

Cause AS is:

Sets of probes: 0 50 100

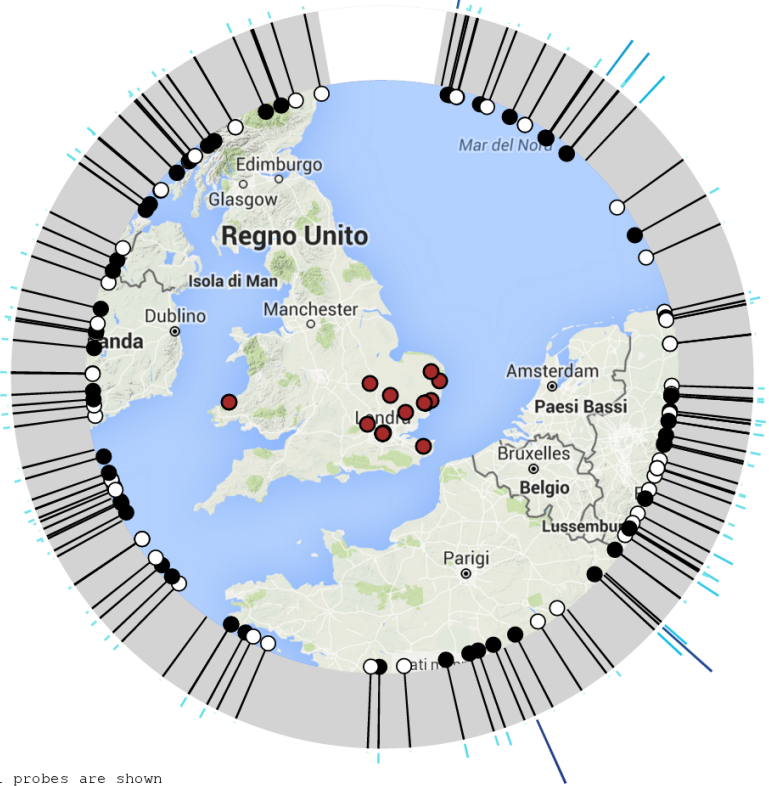
Edge count cap (max:17292): 0 2000 4000

Time: 0 50 100

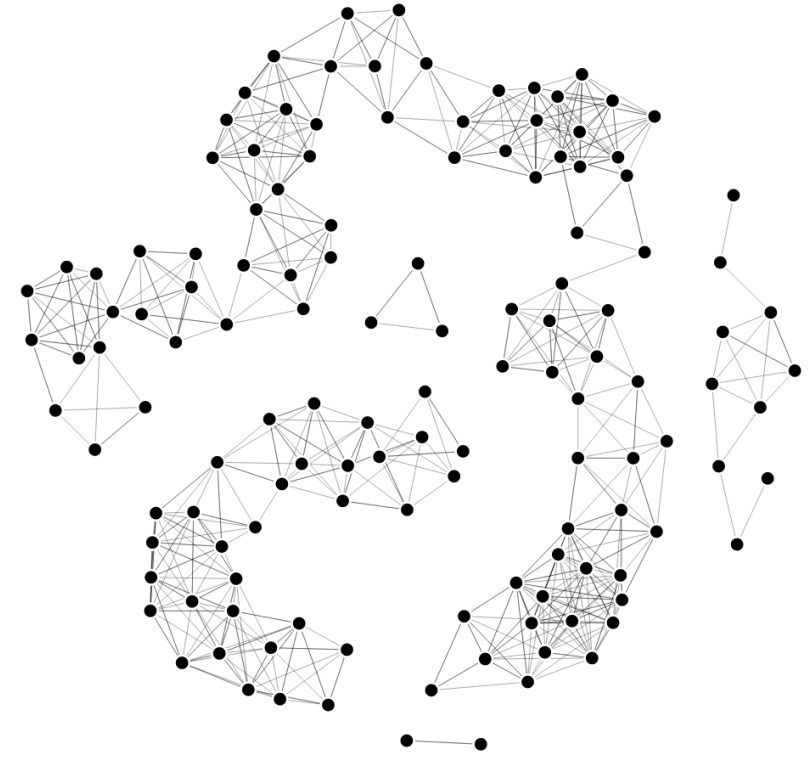
Recurrence:

continuous interaction

Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



all probes are shown



Display events that satisfy the following conditions:

Min impact: 5 10 15 20 AND Target is:

Impacted AS is:

Cause AS is:

Edge count cap (max:17292): 0 2000 4000

Compute similarity between events considering:

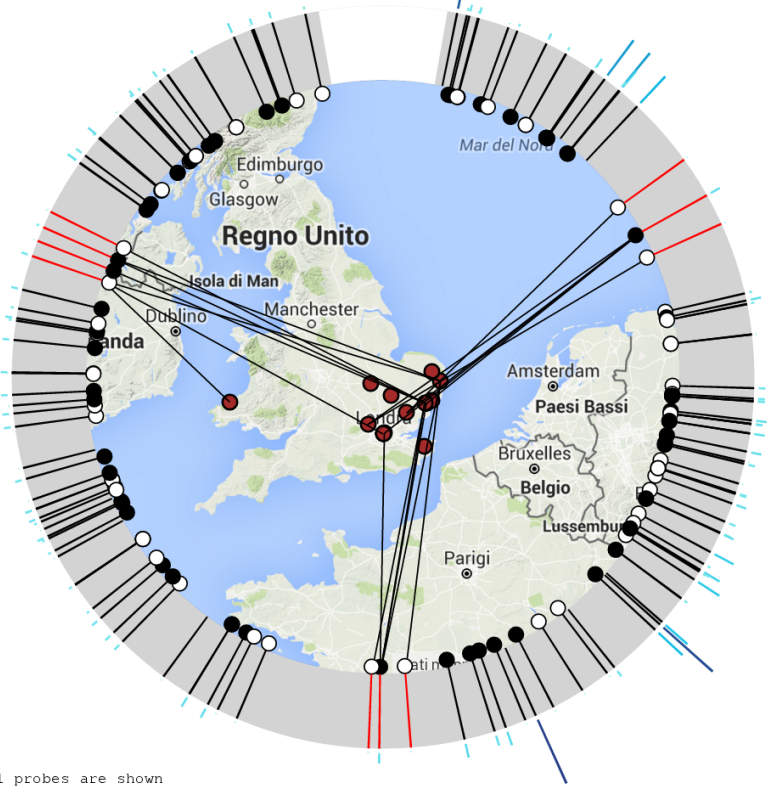
Sets of probes: 0 50 100

Sets of causes: 0 50 100

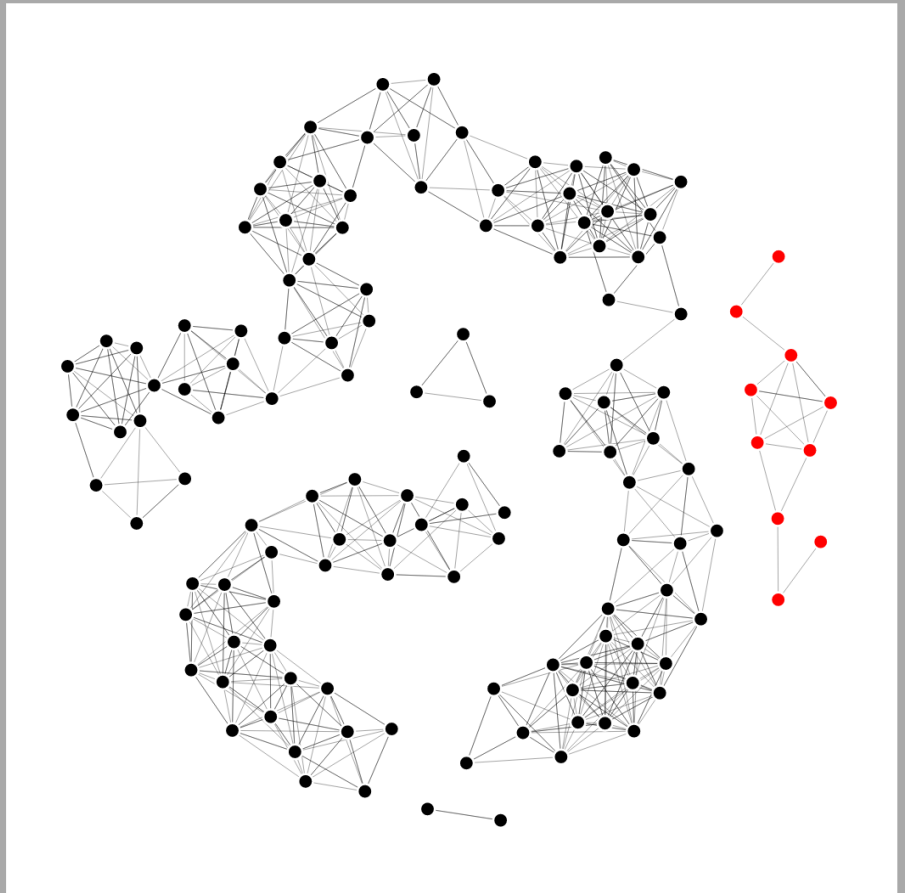
Time: 0 50 100

Recurrence:

Tue Apr 08 2014 15:23:00 Sat Apr 05 2014 18:17:15



all probes are shown



Display events that satisfy the following conditions:

Min impact 5 10 15 20 AND Target is:

Impacted AS is:

Cause AS is:

Edge count cap (max:17292) 0 2000 4000

Compute similarity between events considering:

Sets of probes 0 50 100

Sets of causes 0 50 100

Time: 0 50 100

Recurrence:



User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)



User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:

1

5





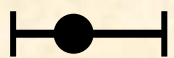
User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:

1

5



■ events are a useful aggregation of routing dynamics



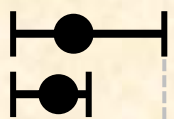
User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:

1

5



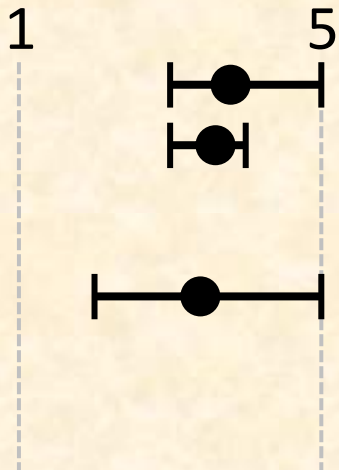
- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events



User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:



- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events
 - the tool supports it effectively



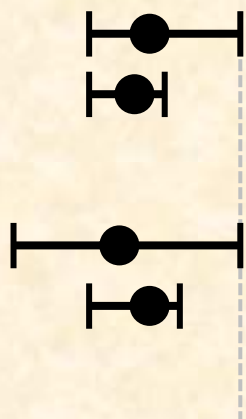
User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:

1

5



- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events
 - the tool supports it effectively
- finding related events is useful



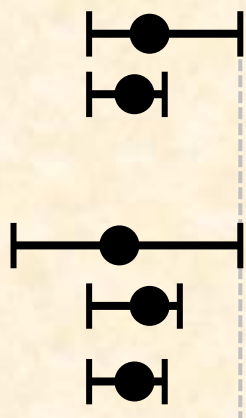
User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:

1

5



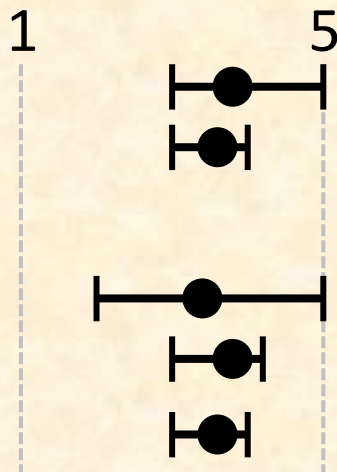
- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events
 - the tool supports it effectively
- finding related events is useful
 - the tool supports it effectively



User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:



- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events
 - the tool supports it effectively
- finding related events is useful
 - the tool supports it effectively



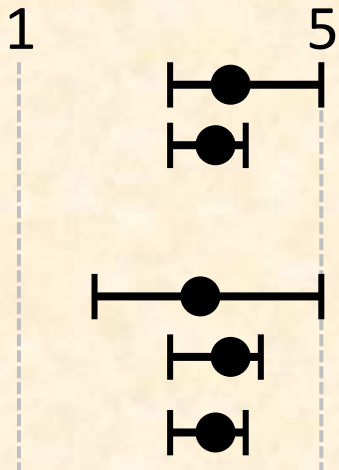
Filters



User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:



- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events
 - the tool supports it effectively
- finding related events is useful
 - the tool supports it effectively



Filters



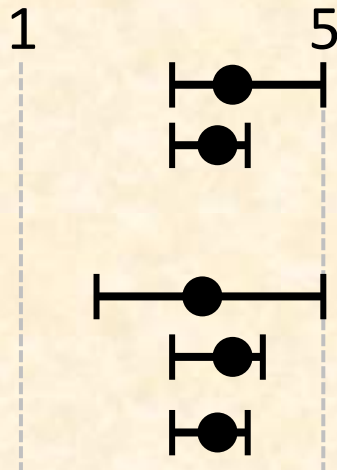
Event patterns



User study



- User sample: employees of the R&D of a prominent italian ISP (experts in IP edge innovation, cyber-security threats, video/multimedia platforms)
- Questionnaire results:



- events are a useful aggregation of routing dynamics
- comparing events by probes/geography/time is useful to find related events
 - the tool supports it effectively
- finding related events is useful
 - the tool supports it effectively



Filters



Event patterns

“A tool for mining traceroutes”

Future Work



Future Work



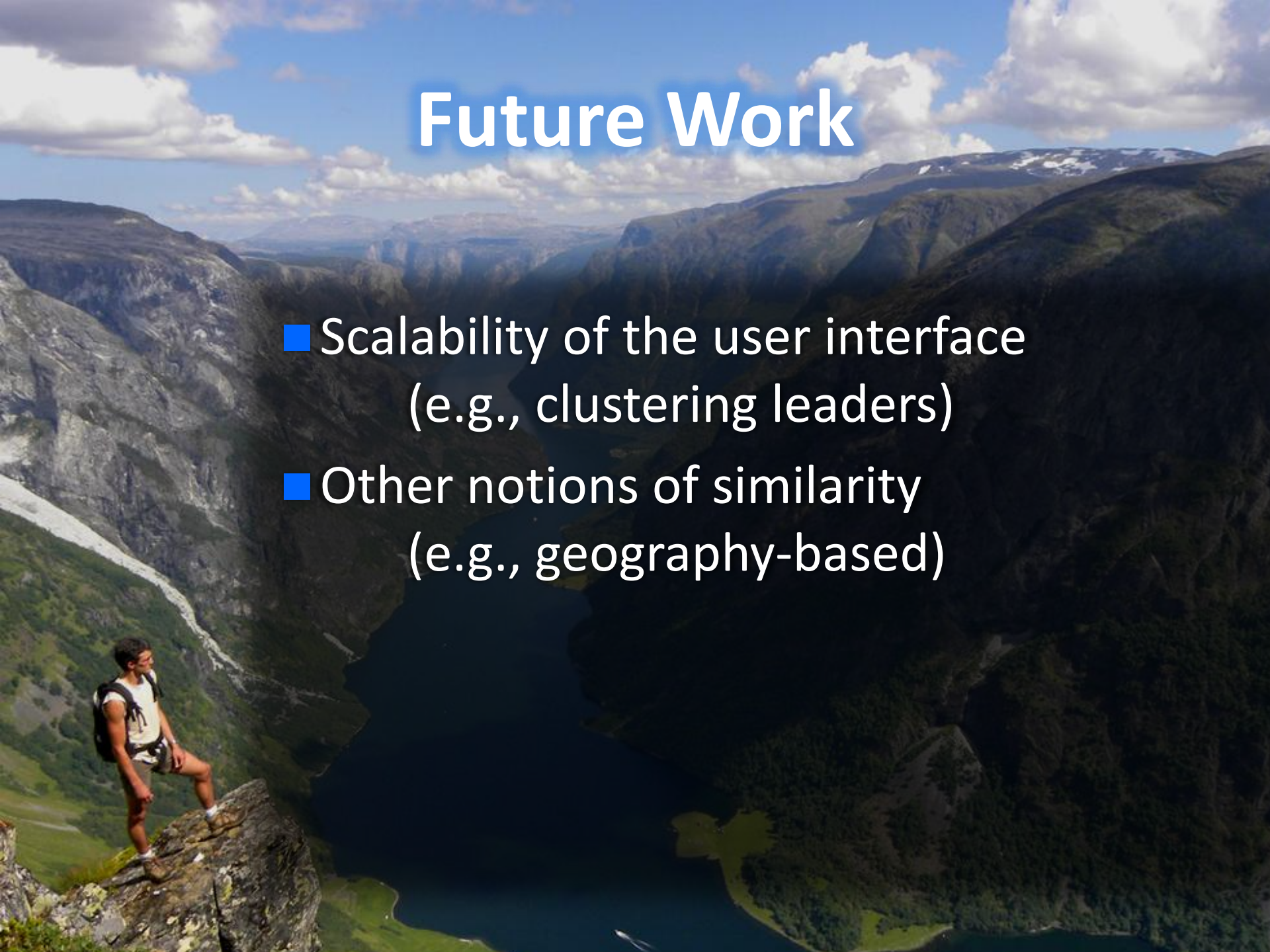
Future Work

- Scalability of the user interface (e.g., clustering leaders)



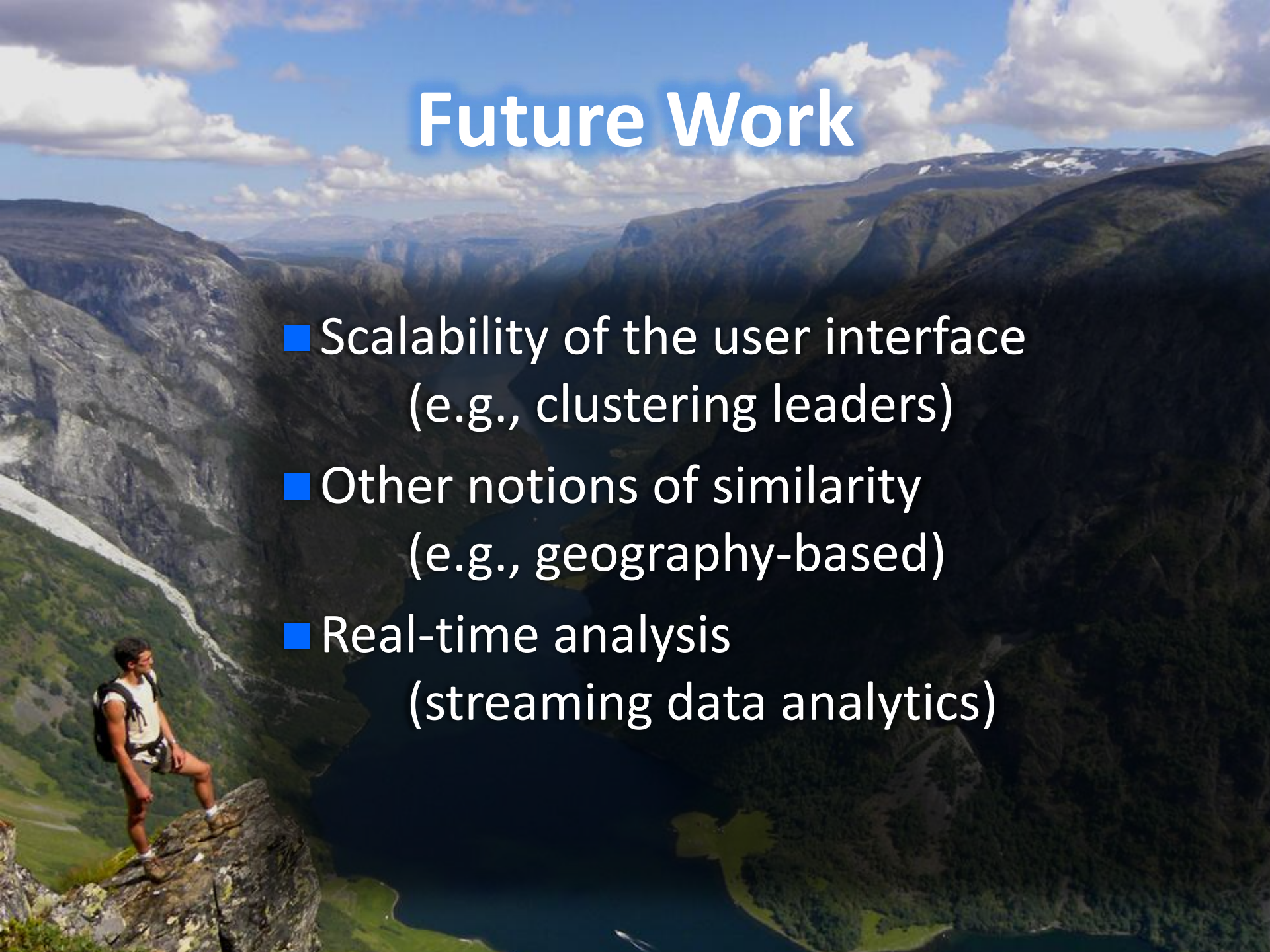
Future Work

- Scalability of the user interface (e.g., clustering leaders)
- Other notions of similarity (e.g., geography-based)



Future Work

- Scalability of the user interface
(e.g., clustering leaders)
- Other notions of similarity
(e.g., geography-based)
- Real-time analysis
(streaming data analytics)



Future Work

A hiker with a backpack is sitting on a rocky ledge in the foreground, looking out over a vast, deep mountain valley. The valley is filled with green vegetation and a winding river. In the distance, there are more mountains, some with patches of snow, under a blue sky with scattered white clouds.

- Scalability of the user interface
(e.g., clustering leaders)
- Other notions of similarity
(e.g., geography-based)
- Real-time analysis
(streaming data analytics)
- Exploration session
(to build a knowledge base)