State of the art of FOSS4G for topology and network analysis

Vincent Picavet

FOSS4G 2010 - Barcelona

Oslandia, who's that ?

Oslandia

Young French SME specialised in Open Source GIS

PostGIS experts: Vincent Picavet & Olivier Courtin

Mainly Focuses on:

- **Spatial Databases** (PostGIS, SpatiaLite)
- OGC, ISO, INSPIRE **Standards** and **SDI architecture**
- **Complex analysis** : Routing, Network and Graph Solutions

Oslandia's ecosystem:

OGC® Member

OSGeo Your Open Source Compass

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Oslandia's Technologies

3D GDAL GEOS

GRASS GraphServer INSPIRE MapServer

OGC PgRouting **PostGIS**

PostgreSQL Spatialite TinyOWS

TileCache PyWPS QGIS

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Oslandia, Find us at FOSS4G

Running long and complexes processes with PostGIS

Vincent Picavet, Wednesday - 12h00 – Sala 6

PostGIS meets the third dimension

Olivier Courtin, Wednesday - 12h30 – Sala 6

State of the Art of FOSS4G for Topology and Network Analysis

Vincent Picavet, Thursday – 14h30 – Sala 5

Breakout Session: Spatial Databases

Code Sprint on Friday: PostGIS

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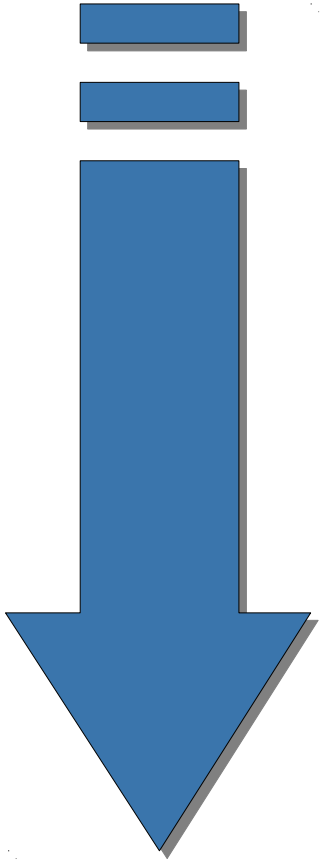
Presentation plan

- Introduction
- What is topology ?
- What is Network Analysis ?
- FOSS4G for topology & NA
- Conclusion
- Perspectives
- Questions



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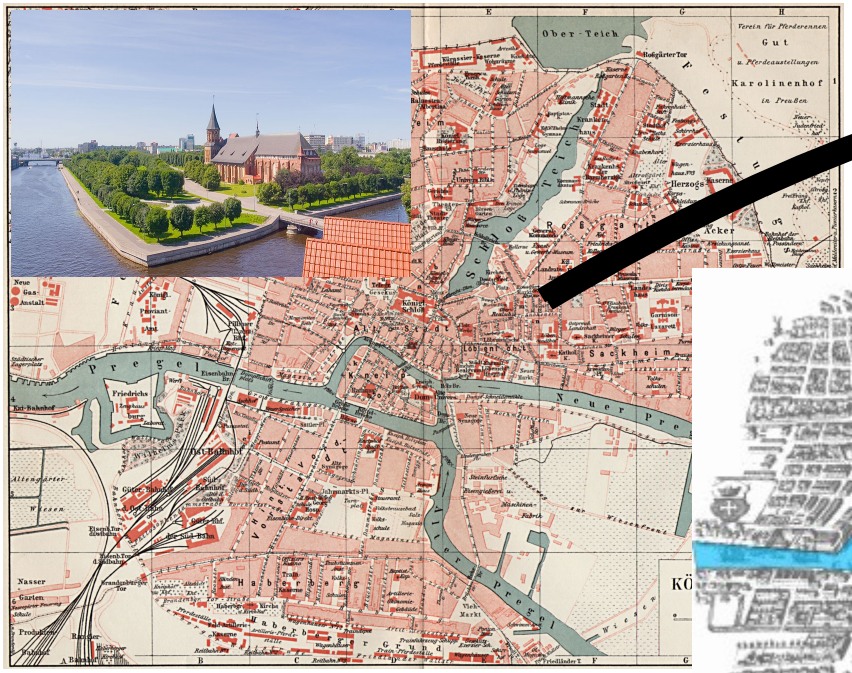
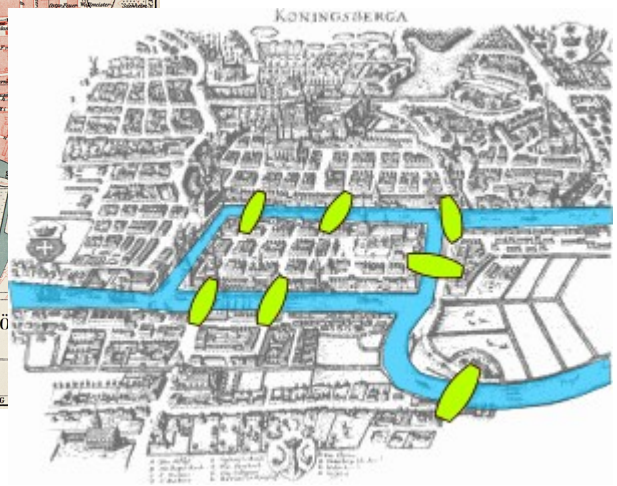
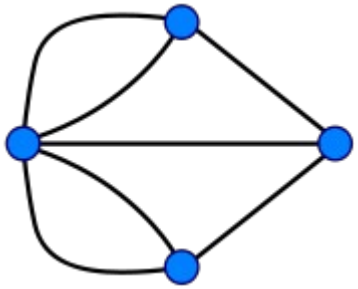
Introduction

Back to the roots

- Problem of the seven bridges of Koenigsberg







$e^{i \cdot \pi} + 1 = 0$

- Topology and graph theory was born !

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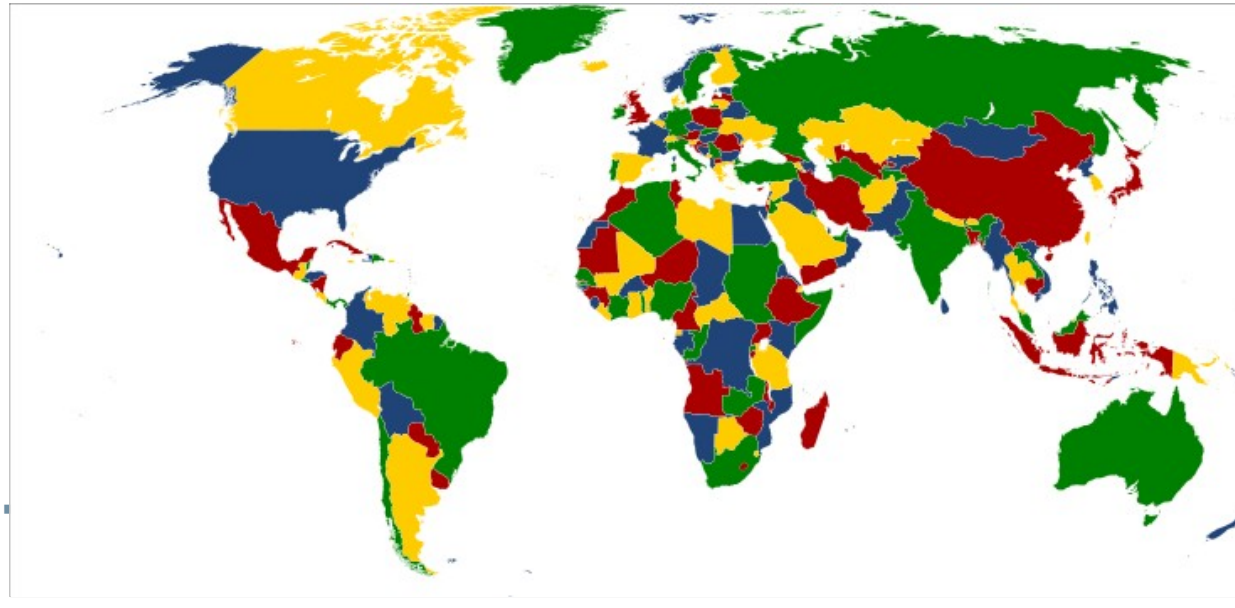
Not so long ago…

- 4 colors map
  - «Given any separation of a plane into contiguous regions, producing a figure called a map, no more than four colors are required to color the regions of the map so that no two adjacent regions have the same color»
- Conjecture in 1852 (Francis Guthrie)
- Proof in 1976
- First computer-assisted proof
- **GIS Problems lead to complex theoretical issues**



Nowadays GIS application fields

- Transportation networks at large
  - Path finding & Routing
  - Network flow
  - Fleet management
  - ...
- Resource allocation
- Crisis management
- Hydrology
- Computer networks
- Geomarketing
- Mobile applications
- ...

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What is topology ?

Topology – General

General :

- *«Area of mathematics concerned with spatial properties that are preserved under continuous deformations of objects»*

- GIS :
  - *«Spatial relationship between geographic features based on location»*
- Implicit on maps : eye-brain system interprets it
- Needs to be explicit for computer systems
- Relations
  - Connectivity, Adjacency, Containment, Proximity, Relative Directions
- Rules based on relations

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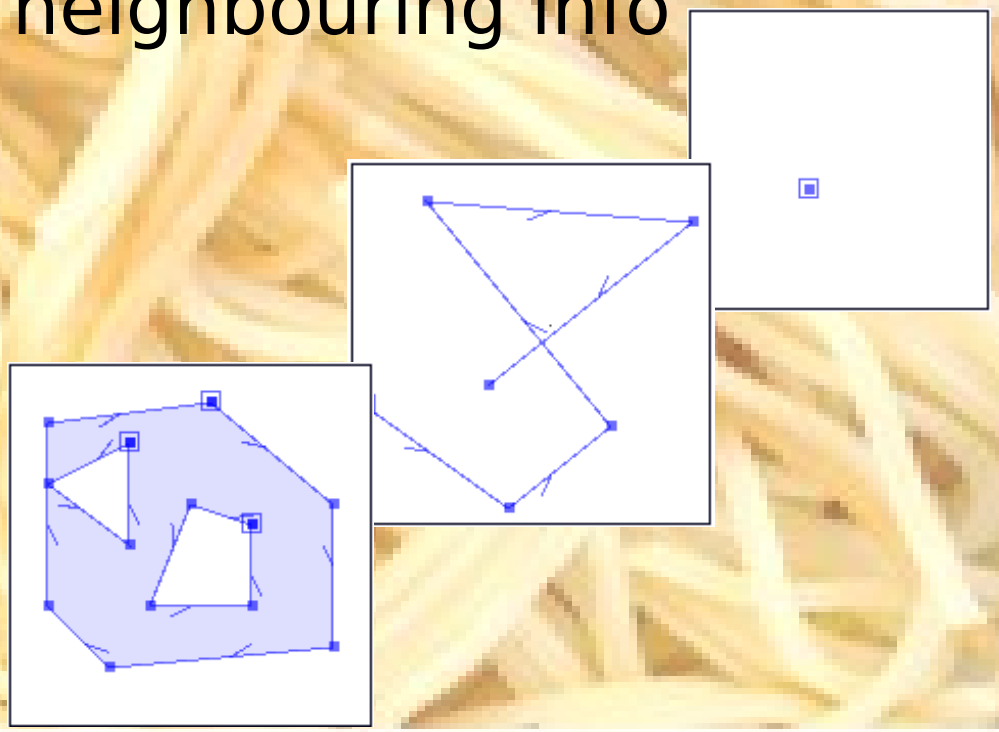
Classic feature model

- aka «Spaghetti model»
- 1-1 translation of analog map
- Line = series of ordered (x, y) points
- Polygon = closed loops define boundaries
- Different lines/Polygons = independent objects
- No explicit connectivity & neighbouring info
- Simple and efficient
  - Cartographic display
  - Used by most CAD DB



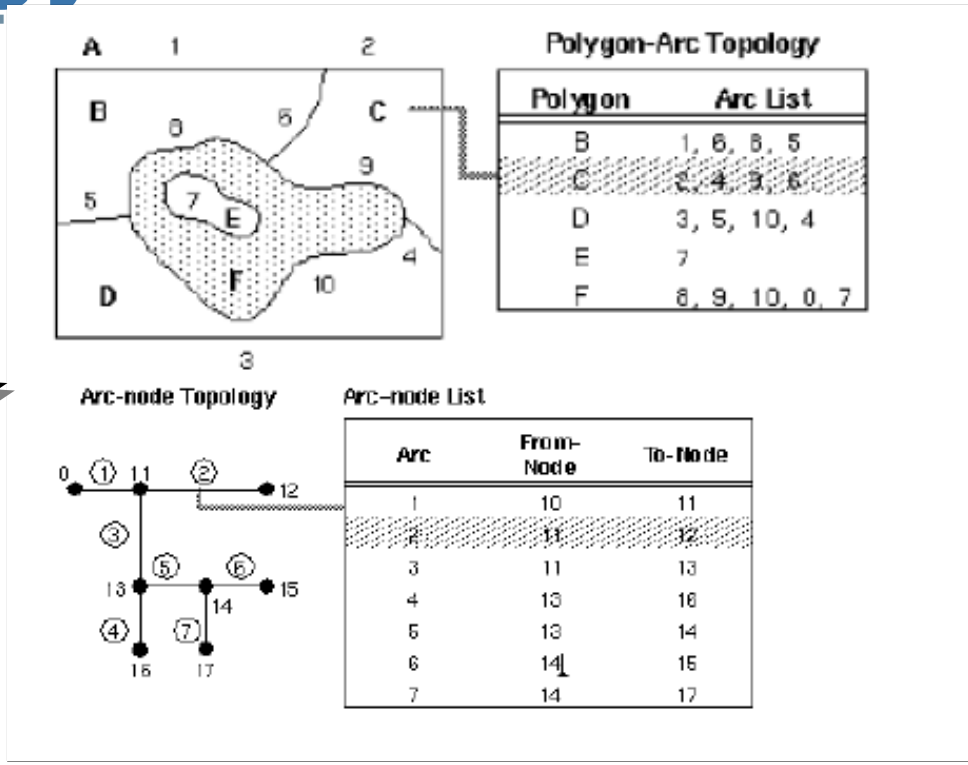
Why topology ?

- Insure correct boundaries
- Enhance analysis
- Insure data quality
- Topological editing and digitizing
- Needed to do network analysis

Get rid of the Spaghetti Monster !

GIS Formats & topology

- Your very own topology
  - Feature-attribute based
  - Use relations and create rules
- Classic topology model
  - Node, arc/edge, face
  - Connectivity, Direction, Adjacency



- Most GIS data format → no topology
  - Except : ArcInfo Coverage, TIGER, DLG, OSM (partly)…

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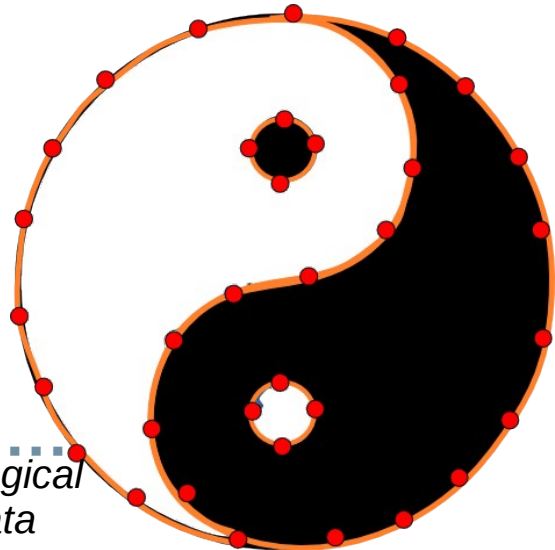
From spaghettis to topological zen

- Multiple ways to build topology from geometry
- Build your own model or use a standard one
- Classic build process steps
  - Extract all shared vertices as nodes
  - Create edges between nodes (lines & polygon boundaries)
  - Create faces with edges (polygons)

Clean & Validate with topology rules

- Data cleaning
  - Automatic
  - Semi automatic
  - Manual

Spaghetti mess



Topological Zen data

Standardization

- Main standard, DB-oriented :
  - BS ISO/IEC 13249-3:2006 aka SQL/MM
- Defines model and operations
- Node-edge-face model, with geometry
  - ST_NODE, ST_EDGE, ST_FACE views
- ST_CreateTopoGeo, ST_ValidateTopoGeo
- Editing functions
- Topology-network model and operations
  - Creation, validation, editing
  - Shortest Path

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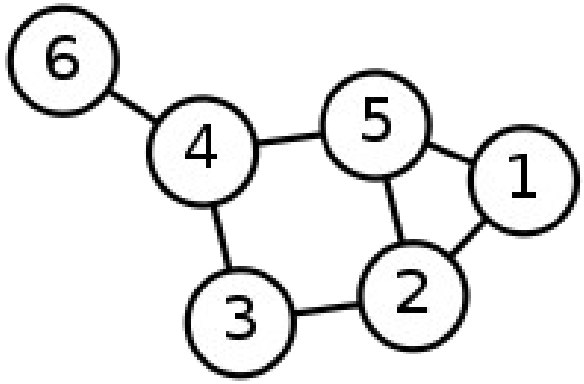
What is Network Analysis ?

Graph Theory – Network theory

- Graph Theory :
  - *«Study of graphs: mathematical structures used to model pairwise relations between objects from a certain collection.»*
- Networks
  - Nodes & Edges
  - Directed / Undirected
  - Weighted or not
  - Definition varies...



- Social Networks, Biology, Link analysis, centrality measures...

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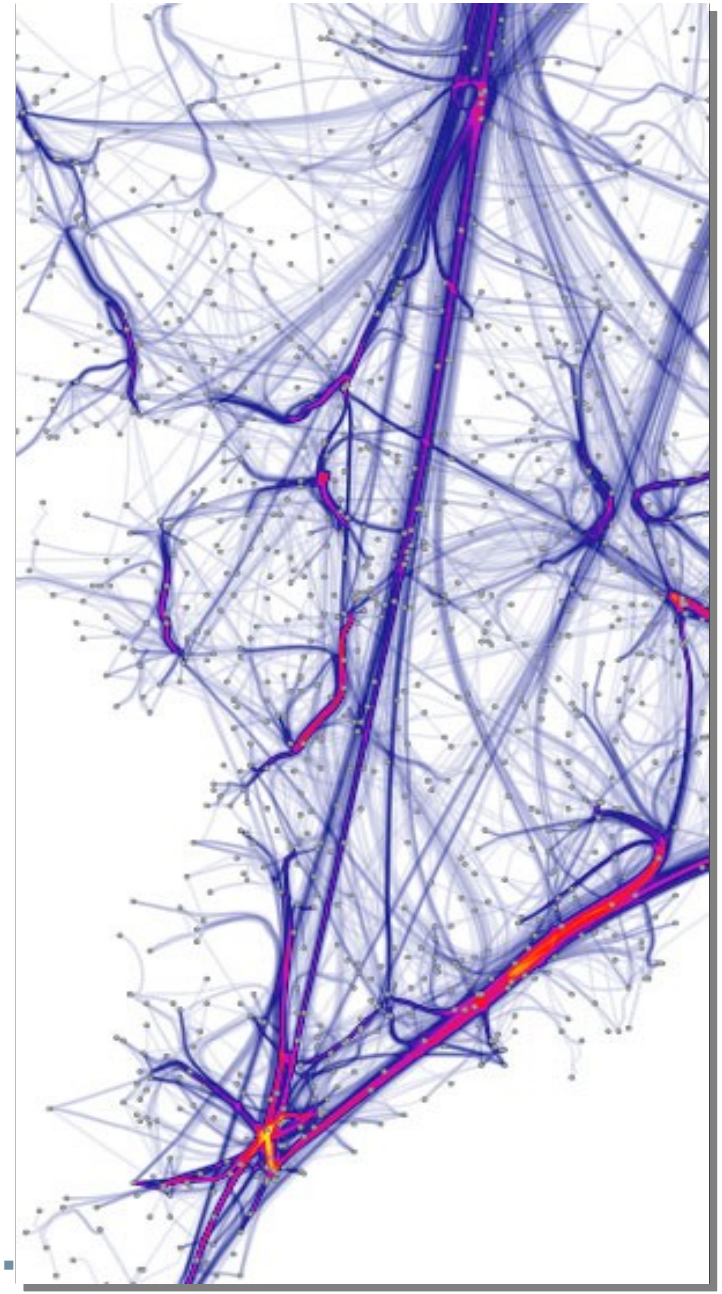
Some network analysis problems

- Enumeration
- Sub-graphs
- Colouring
- Routing
  - Minimum spanning tree
  - Route inspection problem
  - Shortest path problem
  - Steiner tree
  - Travelling salesman problem
- Network flow
- Visibility graph
- Covering problems
- Graph classes



FOSS4G Tools

FOSS4G Softwares

- PostGIS
- PgRouting
- GvSIG
- GraphServer
- Spatialite
- GRASS

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PostGIS

- SQL/MM Topology Model
- Partial implementation
  - No network analysis
- Node-Edge-Face
- Create, Validate
- Raw edit
- SQL/MM interface for editing, Geo/topo operations

```
SELECT topology.CreateTopology(name, [srid], [tolerance [srid]], [tolerance]);
SELECT * FROM topology.ValidateTopology(name) ; -- topology validation

INSERT INTO mytopology.edge … ;
INSERT INTO mytopology.face … ;
INSERT INTO mytopology.node … ;
SELECT ST_AddIsoNode(…) ;
SELECT ST_ChangeEdgeGeom(…);

SELECT topology.Geometry(TopoGeometry) ; -- get geometry from topology object
SELECT topology.DropTopology(name) ;
```

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PgRouting

- PostGIS Plugin
- Own network model
- Shortest path
- Driving distances
- Travelling Salesman Problem
- Algorithms
  - Dijkstra
  - A*
  - Shooting star (with restrictions)
- Network building tool & OSM import tool

```
SELECT * FROM
shortest_path_astar('SELECT gid AS id, source::int4, target::int4, length::double
precision AS cost, x1, y1, x2, y2 FROM dourol' , 3, 7, false, false);
```

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GvSIG – Topology extension

- Full topology management
- Multi-Layer topology builder
- Set of topology rules system
  - Complex parameterized rules
  - Multi-layer rules
- Topology validation & partial validation
- Topological digitizing
- Topology exceptions management
- Automated, semi-automated and manual cleaning
- Full GUI
  - Native GvSIG integration
- Geoprocessing
  - generalization, Voronoi, Poly2lines, clean, translate…

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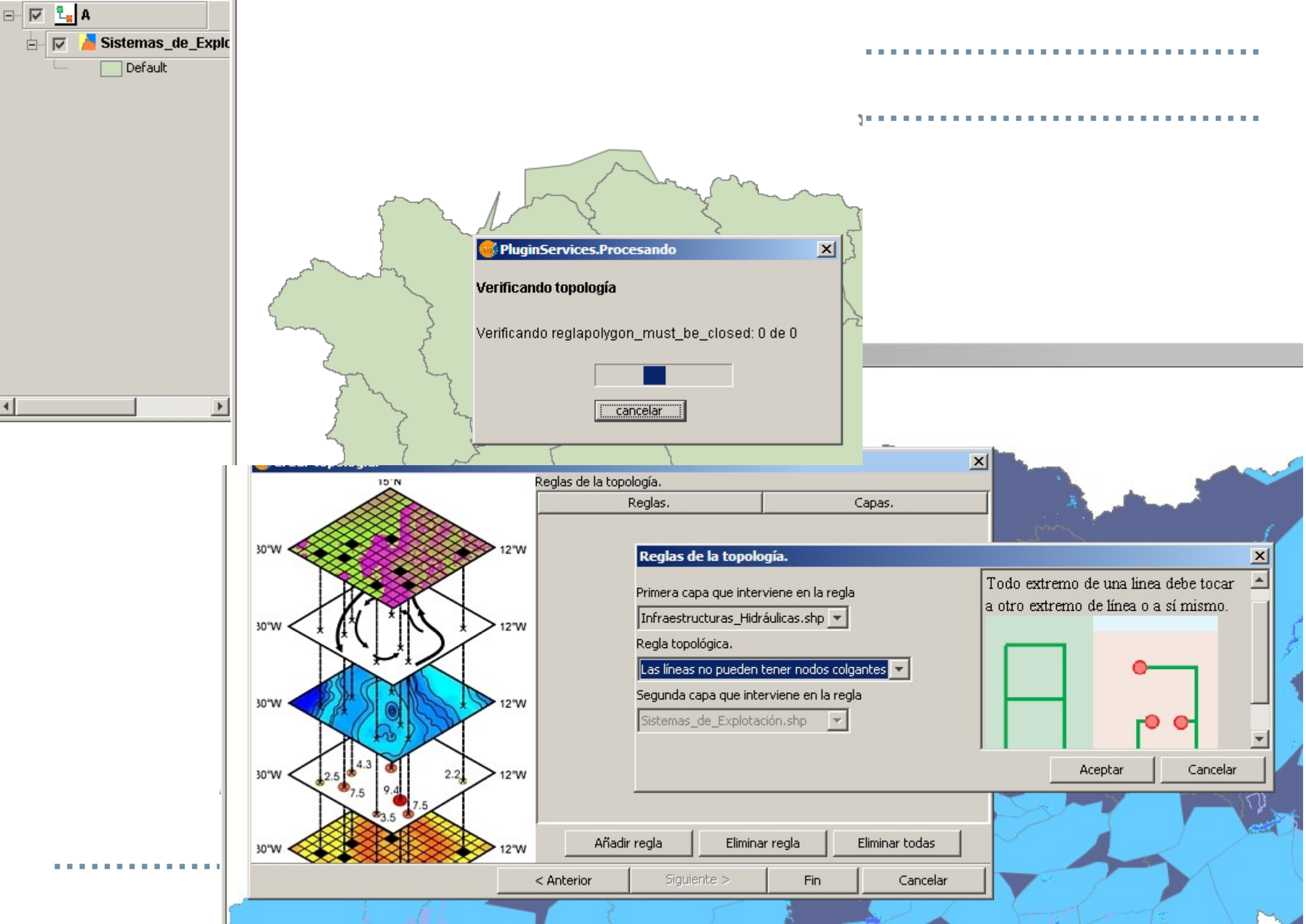
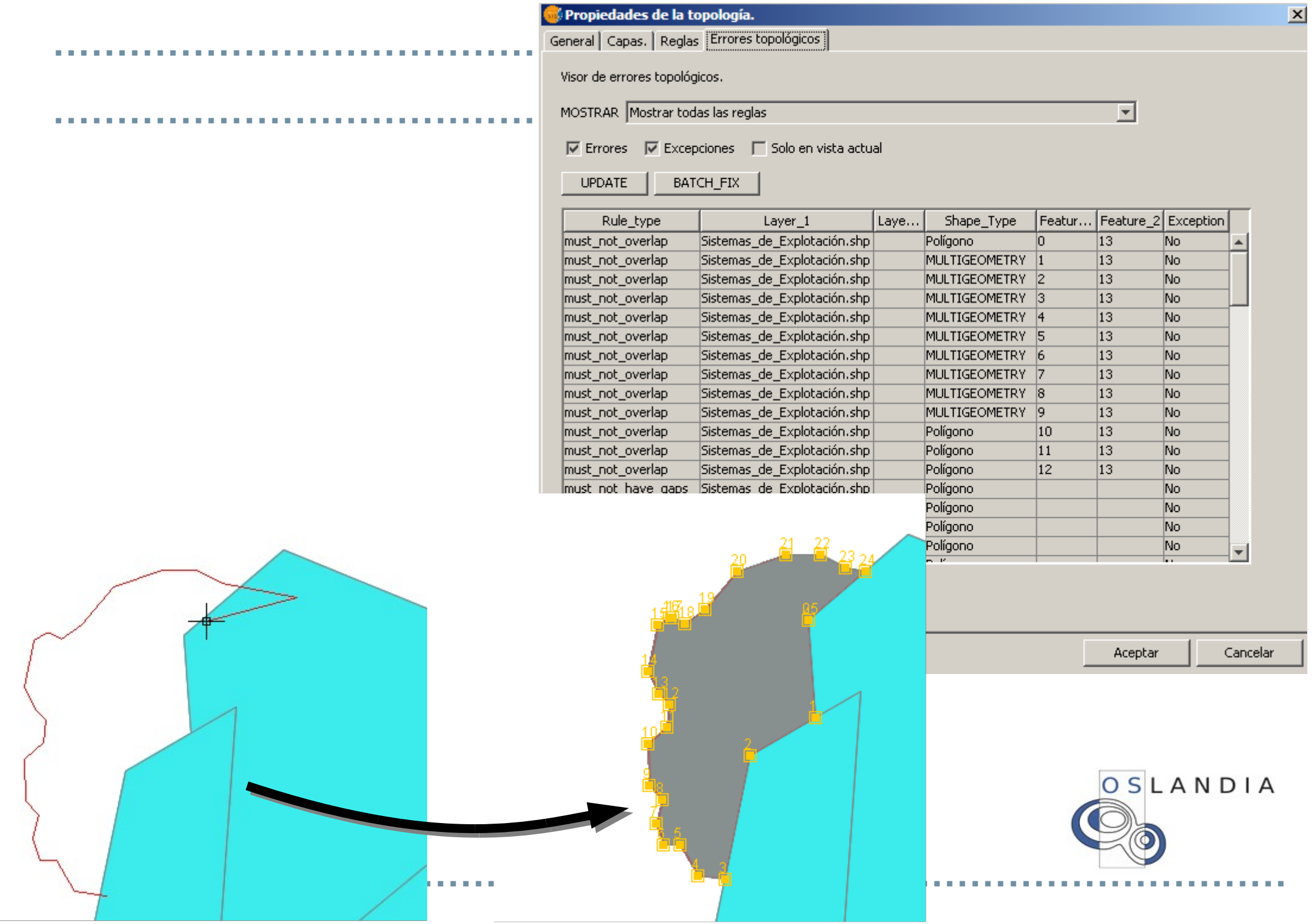

A
Sistemas_de_Explo
Default
PluginServices.Procesando
Verificando topología
Verificando reglapolygon_must_be_closed: 0 de 0
cancelar
Reglas de la topología.
Reglas.
Capas.
Reglas de la topología.
Primera capa que interviene en la regla
Infraestructuras_Hidráulicas.shp
Regla topológica.
Las líneas no pueden tener nodos colgantes
Segunda capa que interviene en la regla
Sistemas_de_Explotación.shp
Todo extremo de una linea debe tocar a otro extremo de línea o a sí mismo.
Aceptar
Cancelar
Añadir regla
Eliminar regla
Eliminar todas
< Anterior
Siguiente >
Fin
Cancelar
30°W
12°W
2.5
4.3
7.5
9.4
2.2
7.5
3.5


Propiedades de la topología.
General
Capas.
Reglas
Errores topológicos
Visor de errores topológicos.
MOSTRAR
Mostrar todas las reglas
Errores
Excepciones
Solo en vista actual
UPDATE
BATCH_FIX
Rule_type
Layer_1
Laye...
Shape_Type
Featur...
Feature_2
Exception
must_not_overlap Sistemas_de_Explotación.shp Polígono 0 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 1 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 2 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 3 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 4 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 5 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 6 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 7 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 8 13 No
must_not_overlap Sistemas_de_Explotación.shp MULTIGEOMETRY 9 13 No
must_not_overlap Sistemas_de_Explotación.shp Polígono 10 13 No
must_not_overlap Sistemas_de_Explotación.shp Polígono 11 13 No
must_not_overlap Sistemas_de_Explotación.shp Polígono 12 13 No
must_not_have_gaps Sistemas_de_Explotación.shp Polígono No
Polígono No
Polígono No
Polígono No
Aceptar
Cancelar
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GvSIG – Network extension

- Network Analysis
- Topology builder
  - Save / reload function (specific format)
- Interactive GUI for network management
- Algorithms
  - Shortest path
  - Connectivity
  - Minimal spanning tree
  - Origin/destination matrix
  - Finding providers for events
  - Service zone

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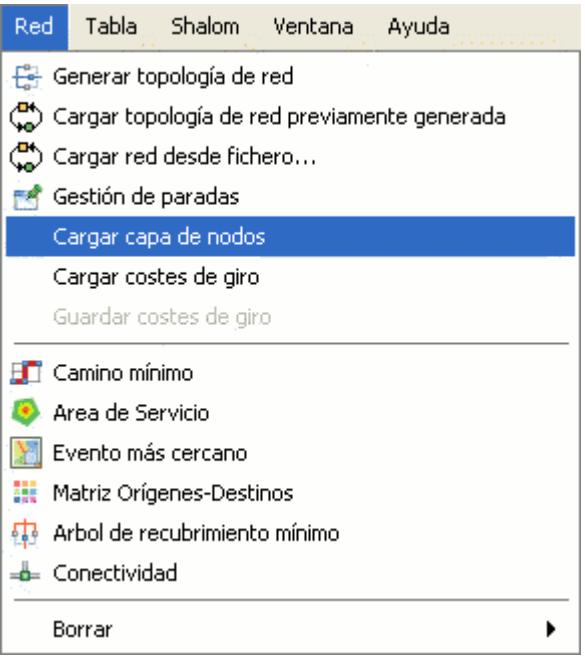
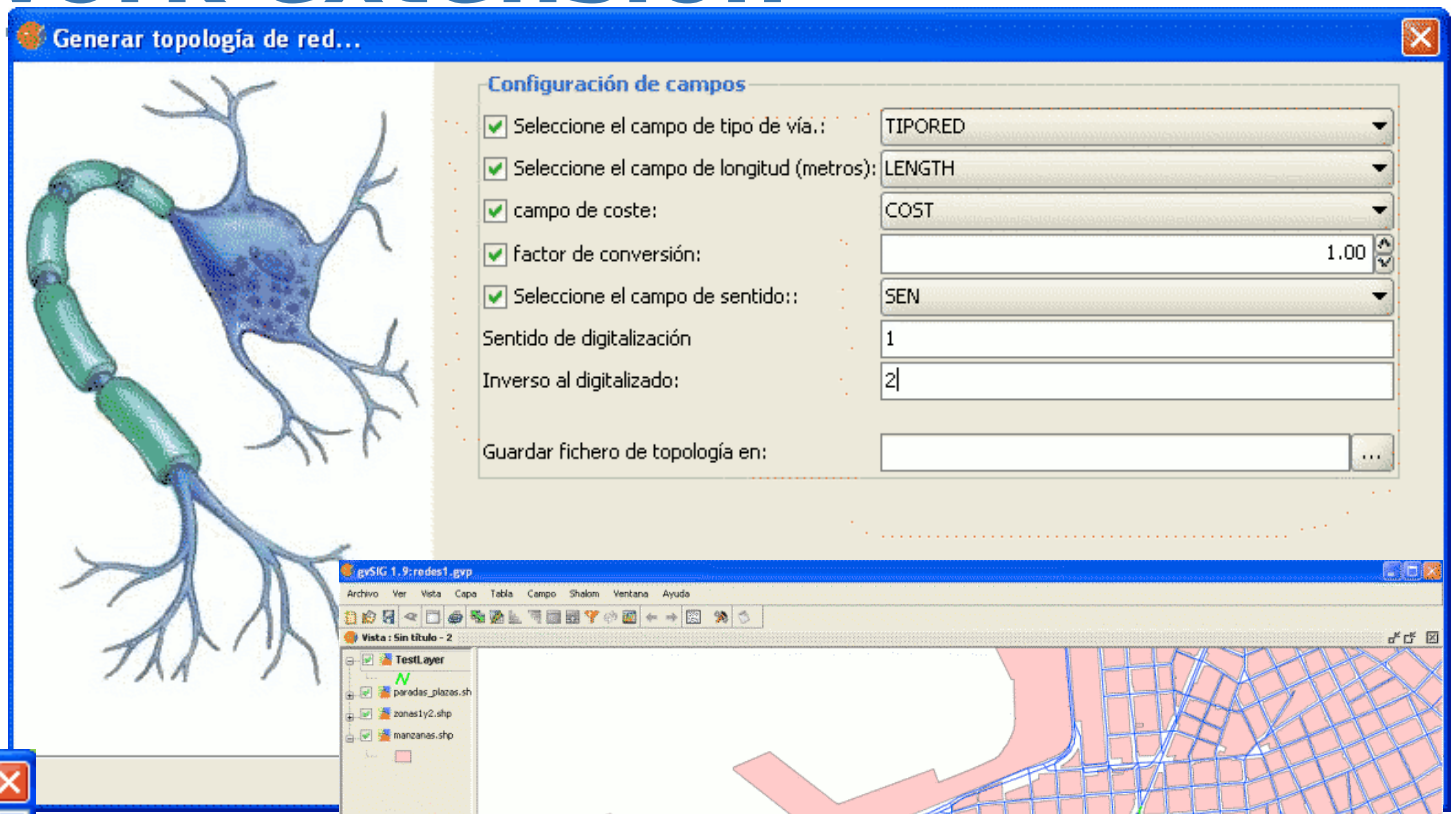
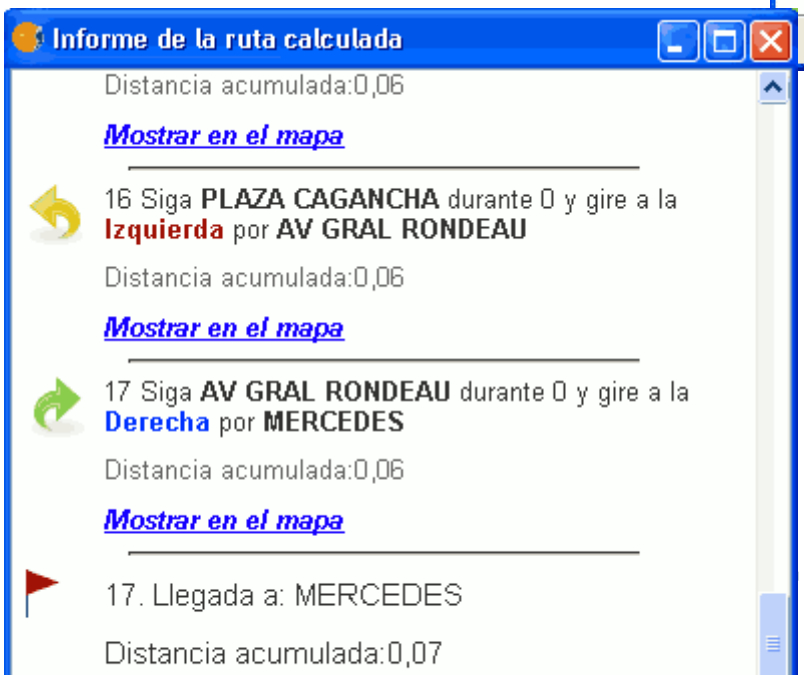
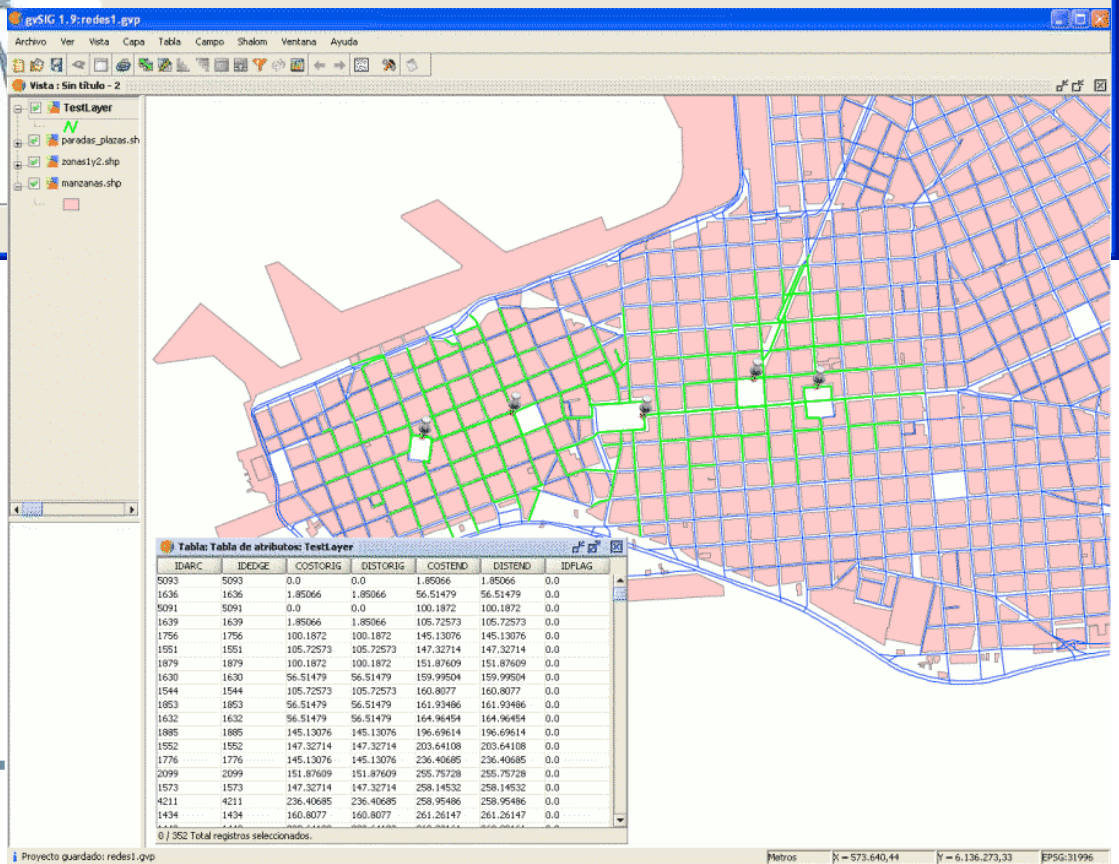
GvSIG – Network extension



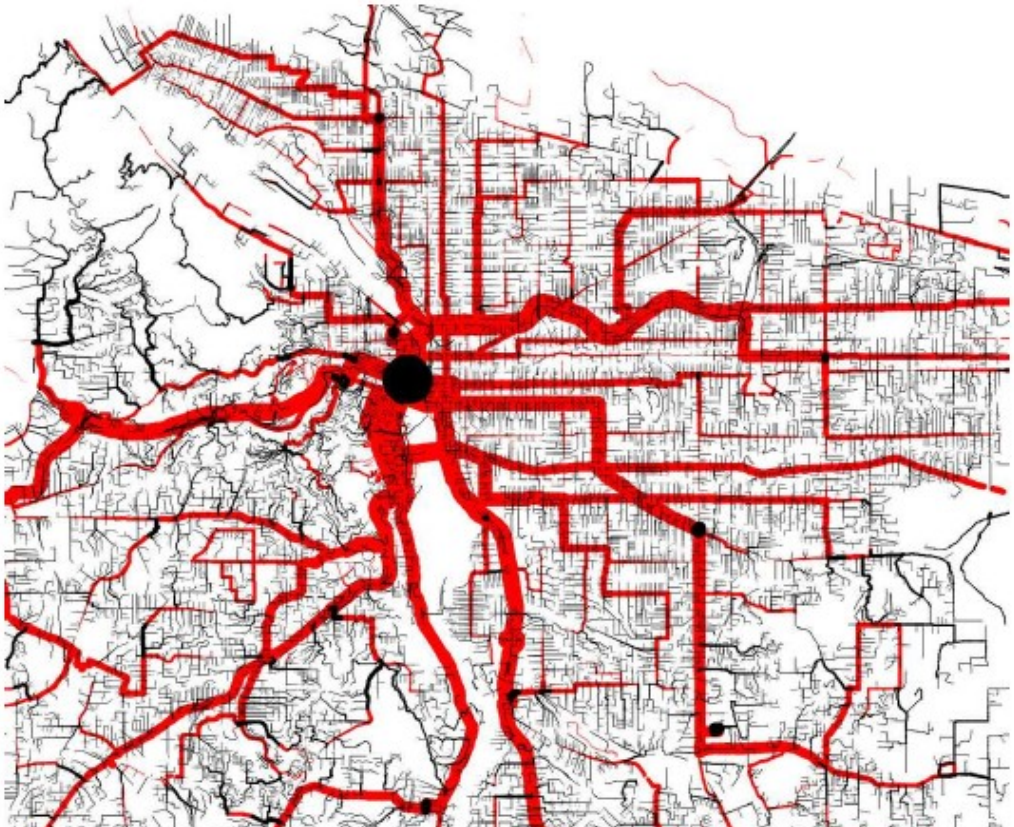






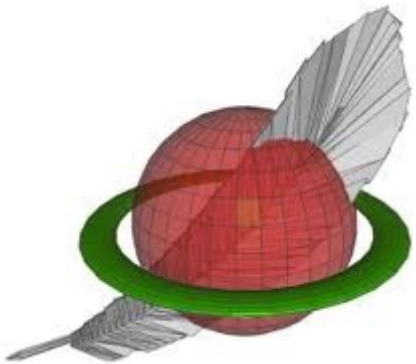
GraphServer

- Standalone routing server
- Algorithms
  - Shortest path (Fast Dijkstra implementation)
  - Driving distances
- Focus on multimodal and GTFS data integration
- OSM import tool
- HTTP interface
- Highly customizable
  - C core
  - Python library
  - Hooks to use as a framework
- Own SQLite data format
- Used in production (Trimet, MapQuest...)



Spatialite

- SQLite-based embedded spatial database framework
- Routing functionalities
- SQL interface
- Network building tools (with GUI)
- Query GUI
  - integrated with Spatialite GUI
- Algorithm
  - Shortest path (Dijkstra)



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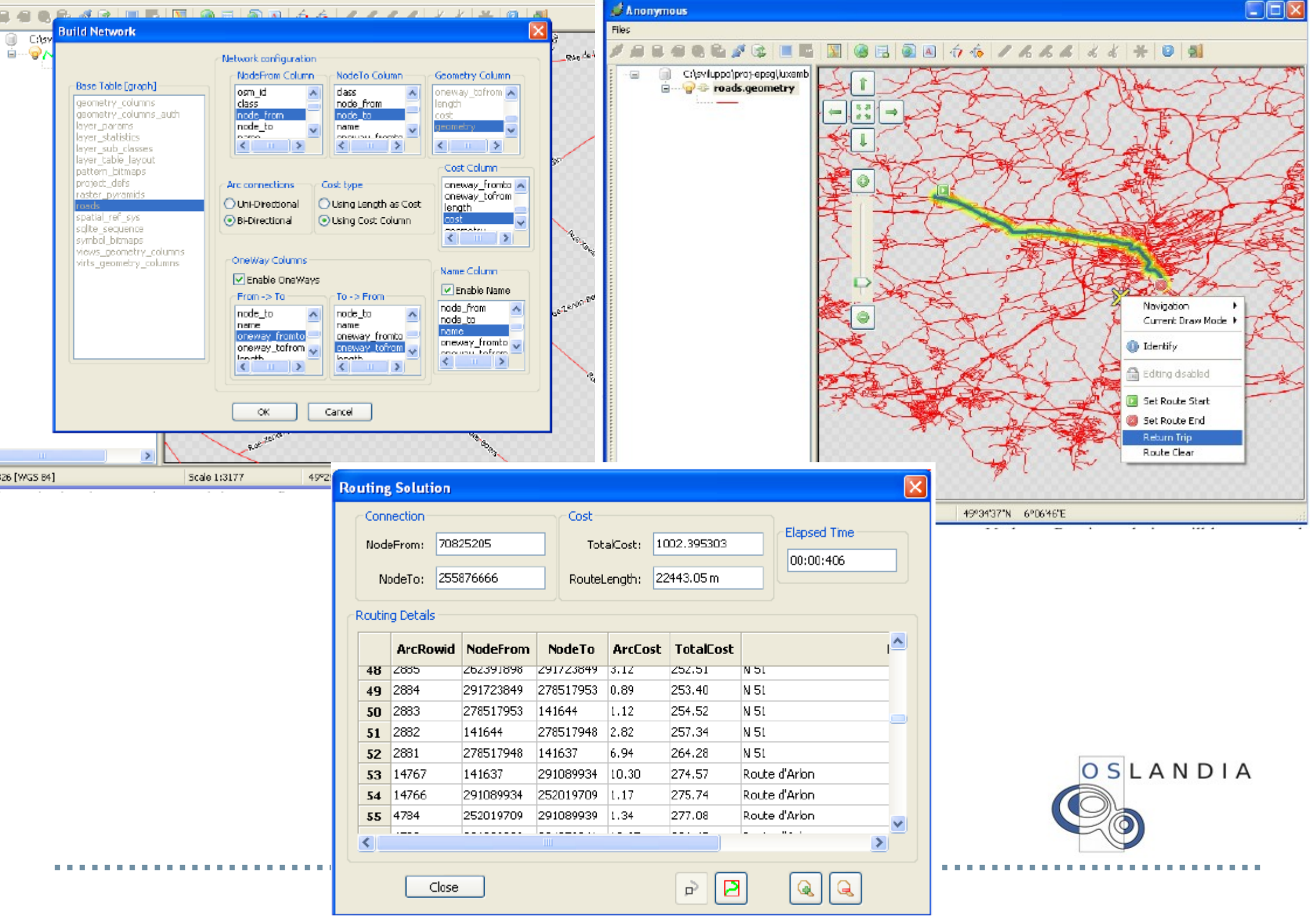
Build Network
Network configuration
NodeFrom Column
NodeTo Column
Geometry Column
Base Table [graph]
Arc connections
Uni-Directional
Bi-Directional
Cost type
Using Length as Cost
Using Cost Column
Cost Column
OneWay Columns
Enable OneWays
From -> To
To -> From
Name Column
Enable Name
OK
Cancel
Anonymous
Files
roads.geometry
Navigation
Current Draw Mode
Identify
Editing disabled
Set Route Start
Set Route End
Return Trip
Route Clear
Routing Solution
Connection
NodeFrom: 70825205
NodeTo: 255876666
Cost
TotalCost: 1002.395303
RouteLength: 22443.05 m
Elapsed Time
00:00:406
Routing Details
ArcRowid NodeFrom NodeTo ArcCost TotalCost
48 2885 262391898 291723849 3.12 252.51 N 51
49 2884 291723849 278517953 0.89 253.40 N 51
50 2883 278517953 141644 1.12 254.52 N 51
51 2882 141644 278517948 2.82 257.34 N 51
52 2881 278517948 141637 6.94 264.28 N 51
53 14767 141637 291089934 10.30 274.57 Route d'Arlon
54 14766 291089934 252019709 1.17 275.74 Route d'Arlon
55 4784 252019709 291089939 1.34 277.08 Route d'Arlon
Close
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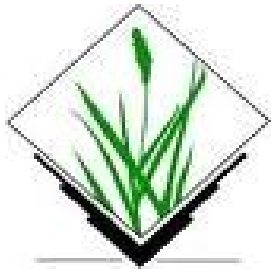
GRASS



- Native N-E-F topology
  - Built automatically
  - Supports digitizing
  - Cleaning module & network maintenance (v.clean, v.net)
- Graph & network analysis modules
  - Through DGLib (Directed Graph Library)
  - Algorithms
    - Shortest path *(v.net.path, d.path, v.net.timtable)*
    - TSP *(v.net.salesman)*
    - Resources allocation *(v.net.alloc)*
    - Minimum Steiner trees *(v.net.steiner)*
    - Iso-distances *(v.net.iso)*
    - Connectivity *(v.net.connectivity)*
- Grass GUI
- Scriptable

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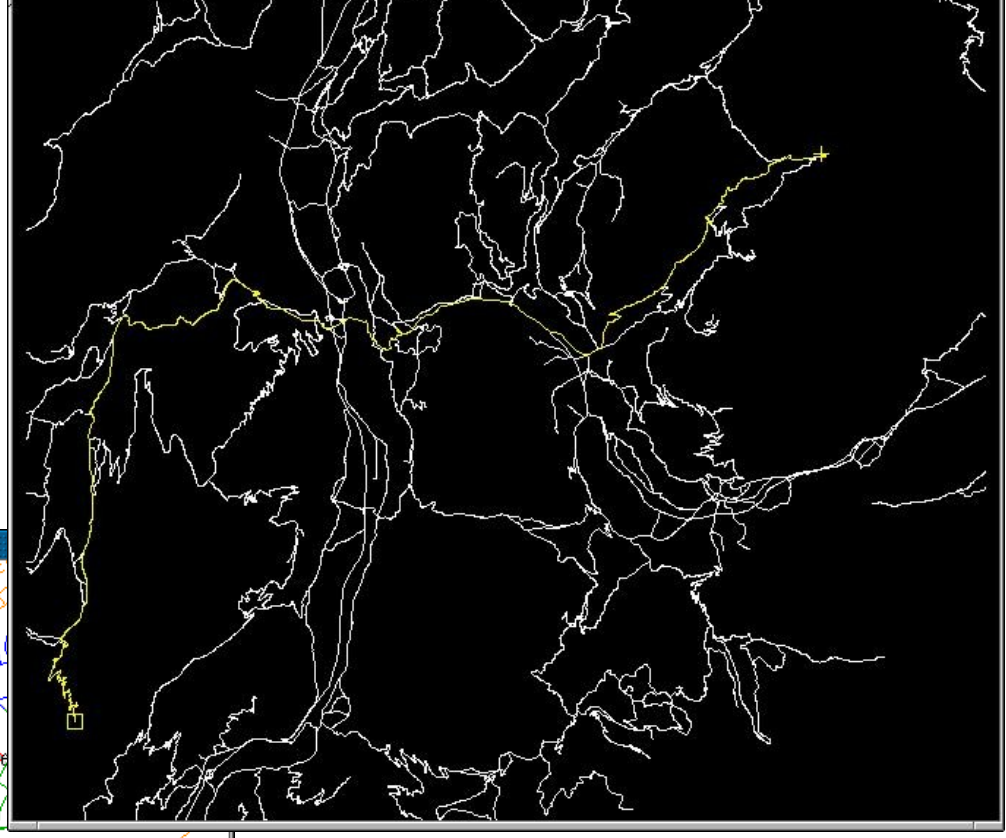
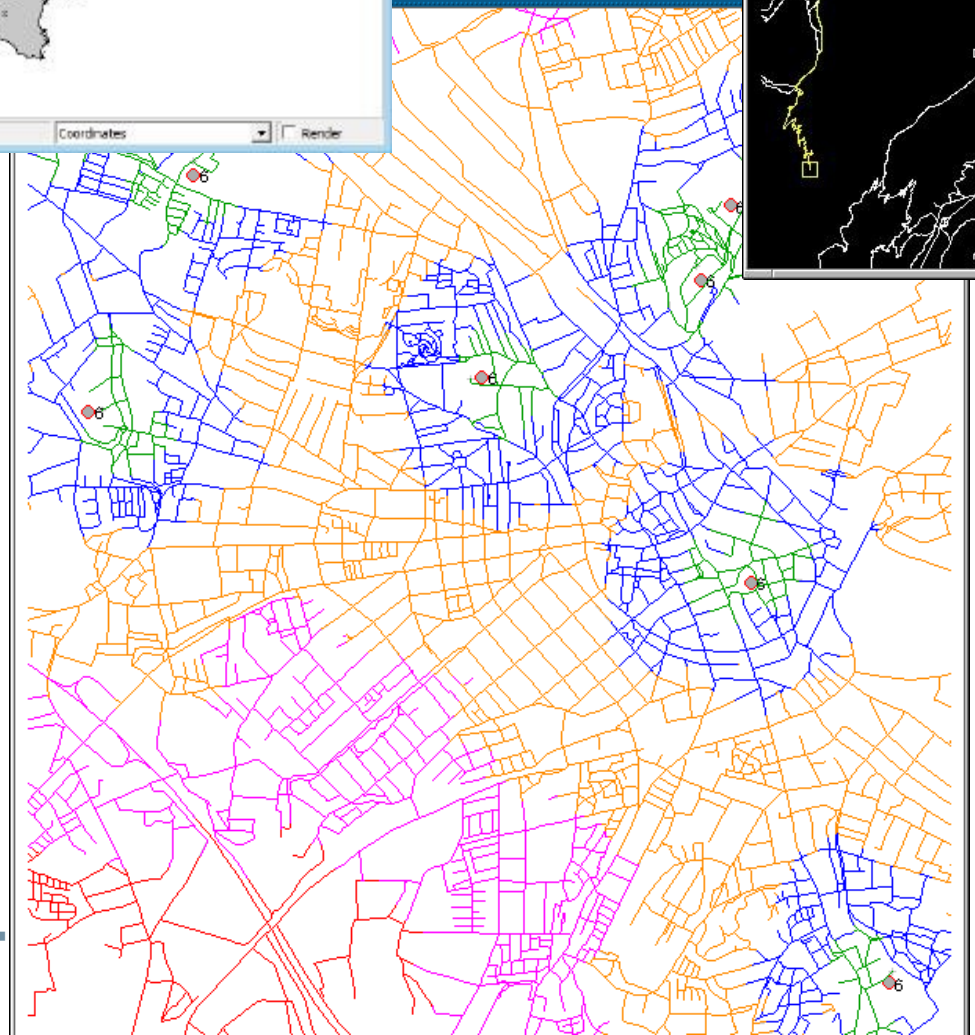
GRASS GIS Map Display: 1 - Location: WGS84-UTM32N
Digitize
596473.44, 3953040.93
Coordinates
Render





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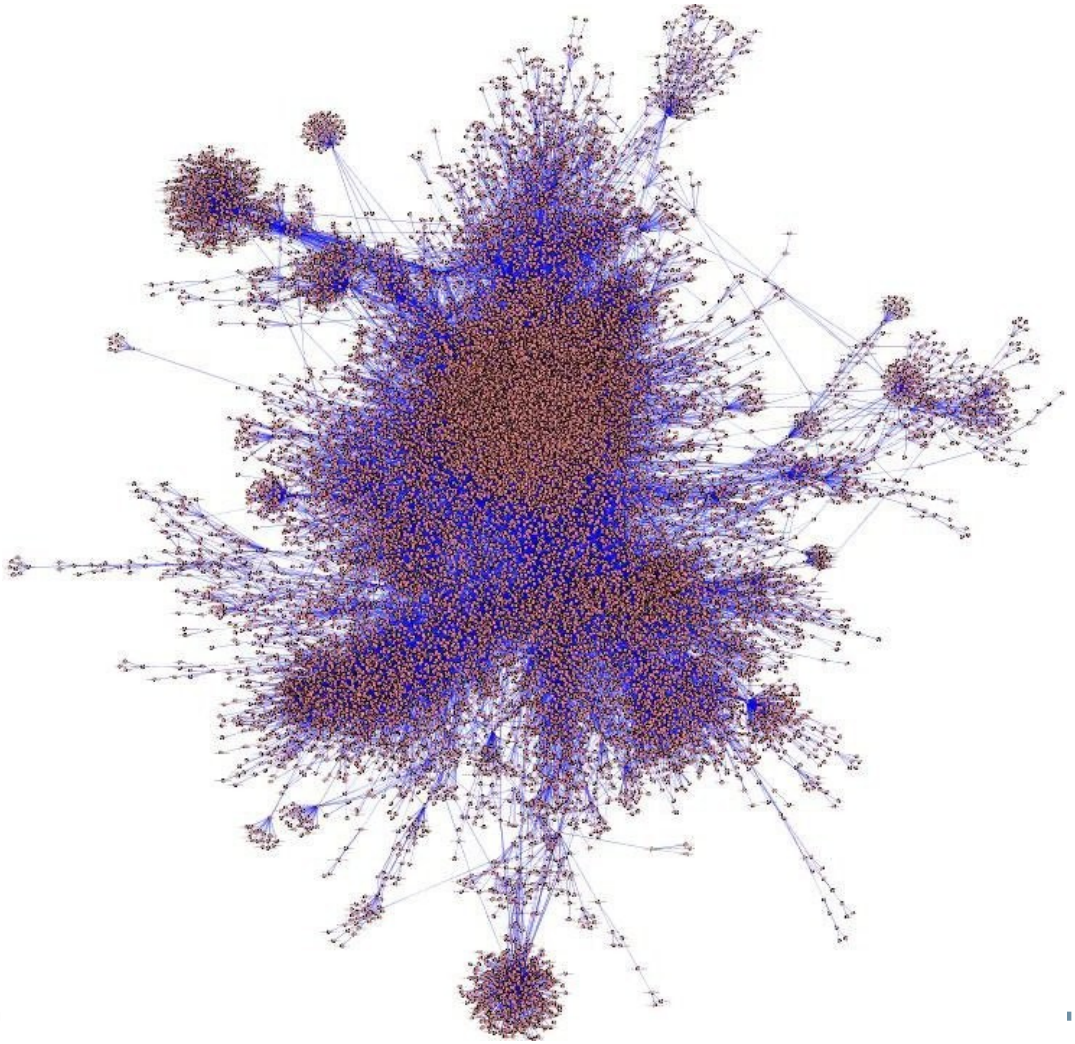
Frameworks

- Boost Graph Library
- Parallel Boost Graph Library
- R - igraph

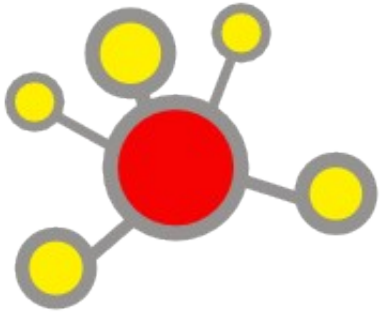


BGL & PBGL

- Boost Graph Library
  - «standard» C++ library
  - High quality & highly customizable
  - Efficient algorithms
- Implements
  - Shortest Path (Dijkstra, Bellman-Ford, Johnson)
  - Minimum Spanning Tree (Kruskal, Prims)
  - Connected components (& strongly & dynamic)
  - Sorting & ordering
  - Colouring
  - Transpose
- Parallel BGL
  - Distributed storage and algorithms
  - Research platform

R - igraph

- Statistics framework
- *igraph* : simple graphs and network analysis
- Graph generation
- Graph manipulation
- Visualization
- Algorithms
  - Shortest path
  - Minimum Spanning Tree
  - Connectivity
  - Structural properties
  - ...



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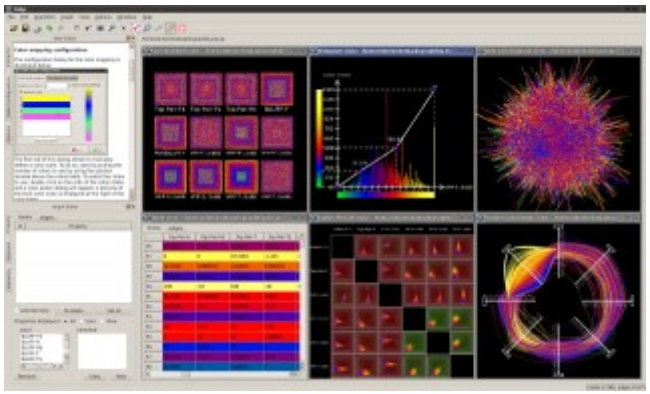
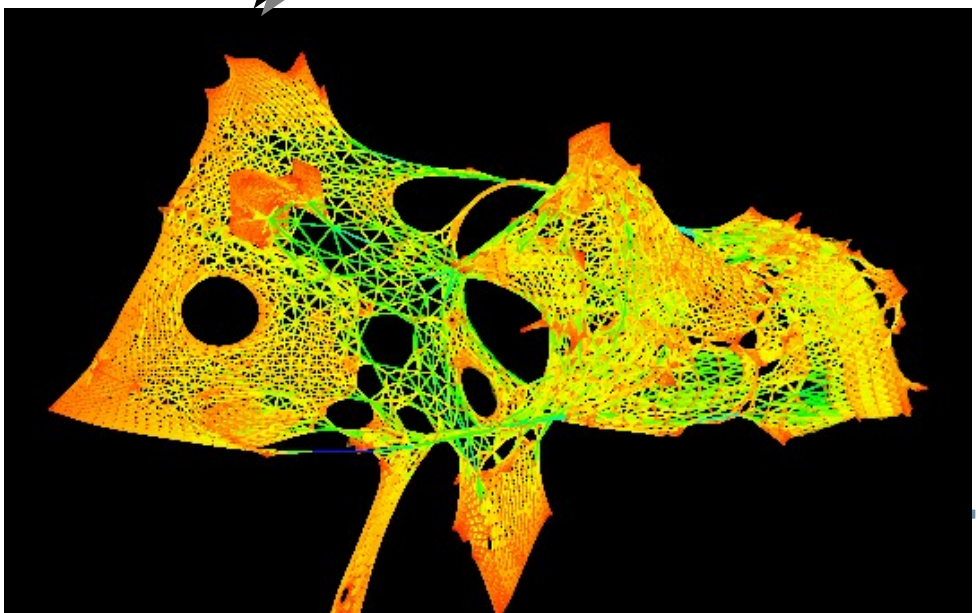
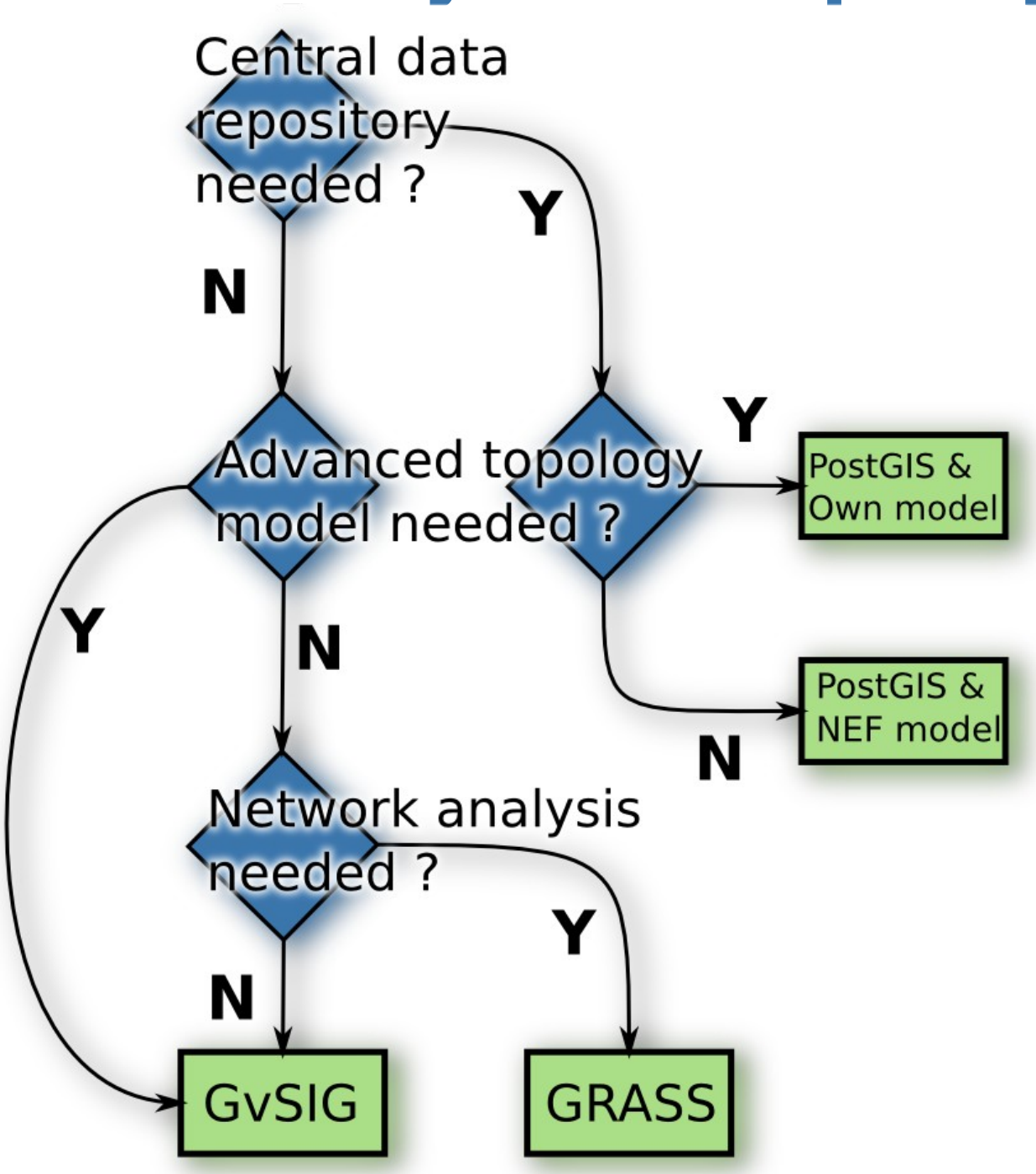
Visualization softwares

- Graph visualization is a problem on its own
- Lots of R&D efforts in this field
- Some OpenSource tools :
  - Tulip
  - Processing
  - Graphviz





What's best for you – Topology ?



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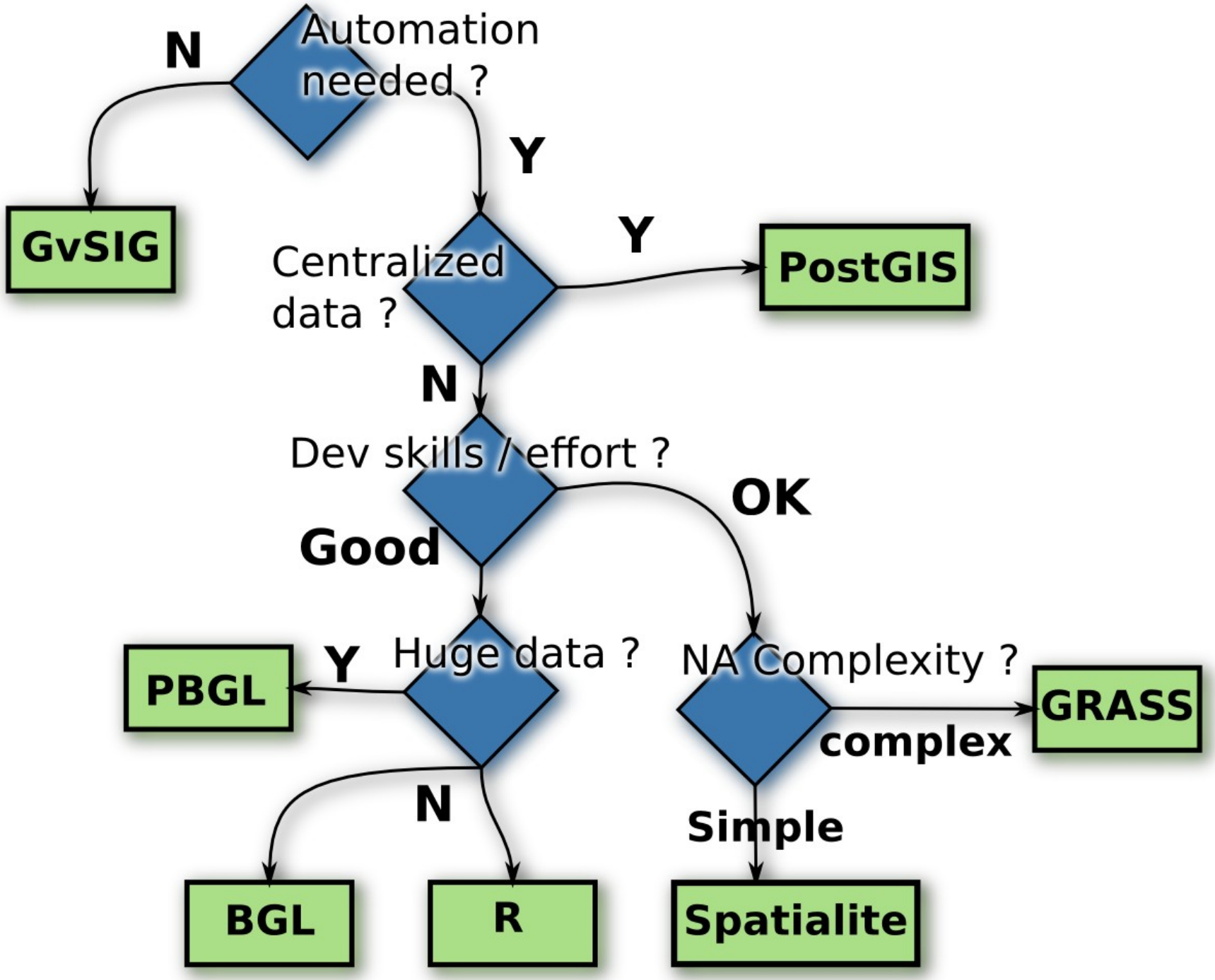
What's best for you — Network Analysis



Perspectives and issues

- Huge volumes
  - Global earth transportation network
  - Multimodal
  - Time dimension
- Parallel processing
- Live data
  - Near-realtime updates
- Interoperability
  - Conversion tool
  - Smooth integration between GIS and large network analysis tools

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That's all folks !

Want to know more ?
Ask now or write to :

Vincent Picavet
vincent.picavet@oslandia.com

www.oslandia.com