UNIVERSITÉ DE TECHNOLOGIE DE BELFORT-MONTBÉLIARD

MetroB: Evaluation and Simulation of Public Transportation System in Small- and Middle-size Towns

Software Design and Bus Network Indicators

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Problems

- Tools for public transportation design and simulation have several drawbacks on the:
  - **accessibility**: require dedicated competencies
  - **efficiency**: long and difficult to create bus network models
  - **visibility**: difficult to understand results provided by existing tools without experts
  - **scalability:** designed for large towns, not for small- and middle-size towns

- MetroB provides functionalities and tools to solve these problems

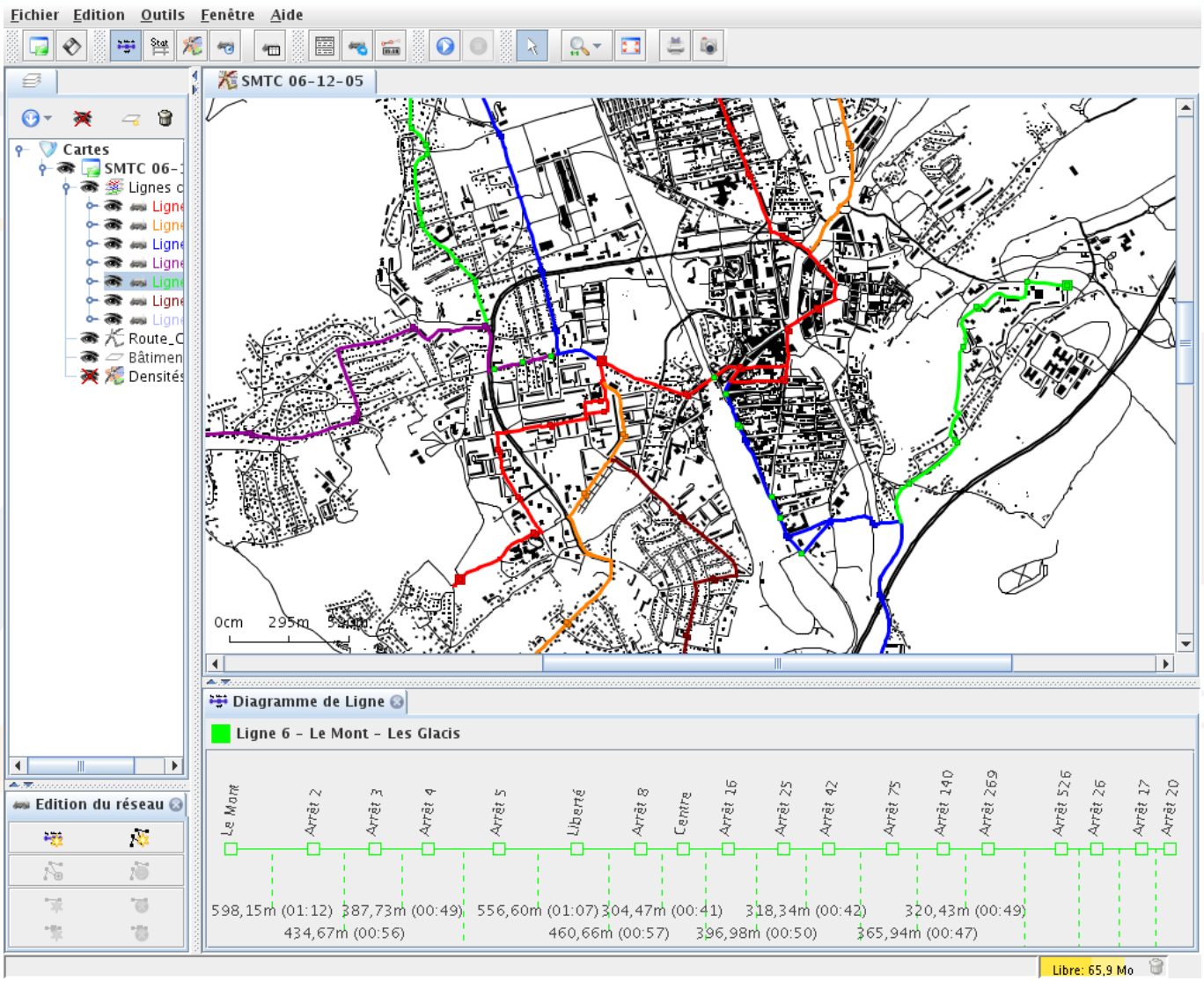
GIS Functionnalities

- **MetroB is able to :**
  - import data collection from Geographical Information Systems (Shape files)
  - import and display geo-TIFF pictures
  - draw several GIS data inside projects and layers (roads, buildings...)
  - export into common GIS formats and picture formats
  - edit GIS object's attributes (name, vehicle capacity...)

Bus Network Functionnalities

- **MetroB provides user-friendly tools to graphically edit bus networks**
  - one click to add or remove a road segment from a bus itinerary
  - one click to add or remove bus stops
  - bus itinerary overview with a line diagram
  - automatic creation of the exchange stations between several bus itineraries

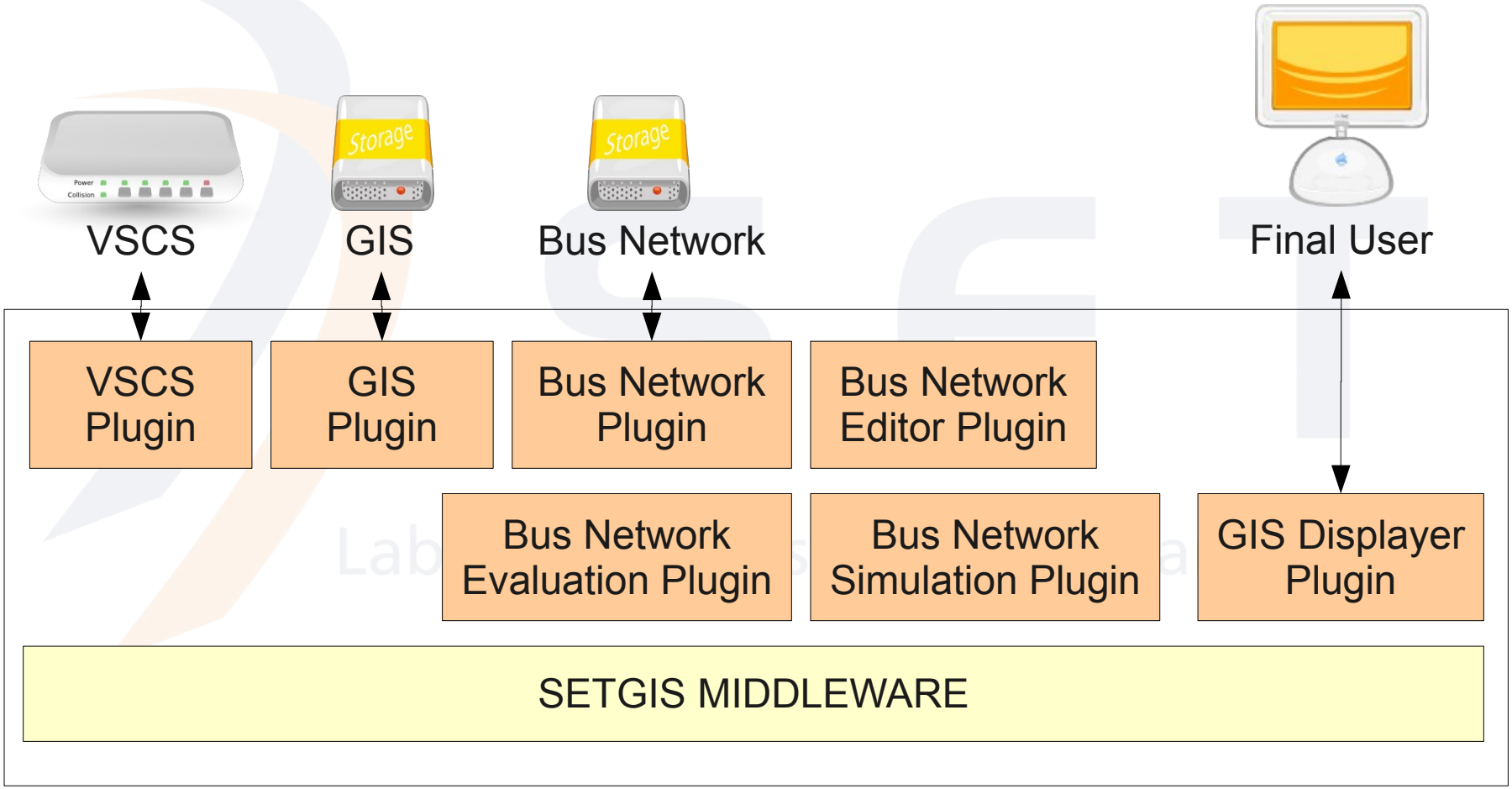
MetroB Screenshot



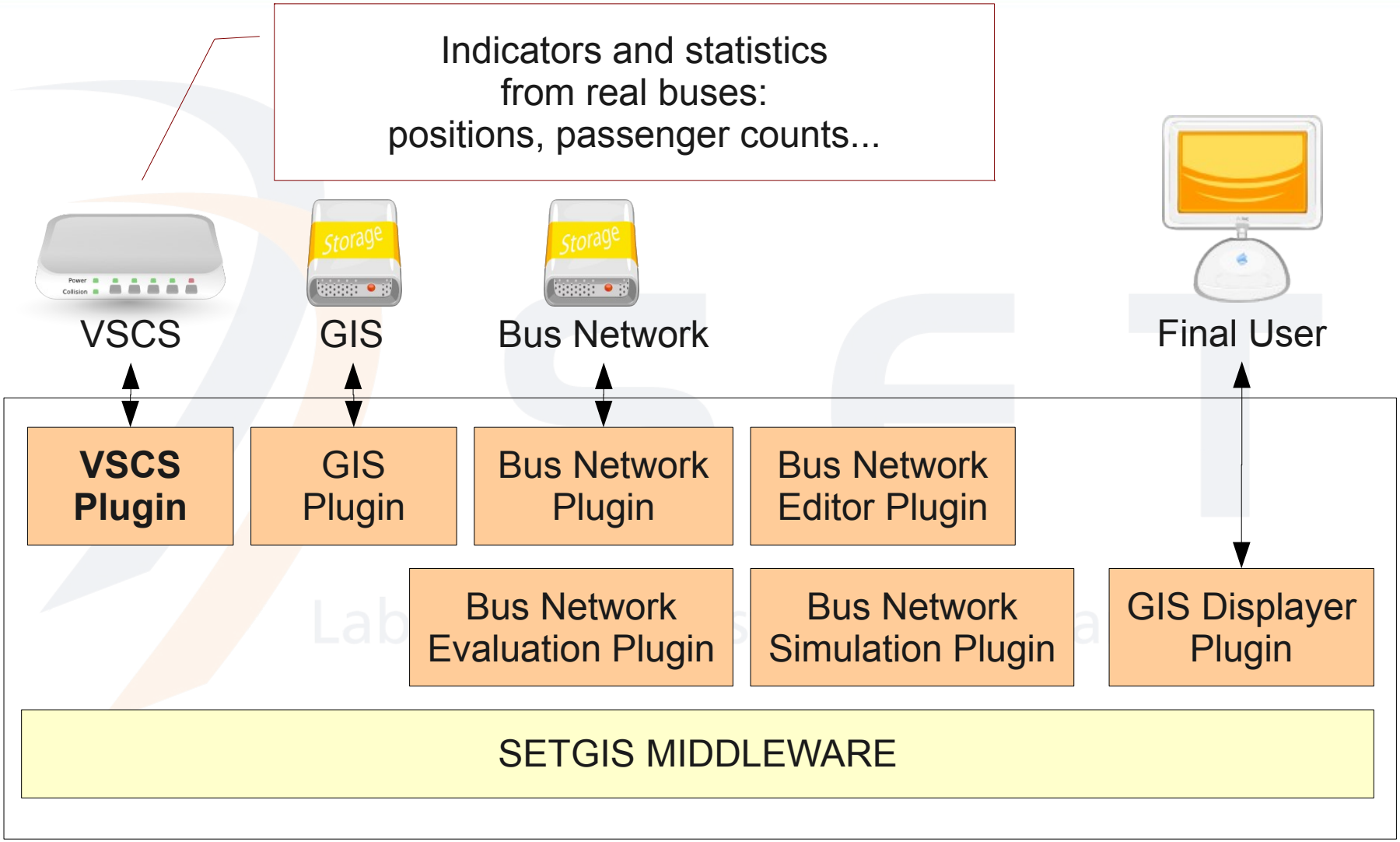
Types of Indicators

- **Static Indicators (static computation):**
  - average speeds and times per itinerary and for the entire network
  - bus network cover indicators based on the population density, cover circles or several attractors (schools...)
- **Dynamic Indicators (simulation):**
  - Distance with pre-defined bus operating schedules
  - Road network bottlenecks and slow-down
  - Blocking bus stops (according to bus users)

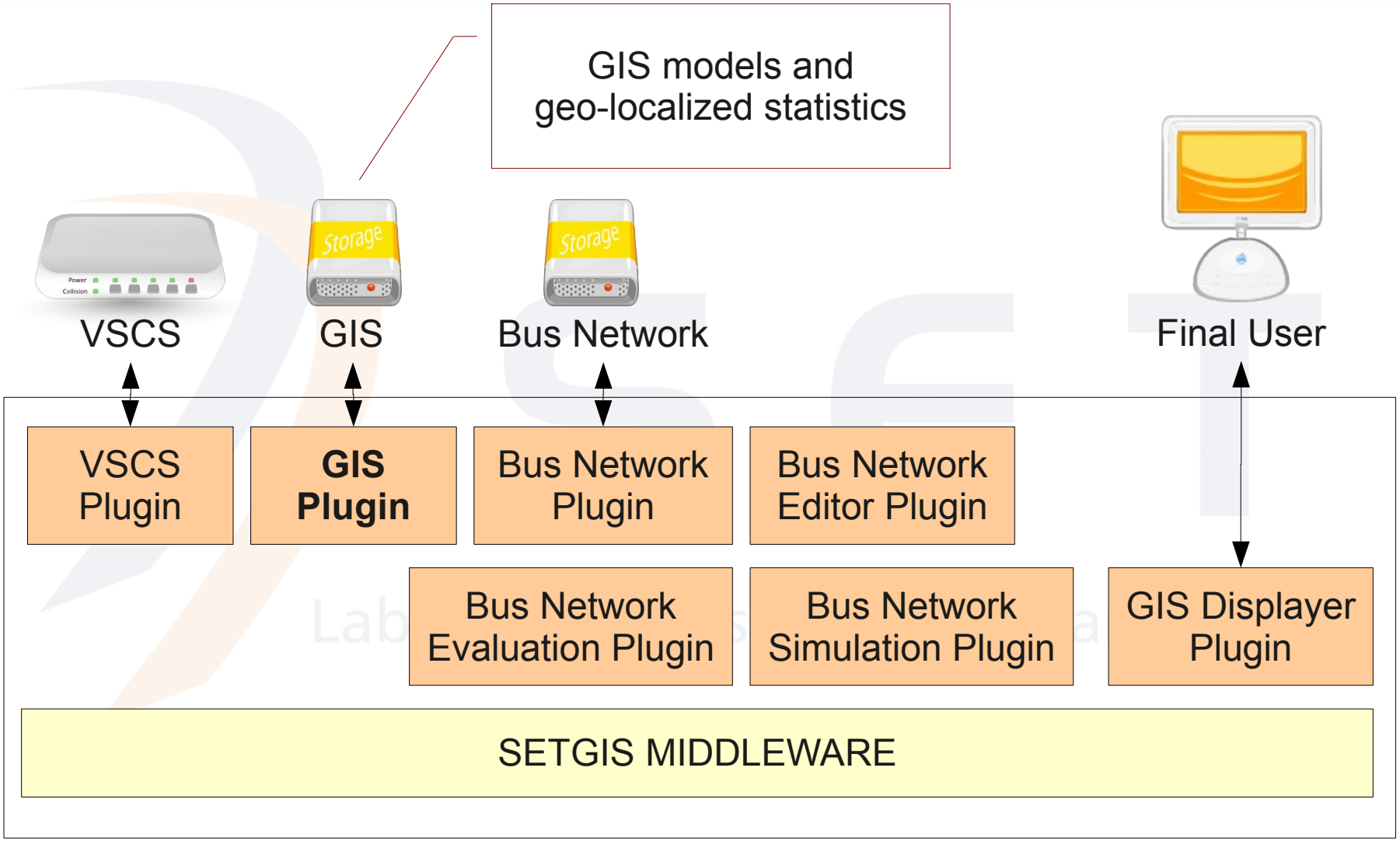
Global Architecture



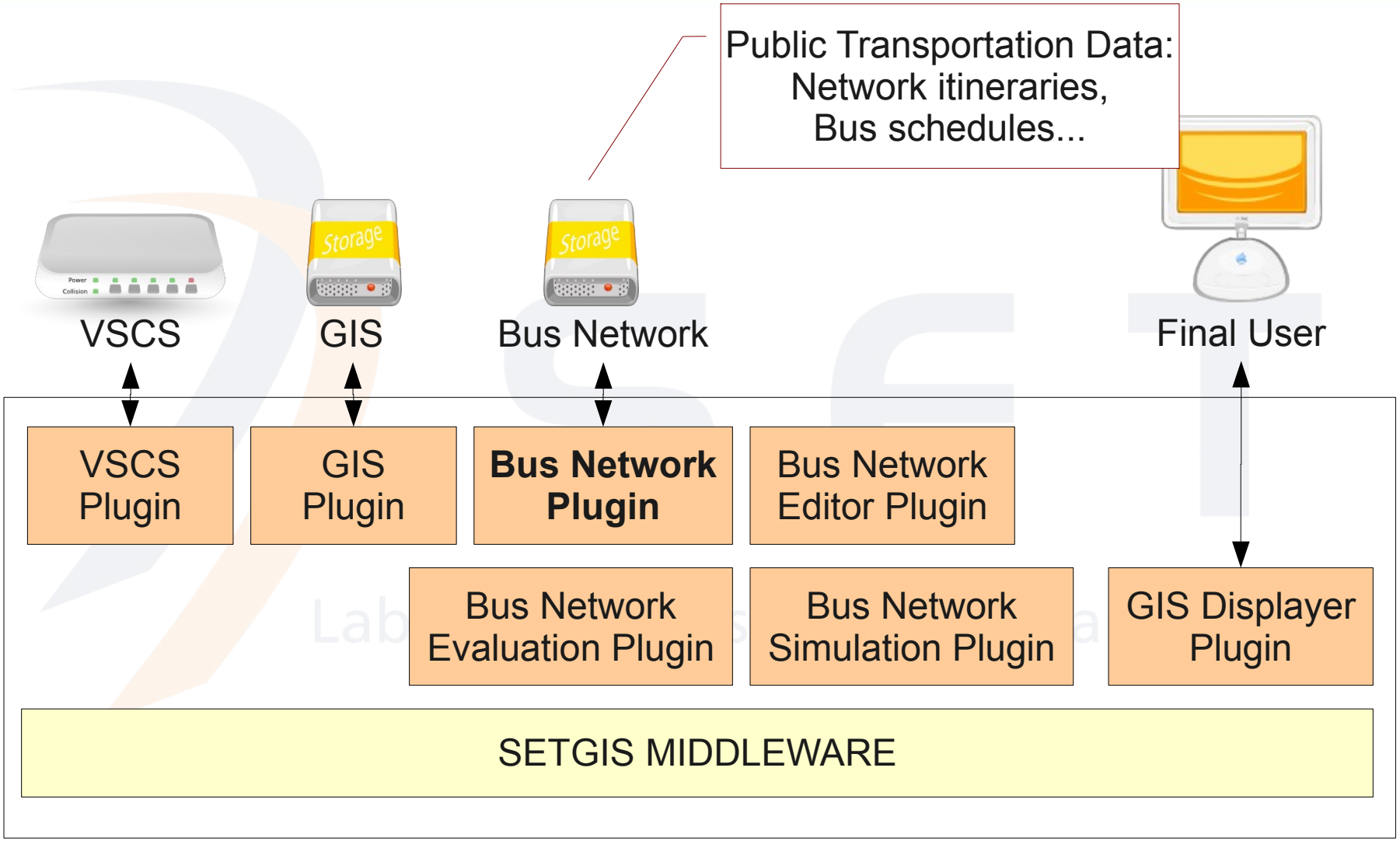
Global Architecture



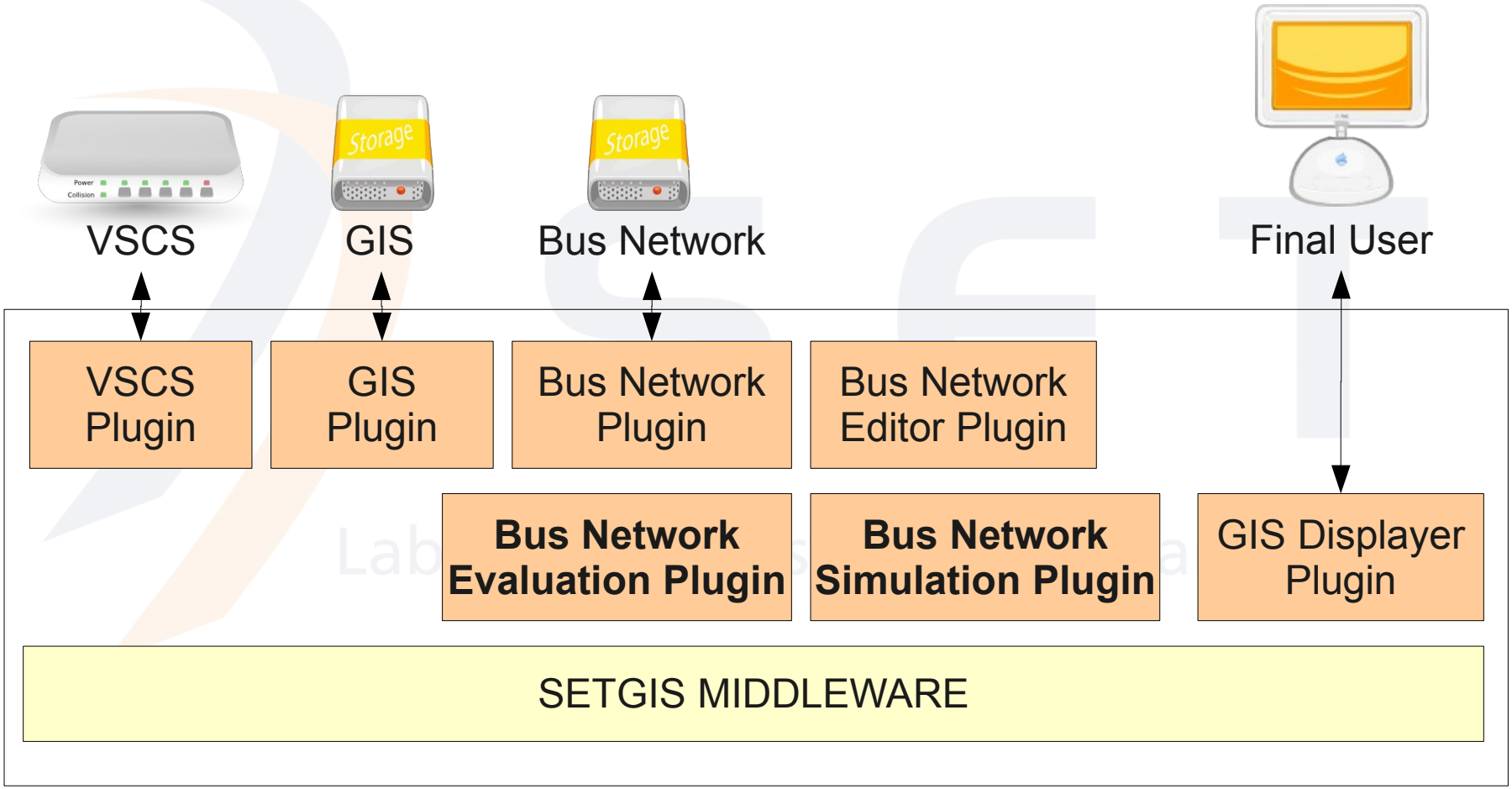
Global Architecture



Global Architecture



Global Architecture



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GIS-inspirated Data Model

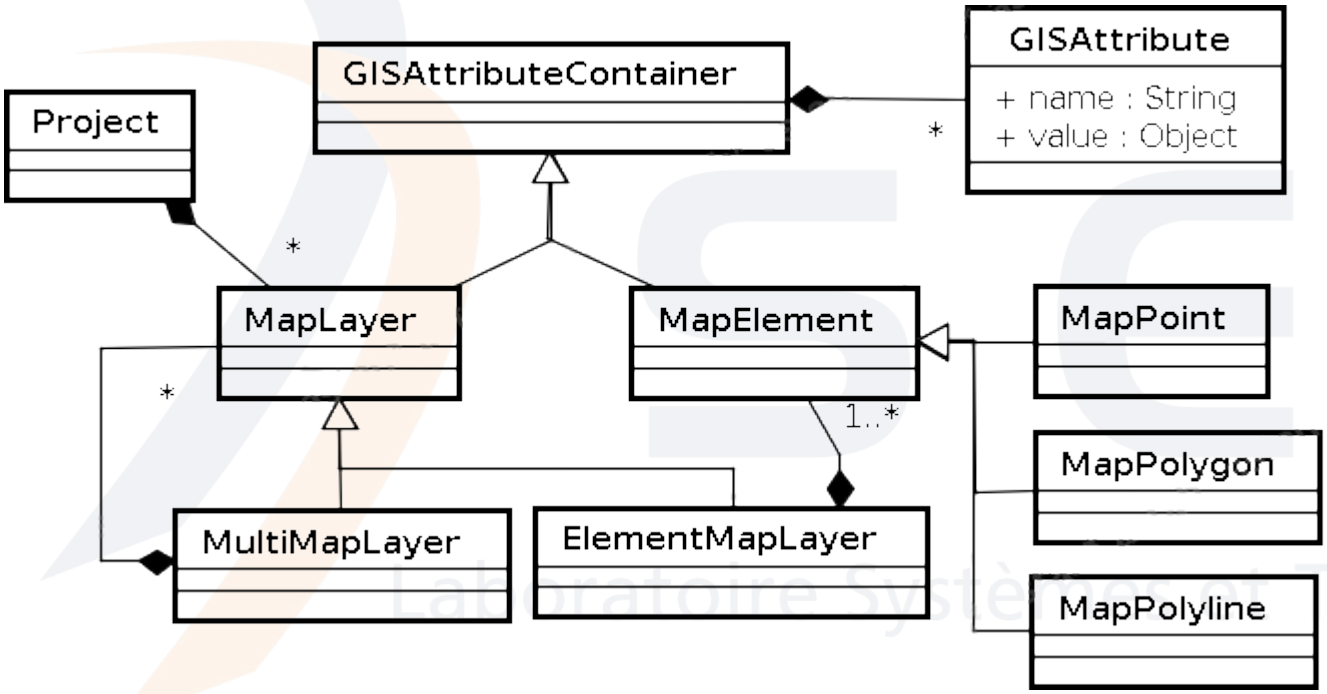
- GIS are commonly organized in map layers
- Each map layer contains a type of data:

  roads, public buildings, schools,

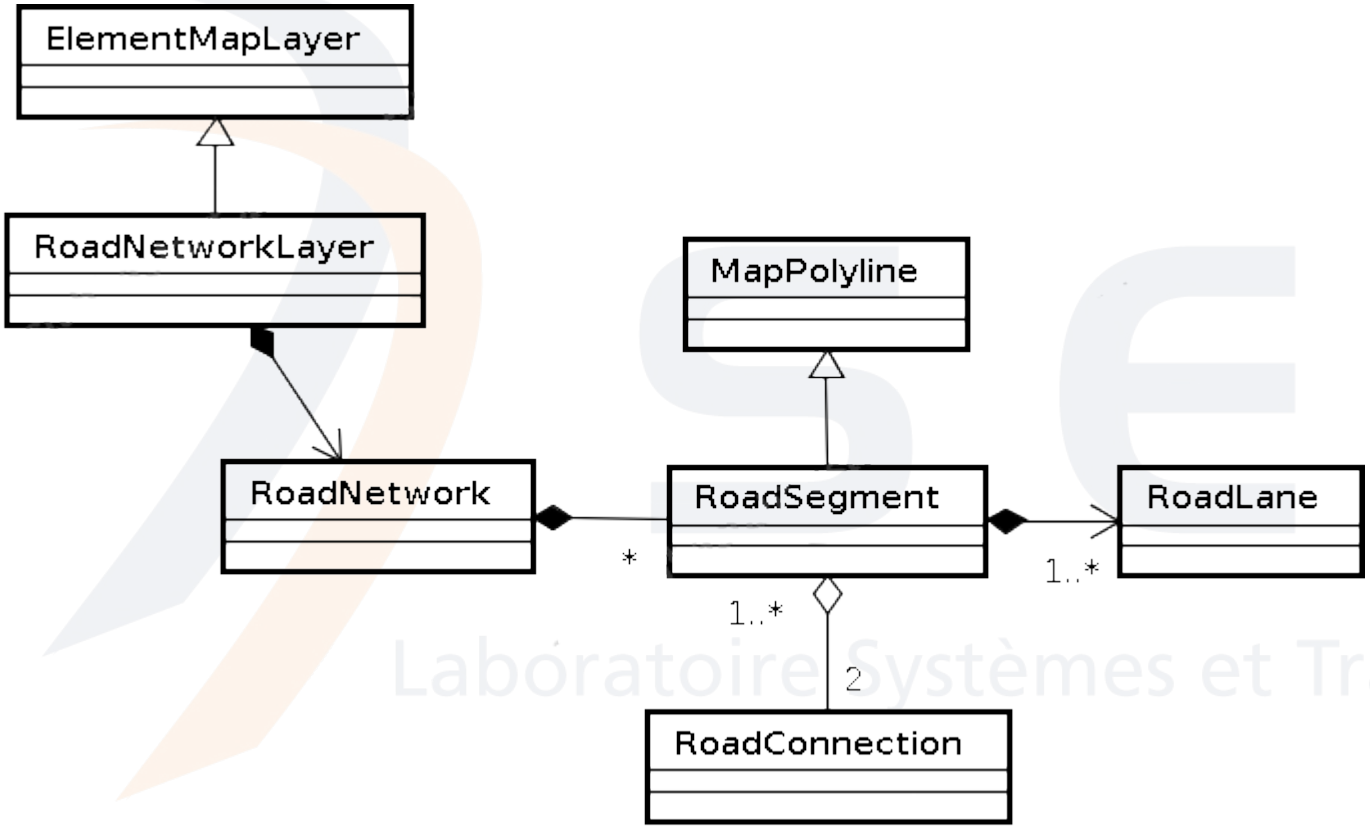
  population density areas...

- Each data is represented by a geo-localized shape: the map element
- Map elements may be lines, polygons, points...

Class Diagram for GIS primitives

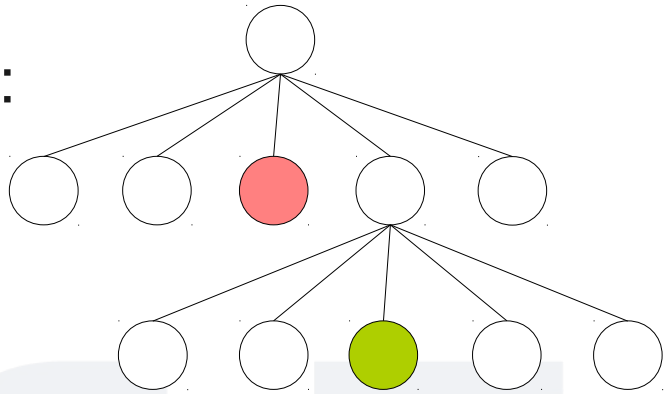


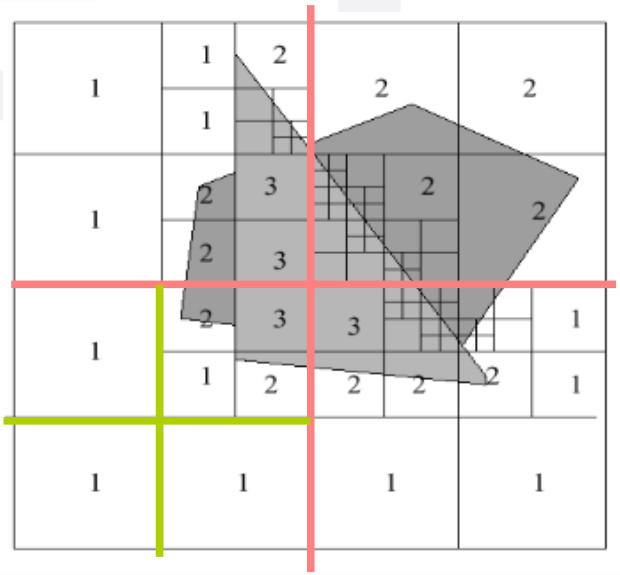
Class Diagram for Road Network



Spatial Tree for Road Network

- Roads are stored inside a spatial tree:
  - QuadTree with icosep heuristic
- Node: portion of space
- Roads are inside leaf nodes
- Upper nodes are divided into 4 sub-spaces
- Additional child for roads intersecting cutting lines

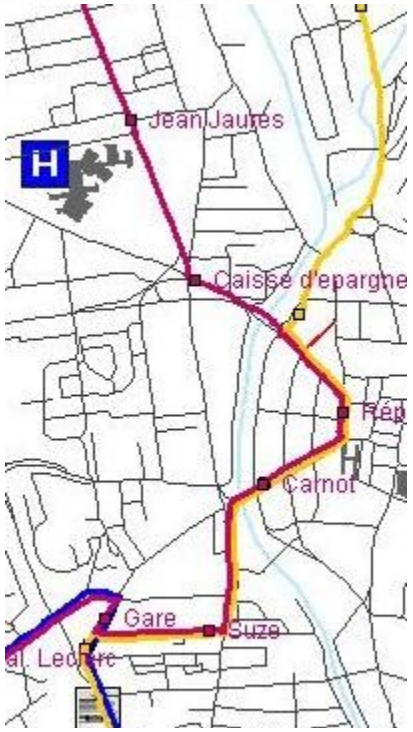




- **Speed up operations:**
  - O(n) to O(log n)

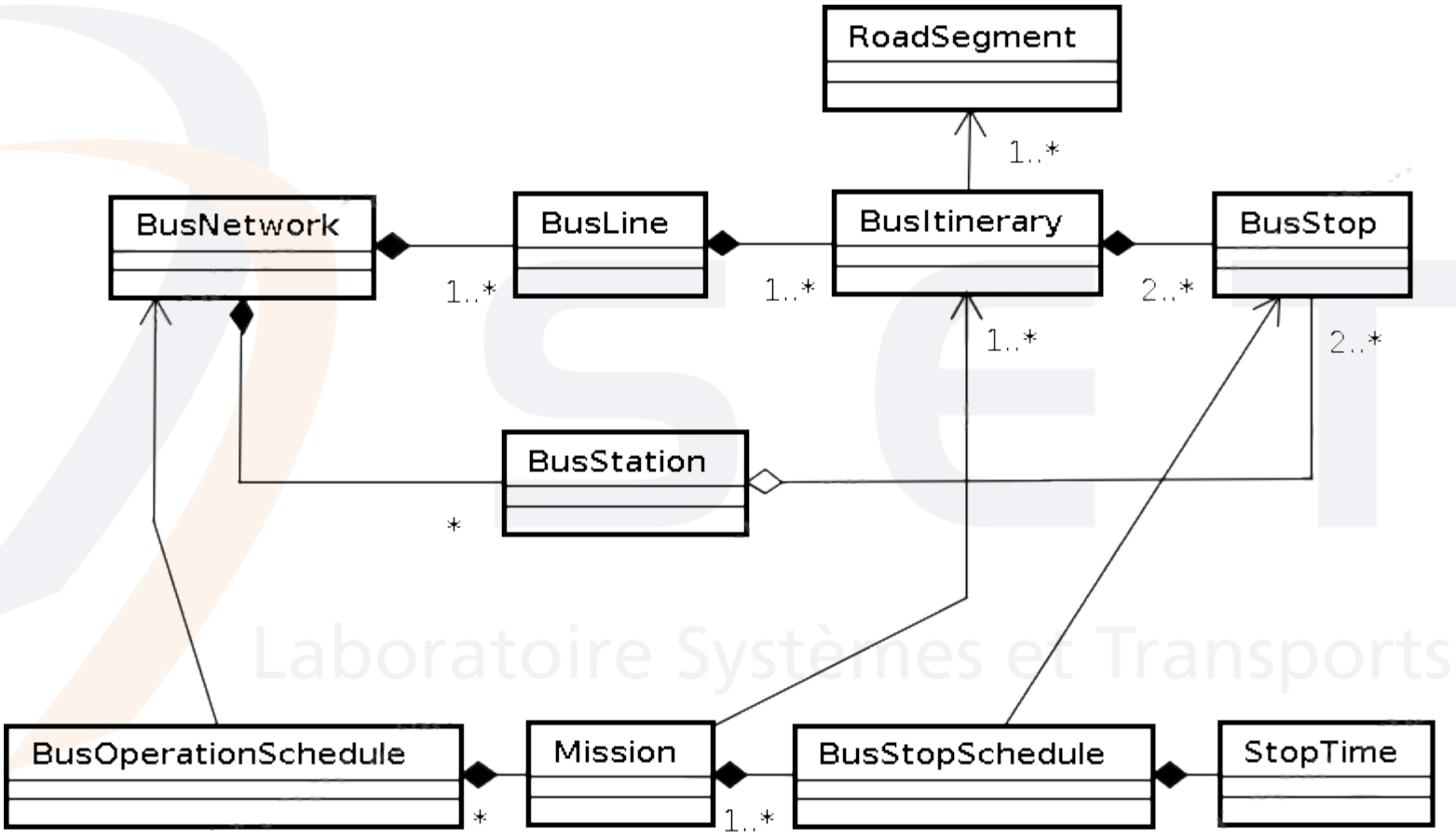
Bus Network Concepts

- **Bus stop**: a geo-localized point at which buses may stop.
- **Bus Itinerary**: an undirectional path along which bus is going, and containing an list of bus stops.
- **Bus Line**: a collection of bus itineraries with same name.
- **Bus Network**: a collection of bus lines.
- **Bus Station:** an exchange point, composed of at least two near bus stops.
- **Bus Operating Schedule**: set of itineraries with times for each bus stop.



Valdoie Mairie	05:58	06:18
Salbert	06:00	06:20
1re armée	06:01	06:21
Marché Vosges	06:03	06:23
Colmar	06:04	06:24
Strasbourg	06:05	06:25
Jaurès Hôpital	06:06	06:26
Caisse d'Épargne	06:08	06:28
République	06:10	06:30
Corbis	06:11	06:31
Fg de France	06:13	06:33
Liberté Madrid	06:16	06:36

Bus Network Class Diagram



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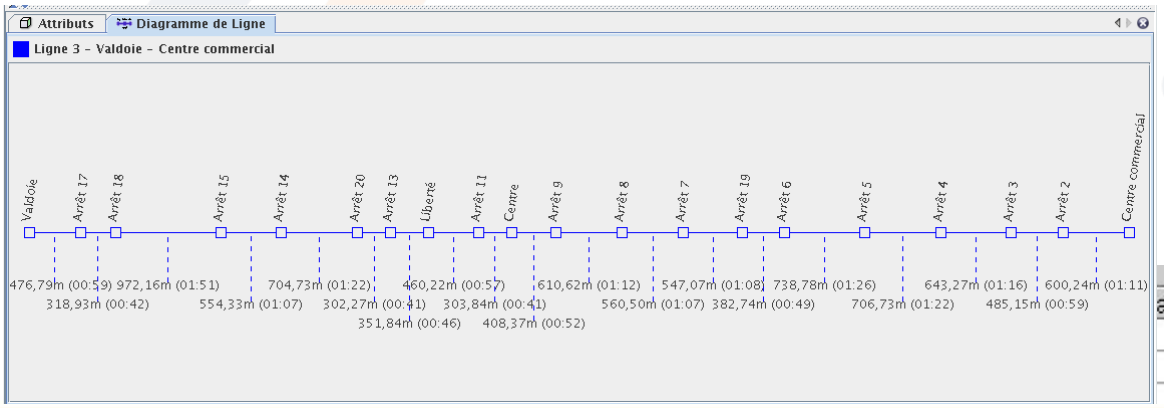
Static Temporal and Spatial Evaluation

- Troneon sizes (distance and time between bus stops)
- Time to follow itineraries with standard cruising speed for buses
  - with waiting at each bus stop
  - without waiting at each bus stop.
- Min, max, average speeds of buses on each troneon



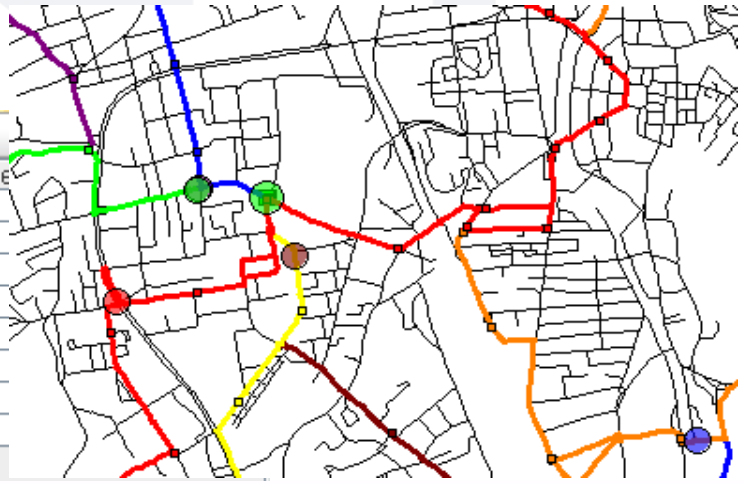
arrêts	Durée sans arrêts	Durée avec arrêts	Vitesse moyenne
	00:17:31	00:25:34	16.4 km/h
	00:23:23	00:33:39	16.6 km/h
	00:21:47	00:31:04	16.8 km/h

Evaluation of the Bus Fleet Size

- Compute the number of buses required to respect constraints:
  - a predefined bus frequency at bus stops (10mn)
  - an given average waiting time for pedestrians at bus stations (5mn)
- Bus operation schedules or average speed may be both used

Paramètres de l'animation

Ligne	Pôle	Fréquence (min.)	Vitesse (km/h)	Nombre bus	Tempo (se
Ligne 8 - Bria...	Briand	1	34.99200000...	1	0
Ligne 7 - Libe...	Arrêt 6	1	34.99200000...	1	0
Ligne 6 - Libe...	Liberté	1	34.99200000...	1	0
Ligne 5 - Bavil...	Bavilliers	1	34.99200000...	1	0
ligne4 - Libert...	Liberté	1	34.99200000...	1	0
Ligne 3 - Vald...	Valdoie	1	34.99200000...	1	0
Ligne 2 - Glaci...	Glacis	1	34.99200000...	1	0
Ligne 1 - Vald...	Valdoie	1	34.99200000...	1	0

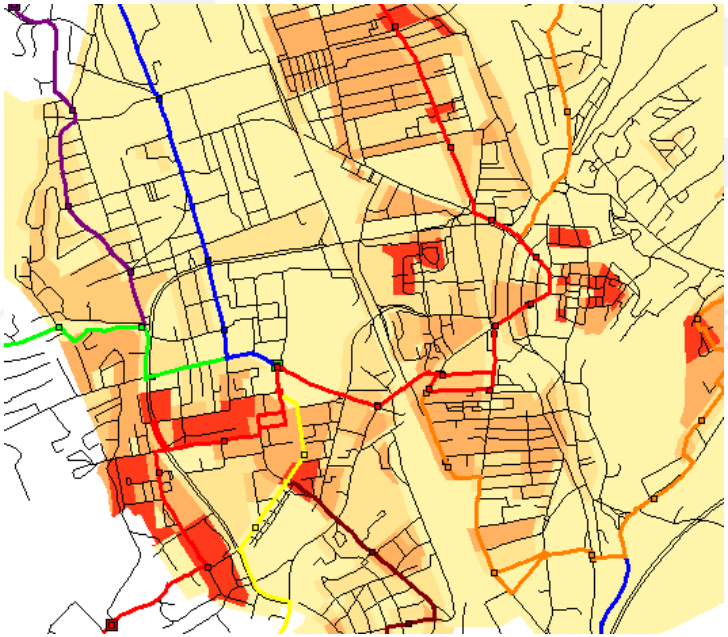


Evaluation of Exchange Stations

- Create a list of available exchanges in a stations
  - When a bus is arriving at a bus station, list all the possible other buses which may be taken after arrival in the same station
- Evaluation minimal, average, and maximal waiting time to proceed the exchange for all bus stations

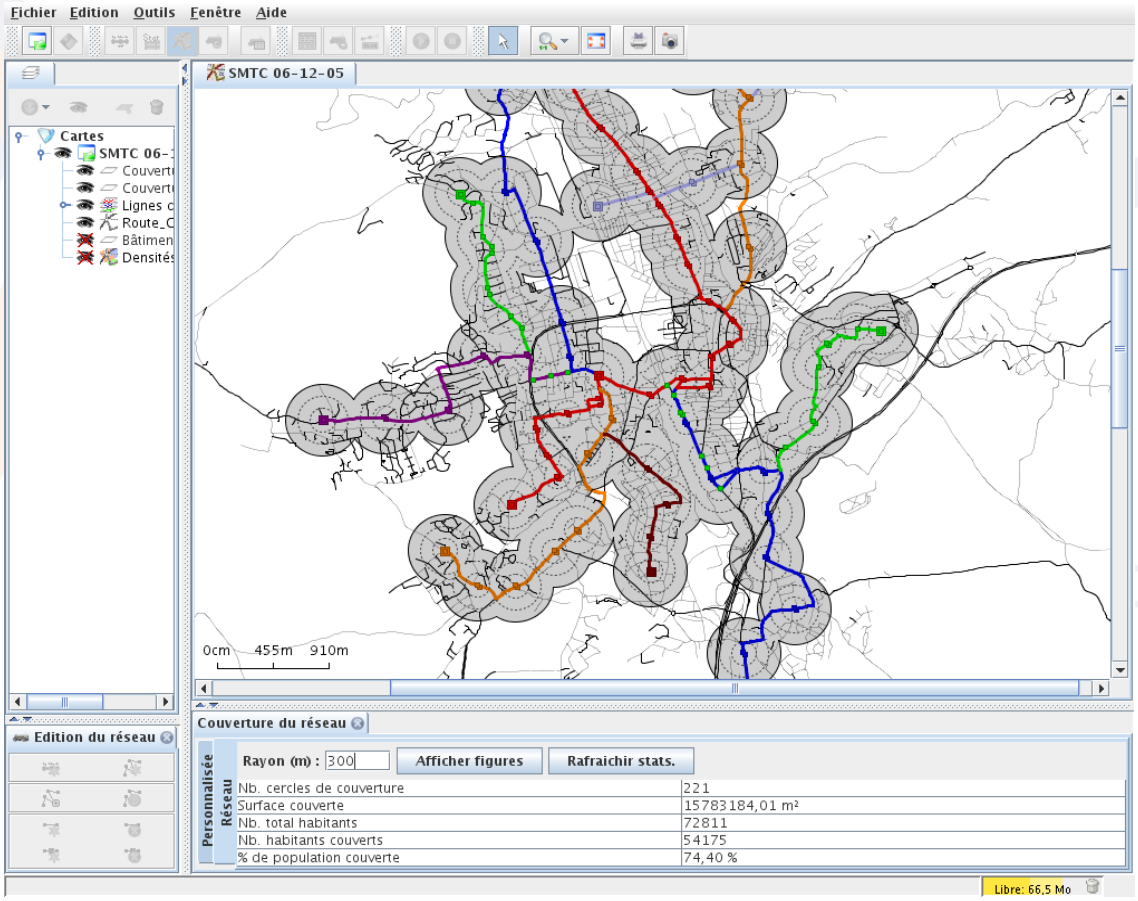
Population Cover Evaluation

- Evaluation proportion of population which is « near » bus stops
- Evaluation is based on population density map:
  - Set of shapes which count of people as attribute



Population Cover Evaluation

- Put circles with selected radius (100m, 400m...) at each bus stop



Population Cover Evaluation

- For each circle, compute the amount of covered population:

$$p_c := \sum \frac{\text{area}(a \cap c) . \text{population}(a)}{\text{area}(a)} : \forall c \in \text{Circle}, \forall a \in \text{DensityMap}, a \cap c \neq \emptyset$$

- For each intersecting circle pairs, substract intersection to one of the circles

$$p_b := p_b - \frac{\text{area}(a \cap b) . p_b}{\text{area}(b)} : \forall a, b \in \text{Circle}, a \cap b \neq \emptyset$$

- Sum all circle's values

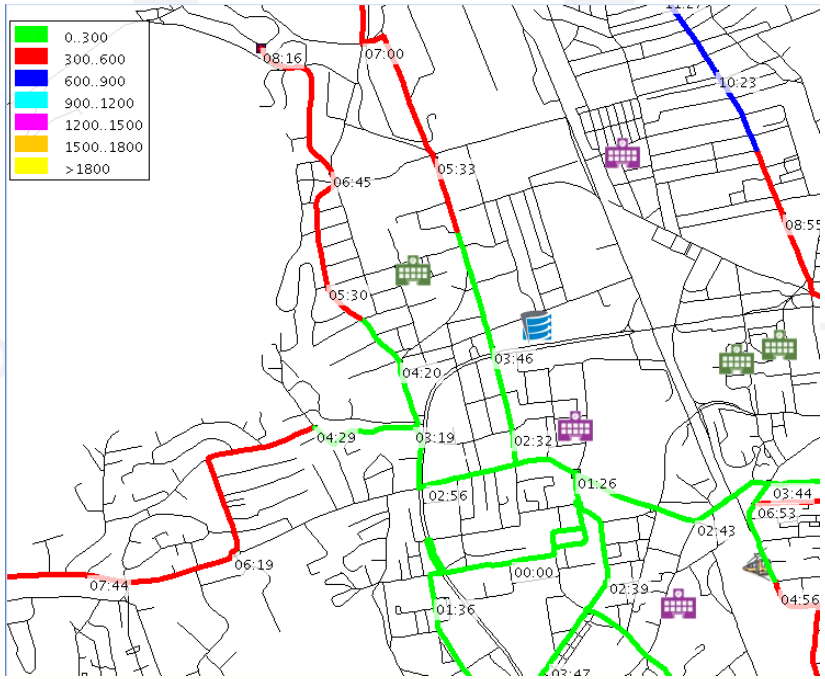
$$C := \sum p_c : \forall c \in \text{Circle}$$

- Compute global population coverage

$$G := \frac{C}{\sum \text{population(a)}} : \forall a \in \text{DensityMap}$$

Travelling Time Evaluation

- From a given bus stop, compute the time to reach all other bus stops
- Use default cruising speed of buses and standard stop duration at each bus stop, or bus operation schedule



Average Travelling Time Evaluation

- Compute shortest paths from the selected bus stops to all the other bus stops (Dijkstra algorithm)

$$s_{a \to b} := \text{dijsktra}(a, b) : \exists ! \, a \in \text{BusStop}, \forall \, b \in \text{BusStop}, a \neq b$$

- Travelling duration is given by:

$$t_{a \to b} := \frac{s}{\text{distance}(s_{a \to b})} + \text{countBusStops}(s_{a \to b}).b$$

where s is the bus cruising speed and
b is the standard waiting duration at bus stop

Travelling Time Evaluation with Bus Operation Schedule

- A departure time must be given: t_0
- Compute shortest paths from the selected bus stops to all the other bus stops (Dijkstra algorithm)
- Path is composed of troneons: segments between bus stops

$$s_{a\to b} := \text{dijsktra}(a,b) = \{r_0, r_1 \dots r_n\} :$$
$$\exists!\, a \in \text{BusStop}, \forall\, b \in \text{BusStop}, a \neq b$$

- Time at which a troneon was passed is given by:

$$\begin{cases} e_{r_0} = t_0 \\ e_{r_n} = \min(t) : \forall\, t \in \text{time}(r_{n-1}, r_n), t \gg s_{r_{n-1}} \\ s_{r_n} = e_{r_n} + \text{duration}(r_0) : n \geq 0 \end{cases}$$

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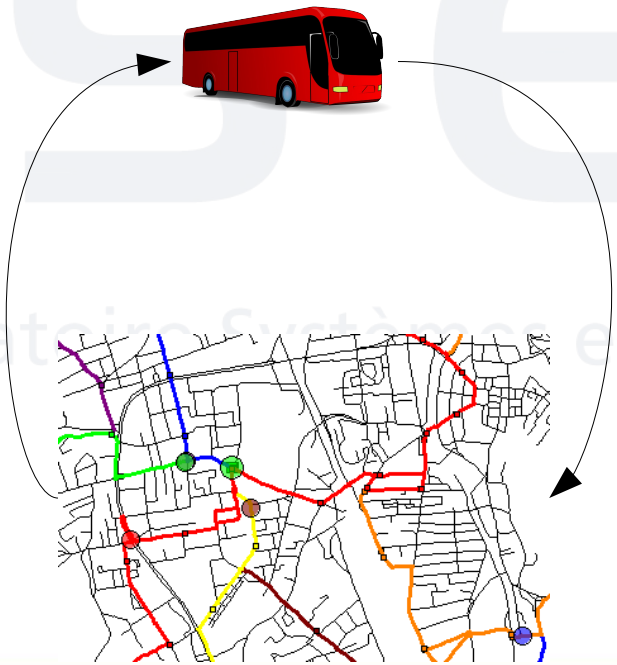
Multiagent Simulation Model

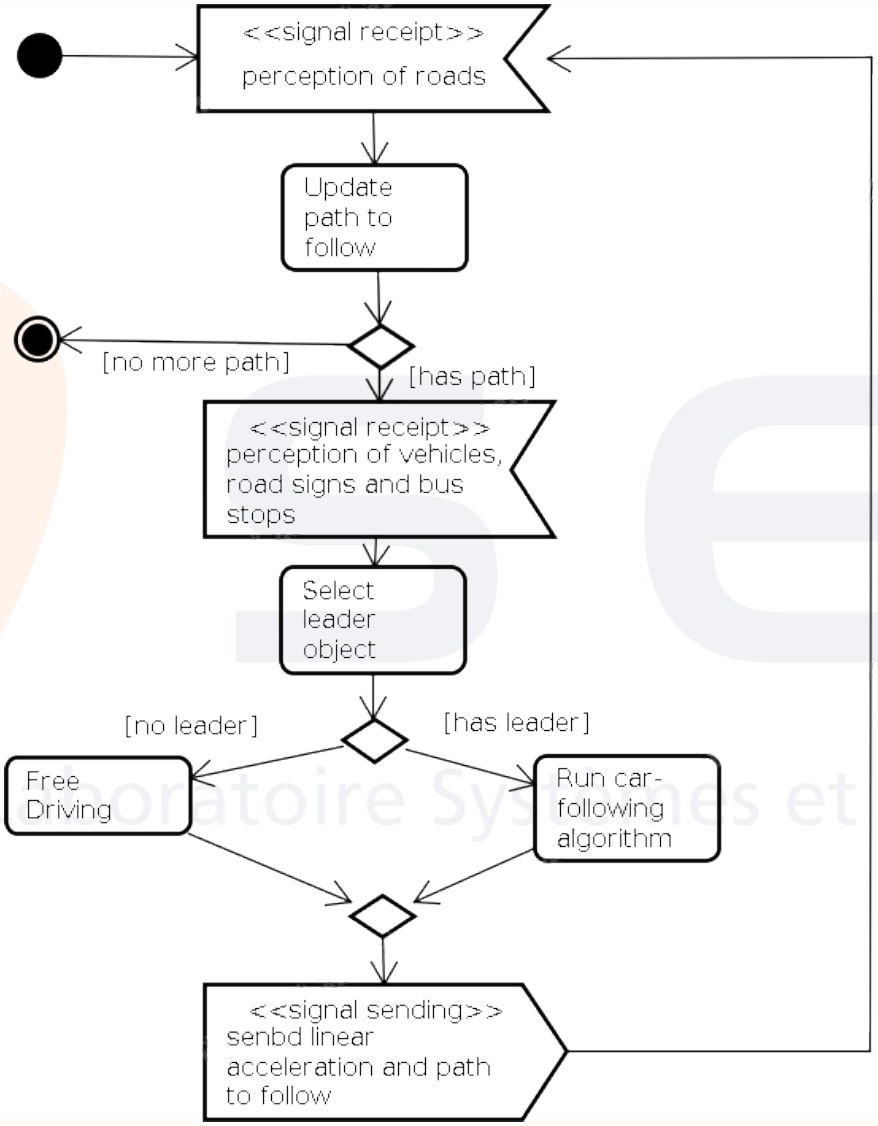
- Each bus and vehicle is simulated with a situated agent:
  - Individual behavior based on IDM,
  - realistic perception frustum, and
  - steering motion based on linear acceleration

Local Perceptions:
- Roads
- Other vehicles
- Road signs



Steering Parameter:
- Linear acceleration

Agent Behavior



Simulation Indicators

- **Inconsistencies against Bus Operation Schedule**
  - How many buses are late or early
  - How much they are late (early buses may wait)
- **Congestions and Delays**
  - What are the roads on which buses are stopping a long time?
- **Bus filling rate**
  - Does all waiting passengers may enter in the first arriving bus?
  - How many passengers are waiting at bus stops?

Simulation Indicators

- These indicators permit to study impact of the following actions on the bus network:
  - Create busways
  - Adapt traffic light policies to prioritize buses
  - Change itineraries
  - Add more buses when bus network has congestions and temporary deny of service

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Conclusion

- MetroB is able to :
  - import and export data in GIS standard formats
  - draw GIS data
  - edit bus network
  - evaluate bus network
  - simulate bus network

- MetroB is dedicated to initial design of public transportation system
- MetroB was successfully used by SMTC to design Belfort's bus network during 2004-2006 period.

Works under Progress

- Support of multi-modality
- Have finest passenger statistics:
  - O-D matrices from individual mobilities, bus pass usages...
  - Estimate passenger numbers from embedded devices (door detectors or video cameras)
- Full connexion to Vehicle Scheduling Control System

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