

Inverse procedural Street Modelling: from interactive to automatic reconstruction

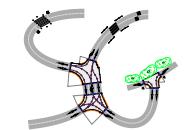
Phd Defense : Rémi Cura, 2016/09/12

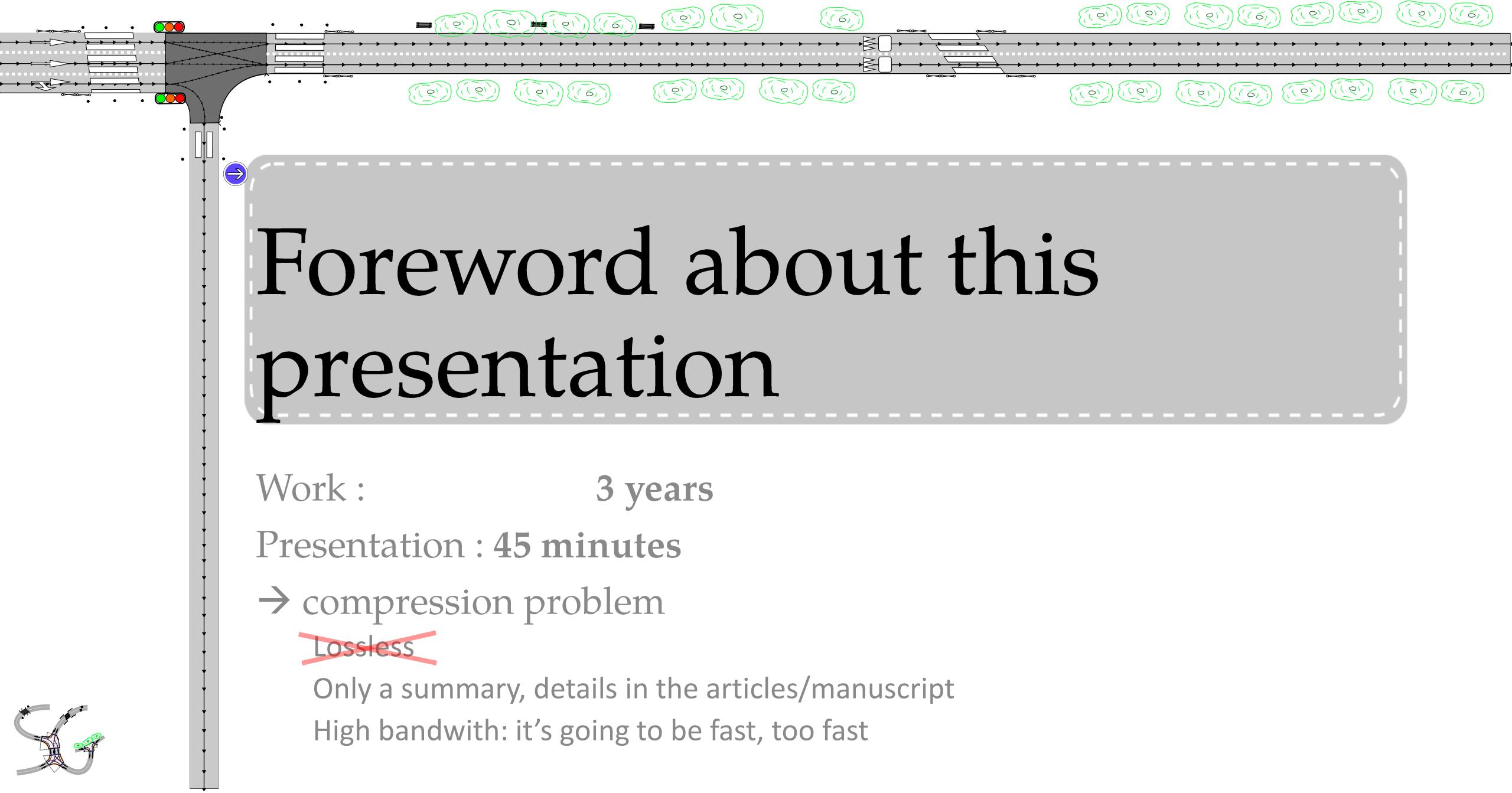
*Université Paris-Est
École Doctorale Mathématiques et Sciences et Technologies
de l'Information et de la Communication (MSTIC)*

Jury:

Pr. Christian Heipke (IPI)
Pr. Peter Van Oosterom (TUDelft)
Dr. Florent Lafarge (INRIA)
Pr. Gilles Gesquière (LIRIS)

Dr. Julien Perret (IGN)
Dr. Nicolas Paparoditis (IGN)
Dr. Kevin Lyvan (Thales)





Foreword about this presentation

Work : 3 years

Presentation : 45 minutes

→ compression problem

~~Lossless~~

Only a summary, details in the articles/manuscript

High bandwith: it's going to be fast, too fast

Abstract

Chapter 2

Sensing data



Chapter 3

Road axis + attributes



Procedural Street Modelling

Chapter 4

Interactive
in base
edition

StreetGen

Chapter 5

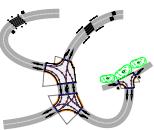
Automatic
Street Model
fitting

Street Modelling

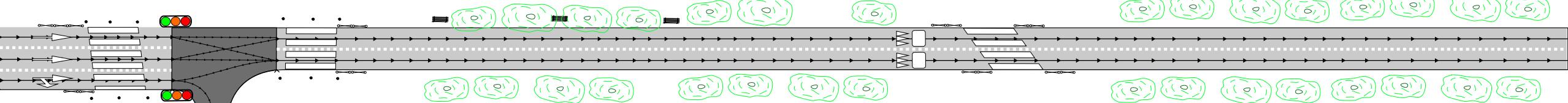
Point Cloud
Server

Chapter 2, 5
Appendix 1

Urban feature observations



PLAN



Intro
State of the Art
StreetGen
Streets
Interaction
Automation
P.C. Server
Fitting
Conclusion



Introduction: Why model streets? (5')

State of the art: How to model streets? (5')

StreetGen : Helping humans model streets

Generating best guess streets (5')

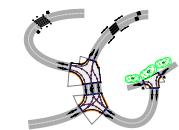
Editing streets (in-base) (5')

Automating the street generation

Data? point cloud server (5')

Fitting the street model (5')

Conclusion (5')



width= 8; lane= 3

width= 6; lane= 2

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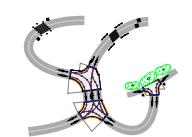
Conclusion

Introduction

Why model streets?

Usages for street model

width= 4; lane= 1



1. Introduction

width= 8; lane= 3

width= 6; lane= 2

- 1.1 Why Model streets ?
 - Streets are important:
 - Streets are essential parts of cities
 - Cities are important places
 - Information is important
 - Modelling of a street = knowledge about this street
 - Used for visualisation / simulation / analysis

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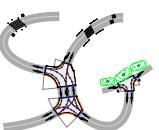
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width= 4; lane= 1



Introduction: Streets are important

width= 8; lane= 3

width= 6; lane= 2

- Cities are important places
 - Many people live in it
 - World : 50% in urban area.
 - France : 80%
 - Concentrate people/power/usages/issues
- Streets are important in cities
 - In paris, streets area > building area
 - Streets = medium between people/occupations

width= 4; lane= 1

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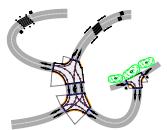
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Introduction: having a model is important

width= 8; lane= 3

width= 6; lane= 2

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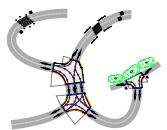
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width= 4; lane= 1

- Modelling the streets
 - Visualisation (map / 3D model)
 - Simulation
 - Analysis
 - ...
- Why would we want an accurate, structured, up to date map of streets?
 - Mapping = maps are classical control/management tools
 - Map war for South America (Madrid, 1750)
 - Mapping = visualising: very helpful for human
 - (demo th. Pythagore visual vs math)



width= 8; lane= 3

width= 6; lane= 2

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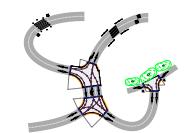
Conclusion

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Why model streets?

Usages for street model

width= 4; lane= 1



Introduction: usages for street model

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width= 6; lane= 2

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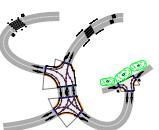
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width= 4; lane= 1

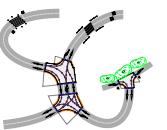
- Cities are actually carefully managed
 - Paris : 100' of people, one dedicated engineer school
 - Requires data (precise, up to date)
 - Visualisation (map / 3D model)
 - Decision making
 - Consultation / communication
 - Simulation
 - Traffic / pollution / noise / parkings ...
 - Analysis (past/present/planning)



Introduction: usages for city model

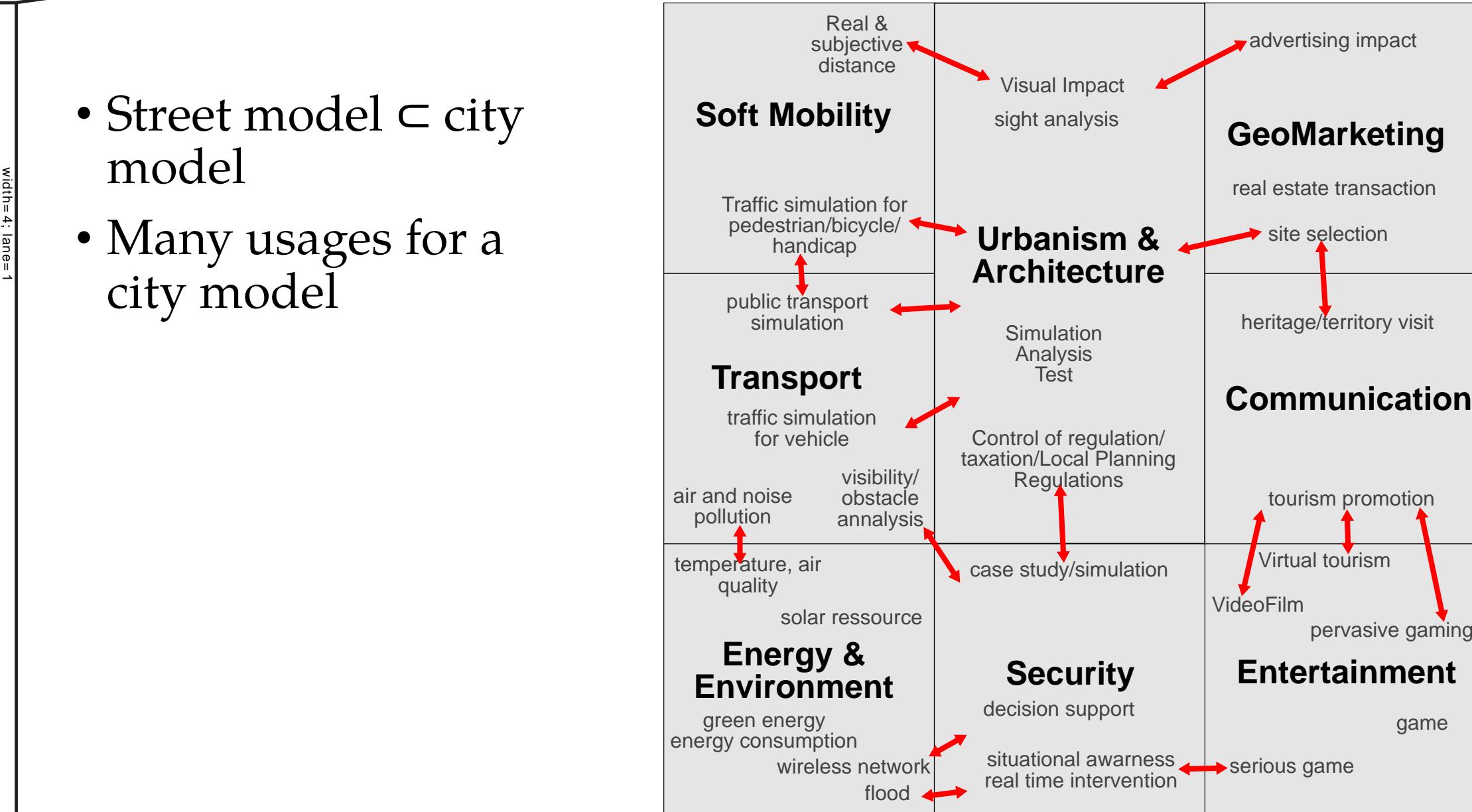
- Street model ⊂ city model
- Many usages for a city model

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width= 8; lane= 3

width= 6; lane= 2



edge_id=15; next_l=16
end_node=3 ...

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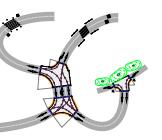
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State of the art

Modelling street, why is it hard?

Existing models



State of the art: modelling street is hard

edge_id=15; next_l=16
end_node=3 ...

edge_id=16; next_l=17
start_node=4 ...

- Even 'regular' streets are hard to model
 - Complex (even for human)
 - Traffic
 - Organised
 - Hard to sense

edge_id=17; next_l=16
start_node=4 ...

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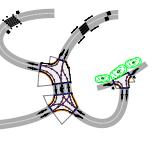
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State of the art: modelling street is hard

edge_id= 15; next_l= 16
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edge_id= 16; next_l= 17
start_node= 4 ...

- Streets are complex

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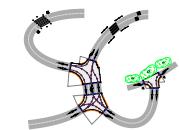
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edge_id= 17; next_l= 16
start_node= 4 ...



State of the art: modelling street is hard

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- Streets are complex

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edge_id= 17; next_l= 16
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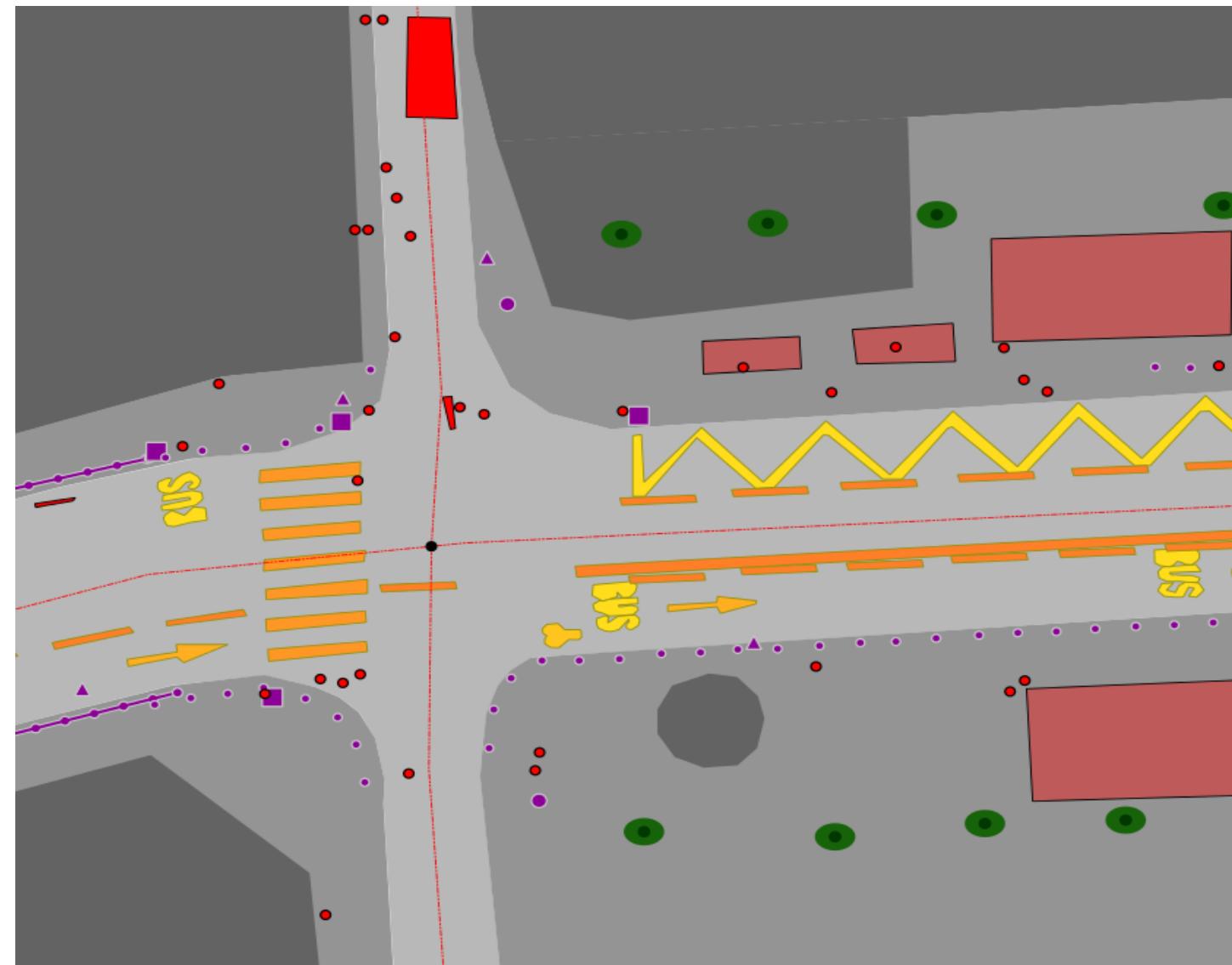
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edge_id=17; next_l=16



road_network

intersection node
road axe

vegetation

tree

mobility

pedestrian

bicycle

vehicle

bus_stop

metro

bus

metro

Signage

bu

ve

fl

pp

ma

street furniture

barrier

bollard

traffic_light

furniture

public_light

WC

land use

road

sidewalk

building

kiosque

terrace

State of the art: modelling street is hard

edge_id= 15; next_l= 16
start_node= 4 ...
end_node= 3 ...

- Streets are a medium supporting all type of traffic



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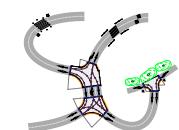
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State of the art: modelling street is hard

edge_id= 15; next_l= 16
end_node= 3 ...

edge_id= 16; next_l= 17
start_node= 4 ...

- Streets are organised (symmetry, hierarchy, part of network ...)

edge_id= 17; next_l= 16
start_node= 4 ...



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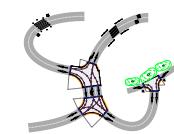
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State of the art: modelling street is hard

edge_id=15; next_l=16
end_node=3 ...

- Streets are hard to sense
 - Manual : millions of objects
 - Automatic :
 - high occlusion
 - Small details are essential (curb)

edge_id=16; next_l=17
start_node=4 ...

edge_id=17; next_l=16
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Active Windows

Accédez aux paramètres de chaque window

edge_id=15; next_l=16
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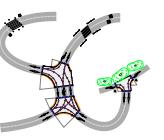
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Modelling street, why is it hard?

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State of the art: Existing models

edge_id=15; next_l=16
end_node=3 ...

edge_id=16; next_l=17
start_node=4 ...

- What should be modelled?

- Street precise geometry (roadway/ sidewalk / ...)
- Street road as part of whole network (= traffic info)
- Street organisation
- Street objects
- Street objects relations
- Material/visual aspects ...

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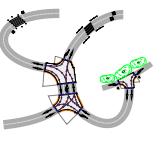
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edge_id=17; next_l=16
start_node=4 ...



State of the art: Existing models

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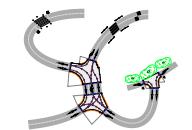
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edge_id=17; next_l=16
start_node=4 ...

- Everybody is interested by different street aspects
 - GIS : road as center line + buffer
 - Traffic simulation : road network / pedestrian space
 - Computer graphics : nice 3D roads blending with surroundings
 - Procedural modelling : road network as start for procedural city
 - Sensing : mostly road surface and markings
 - driving simulator : intersection
 - Automotive industrial : roadway detailed characteristics
 - ...



State of the art: Existing models

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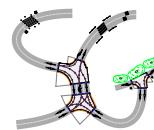
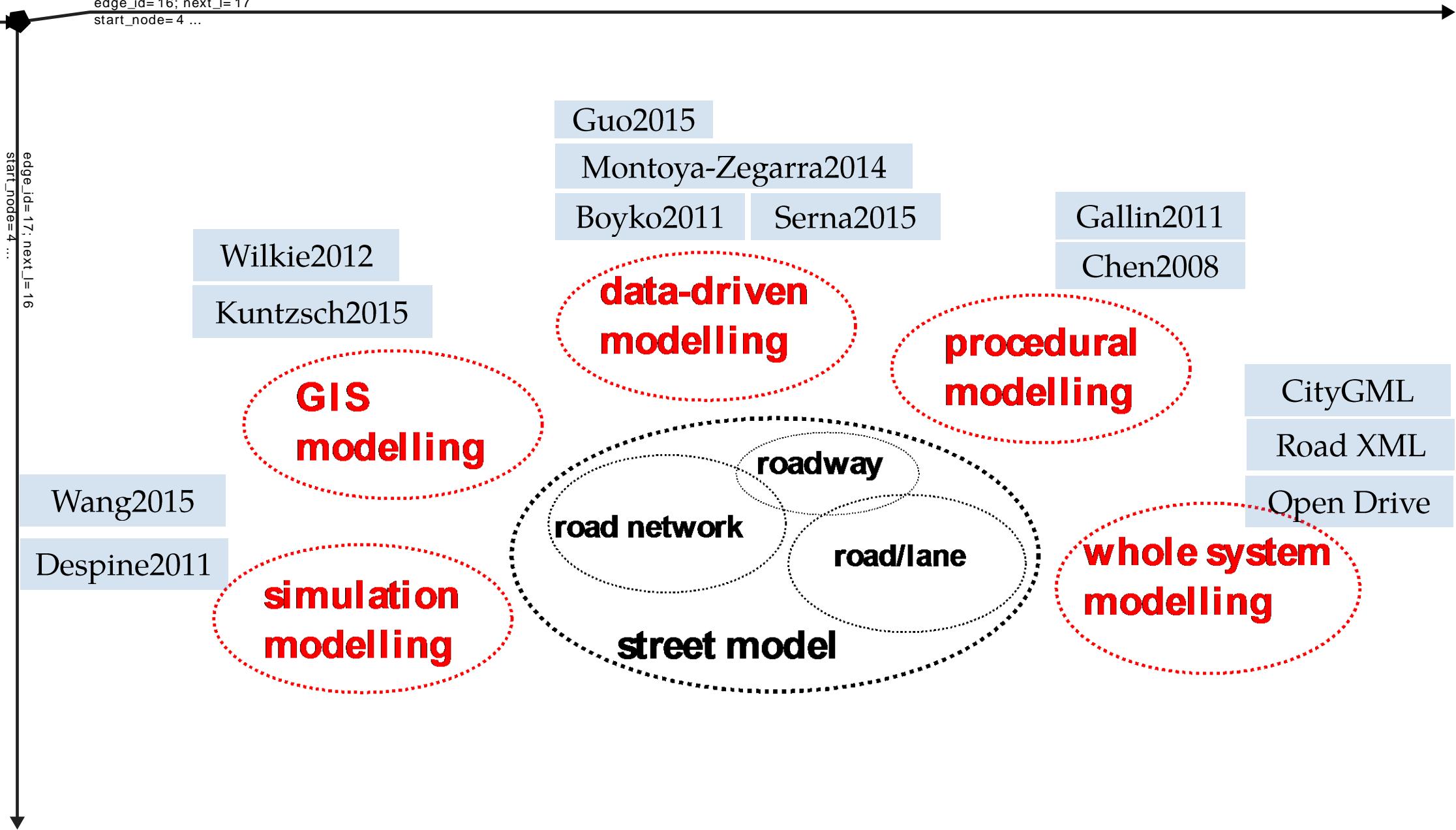
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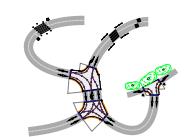
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- Whole system modelling
 - City GML : for city, but contains a road module
 - Road XML : oriented for traffic simulation
 - Open Drive : high geometric details

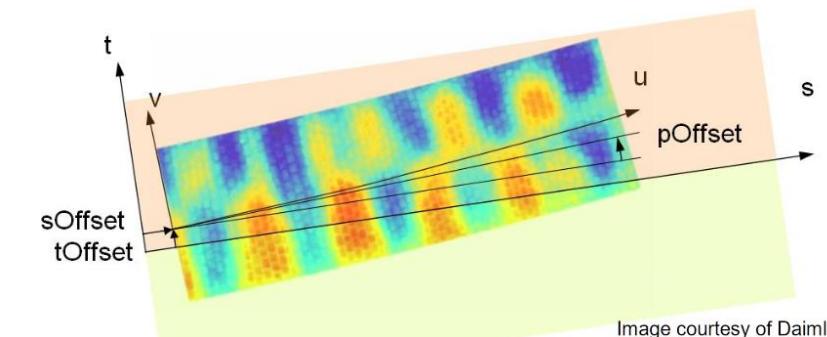
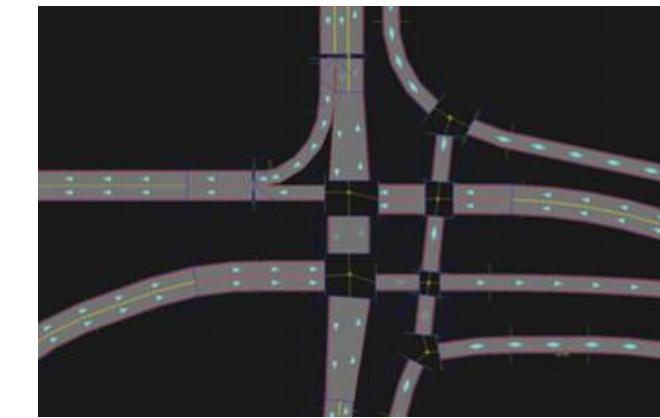
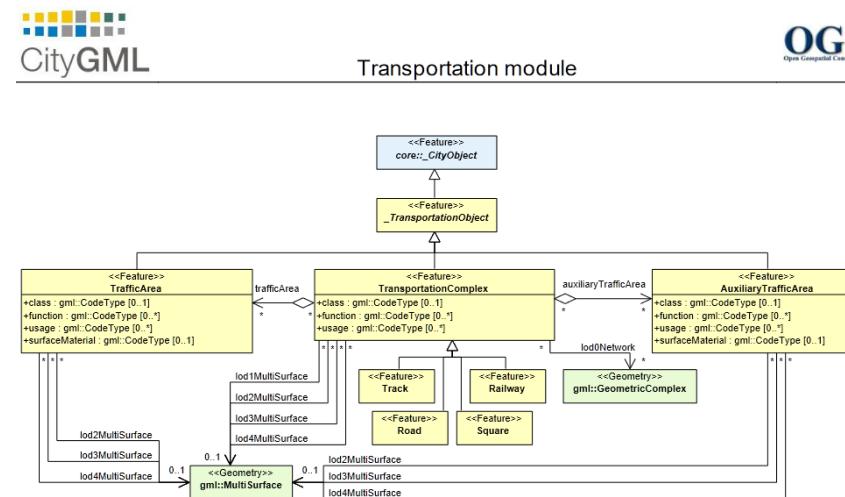


Image courtesy of Daimler AG

State of the art: Existing models

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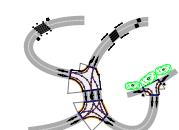
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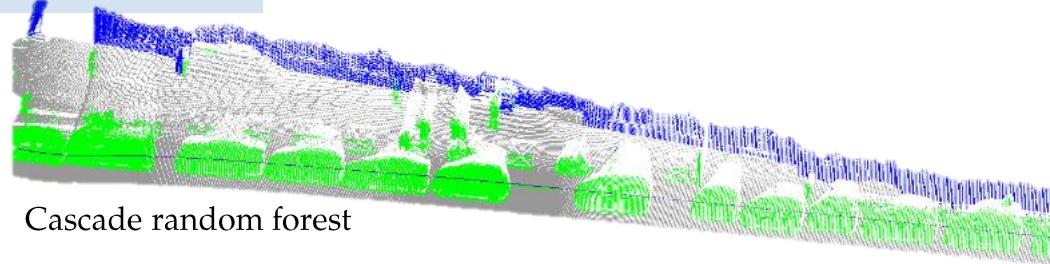
- Data-driven modelling
 - From image/lidar

Guo2015

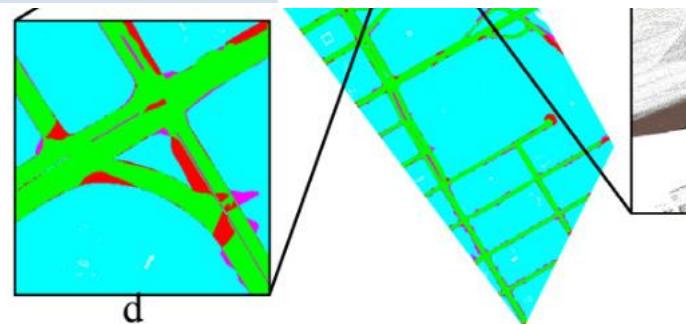


Extraction, raster, template matching

Serna2015



Boyko2011

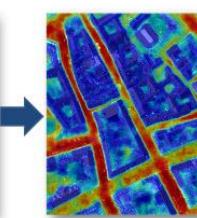


Fitting + active contour

Fig. 9. Classification error map.



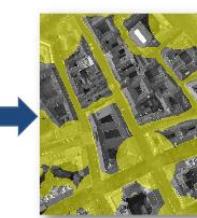
Context-aware road scores
(Section 3.1)



Road likelihoods
(Section 3.2)

Montoya-Zegarra2014

Classif + Context + CRF



Sampling of road candidates
(Section 3.3)



Candidate Selection
(Section 3.4)

State of the art: Existing models

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- GIS-based modelling

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Kuntzsch2015

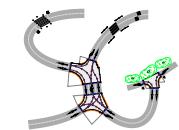


Street segment KDE, intersection with RJ-MCMC

Wilkie2012



Turning radius, network of lane, simulation



State of the art: Existing models

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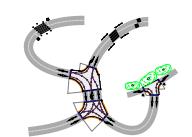
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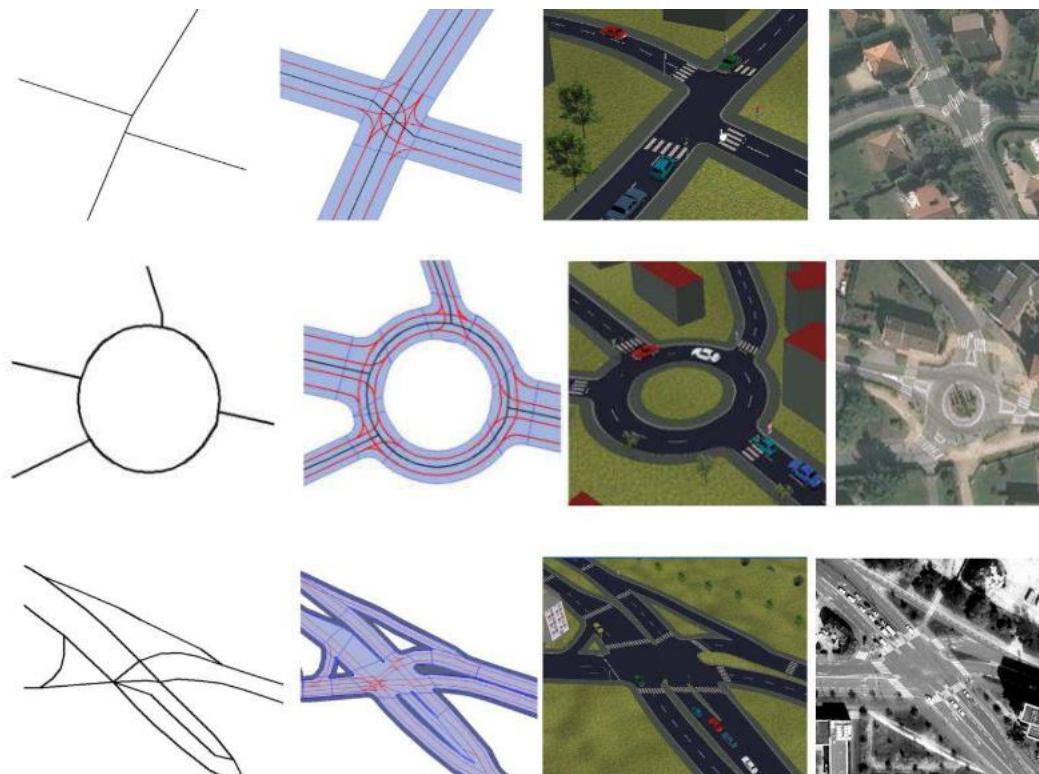
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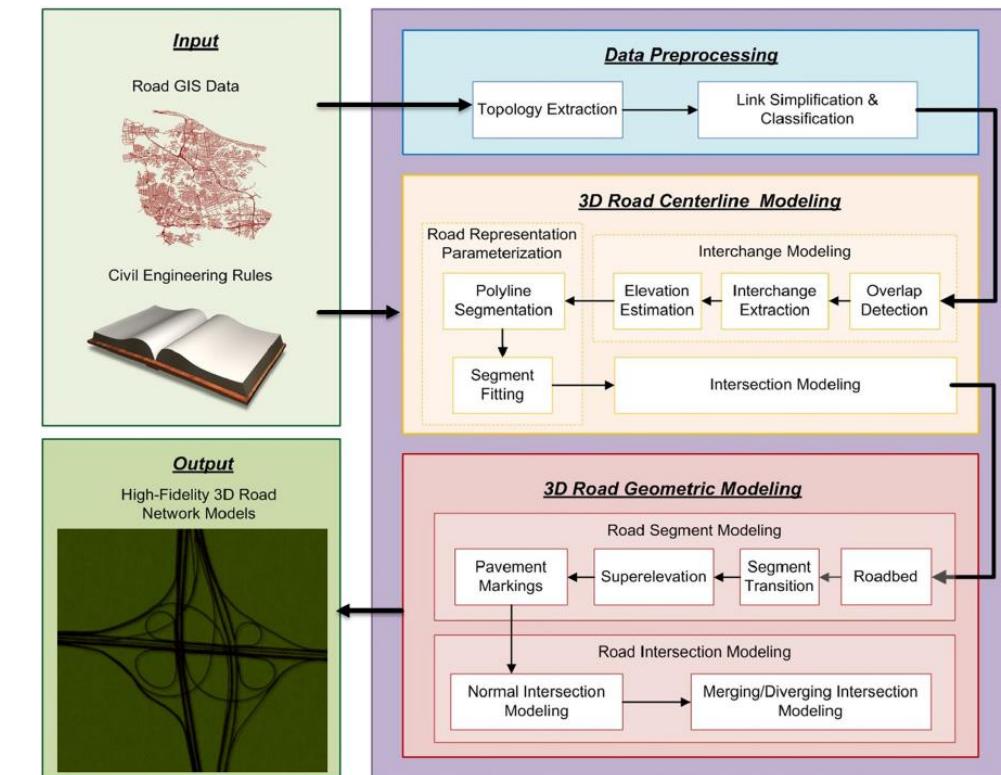
- Simulation-based modelling

Despine2011



Network from data, guessing lane, intersection by continuity, 3D generation

Wang2015



Segment of road parametrisation, intersection...

State of the art: Existing models

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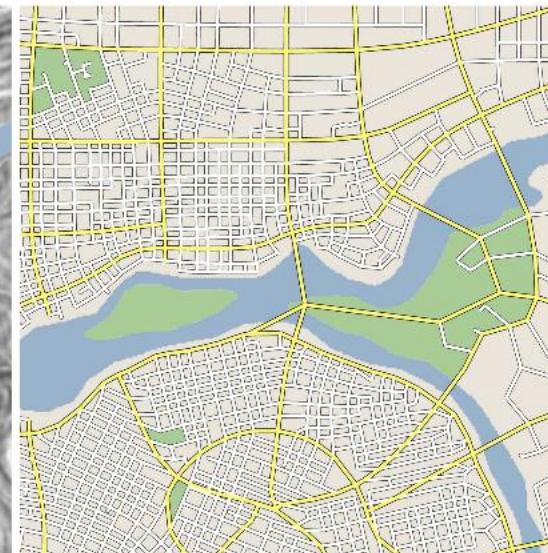
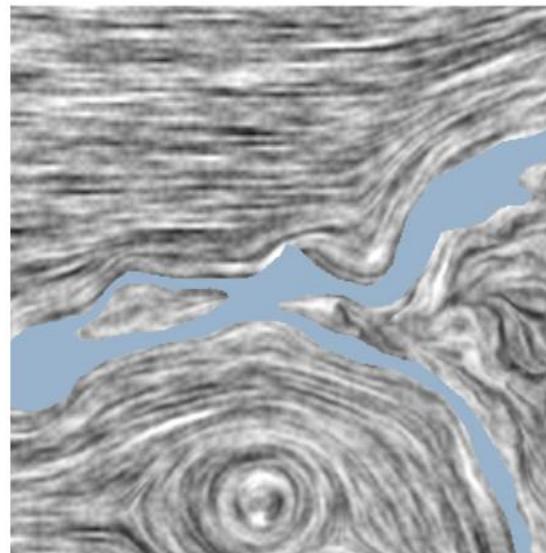
- Procedural modelling

Gallin2011



Terrain, graph : shortest path and merging,
procedural generation

Chen2008



Tensor, stream line, grammar

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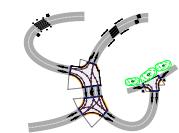
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StreetGen : generate streets

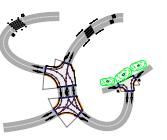
Design Principle

Kinematic hypothesis

Road surface

Traffic support

Street objects



StreetGen : design principle

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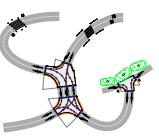
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- To Design = to compromise
- Goals?
 - Model streets of whole Paris (scale, robustness)
 - Work with limited GIS data (best guess)
 - Model used for various outputs (analysis / 3D visu / traffic simulation...)
 - Multi-user editing
- Our approach:
 - Limited data : based on road axis, use simple kinematic hypothesis
 - Scaling & multi-user : use a RDBMS
 - Coherent structured model : use a RDBMS

StreetGen : design principle

edge_id= 15; next_l= 16
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- Not a model for all streets, but a model for most of streets
- 3 observations on streets
 - Structured by street axis
 - 2 type of parts : morphologically constant or varying
 - Adapted to vehicle traffic
- Kinematic hypothesis :
 - Allows to rough out a road model
- Scaling/multi-user/GIS data → use a RDBMS

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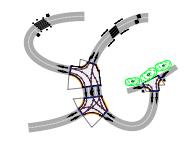
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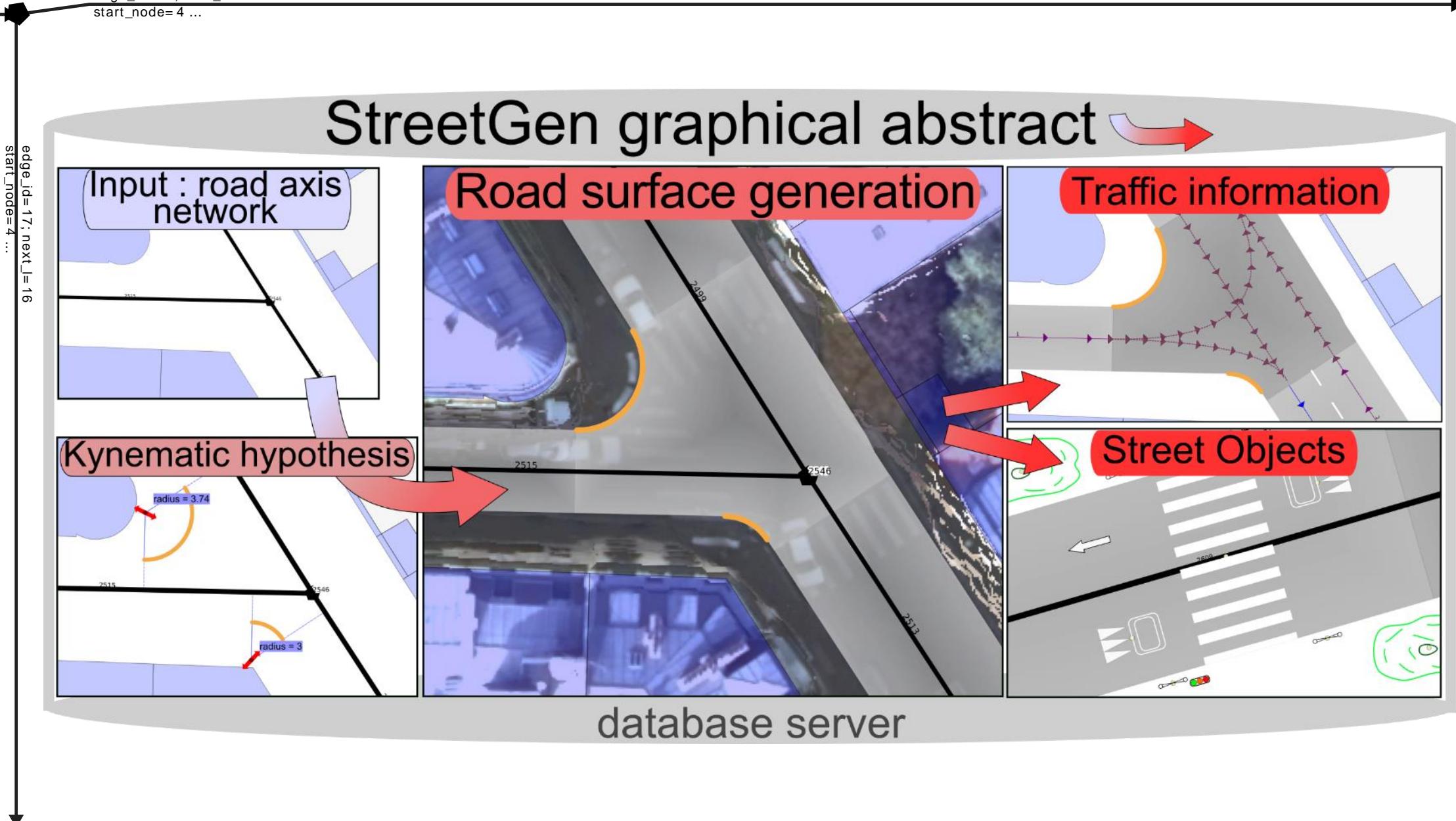
Conclusion



StreetGen : graphical abstract

edge_id= 15; next_l= 16
end_node= 3 ...

edge_id= 16; next_l= 17
start_node= 4 ...



StreetGen : design principle

edge_id= 15; next_l= 16
end_node= 3 ...

edge_id= 16; next_l= 17
start_node= 4 ...

edge_id= 17; next_l= 16
start_node= 4 ...

- StreetGen road model

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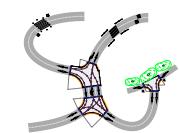
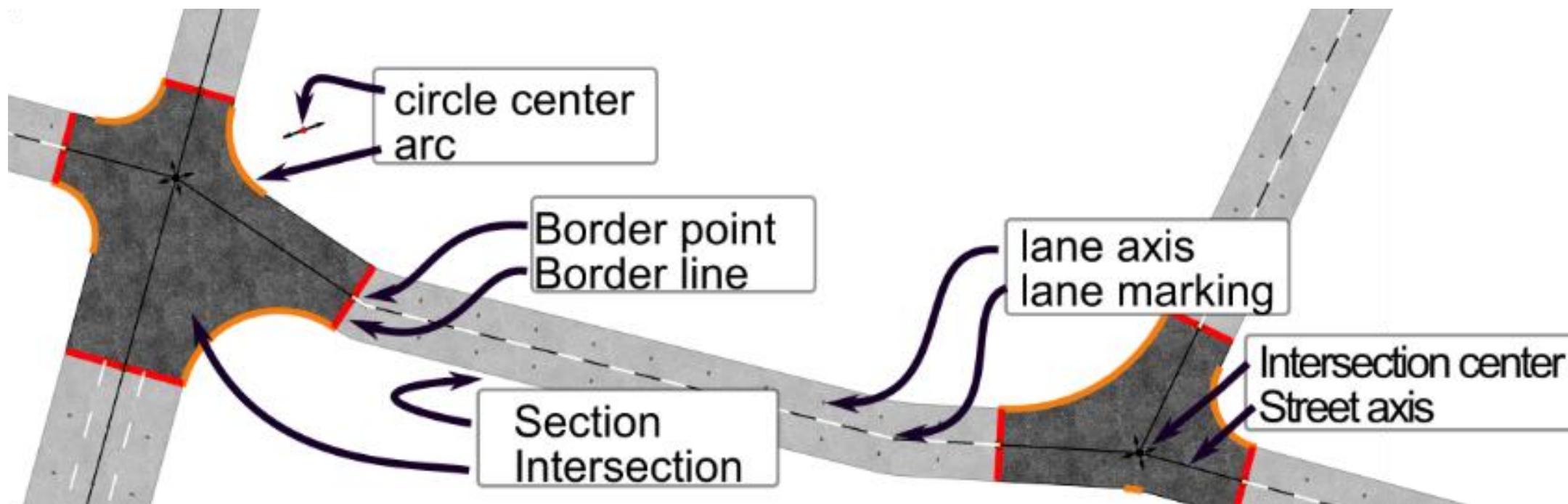
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StreetGen : design principle

edge_id= 15; next_l= 16
end_node= 3 ...

How to deal with several users?
Use a RDBMS !

- ~~Read file , process, write results in a file~~
- RDBMS : made to abstract & secure data

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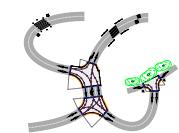
Interaction

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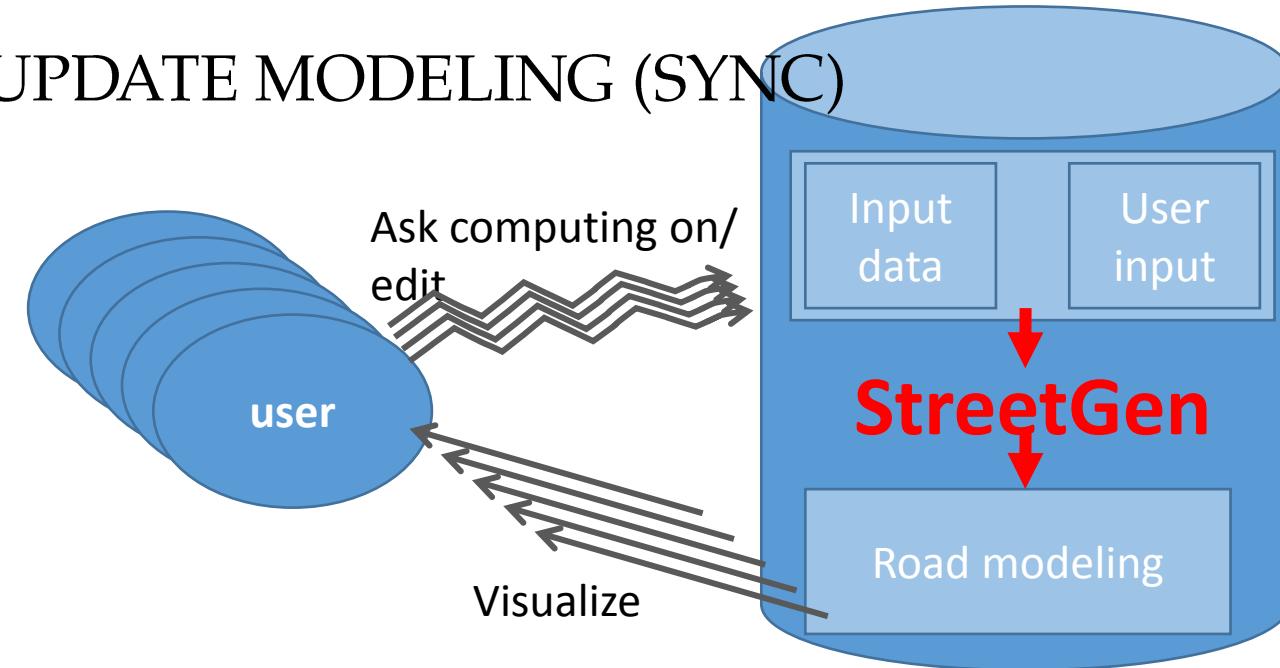
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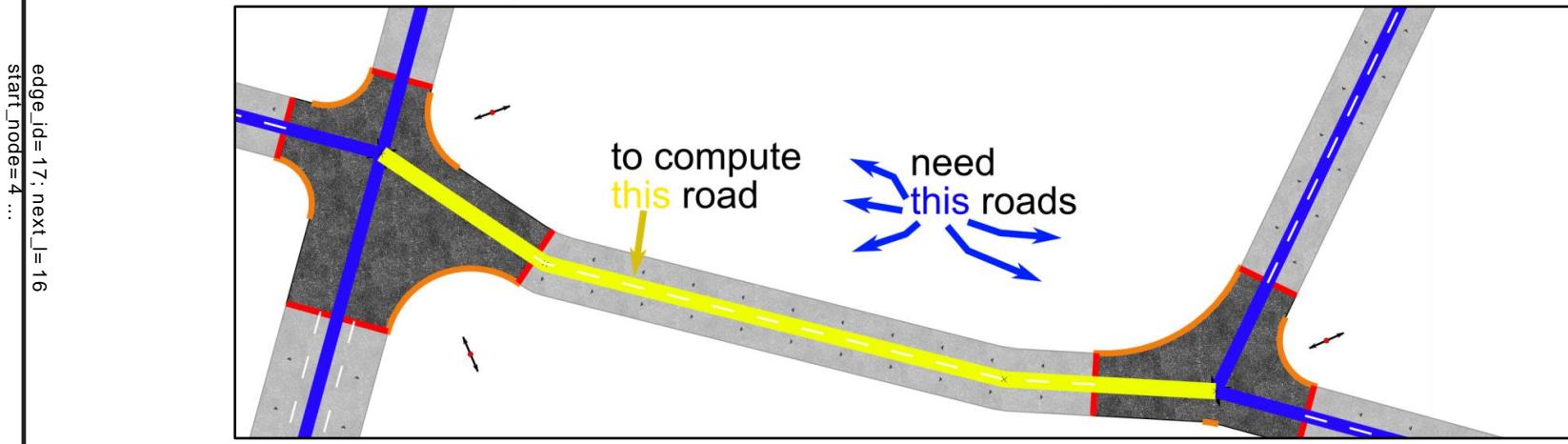
UPDATE MODELING (SYNC)



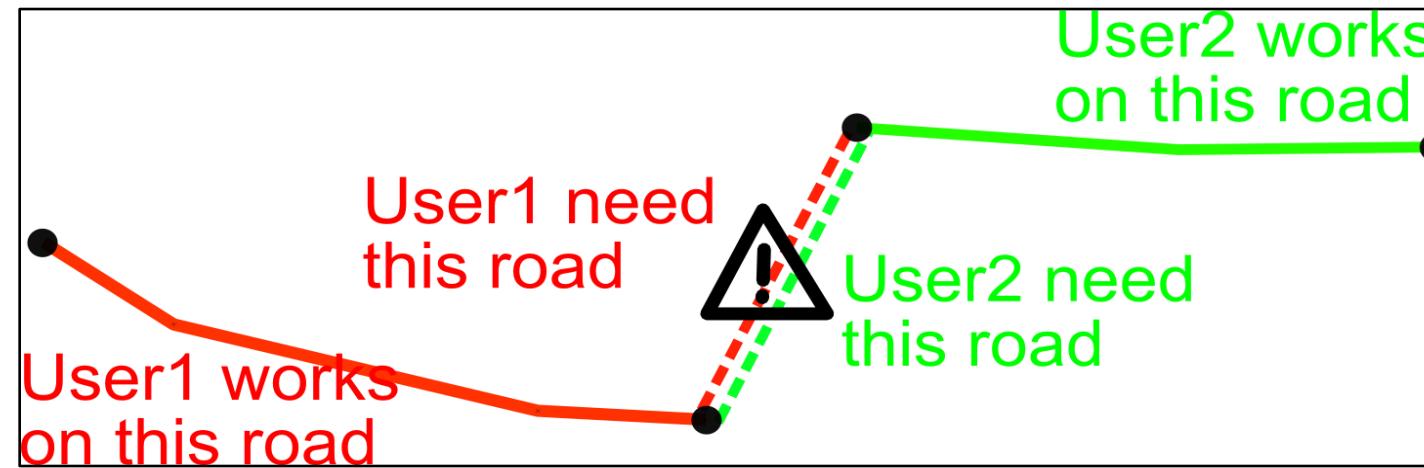
StreetGen : design principle

edge_id= 15; next_l= 16
end_node= 3 ...

- Need 1-neighbourhood to compute a street



- May be computed simultaneously



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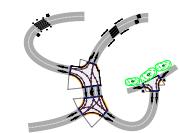
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edge_id= 15; next_l= 16
end_node= 3 ...

edge_id= 16; next_l= 17
start_node= 4 ...

edge_id= 17; next_l= 16
start_node= 4 ...

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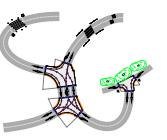
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StreetGen : generate streets

Design Principle
Kinematic hypothesis
Road surface
Traffic support
Street objects



StreetGen : Kinematic hypothesis

edge_id= 15; next_l= 16
end_node= 3 ...

edge_id= 16; next_l= 17
start_node= 4 ...

edge_id= 17; next_l= 16
start_node= 4 ...

- Hypothesis

- road border is defined by a vehicle driving along it at a given speed, while making comfortable turns.

- Street type → vehicle speed
 - Vehicle speed → turning radius
 - Turning radius → road surface

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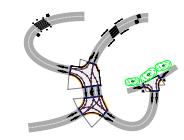
Interaction

Automation

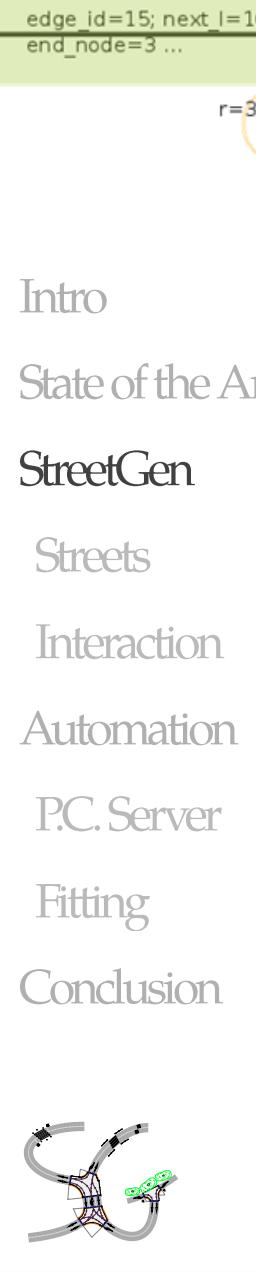
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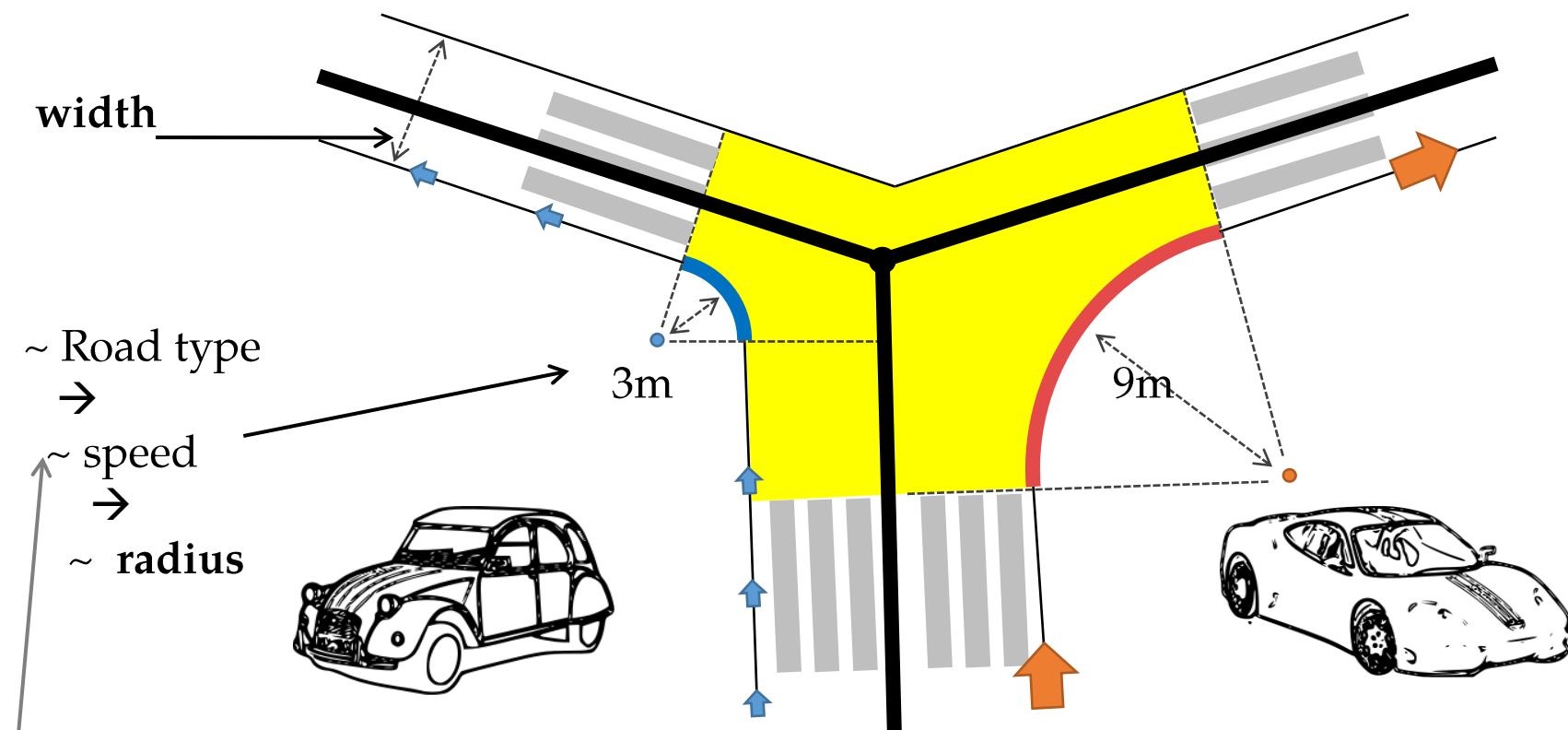
Conclusion



StreetGen : Kinematic hypothesis

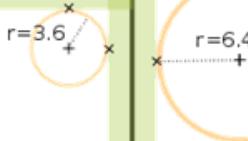


- Illustrations :



StreetGen : Kinematic hypothesis

edge id=15; next_l=16
end_node=3 ...



- Various radius in Paris

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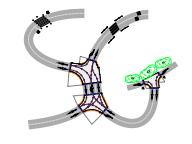
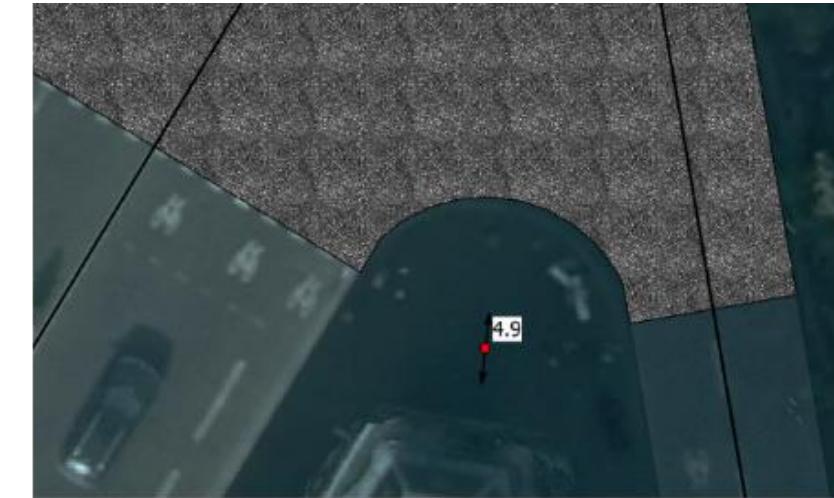
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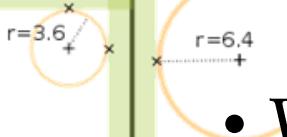
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edge id=16; next_l=17
start_node=4 ...



StreetGen : Kinematic hypothesis

edge id=15; next_l=16
end_node=3 ...



- We have road axis, road width
 - How to compute circle center and arcs?
 - ~~analytical computing (vector, angle) ?~~

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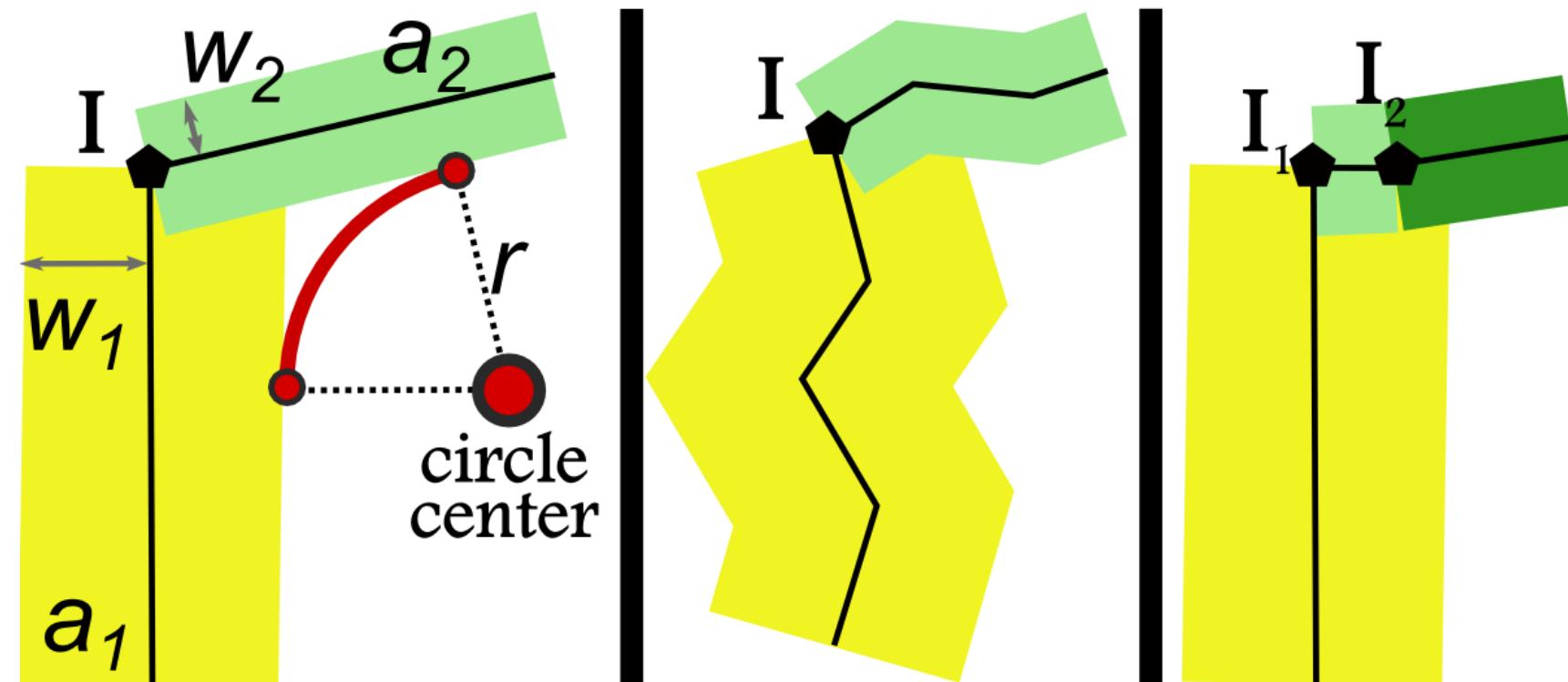
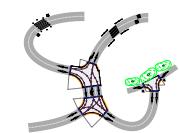
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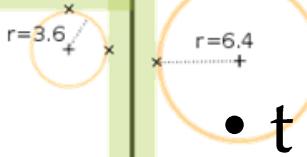
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StreetGen : Kinematic hypothesis

edge id=15; next_l=16
end_node=3 ...



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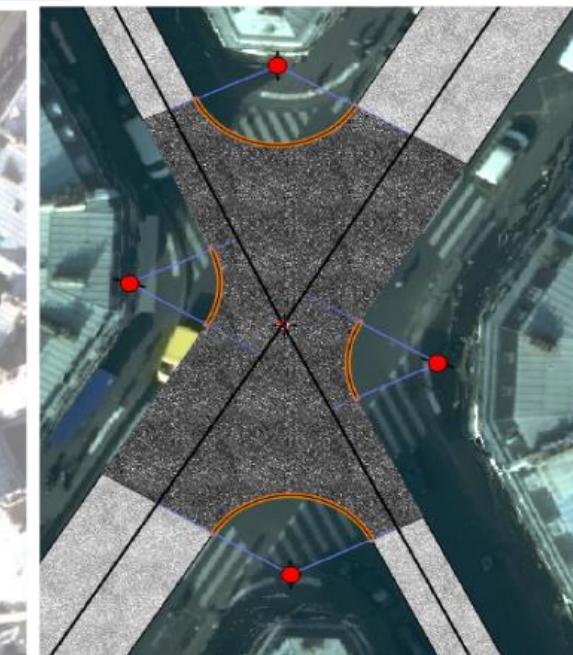
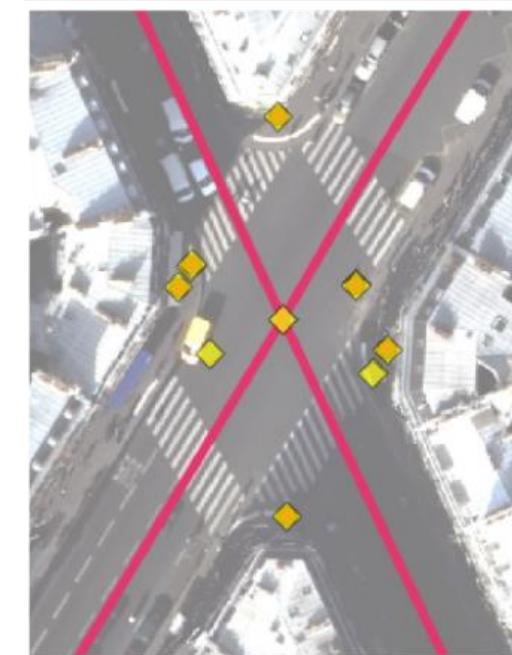
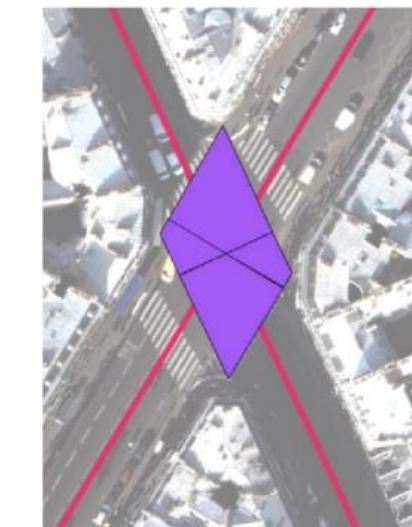
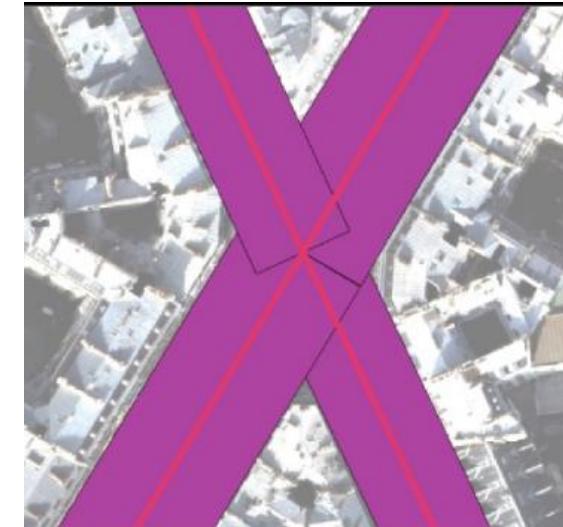
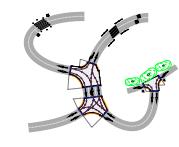
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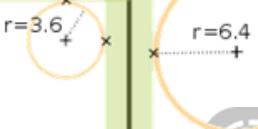
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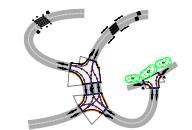
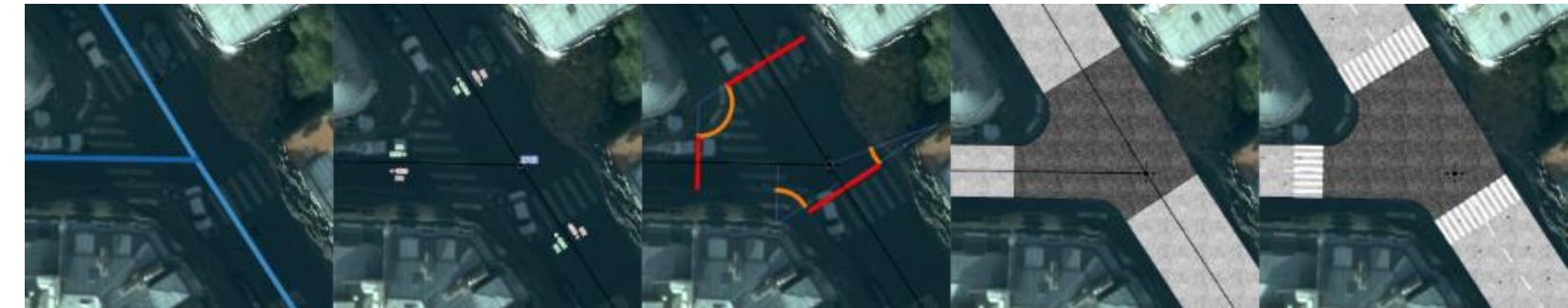
edge id=15; next_l=16
end_node=3 ...



edge_id=17; next_l=16
start_node=4 ...

StreetGen : generate streets

Design Principle
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Road surface
Traffic support
Street objects



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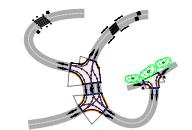
P.C. Server

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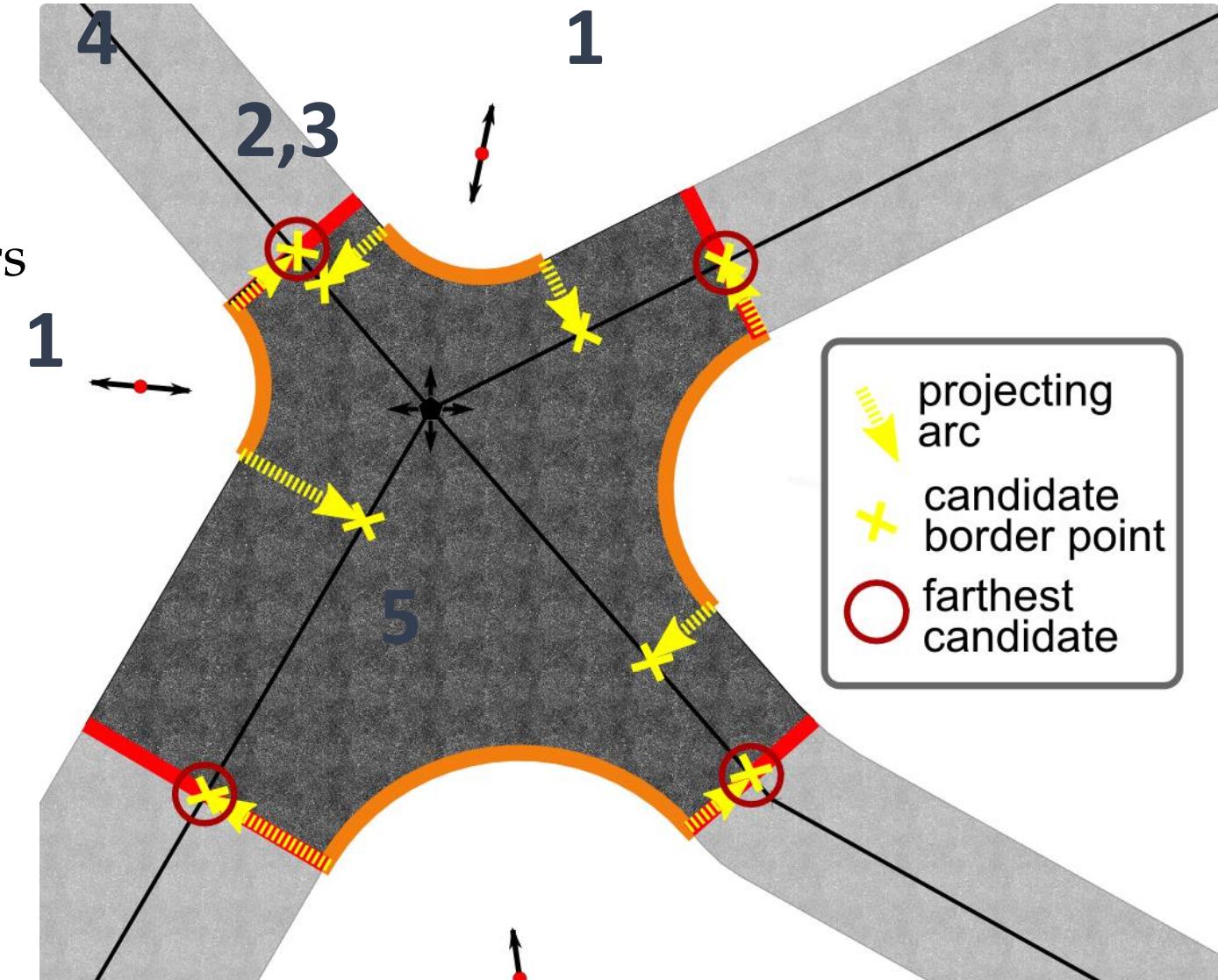
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StreetGen : Road surface

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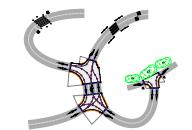


- Find intersection limit :
 - Project circle centers
 - Farthest per axis

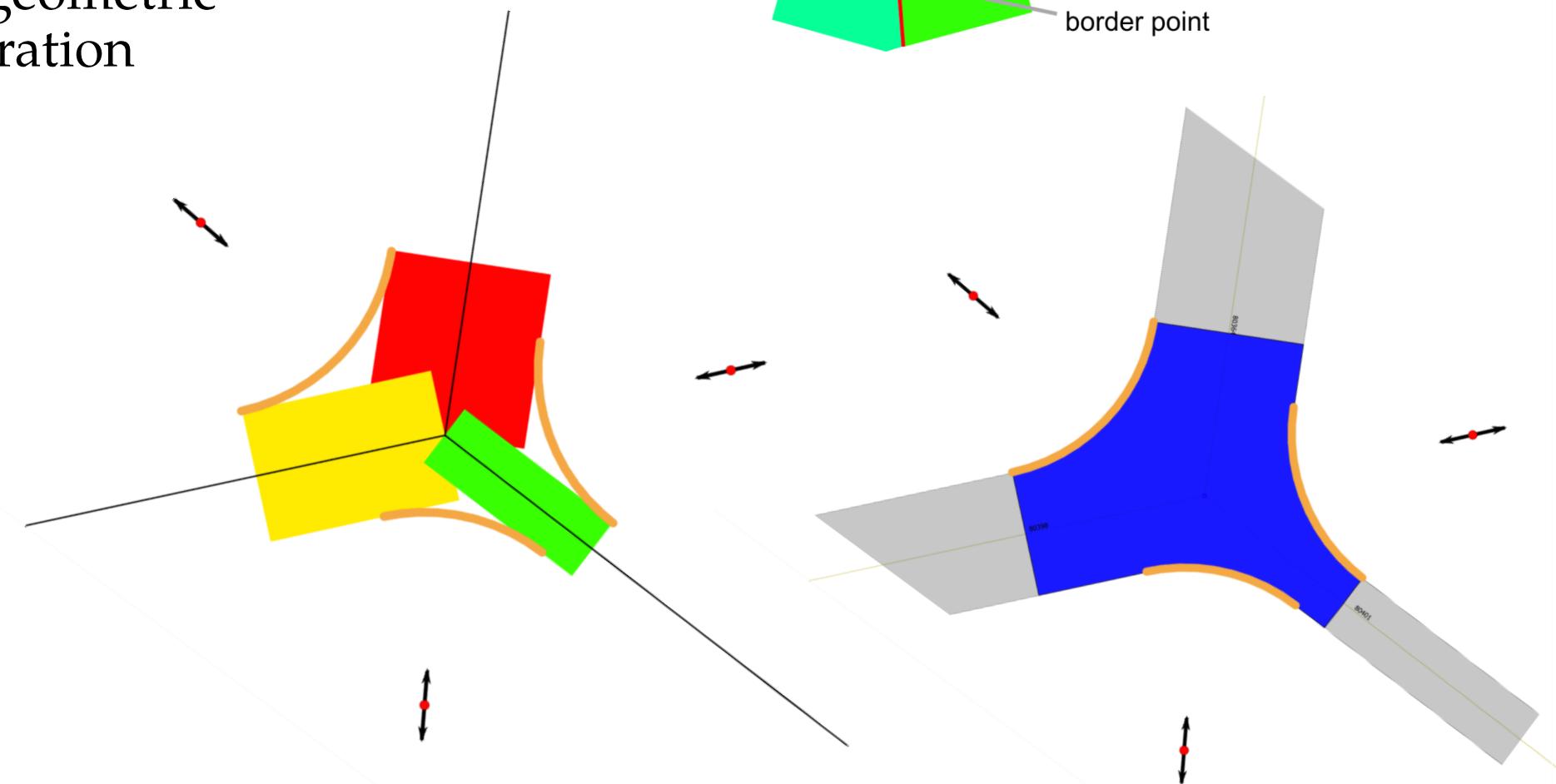
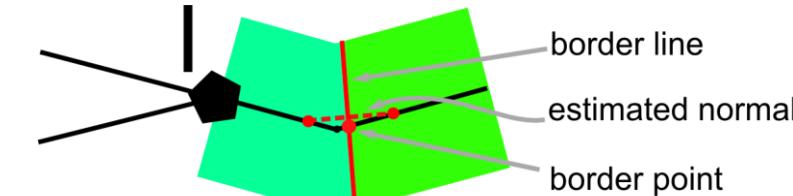


StreetGen : Road surface

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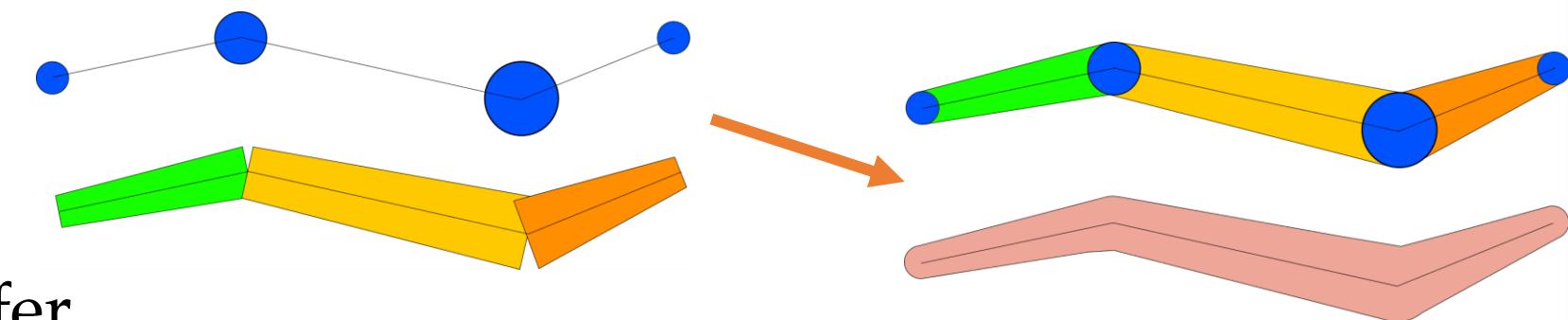
- Intersection surface :
 - By geometric operation



StreetGen : Road surface

edge id=15; next_l=16
end_node=3 ...

- Special intersection:
- Variable buffer



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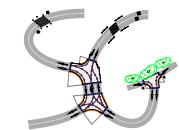
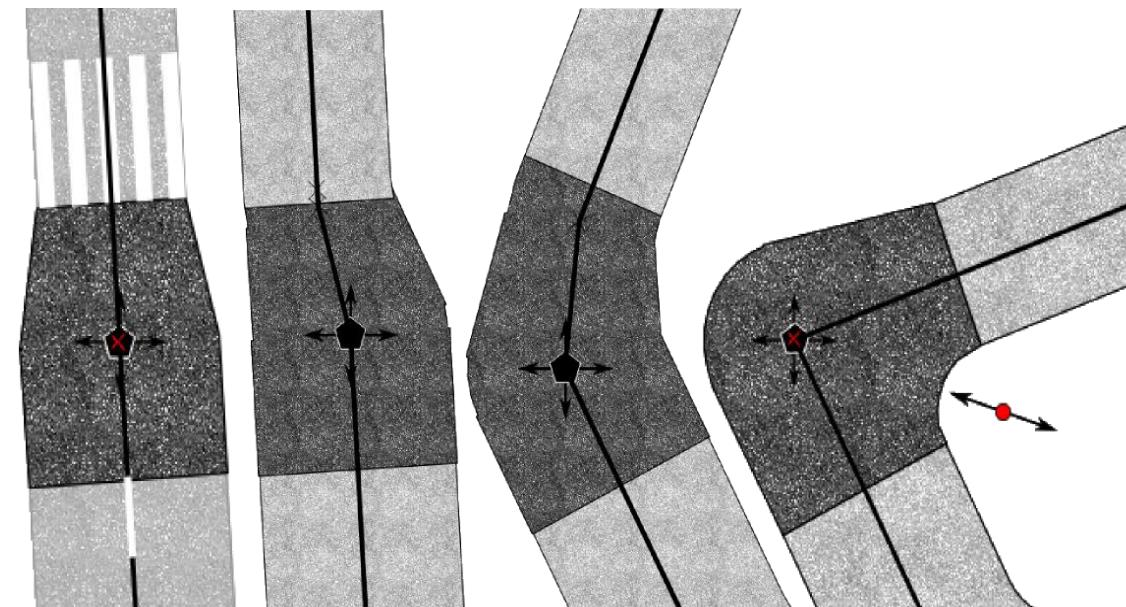
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StreetGen : Road surface

edge id=15; next_l=16
end_node=3 ...

- results

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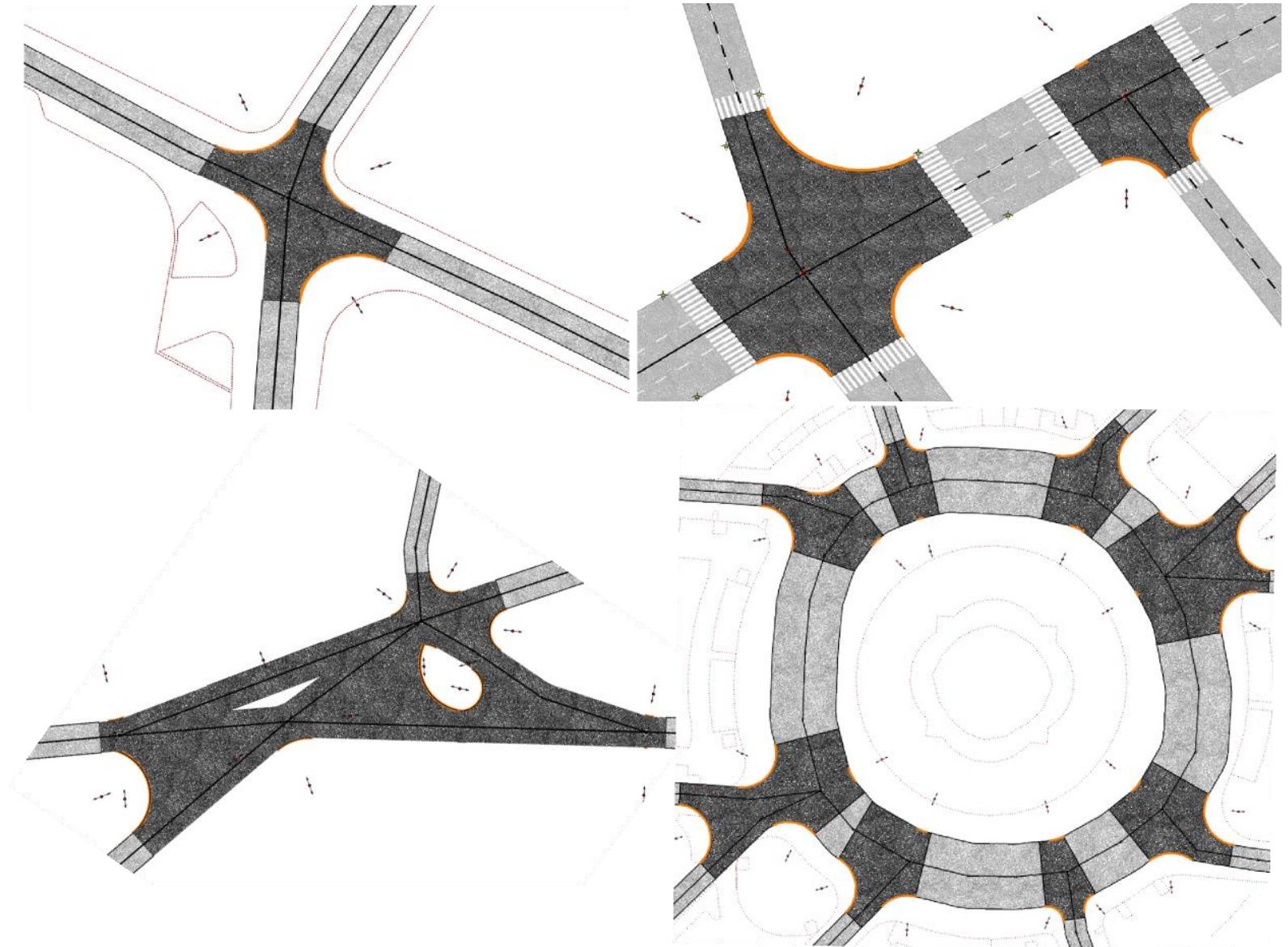
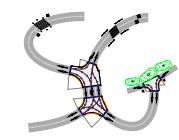
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StreetGen : Road surface

edge id=15; next_l=16
end_node=3 ...

- Results whole Paris

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edge id=15; next_l=16
end_node=3 ...

edge id=16; next_l=17
start_node=4 ...

edge_id=17; next_l=16
start_node=4 ...

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StreetGen : generate streets

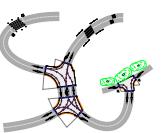
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Kinematic hypothesis

Road surface

Traffic support

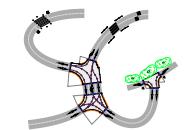
Street objects



StreetGen : Traffic Support

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- For traffic simulation:
 - Lanes
 - Possible trajectories in interconnections.
- A real traffic simulation requires much more
 - Average speed
 - Type of intersection (roundabout/traffic light)
 - Etc ...
- But : without further information, we do what we can!



StreetGen : Traffic Support

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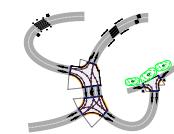
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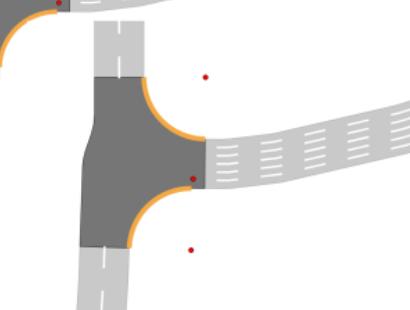
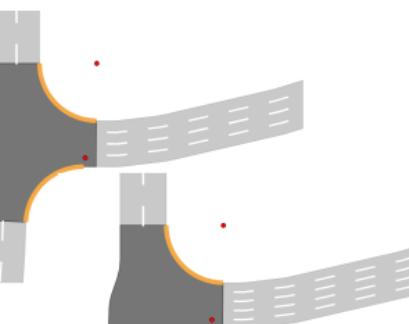
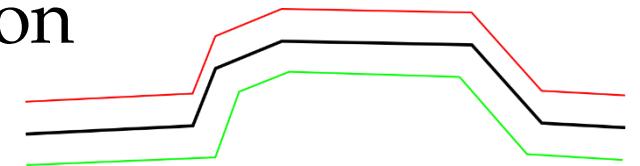
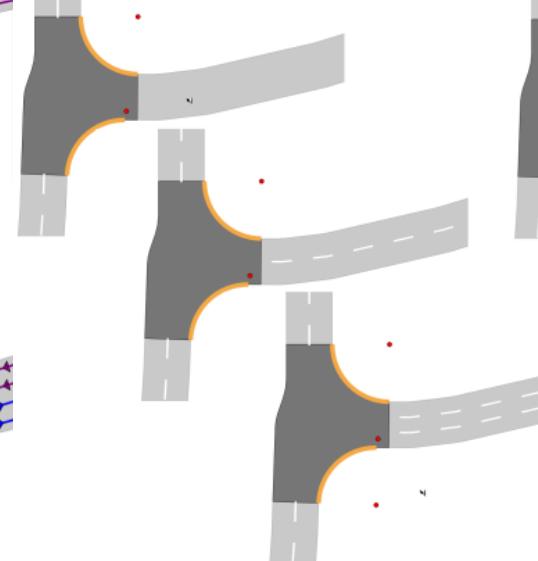
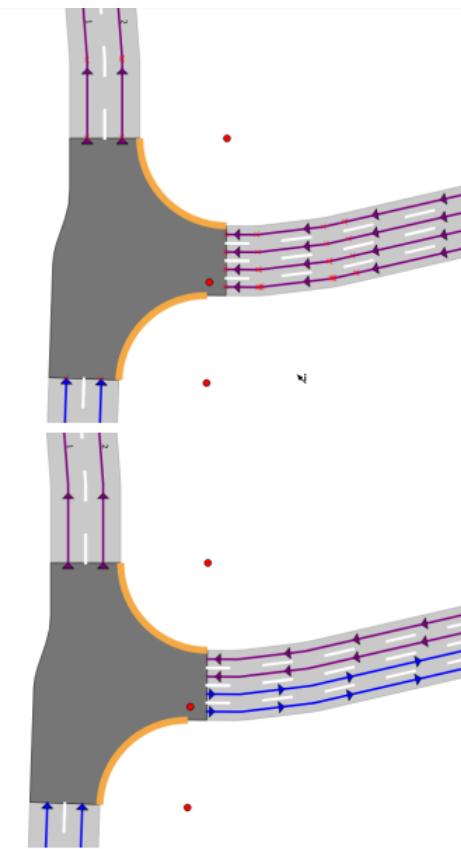
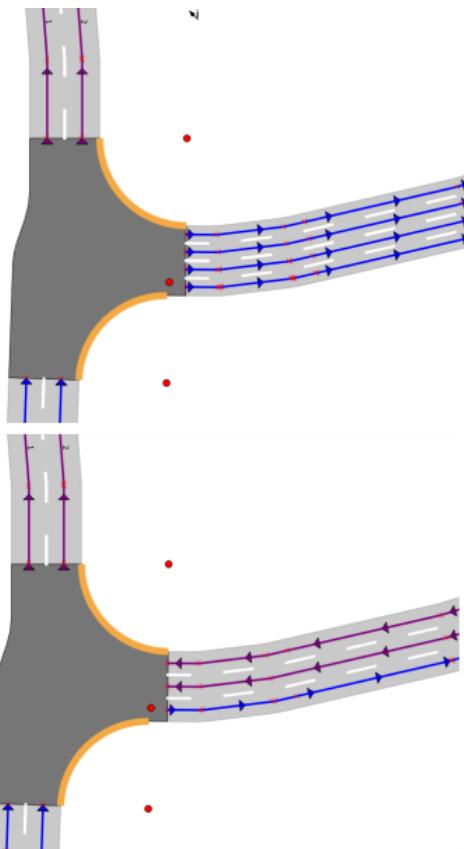
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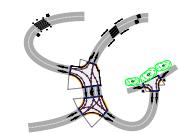


- Lane based on road axis : but not translation

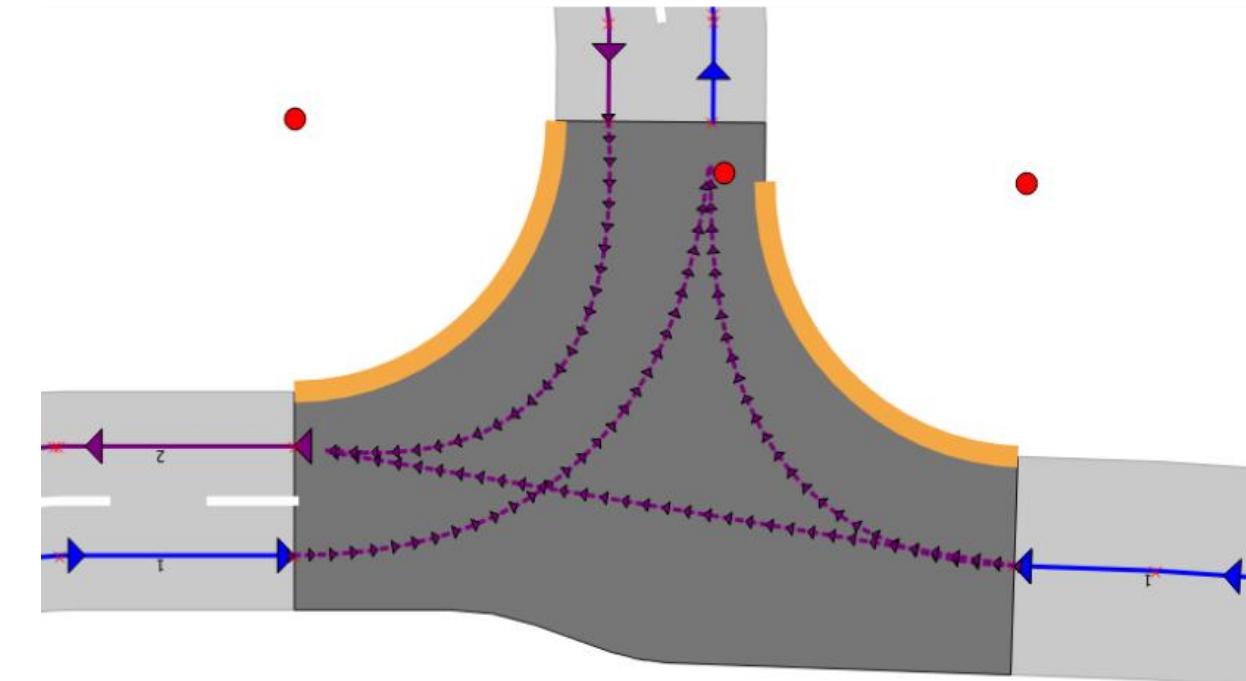
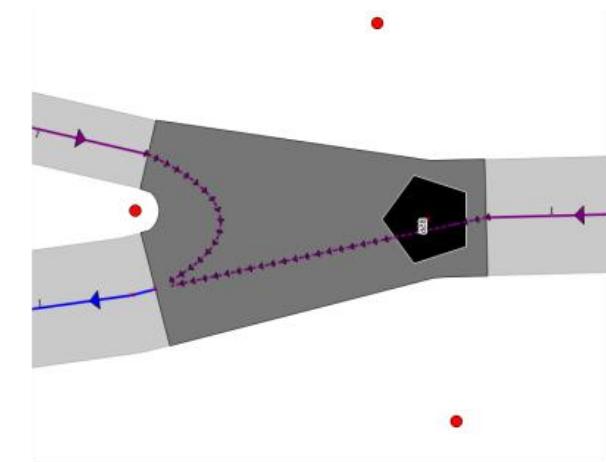
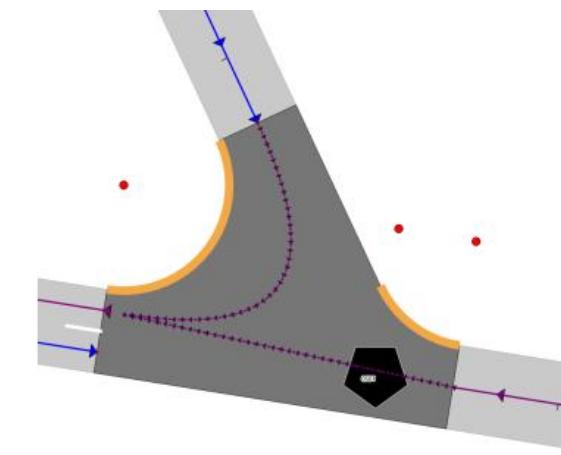


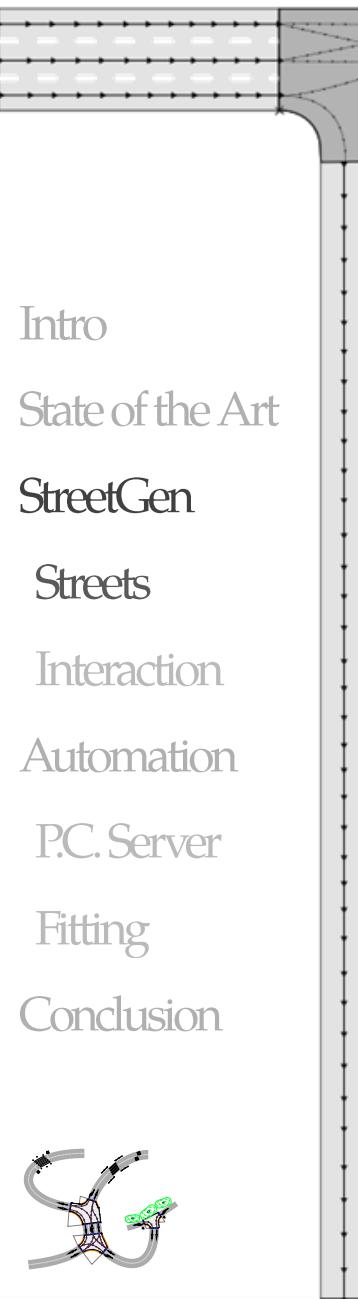
StreetGen : Traffic Support

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- Intersection trajectory : Bezier curves:
 - Not accurate (cinematically), but easy to create and edit
 - Involves center of intersection in special cases

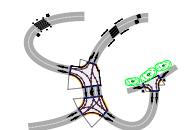




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StreetGen : street objects

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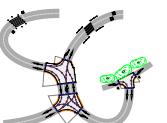
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- Streets objects : incredibly varied
 - 13k references on ArchiExpo
 - Markings : 1k pages of norms
 - ...
 - Objects are in relation (hierarchical, spatial, semantic ...)
 - Not many common points between all kind of street objects
 - Street objects are often spatially organized relatively to the street axis

StreetGen : street objects

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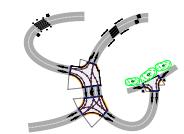
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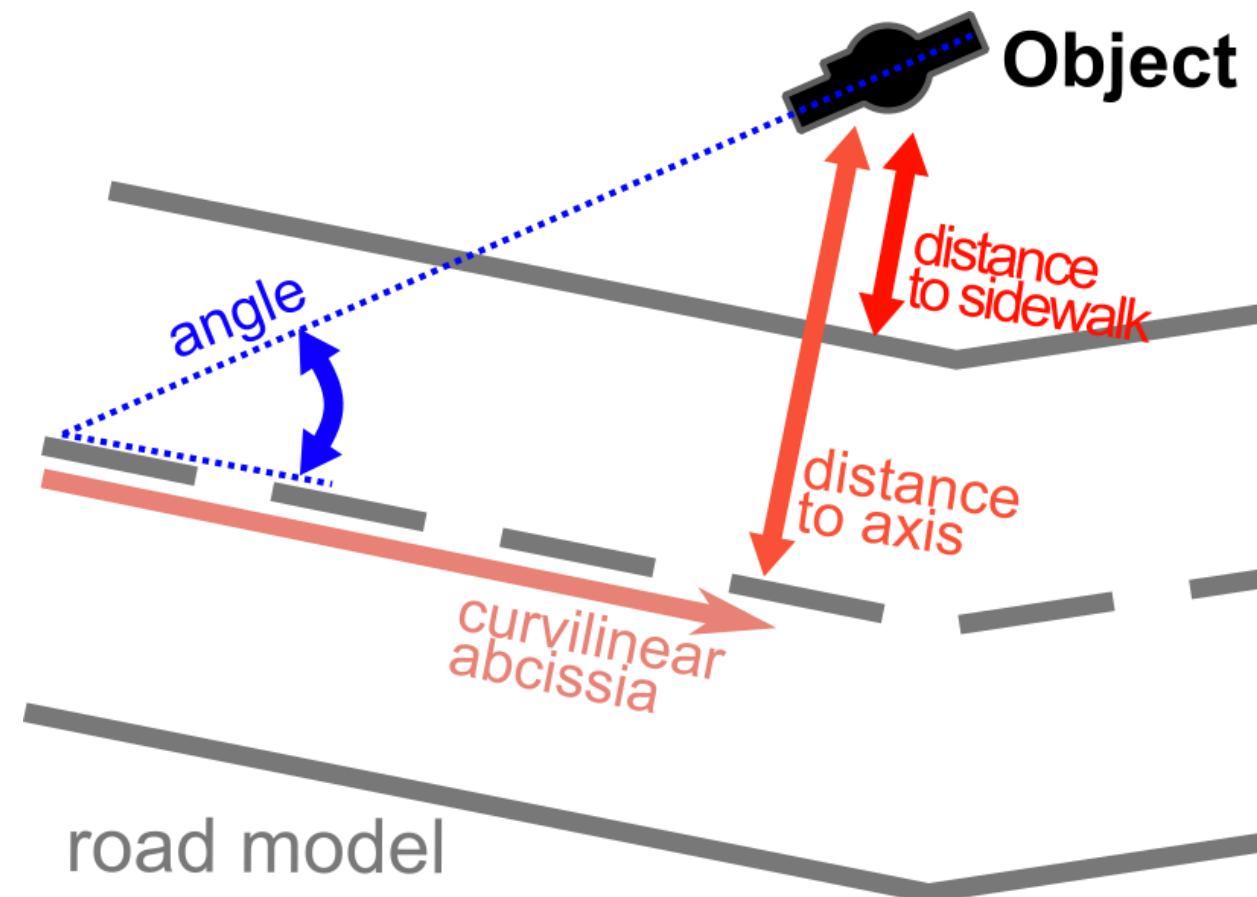
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- So we use generic objects
 - Positioned/oriented relatively to street axis



StreetGen : street objects

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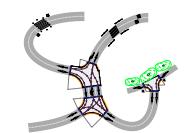
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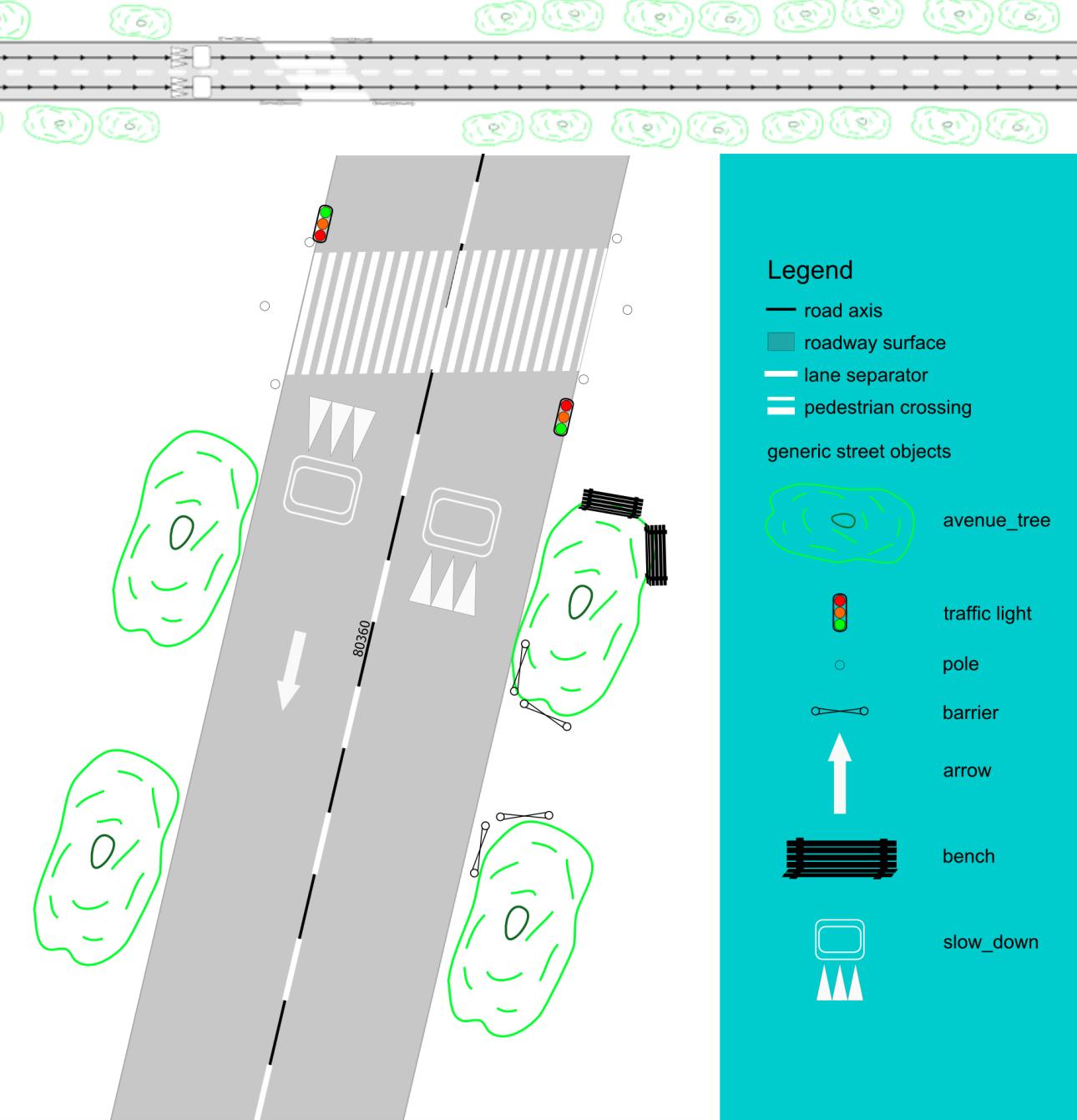
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- Objects are points with semantic
- DBMS can support any relation (hierarchy, semantic...)



StreetGen : street objects

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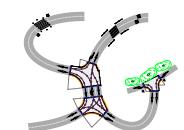
Interaction

Automation

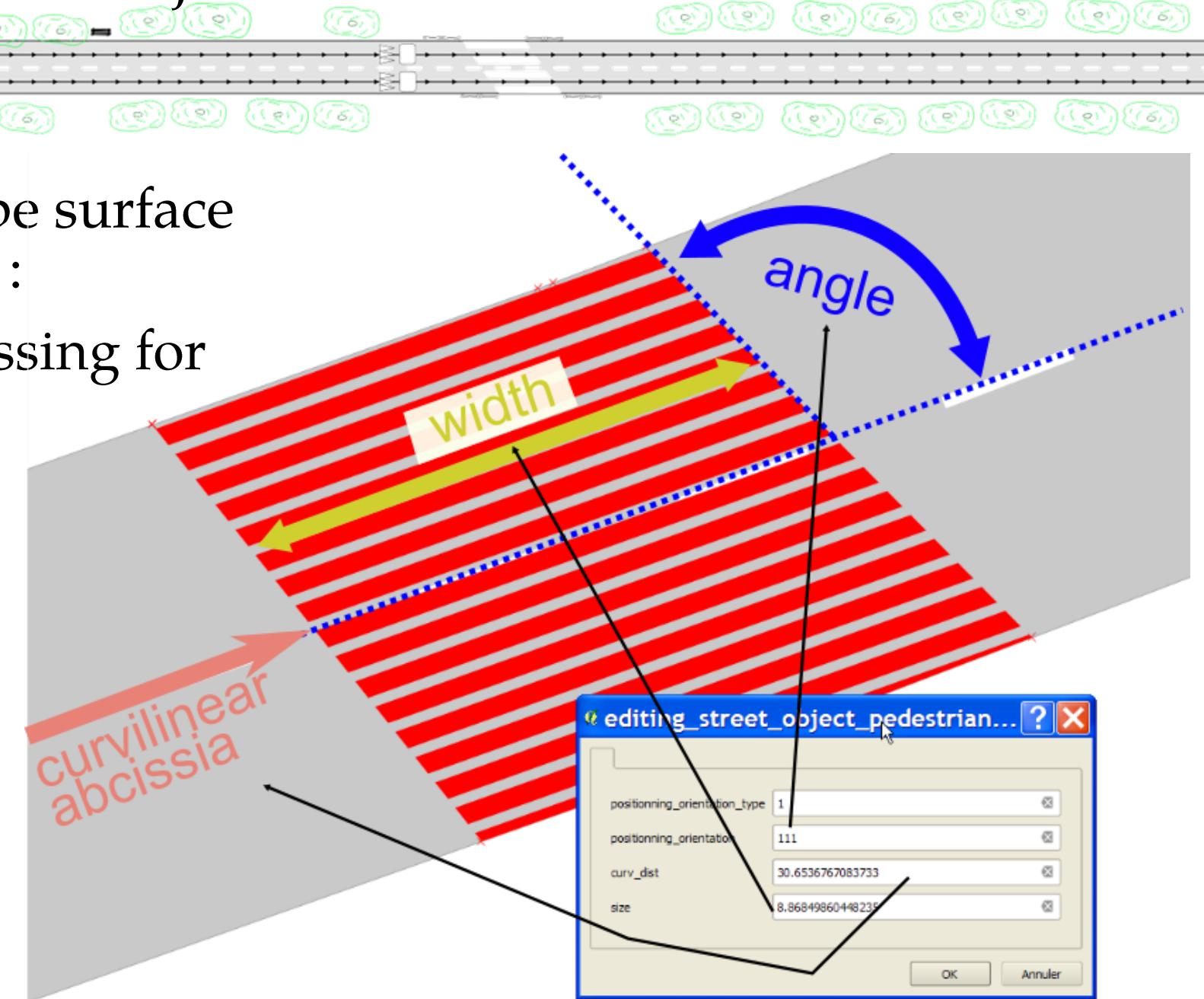
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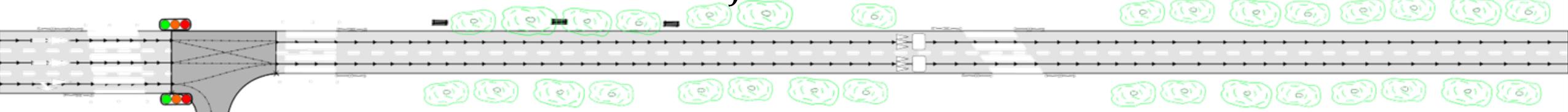
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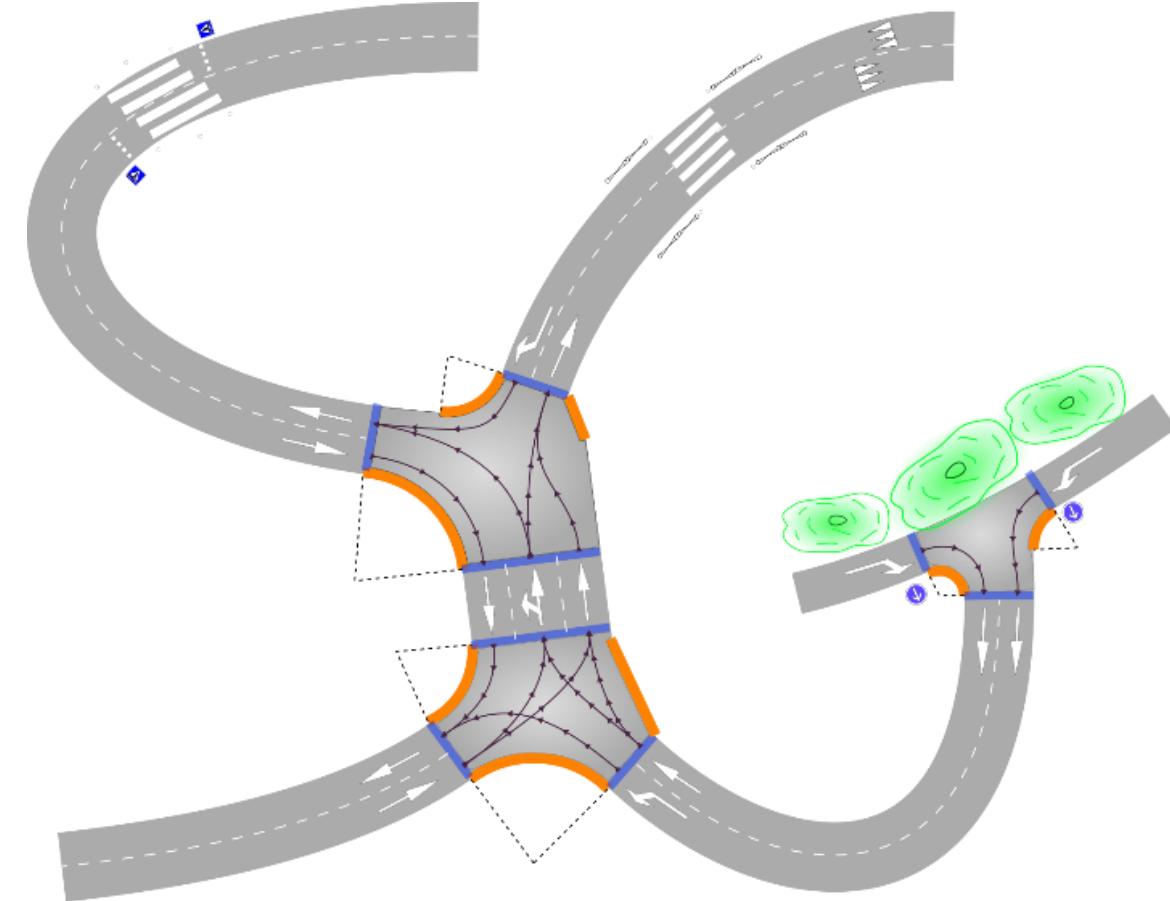
- Also can also be surface (or polylines?) :
- Pedestrian crossing for instance



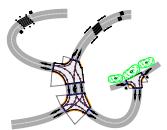
StreetGen : street objects



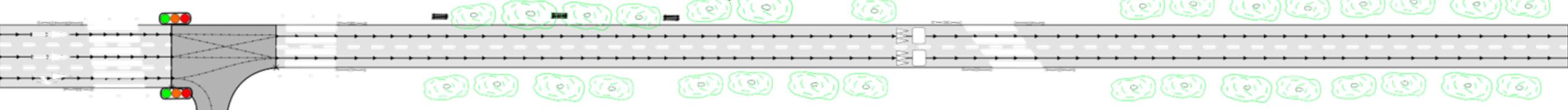
- Whole Paris in 10 min.
- Tested for simulation (SimuVia)
- Tested for 3D visu (Thales DBMaker)
- Tested to model other cities (Mali)
- Tested to model airport runway



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StreetGen : street objects



- Of course, lot of limitations
 - Street model:
 - Not enough for some street
 - Radius seems to be historical rather than related to speed
 - Technical
 - Technical glitches/bugs
 - Precision issues
 - Traffic
 - All possible interconnection : too much
 - Objects
 - Lack linear objects

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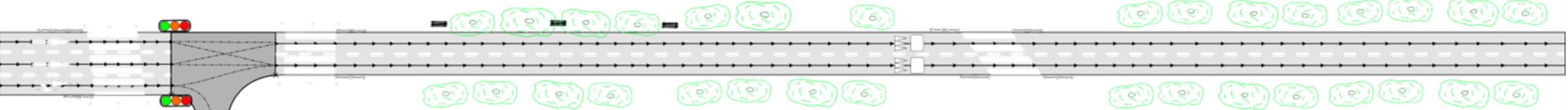
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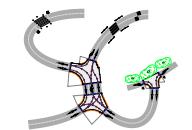


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StreetGen : editing streets (in-base)

In-base interaction Principle

- Edit road model
- Edit traffic
- Edit objects



StreetGen : street objects

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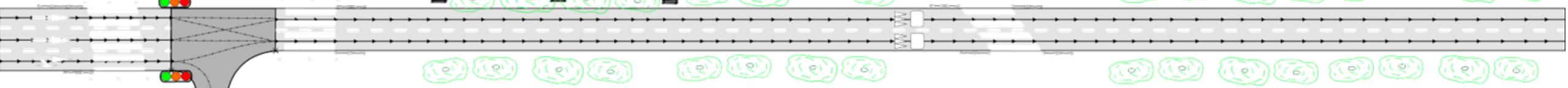
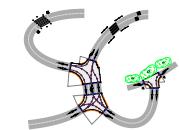
Interaction

Automation

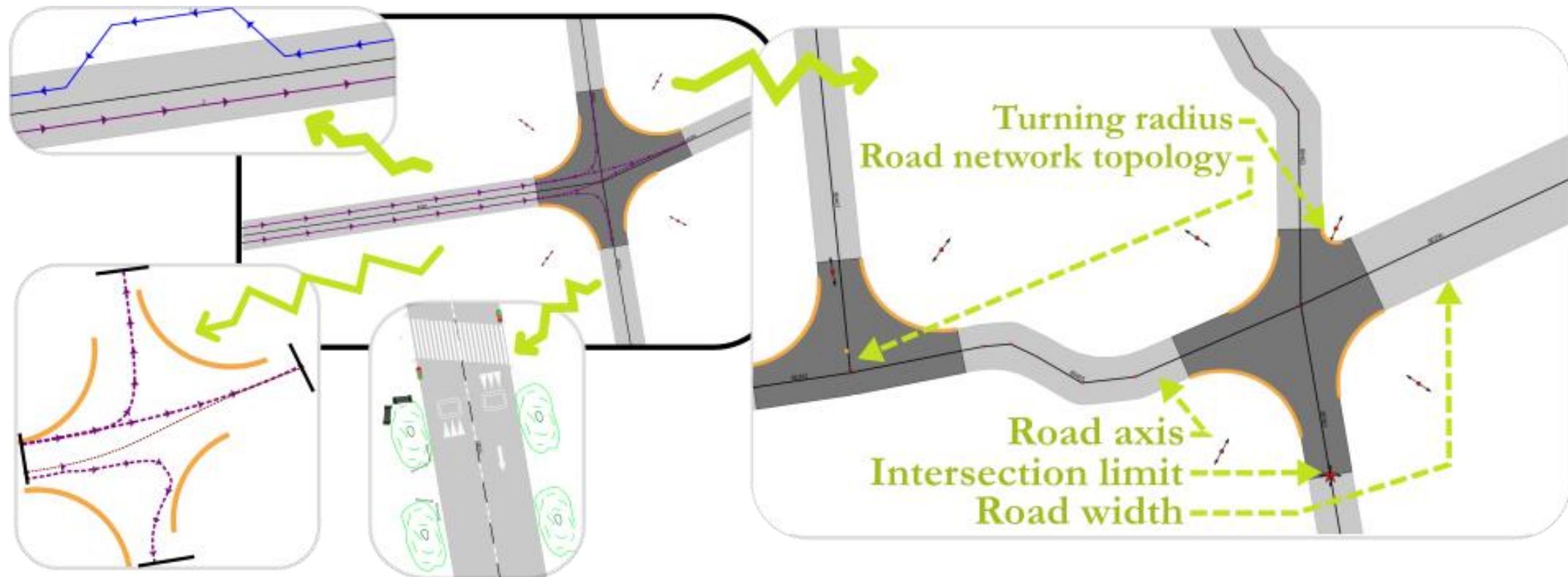
P.C. Server

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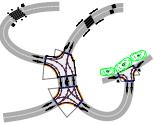


- How to edit street model easily (several concurrent users) ?

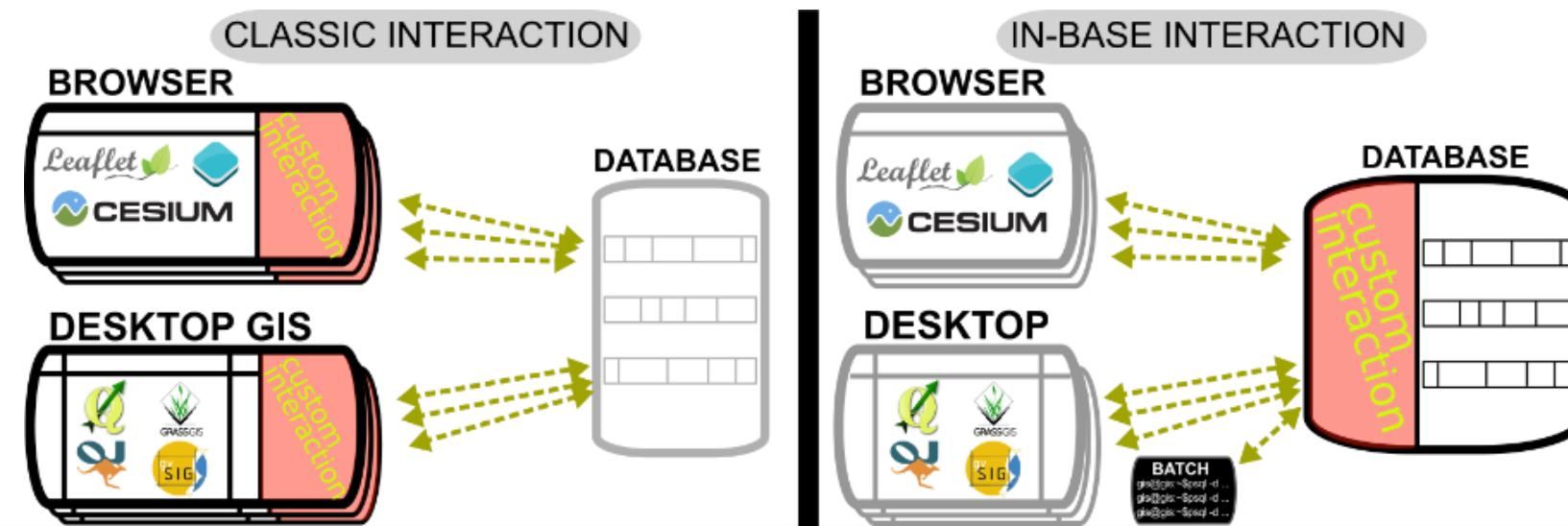


StreetGen : street objects

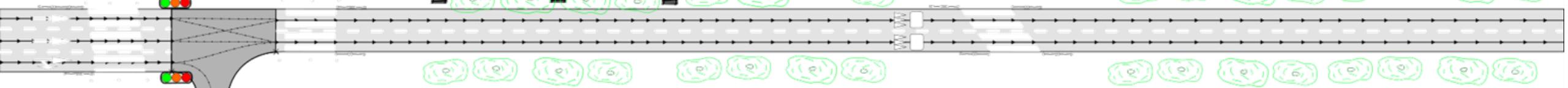
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- Fact : developing a Graphical User Interface (GUI) is hard, long and risky (maintenance)
- Many GUI for many tools (web/desktop/...)
 - Need to create plugins/interfaces/...
- Idea : use existing tools
 - GIS tools can already edit vector and attributes
 - specific interactions are in base



StreetGen : street objects



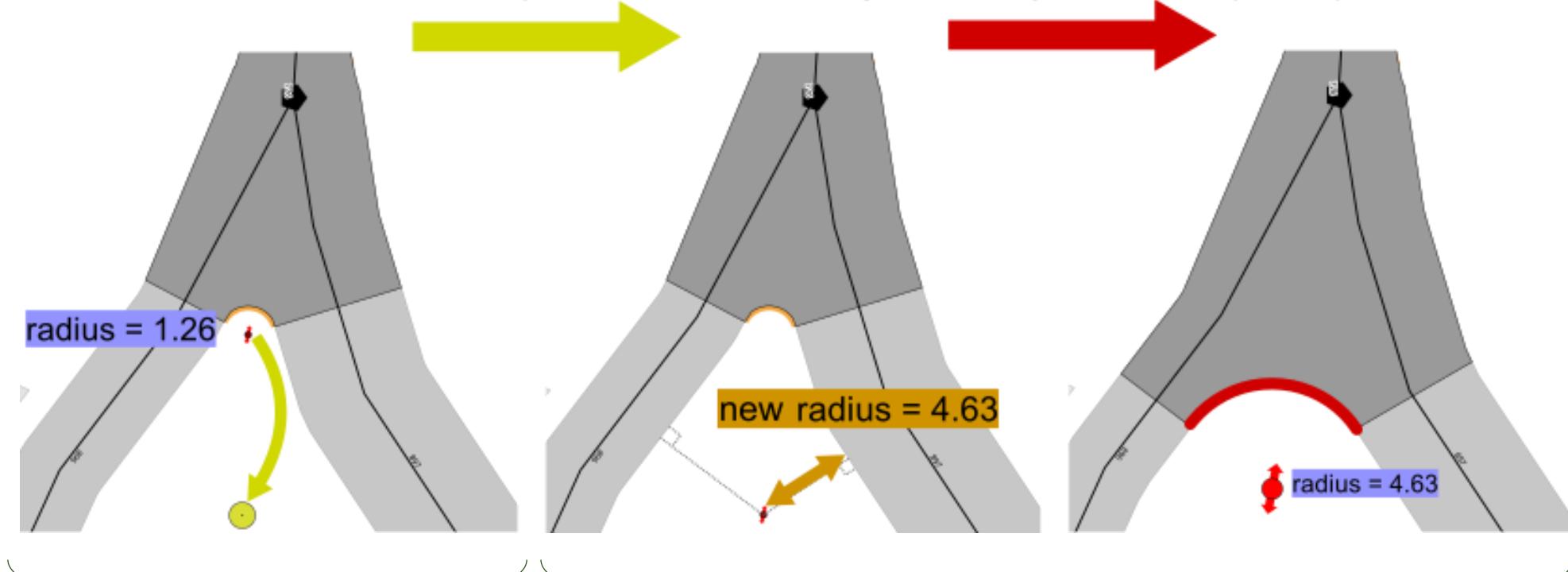
- example:

User

User edited proxy view:
interpret to get new radius

Automated

Radius has been changed :
generate geometries (arc ...)



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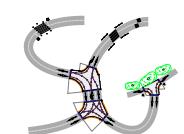
Interaction

Automation

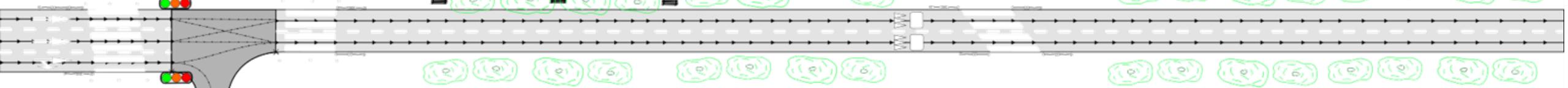
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StreetGen : street objects



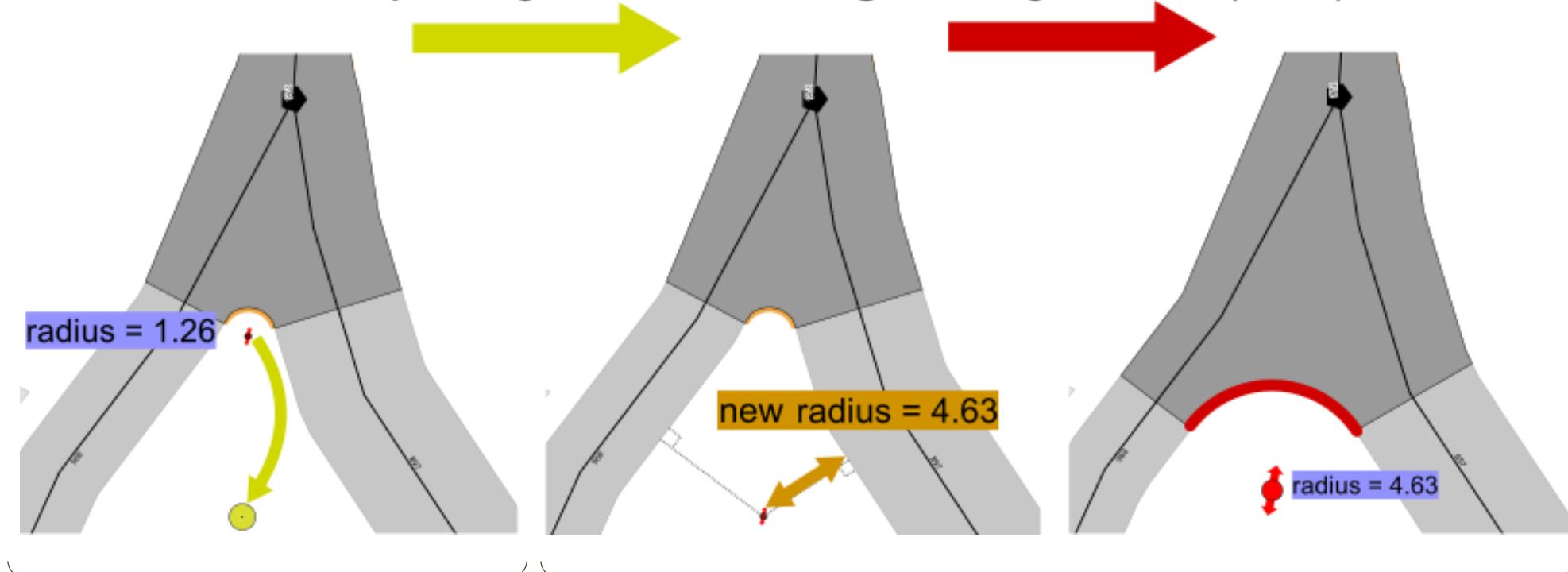
- example:

User

User edited proxy view:
interpret to get new radius

Automated

Radius has been changed :
generate geometries (arc ...)



In GIS software

In base

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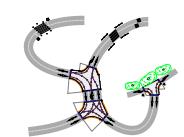
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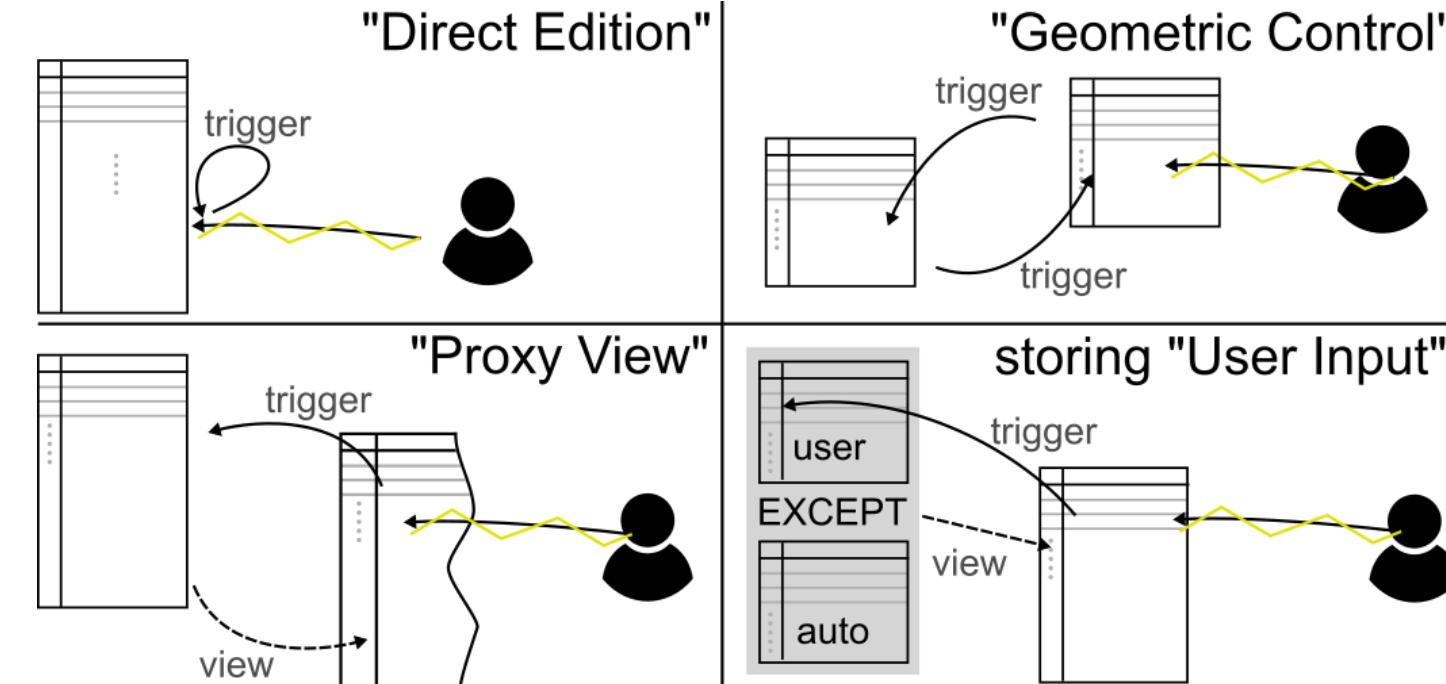


StreetGen : street objects

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- In-base interaction are generic and powerful
 - Extensively uses triggers
 - Several design patterns
 - Help create interactions
 - Help manage user input



StreetGen : street objects

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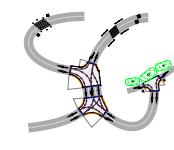
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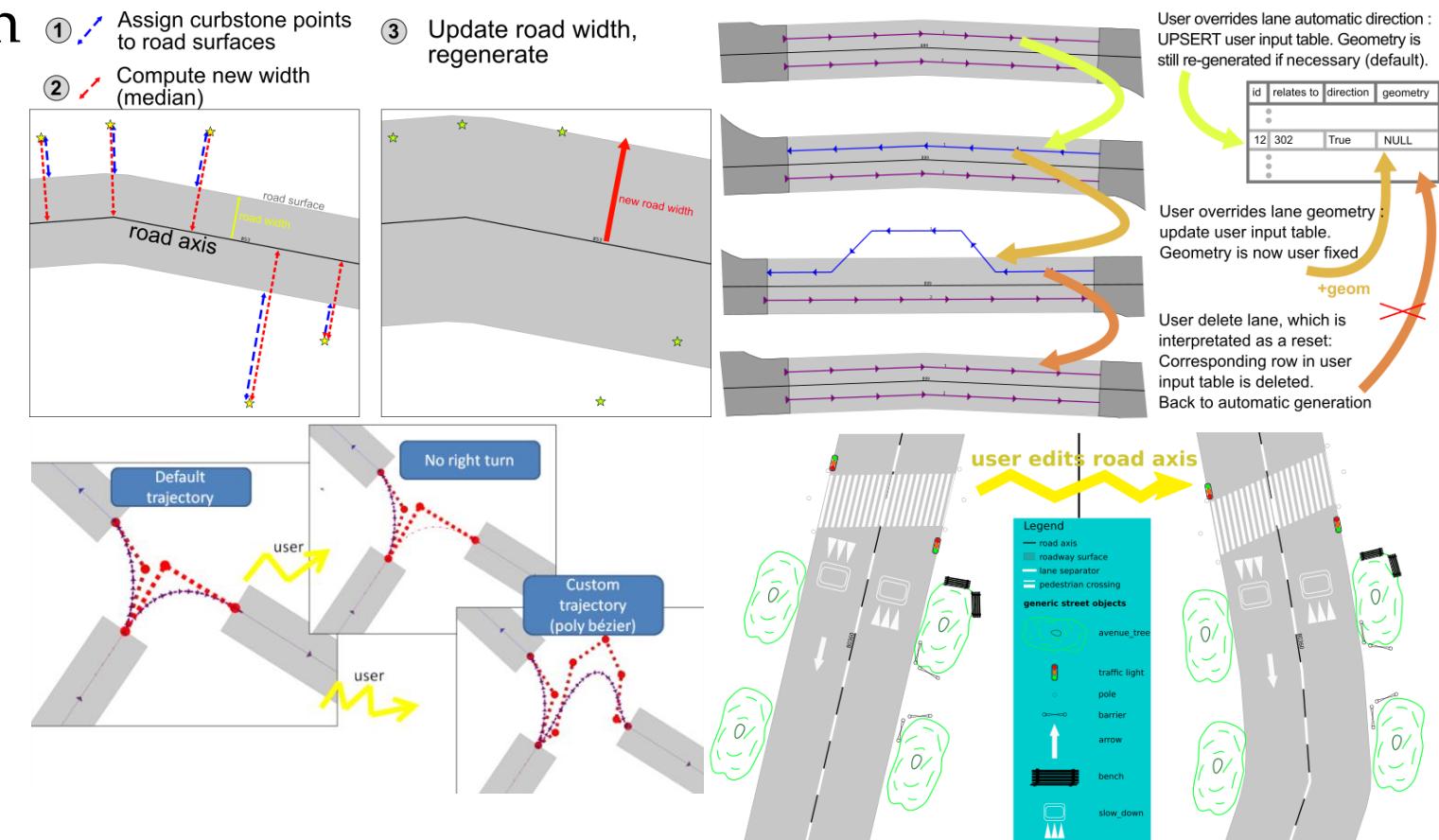
Fitting

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- All StreetGen street model can be edited concurrently

- Road axis / width
- Radius
- Lane
- Interconnection
- objects



StreetGen : street objects

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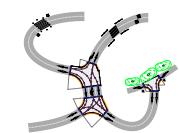
Interaction

Automation

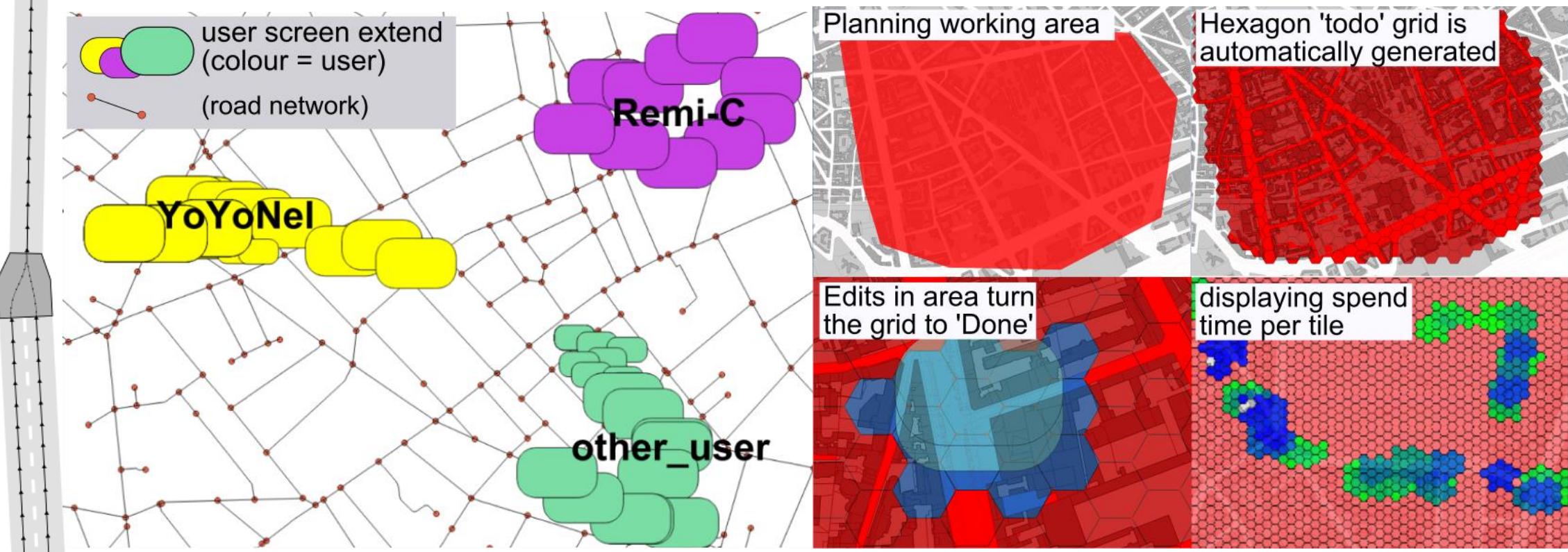
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- Multi-user editing can be facilitated
- “Interactive Map Tracking” QGIS plugin with Lionel Atty



StreetGen : street objects

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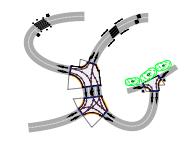
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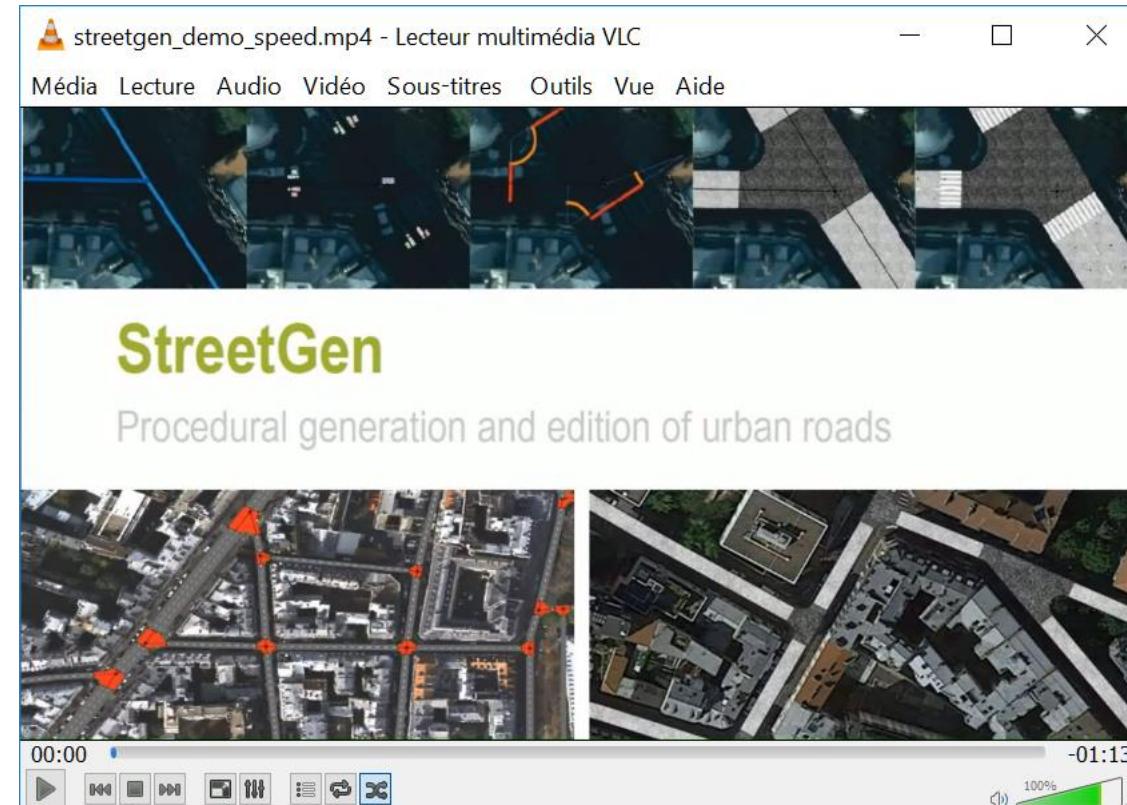
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- Results:

- Interaction are fast enough to be interactive

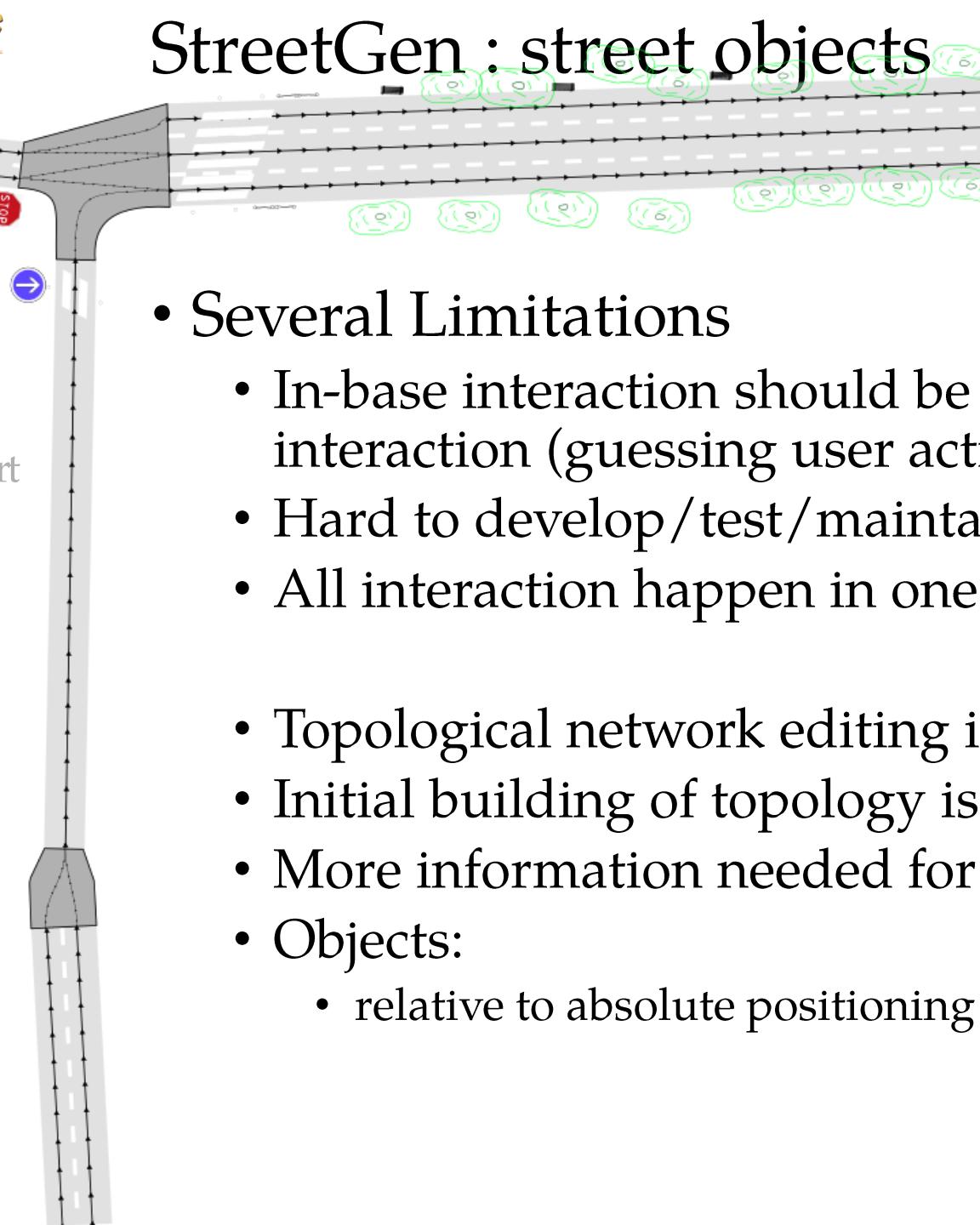
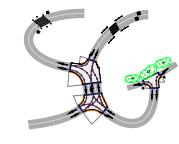


Video

<https://youtu.be/fQZoEfUcNHA>

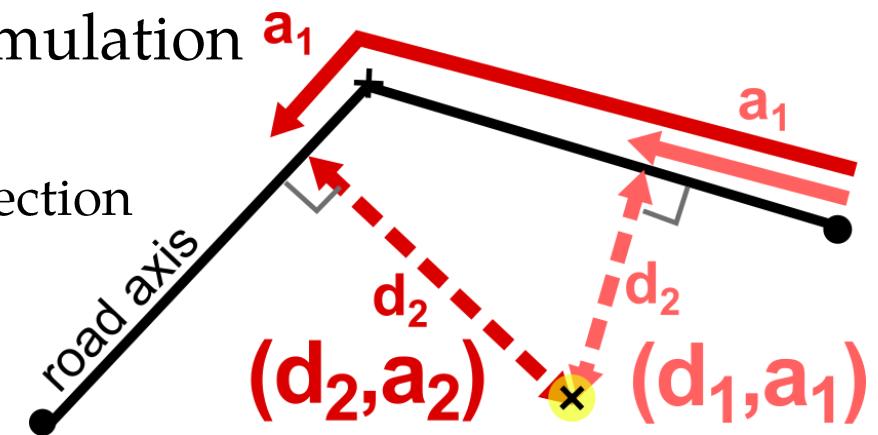
StreetGen : street objects

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- Several Limitations

- In-base interaction should be limited to straightforward interaction (guessing user action is easy)
- Hard to develop/test/maintain (no modern signal feature)
- All interaction happen in one transaction → should be short
- Topological network editing is limited (ill-posed problem)
- Initial building of topology is slow
- More information needed for traffic simulation
- Objects:
 - relative to absolute positioning is not a bijection



width= 8; lane= 3

width= 6; lane= 2

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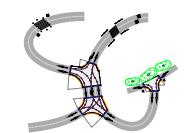
width= 4; lane= 1

Automating street modelling

Inverse procedural modelling

Data: Point Cloud Server

Fitting model to real streets



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

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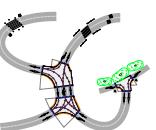
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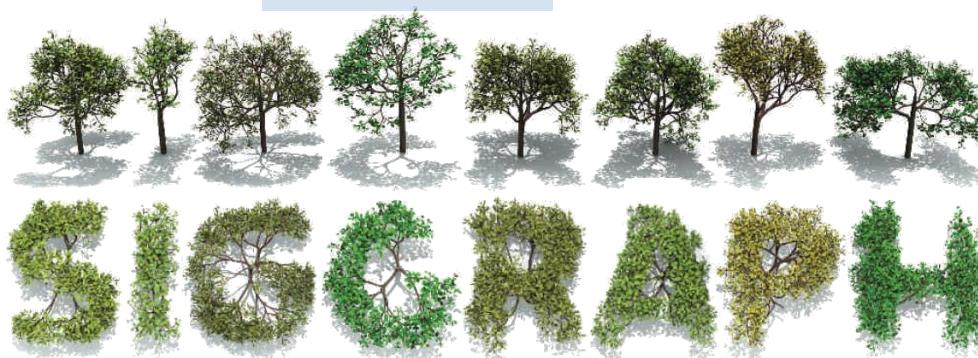
Fit a generic
procedural model to a
specific situation

Specific situation?
→ We need data!

Simon2011



Talton2011



Abstract

Chapter 2

Sensing data



Chapter 3

Road axis + attributes



Point Cloud Server

Chapter 2, 5
Appendix 1

Urban feature observations



Chapter 4

Interactive
in base
edition

StreetGen

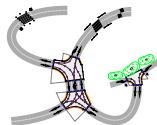
Chapter 5

Automatic
Street Model
fitting

Street Modelling



Procedural Street Modelling



Abstract

Chapter 2

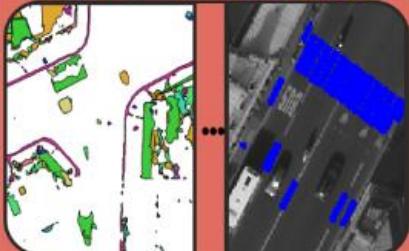
Sensing data



Point Cloud Server

Chapter 2, 5
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Urban feature observations



Road axis + attributes



Chapter 3

Inverse Procedural Street Modelling

Chapter 4

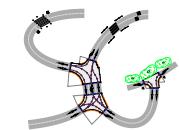
Interactive in base edition

StreetGen

Chapter 5

Automatic Street Model fitting

Street Modelling



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

- What type of data for streets?

- Precise
- Good coverage
- Frequent

- Aerial image? 

→ Too far!



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

- IGN dedicated mobile mapping: Stereopolis
 - Cameras
 - Lidar

width= 4; lane= 1



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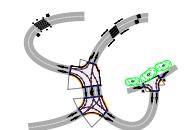
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StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Street view:

- Good coverage



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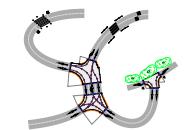
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width= 4; lane= 1



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Lidar: 3D point clouds

- precise 3D



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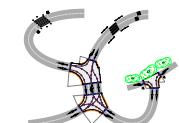
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width= 4; lane= 1



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Demo mobile mapping Lidar (Velodyne)

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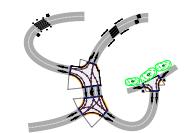
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width= 4; lane= 1

Demo Lidar



width= 8; lane= 3

width= 6; lane= 2

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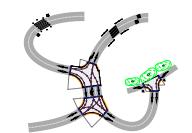
width= 4; lane= 1

Automating street modelling

Inverse procedural modelling

Data: Point Cloud Server

Fitting model to real streets



Point Cloud Server



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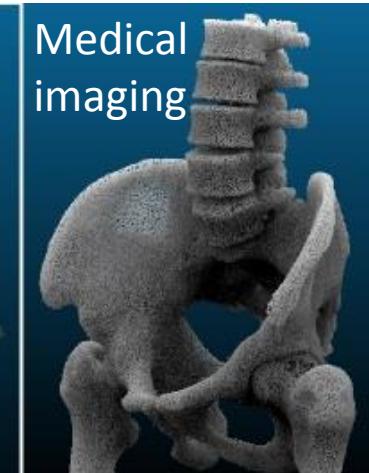
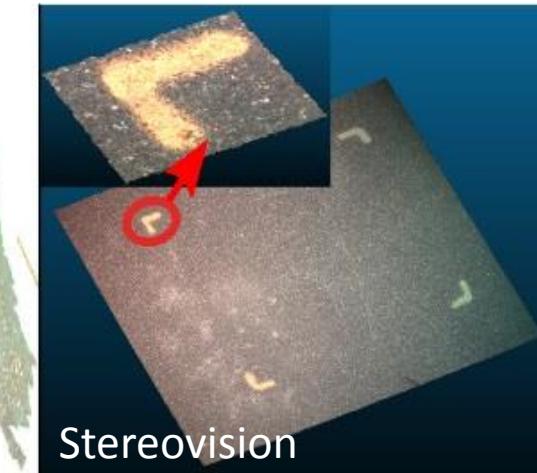
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- Point Cloud Server : manage massive amounts of geospatial point clouds in a database.
- Many type of geospatial point clouds



Point Cloud Server: Problems

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- Problem:
 - Massive data → need
 - Sharing
 - Filtering
 - Efficient I/O
 - Compression
 - Very specific for various purposes
(many tools/format/usage)
 - Point cloud != only processing
 - need to manage the entire pipeline
 - need meta data / contextual information
 - cross use with other data

Point Cloud Server: State of the art

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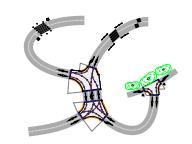
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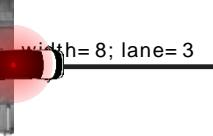
Conclusion



- File-based
 - Simple, no concurrency
 - Can't do much with points
- DBMS (point storing)
 - Powerful
 - Can't scale
- NoSQL
 - Scale well
 - Specific and tailored
- Cloud
 - Ultimate scaling
 - Theoretical problem with indexing
- DBMS (group of points storing)
 - All inclusive
 - Points need to be group-able

width=6; lane=2

width=4; lane=1



Otepka et al., 2013

Rieg et al., 2014

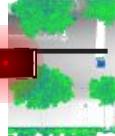
van Oosterom et al., 2015

Managing
billions of nD-
points : difficult !

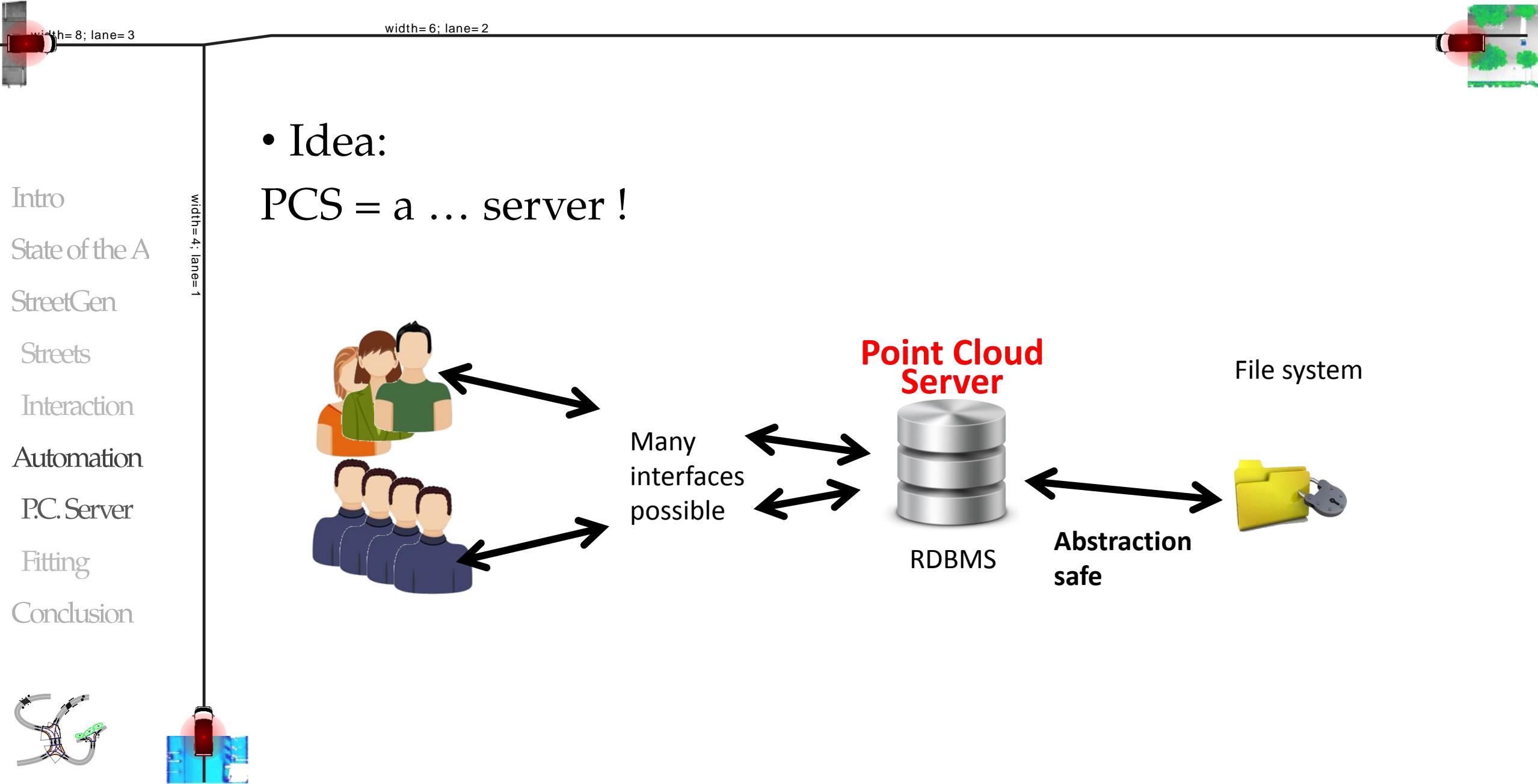
Greyhound



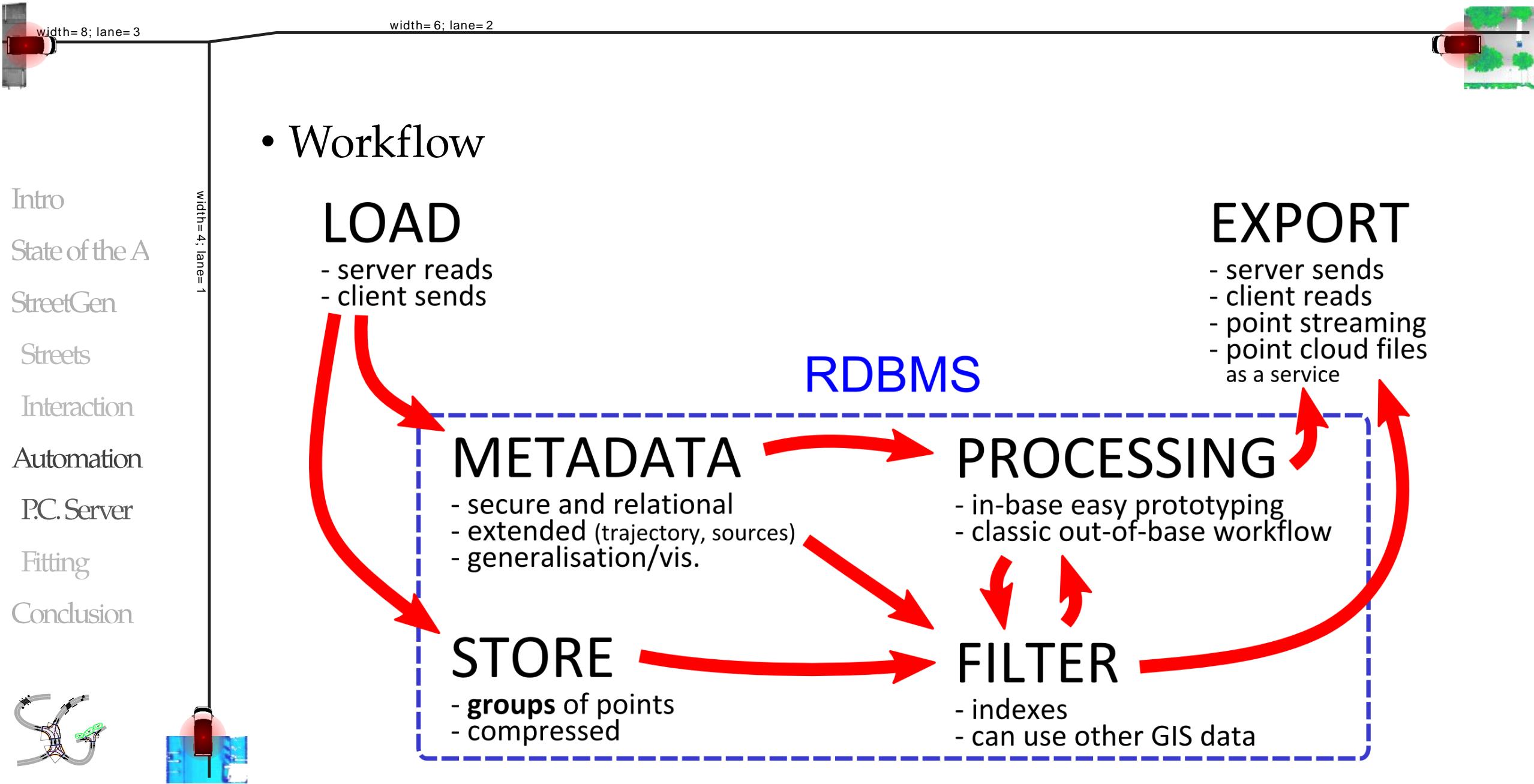
Managing **millions** of
groups of points: easy!



Point Cloud Server: Method



Point Cloud Server: Method



Point Cloud Server: Method

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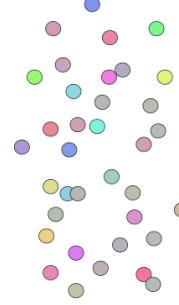


- Main idea about storing

1 point =

GPS_time (s)	X (m)	Y(m)	Z(m)	reflectance (....)
54160.295	2068.230	20690.025	45.934	-9.4497 (....)

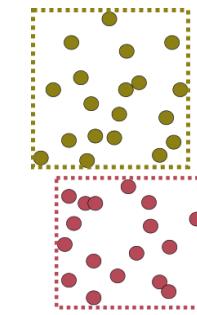
1 row = 1 point
Analogy : Pixels



Billions points



1 row = N points
Analogy : Image

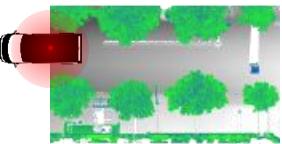


Million groups



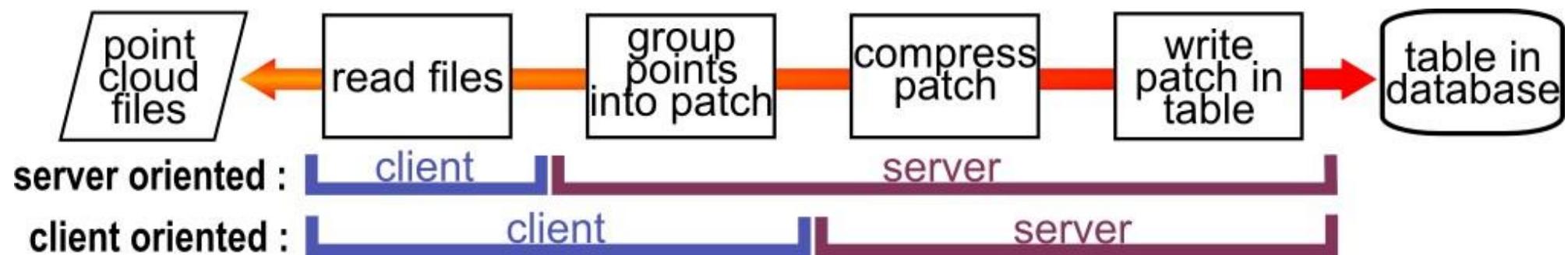
Usage : do we really need
to get points 1 by 1?





Point Cloud Server: Loading/Exporting

- Loading/exporting points into the PCS:
 - 2 flavors : how much does the server work?



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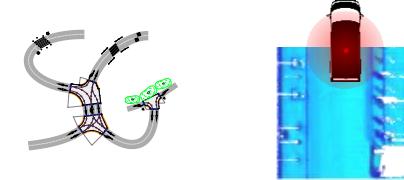
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Point Cloud Server: Loading/Exporting



Paris

- Terrestrial lidar
- 2.15 B points
- 750 ply files
- 42 linear km
- 21 attributes
- Typical resolution: 1 cm

Point Cloud Server: Loading/Exporting



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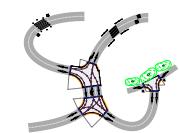
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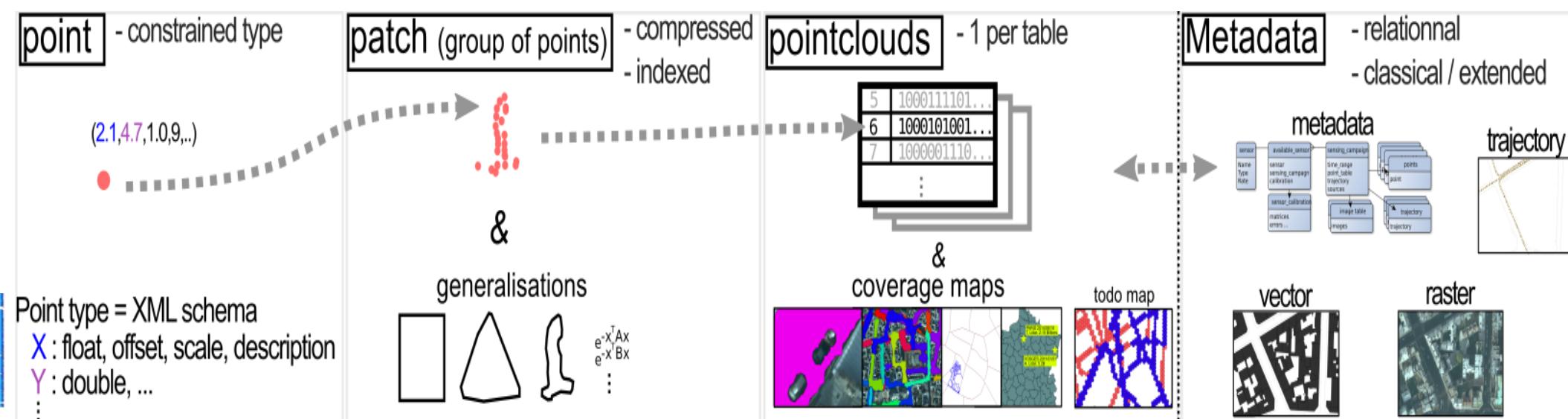
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- Paris loading speed: 75k pts/s writing : 200k pts/s
 - Not far from actual sensing speed
 - Could be faster ([Vanoosterom2015](#))
- We load point clouds, but how are they stored?

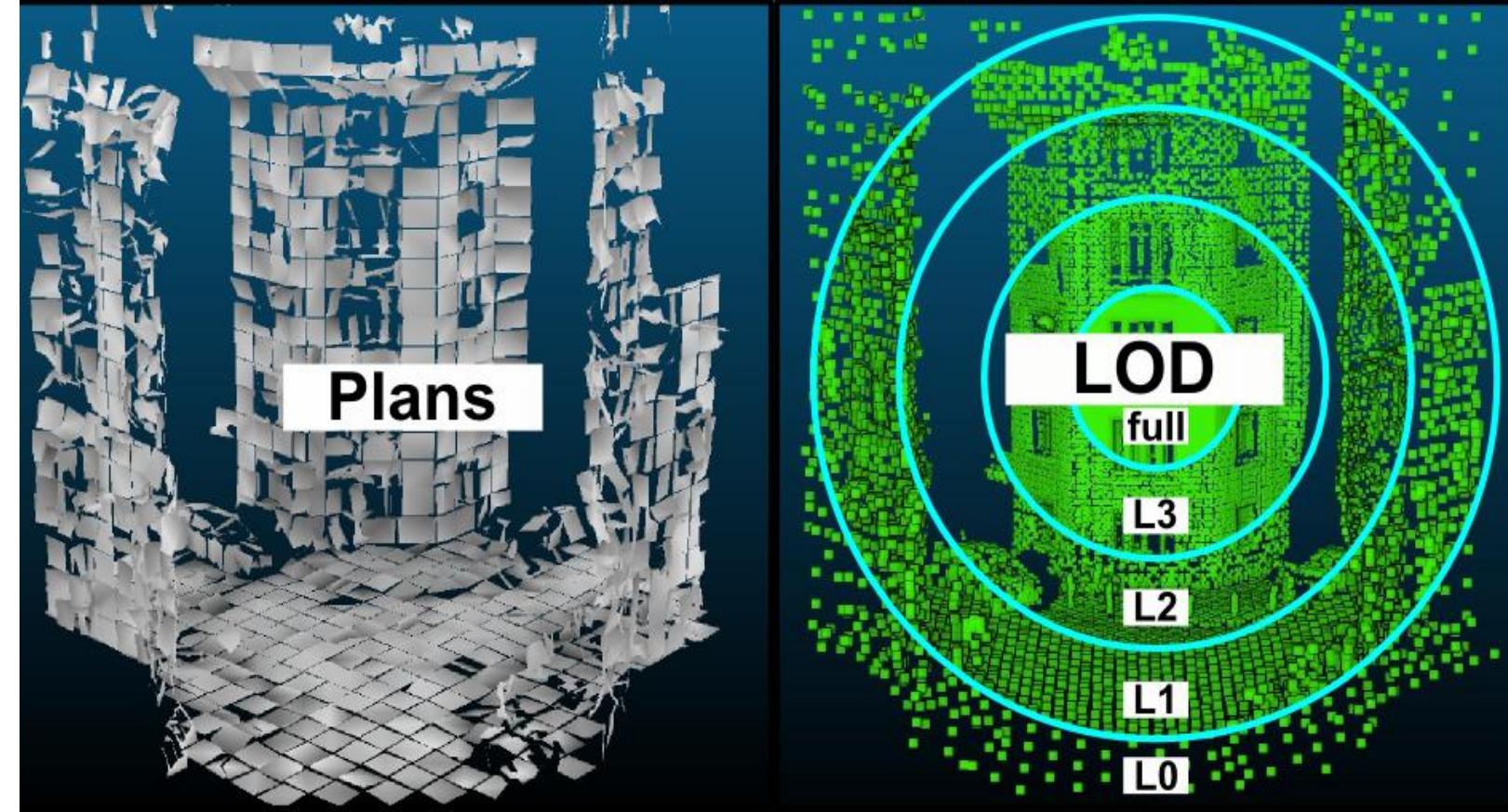


Point Cloud Server: generalisation



- Group of points (aka patch) generalisation
 - Generalisation = abstraction

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Point Cloud Server: generalisation



- Other generalisation

- Essential : abstracting the data = more abstract usage
- Ex : points within flat neighborhood vertical VS points in a wall

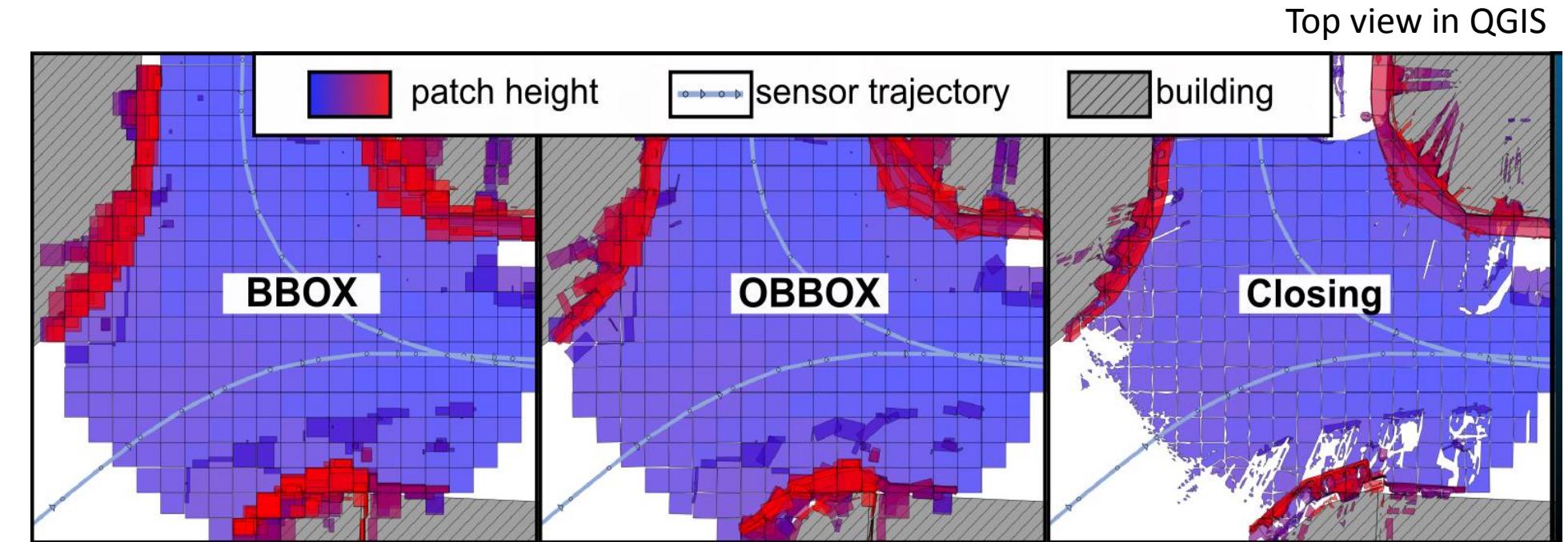
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width=4; lane=1

width=6; lane=2

width=8; lane=3



Point Cloud Server: processing



- More generalisation

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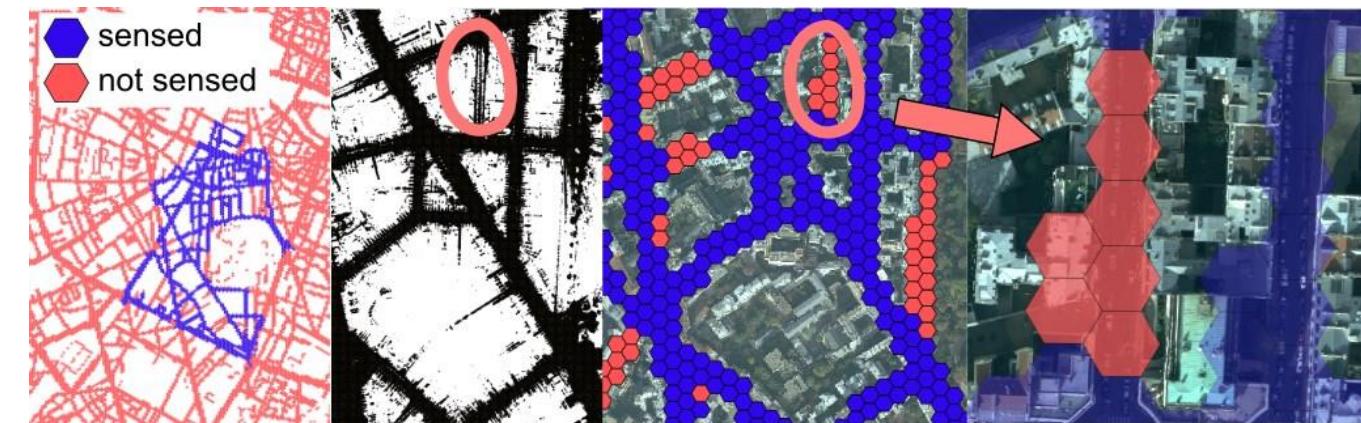
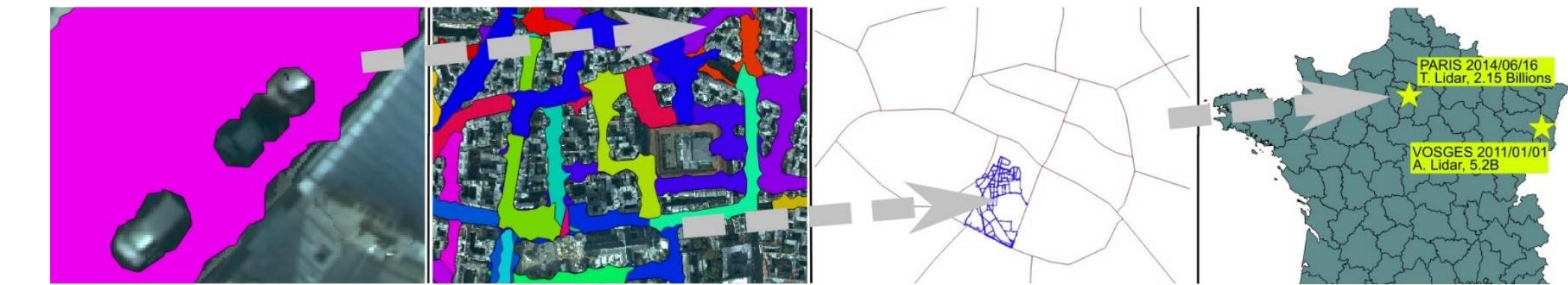
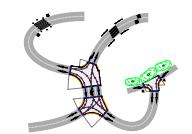
Interaction

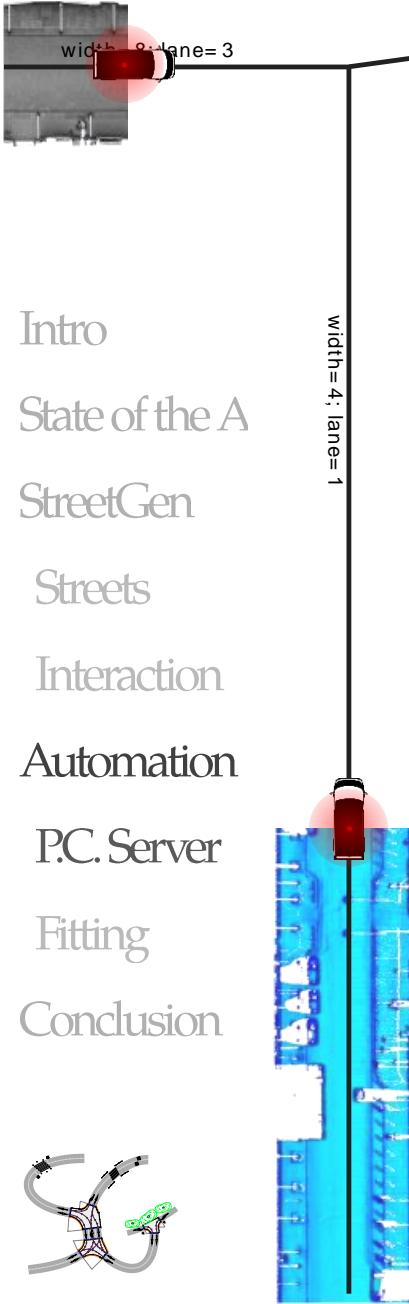
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Point Cloud Server: filtering

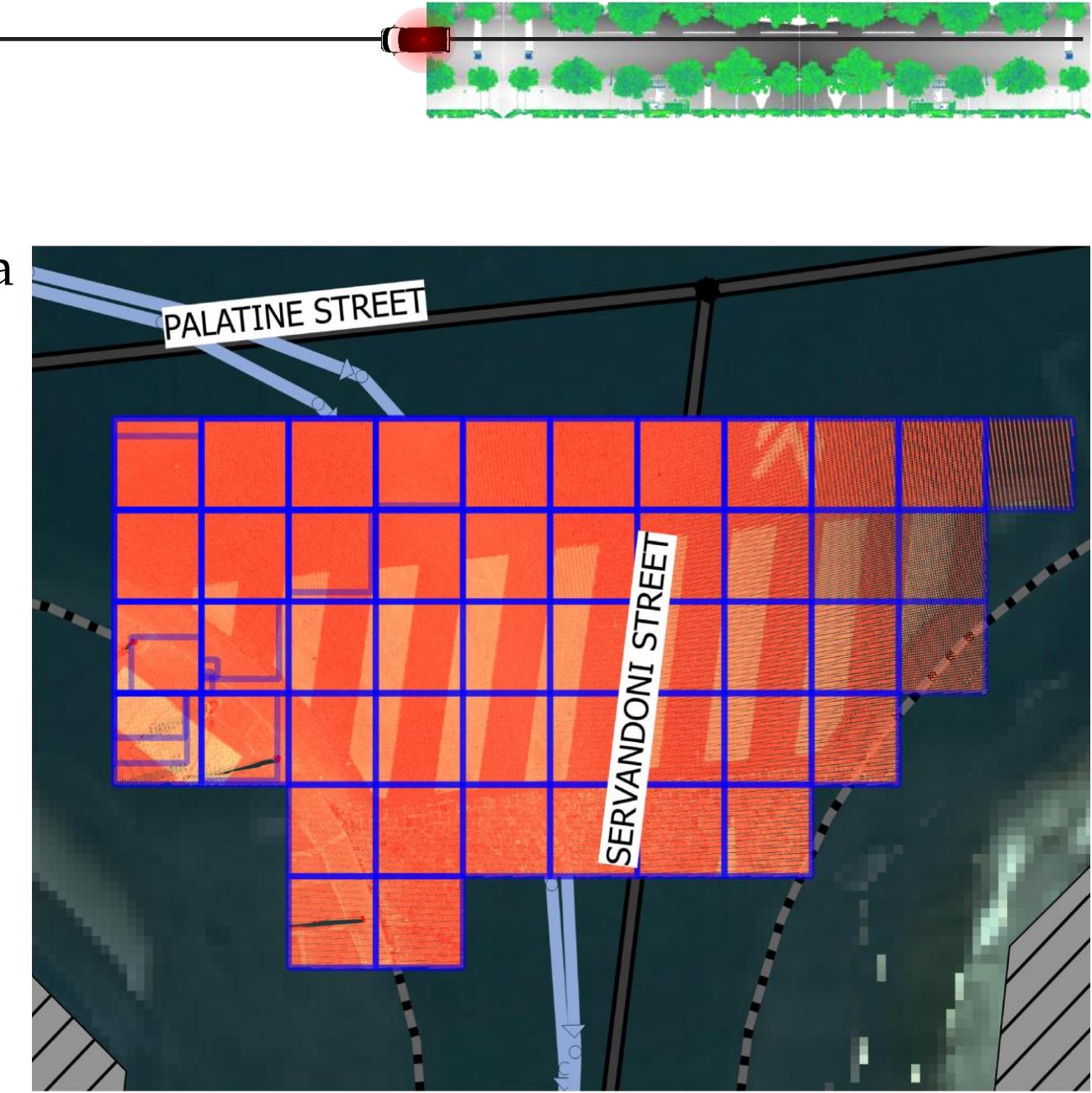
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With so much data:

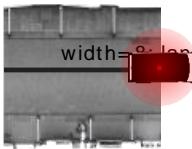
- Essential to access only a part of it : example

Patches that are

- far from buildings
- close to the intersection these 2 streets
- aerial view color ≈ pedestrian crossing
- close trajectory
- with high point density



Point Cloud Server: filtering



width = 8; lane = 3



width = 6; lane = 2

- Result : finding millions of points amongst billions :
100 ms if indexed !

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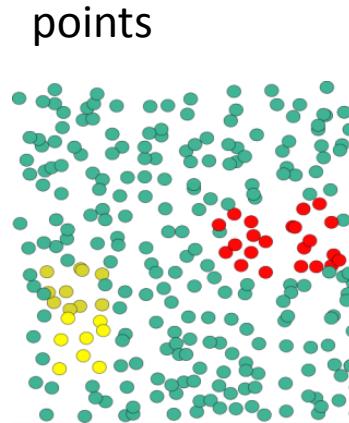
Interaction

Automation

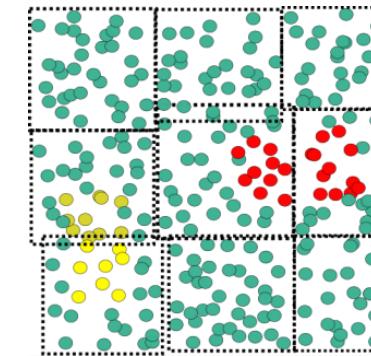
P.C. Server

Fitting

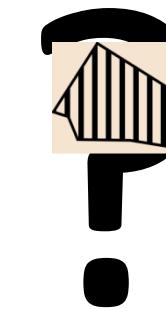
Conclusion



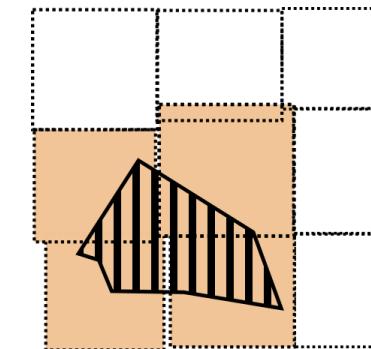
Points in patch



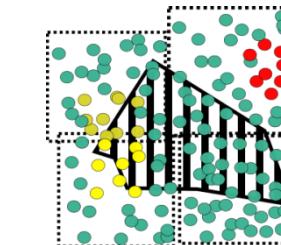
Which points
are inside the
polygon?



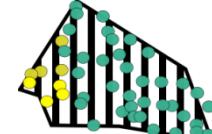
Which **patchs**
are inside the
polygon?



Get points in
these patches



Which
points are
inside the
polygon?



Point Cloud Server: processing



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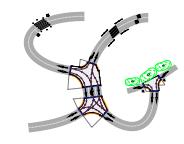
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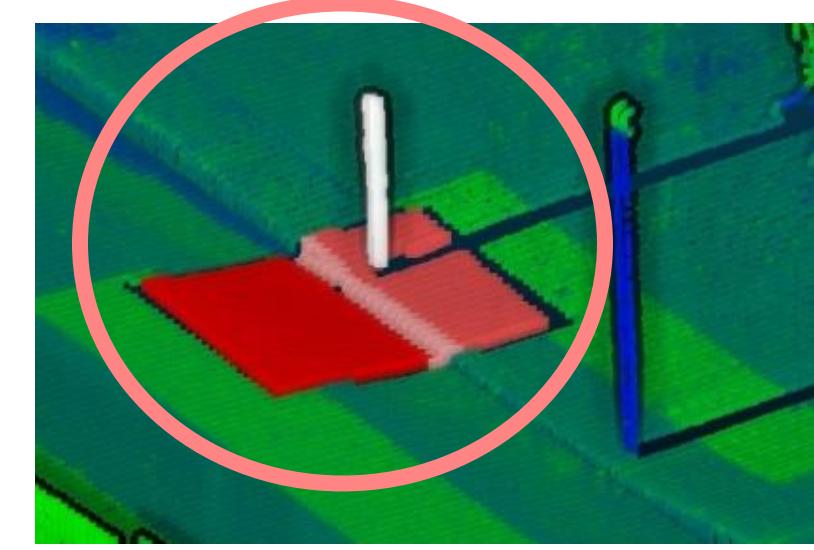
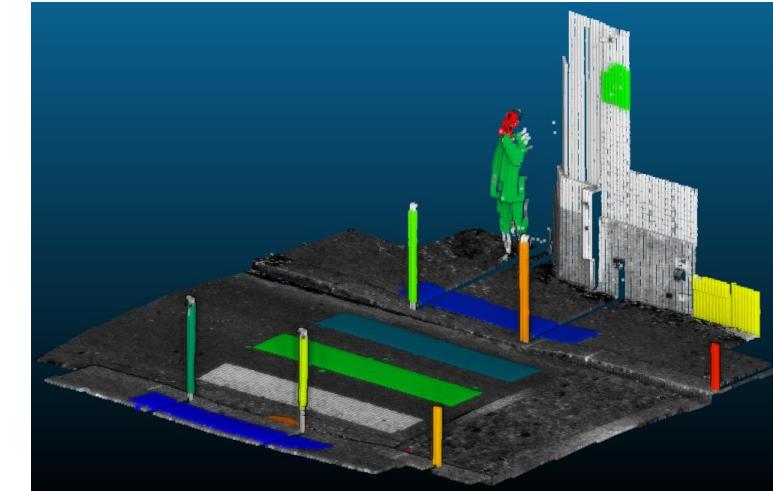
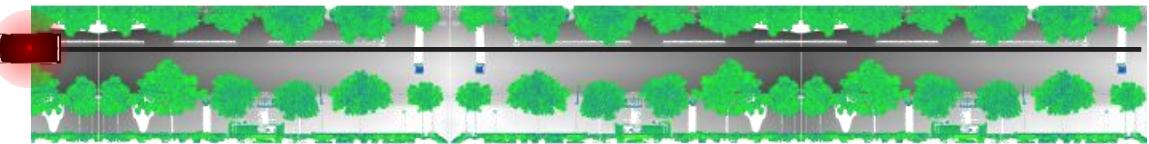
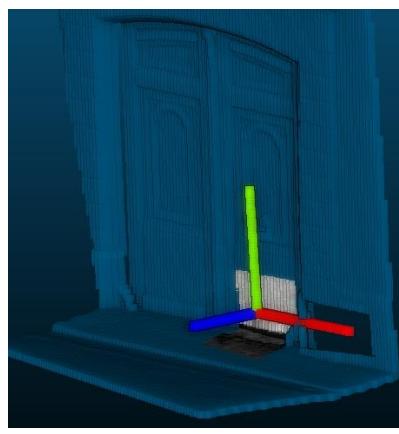


- Postgresql: easy to add in-base processing

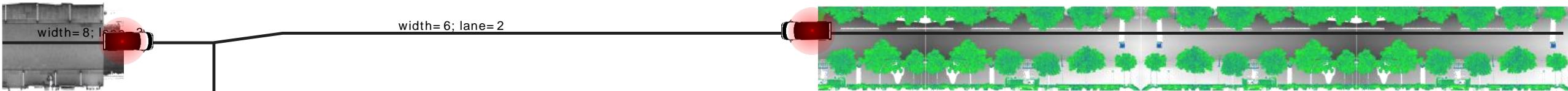
- C/Cpp → for performance
 - R/Python → for fast prototyping

- Example :

- Verticality descriptor
 - Unsupervised clustering
 - Plane & cylinder detection



Point Cloud Server: processing



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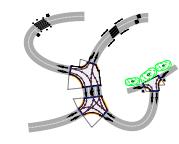
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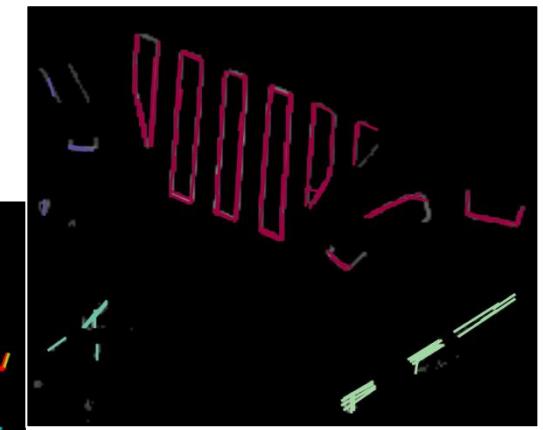
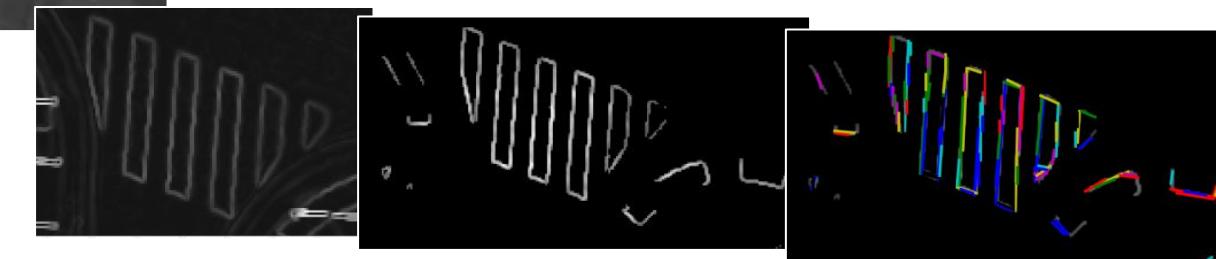
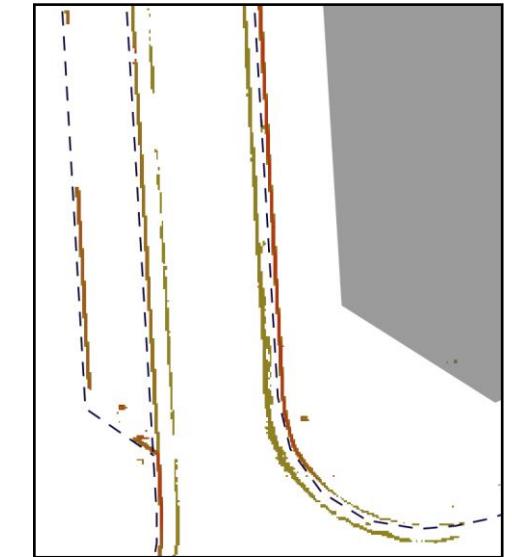
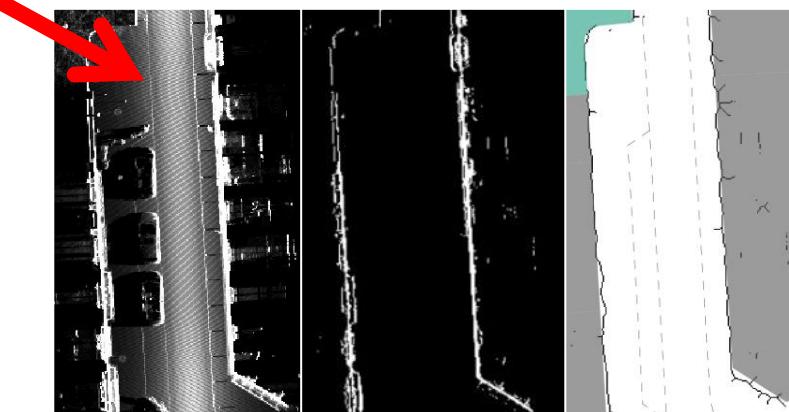
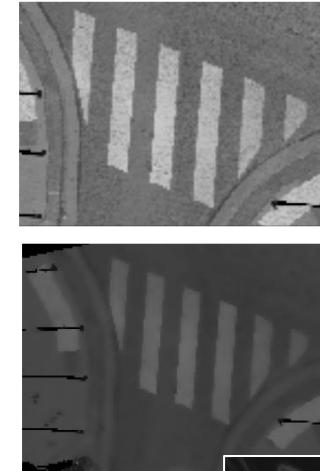
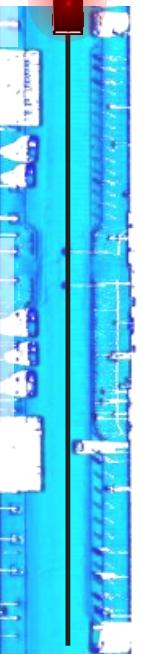
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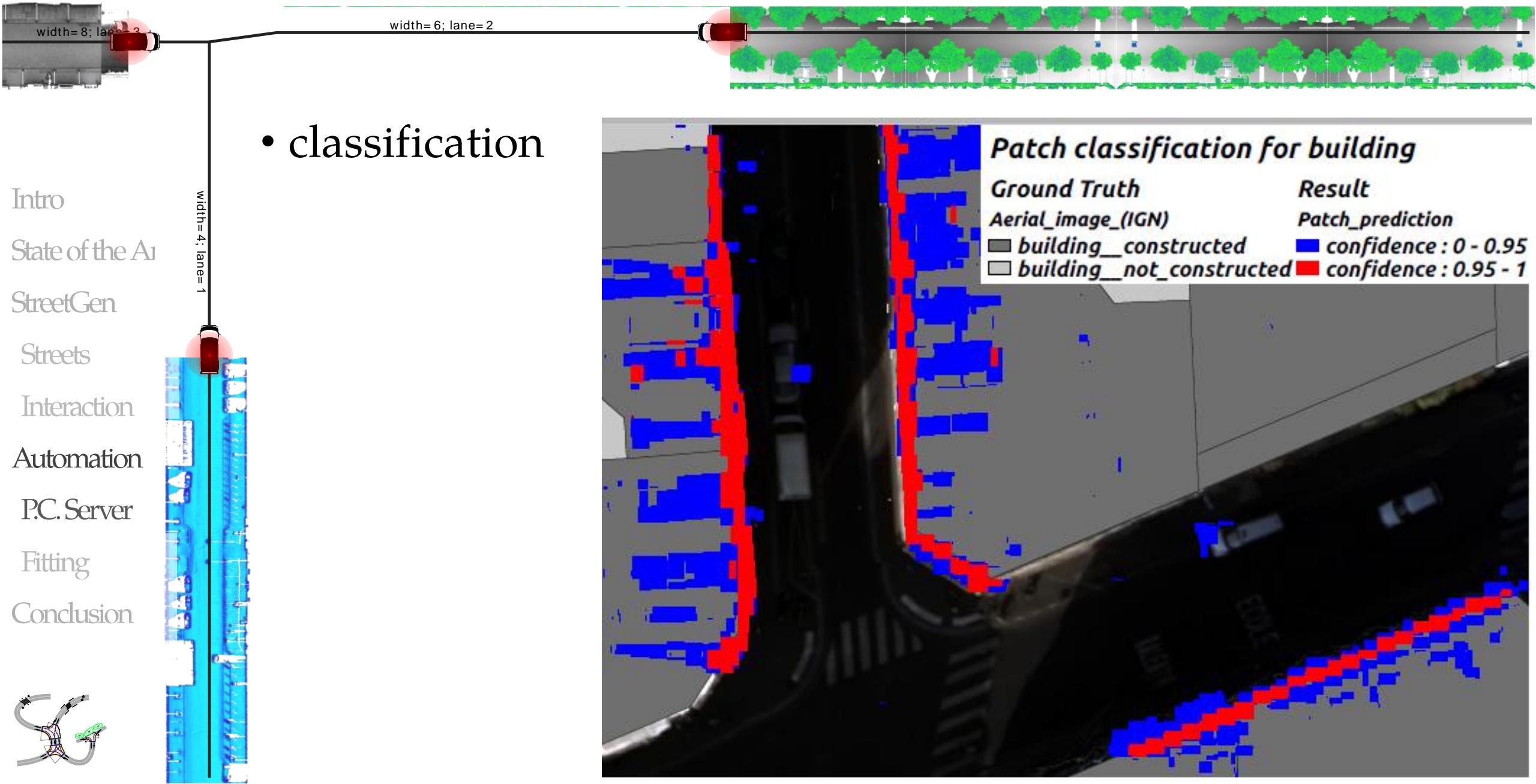
Conclusion



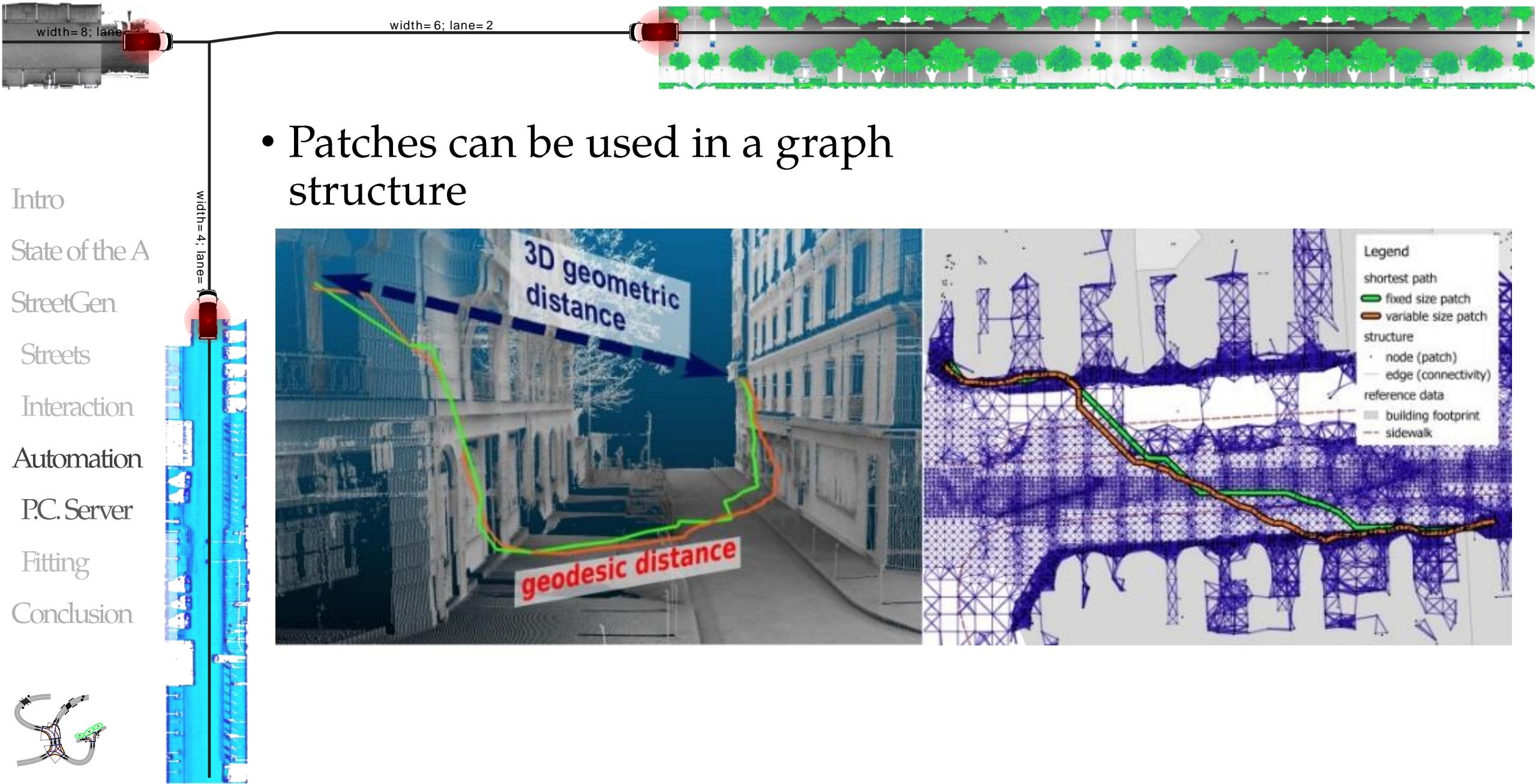
- Converting patch to raster
 - Cornerstone detection
 - Marking detection
 - Façade detection



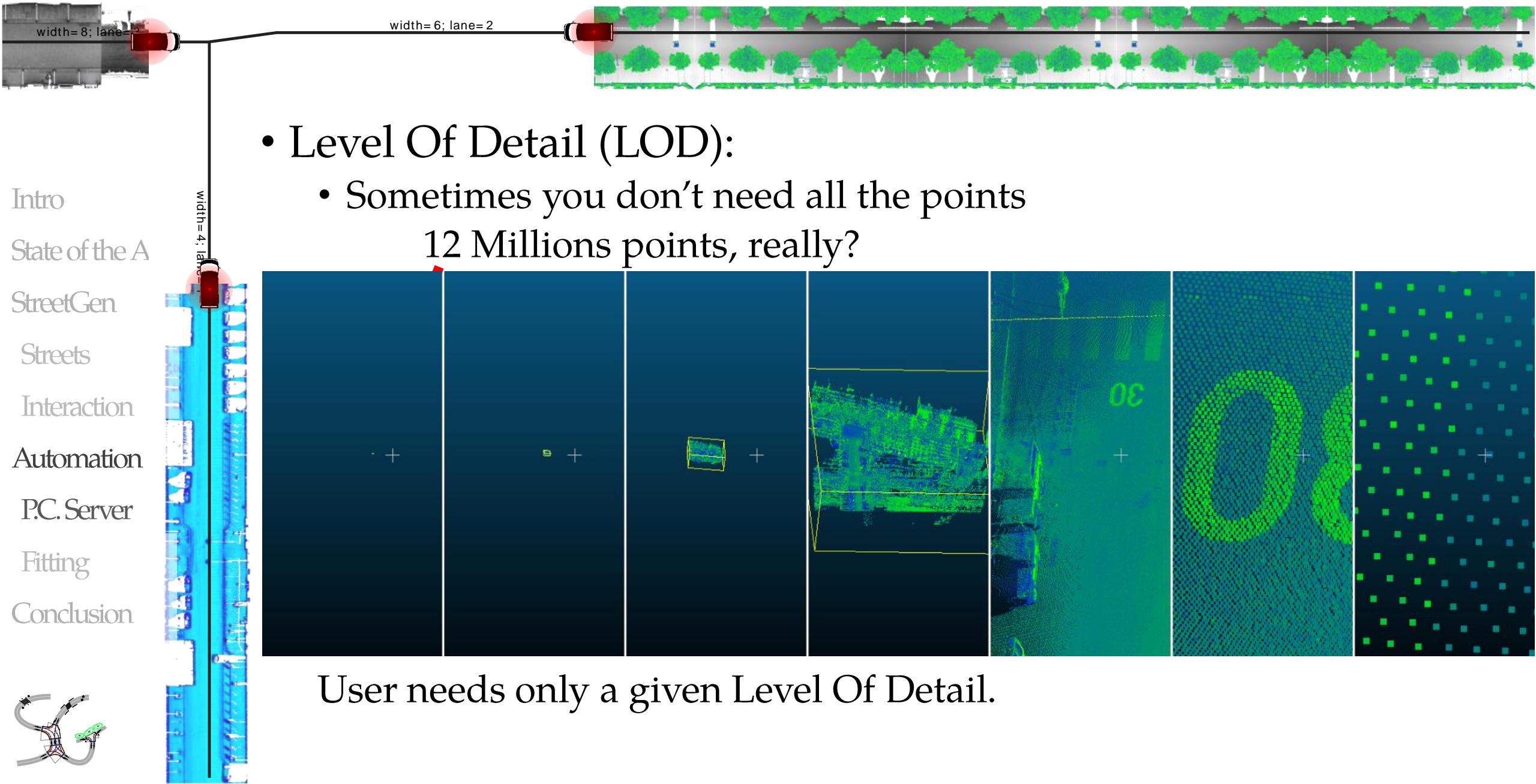
Point Cloud Server: processing



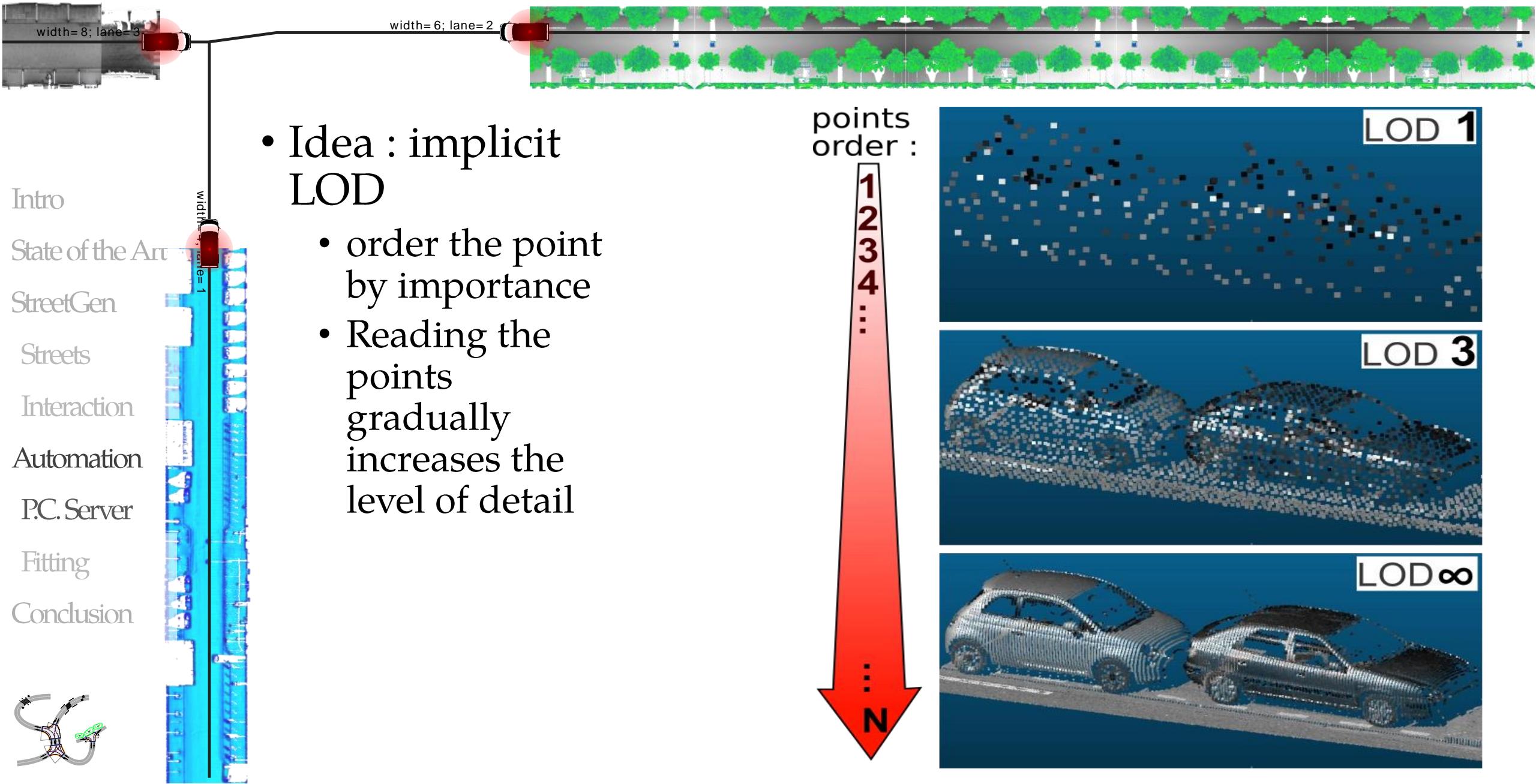
Point Cloud Server: processing



Point Cloud Server: Level Of Detail



Point Cloud Server: Level Of Detail



width=8; lane=3

width=6; lane=2

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SG

- Idea : implicit LOD
 - order the point by importance
 - Reading the points gradually increases the level of detail

points order :

1
2
3
4
:

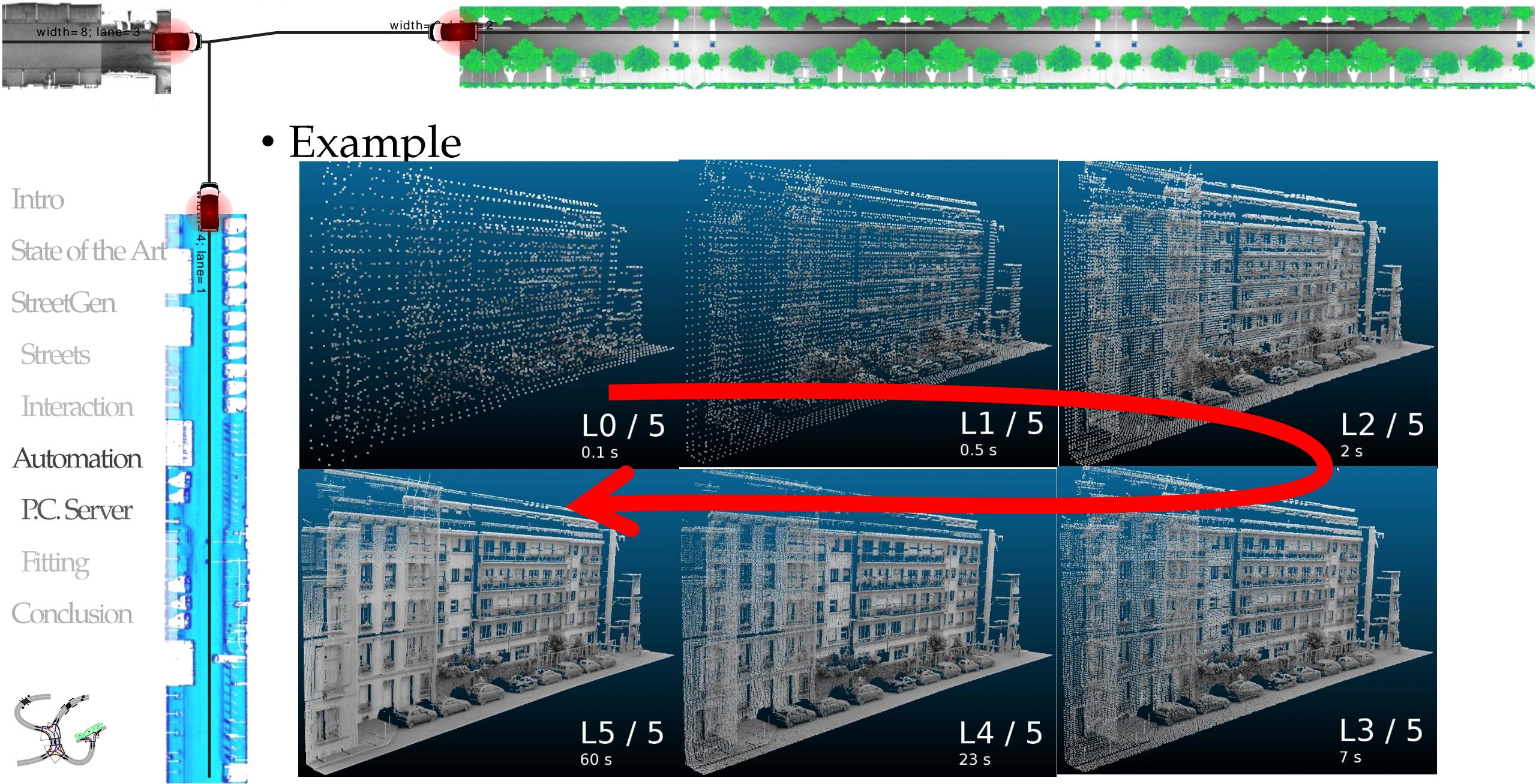
N

LOD 1

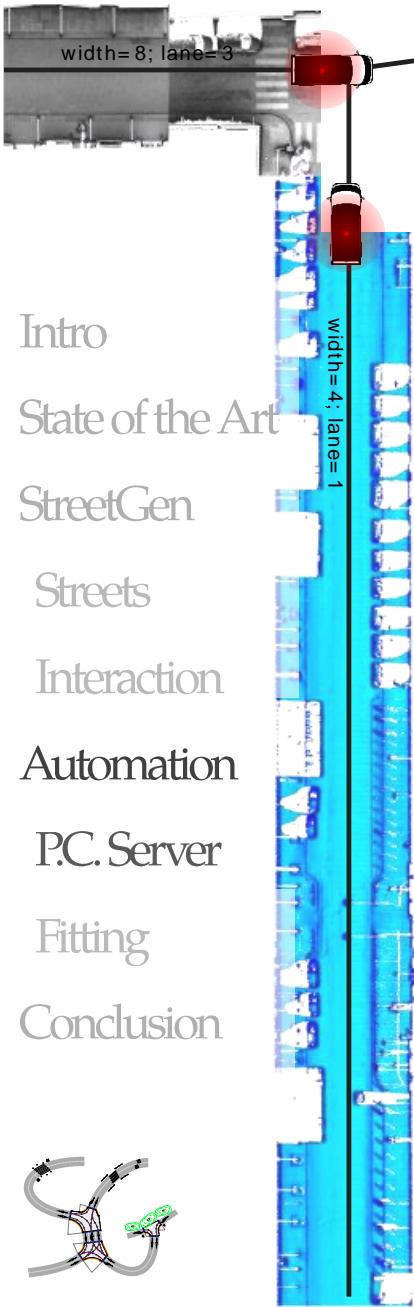
LOD 3

LOD ∞

Point Cloud Server: Level Of Detail



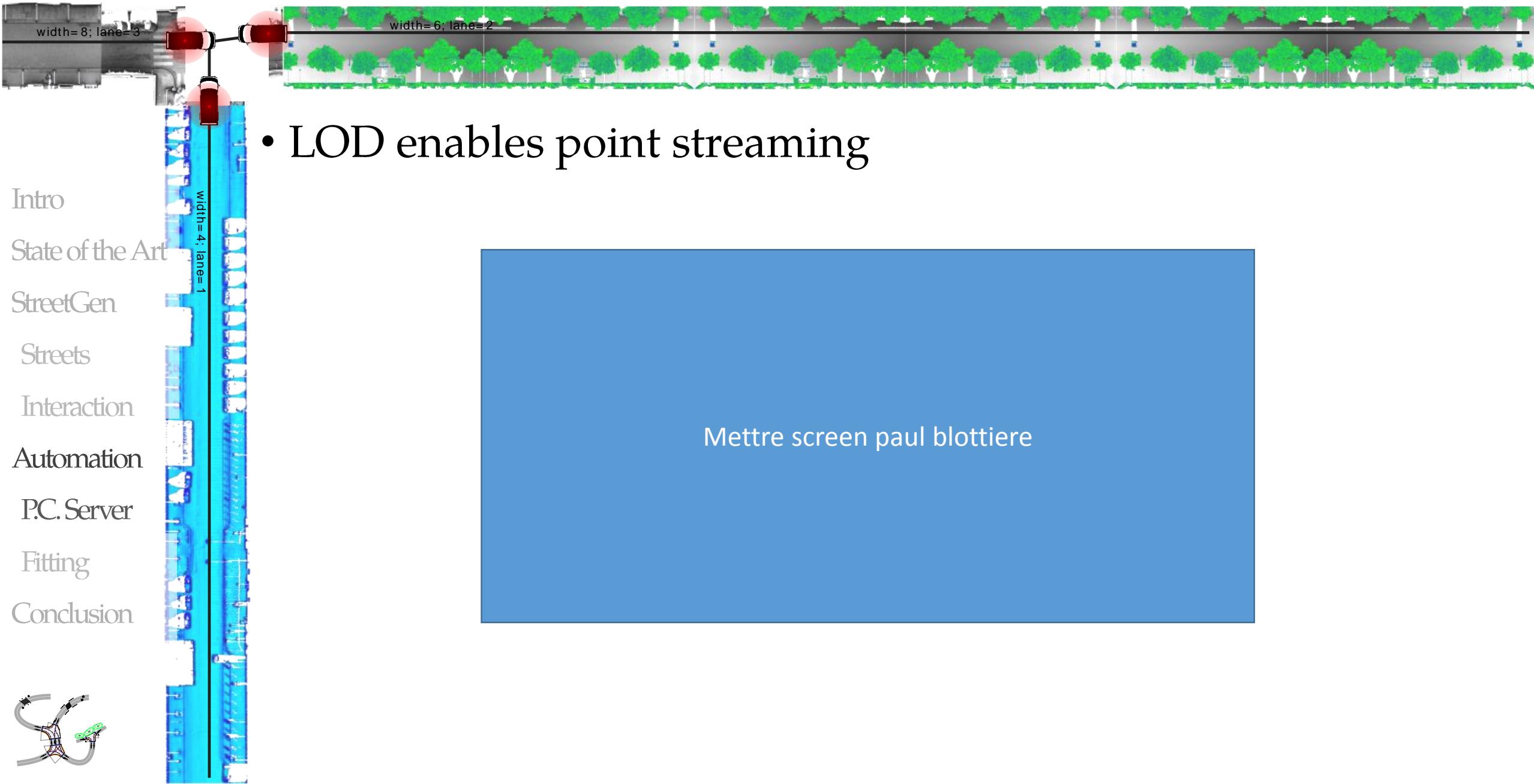
Point Cloud Server: Level Of Detail



- For visualization, LOD depends on distance to camera



Point Cloud Server: Level Of Detail



Point Cloud Server: Level Of Detail

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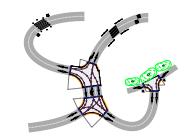
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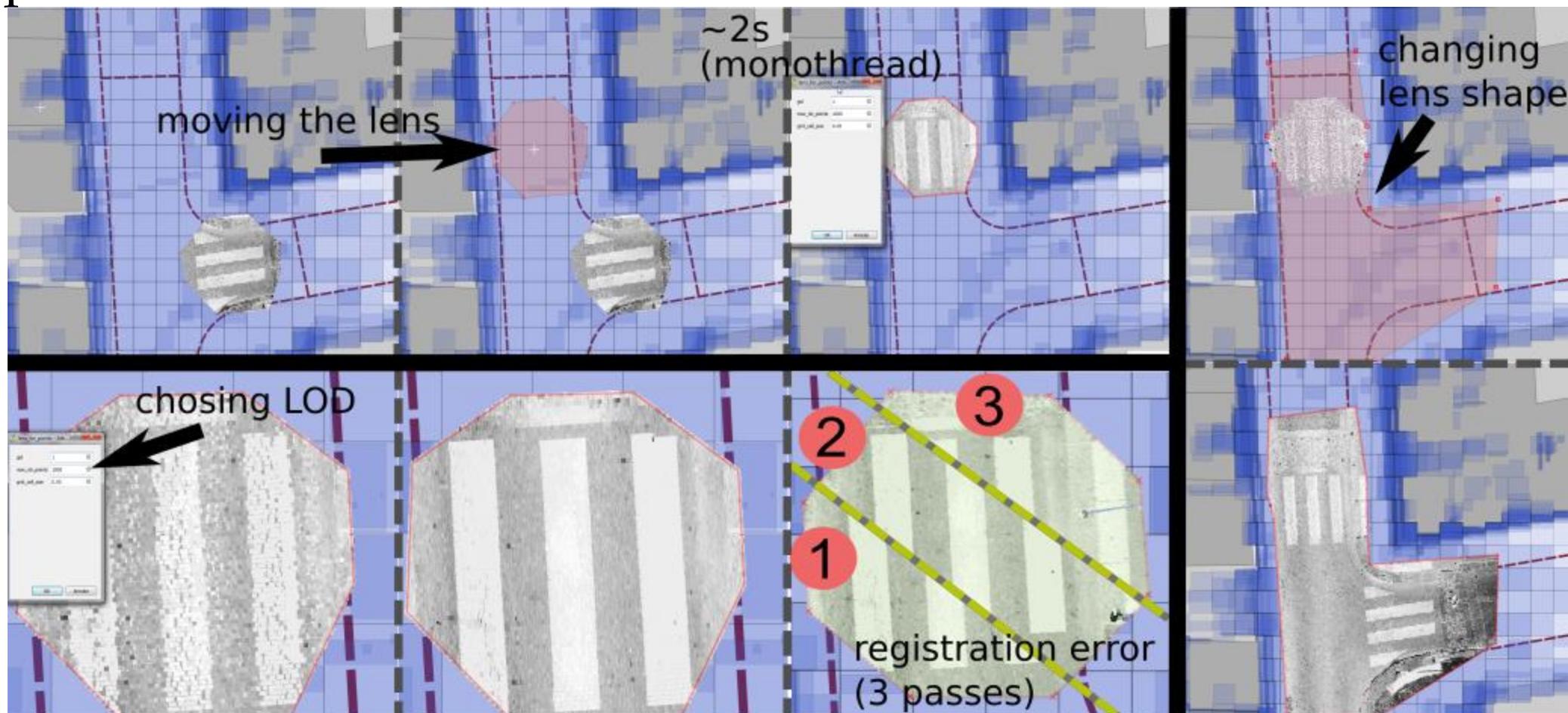
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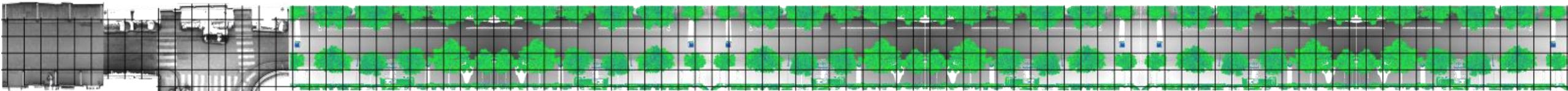
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- Also for classical GIS soft that can't deal with too many points



Point Cloud Server: Level Of Detail



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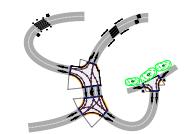
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- Limitations

- Points have to be group-able
- Our Loading/export could be much faster
- Filtering is fast at patch level($O(\ln(n))$), not point level ($O(n)$)
- LOD : rely on ordering the points !
 - You have to use it
 - May be slow to build
 - For the moment, getting a part of the patch require to read it entirely

width= 8; lane= 3

width= 6; lane= 2

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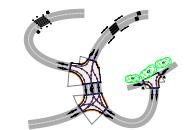
width= 4; lane= 1

Automating street modelling

Inverse procedural modelling

Data: Point Cloud Server

Fitting model to real streets



Inverse Procedural modelling: method

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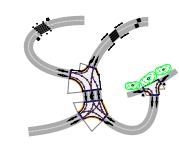
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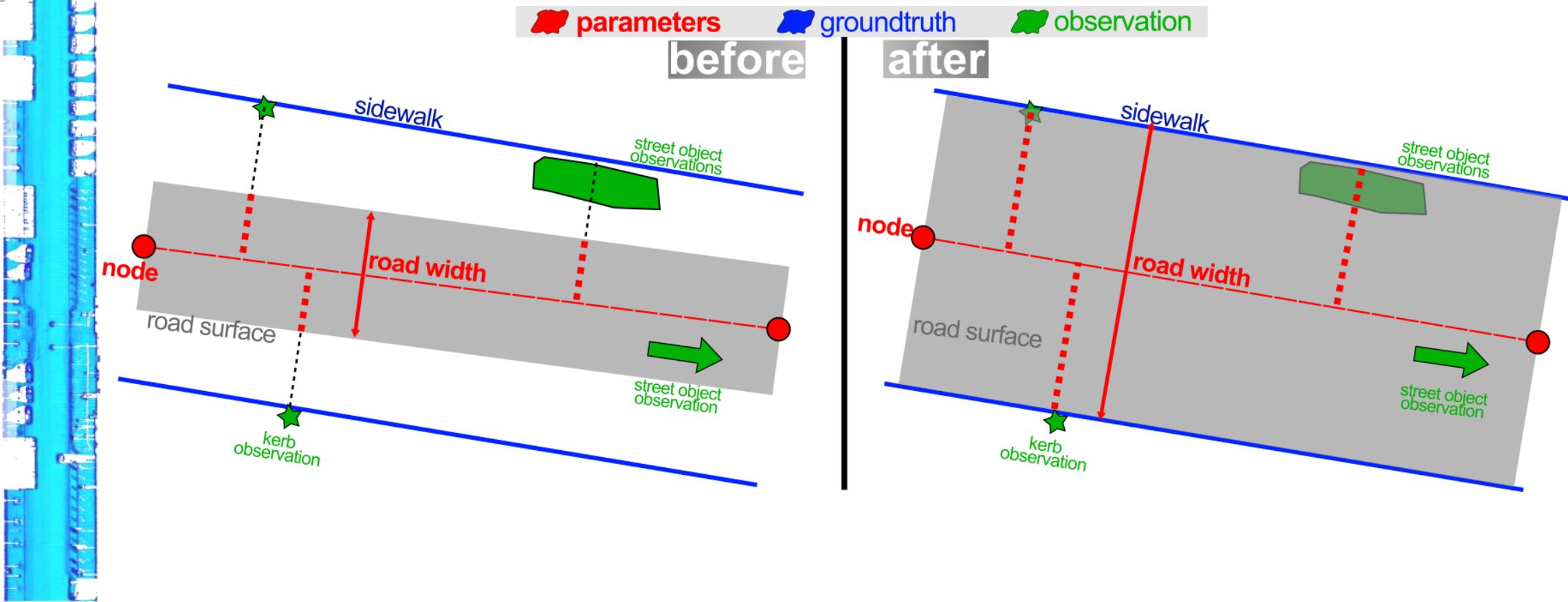
P.C. Server

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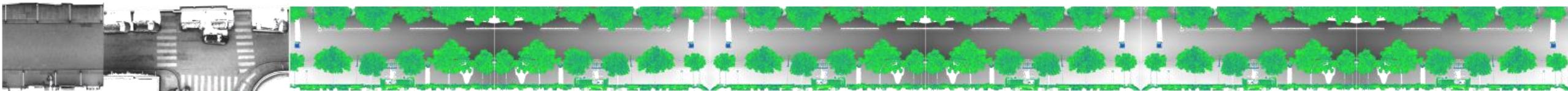
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- Initial road model + observation → optimisation → fit road model



Inverse Procedural modelling: method



- Initial road model + observation → match observation to axis optimisation → fit road model

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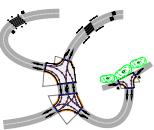
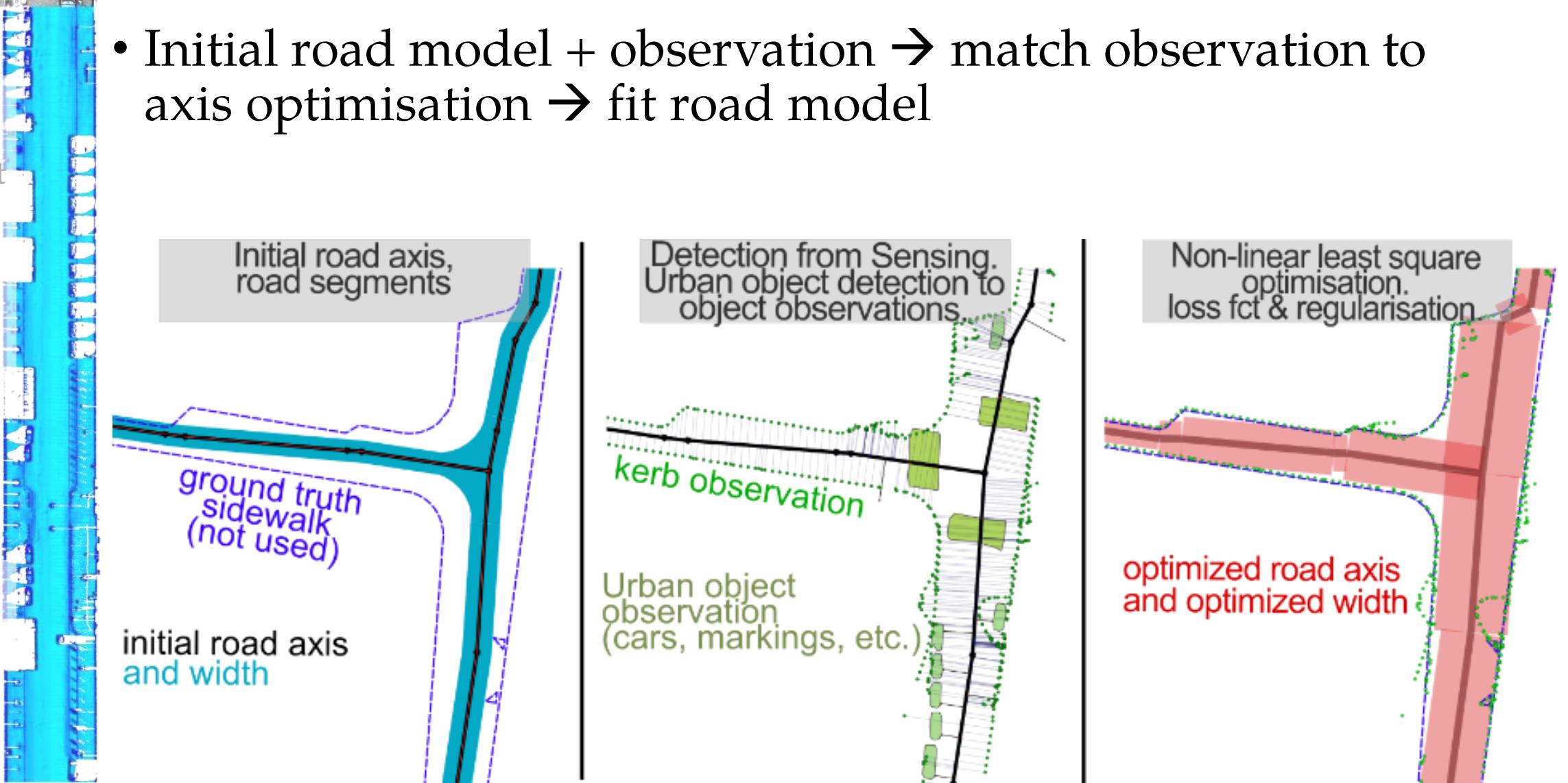
Interaction

Automation

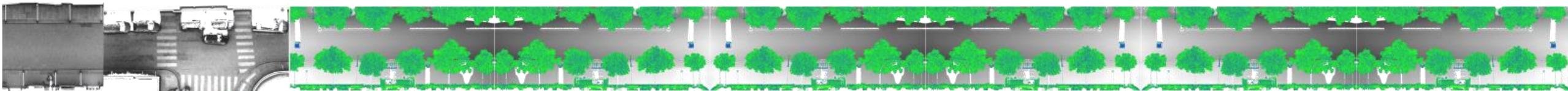
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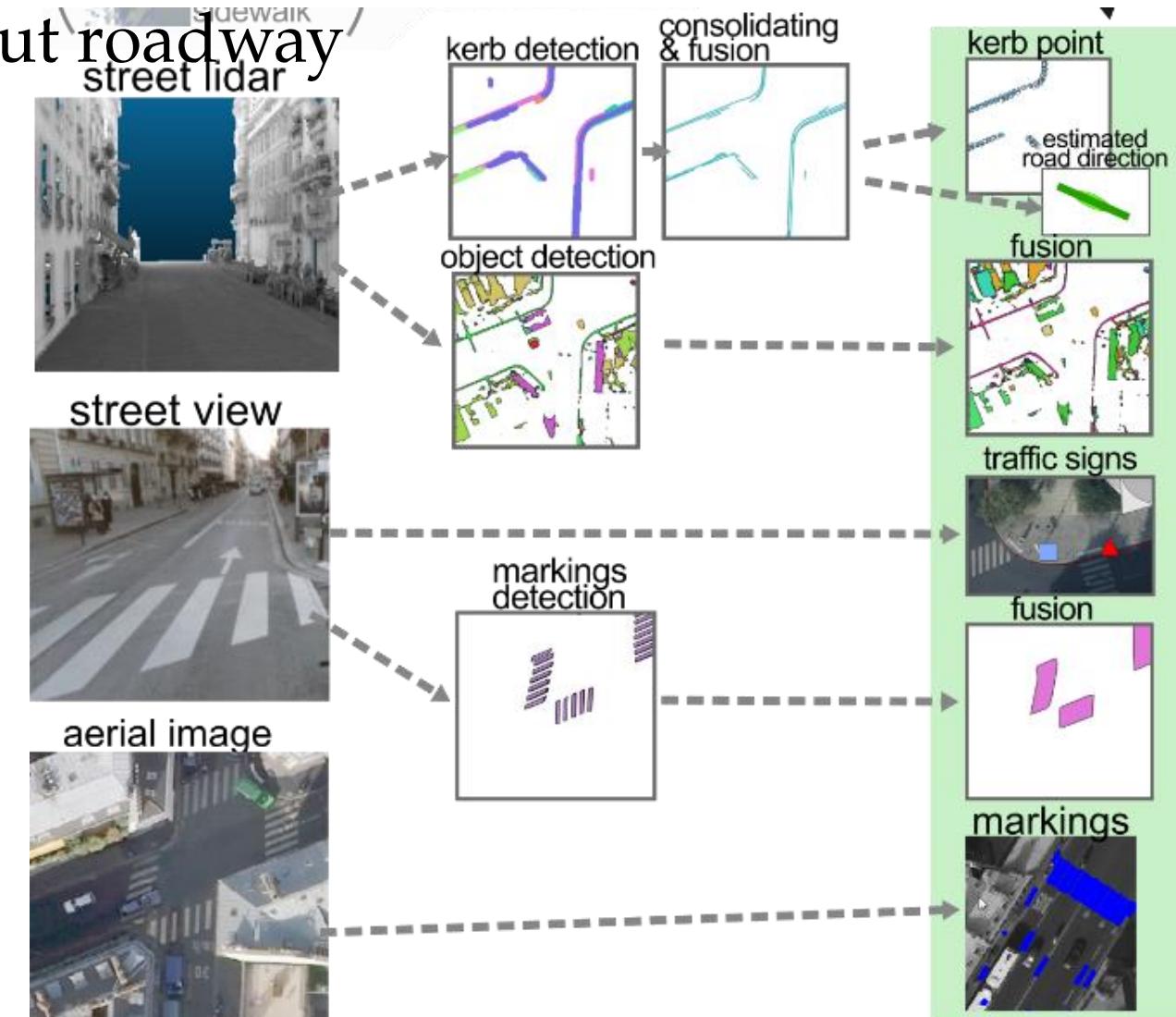


Inverse Procedural modelling: observations

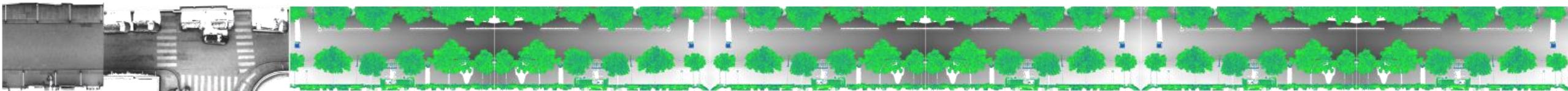


- Observation = clues about roadway

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Inverse Procedural modelling: observations



- Observation = clues about roadway

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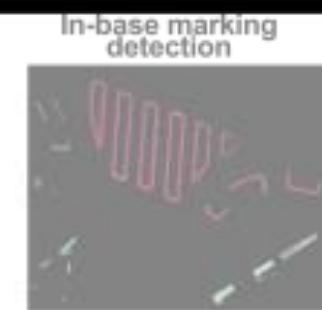
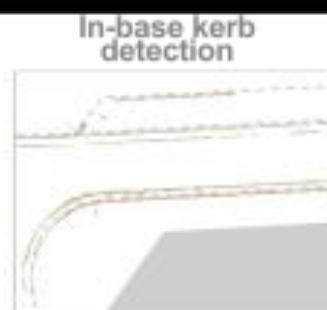
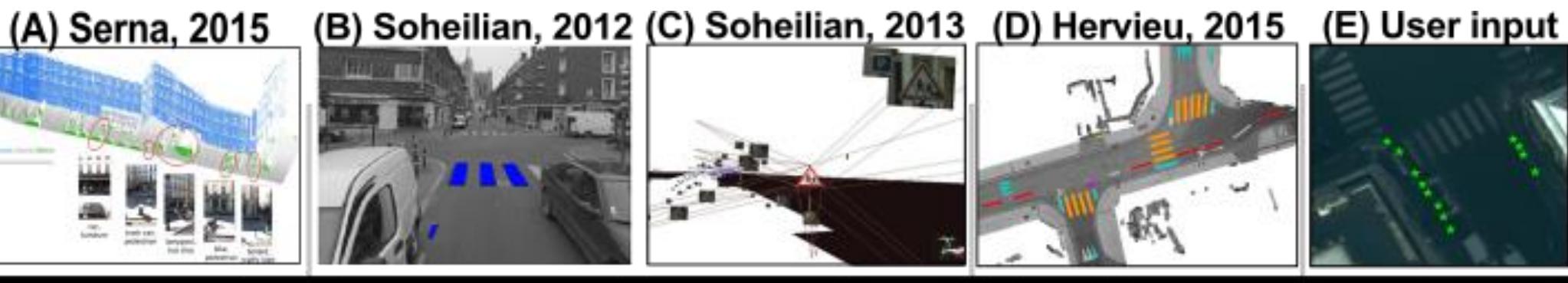
Interaction

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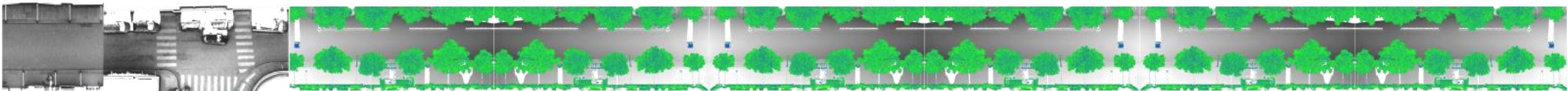
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Inverse Procedural modelling: forces



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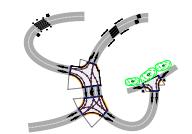
Interaction

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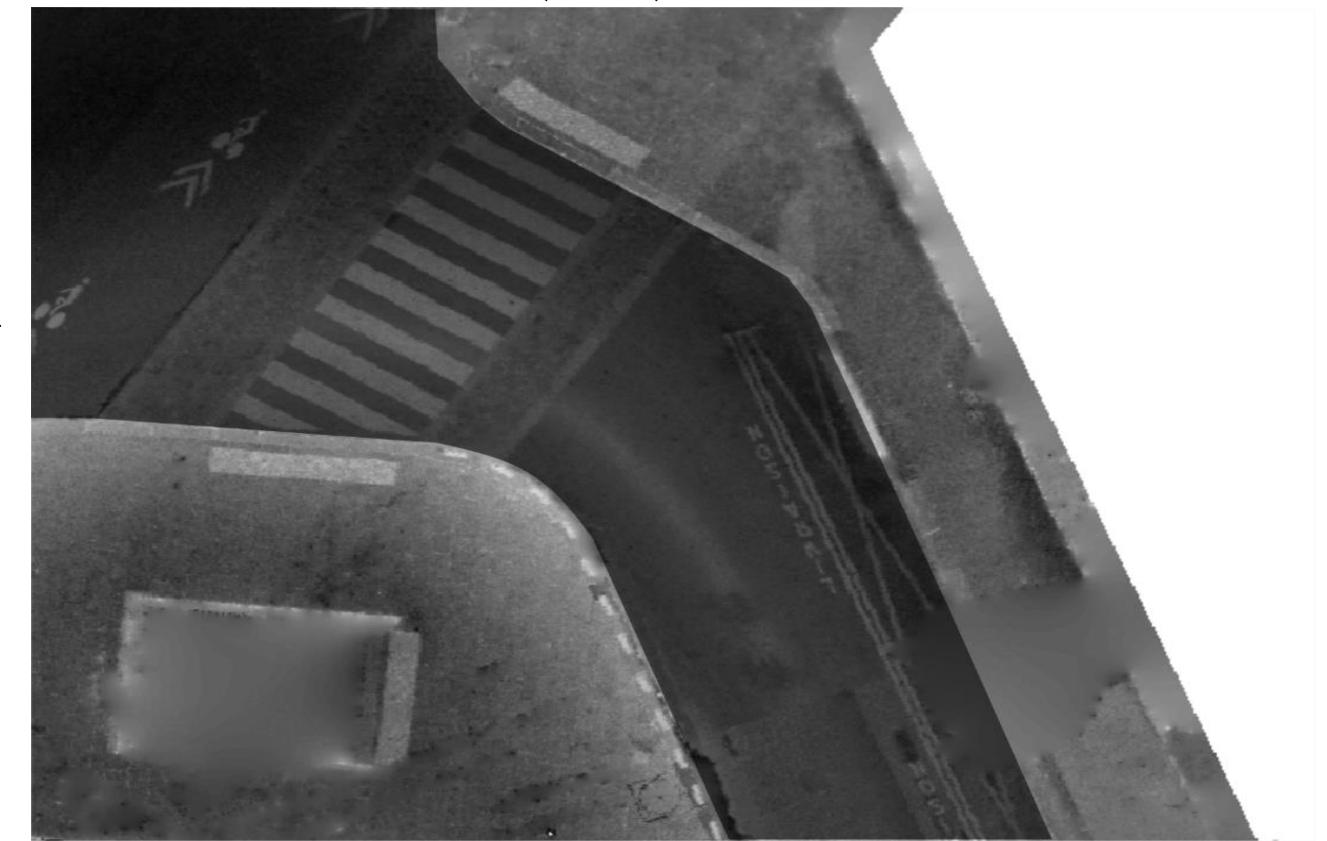
P.C. Server

Fitting

Conclusion



- Observations generate forces on road axis/width
- Each street object type has an expected position:
 - IN/OUT + BORDER_IN/BORDER_OUT (dist)
- Ex :
 - road markings : IN
 - Pedestrian crossing marking : BORDER_IN (0.2 m)
 - Traffic sign : OUT
 - No parking markings : BORDER_OUT (0.1m)



Inverse Procedural modelling: forces

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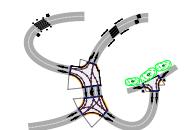
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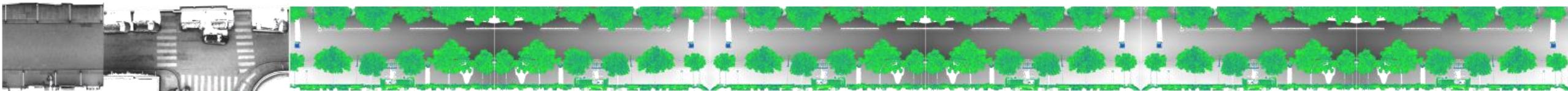
Conclusion



- Each type of street object expected position is defined in a table

object	COLLECTION	UNDEF	0	0	0
other static	POINT	UNDEF	0	0	0
punctual object	POINT	UNDEF	0	0	0
other punctual	POINT	UNDEF	0	0	0
post	POINT	OUT	1	1	0
bollard	POINT	OUT	0.2	1	0.1
floor lamp	POINT	BORDER	0.2	1	0.2
traffic light	POINT	UNDEF	1	0	0
traffic sign	POINT	OUT	1	0	0
signboard	POINT	UNDEF	1	0	0
mailbox	POINT	OUT	0	1	0.2
trash can	POINT	OUT	0.5	1	0
meter	POINT	OUT	0	1	0.2
Velib terminal	POLYGON	UNDEF	0	0	0
linear	LINESTRING	UNDEF	0	0	0
other linear	LINESTRING	UNDEF	0	0	0
barrier	LINESTRING	BORDER_OUT	0.2	1	0.1
roasting	LINESTRING	OUT	0.2	1	0.1
grid	LINESTRING	OUT	0.2	1	0.1

Inverse Procedural modelling: forces



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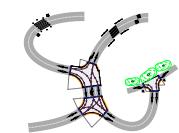
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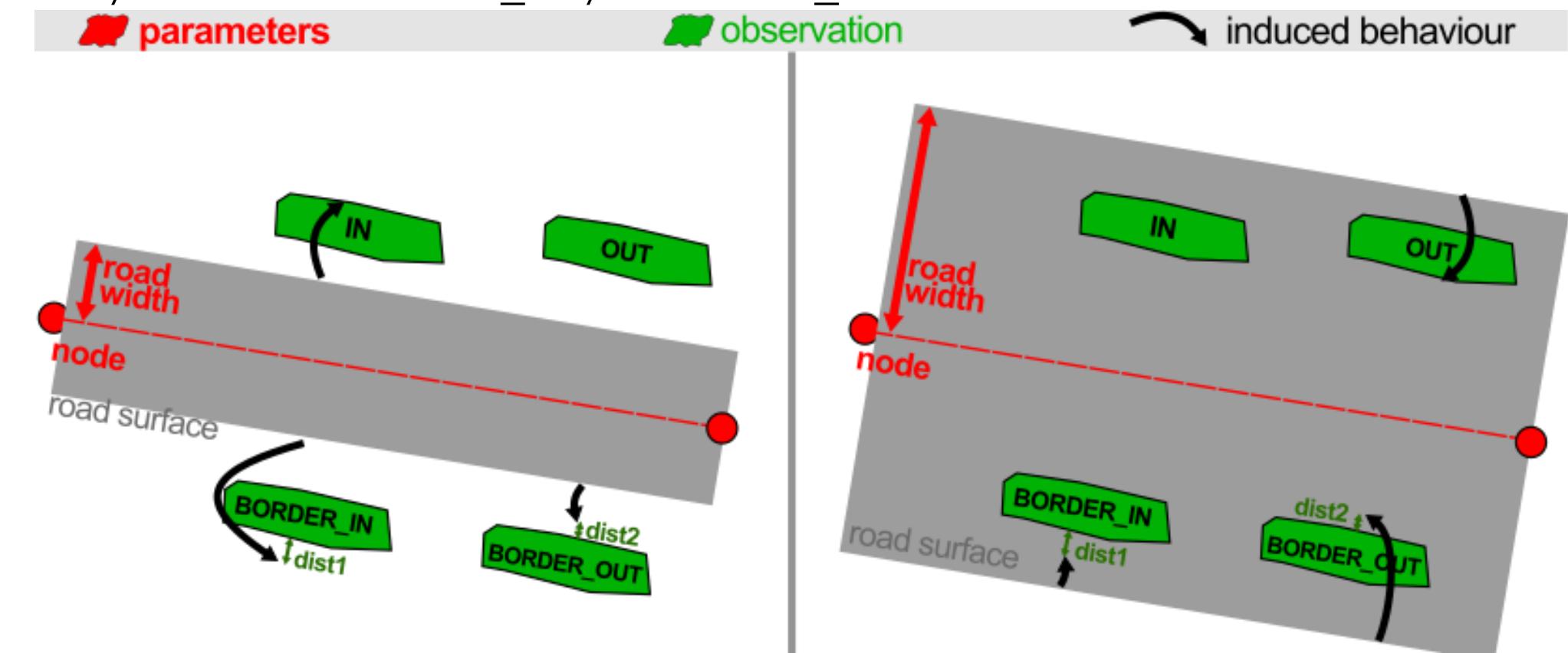
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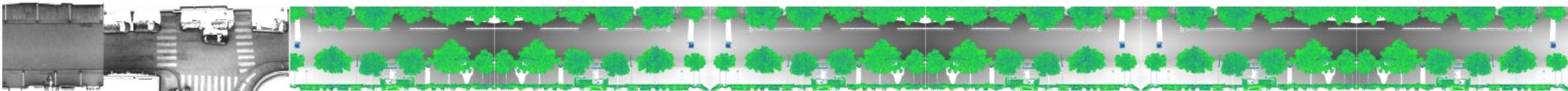
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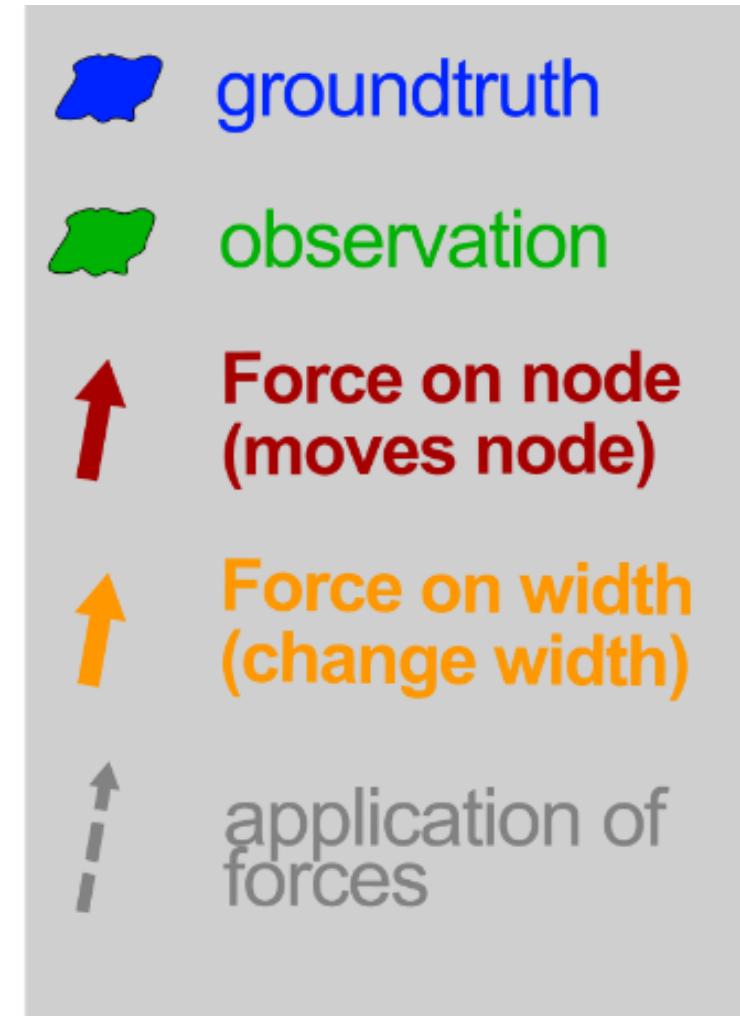
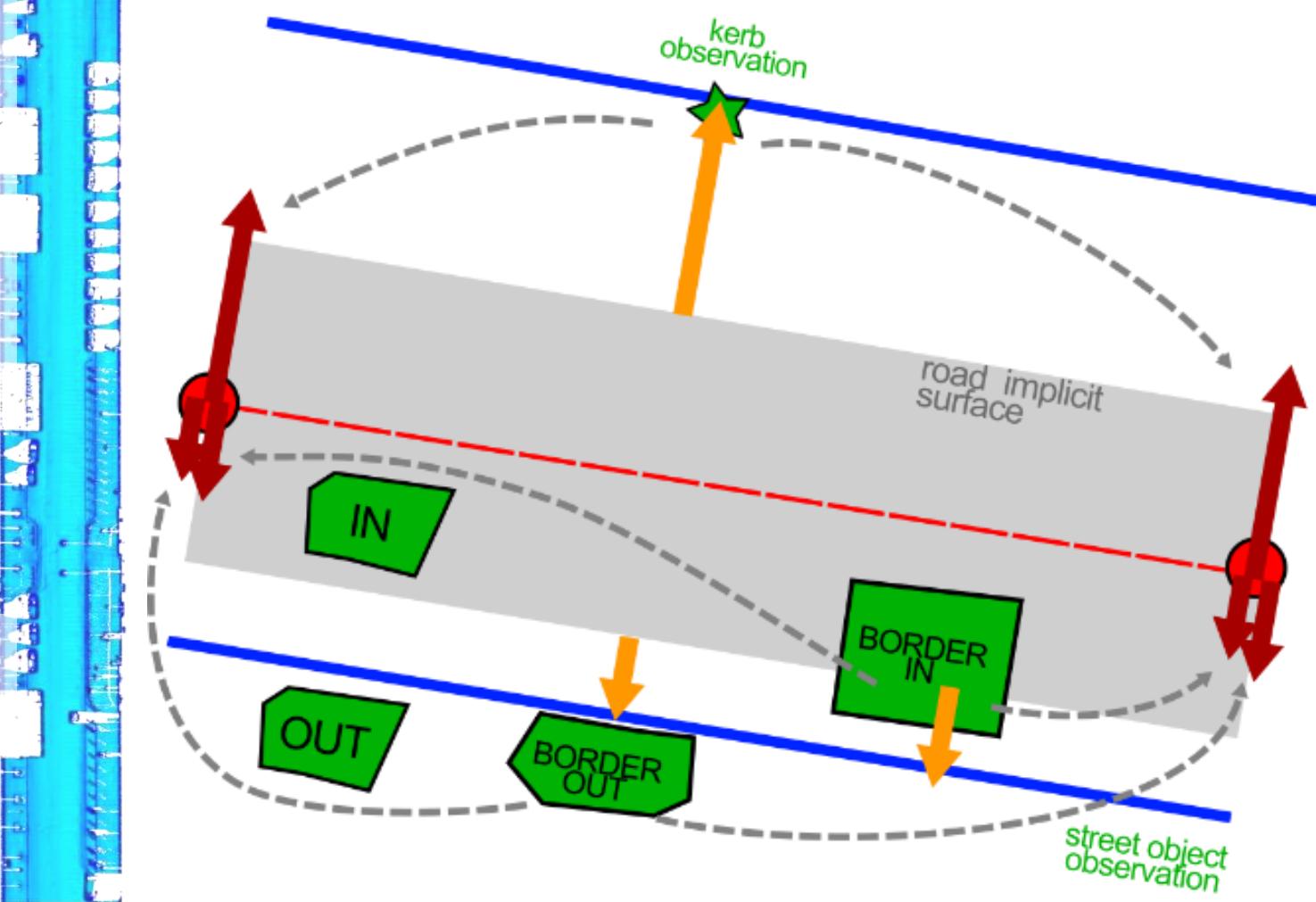
- Observations generate forces on road axis/width
- Each street object type has an expected position:
 - IN/OUT + BORDER_IN/BORDER_OUT + dist



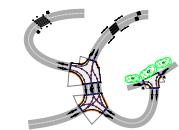
Inverse Procedural modelling: forces



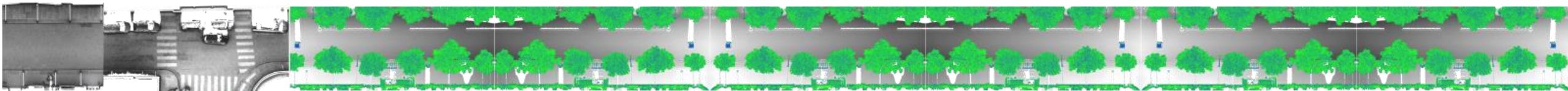
- So if we sum up forces from observations :



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Inverse Procedural modelling: forces



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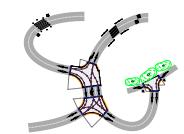
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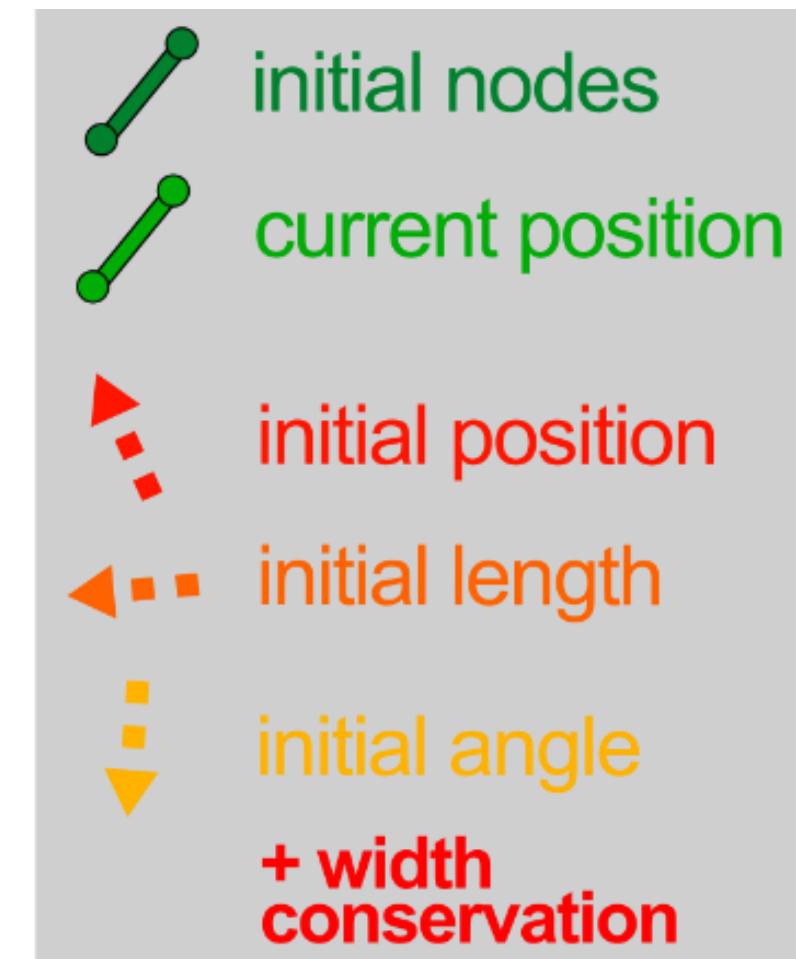
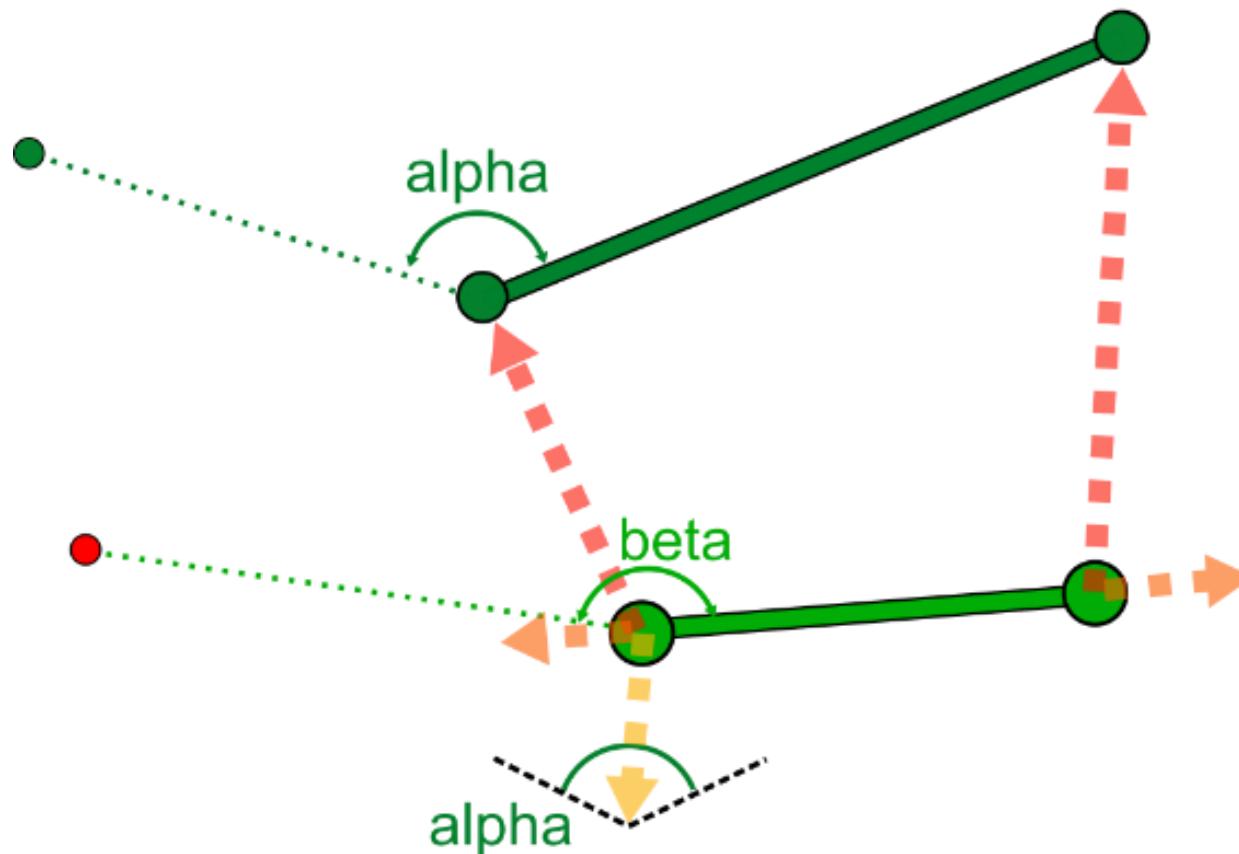
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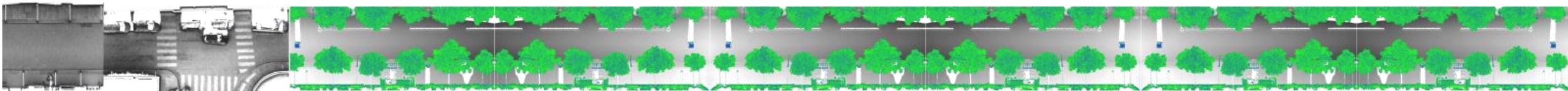
Conclusion



- Others forces: resisting changes : express confidence in initial road model



Inverse Procedural modelling : matching



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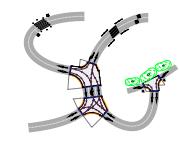
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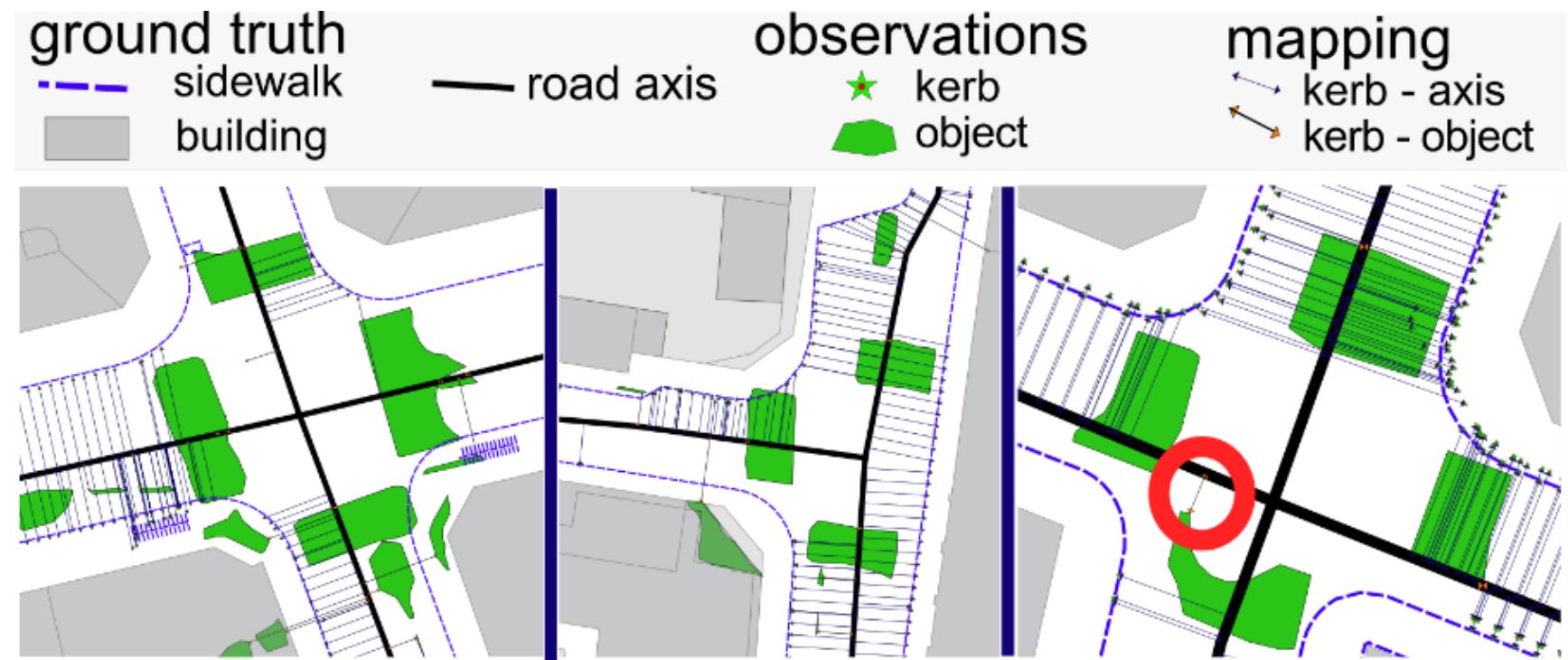
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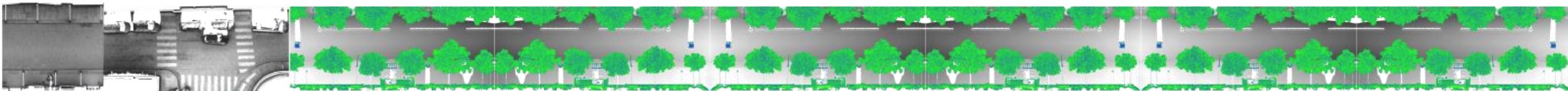


- Observations generate force on road axis/width,
But first :

- Observation ←matching→ road axis:
 - Closest road surface



Inverse Procedural modelling: matching



- In intersection : can't use observations:
 - We would need to optimise full road surface model

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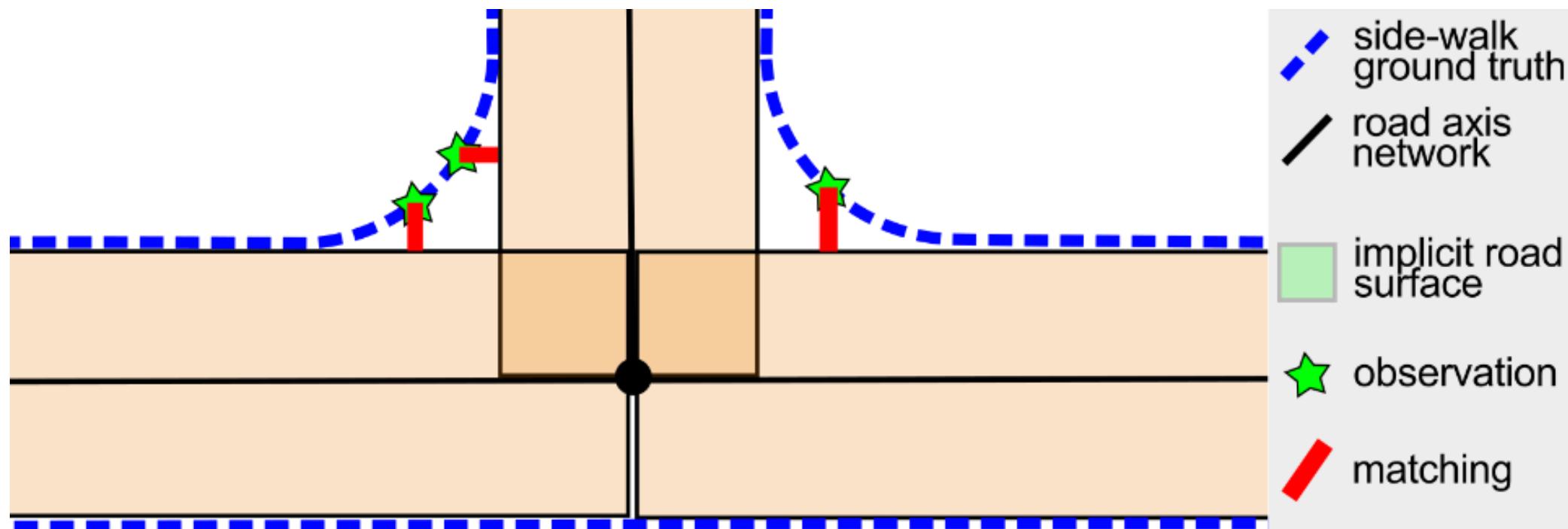
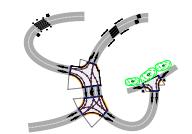
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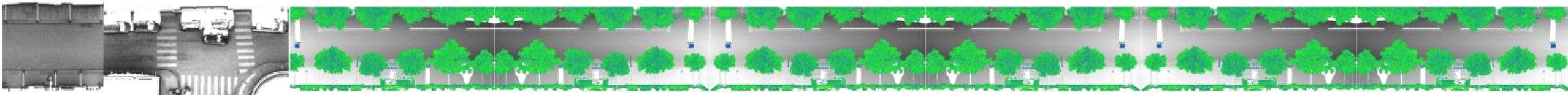
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Inverse Procedural modelling: experiment



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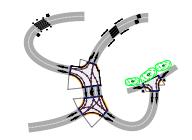
Interaction

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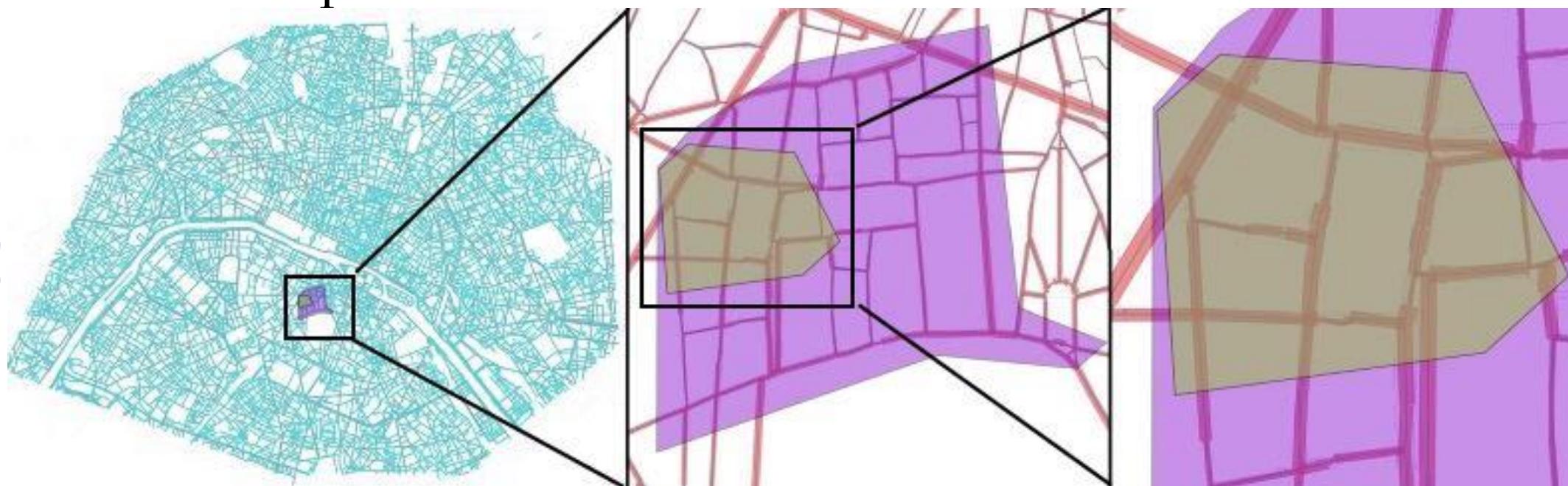
P.C. Server

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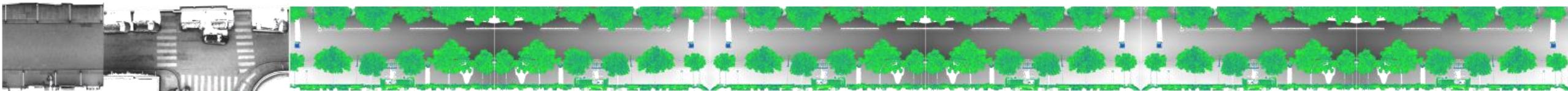
Conclusion



- Optimisation = Non-linear least square
 - → no guarantee to find the optimal solution, robust, very fast
- Open source : [Ceres solver](#)
- Areas of experiment:



Inverse Procedural modelling : small area



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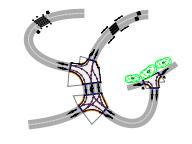
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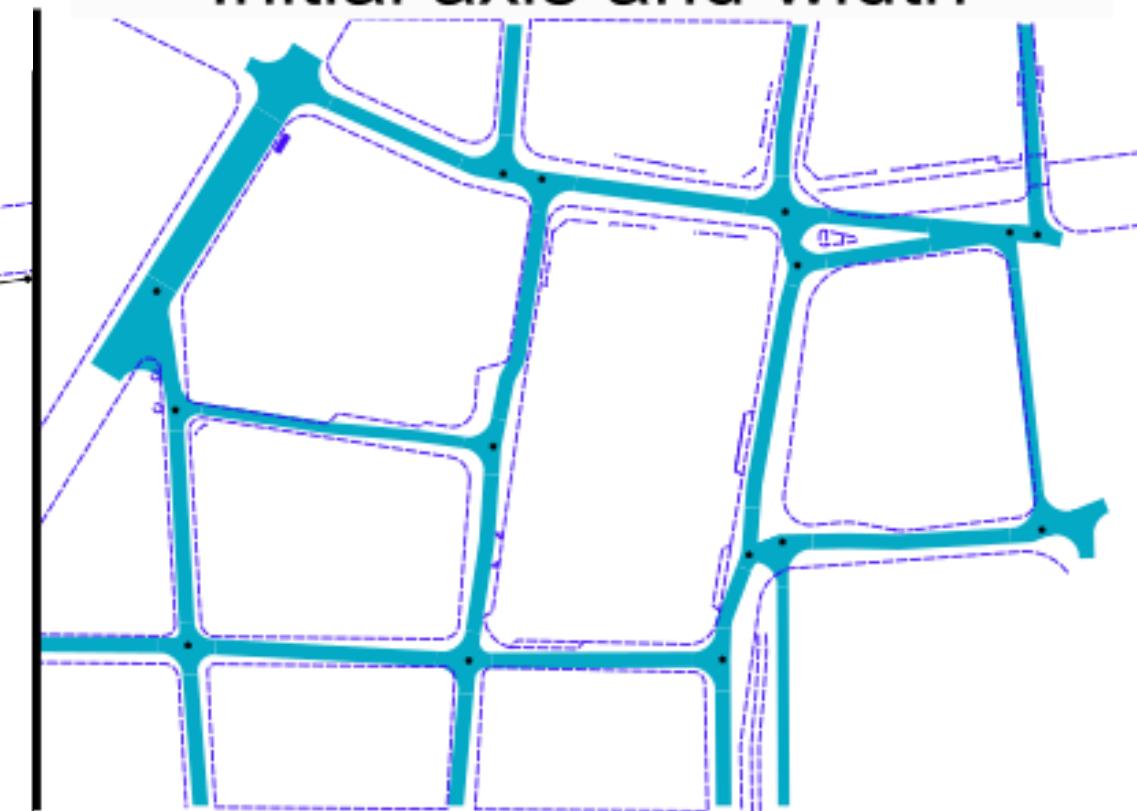
Conclusion



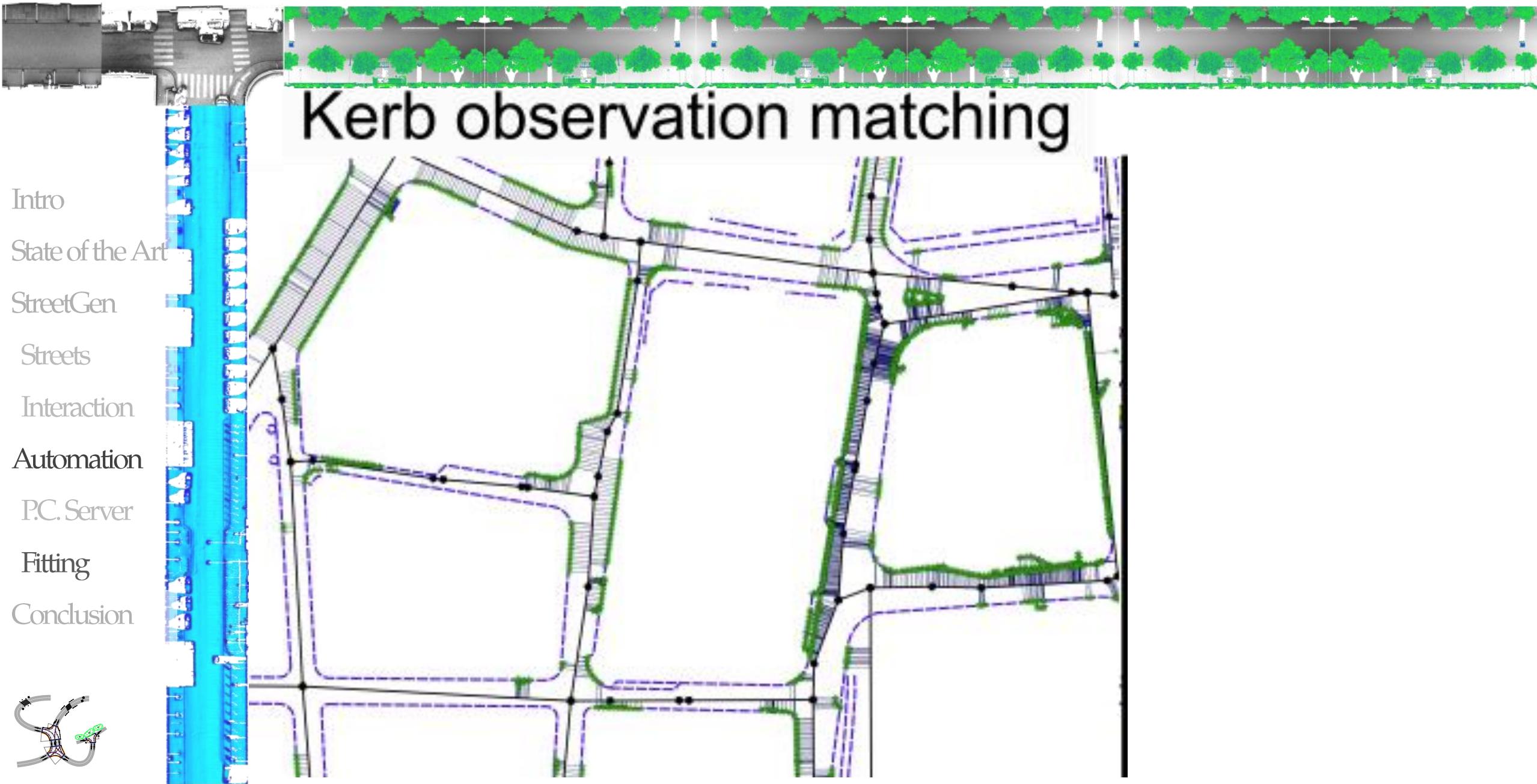
Ground truth sidewalk



Initial axis and width



Inverse Procedural modelling : small area



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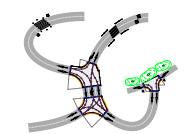
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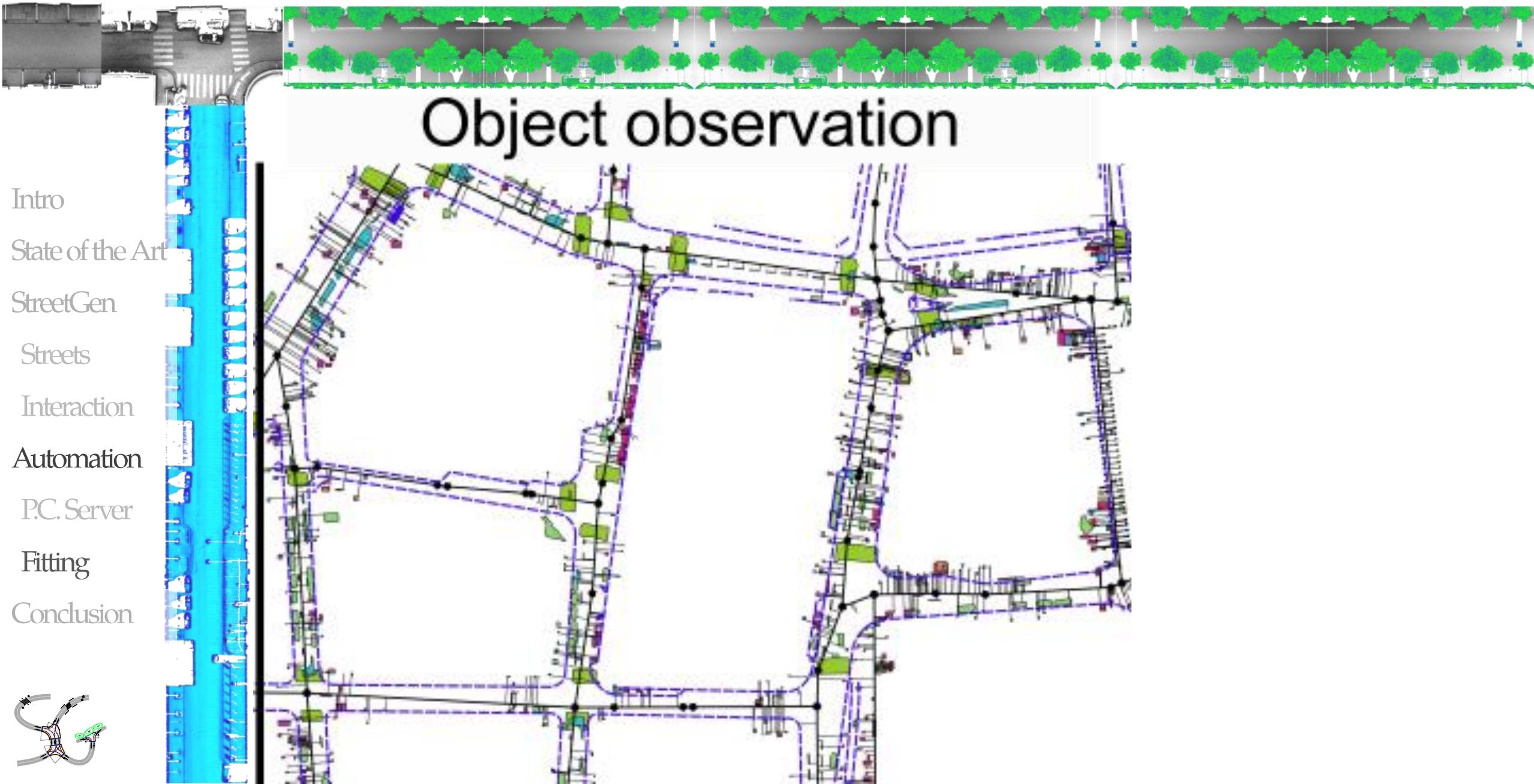
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Inverse Procedural modelling : small area



Inverse Procedural modelling : small area



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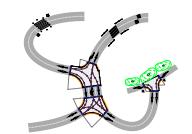
Interaction

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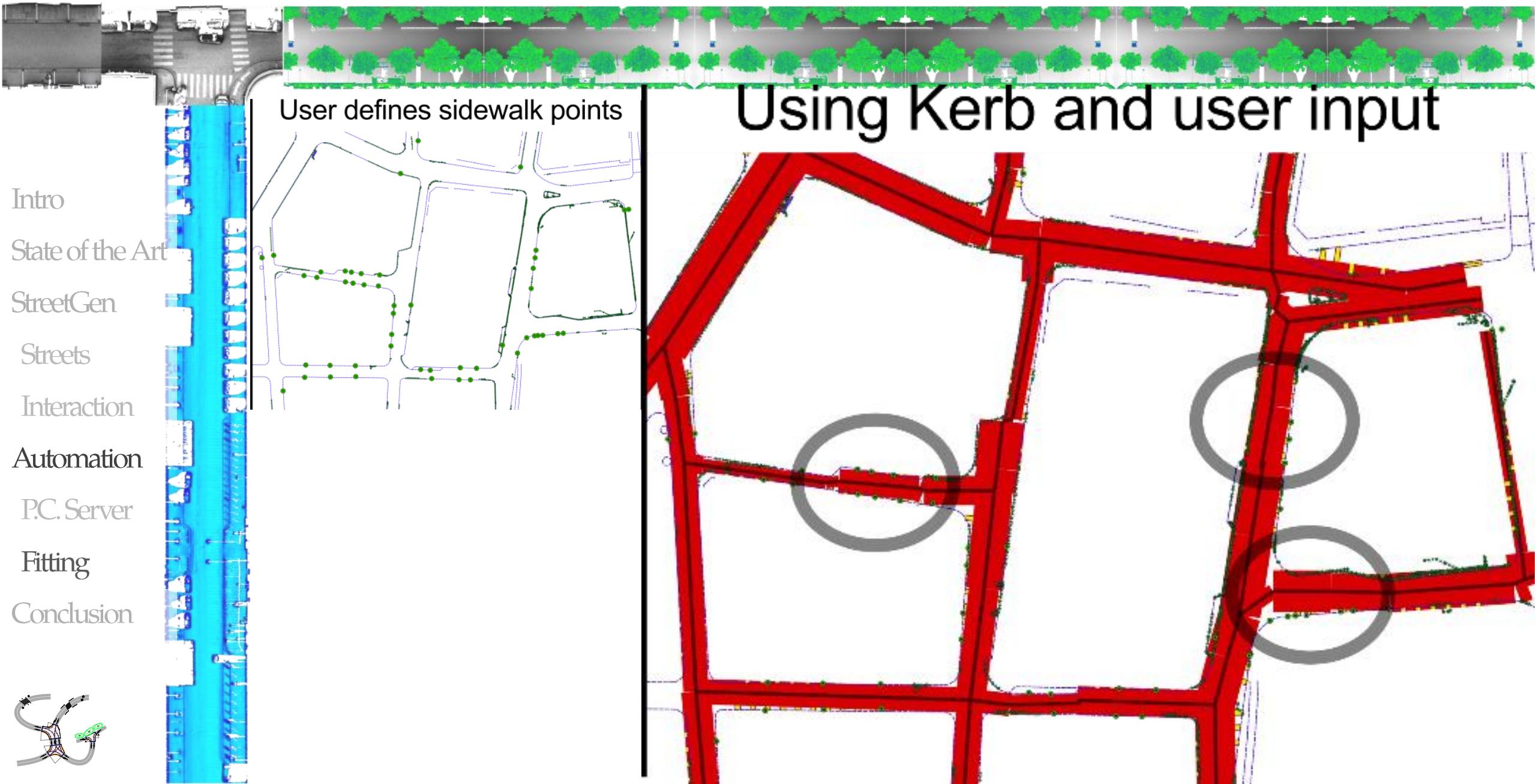
P.C. Server

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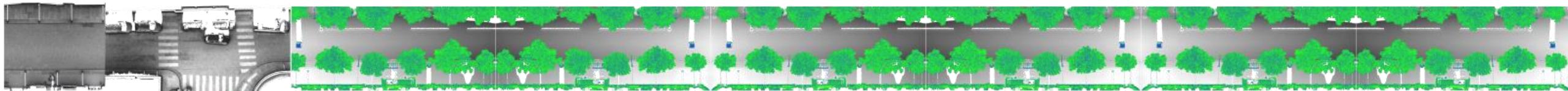
Conclusion



Inverse Procedural modelling : small area



Inverse Procedural modelling : small area



- Quantitative evaluation:

- Only kerb observation:
 - Median dist to sidewalk : from 1.8m → 0.4m
- Kerb observation + user input
 - Median dist to sidewalk : from 1.8m → 0.34m

It's much better in a challenging area!

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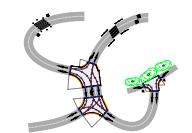
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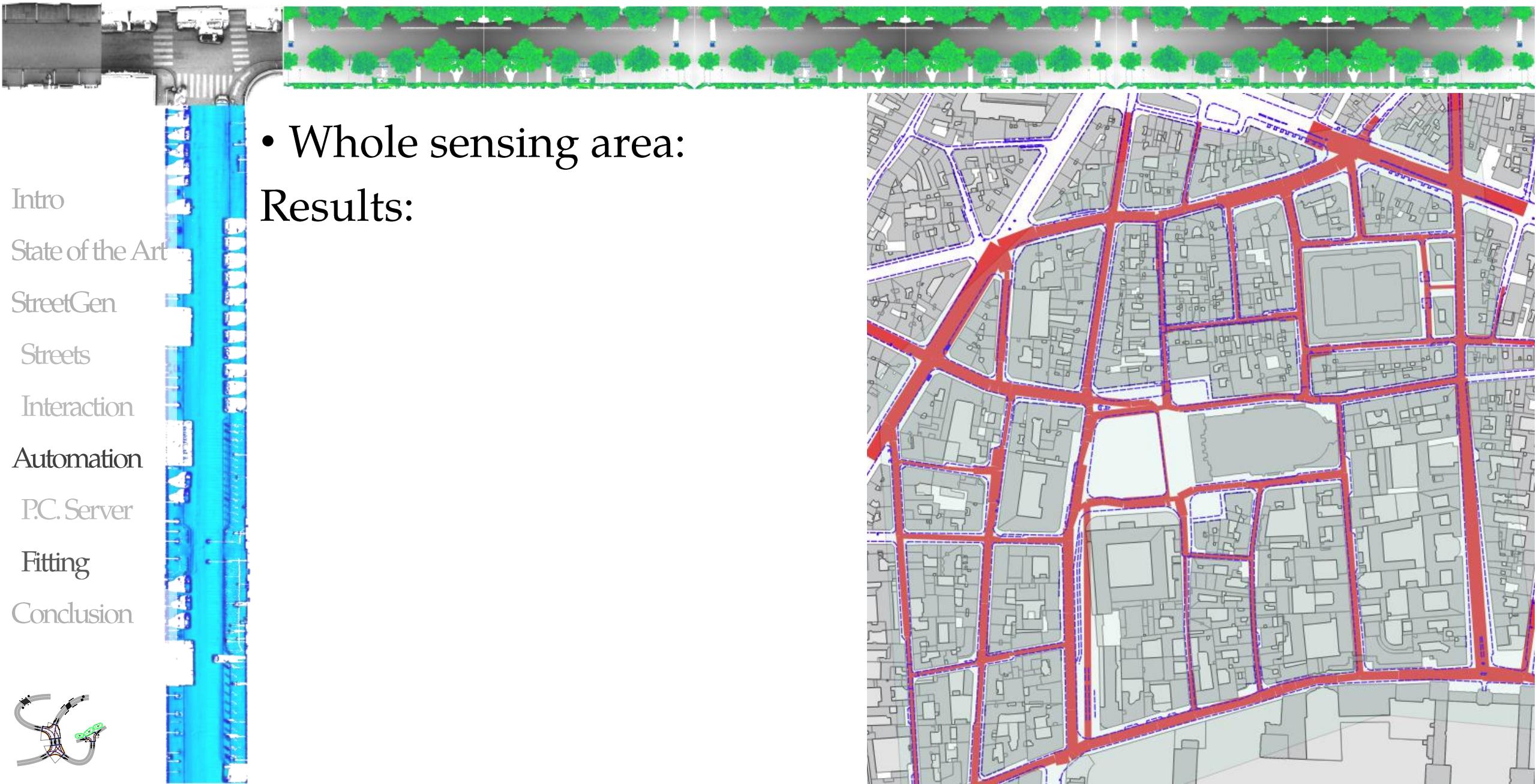
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Inverse Procedural modelling : sensing area



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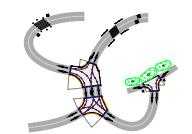
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Inverse Procedural modelling : sensing area

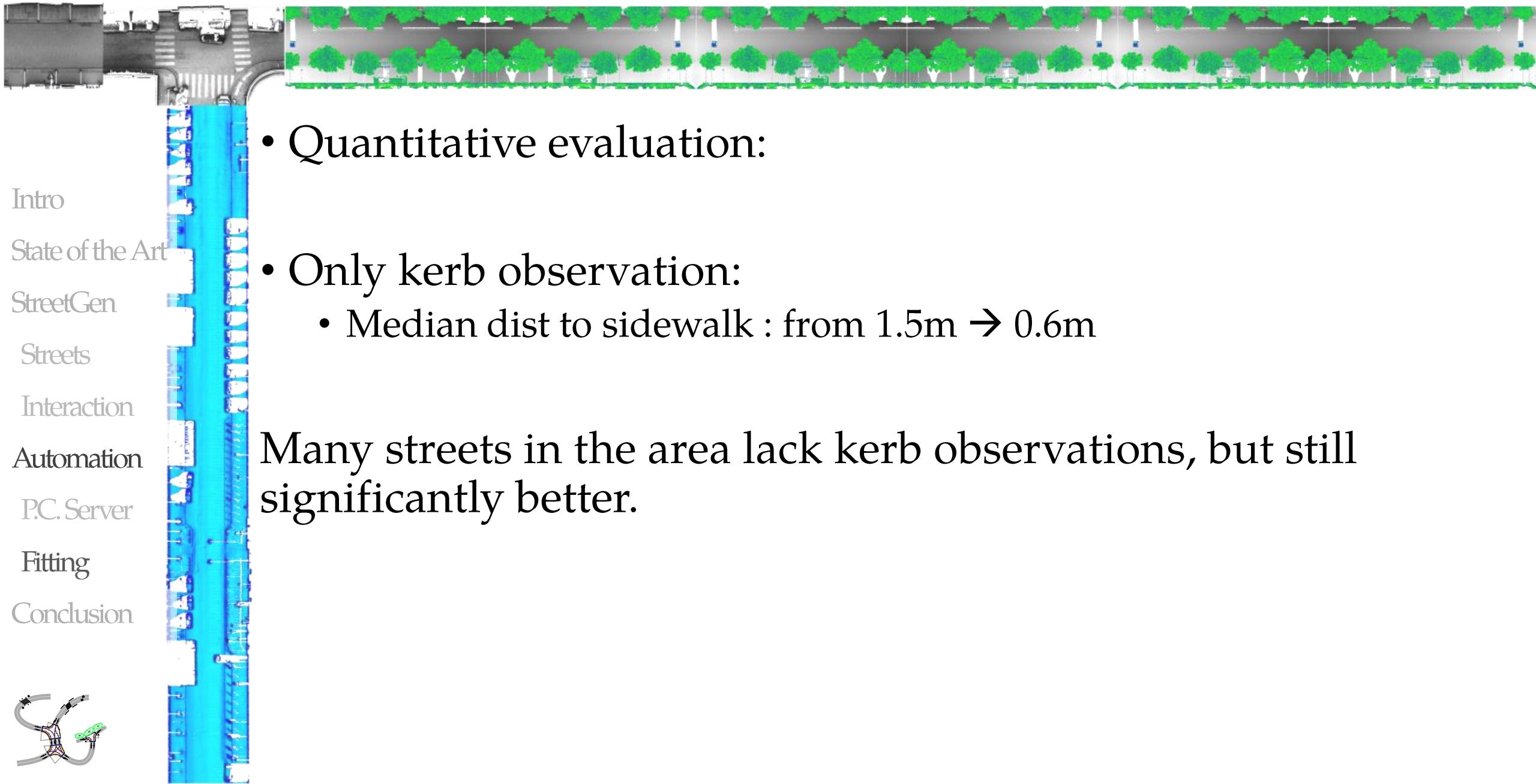
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- Yellow circle are proportional to error:
- Most of the cases :
 - Not enough curb detection!
- Sometime:
 - Road model not sufficient
- Seldom:
 - Optimisation not optimal



Inverse Procedural modelling : sensing area



- Quantitative evaluation:
 - Only kerb observation:
 - Median dist to sidewalk : from 1.5m → 0.6m
- Many streets in the area lack kerb observations, but still significantly better.

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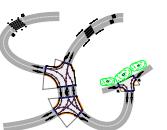
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Inverse Procedural modelling : Paris area

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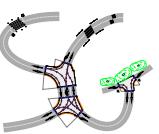
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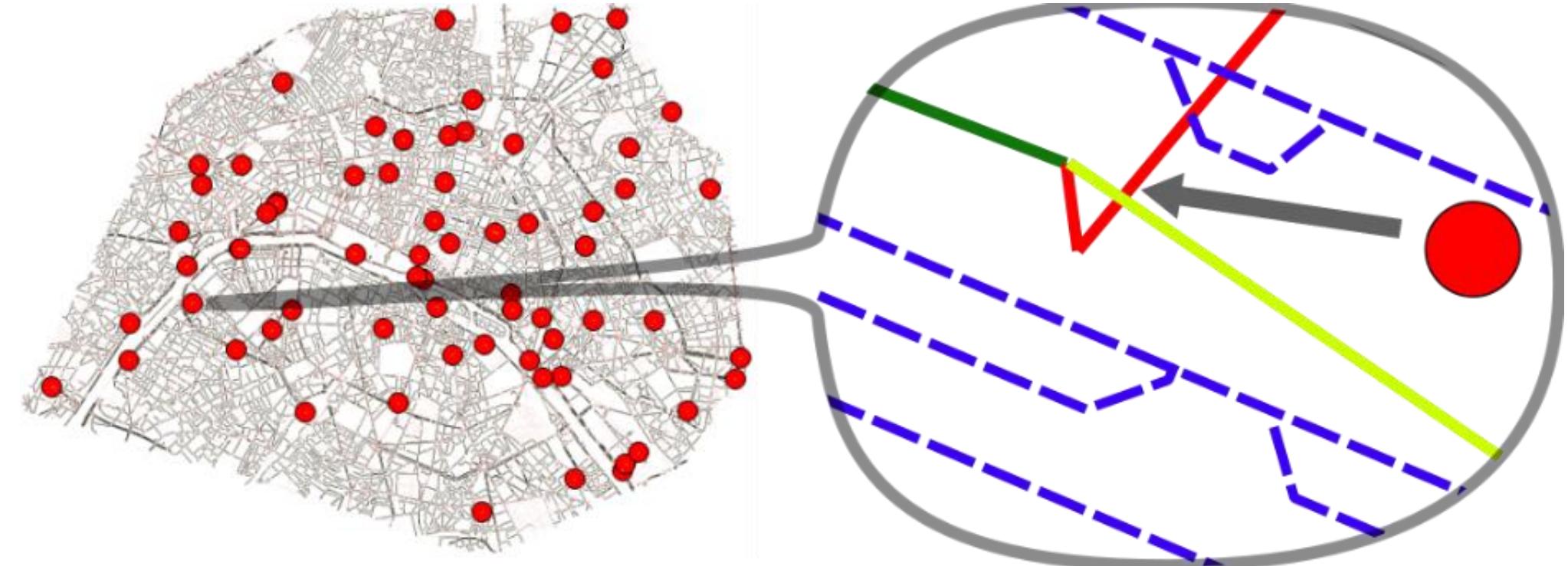
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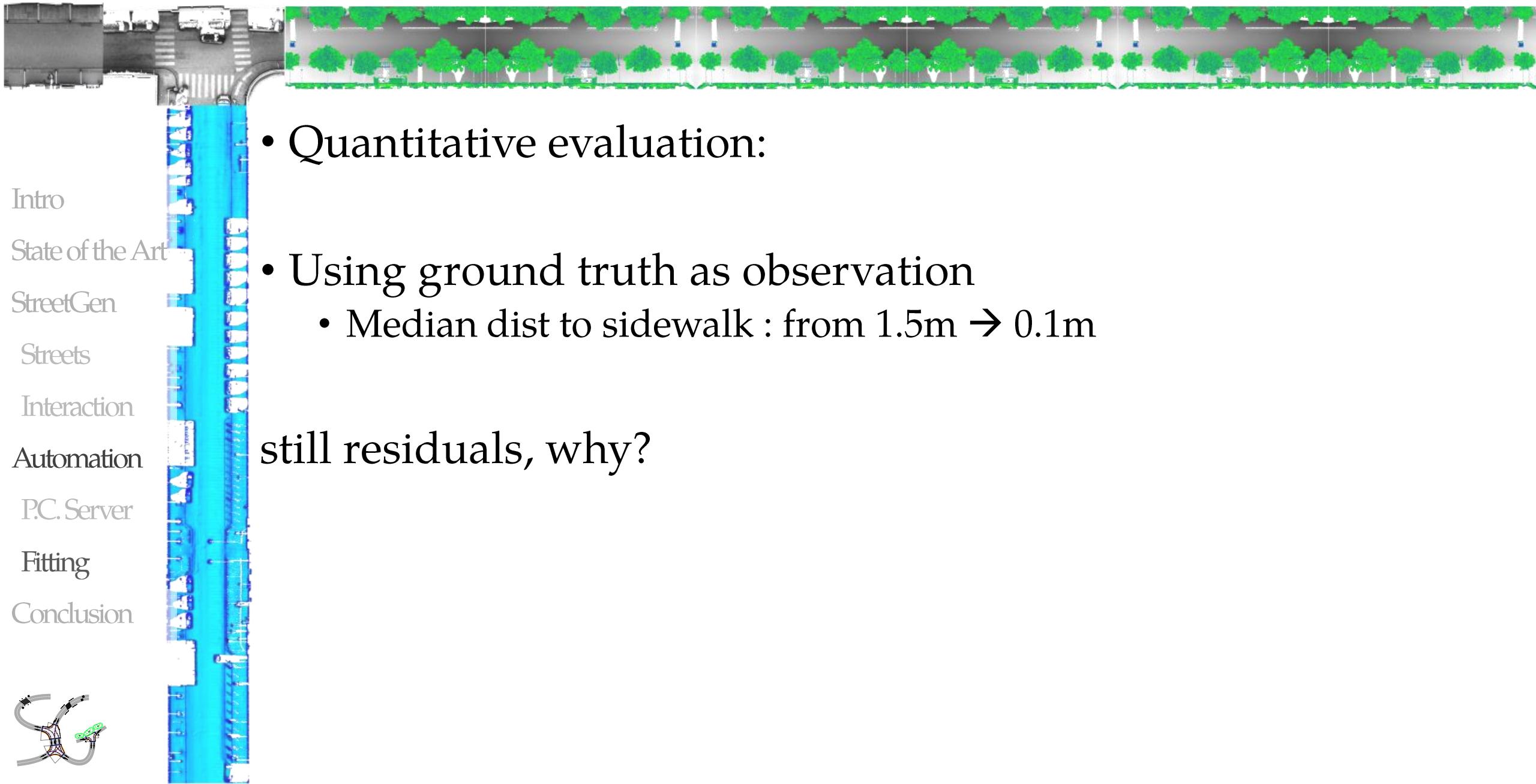
Conclusion



- Whole Paris : topology is broken at few points
 - Few enough to manually correct



Inverse Procedural modelling: Paris area



- Quantitative evaluation:

- Using ground truth as observation
 - Median dist to sidewalk : from 1.5m → 0.1m

still residuals, why?

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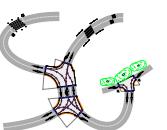
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Inverse Procedural modelling: error sources

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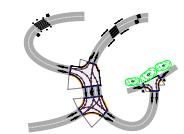
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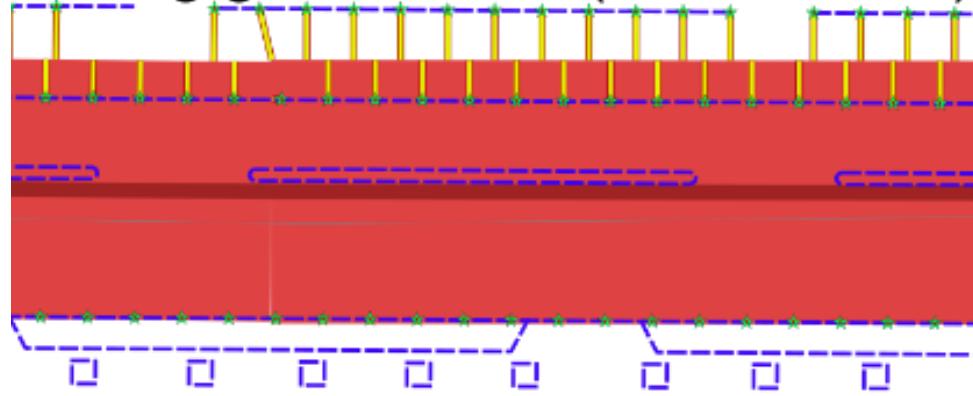
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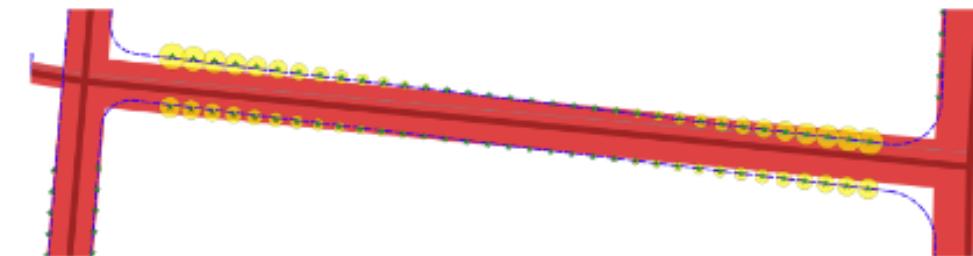


- Residual sources

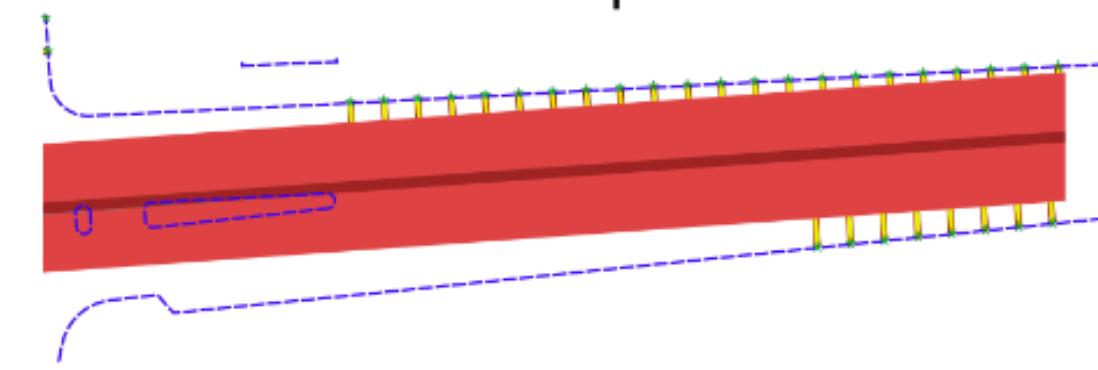
Wrong ground truth (blue dashes)



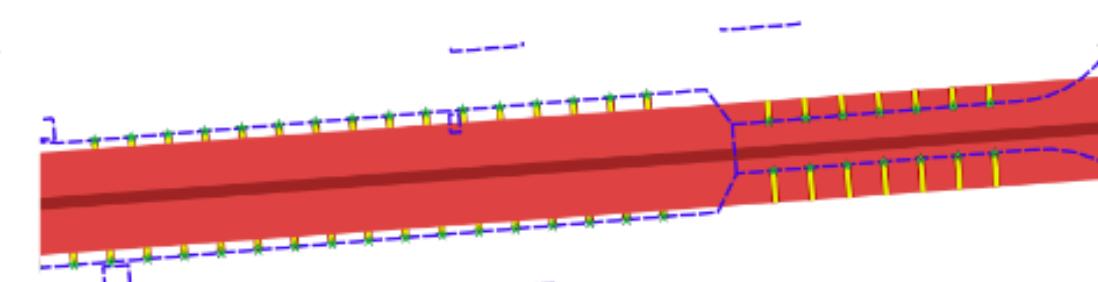
Over constrained (not enough split)



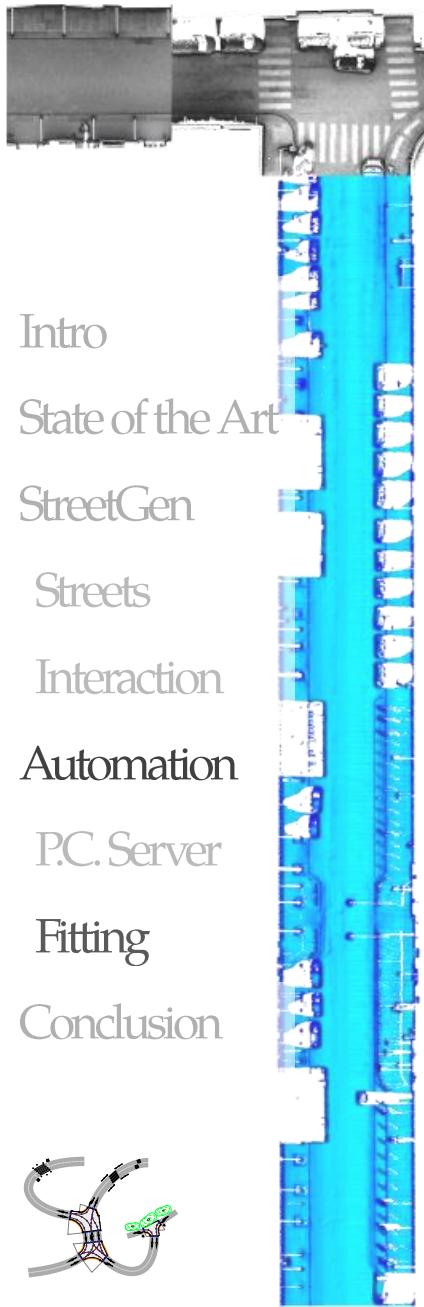
Road model too simple



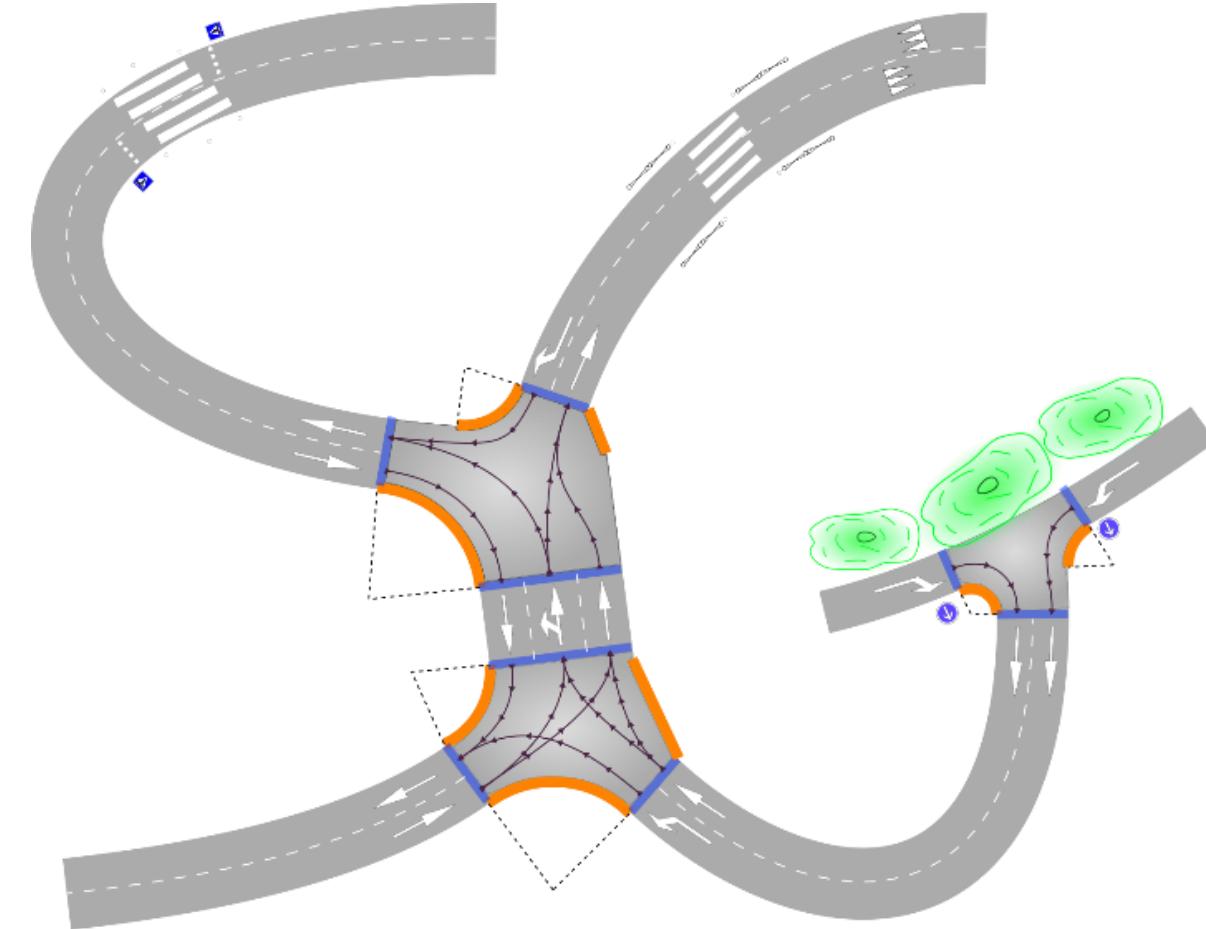
Over constrained (not enough split)



Inverse Procedural modelling: Streetgen on optim



- Once simple road model is optimised, we can generate streets with StreetGen



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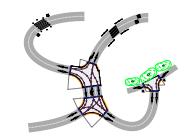
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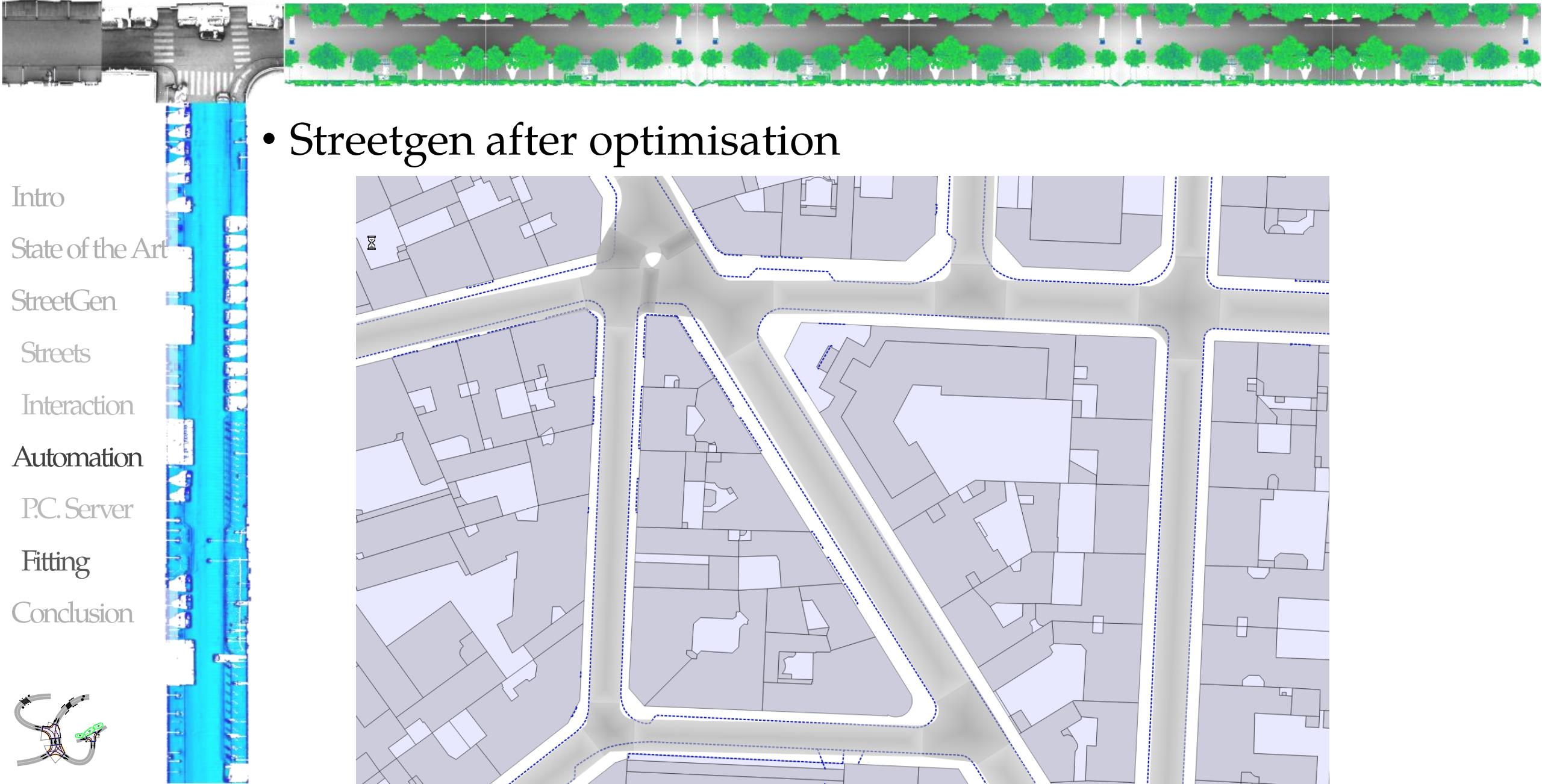
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Inverse Procedural modelling: Streetgen on optim



- Streetgen after optimisation

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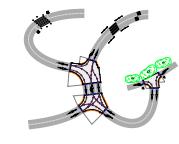
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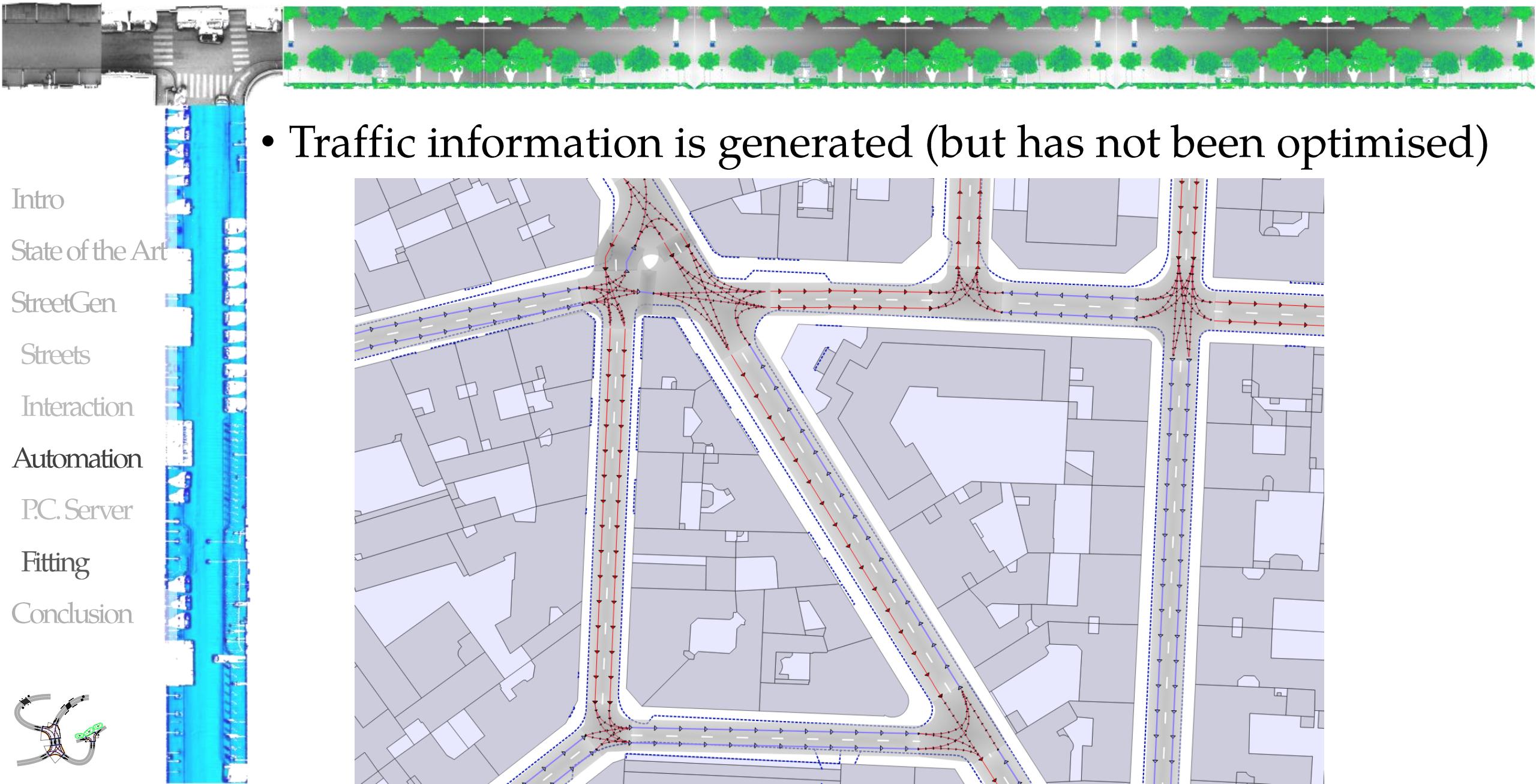
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Inverse Procedural modelling: Streetgen on optim



- Traffic information is generated (but has not been optimised)

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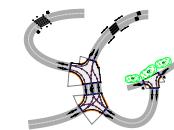
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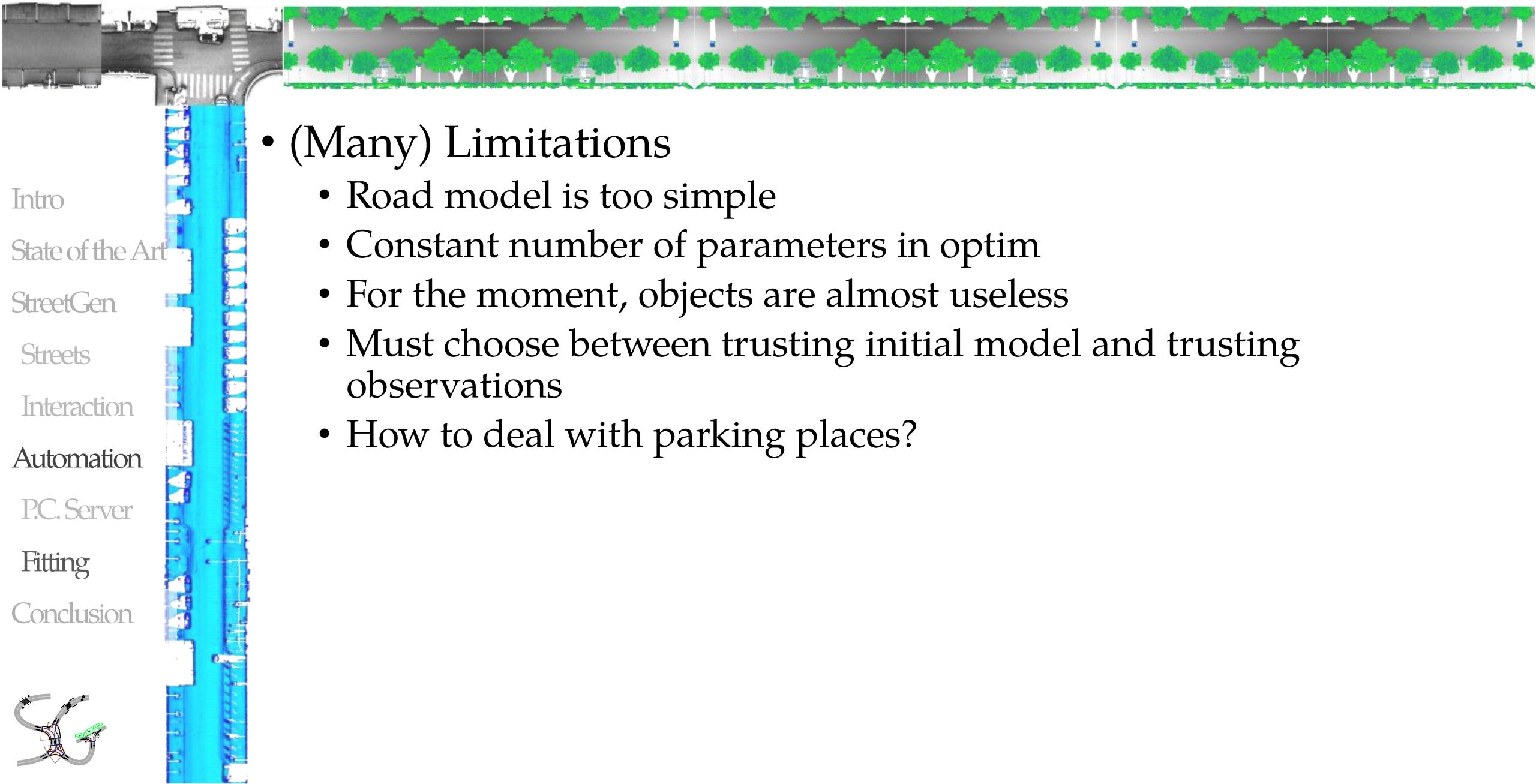
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Inverse Procedural modelling: Limitations



- (Many) Limitations
 - Road model is too simple
 - Constant number of parameters in optim
 - For the moment, objects are almost useless
 - Must choose between trusting initial model and trusting observations
 - How to deal with parking places?

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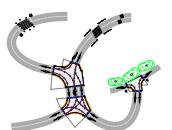
Interaction

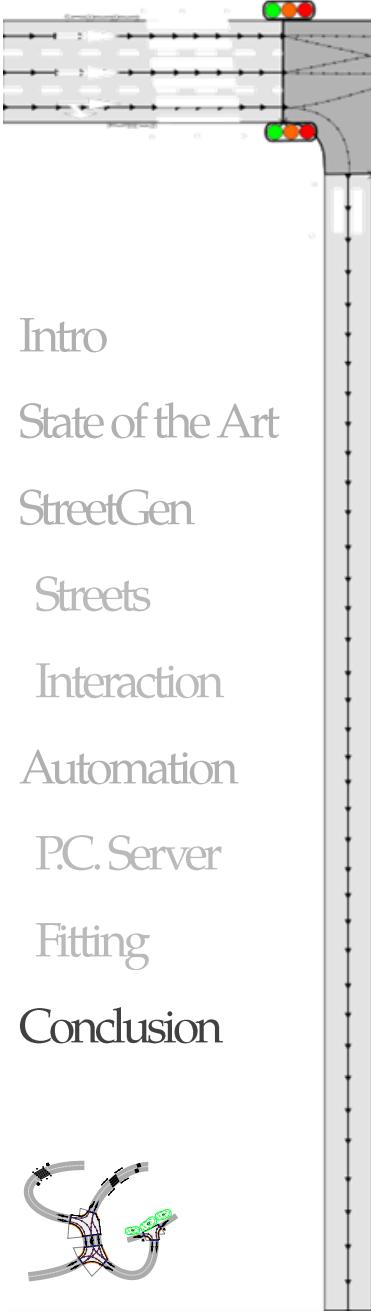
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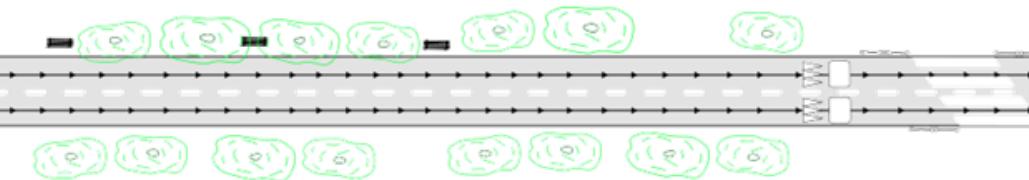
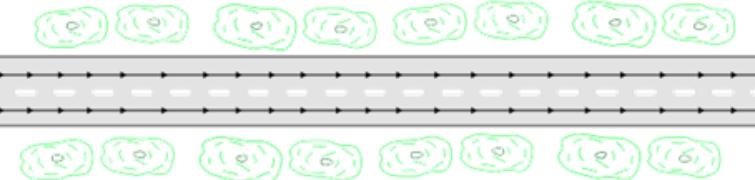
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Conclusion: Summary

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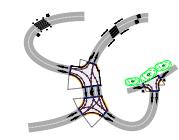
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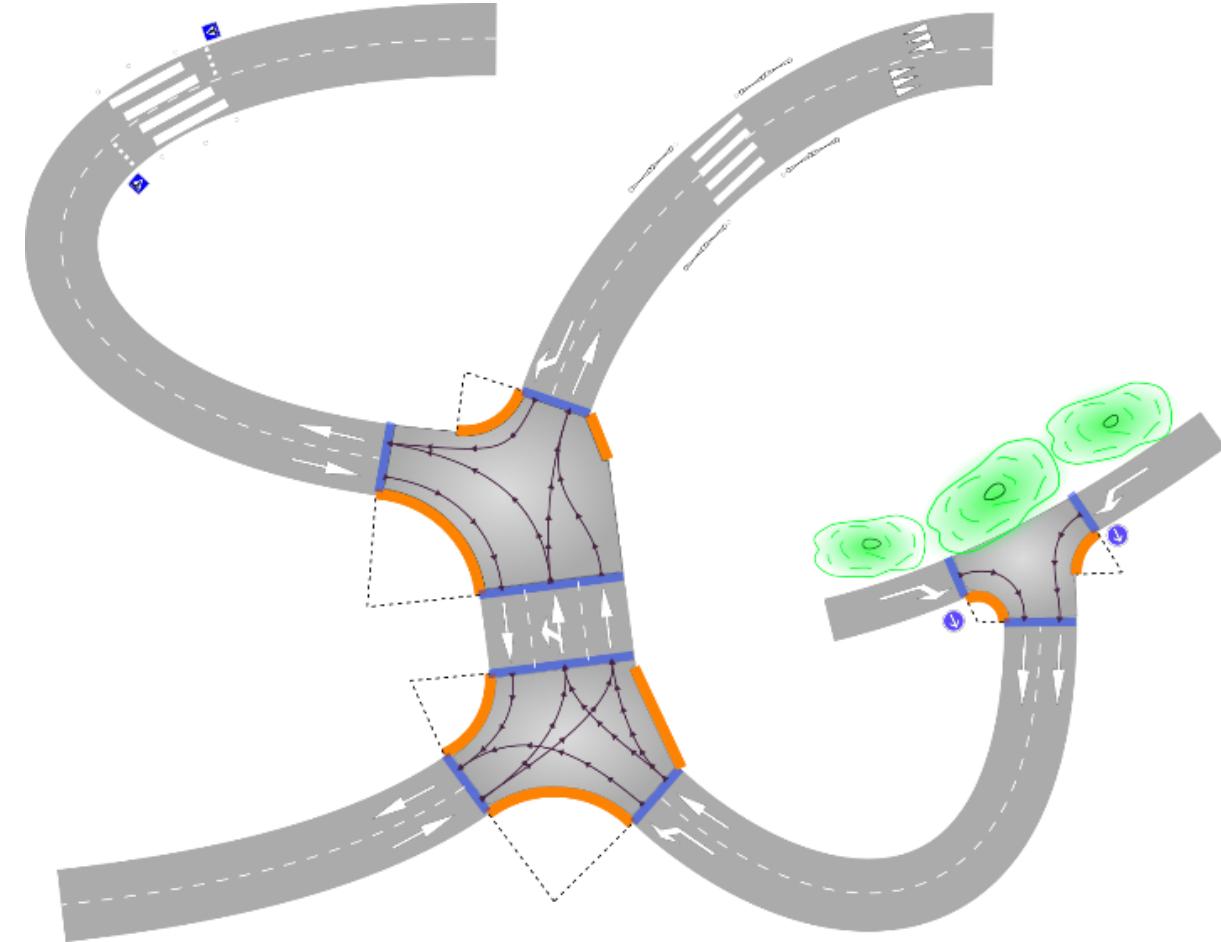
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- From low information: generate best guess street model at Paris scale and edit it (multi-user, using many GIS software): StreetGen



Conclusion: Summary

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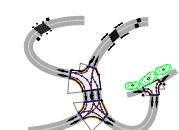
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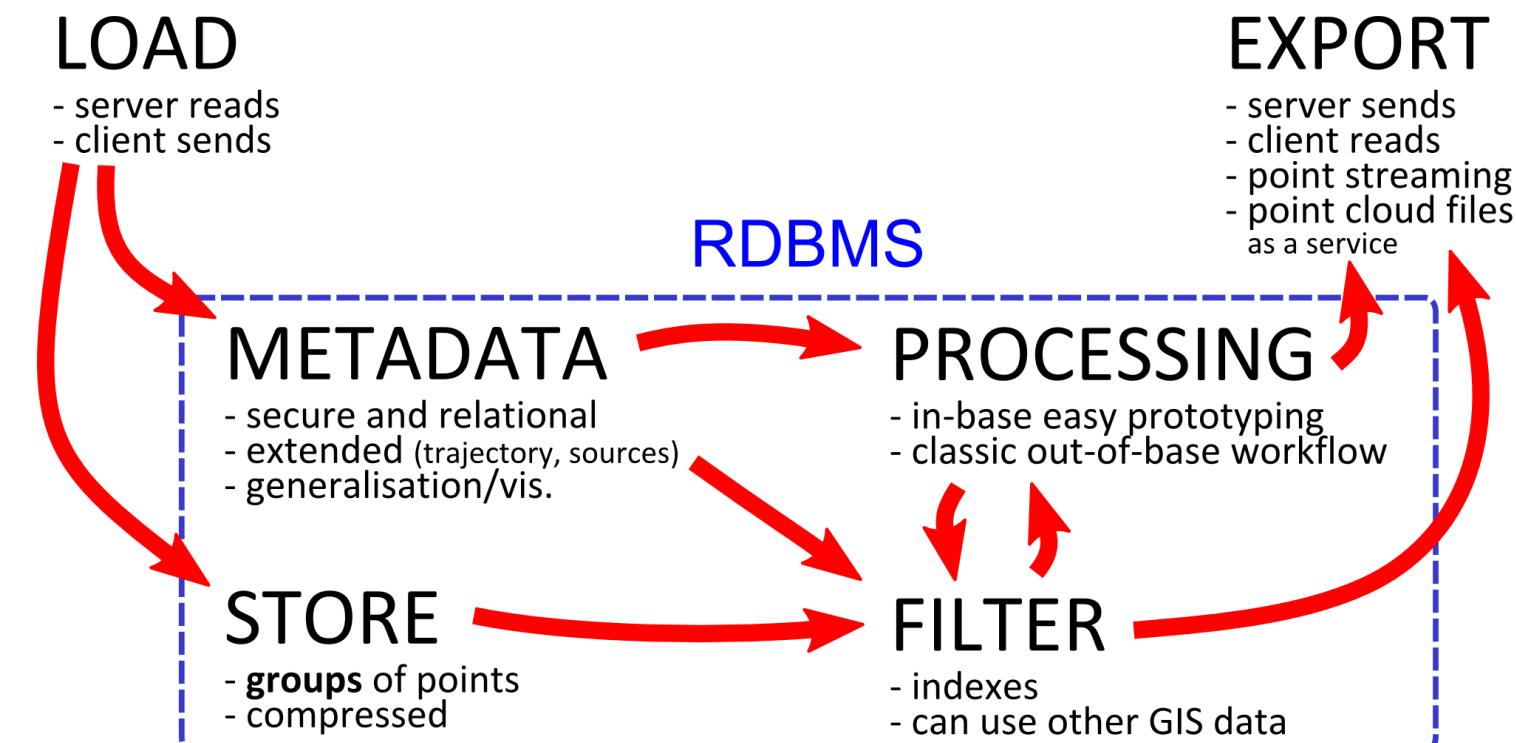
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- Manage a massive amount of 3D points (from mobile mapping). Act as a service for usage/processing/visu:
Point Cloud Server



Conclusion: Summary

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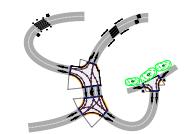
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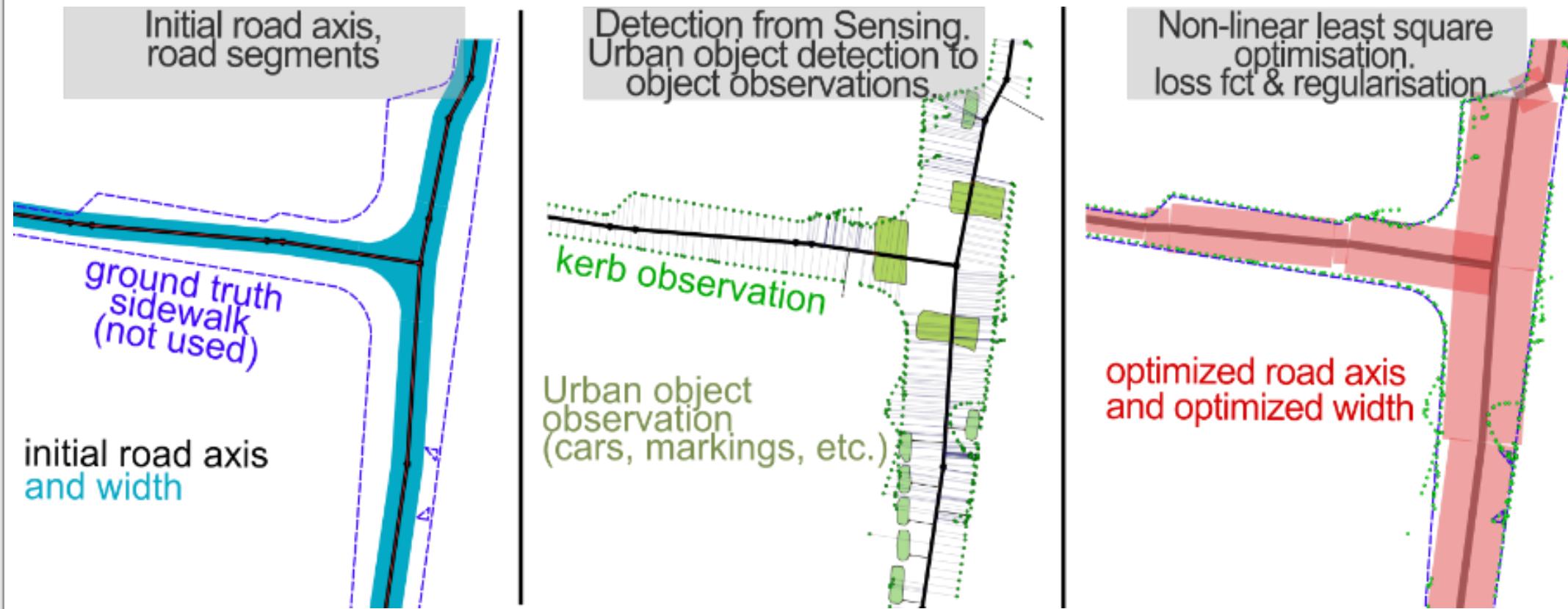
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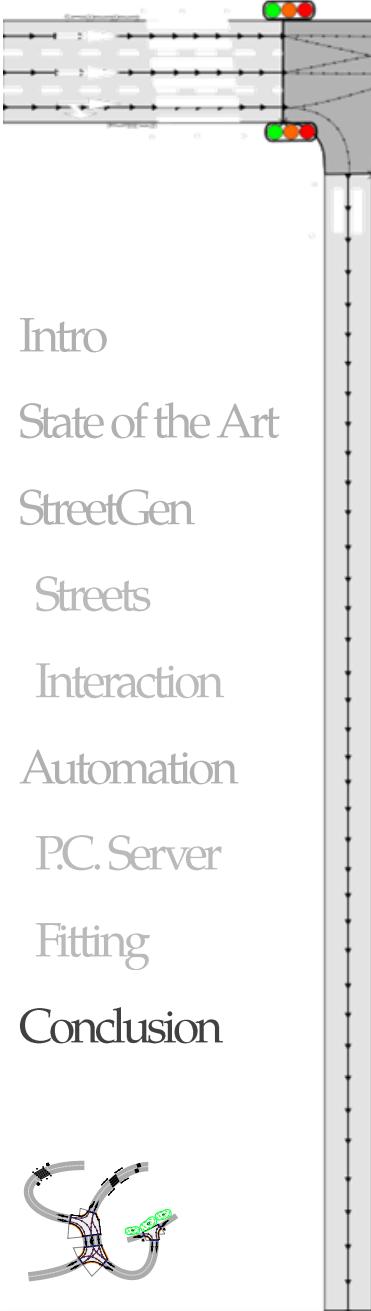
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- Perform inverse procedural modelling by fitting a road model to various observations





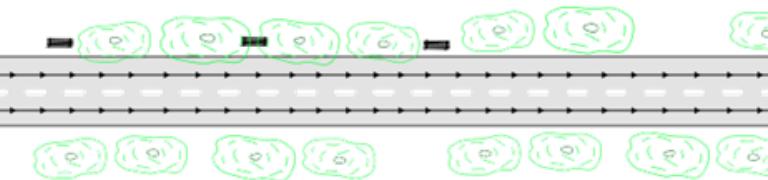
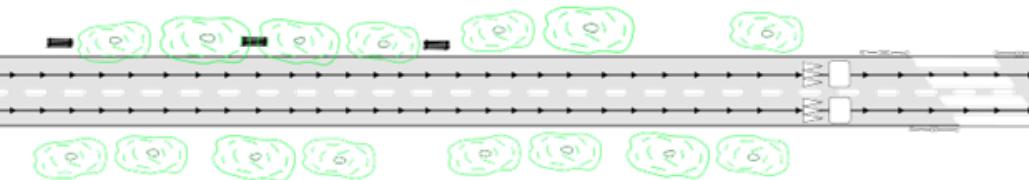
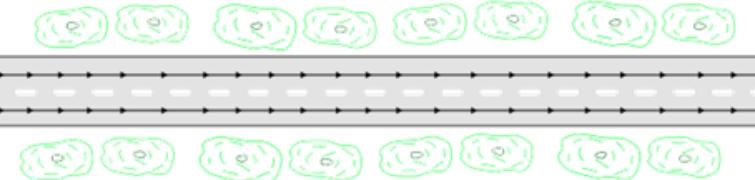
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Conclusion: Limitations

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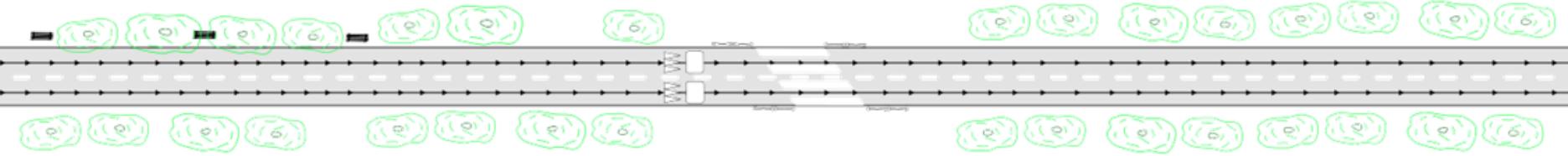
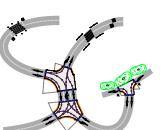
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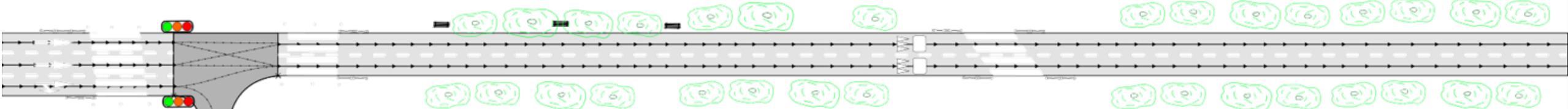
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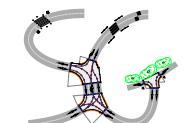
- Very simple street model: revolves around street axis.
 - Too simple?
 - Pedestrian street?
 - Based on topology → hard to maintain/scale/edit
- Point Cloud Server :
 - Need several processing methods to extract observations
 - Coupling with street images missing
 - 3D from images? Updating?
- Objects are created/edited manually by user
 - Tedious, not much sense



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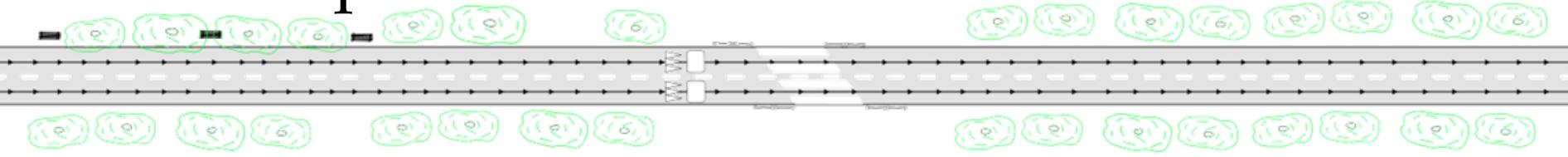
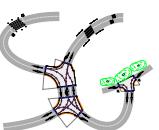
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- Only the beginning of inverse procedural street modelling.
 - Dealing with objects and road model simultaneously calls for much stronger modelling and optimisation methods
 - Object should be created by template/ pattern/ grammar/procedural functions!
 - Optimisation should be more powerfull (RJ-MCMC)

Conclusion: Perspectives

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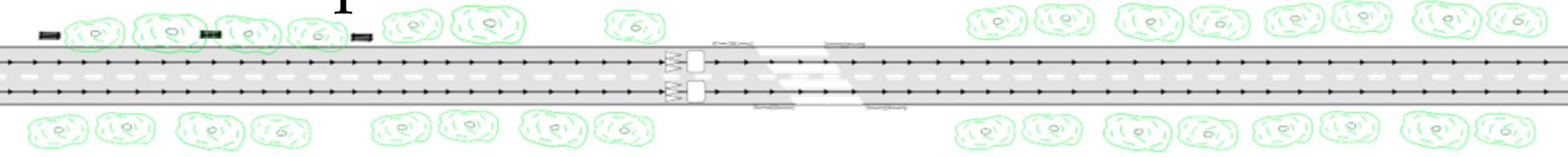
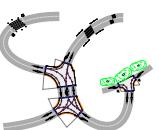
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- Since the beginning of the thesis :
 - Major trend in smart vehicle/autonomous cars
 - → maps no more required only by traditional data provider
 - → maps potentially required by every (Billion) cars
- Many methods on low level classification
 - Different cars with different hard → need a more abstract street model

Conclusion: Perspectives

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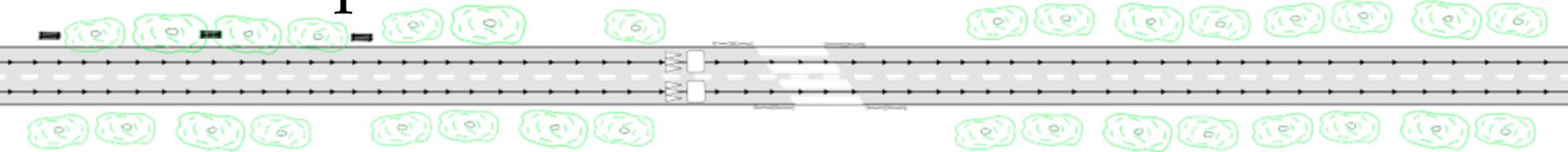
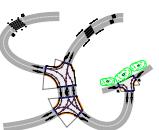
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- “smart city” is trending
 - There is several cities in one city:
 - Saint Mandé entry roundabout .
 - Day : next to Lenotre: luxury caterer
 - Night: hookers
 - Time is essential (simulation/understanding)
 - 4D street modelling ? (garbage/ café terrace/ parking behaviour)

Conclusion: Perspectives

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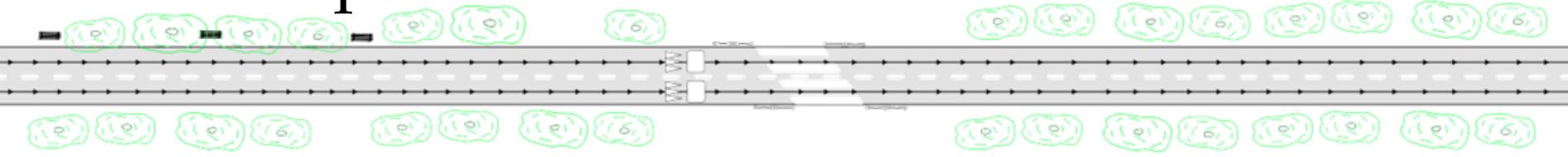
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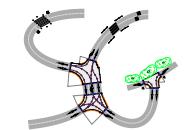


- Understanding city may be key to planning
- To understand → study city history

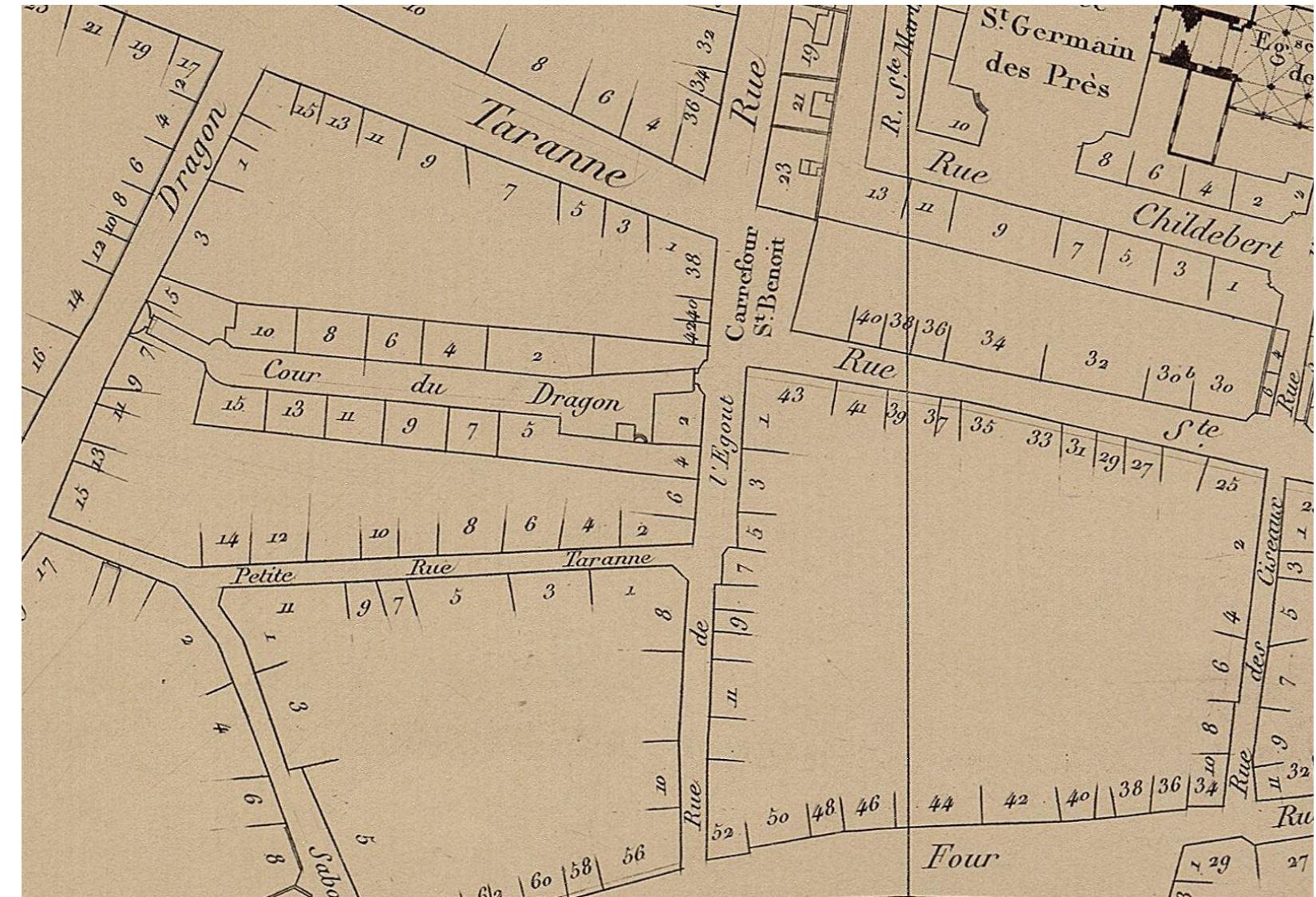
- Historical geodata
 - Hand drawn maps
 - Information needs to be extracted

Conclusion: Perspectives

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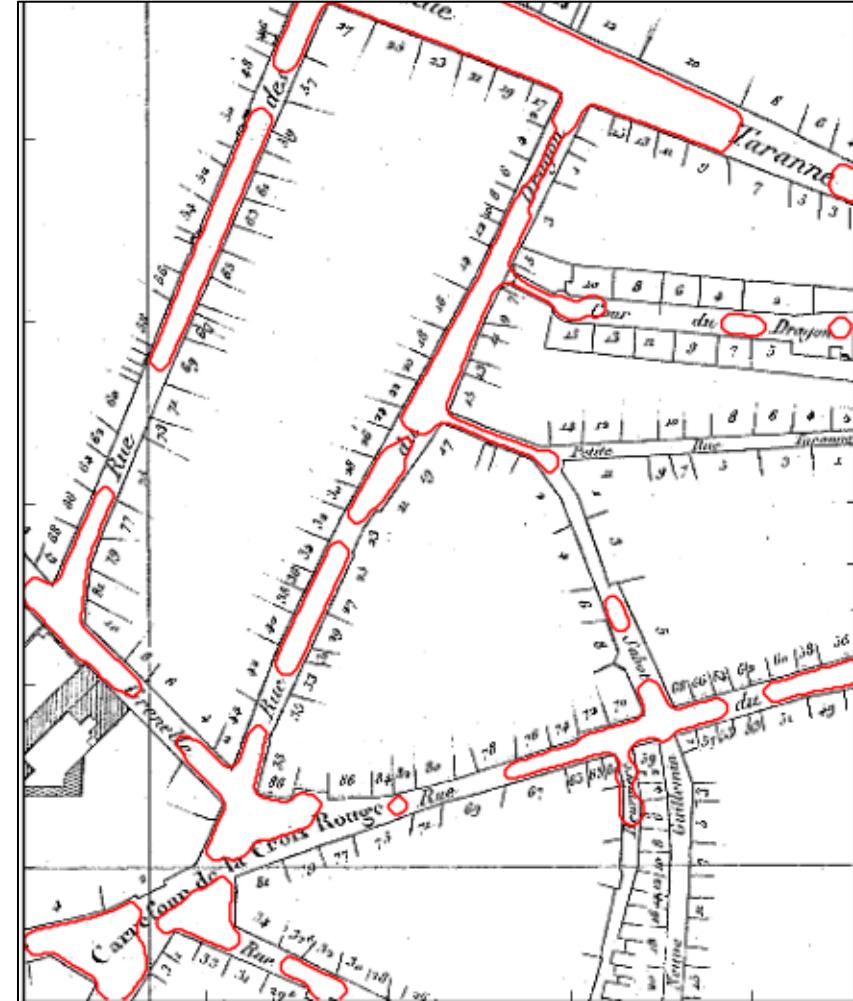
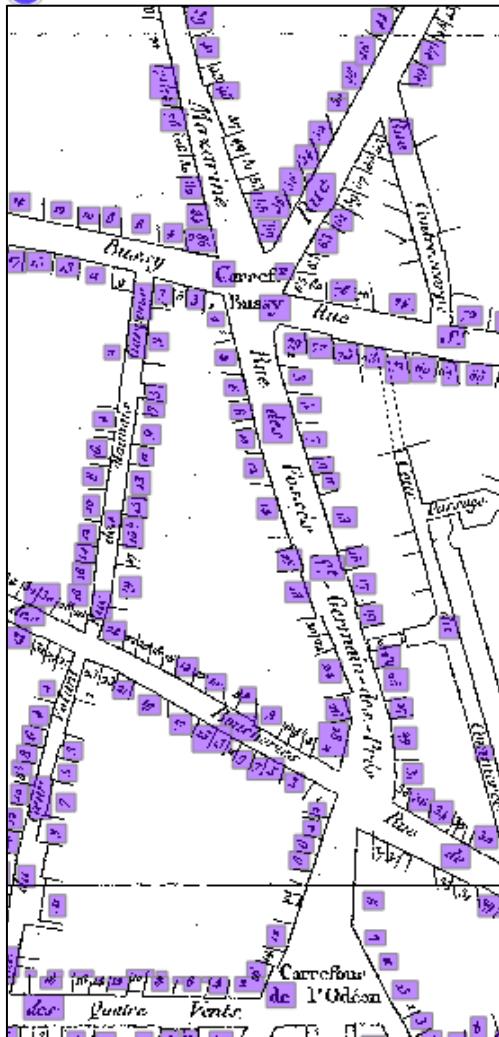
- Jacoubet,
1810-1836 :
- road model
with
optimisation
& Streetgen
?



Conclusion: Perspectives

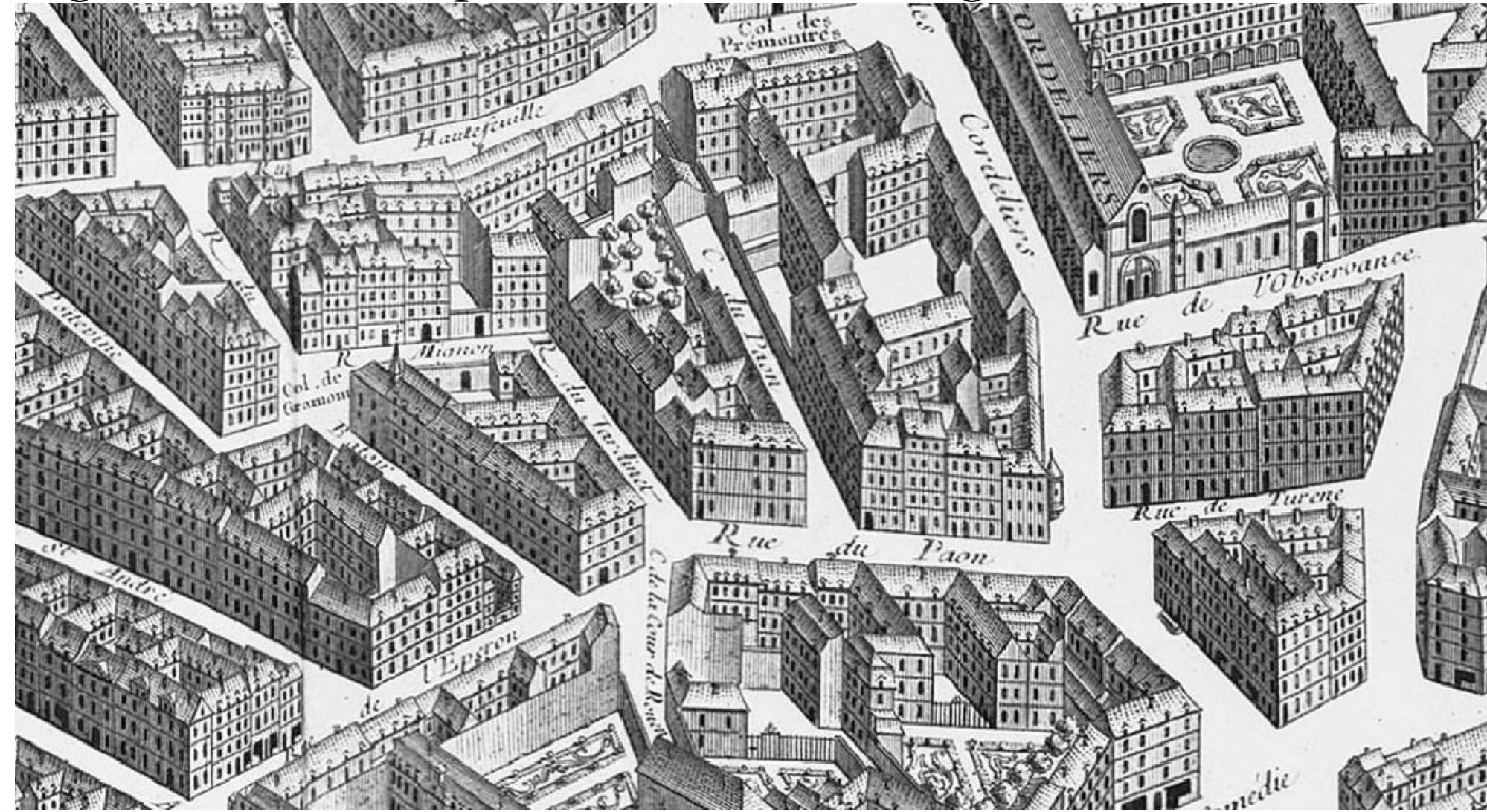
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- Extract building number



Conclusion: Perspectives

- Turgot, 1734-1739 : procedural modelling candidate?



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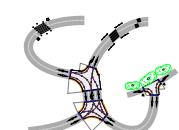
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QUESTIONS

- Thanks
- Questions?

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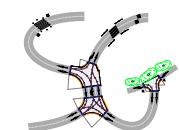
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TODO

- Finish layout for optim
 - Use it in optim and in conclusion part
- Last “question” slide with streetgen
- Conclusion need illustrations and splitting slides

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