

Inverse procedural Street Modelling: from interactive to automatic reconstruction

Phd Defense : Rémi Cura, 2016/09/12

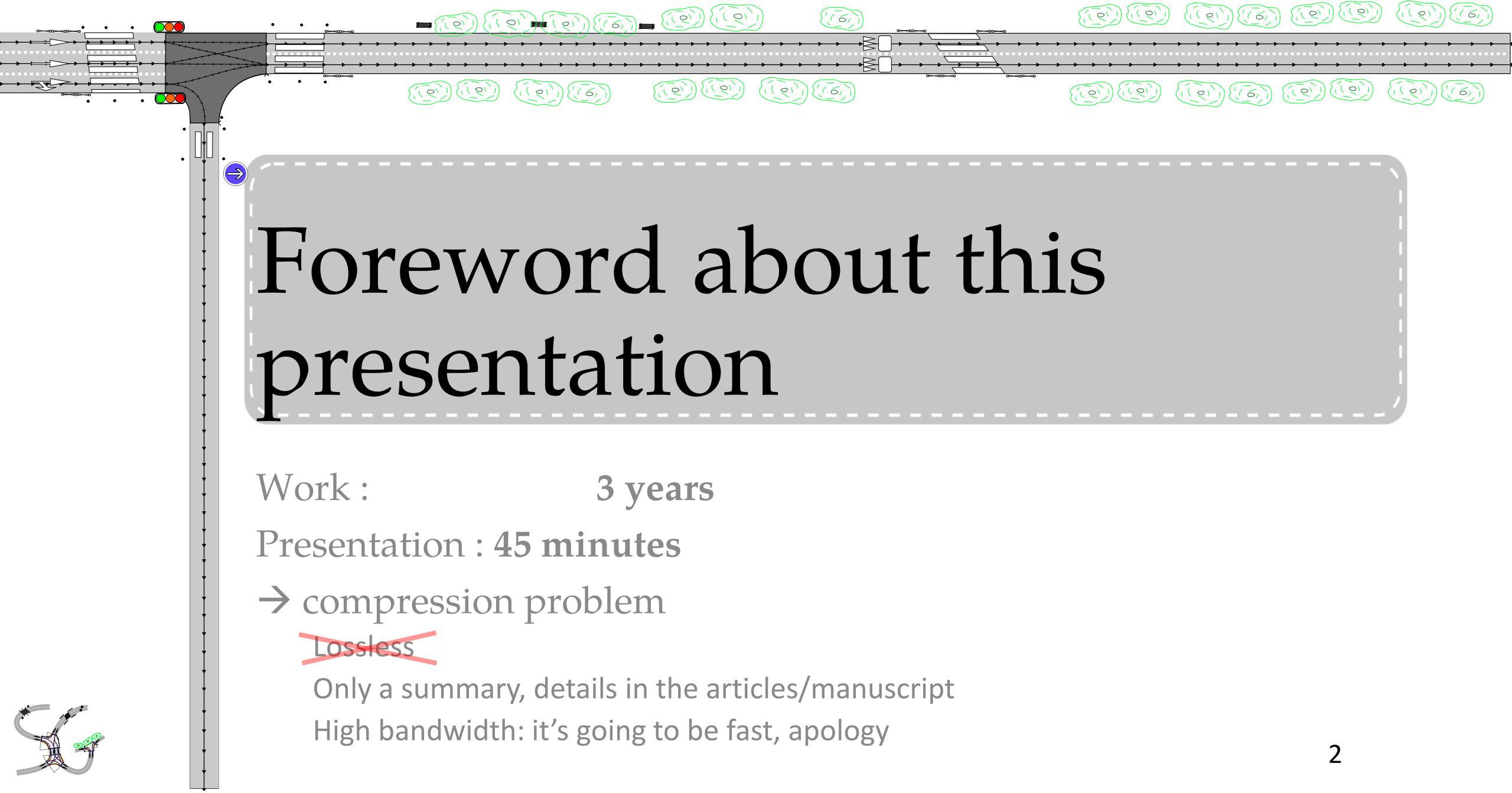
*Université Paris-Est
École Doctorale Mathématiques et Sciences et Technologies
de l'Information et de la Communication (MSTIC)*

Jury:

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

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





Foreword about this presentation

Work : **3 years**

Presentation : **45 minutes**

→ compression problem

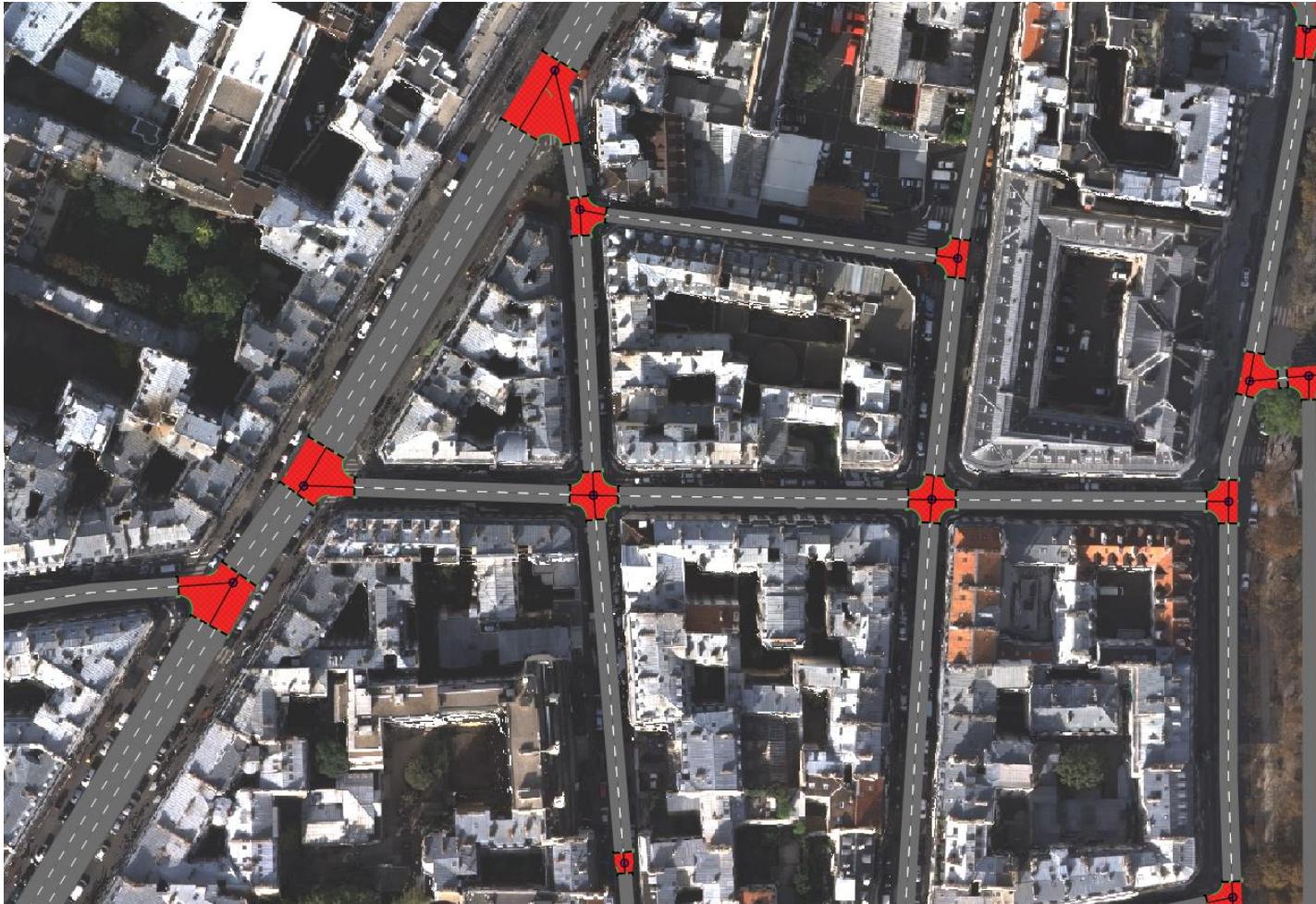
~~Lossless~~

Only a summary, details in the articles/manuscript

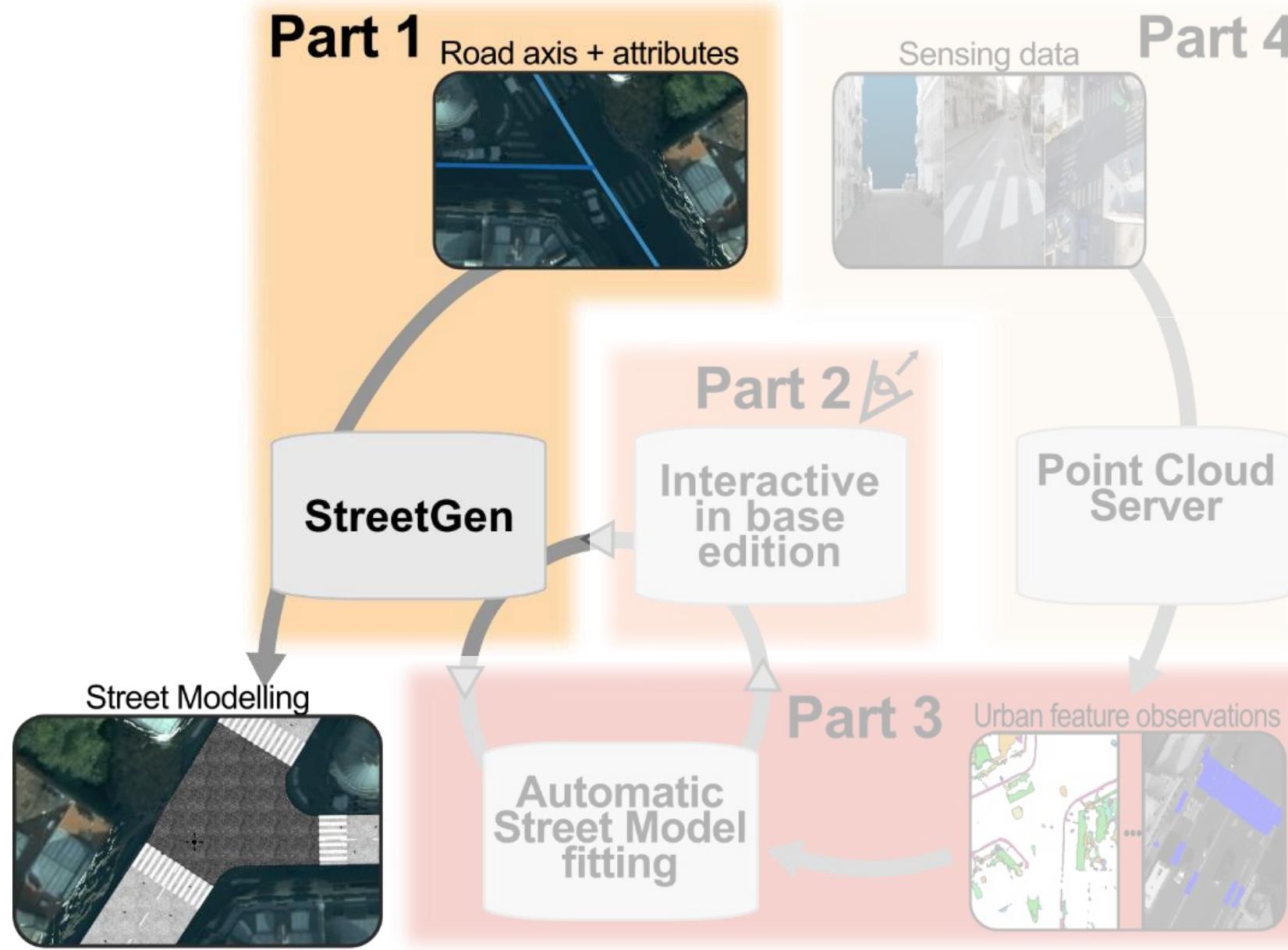
High bandwidth: it's going to be fast, apology

Abstract

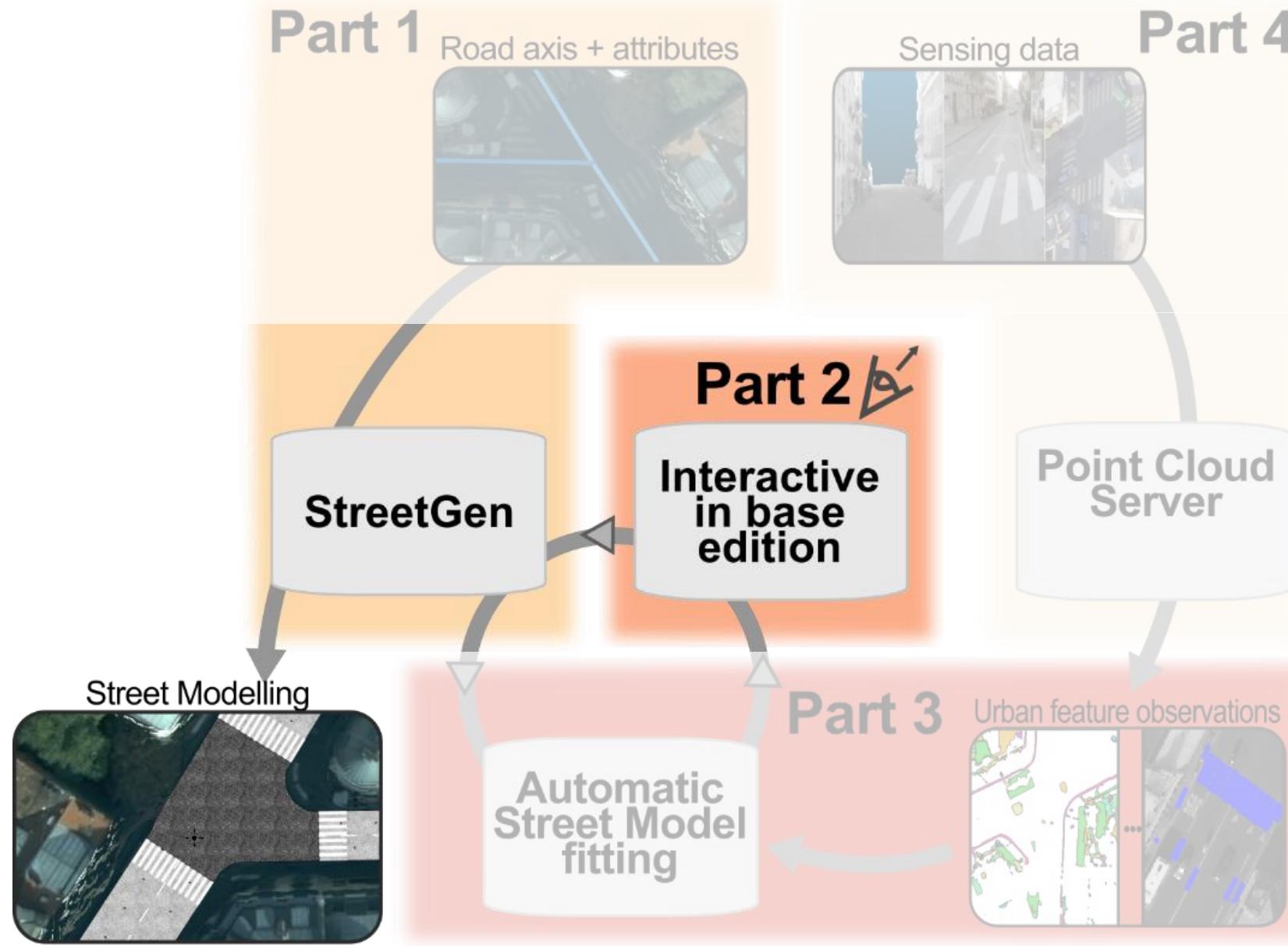
- Procedural street modelling:
- Have a mode of streets!



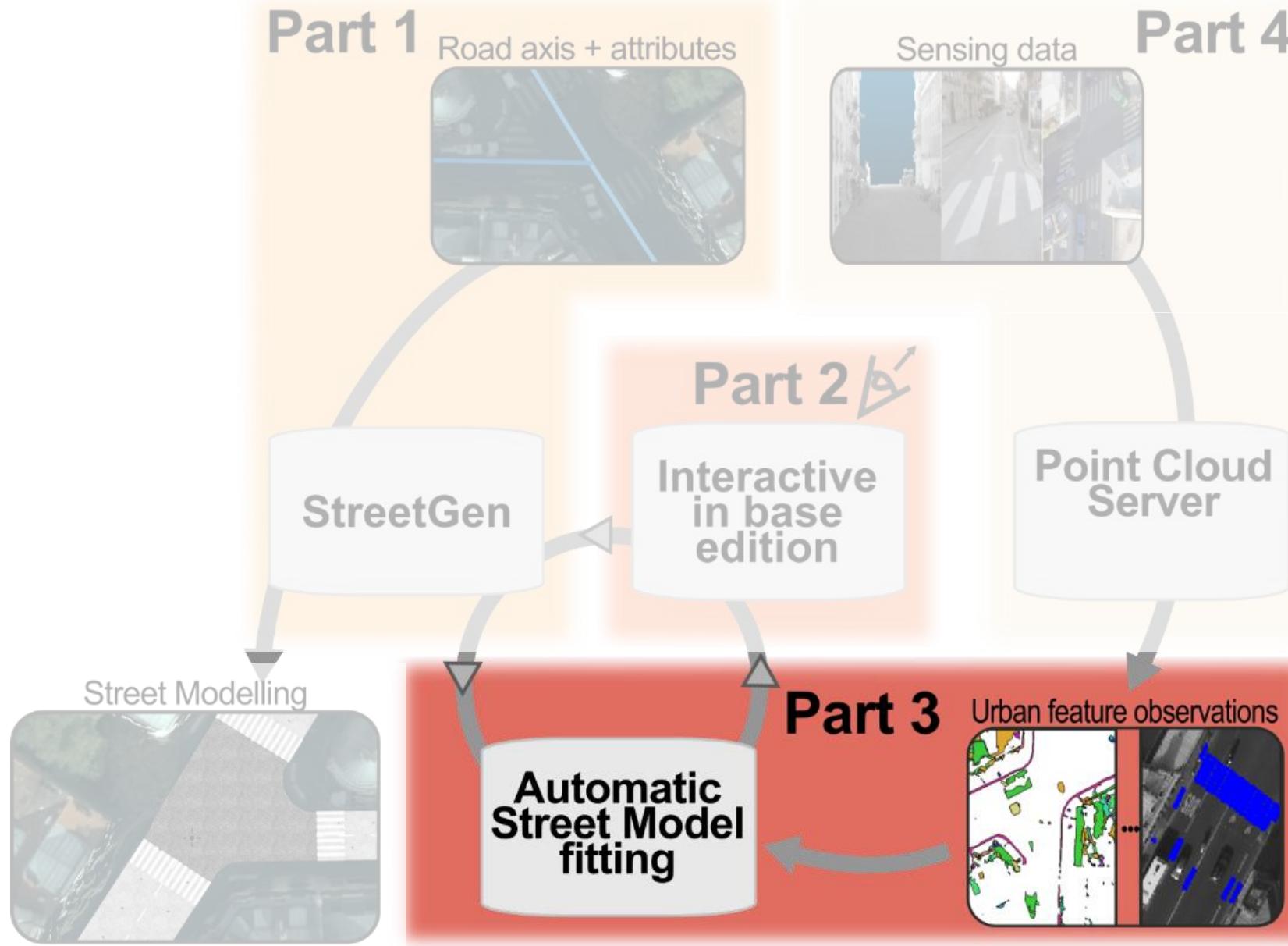
Abstract



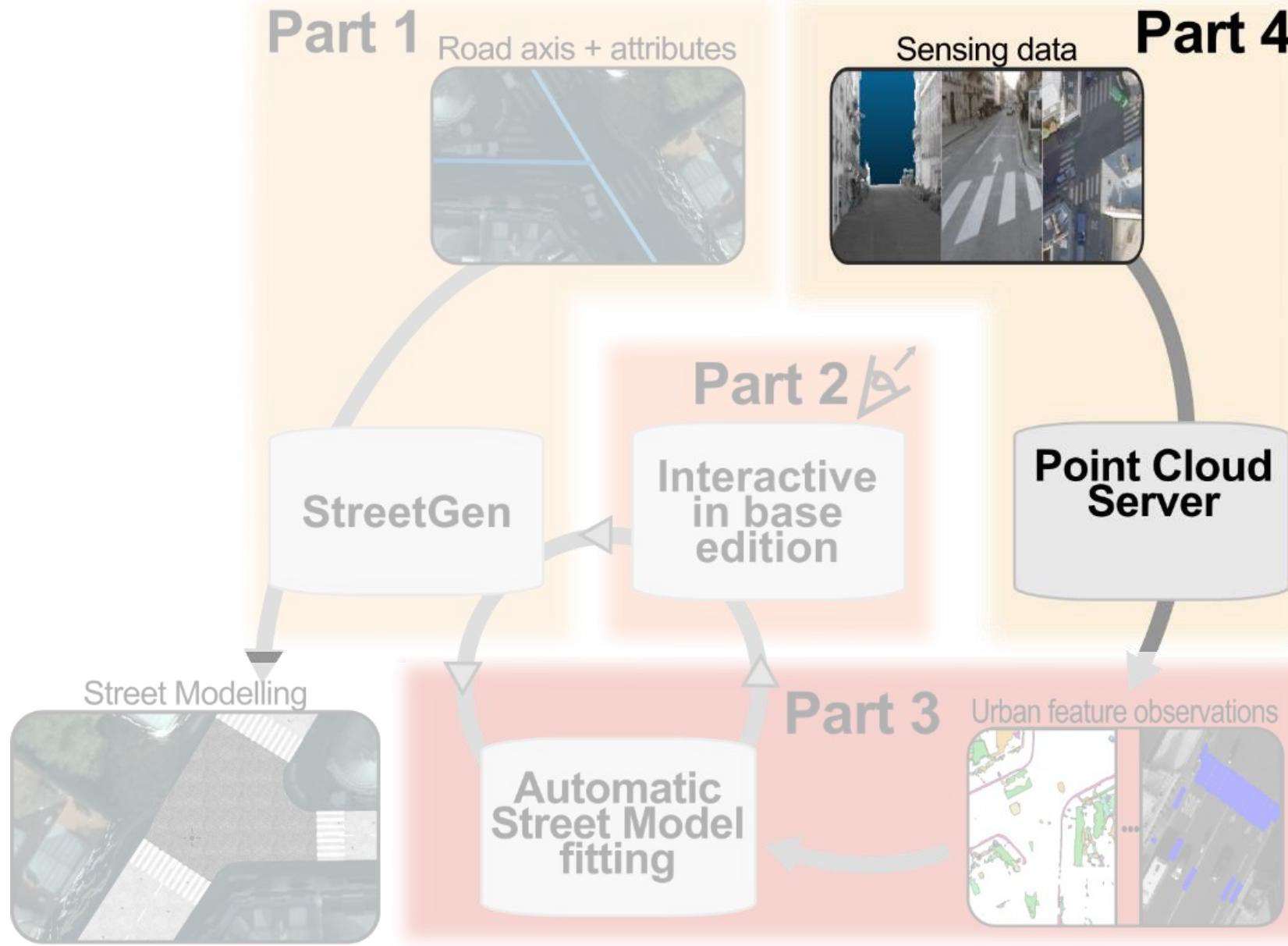
Abstract



Abstract

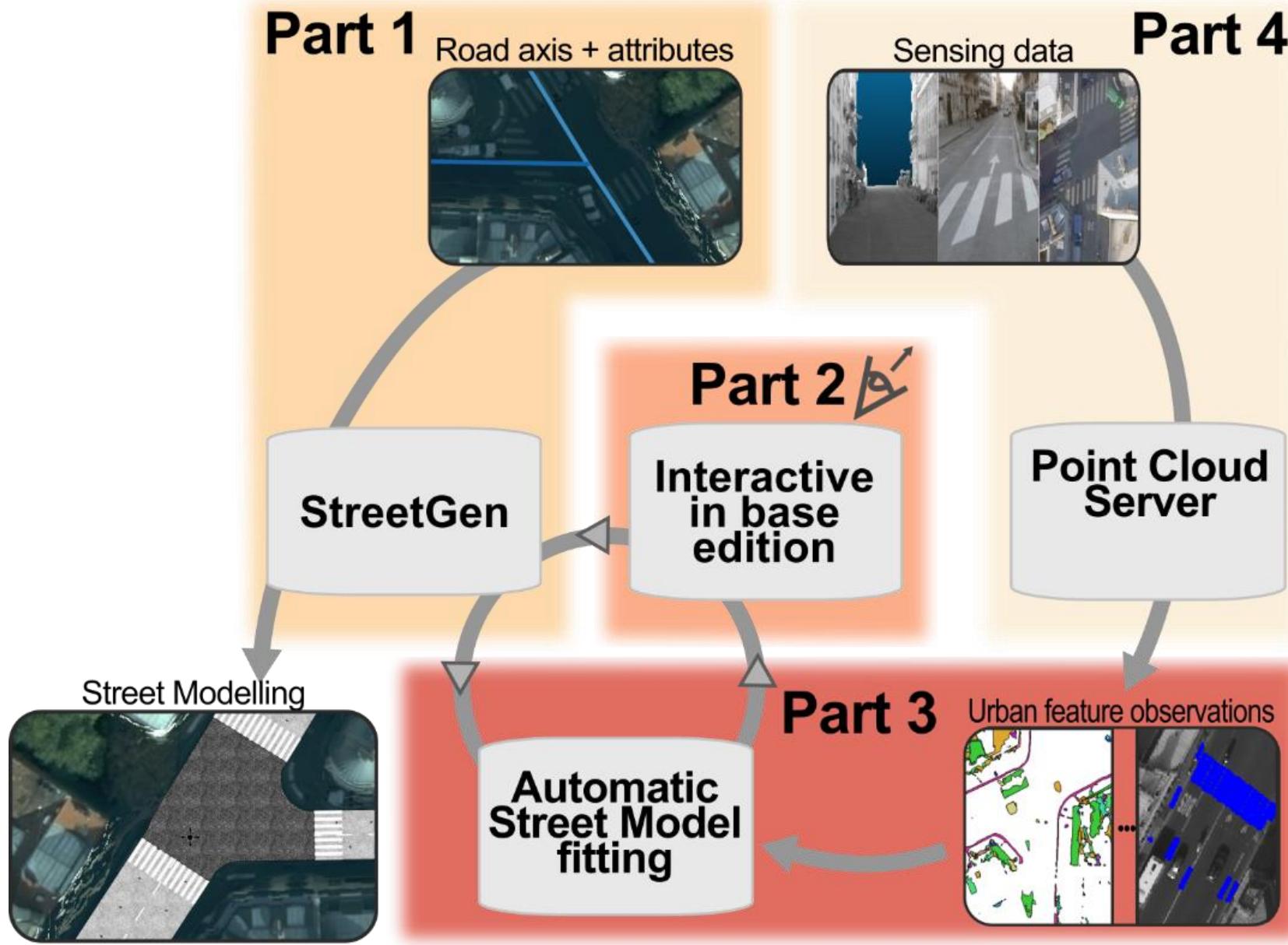


Abstract



Abstract

All parts +
Intro
State of the art
conclusion



width= 8; lane= 3

width= 6; lane= 2

Intro

State of the Art

StreetGen

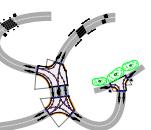
Streets

Interaction

Automation

P.C. Server

Conclusion



Introduction

Why model streets?

Usages for street model

Introduction: Streets are important

width= 8; lane= 3

width= 6; lane= 2

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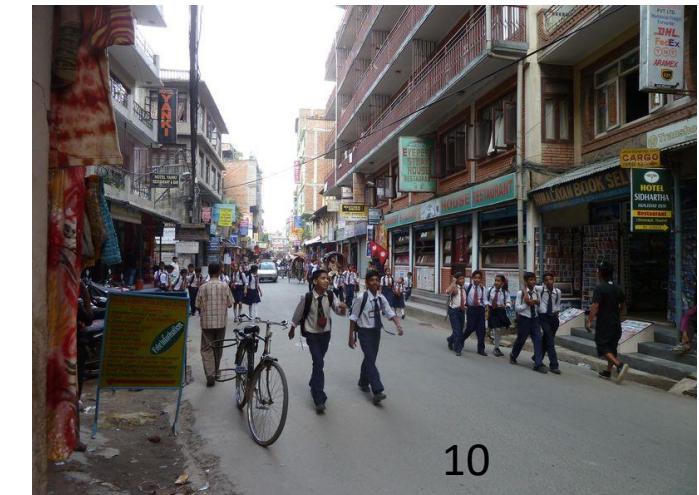
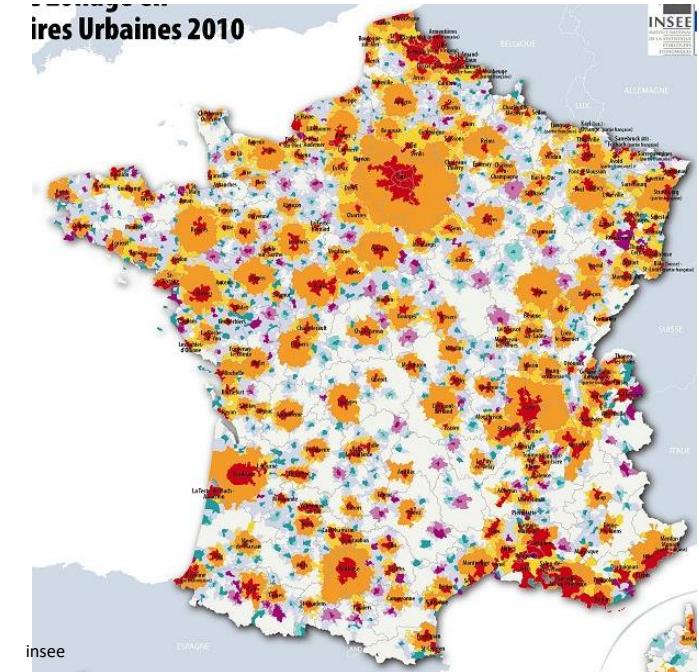
Interaction

Automation

P.C. Server

Conclusion

- 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



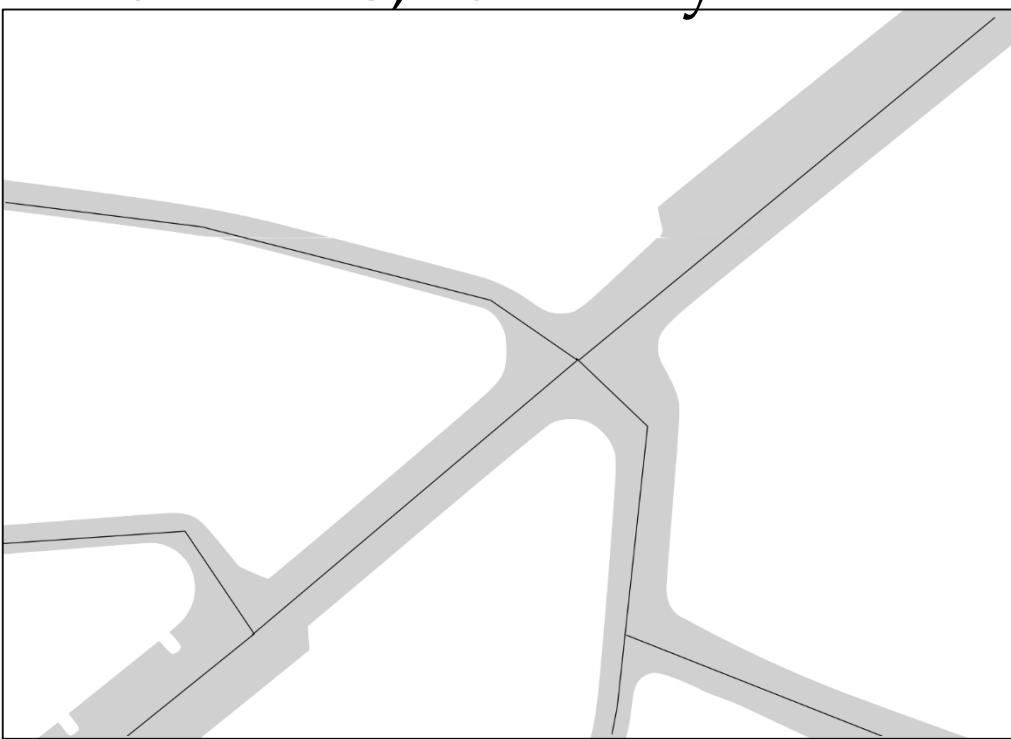
Introduction: Streets are important

width= 8; lane= 3

width= 6; lane= 2

- Road axis, roadway

width = 4; lane = 1

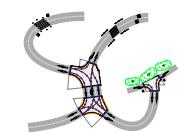


vs

Street



Open Data Paris



Introduction: having a model is important

width= 8; lane= 3

width= 6; lane= 2

- 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

width= 4; lane= 1

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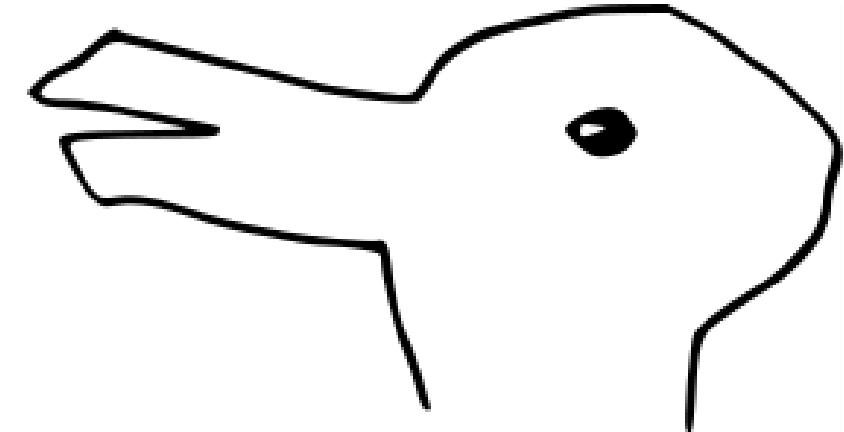
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width= 8; lane= 3

width= 6; lane= 2

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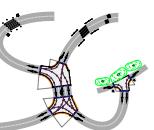
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Introduction

Why model streets?

Usages for street model

Introduction: usages for street model

width= 8; lane= 3

width= 6; lane= 2

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Conclusion

- Cities and streets are carefully managed
 - Paris : 100s of people, one dedicated engineer school
 - Requires data (precise, up-to-date)
- Visualisation
- Analysis
- Simulation



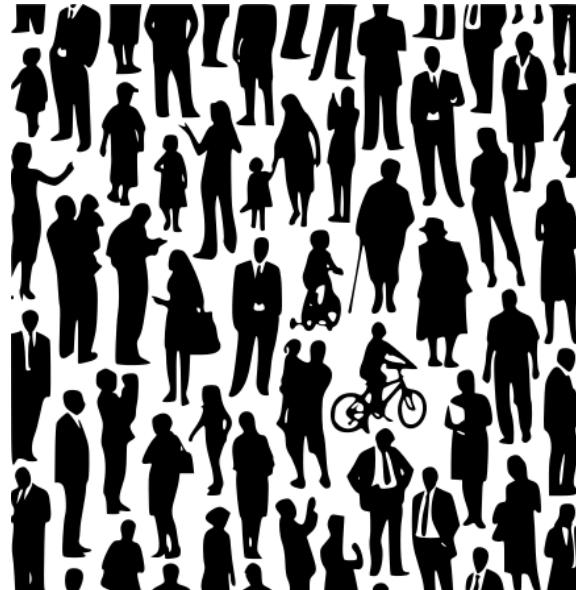
Introduction: usages for street model

width= 8; lane= 3

width= 6; lane= 2

Visualisation / analysis / simulation

- Visualisation
 - map / 3D model
 - Consultation / communication



Intro

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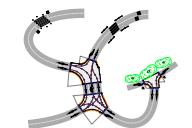
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Introduction: usages for street model

width= 8; lane= 3

width= 6; lane= 2

Visualisation / analysis / simulation

- Analysis
 - Past
 - Present
 - planning



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Introduction: usages for street model

width= 8; lane= 3

width= 6; lane= 2

Visualisation / analysis / simulation

- Simulation
 - Traffic / pollution / noise ...

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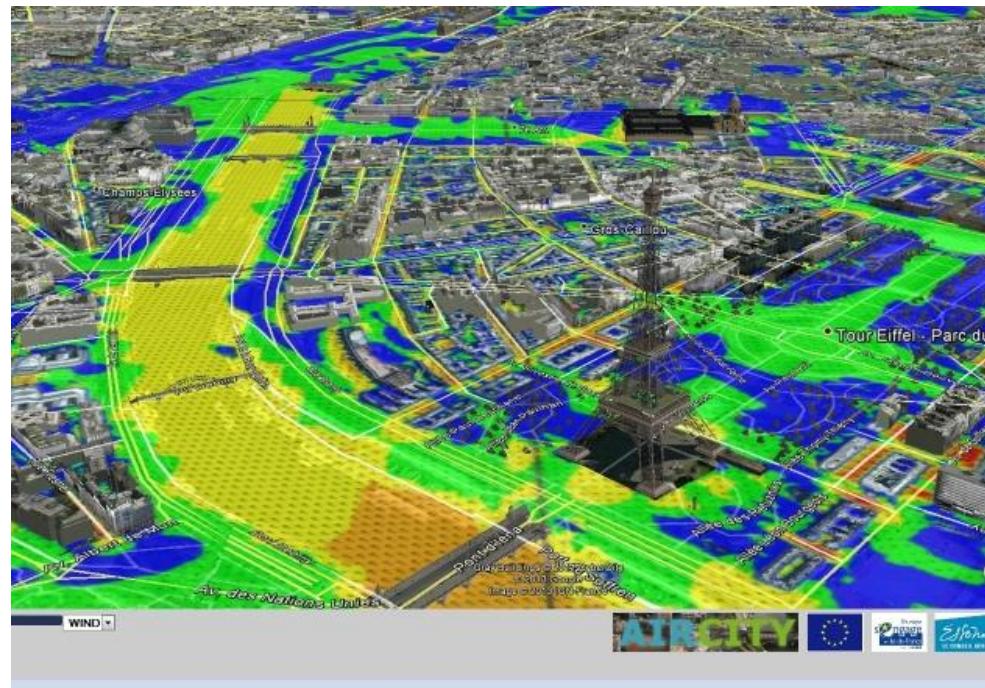
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Air city: pollution



Ifstar : noise

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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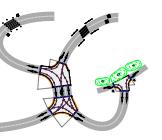
P.C. Server

Conclusion

State of the art

Modelling street, why is it hard?

Existing methods



State of the art: modelling street is hard

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

- 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 ...



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 ...

- complex / traffic / organisation/ sensing

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



State of the art: modelling street is hard

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

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- complex / traffic / organisation/ sensing

edge_id= 17; next_l= 16
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Intro

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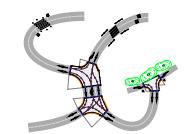
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State of the art: modelling street is hard

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- complex / traffic / organisation/ sensing

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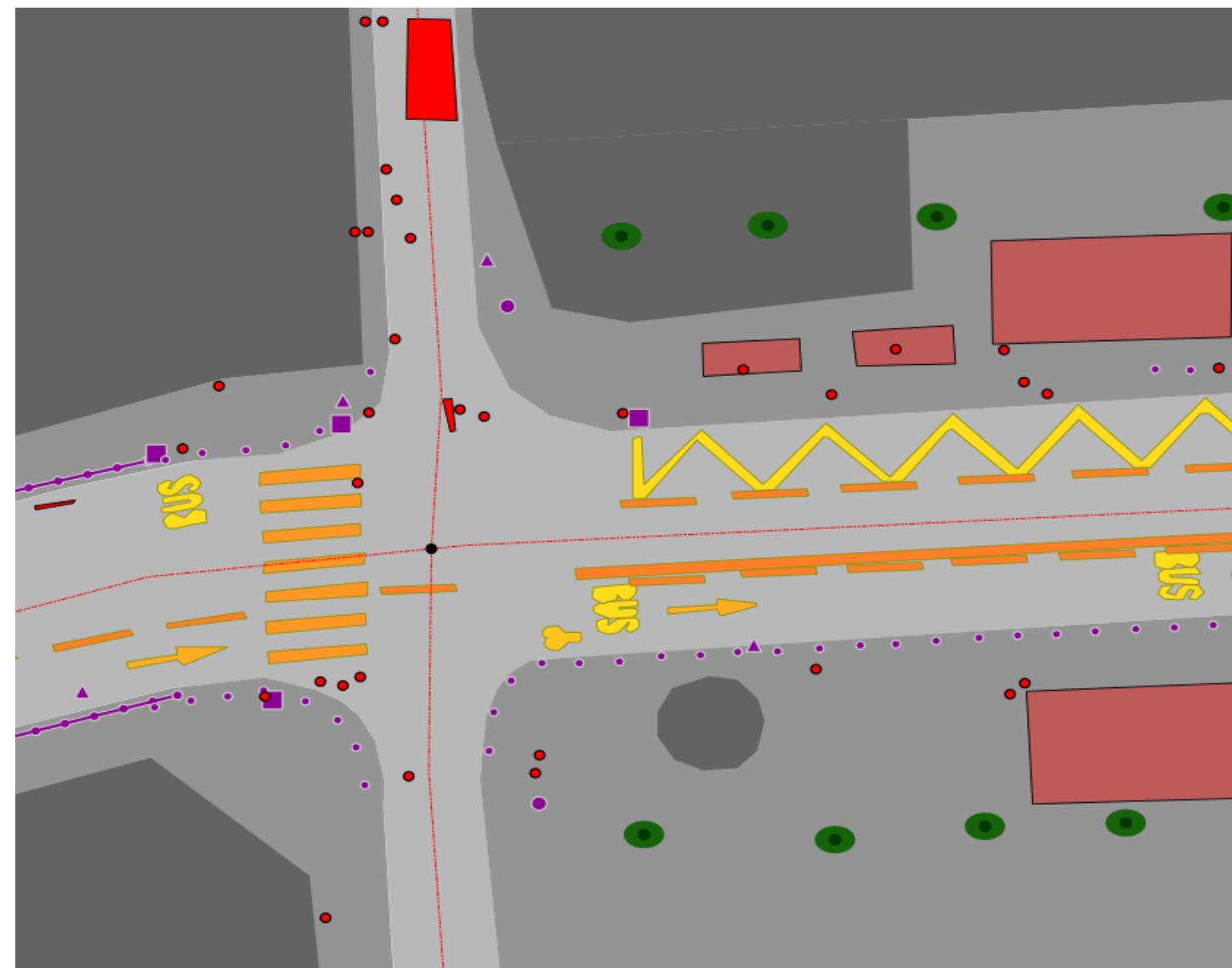
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edge_id= 17; next_l= 16



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
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- complex / traffic / organisation/ sensing

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State of the art: modelling street is hard

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- complex / traffic / organisation/ sensing

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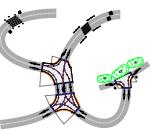
Streets

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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
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- complex / traffic / organisation/ sensing

- Manual : millions of objects
- Automatic :
 - high occlusion
 - Small details are crucial (curb)



edge_id=15; next_l=16
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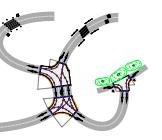
P.C. Server

Conclusion

State of the art

Modelling street, why is it hard?

Existing methods



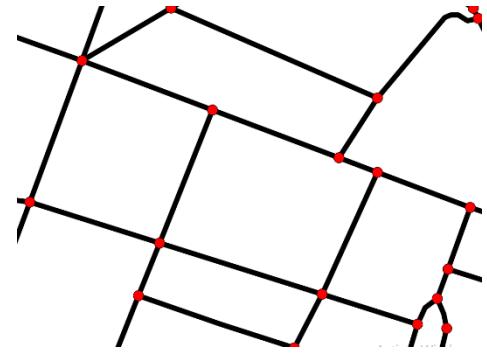
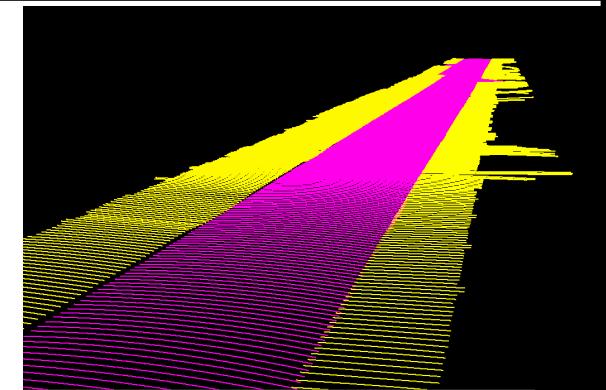
State of the art: Existing models

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

- What « street» should be modelled?
 - street precise geometry (roadway / sidewalk / ...)
 - Street road as part of whole network (= traffic info)
 - Street objects
 - Material/visual aspects ...

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

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



Intro

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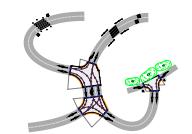
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State of the art: Existing models

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Conclusion

**data-
driven**

**model-
driven**

**for traffic
simulation**

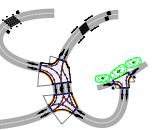
procedural

roadway

road/lane

network

street



State of the art: Existing models

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

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

Guo2015 Boyko2011

Montoya2014

Fischler1981

Wilkie2012

Kuntzsch2015

Wang2015

Despine2011

Gallin2011

Chen2008

Intro

State of the Art

StreetGen

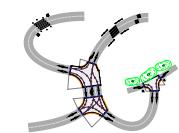
Streets

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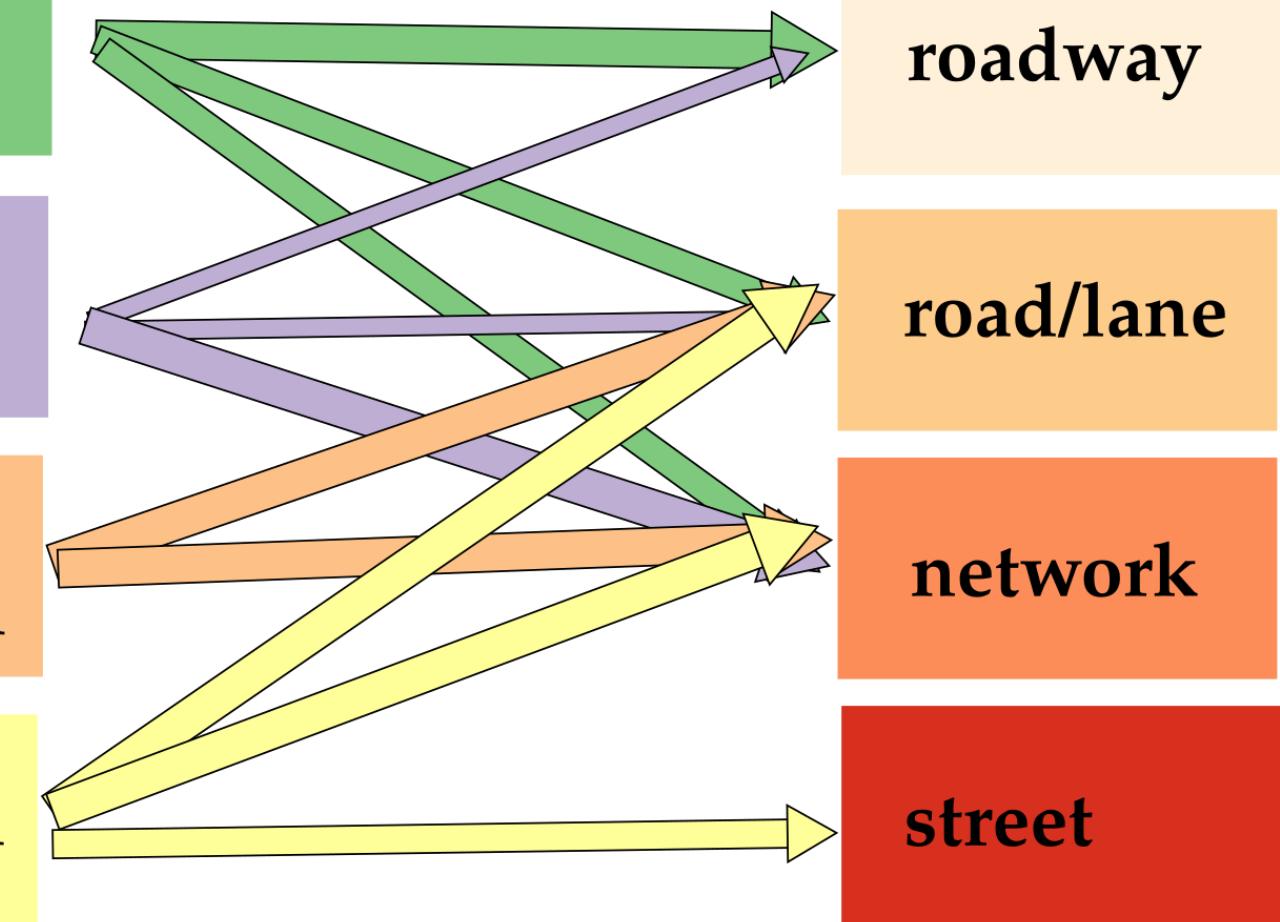


data-driven

model-driven

for traffic simulation

procedural



State of the art: Existing models

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

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Data-driven / Model driven / traffic simulation / Procedural

- Data-driven modelling
 - From lidar

Boyko2011



Intro

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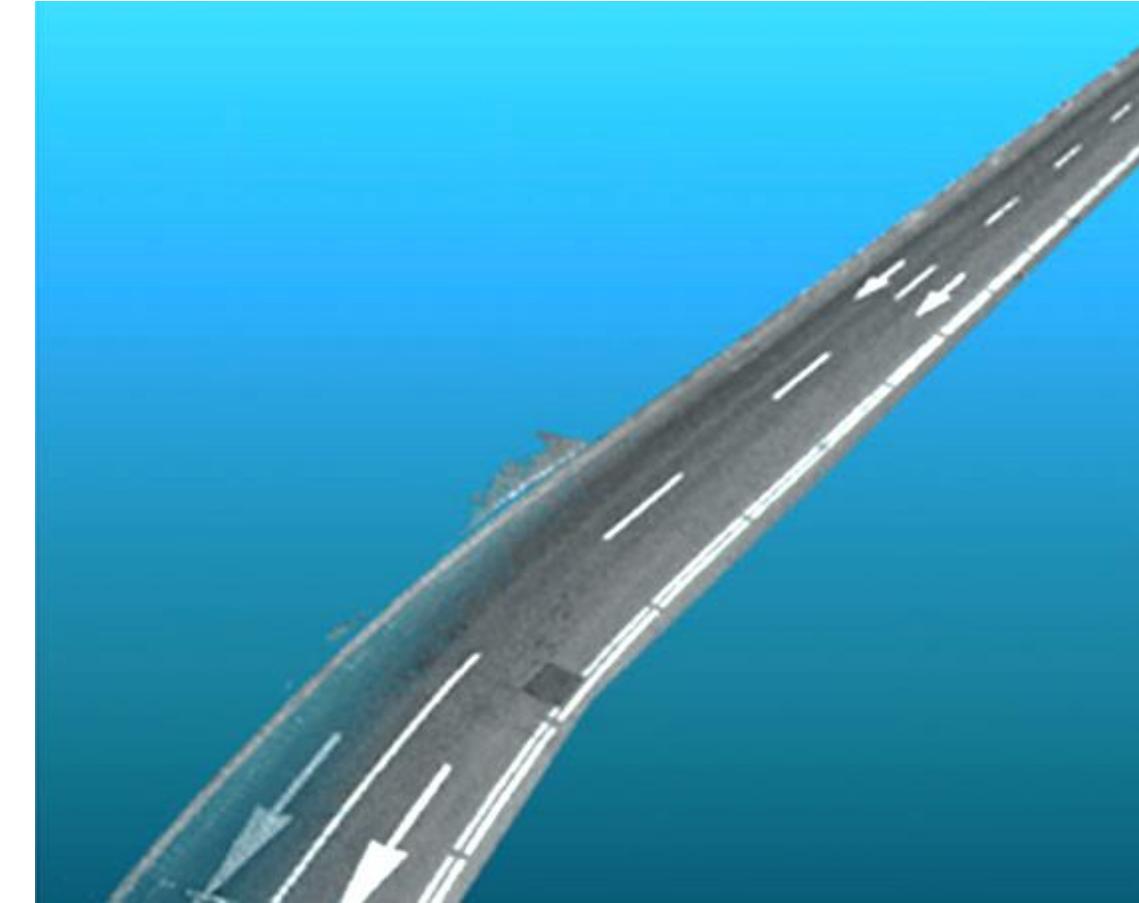
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edge_id=17; next_l=16
start_node=4 ...



Guo2015

Extraction, raster, template matching

State of the art: Existing models

edge_id=15; next_l=16
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Data-driven / Model driven / traffic simulation / Procedural

- Data-driven modelling
 - From aerial images

Intro

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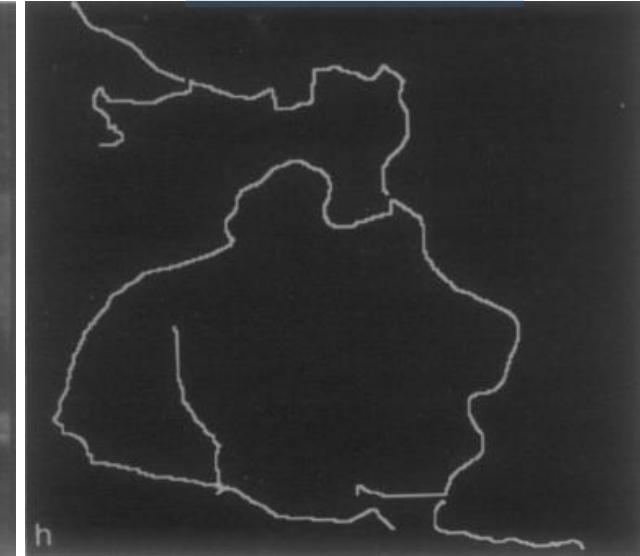
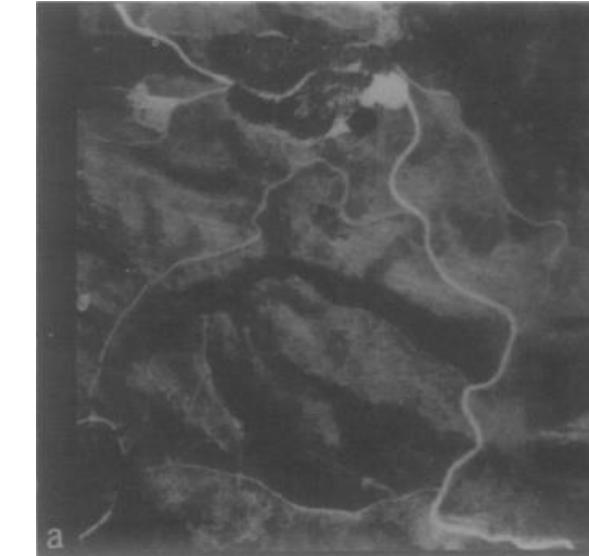
Interaction

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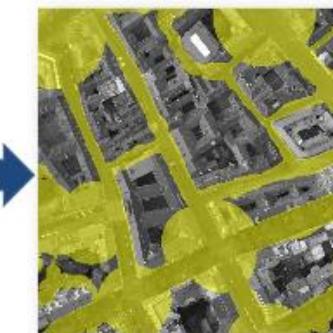
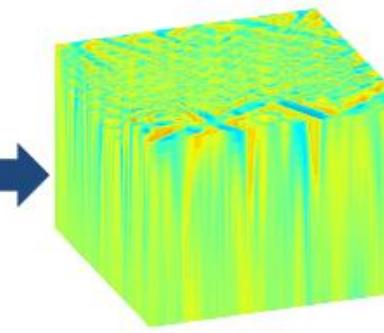
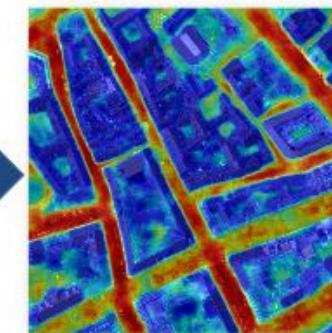
Conclusion

Fischler1981

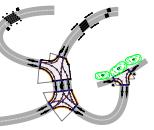


High prec low recall + low prec high recall + F* (includes cost)

Montoya-Zegarra2014



Classif + Context + CRF



State of the art: Existing models

edge_id=15; next_l=16
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Data-driven / Model-driven / Traffic simulation / Procedural

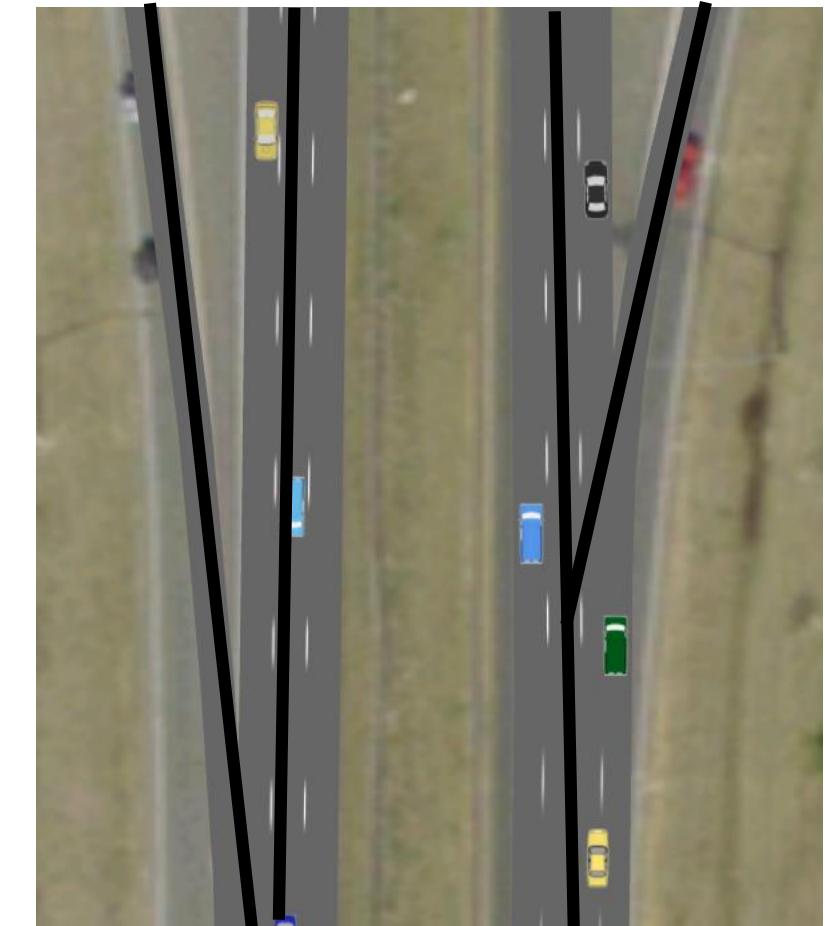
- GIS-based modelling

Kuntzsch2015



Street segment KDE, intersection with RJ-MCMC

Wilkie2012



Turning radius, network of lane, simulation

State of the art: Existing models

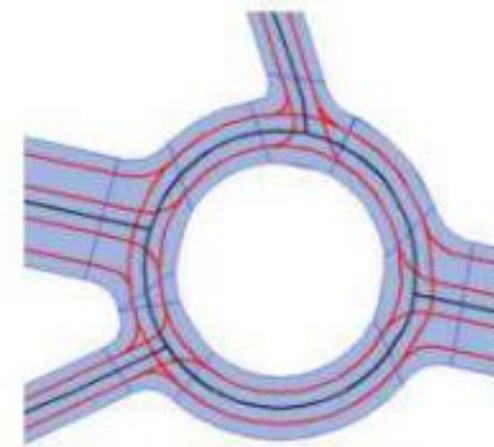
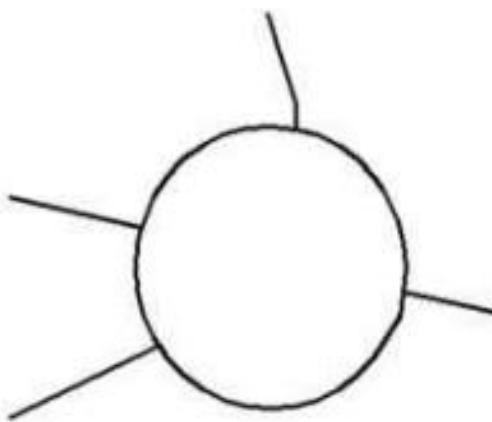
edge_id=15; next_l=16
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Data-driven / Model-driven / Traffic simulation / Procedural

- Simulation-based modelling

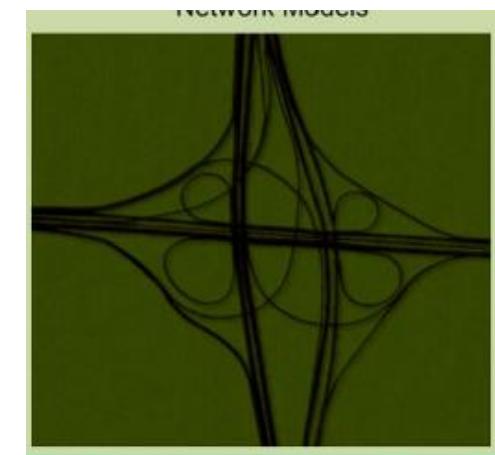
Network from data, guessing lane, intersection by continuity, 3D generation



Despine2011

Wang2015

Segment of road parametrisation, intersection...



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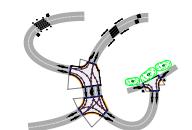
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Data-driven / Model-driven / Traffic simulation / Procedural

- Procedural modelling

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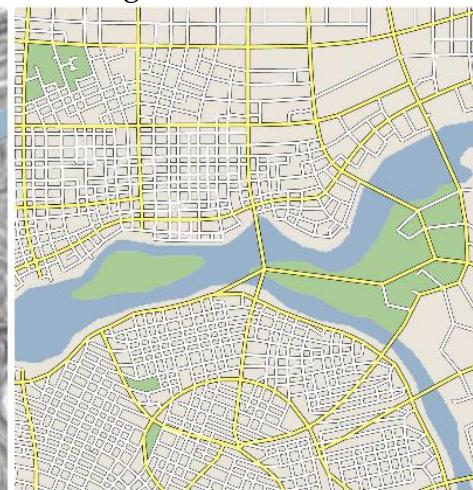
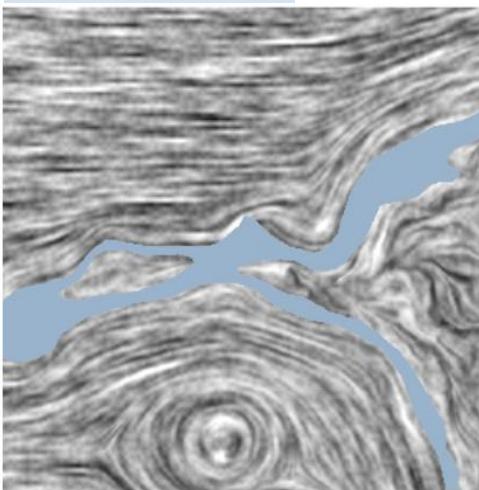
edge_id=17; next_l=16
start_node=4 ...

Gallin2011



Chen2008

Tensor, stream line, grammar



Terrain, graph : shortest path and merging,
procedural generation

State of the art: Existing models

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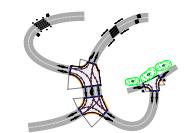
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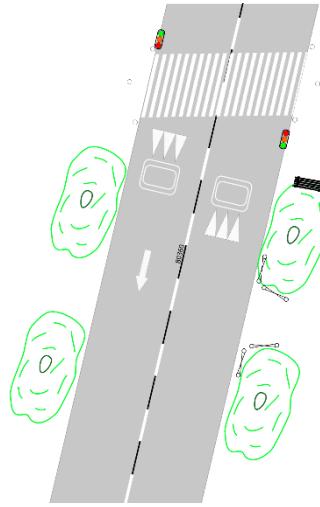


data-driven

model-driven

for traffic simulation

procedural



Our work

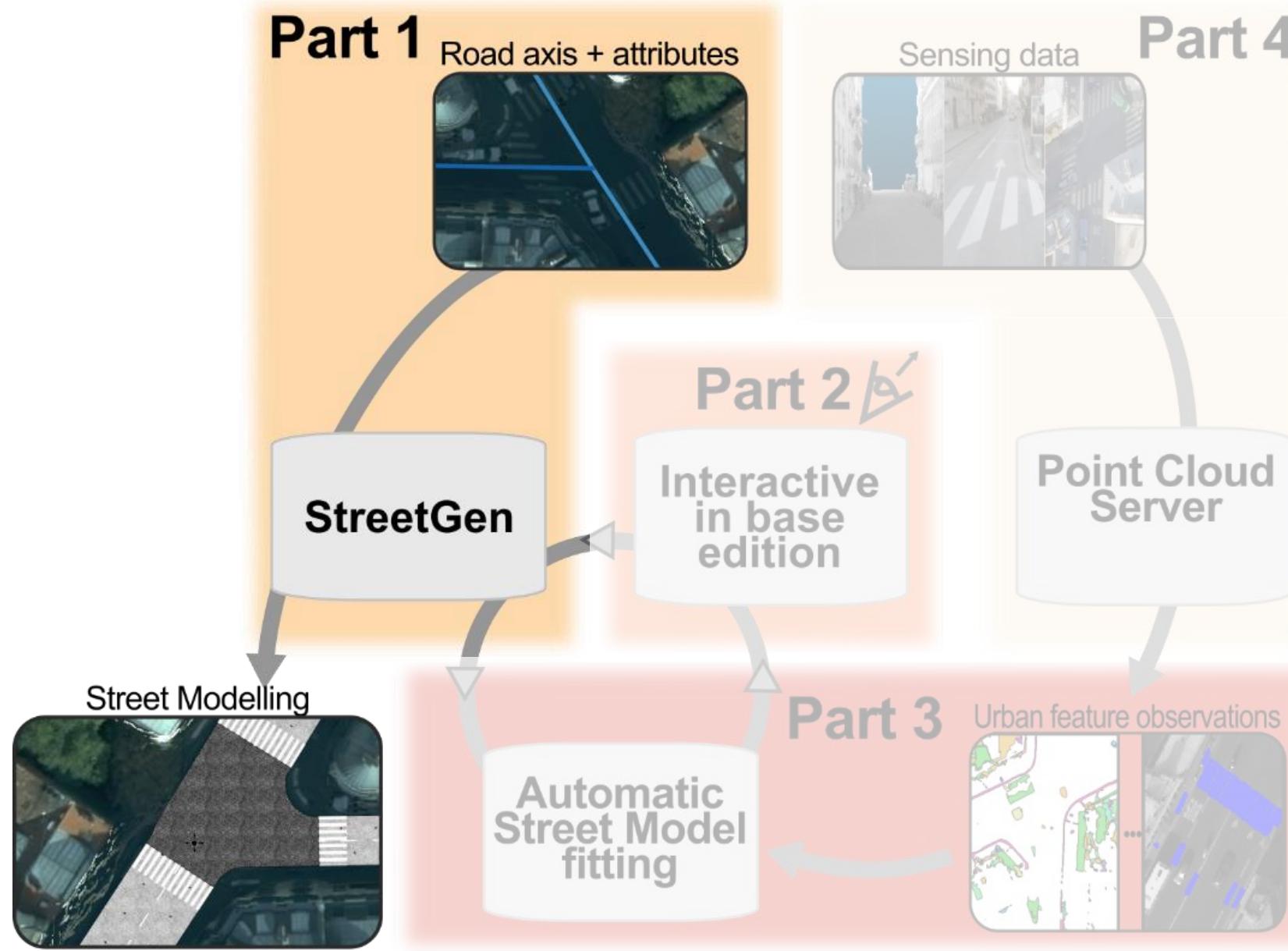
roadway

road/lane

network

street

Abstract



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StreetGen : generate streets

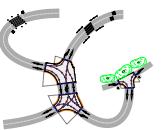
Design Principle

Kinematic hypothesis

Road surface

Traffic support

Street objects



StreetGen : design principle

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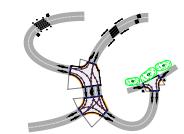
Streets

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Conclusion



- Goals?
 - A generic, simple street model
 - Use it to model Paris streets
 - Model used for various outputs (analysis / 3D visu / traffic simulation...)
- Our approach:
 - based on road axis, use simple hypothesis to amplify
 - use a RDBMS (=database)



StreetGen : design principle

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

- a model for most streets
- Streets are : structured by axis | constant/varying

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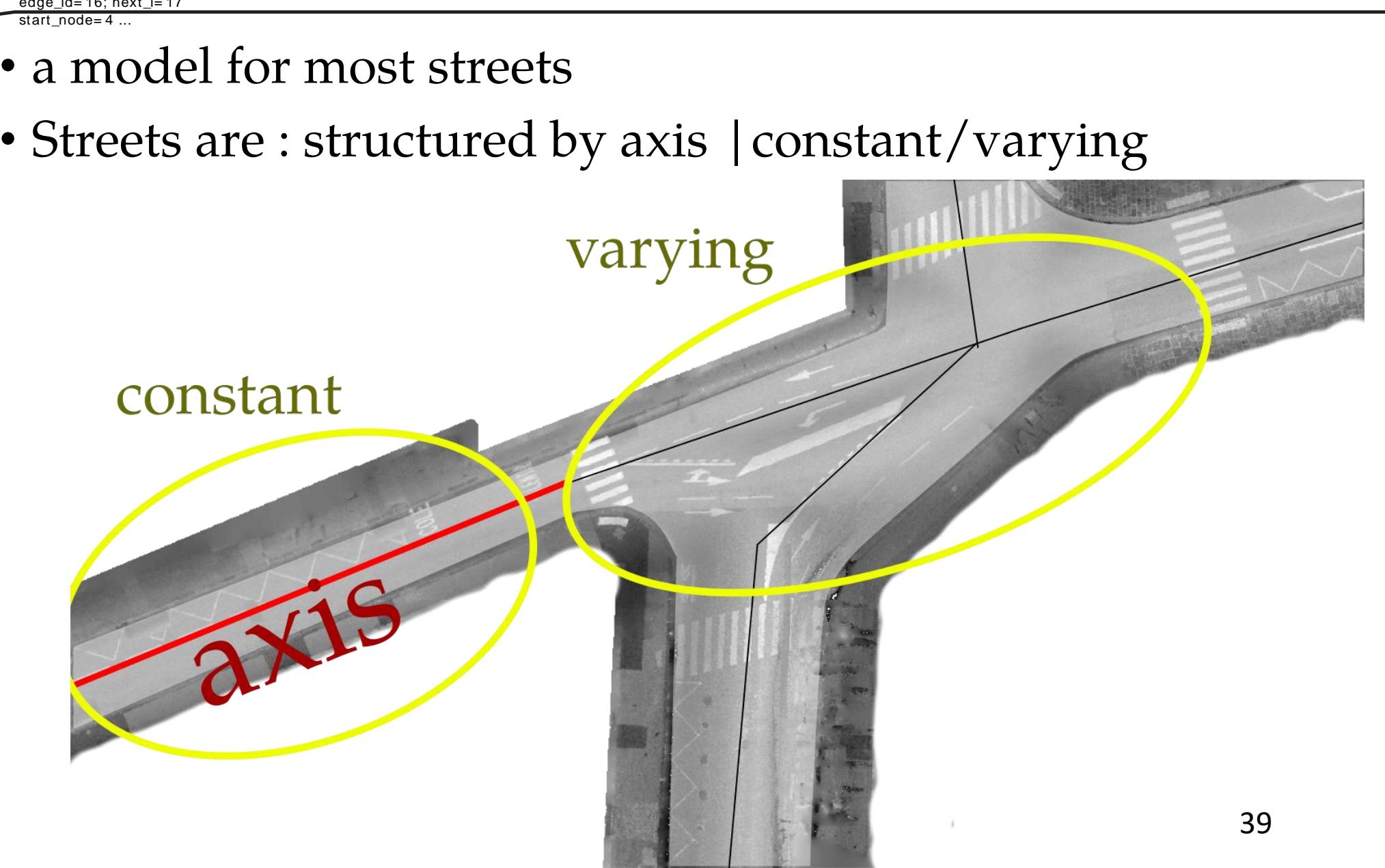
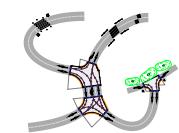
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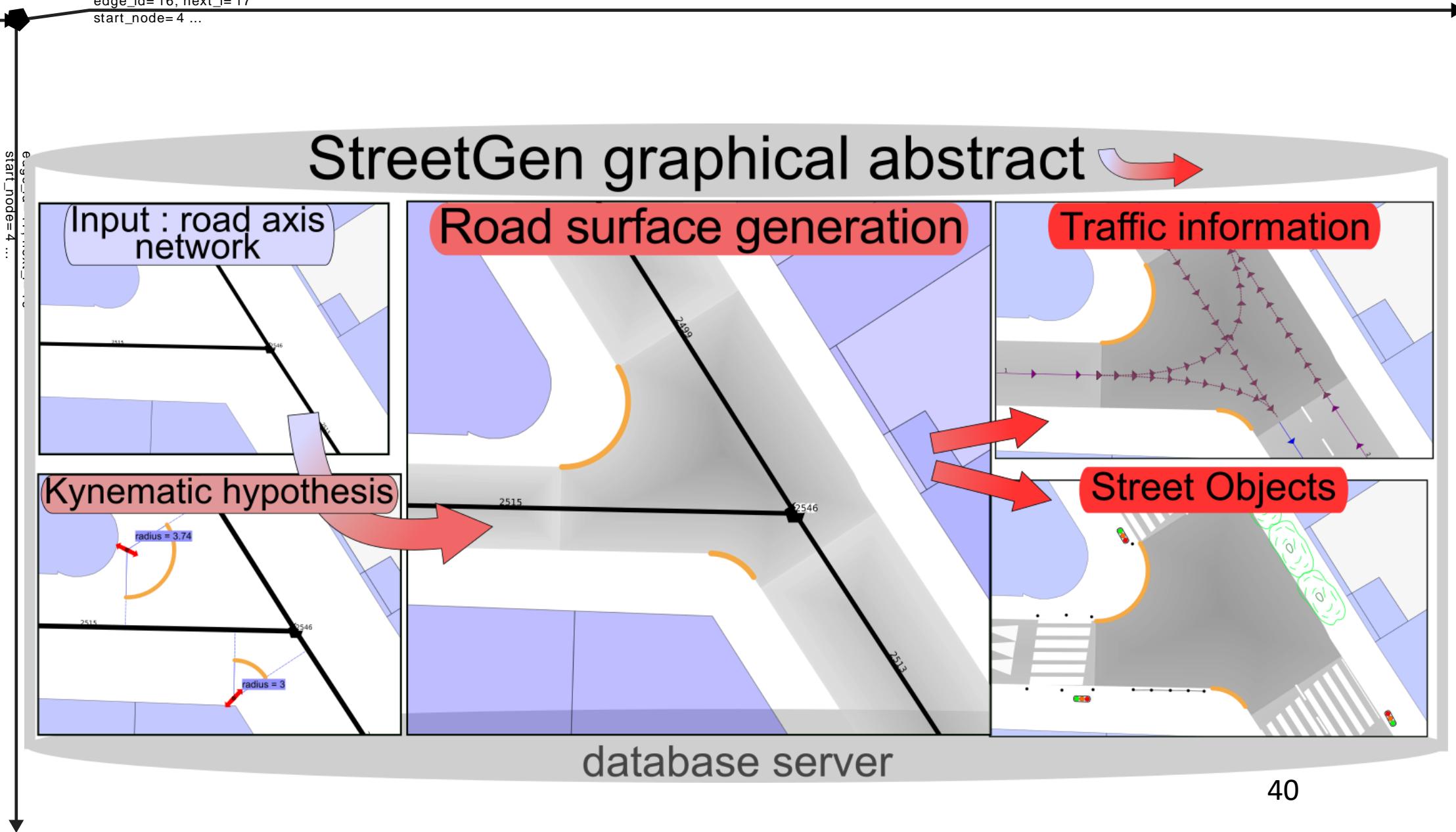
Conclusion



StreetGen : graphical abstract

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

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StreetGen : design principle

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

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

start_node= 4 ...

- StreetGen road model:
 - axes + width + radius → circle center → section + intersection+ lane+...

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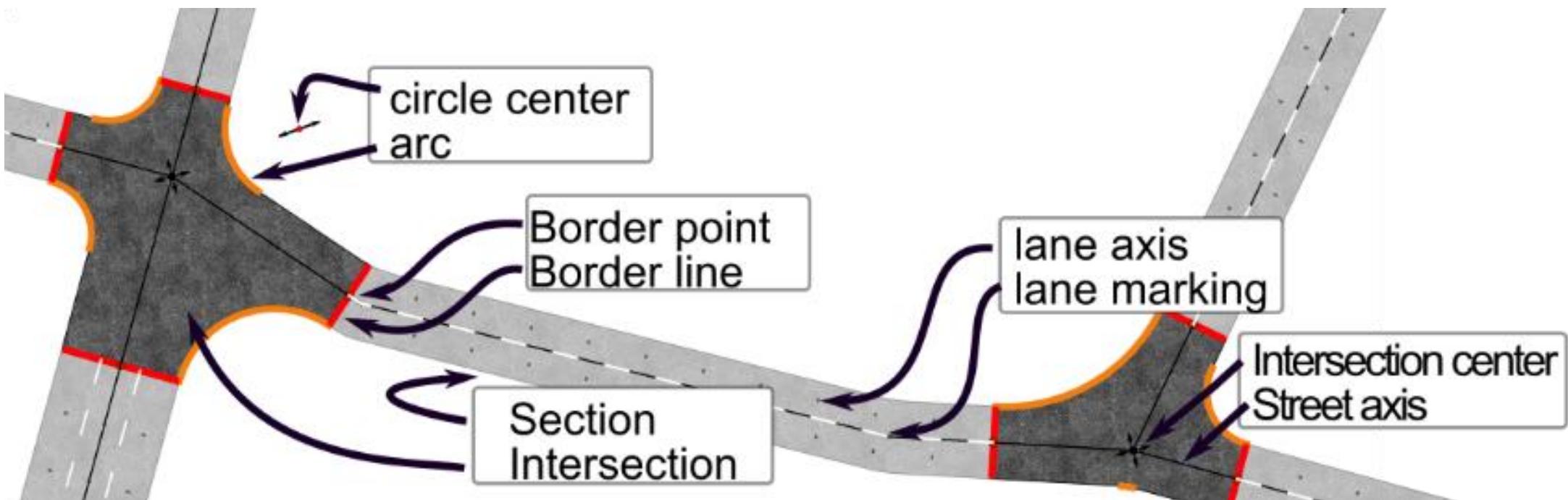
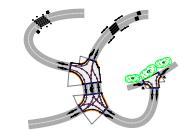
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StreetGen : design principle

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

edge_id= 16; next_l= 17
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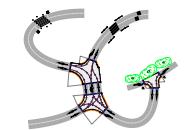
Classical processing method:

edge_id= 17; next_l= 16



Change? → redo everything
Several user → no sharing

↓



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 :

input data + method + results in a database

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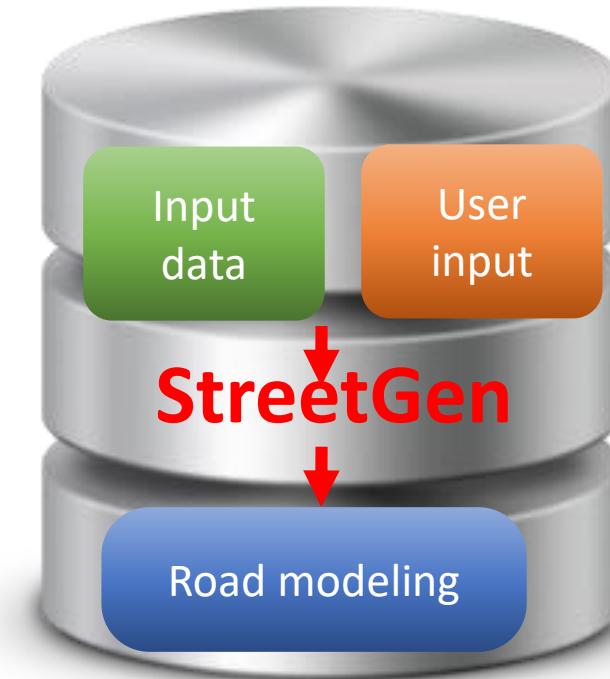
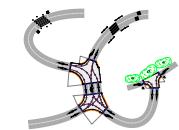
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StreetGen : design principle

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 : input data + method + results in a RDBMS(database)

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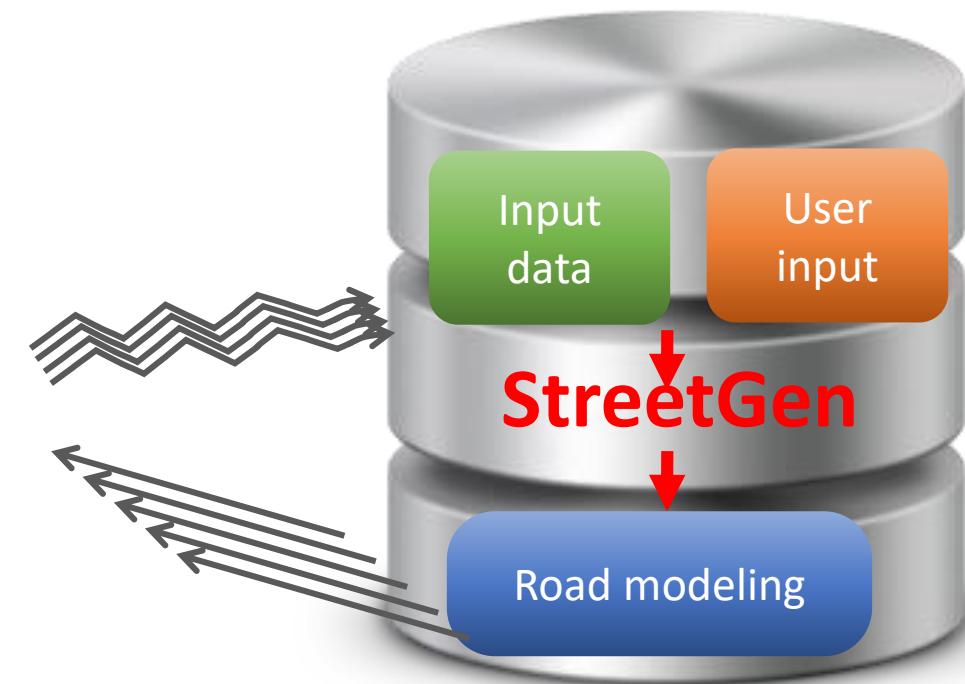
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edge_id= 15; next_l= 16
end_node= 3 ...

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

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

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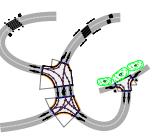
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StreetGen : generate streets

Design Principle
Kinematic hypothesis
Road surface
Traffic support
Street objects



StreetGen : Kinematic hypothesis

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

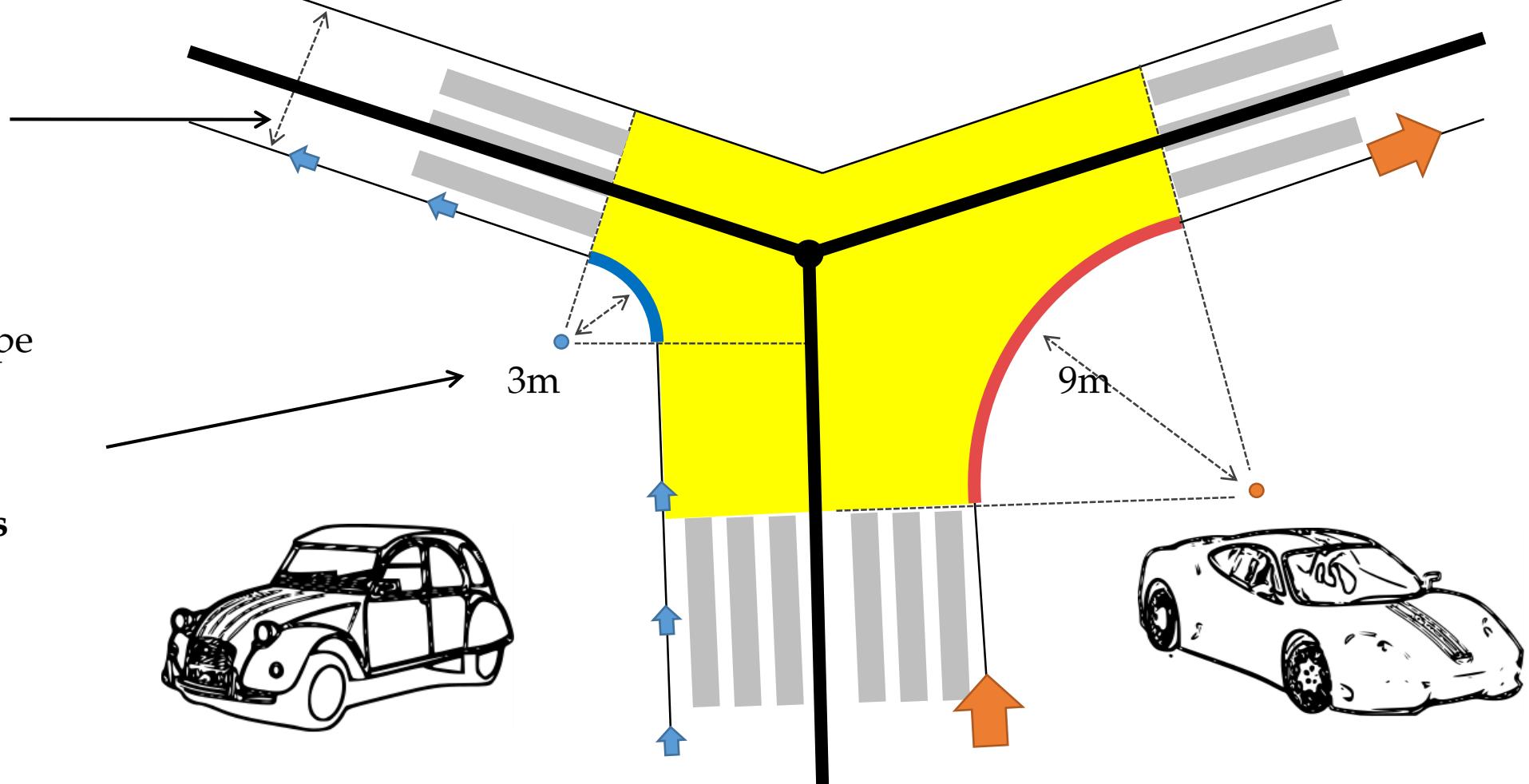
edge id=16; next_l=17
start_node=4 ...



- Kinematic hypothesis

width

Road type
 ↓
 speed
 ↓
 radius



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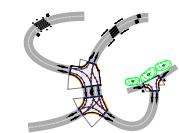
Streets

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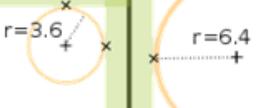
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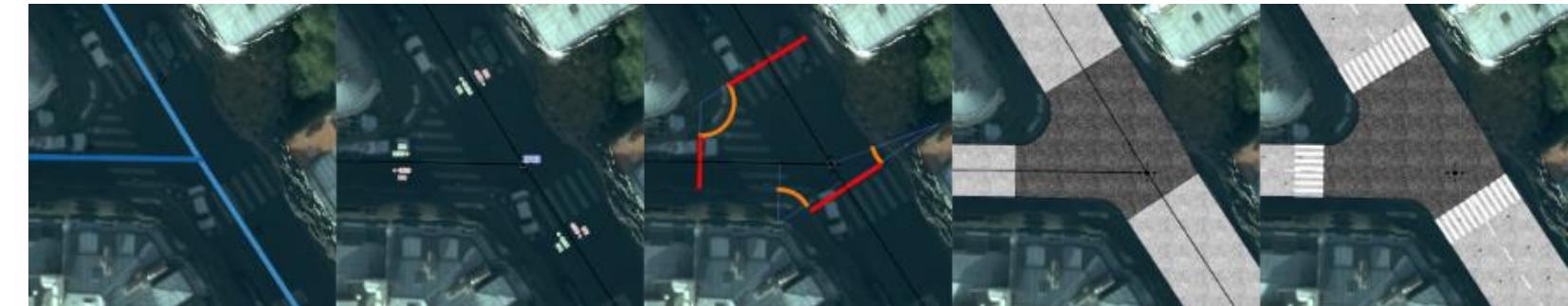
edge id=15; next_l=16
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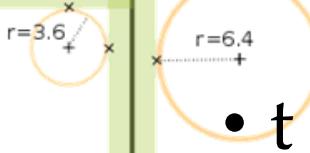
StreetGen : generate streets

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StreetGen : Road surface

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



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

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StreetGen : Road surface

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

- Results:
Hypothesis OK
Robust
Generic

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

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

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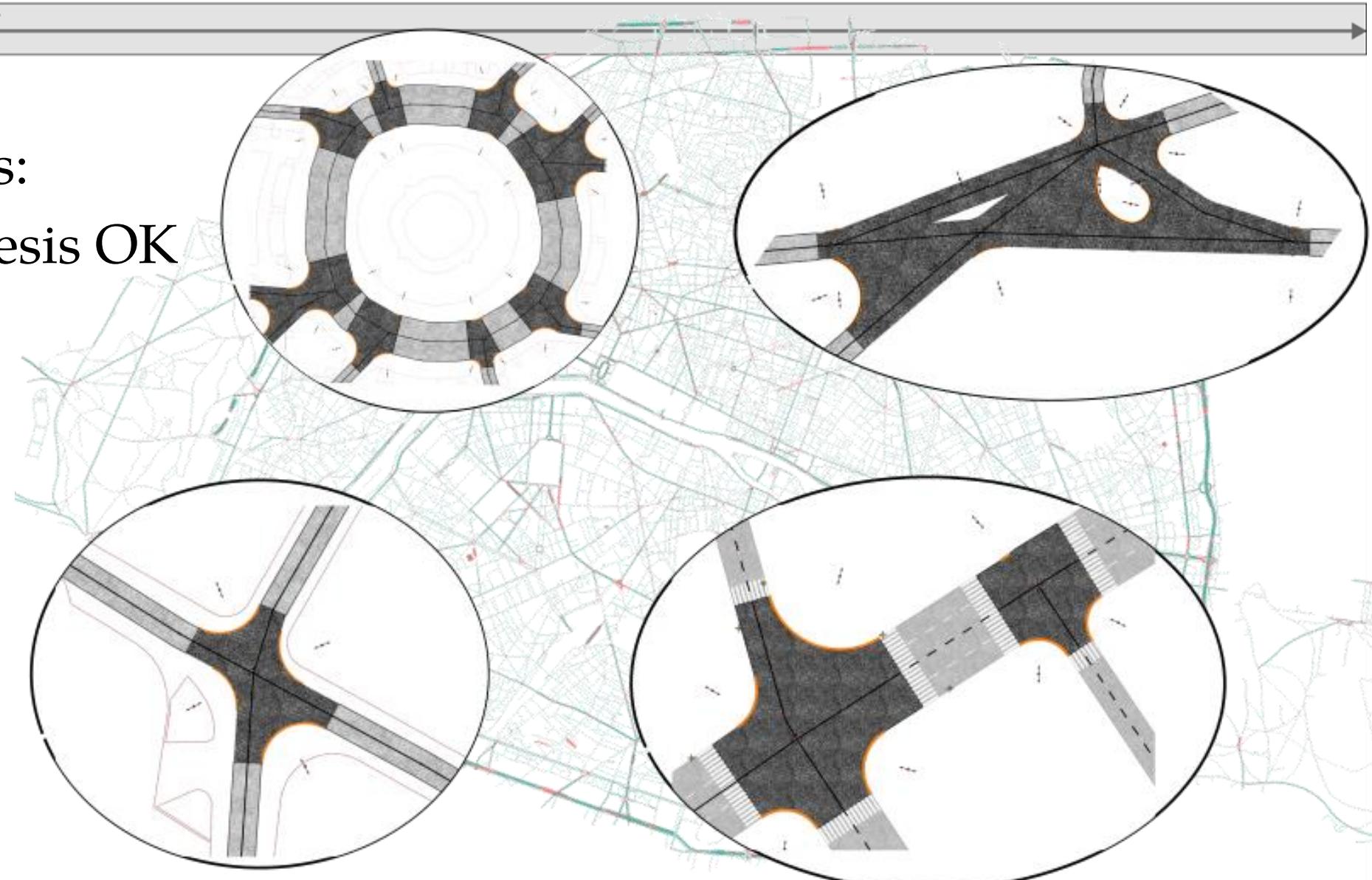
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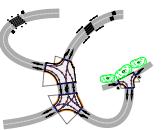
edge id=15; next_l=16
end_node=3 ...

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

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StreetGen : Traffic Support

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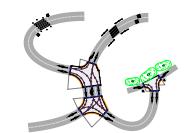
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Conclusion

- For traffic simulation:
 - Lanes
 - Possible trajectories in interconnections.
- Traffic simulation requires much more
 - Average speed
 - Type of intersection (roundabout/traffic light)
 - Etc ...



StreetGen : Traffic Support

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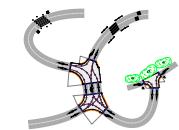
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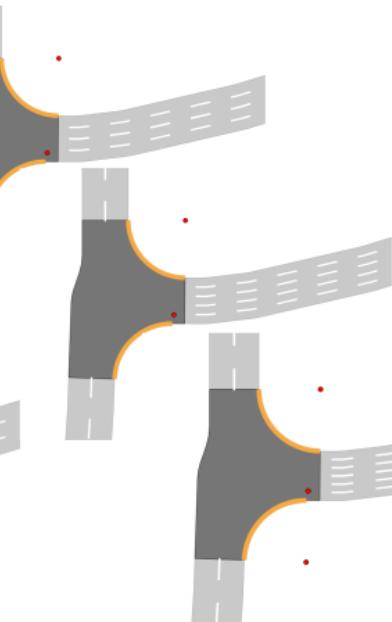
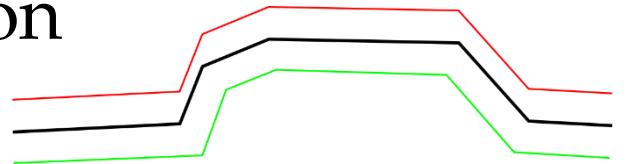
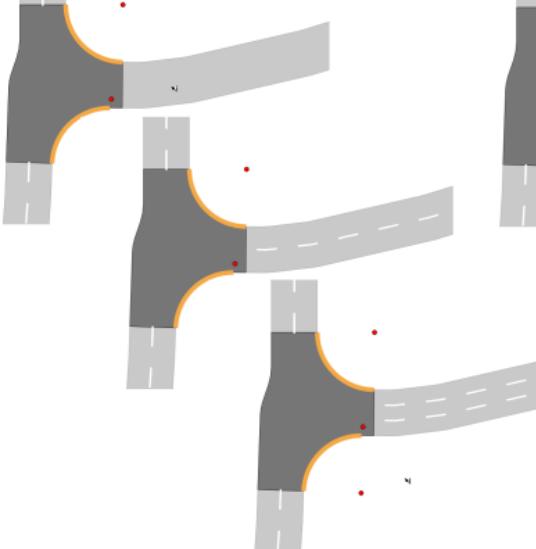
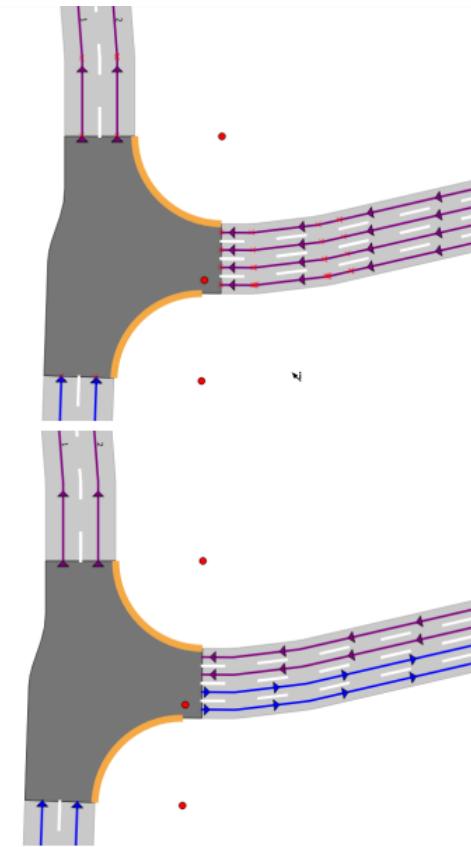
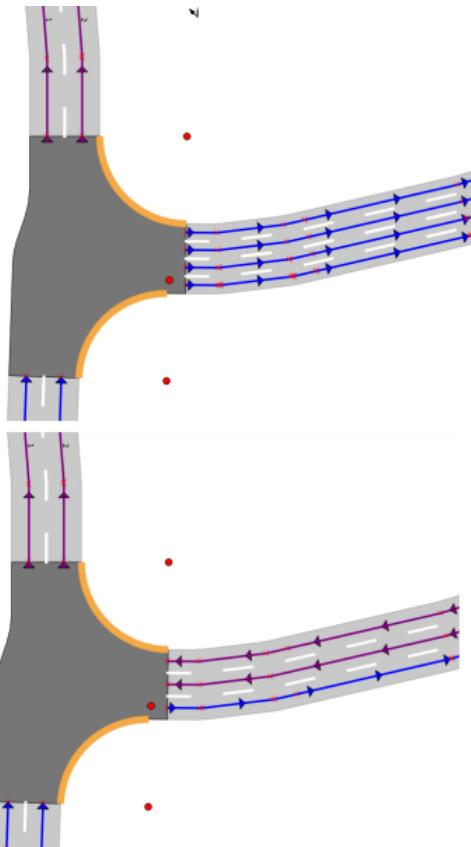
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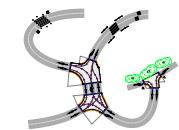


- Lane based on road axis : but not translation

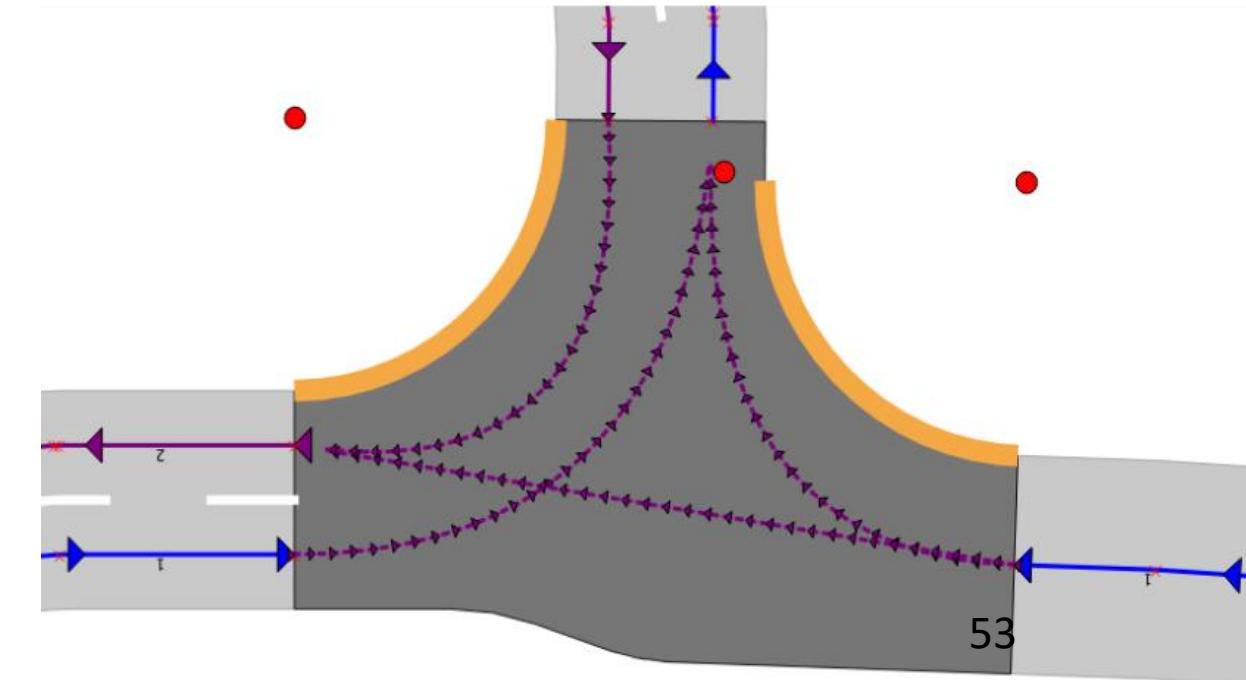
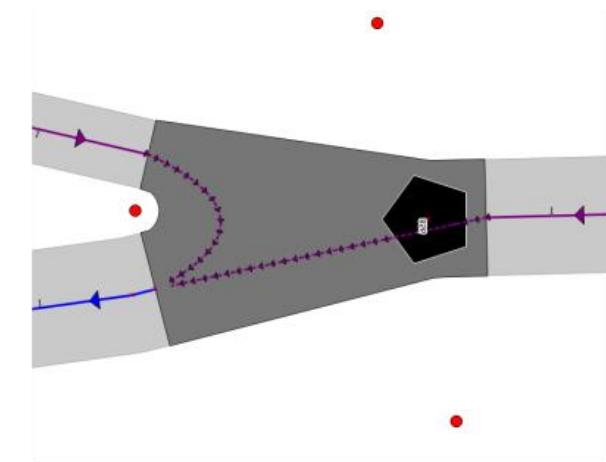
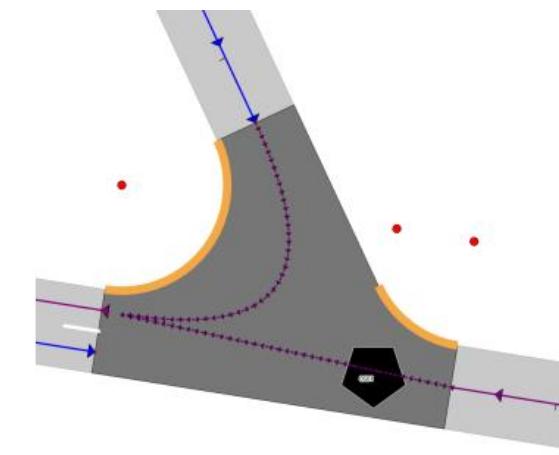


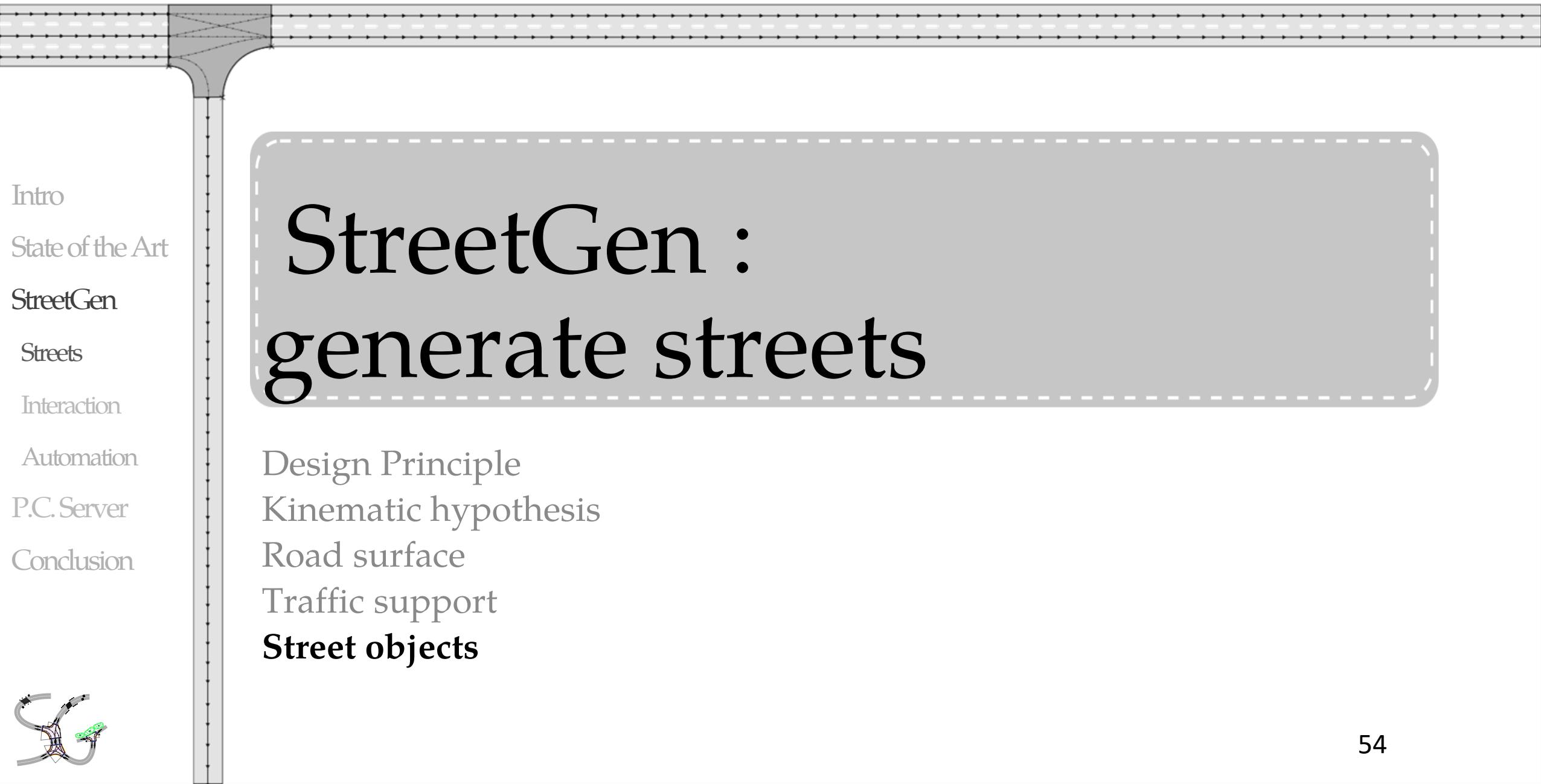
StreetGen : Traffic Support

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

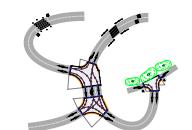




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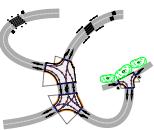
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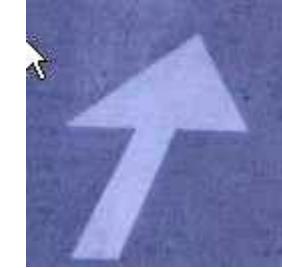


StreetGen : street objects

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- Streets objects : incredibly varied
 - 13k references on www.ArchiExpo
 - Norms : « Instruction Interministérielle sur la signalisation routière » : 1000 pages
 - ...
 - Objects are in relation (hierarchical, spatial, semantic ...)



StreetGen : street objects

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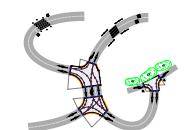
Streets

Interaction

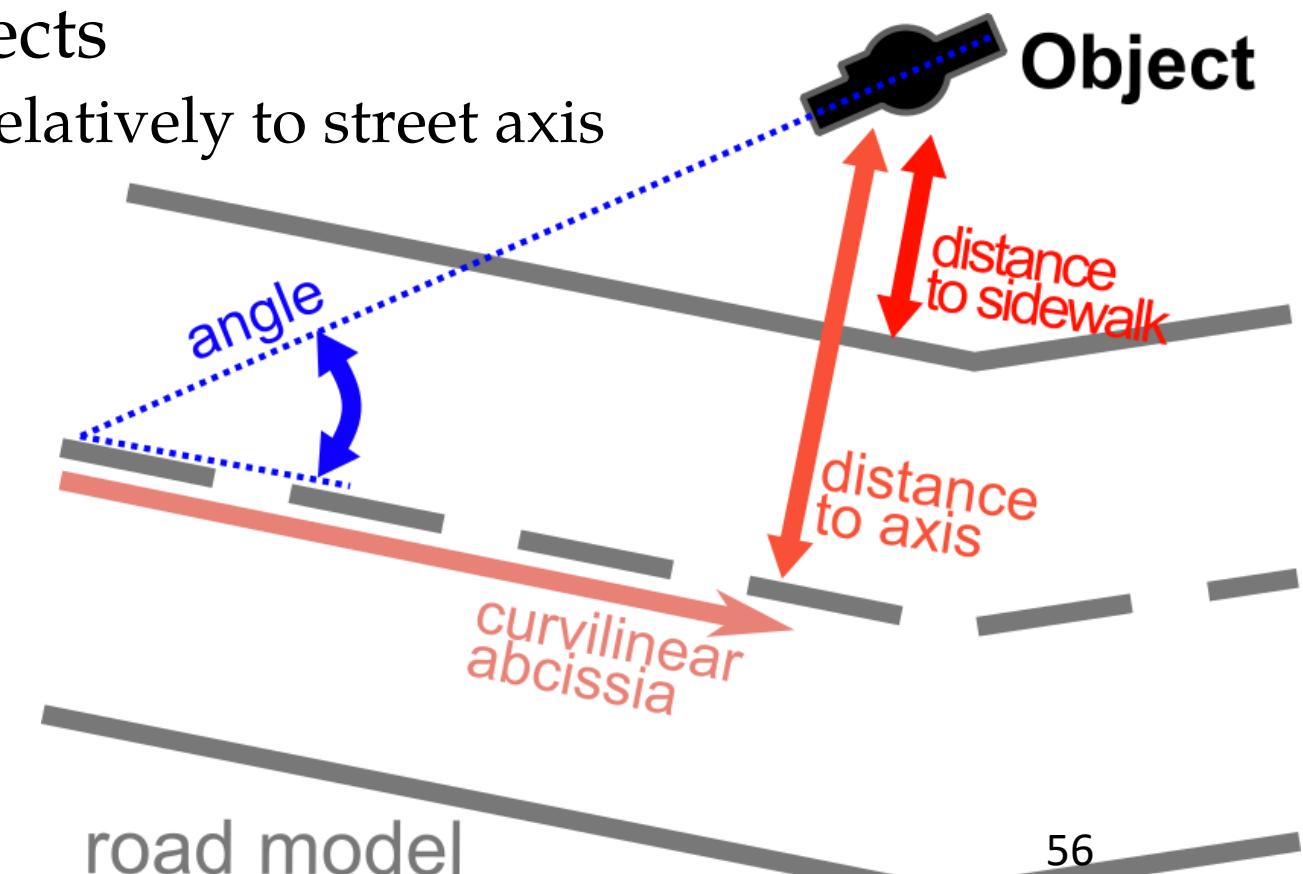
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- Street objects are often spatially organised (position and orientation) relatively to the street axis
- So we use generic objects
 - Positioned/oriented relatively to street axis



road model

StreetGen : street objects

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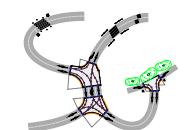
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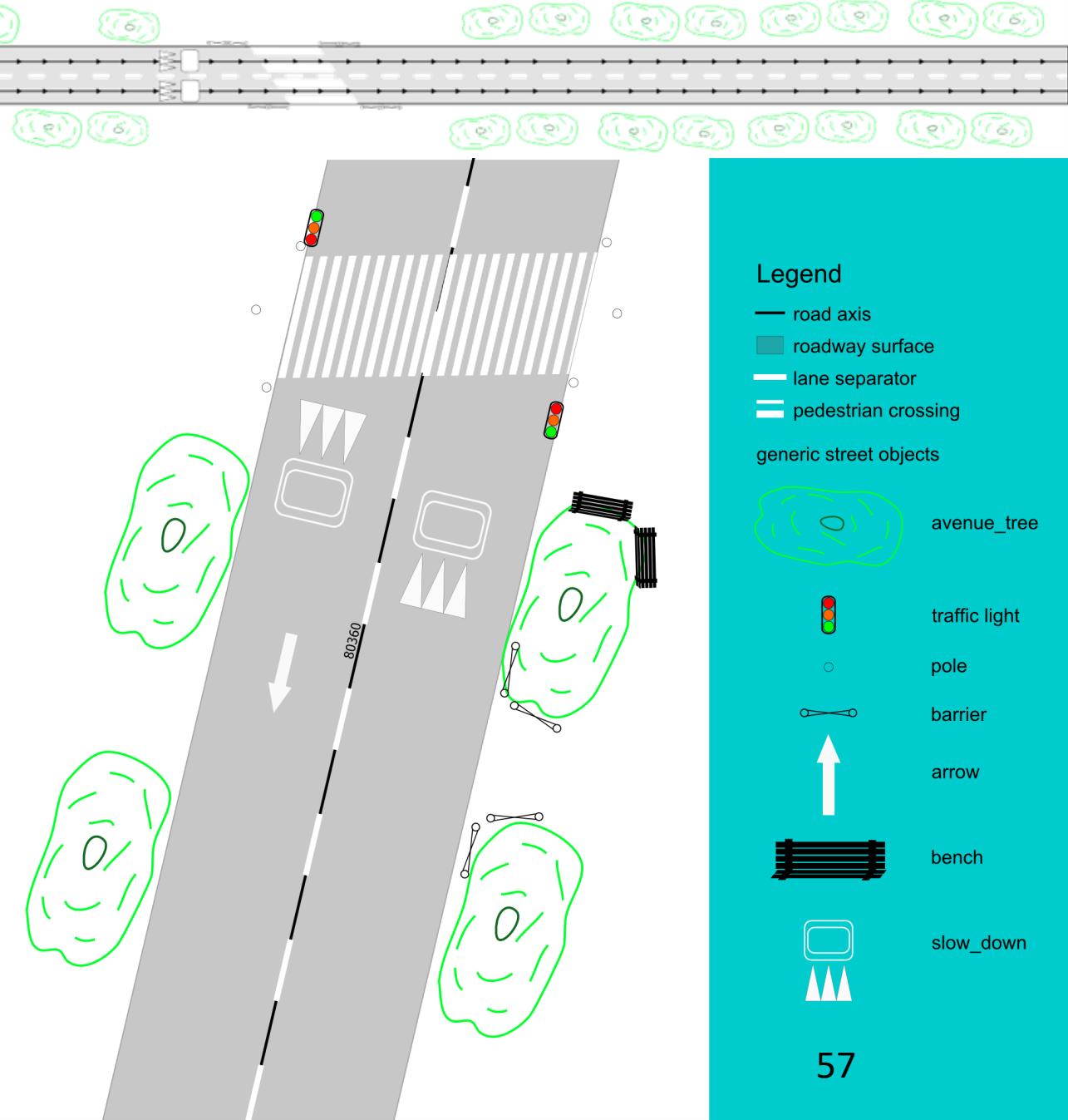
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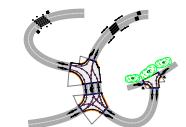


- Objects are **points** with semantic
- DBMS can support any relation (hierarchy, semantic...)

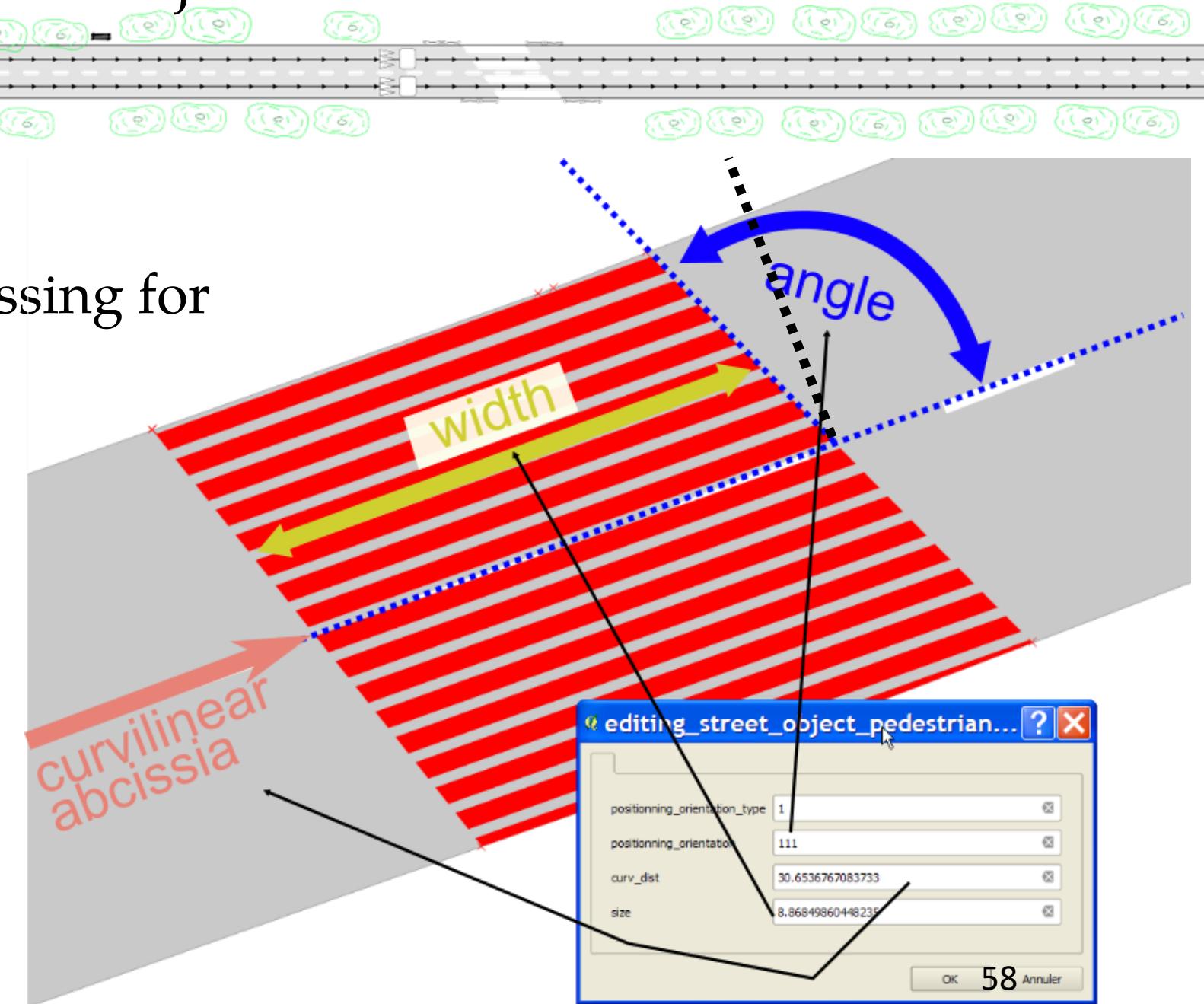


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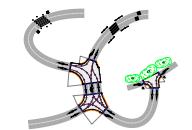
- Also surface
- Pedestrian crossing for instance



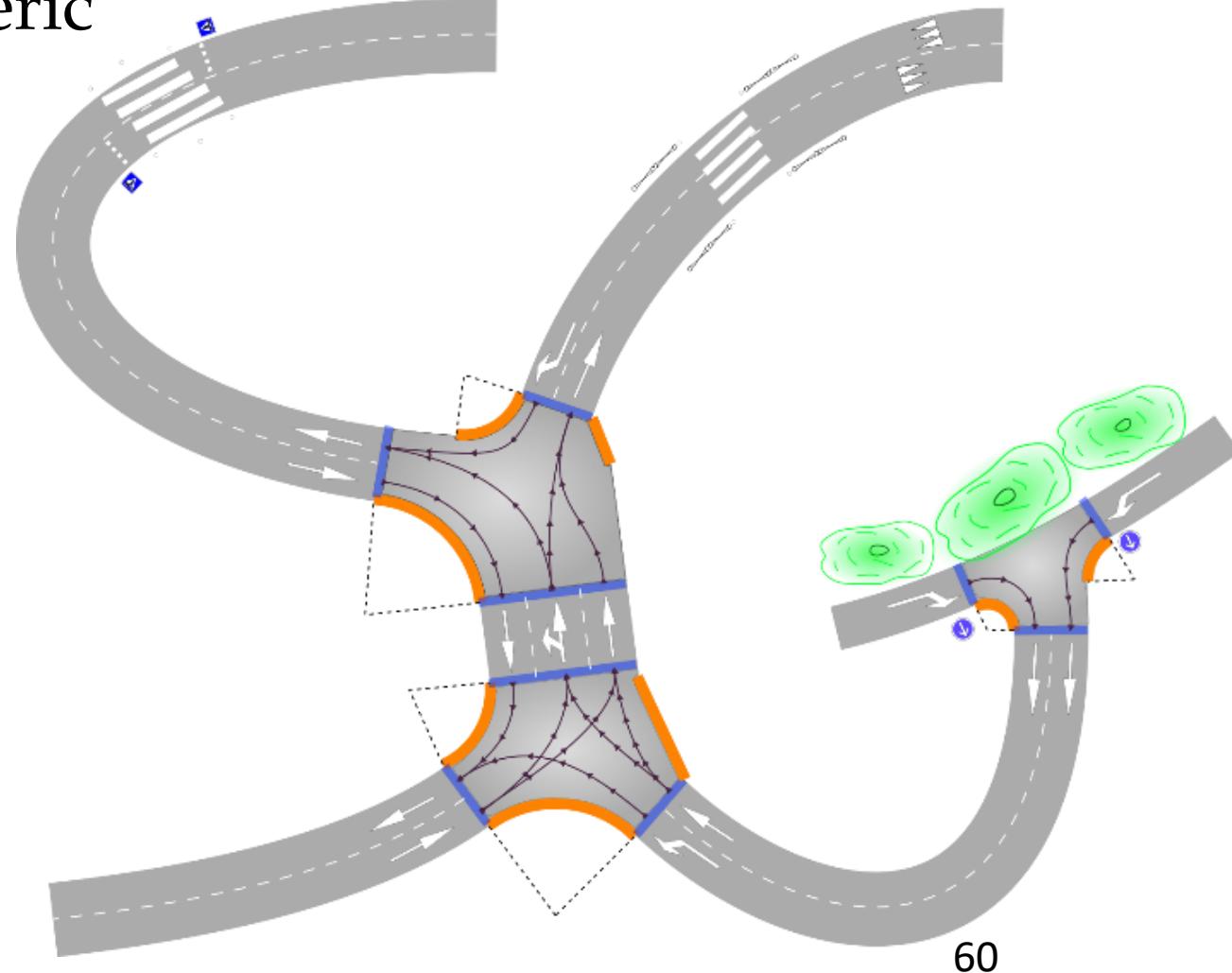
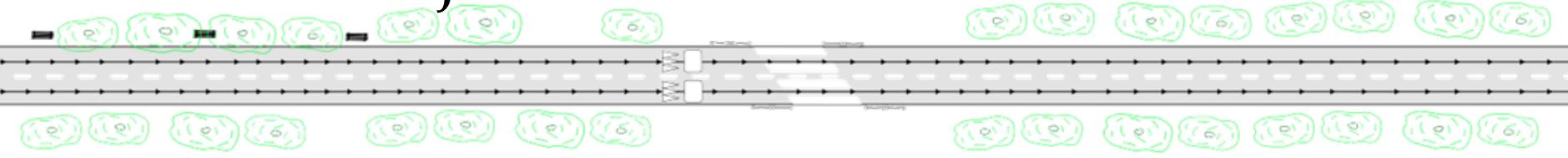


StreetGen : street objects

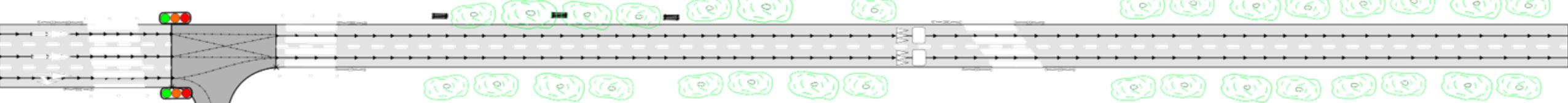
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- Model simple and generic
- OK for most of streets
- Whole Paris in 10 min
(2' //)



StreetGen : street objects



- Tested for 3D visualisation
 - Thales NeoDBGS

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StreetGen : street objects

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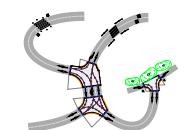
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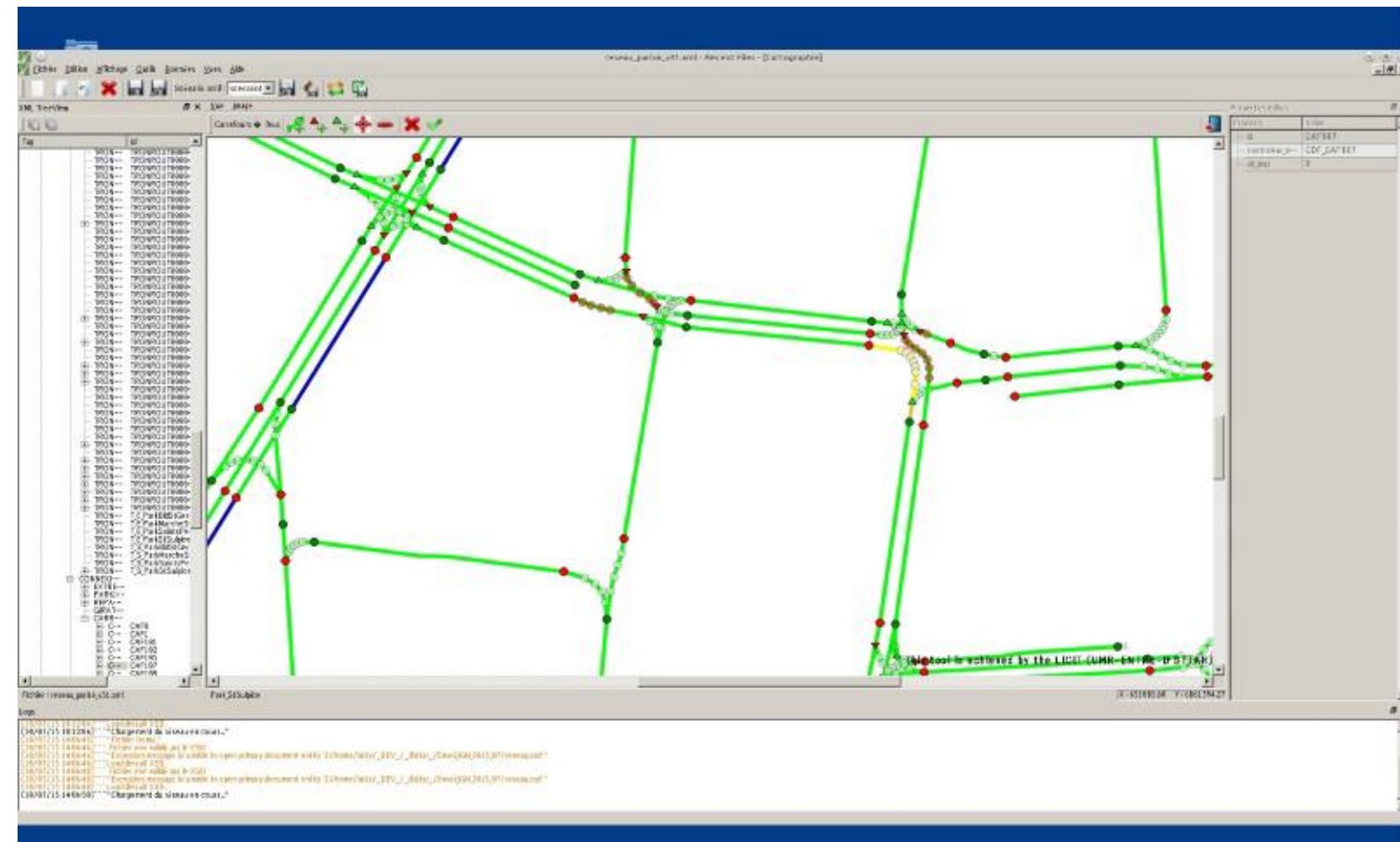
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- Tested for simulation
(SimuVia)



StreetGen : street objects

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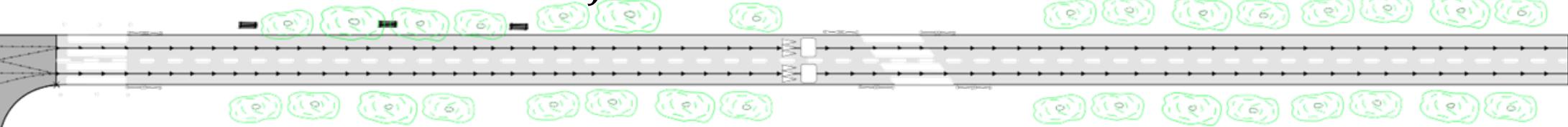
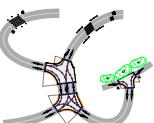
Streets

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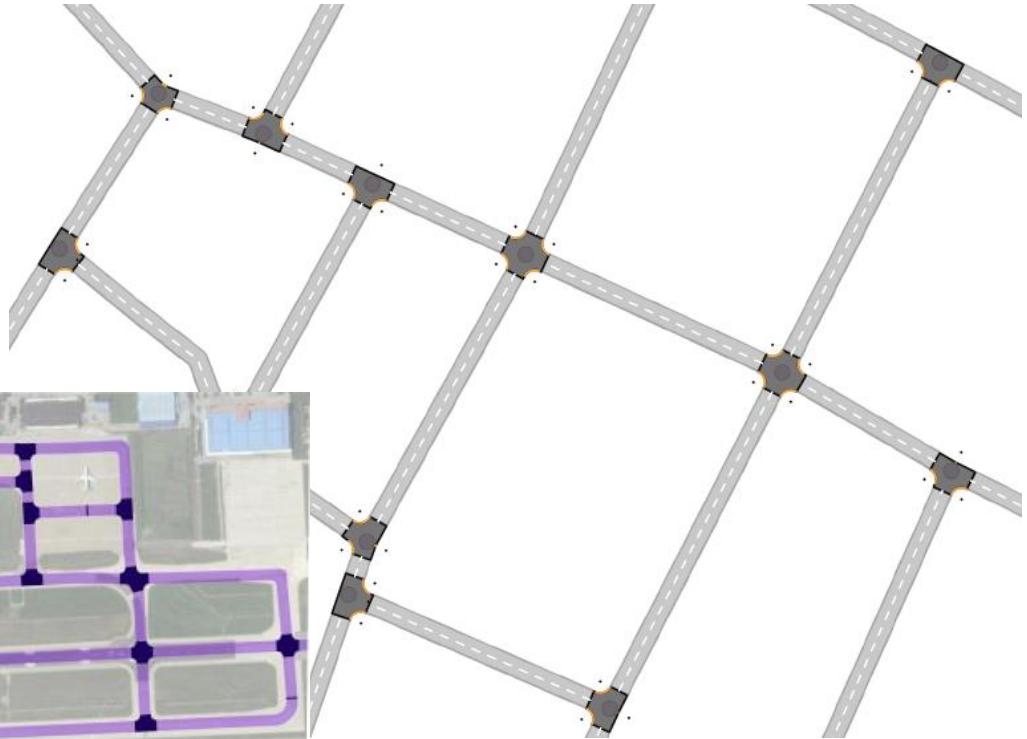
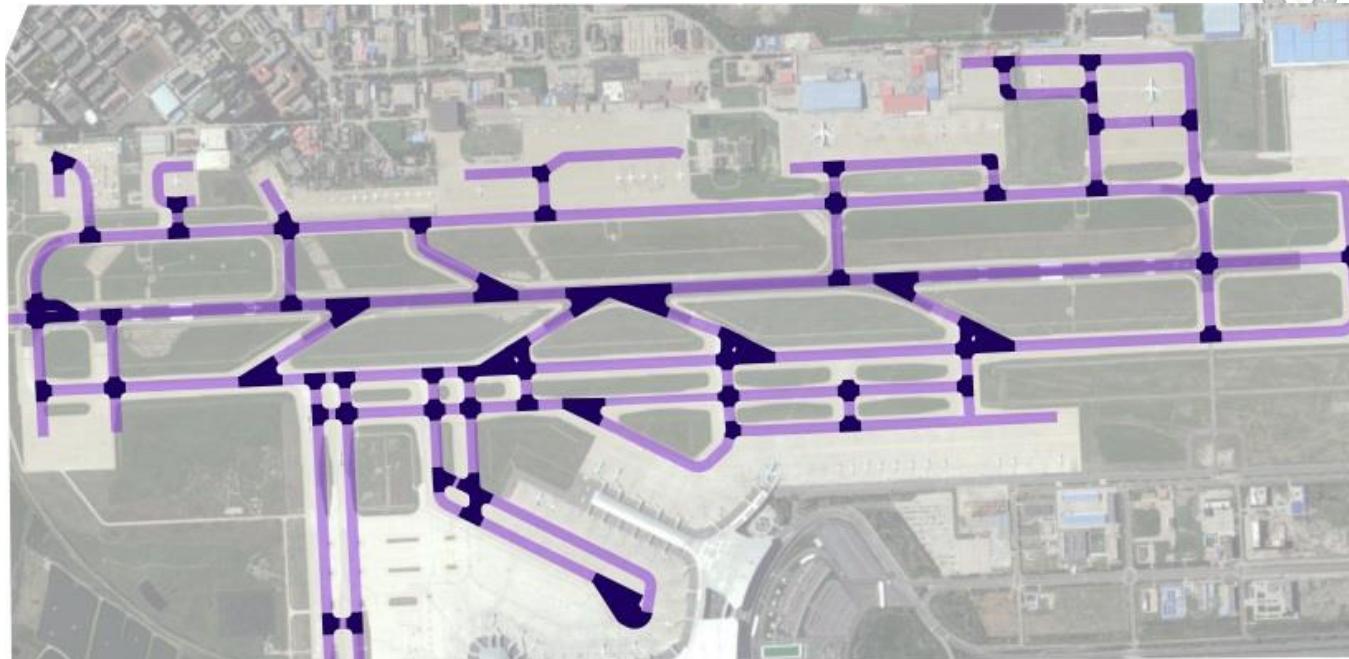
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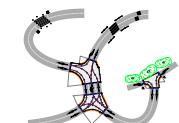


- Tested to model other cities (West Africa)
- Tested to model airport runway



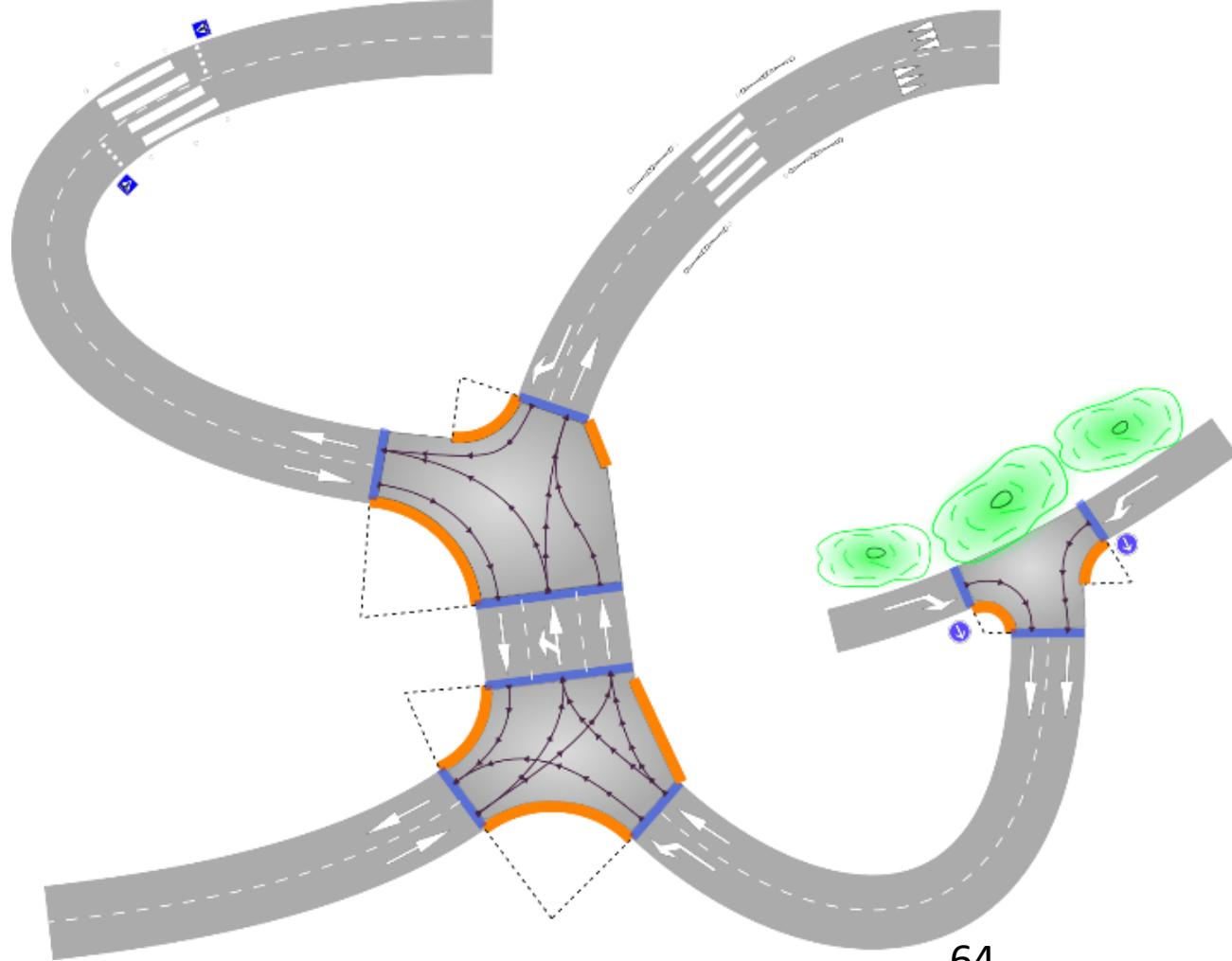
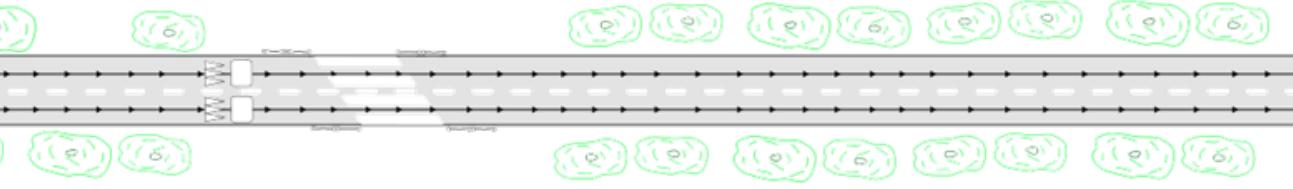
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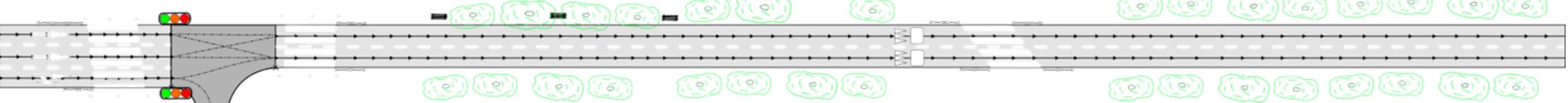


Contributions

- Data, method, result in RDBMS
- Robust road surface computing
- Fast (interactive for few streets) & scale well

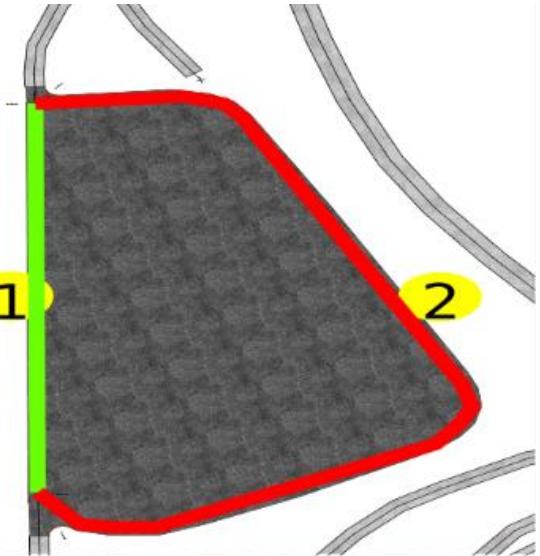


StreetGen : street objects



- Of course, lots of limitations

- Street model:
 - Not enough for some street
 - Radius seems to be historical rather than related to speed
- Technical
 - Precision issues
- Objects
 - Lacks linear objects



StreetGen : street objects

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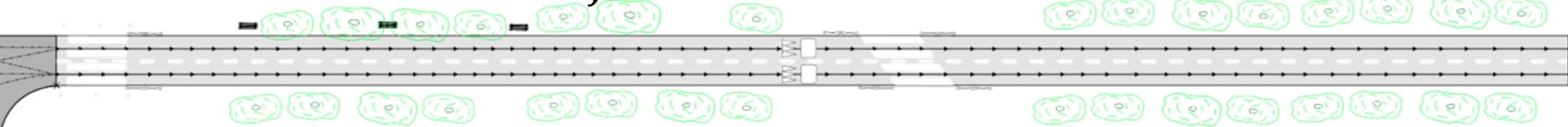
Streets

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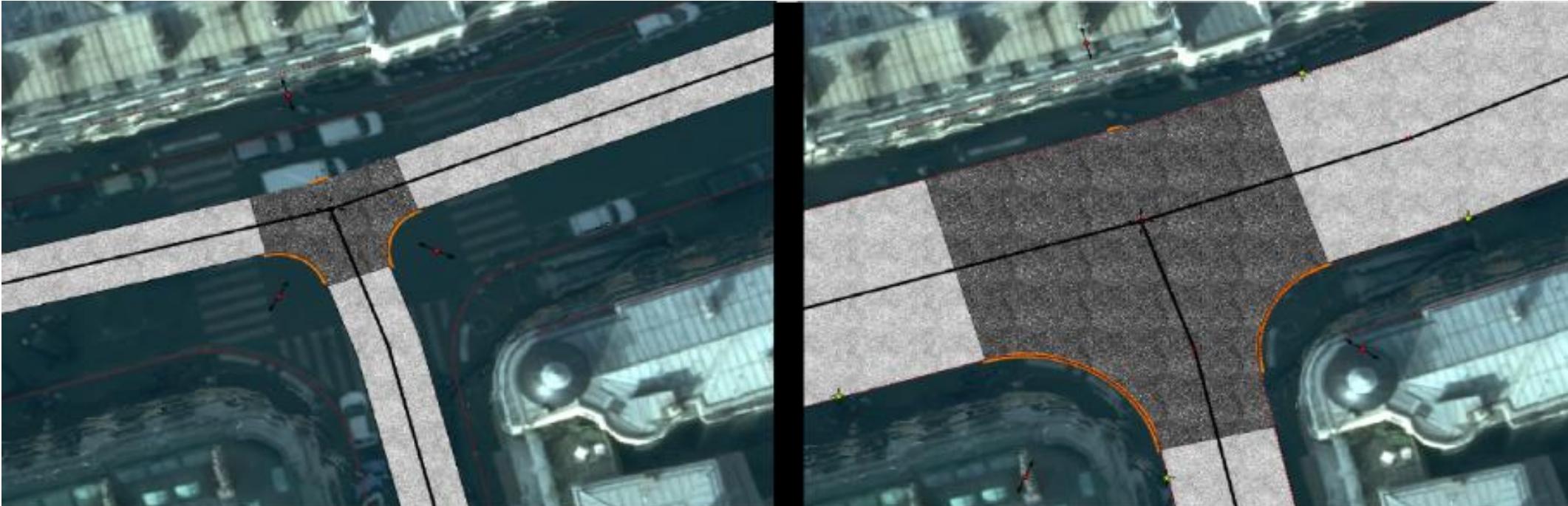
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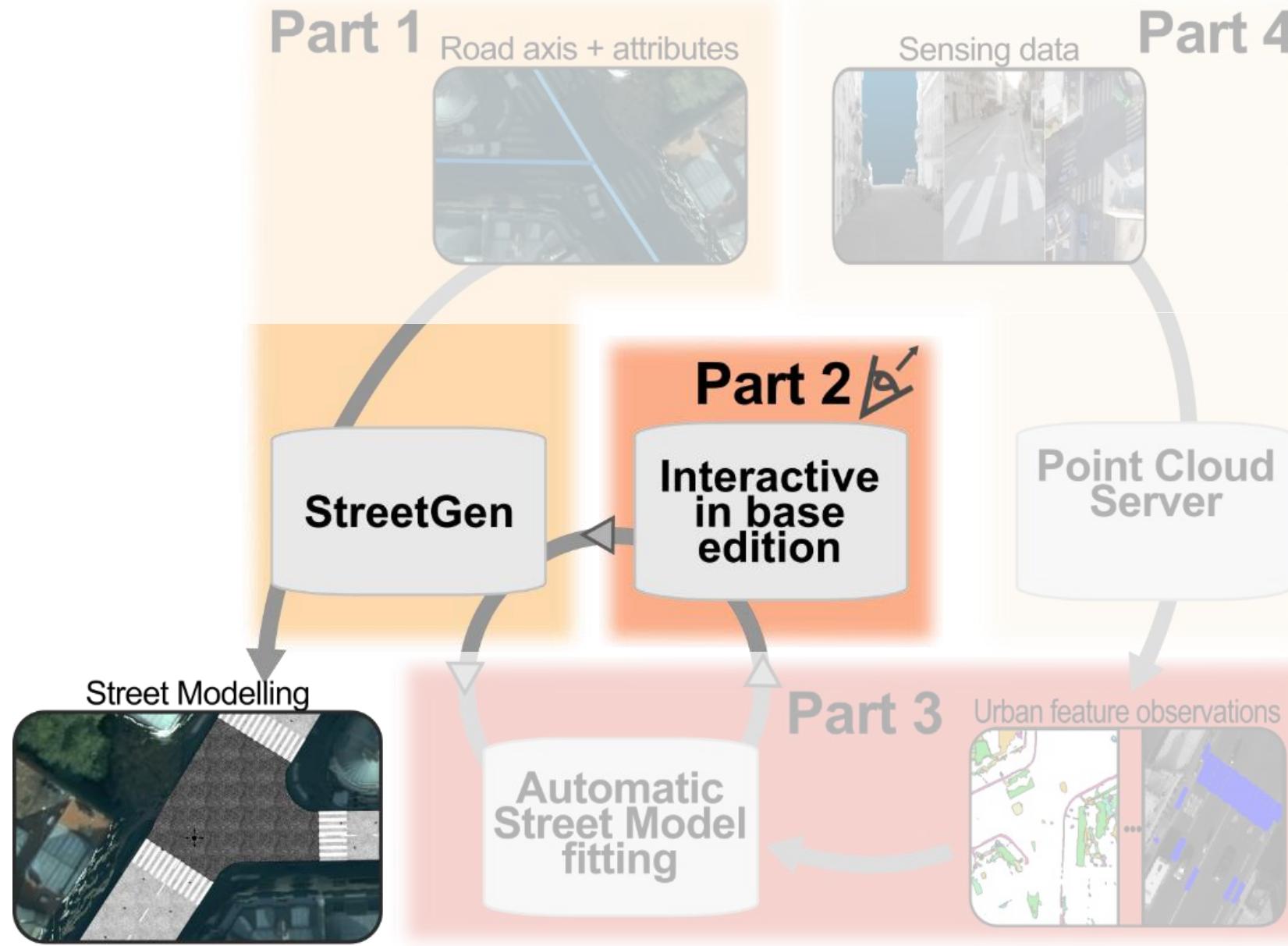
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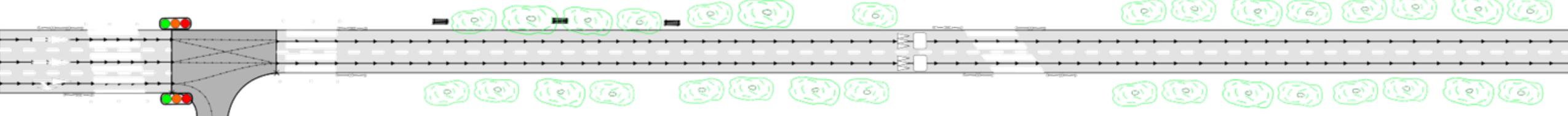


- Input data: not precise
 - For better results, need editing



Abstract



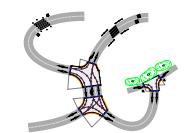


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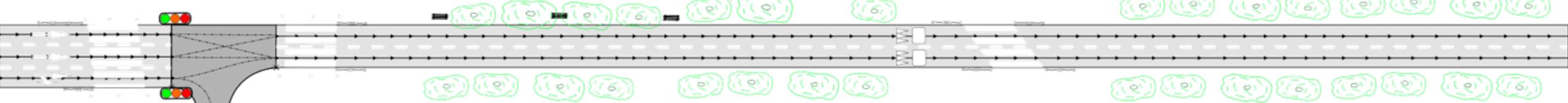
StreetGen : editing streets (in-base)

In-base interaction Principle

- Edit road model
- Edit traffic
- Edit objects



StreetGen : street objects



- How to edit street model easily?

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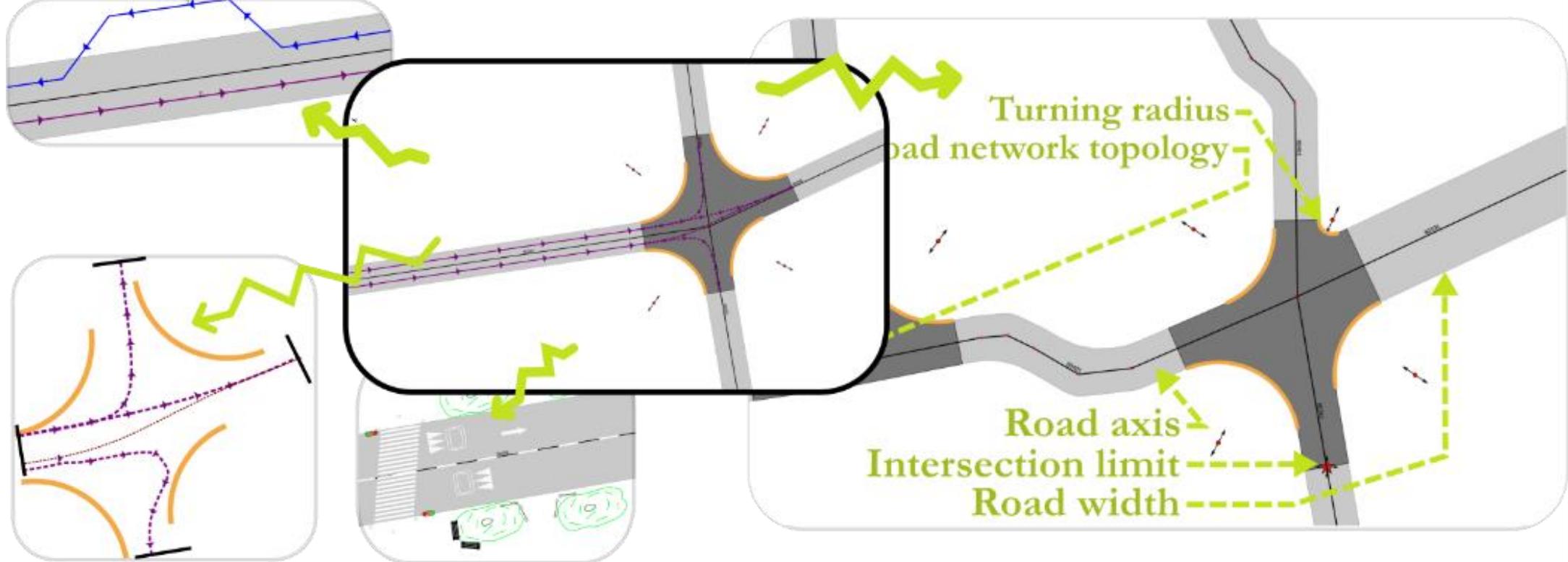
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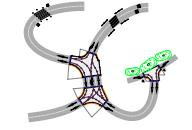
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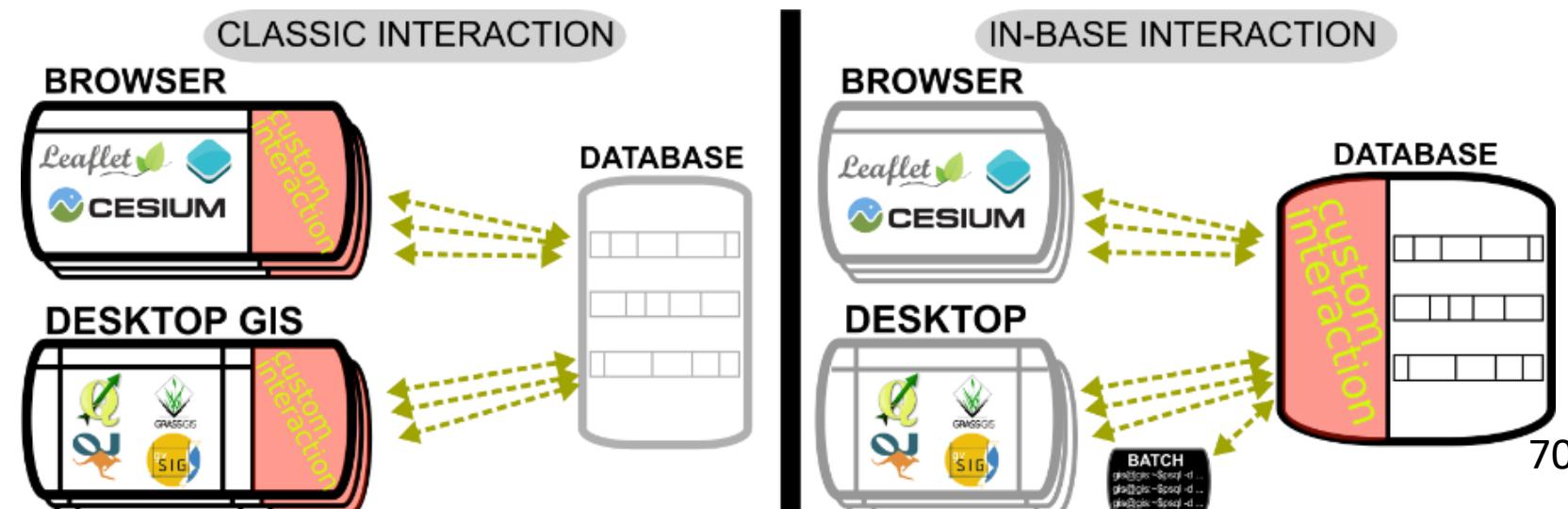


StreetGen : street objects

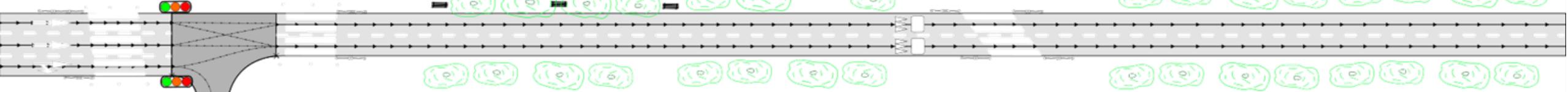
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- Fact : Graphical User Interface (GUI) → hard
- Many GUI for many tools (web/desktop/...)
 - Need to create plugins/interfaces/...
- Use existing tools !
 - GIS tools can already edit vector and attributes
 - specific interactions are in base



StreetGen : street objects



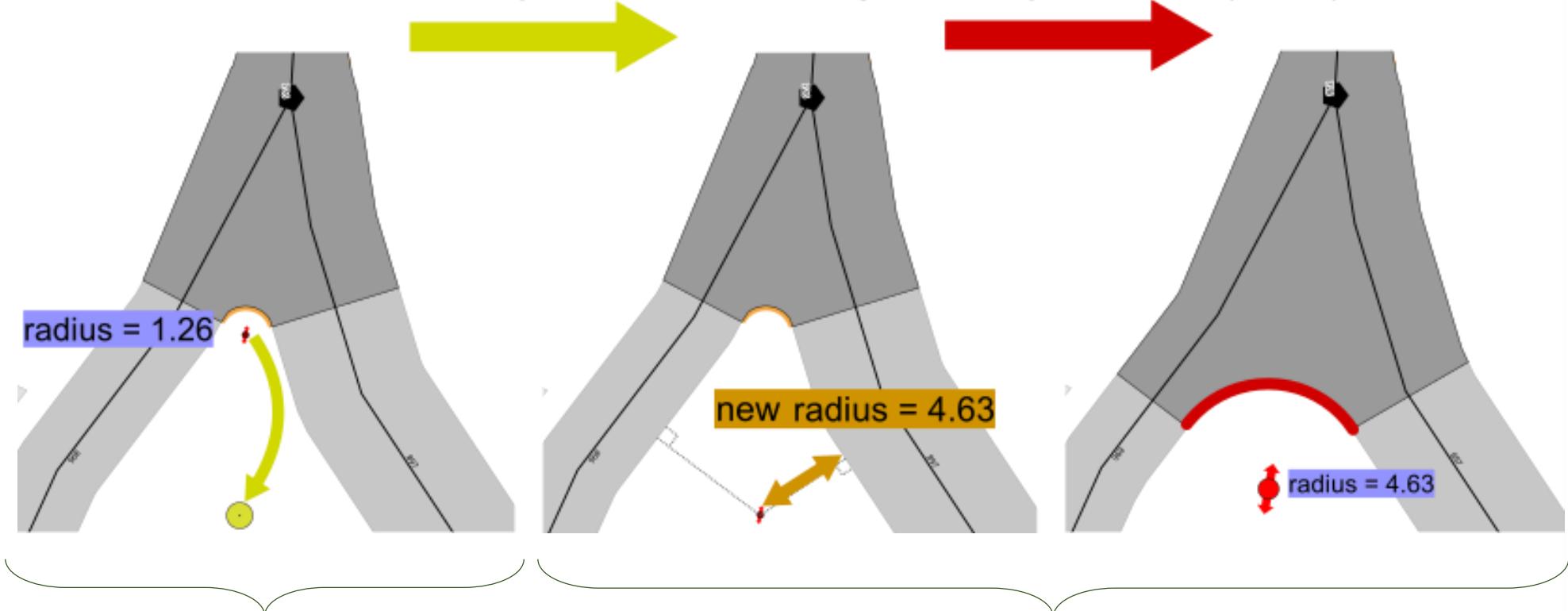
- example:

User

User edited proxy view:
interpret to get new radius

Automated

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



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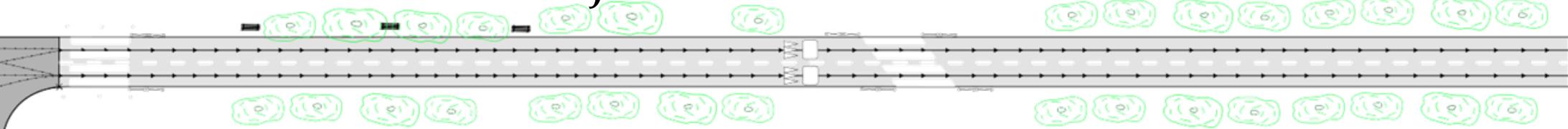
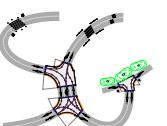
Streets

Interaction

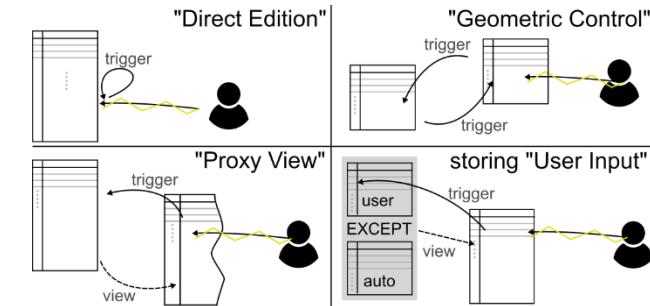
Automation

P.C. Server

Conclusion



- In-base interaction are generic and powerful
 - Design pattern to help use it for other applications



StreetGen : street objects

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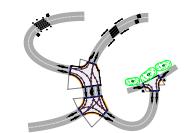
Streets

Interaction

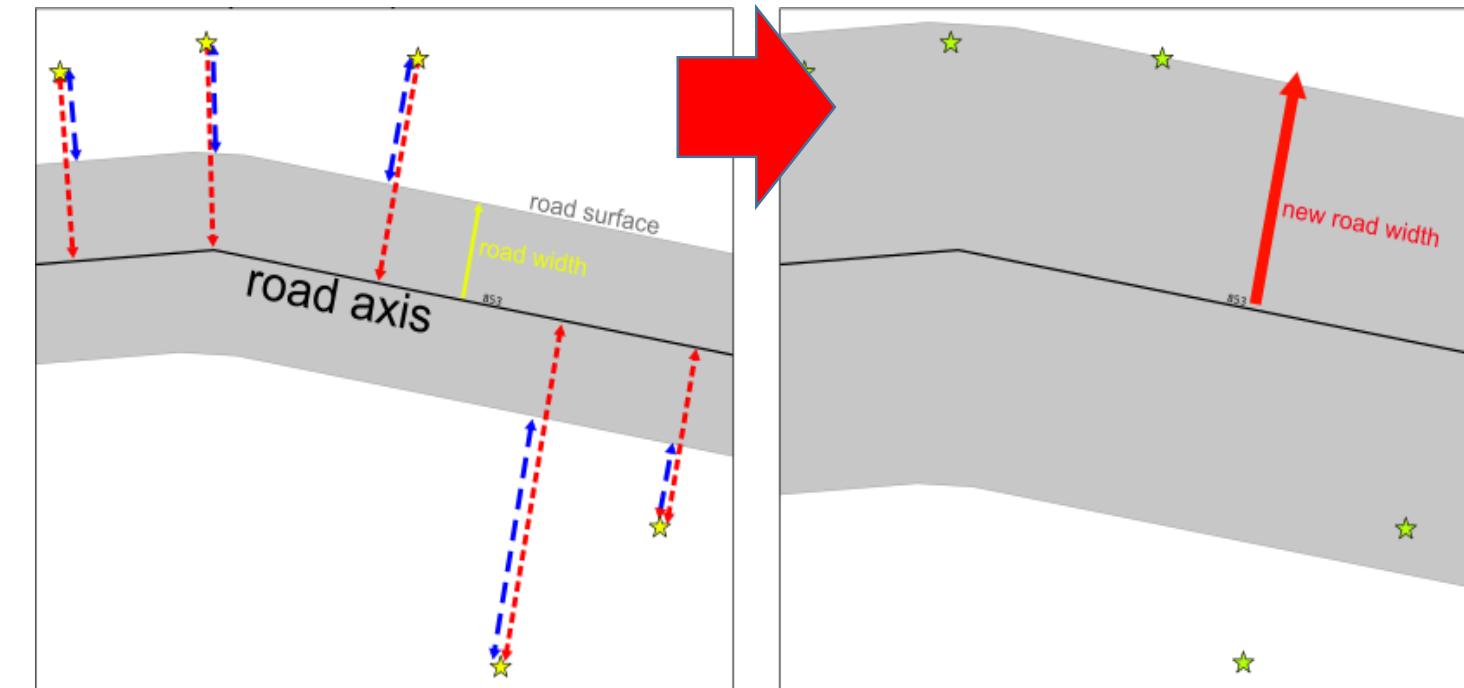
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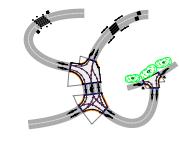


- All StreetGen street model can be edited concurrently
 - Road axis/ width/topology
 - Radius
 - Lane
 - Interconnection
 - objects

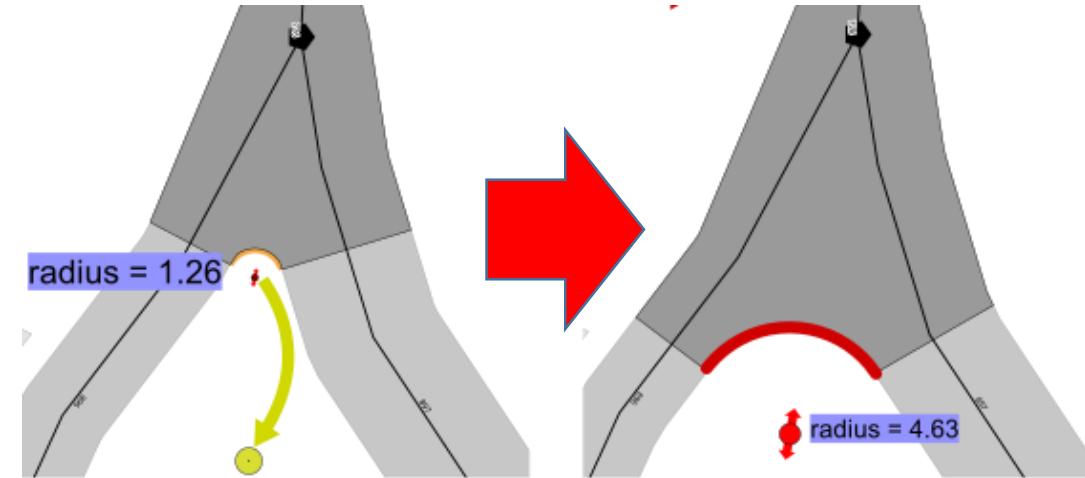


StreetGen : street objects

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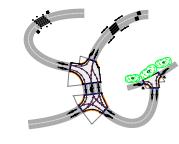


- All StreetGen street model can be edited concurrently
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 - Radius
 - Lane
 - Interconnection
 - objects

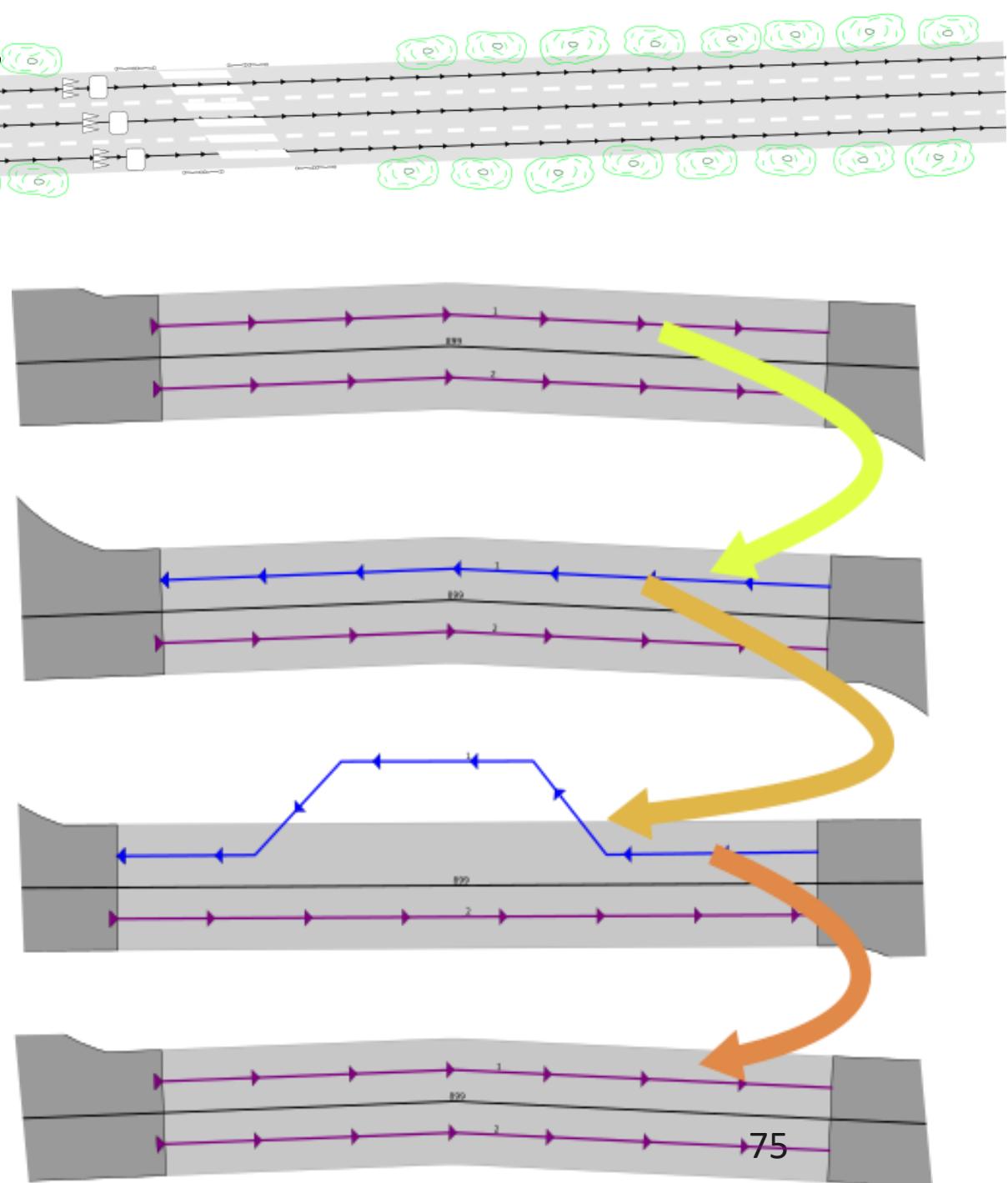


StreetGen : street objects

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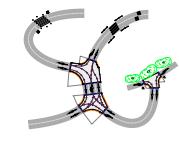


- All StreetGen street model can be edited concurrently
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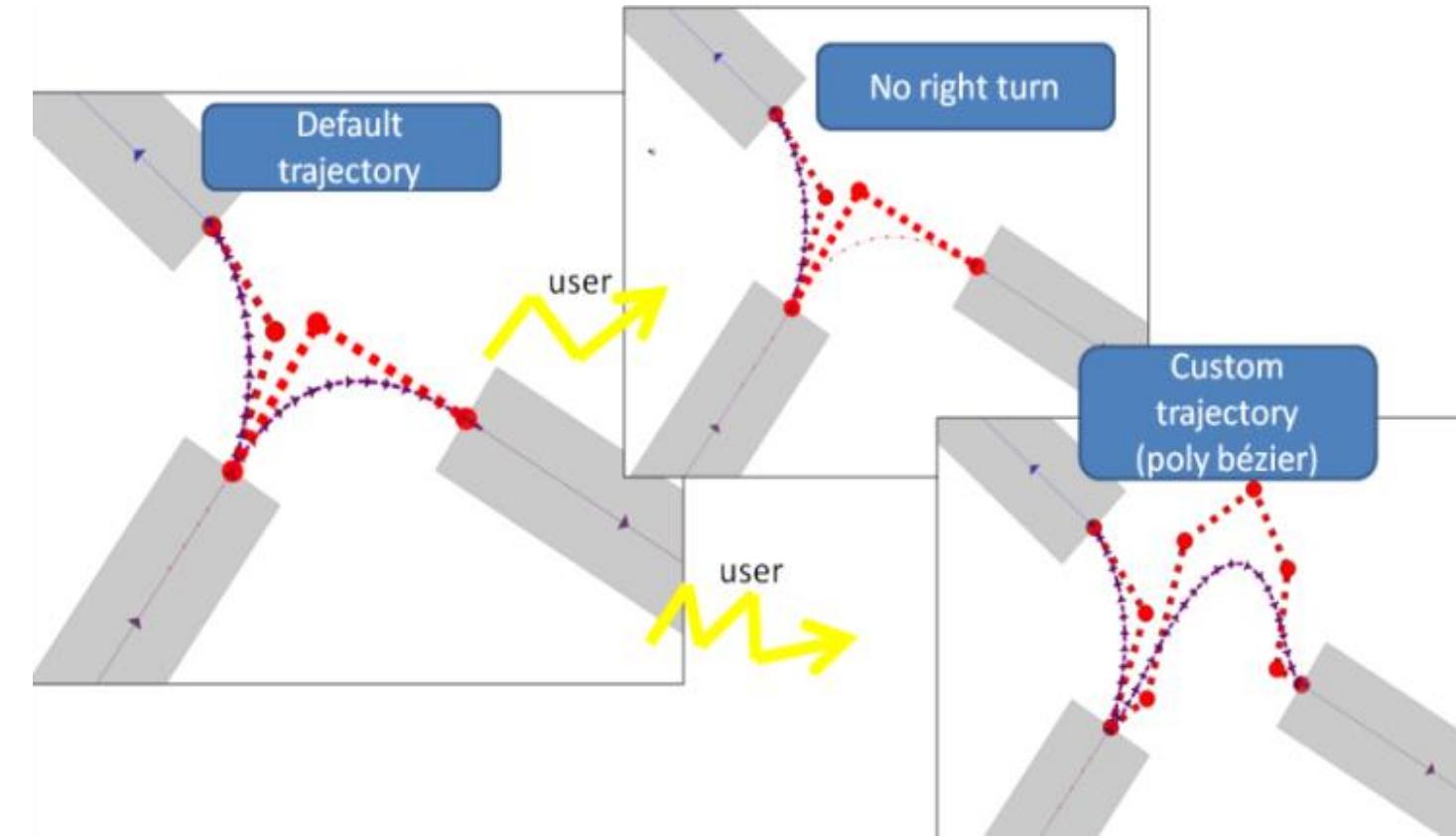


StreetGen : street objects

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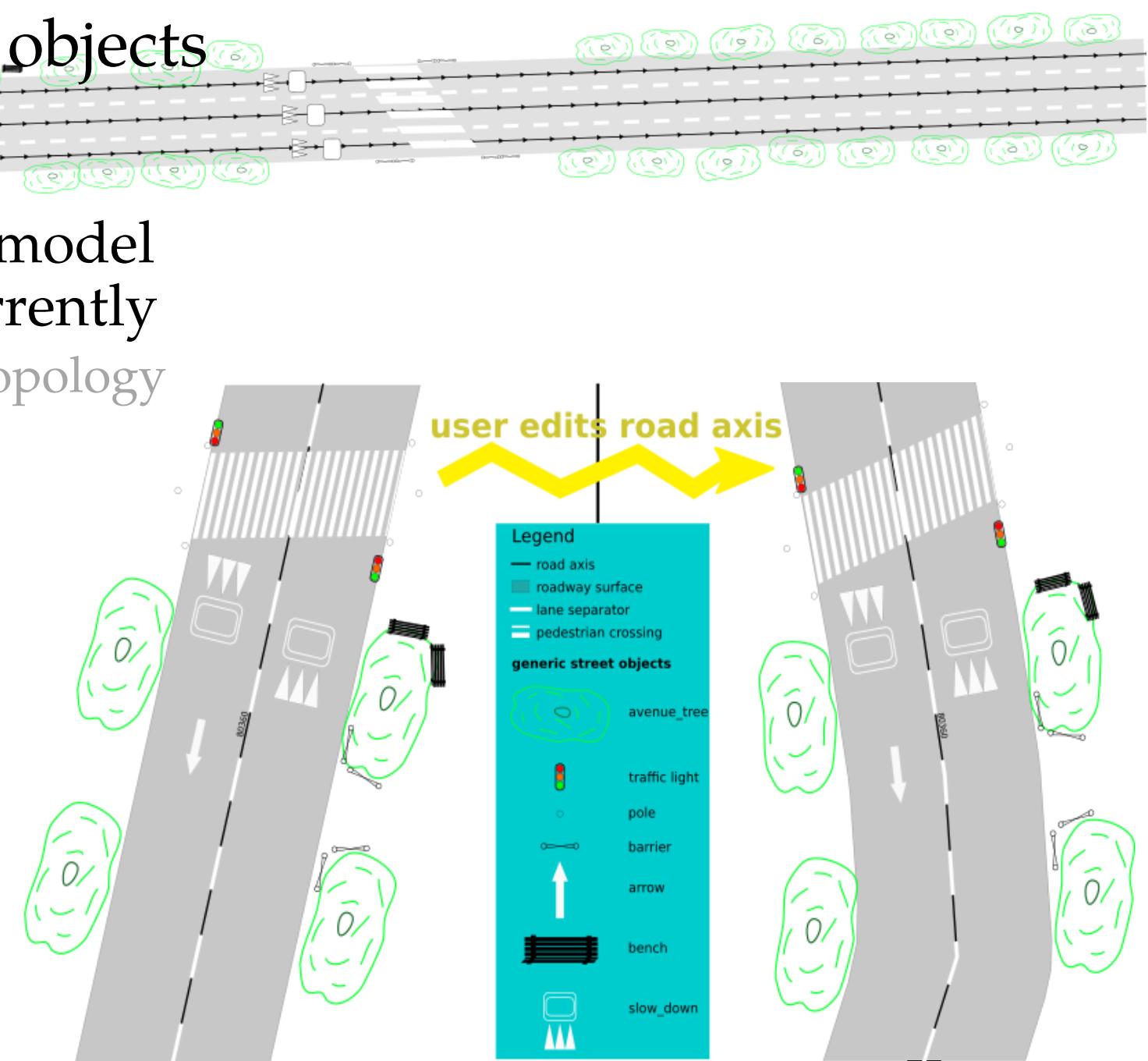


- All StreetGen street model can be edited concurrently
 - Road axis/ width/topology
 - Radius
 - Lane
 - Interconnection
 - objects



StreetGen : street objects

- All StreetGen street model can be edited concurrently
 - Road axis/ width/topology
 - Radius
 - Lane
 - Interconnection
 - objects



StreetGen : street objects

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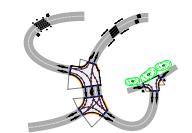
Streets

Interaction

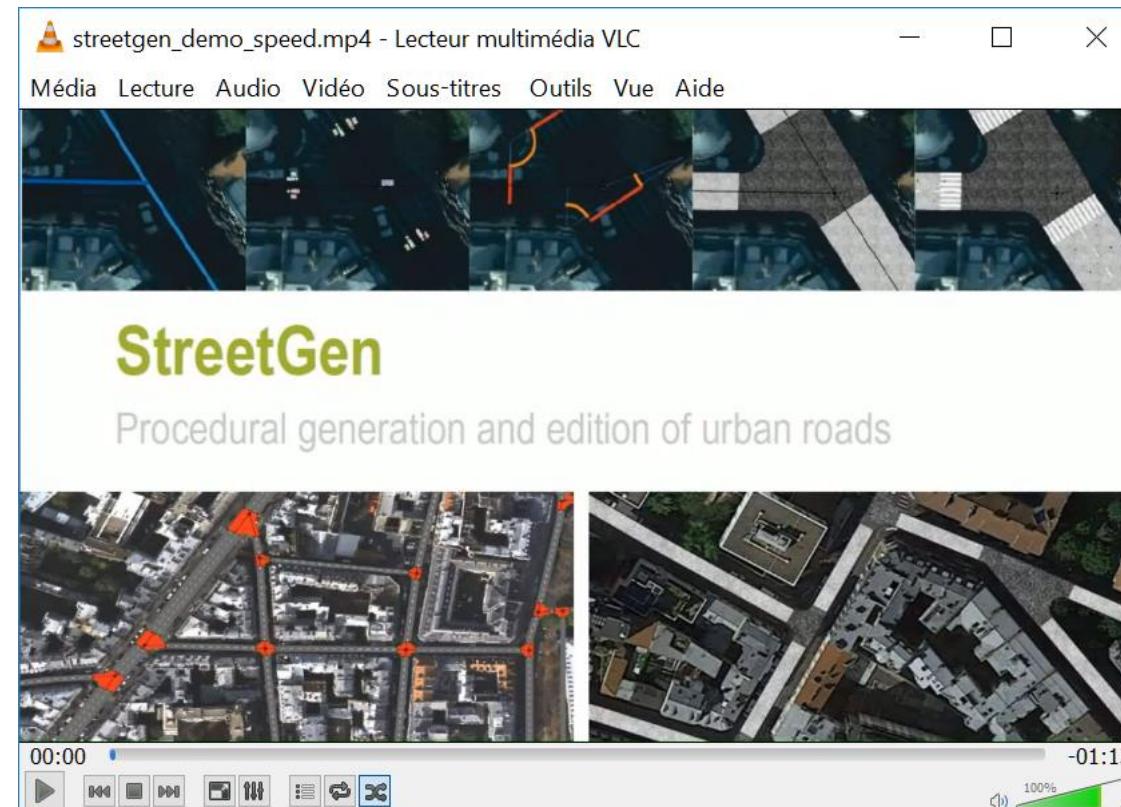
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- Results:
 - Interactions are fast enough to be interactive



Video

<https://youtu.be/fQZoEfUcNHA>

StreetGen : street objects

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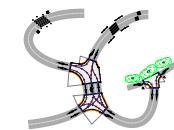
Streets

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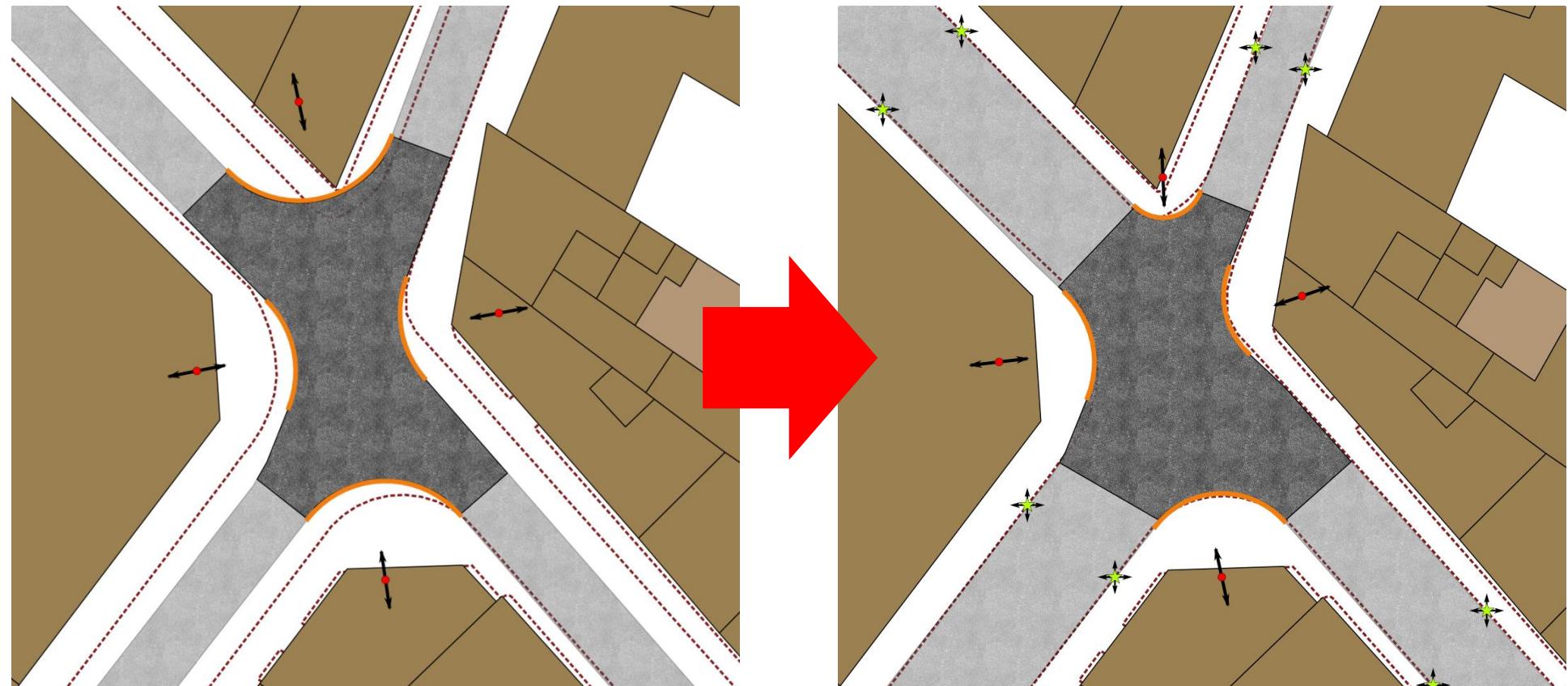
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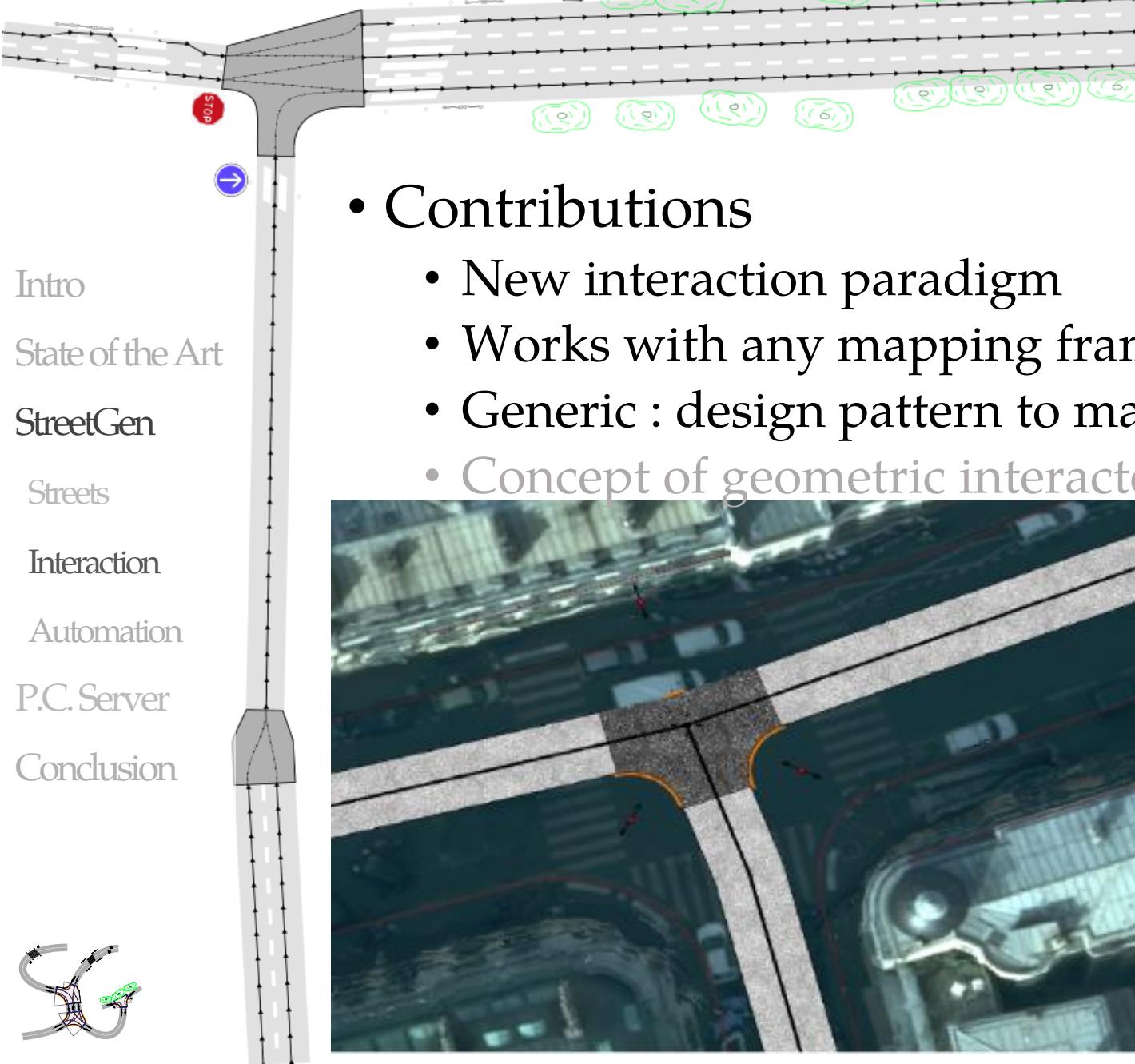
Conclusion



- Results:

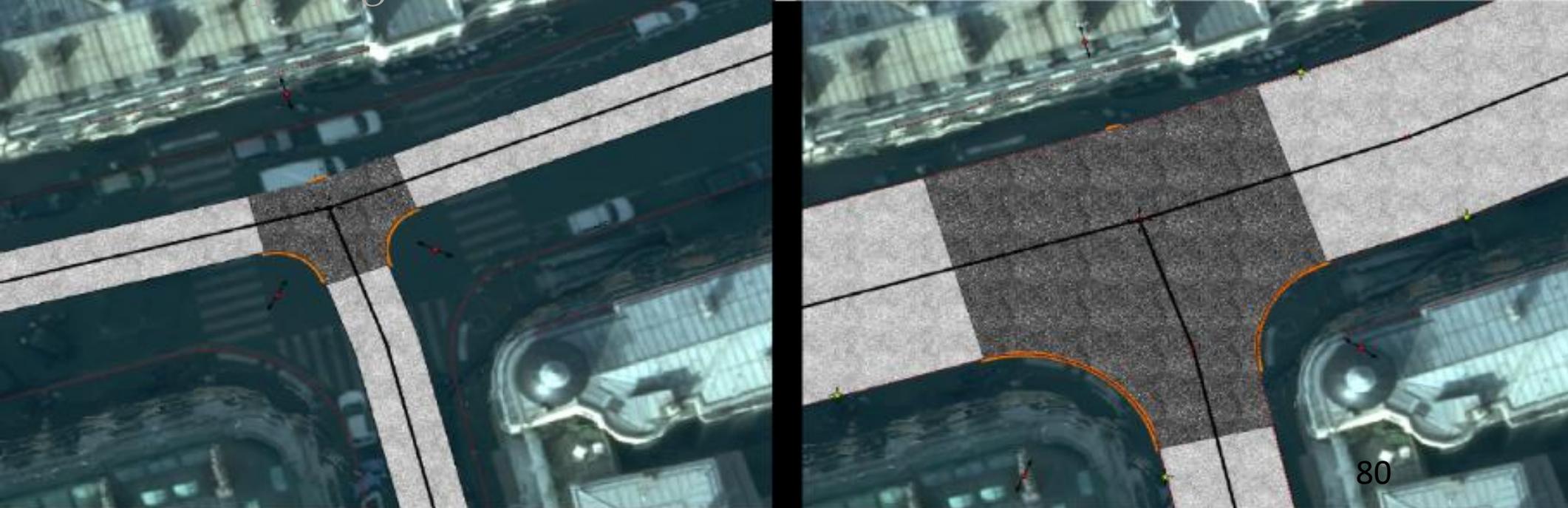


StreetGen : street objects



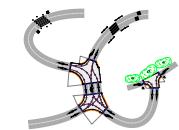
- Contributions

- New interaction paradigm
- Works with any mapping framework
- Generic : design pattern to manage interactions and user input
- Concept of geometric interactors



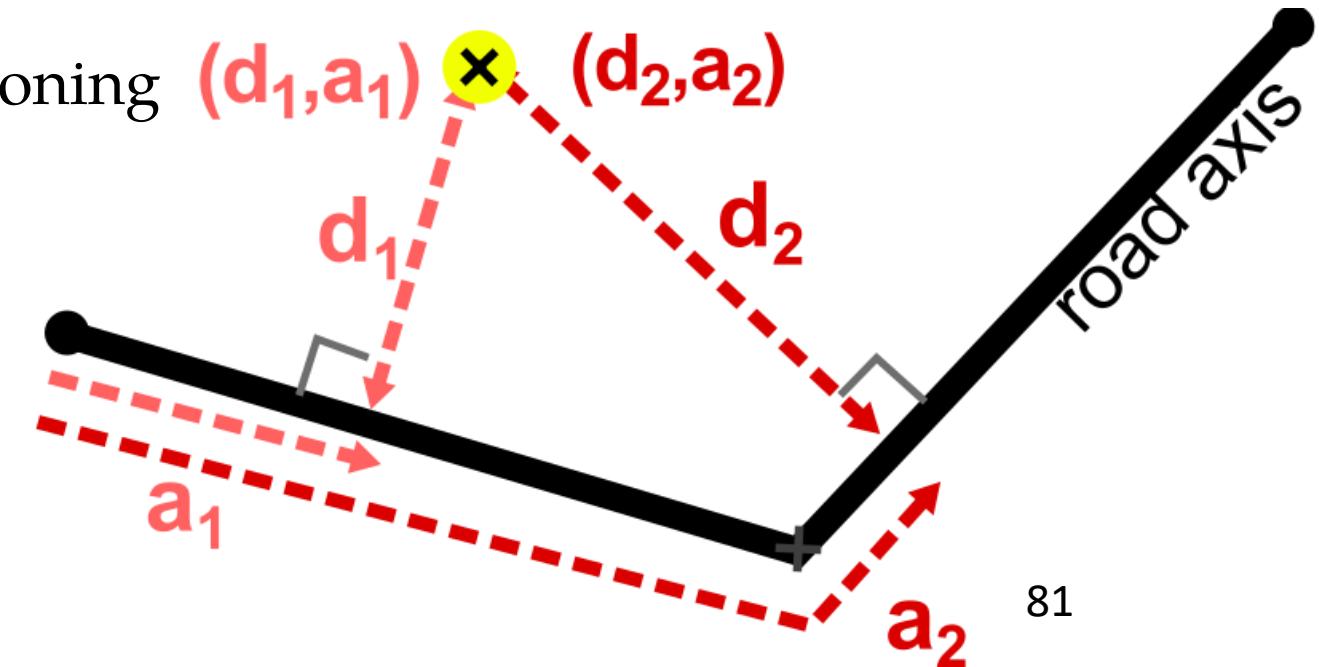
StreetGen : street objects

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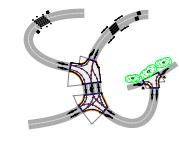
- Several Limitations

- limited to straightforward interaction
(guessing user action is easy)
- Old school : Hard to develop/test/maintain
- one transaction → should be short
- Objects: relative positioning
may be ambiguous

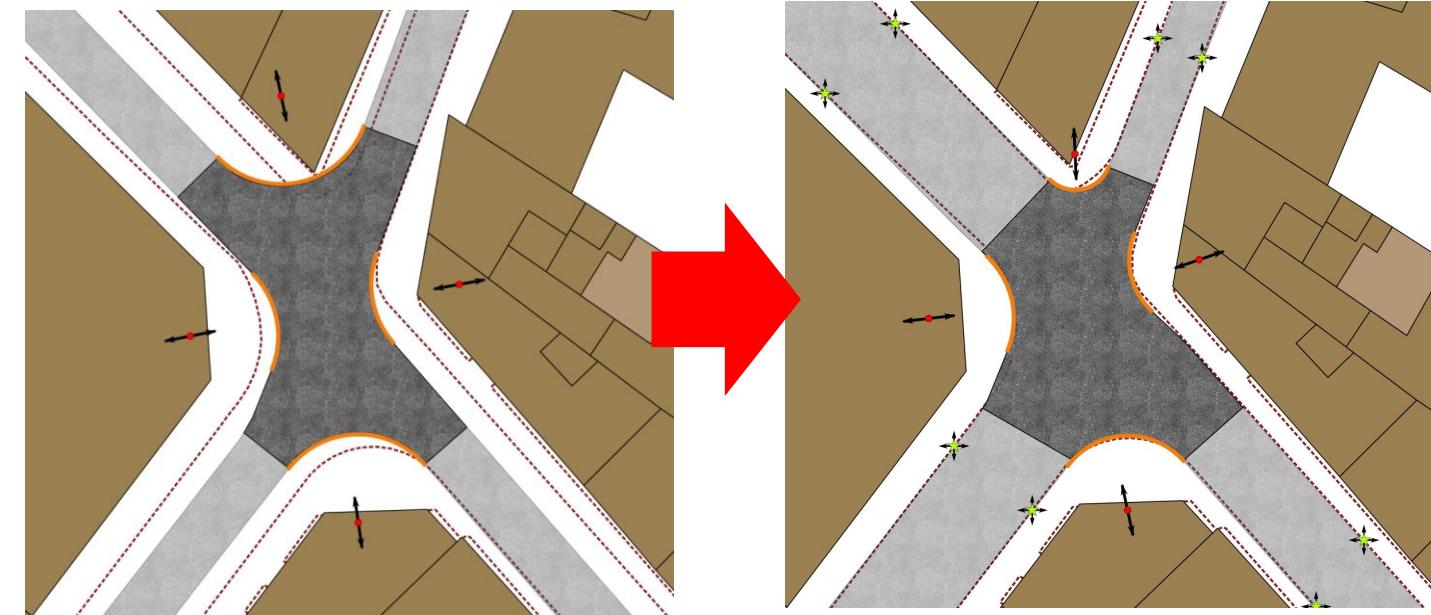


StreetGen : street objects

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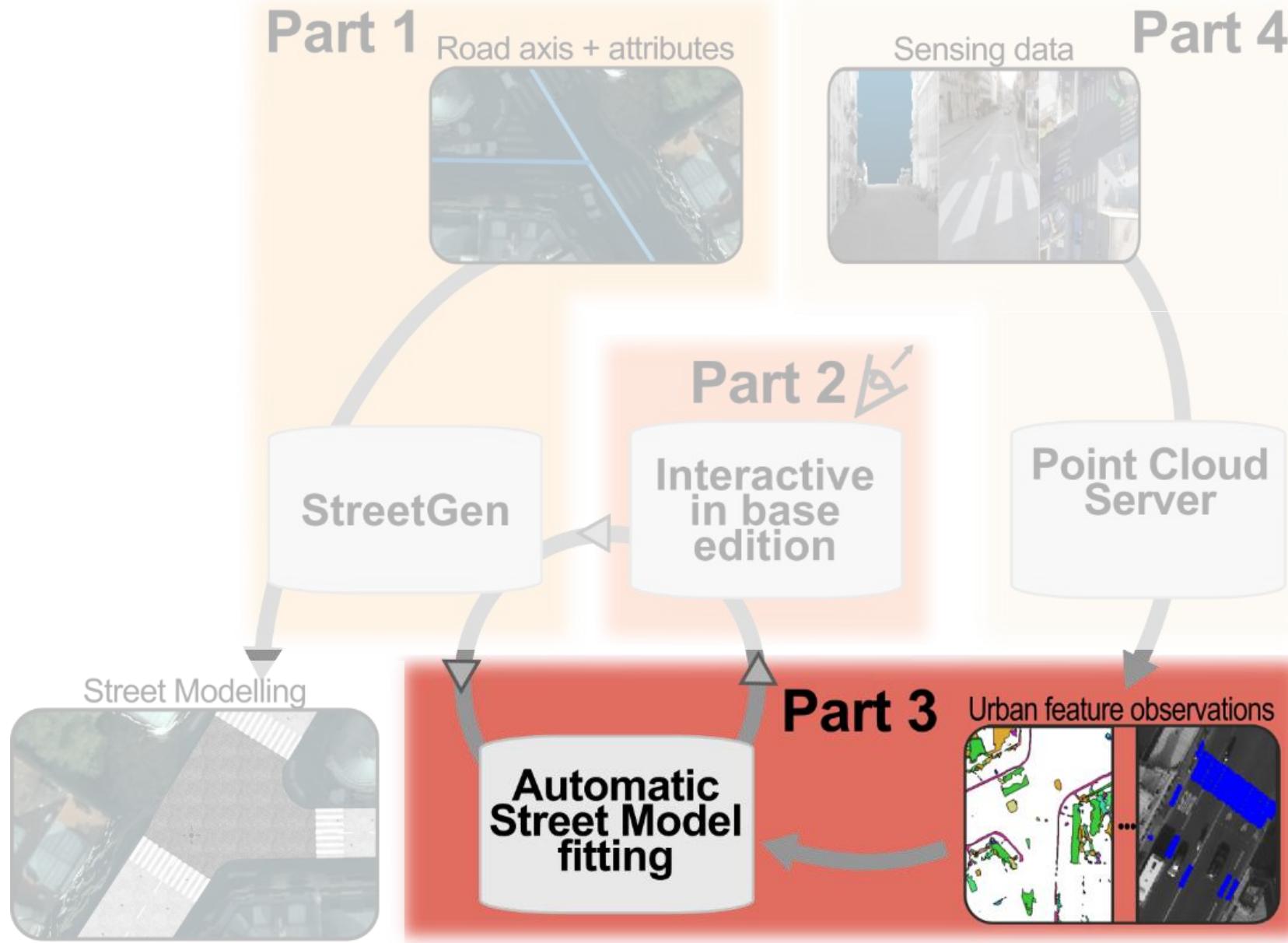


- Manual fitting : we can come close to real streets
 - Tedious
 - Lengthy !



Can we teach the machine to do it for us?

Abstract



width= 8; lane= 3

width= 6; lane= 2

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width= 4; lane= 1

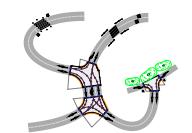
Automating street modelling

Inverse procedural modelling concept

Street objects observations

Fitting principle

Results



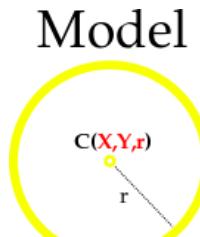
StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

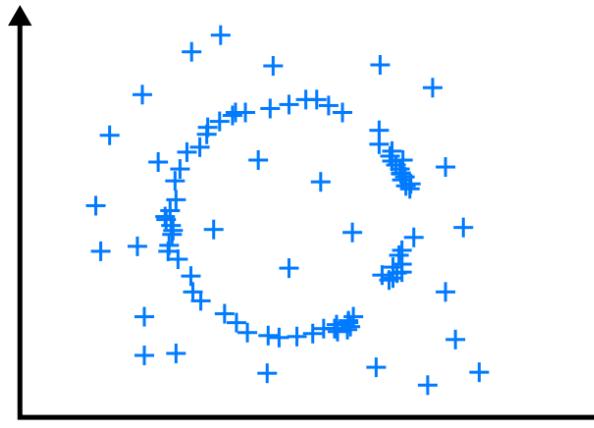
Inverse Problem:

width= 4; lane= 1



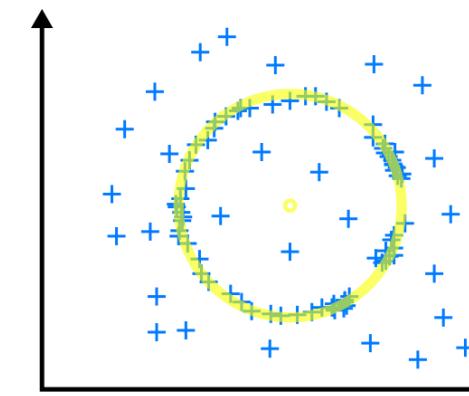
+

observations



fit
→

Model = C(3.2,2.1,1.5)



Procedural model

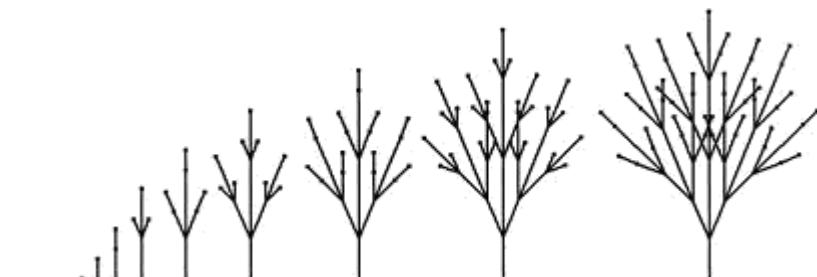
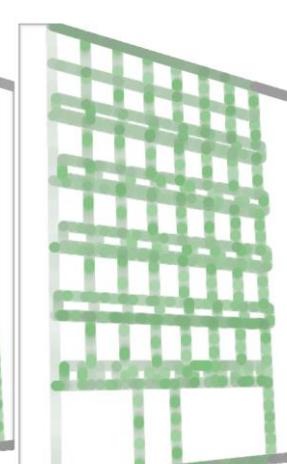
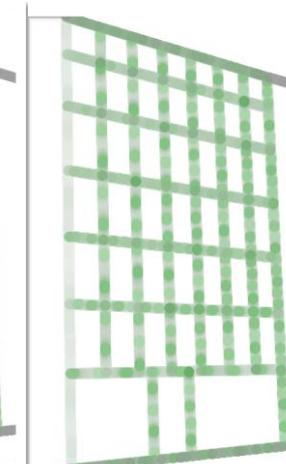
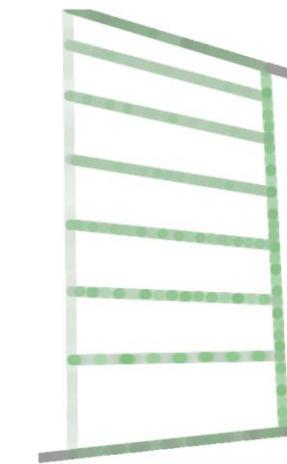


Image : Three-dimensional modelling and visualisation of vegetation for landscape simulation



Thales: Building maker



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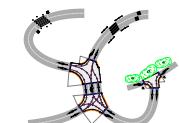
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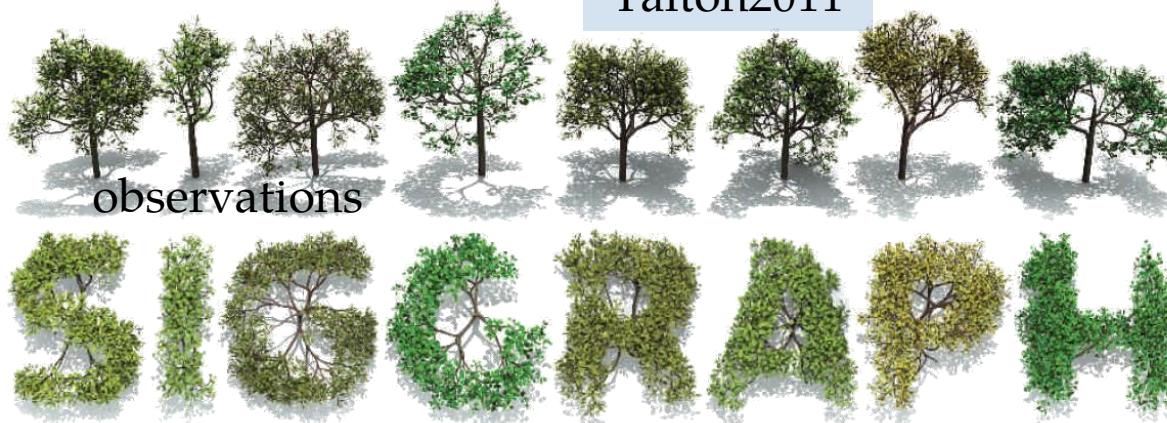
StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

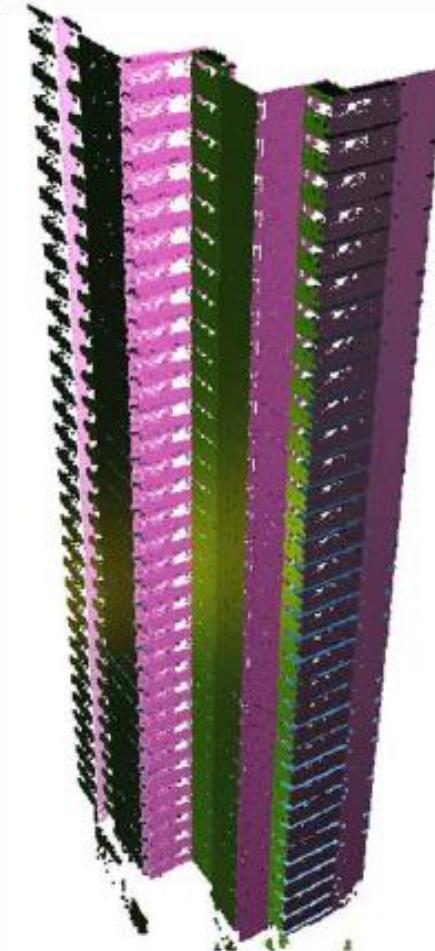
Fit a generic
procedural model to a
specific situation

Specific situation?
→ We need data!



Talton2011

observations



Wan2012



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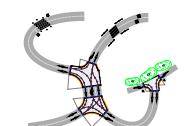
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StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

In this work:

Procedural model = StreetGen for road

Observations = any street object

from other works

width= 4; lane= 1

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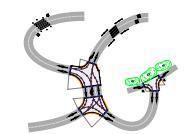
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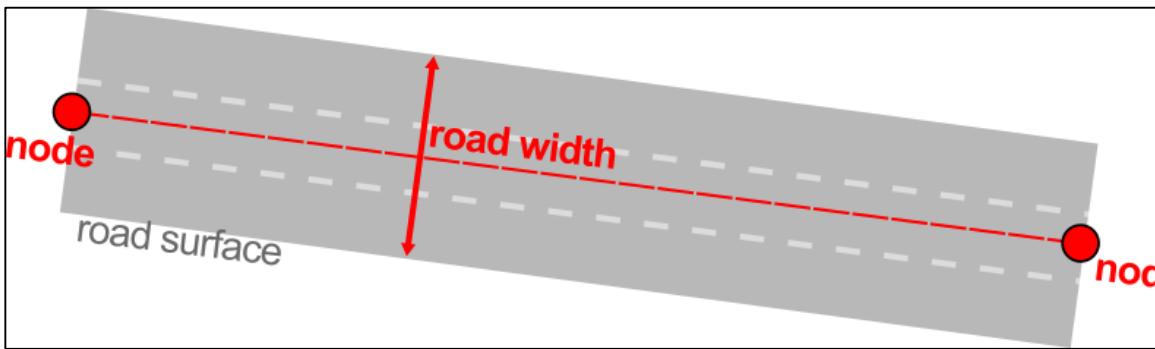
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Inverse Procedural modelling: method

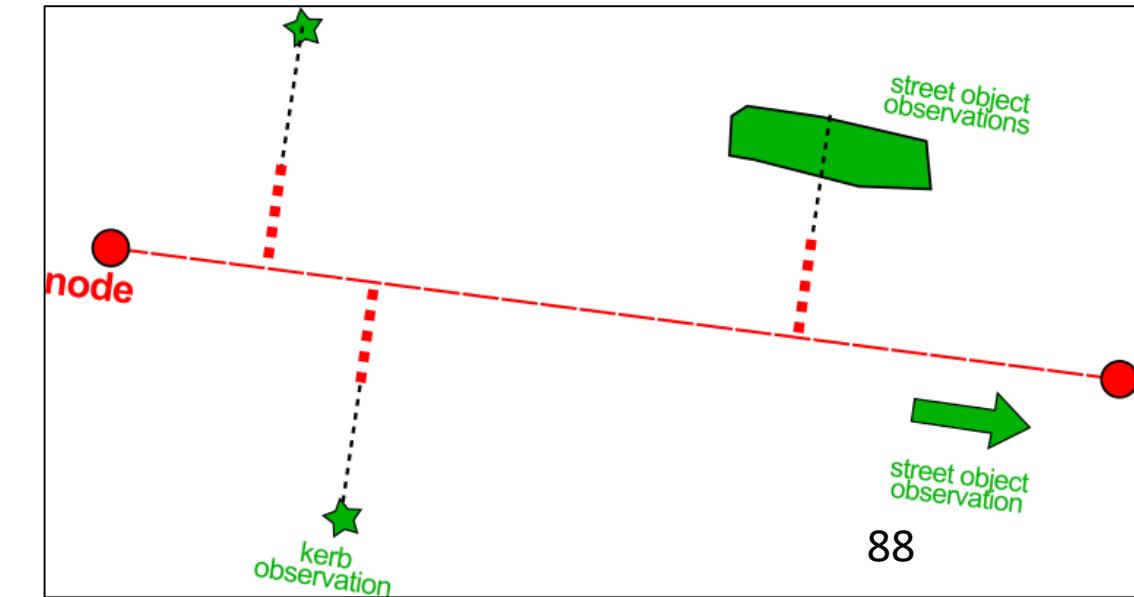
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- Initial road model (< StreetGen) + observation



observations

- Observations = any street object detection



Inverse Procedural modelling: method

- Initial road model + observation → fitted road model

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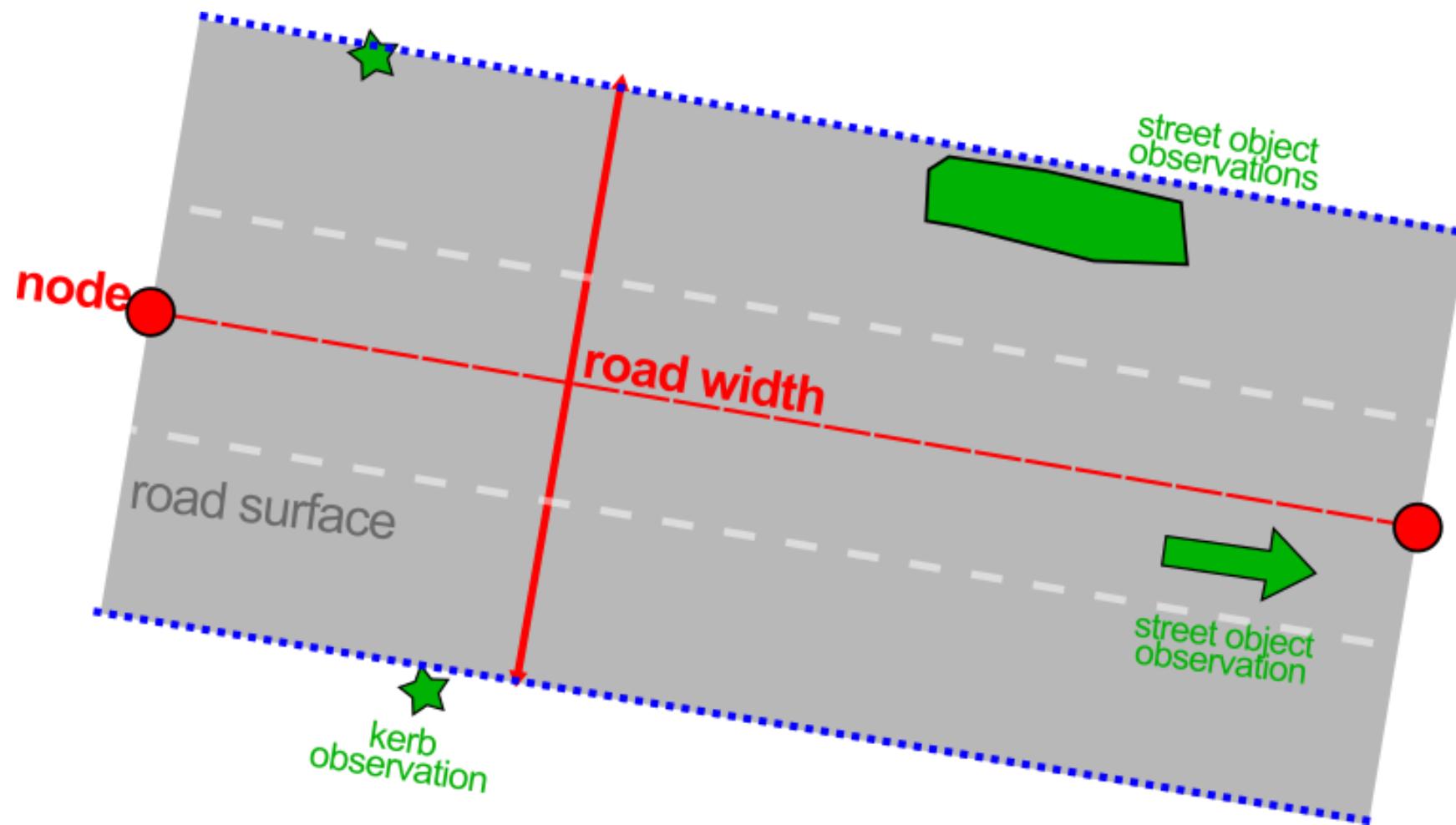
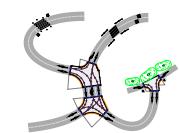
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width= 8; lane= 3

width= 6; lane= 2

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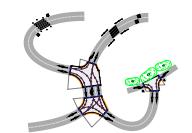
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StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

- To fit, we need observations describing street.
- Where from?

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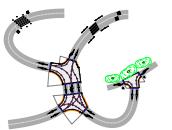
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width= 4; lane= 1



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

width= 4; lane= 1

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- What type of data for streets?

- Precise
- Good coverage
- Frequent

- Aerial image?

- Good coverage
- Low 3D precision



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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StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Street view:

- Good coverage



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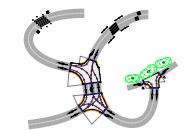
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width= 4; lane= 1



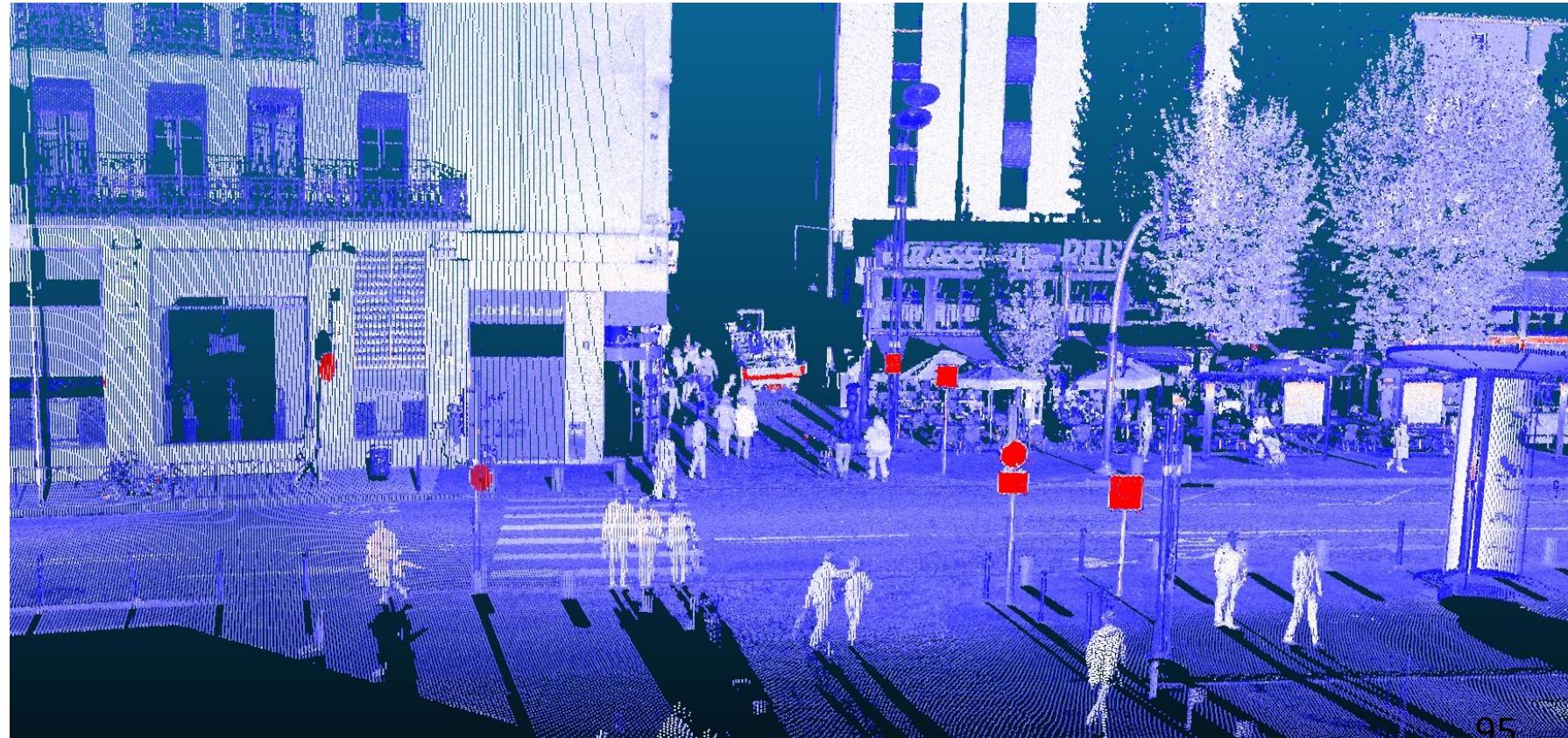
StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Lidar: 3D point clouds

- precise 3D



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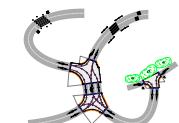
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StreetGen : Inverse procedural modelling

width= 8; lane= 3

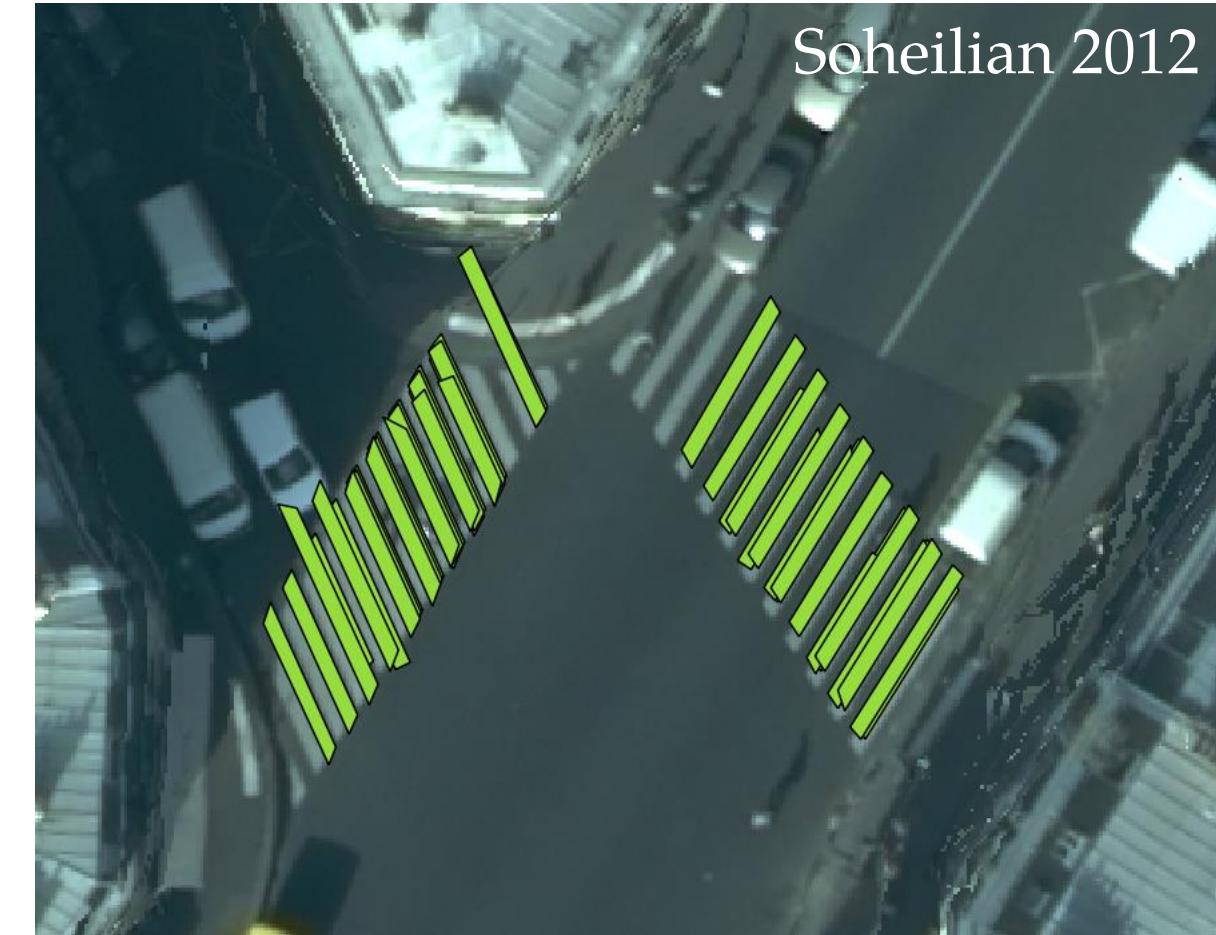
width= 6; lane= 2

Observations are detected street objects.

Street object have an expected position.

Pedestrian crossing:
Within the roadway!

width= 4; lane= 1



Inverse Procedural modelling: forces

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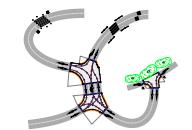
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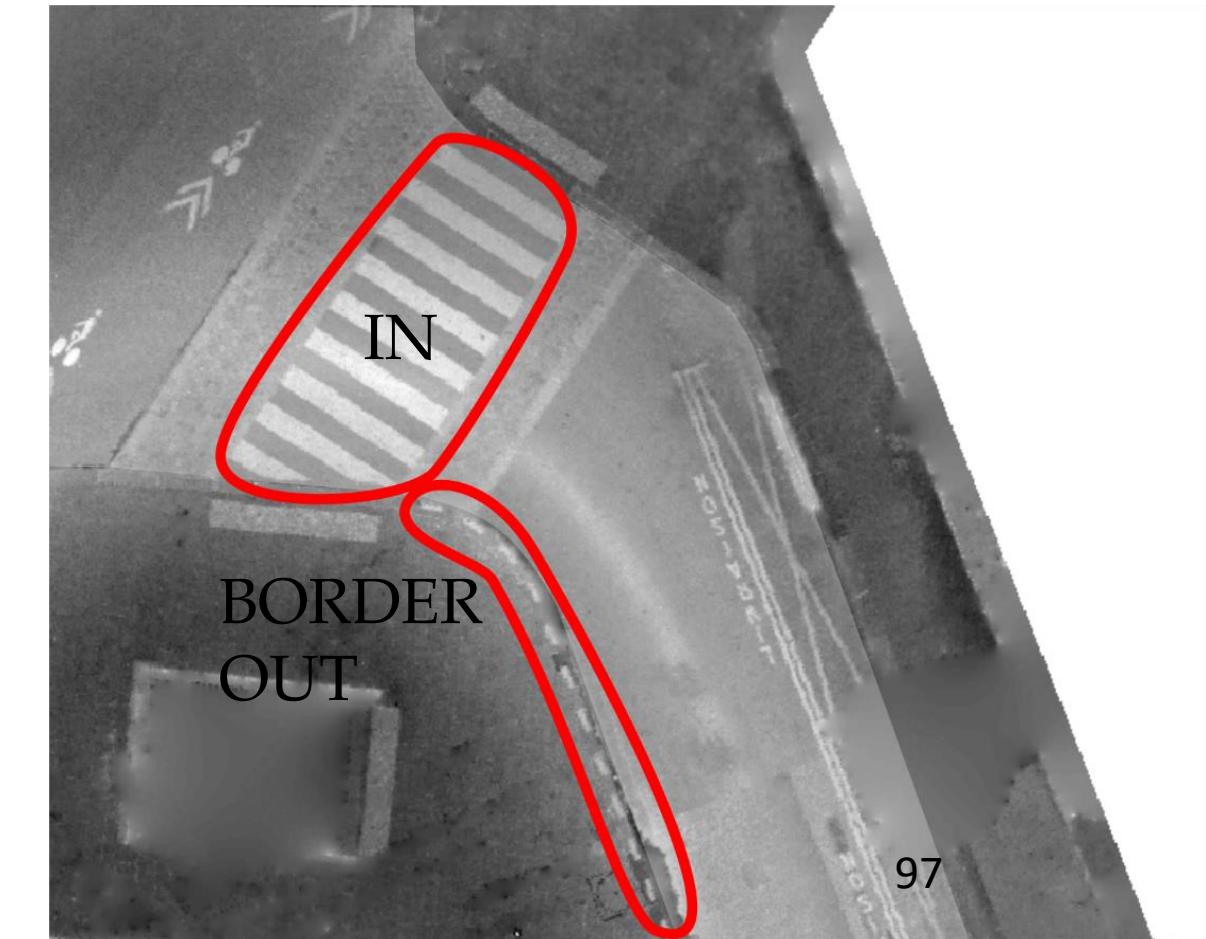
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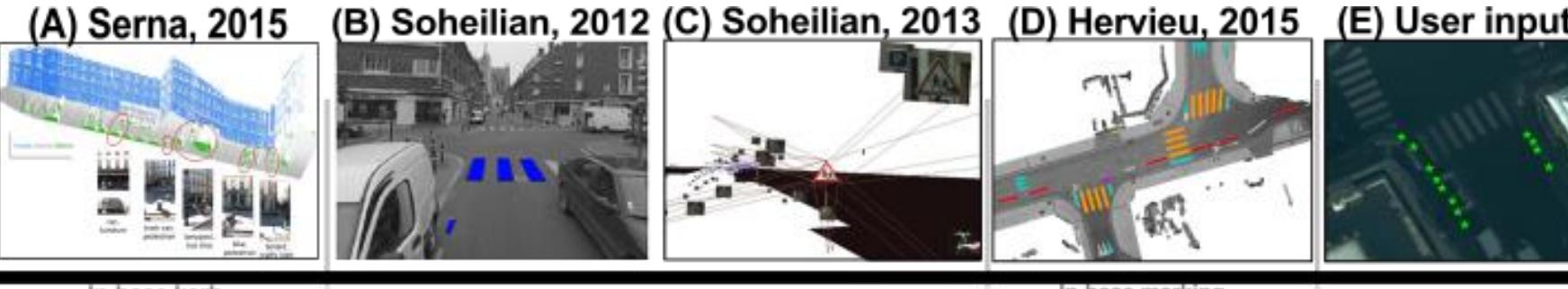
- Each street object type has an expected position:
 - IN/OUT + BORDER_IN/BORDER_OUT (dist)



Inverse Procedural modelling: observations

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- Observation = clues about roadway
- We rely on other's work:
(We can use any street object detection)



In-base kerb detection



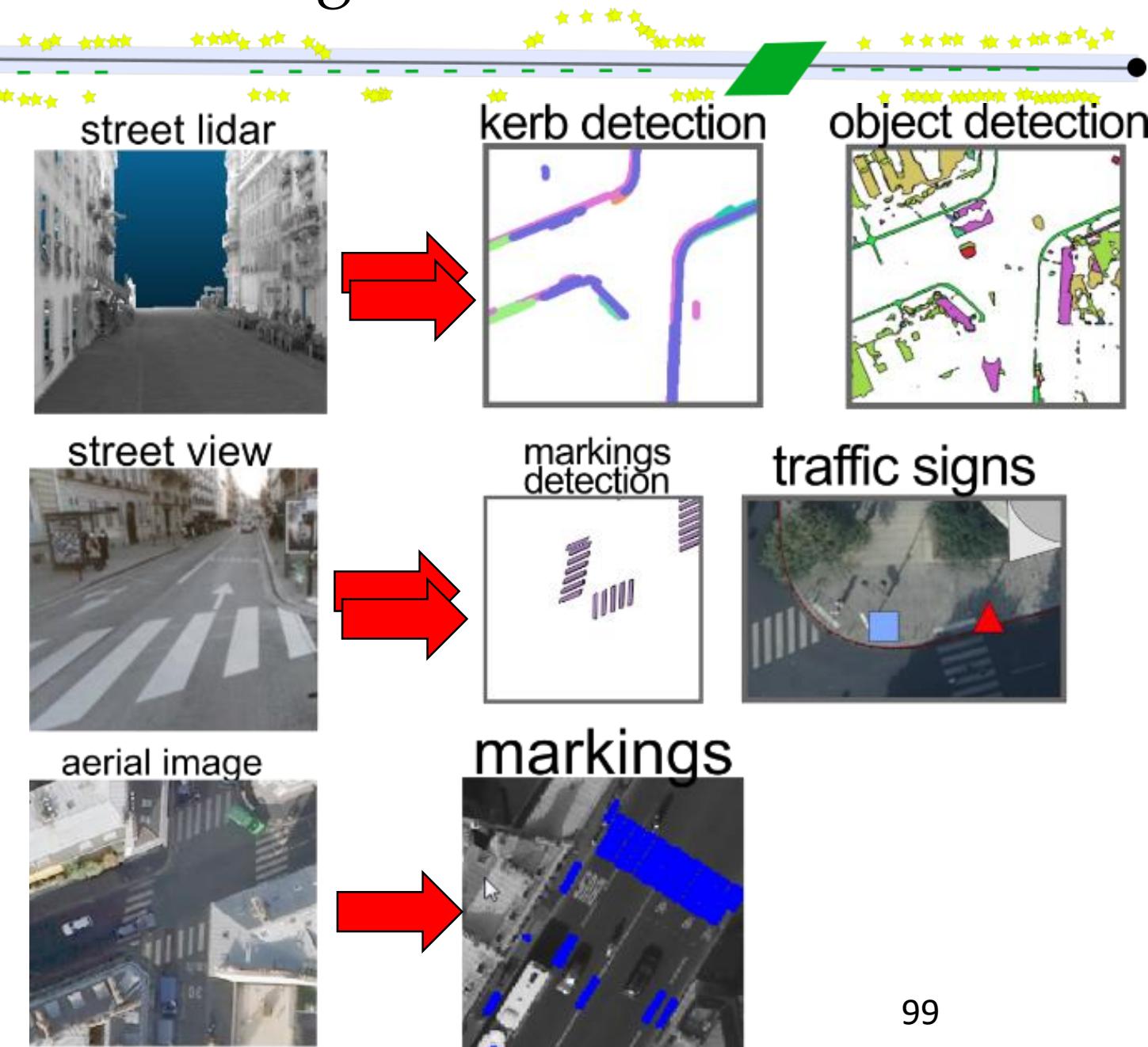
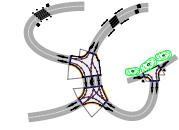
In-base marking detection



Inverse Procedural modelling: observations

- Observation = clues about roadway

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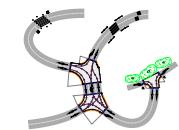
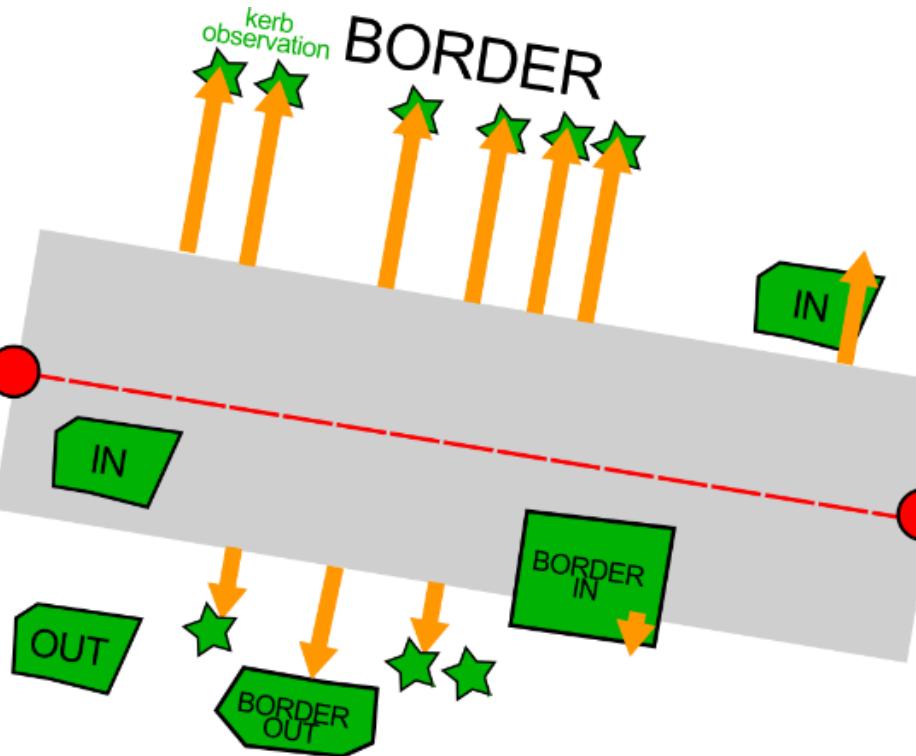
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- Mechanical analogy:
- Each observation push/pull road model



Inverse Procedural modelling: forces

- they may be residuals errors! (observations are unprecise)

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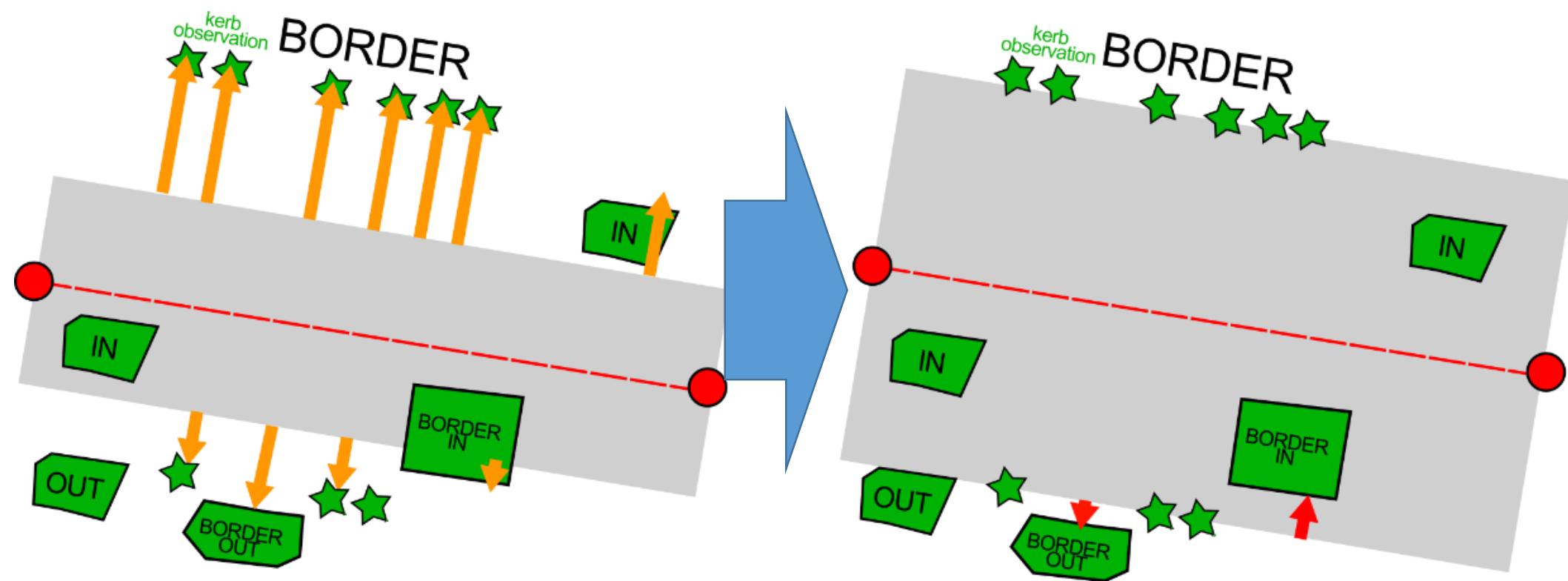
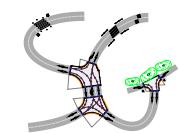
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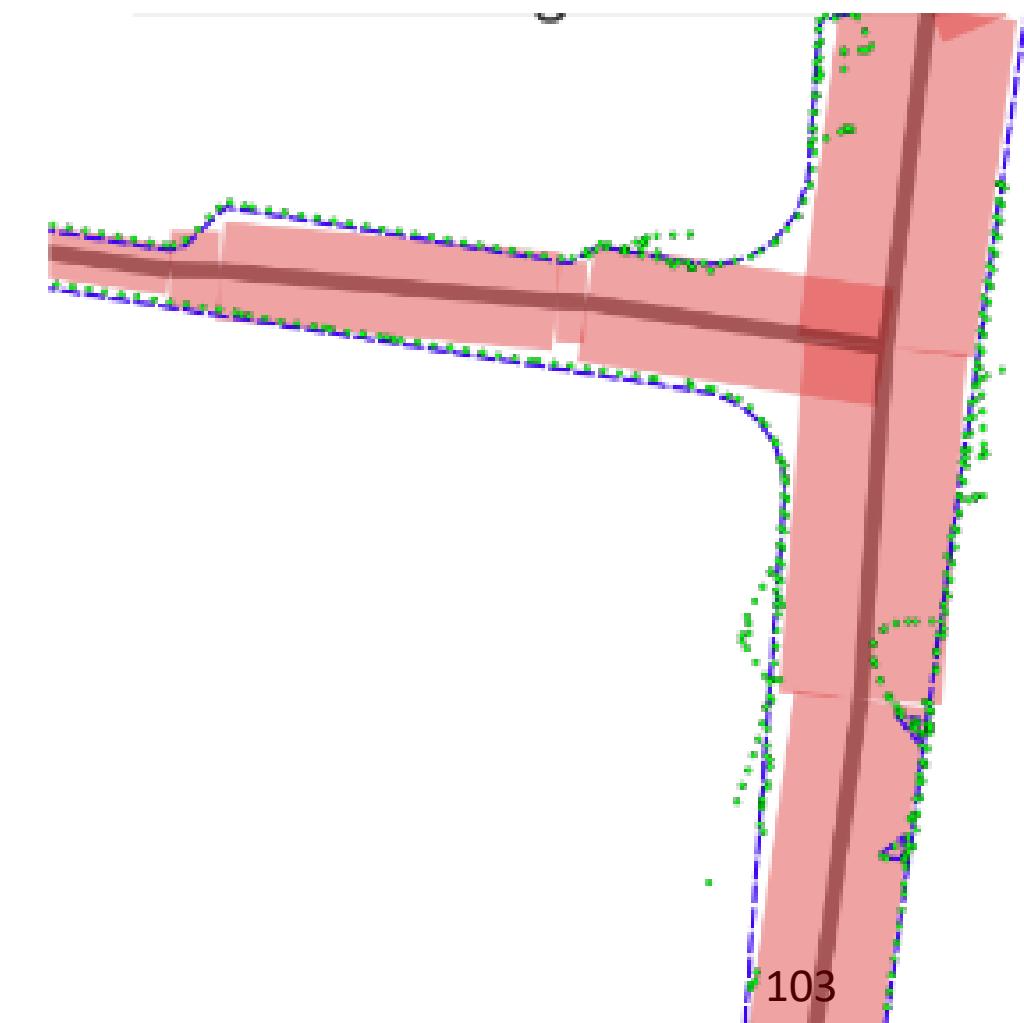
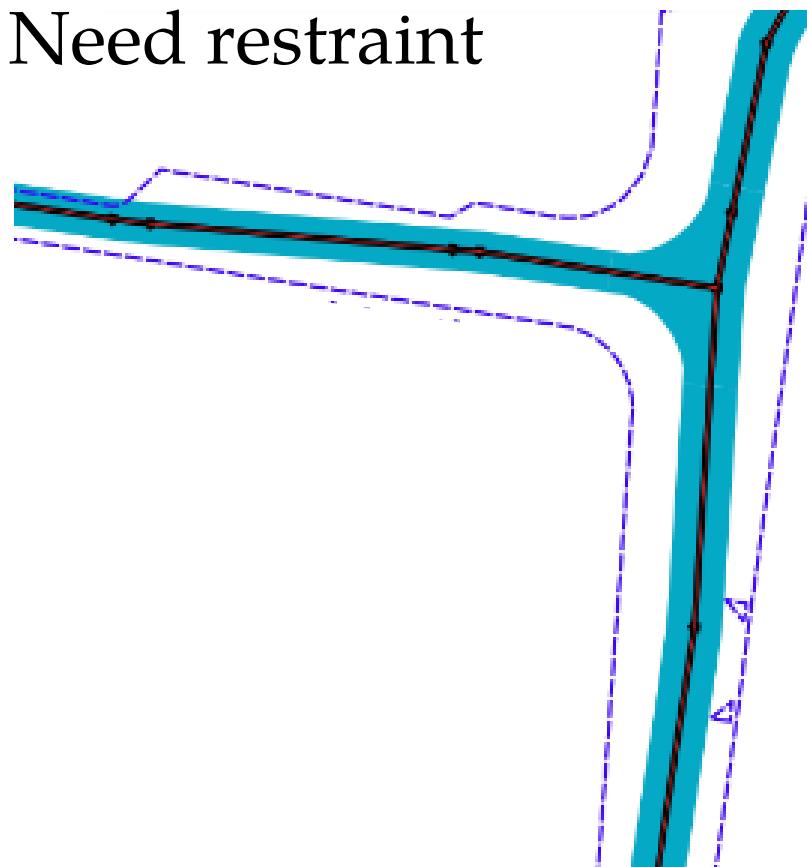
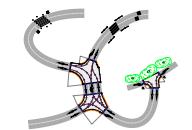
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Inverse Procedural modelling: method

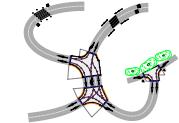
- Real data :
- Some bad observations
- Need restraint

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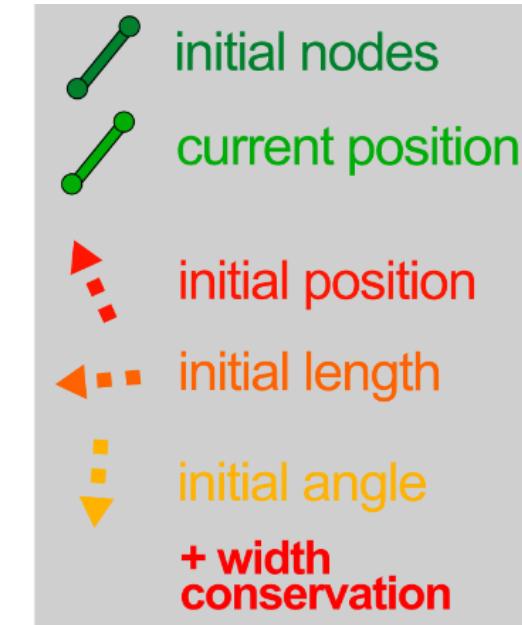
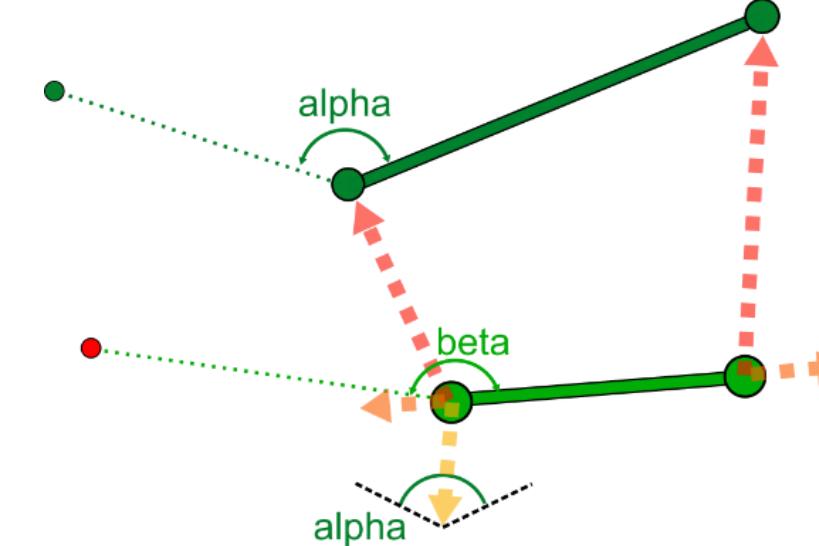


Inverse Procedural modelling: forces

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



Inverse Procedural modelling: experiment

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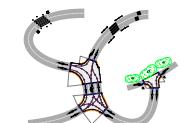
Streets

Interaction

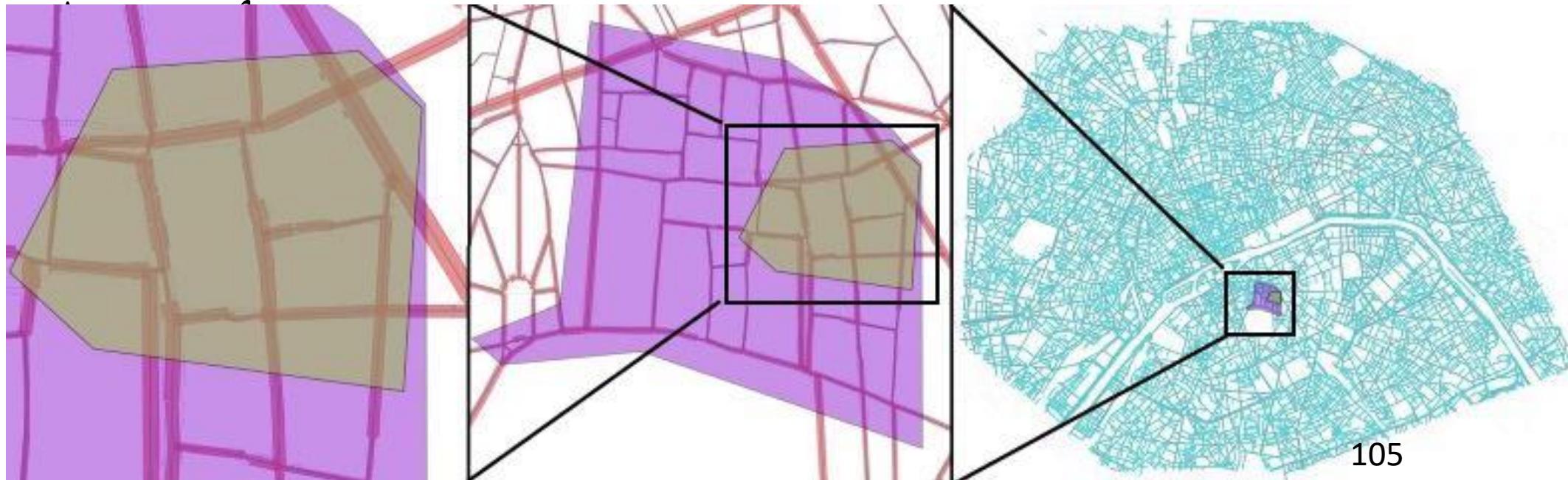
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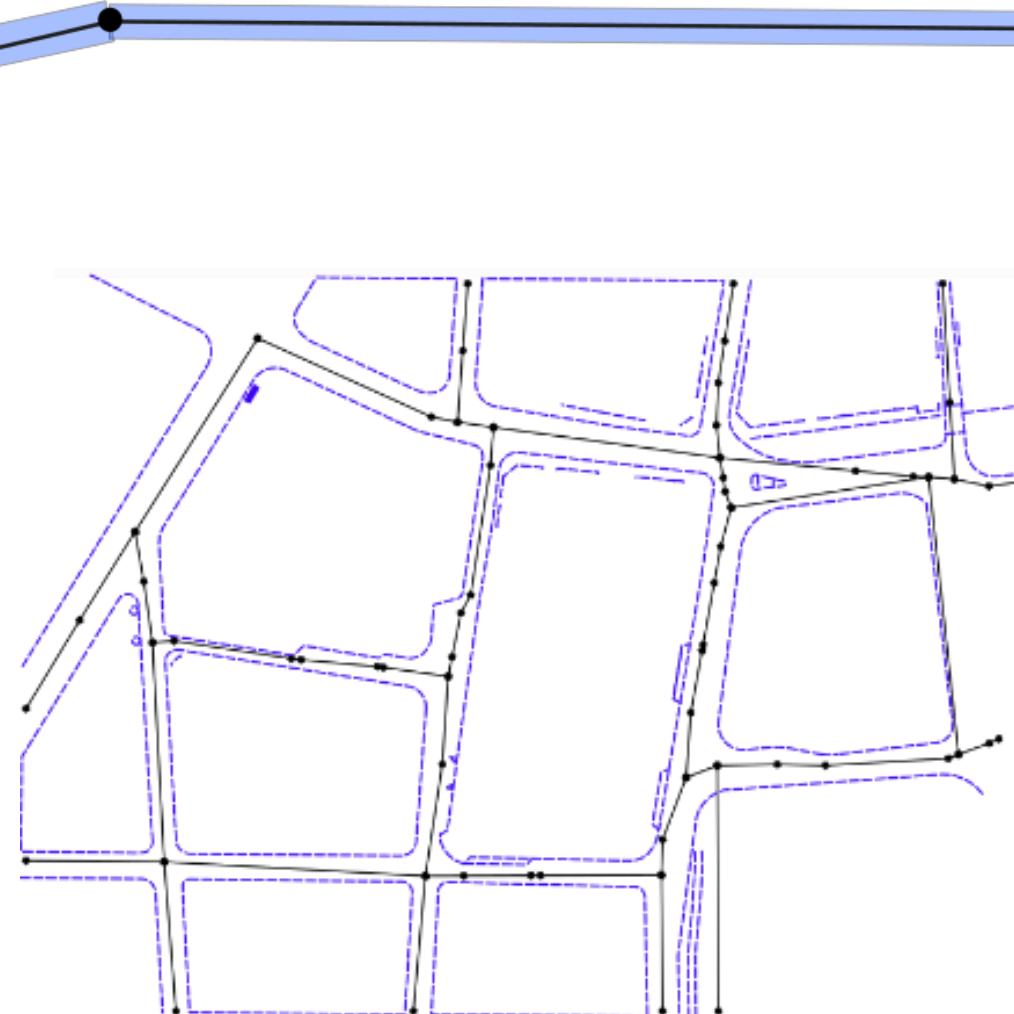


- Optimisation = Non-linear least square
 - → no guarantee to find the **global** optimal solution, robust, very fast
- Open source : [Ceres solver](#)

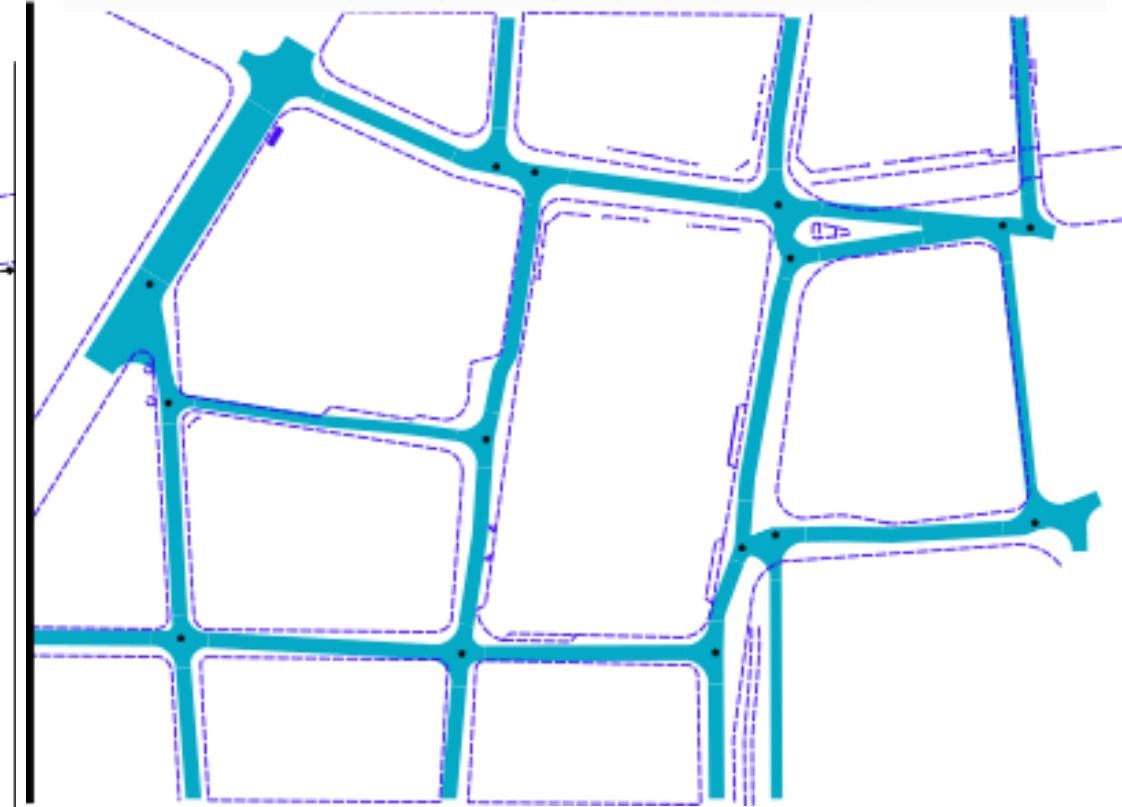


Inverse Procedural modelling : small area

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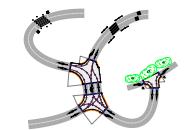


Initial axis and width



Inverse Procedural modelling : small area

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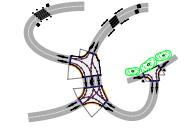


Kerb observation matching



Inverse Procedural modelling : small area

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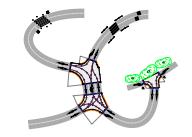


Object observation



Inverse Procedural modelling : small area

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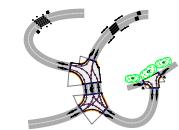


Using Kerb observation



Inverse Procedural modelling : small area

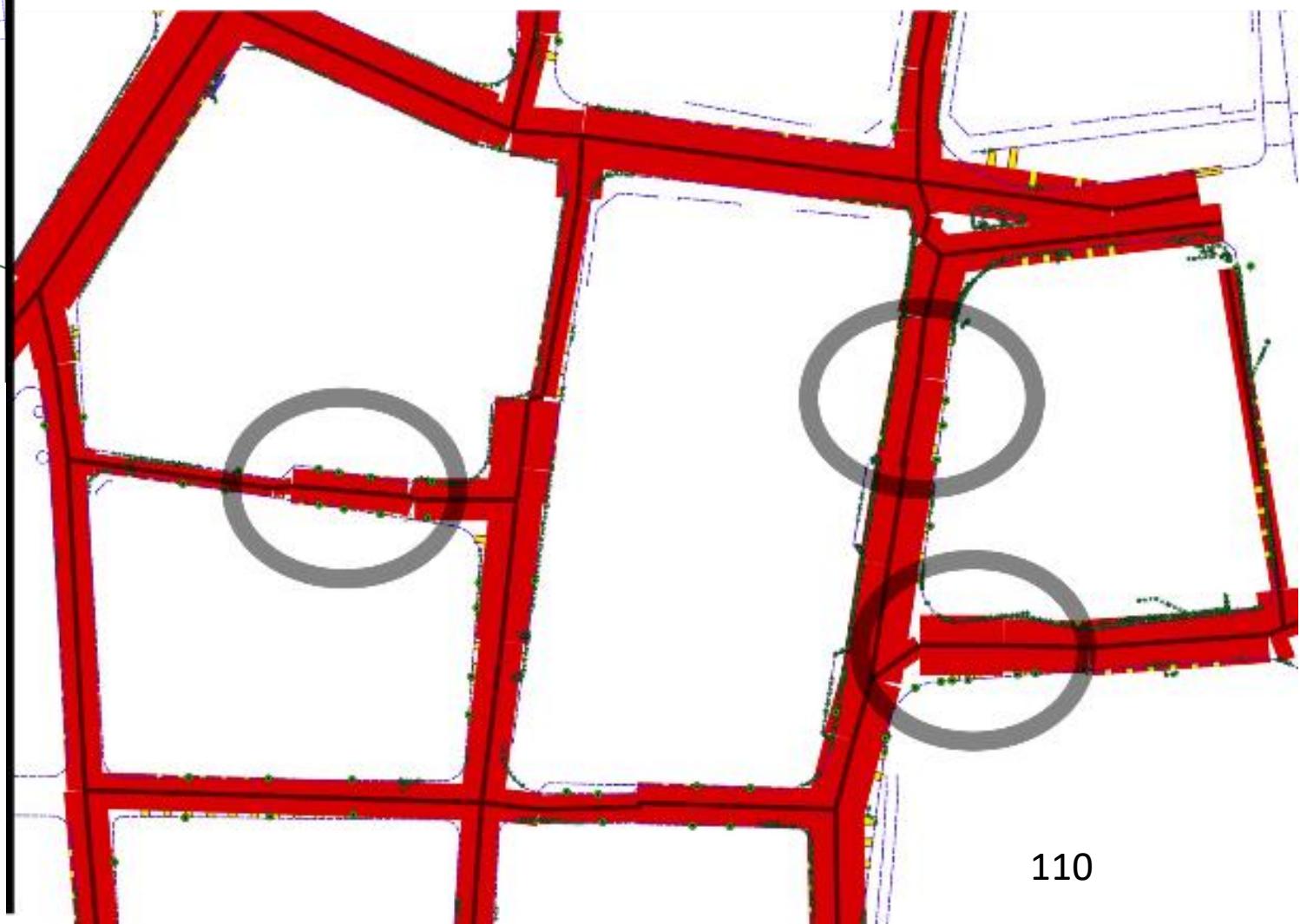
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User defines sidewalk points



Using Kerb and user input



Inverse Procedural modelling : small area

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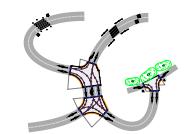
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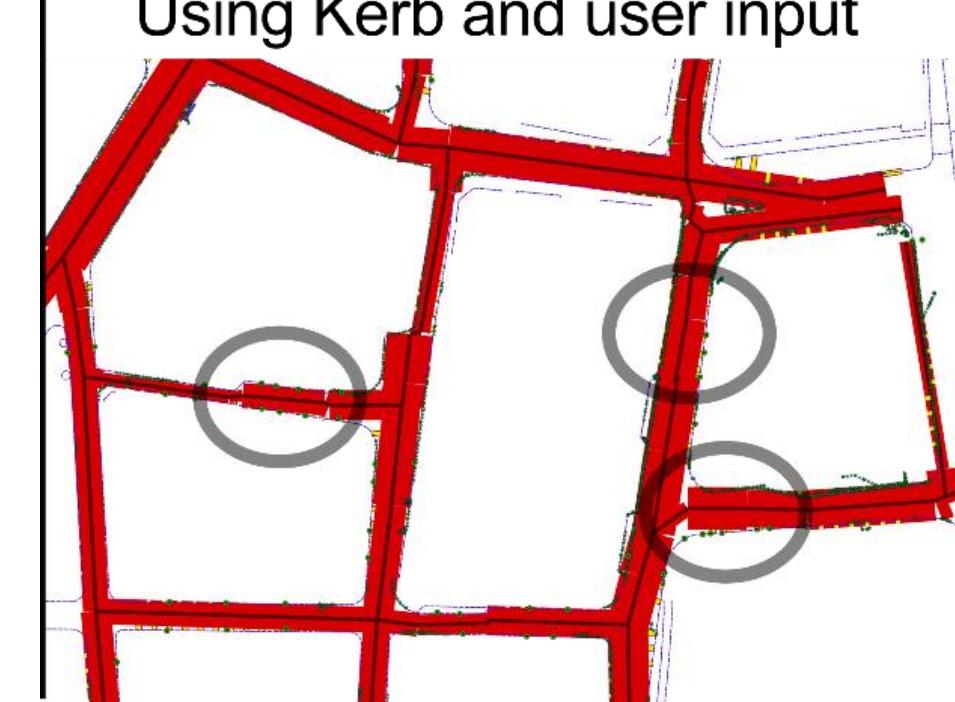
Conclusion



- Using Only kerb observation:
 - Median dist to Open Data Paris sidewalk :
 - **from 1.8m → 0.4m**
(with user input: 0.34m)

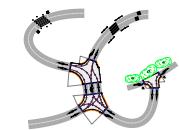
It's much better, robust and fast
(50ms)!

Using Kerb and user input

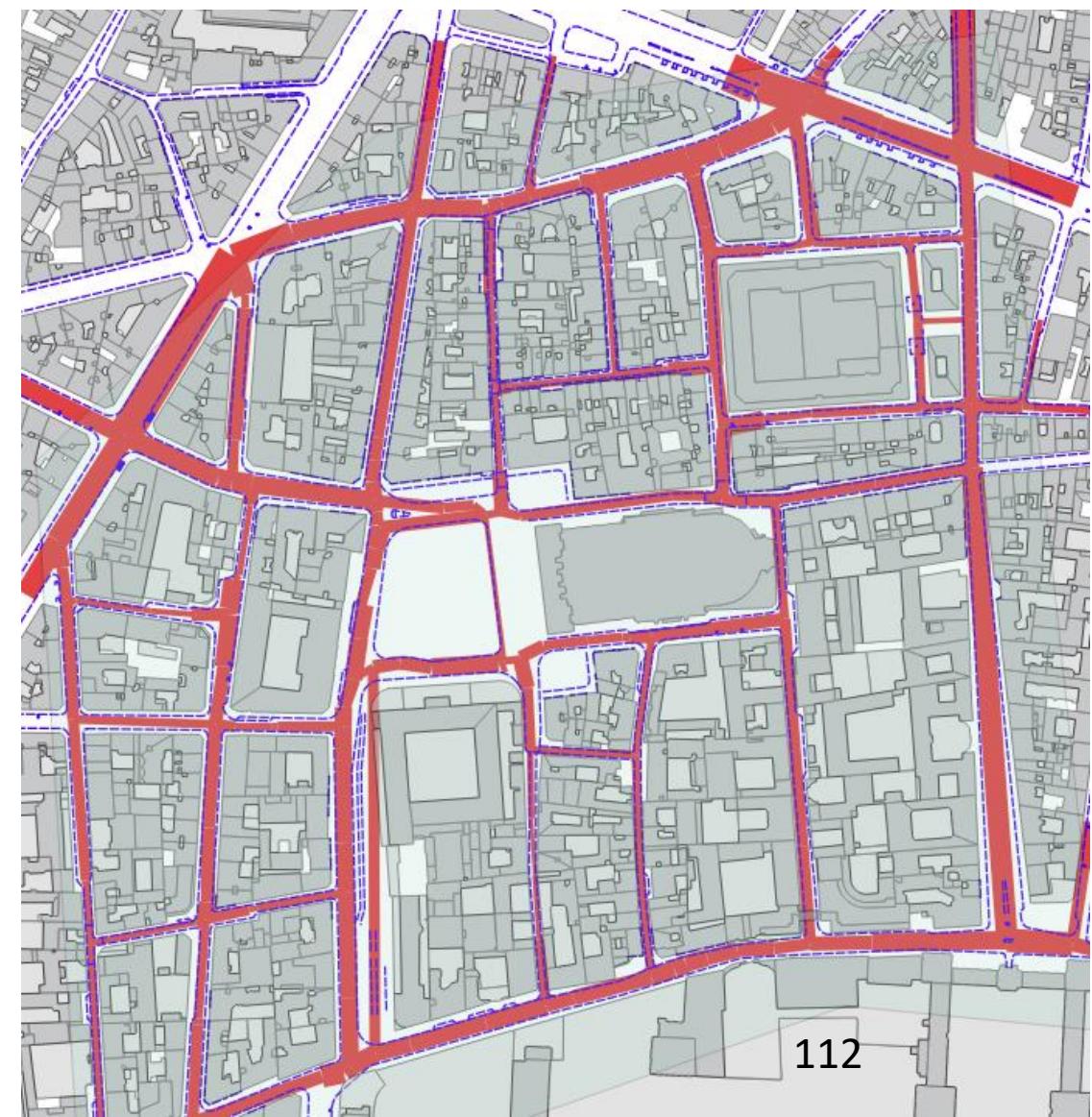


Inverse Procedural modelling : sensing area

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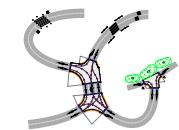


- Whole sensing area:
Results:
Looks ok, but,



Inverse Procedural modelling : sensing area

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- Not enough observations!
 - Yellow circles are proportional to error:
- Median dist :
from 1.5 m → 0.6 m
 - → it's still way better



Inverse Procedural modelling : Paris area

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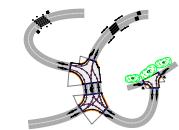
Streets

Interaction

Automation

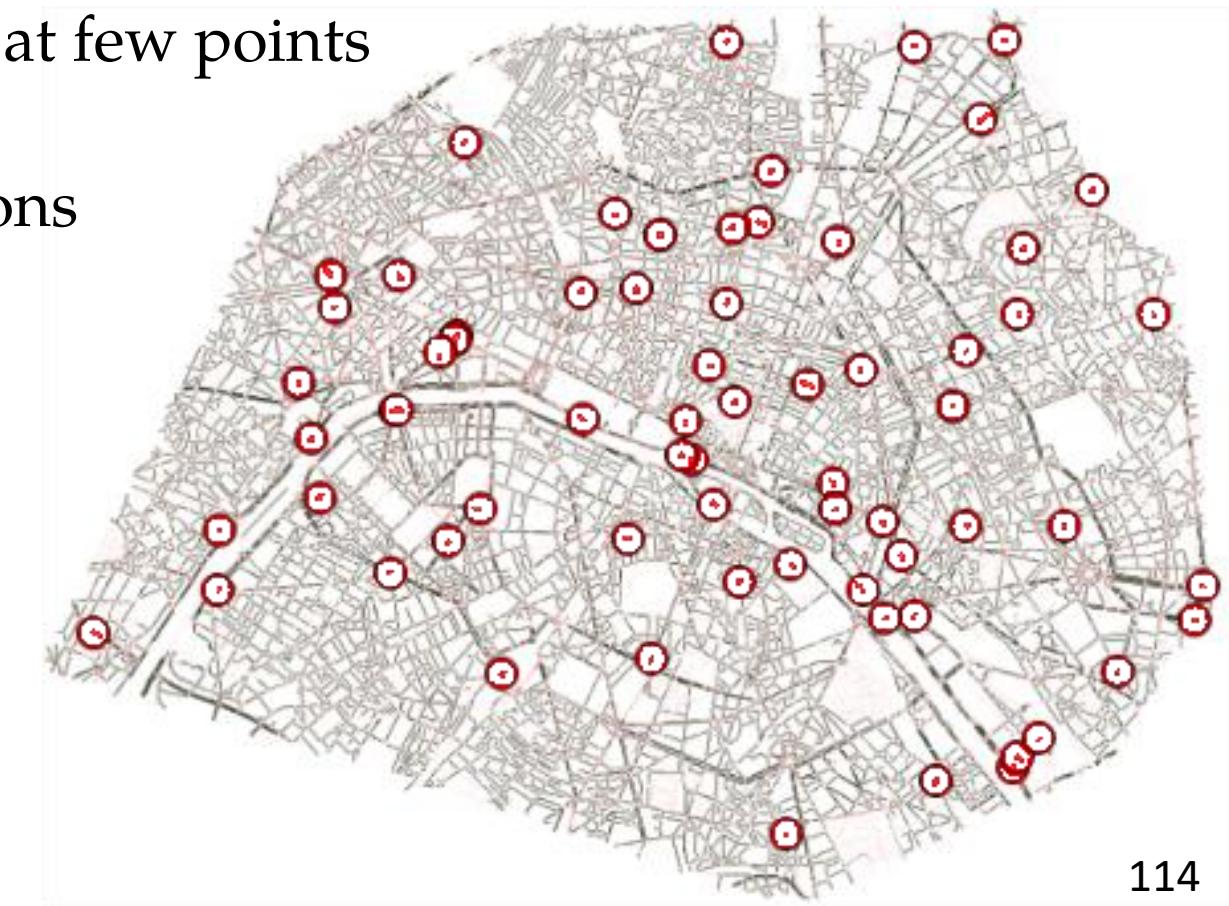
P.C. Server

Conclusion



- Whole Paris with Open Data Paris (Ideal data) : works but :

- topology is broken at few points
 - About 0.5%
 - → manual corrections
-
- from 1.5m → 0.1m



Inverse Procedural modelling: Streetgen on optim

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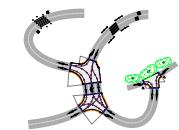
Streets

Interaction

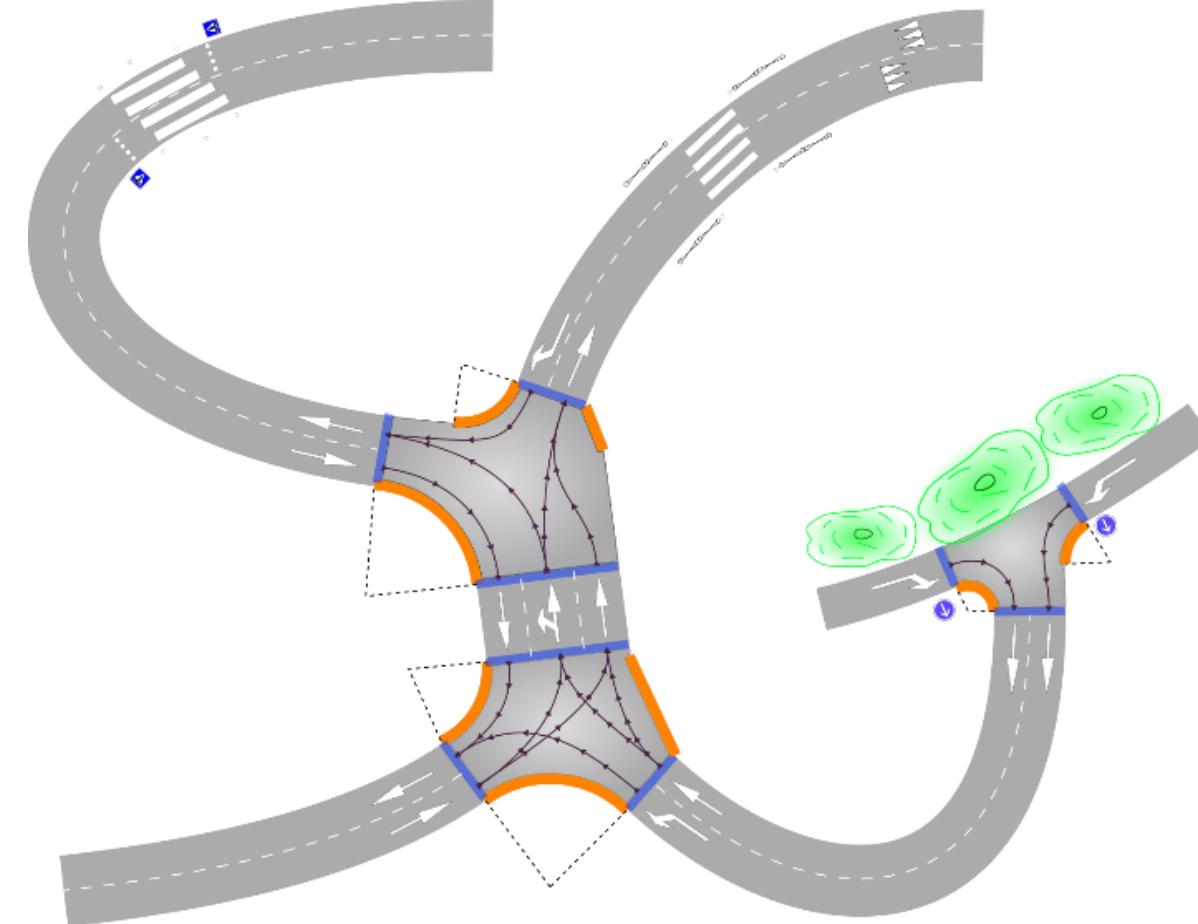
Automation

P.C. Server

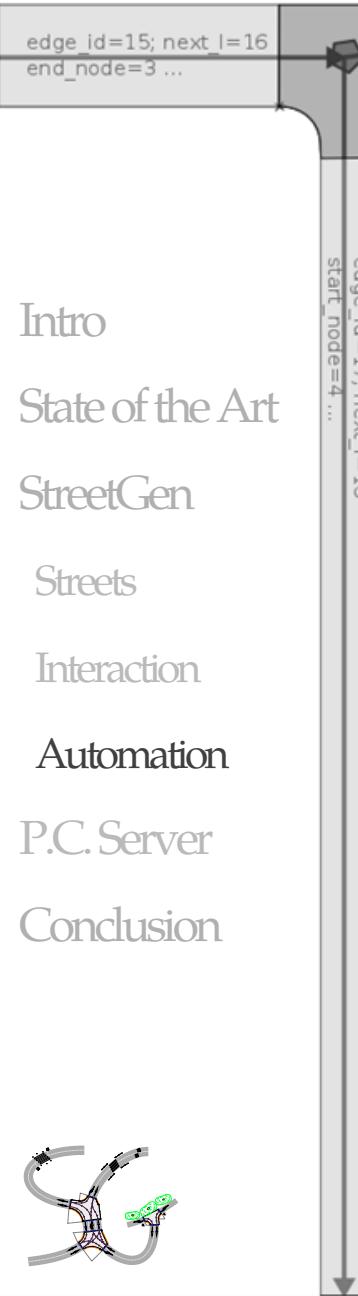
Conclusion



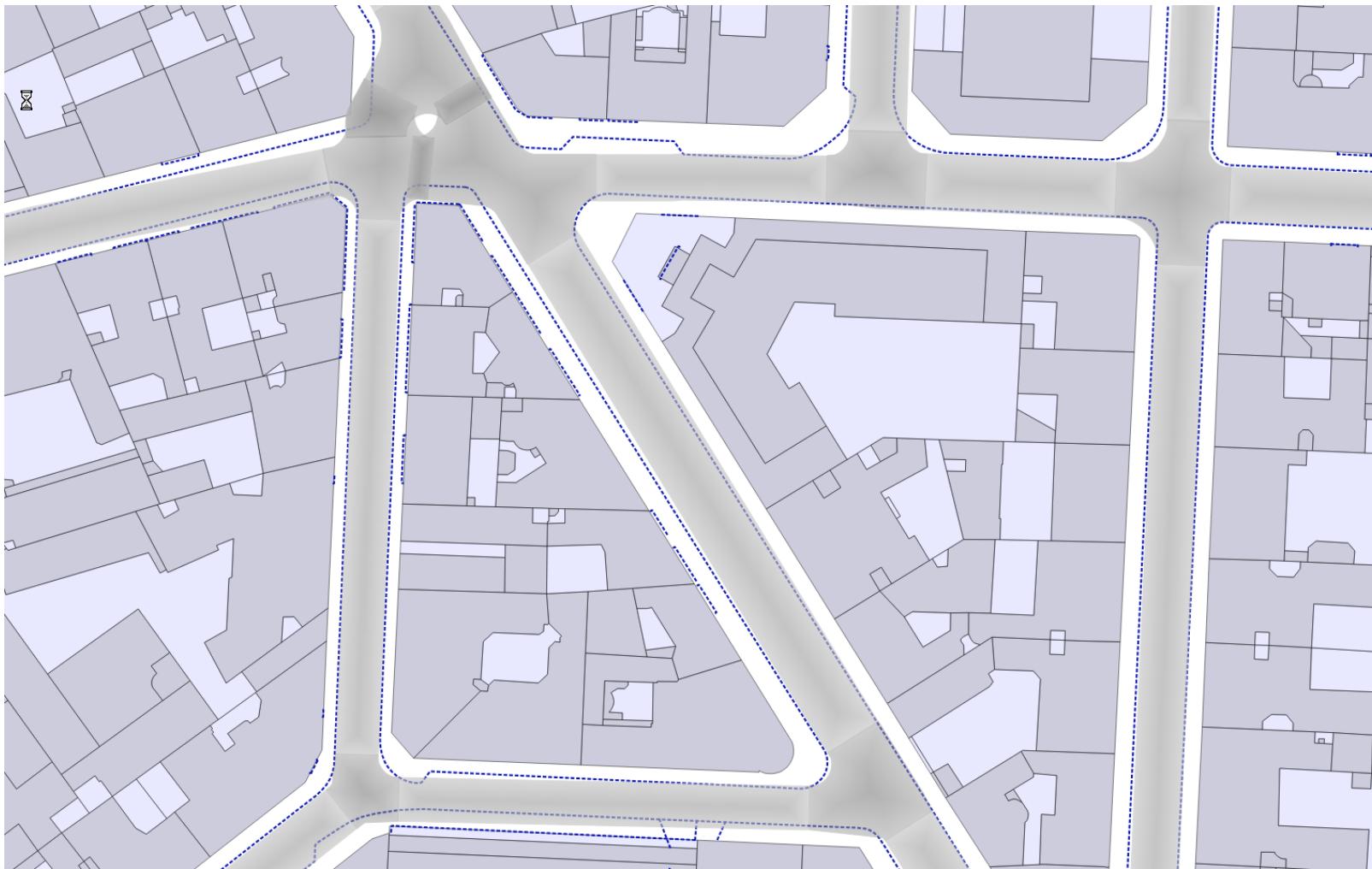
- Once simple road model is optimised,
we can generate streets with StreetGen



Inverse Procedural modelling: Streetgen on optim

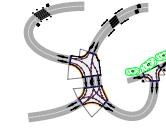


- Streetgen after optimisation

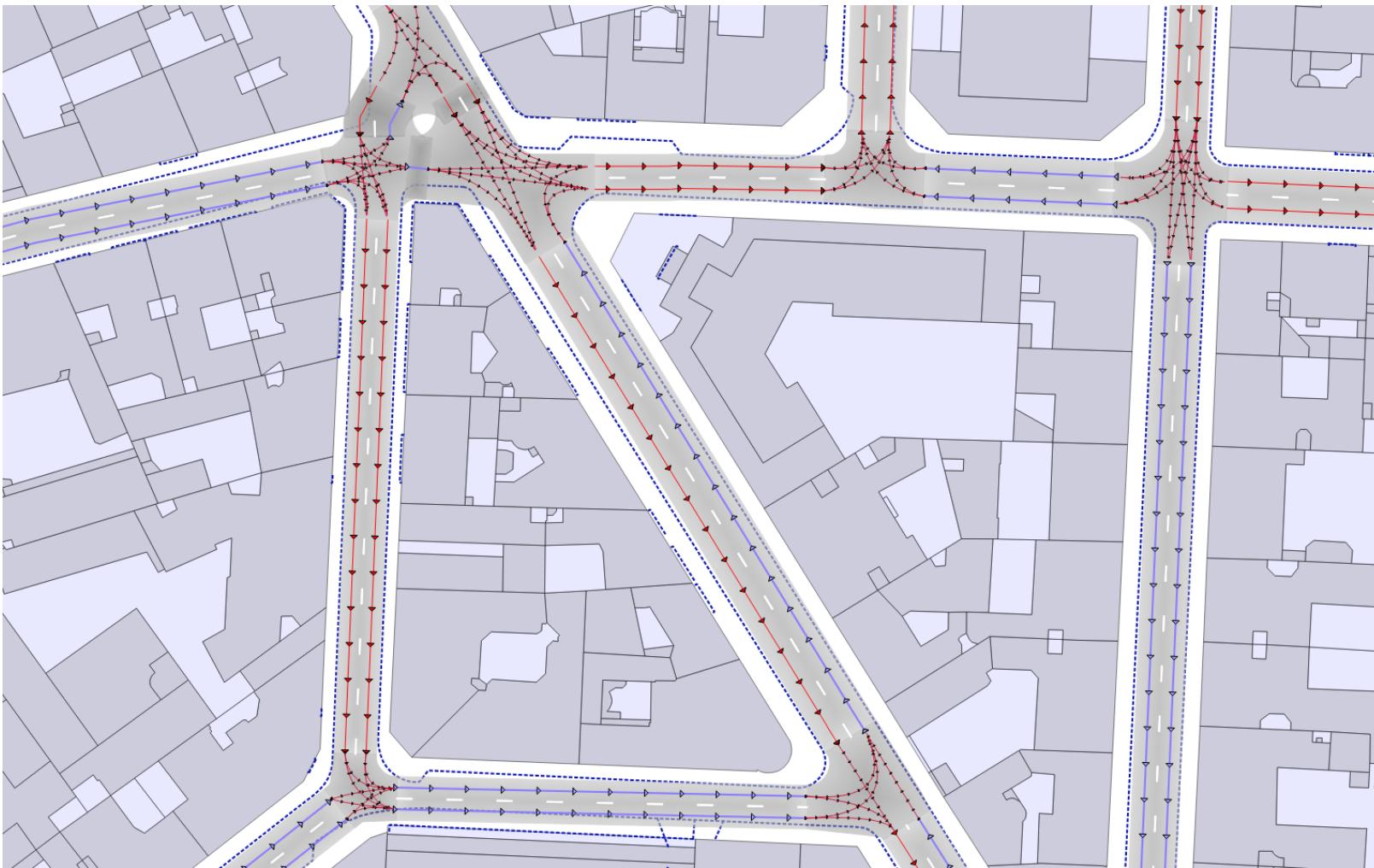


Inverse Procedural modelling: Streetgen on optim

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



Inverse Procedural modelling: error sources

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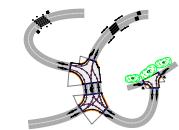
Streets

Interaction

Automation

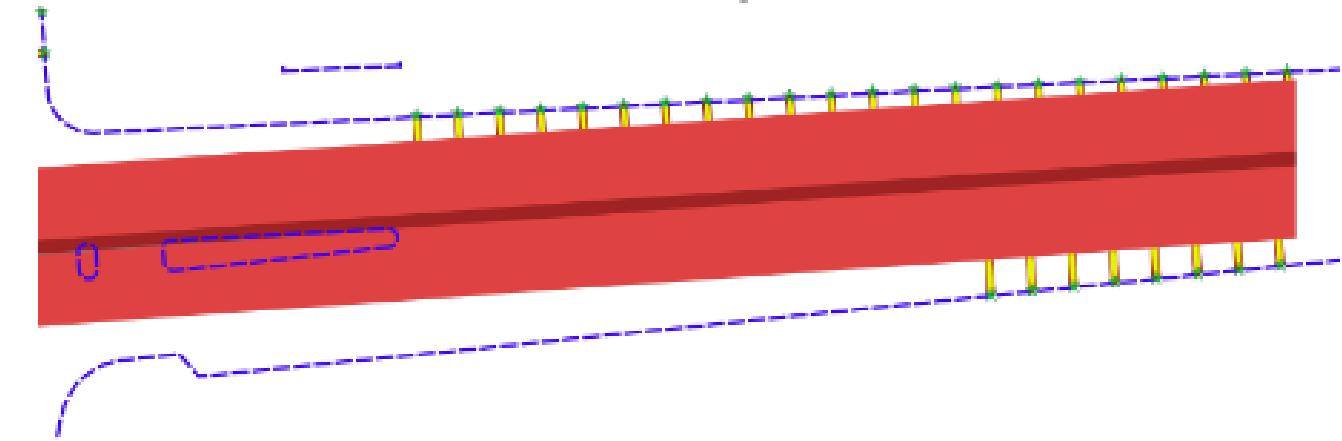
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Conclusion

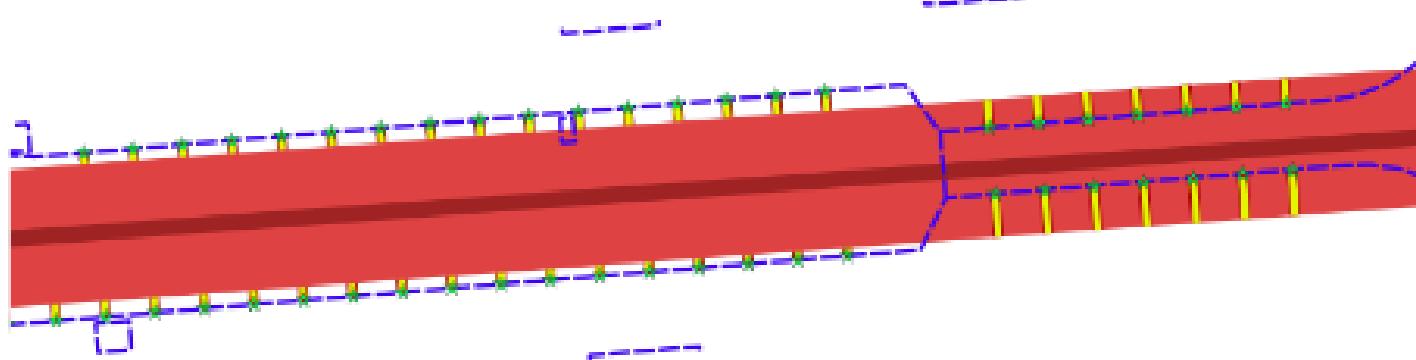


- Residual errors sources

Road model too simple

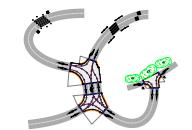


Over constrained (not enough split)



Inverse Procedural modelling: Limitations

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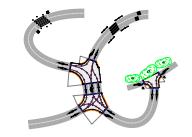


Contributions:

- Inverse procedural road modelling at city scale
- Fast (few roads = interactive) and robust
- Generic observations formulation: can work with any object observation

Inverse Procedural modelling: Limitations

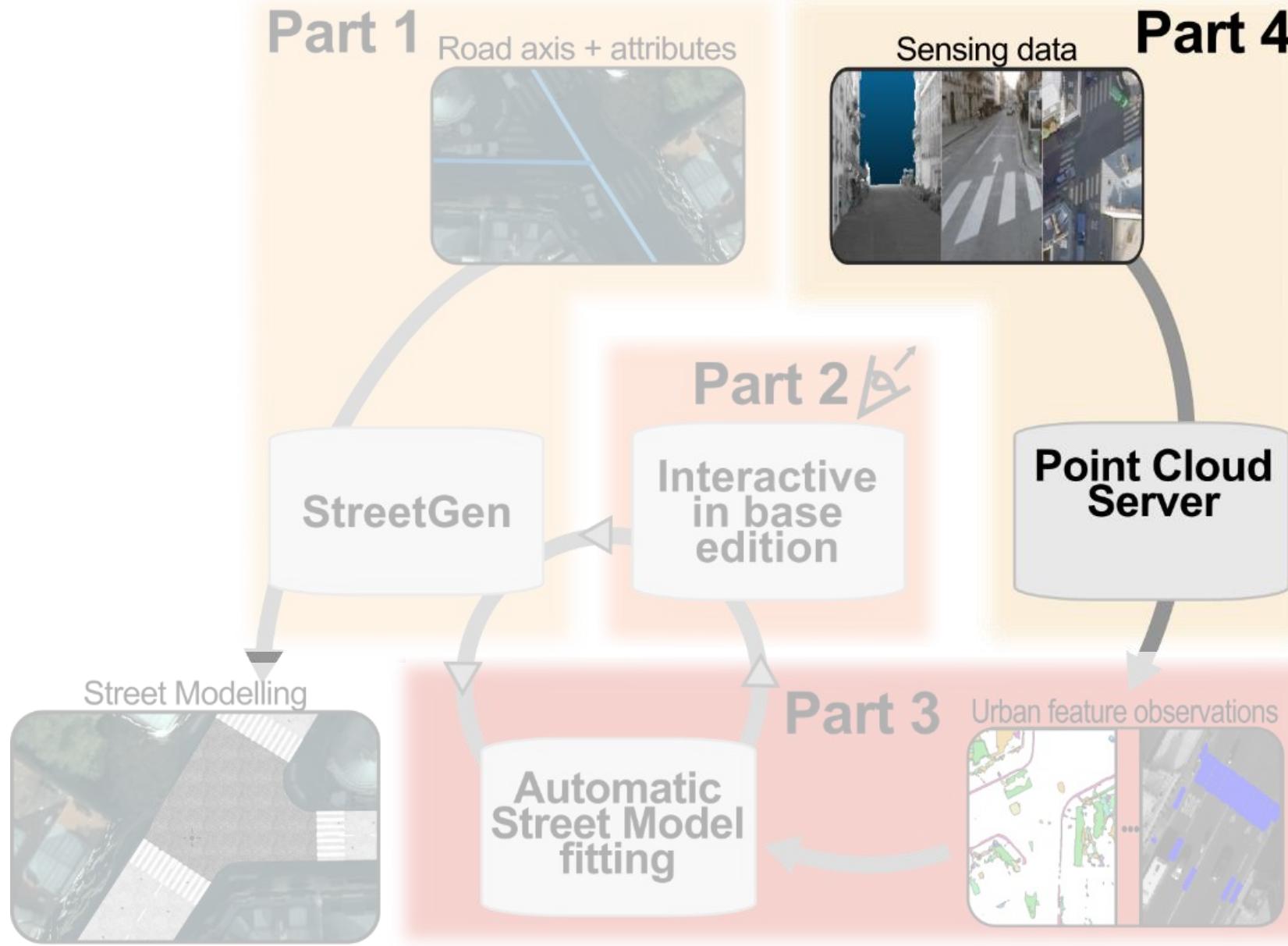
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- **Limitations**

- Only optimising a simplified road model (no radius, lanes, etc.)
- Road model is too simple
- Must choose between trusting initial model and trusting observations
- Lacking regularisation forces for width (propagation)

Abstract



width= 8; lane= 3

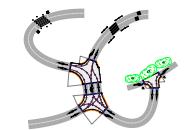
width= 6; lane= 2

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width= 4; lane= 1

Point Cloud Server: Data for observations

**Short introduction to Lidar
Point Cloud Server**



StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Demo Live mobile mapping Lidar (Velodyne)

Intro

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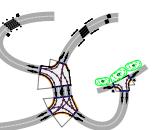
Streets

Interaction

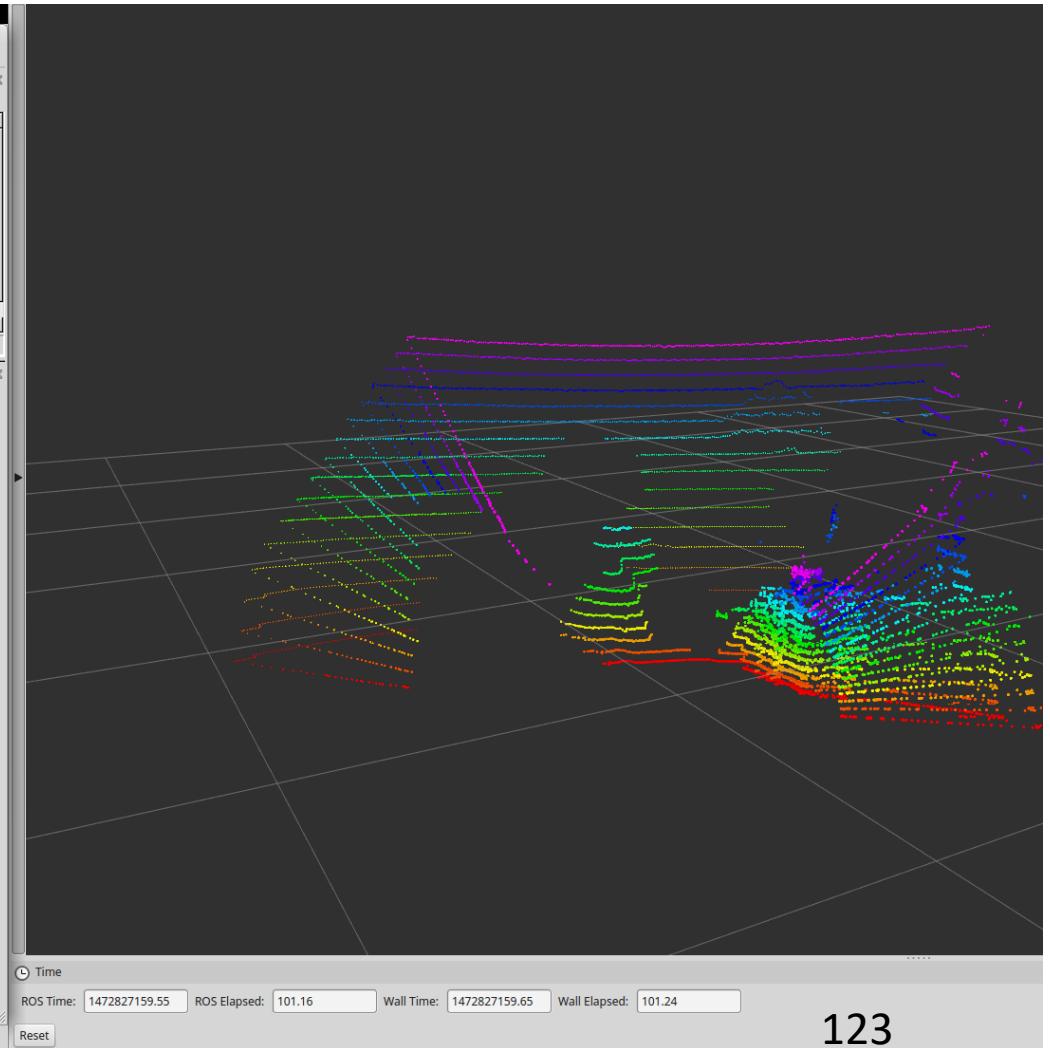
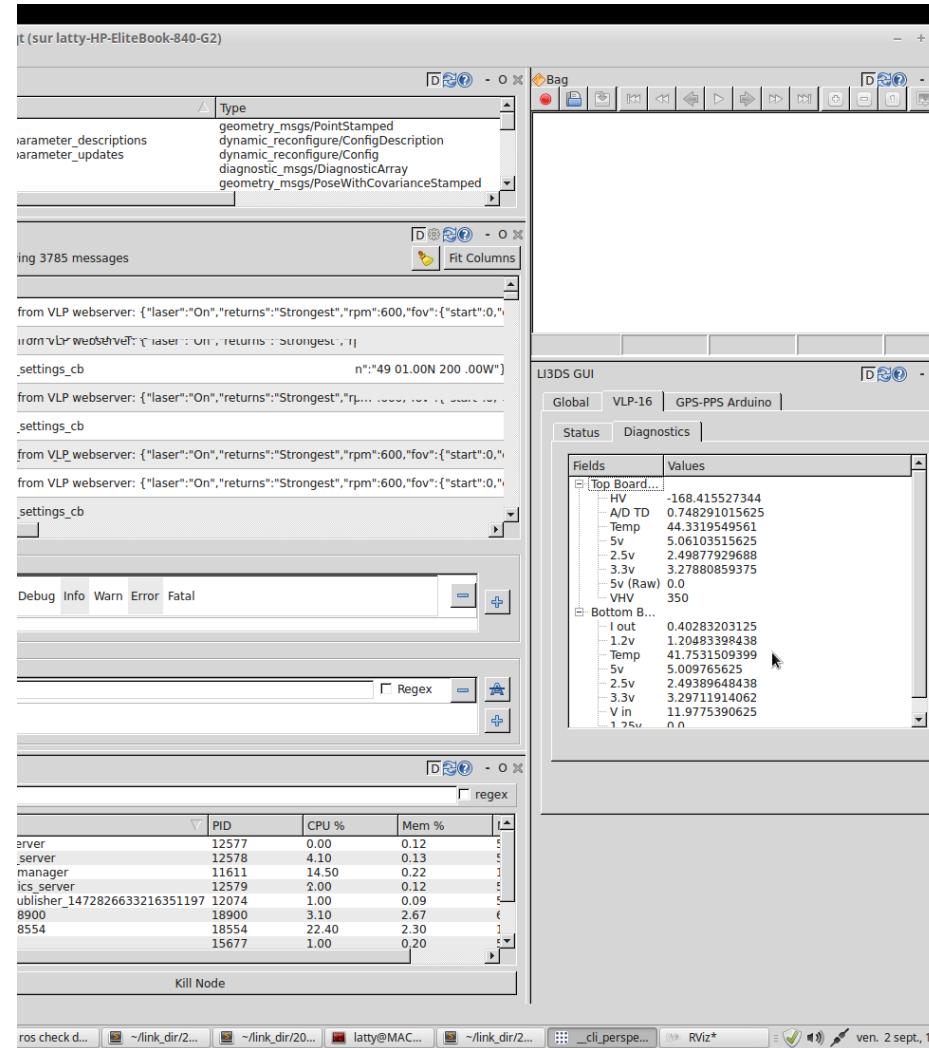
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width= 4; lane= 1



width= 8; lane= 3

width= 6; lane= 2

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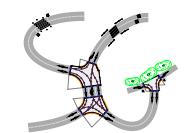
Conclusion

width= 4; lane= 1

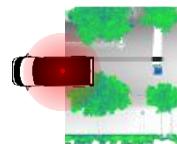
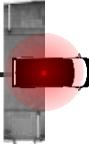
Data for observations: Point Cloud Server

Short introduction to Lidar

Point Cloud Server



Point Cloud Server



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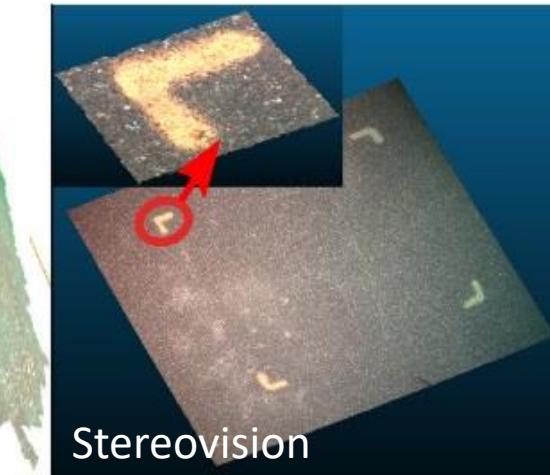
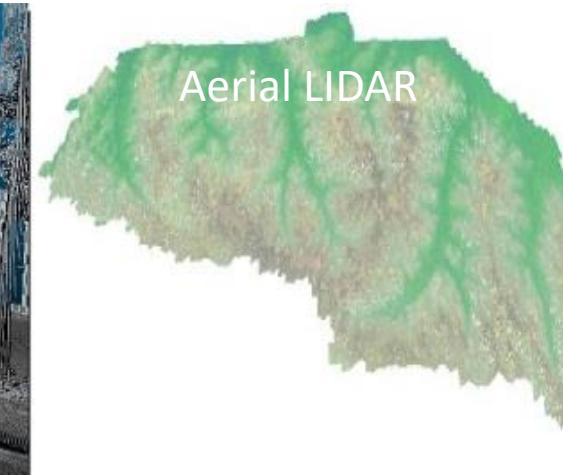
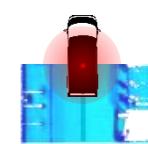
Streets

Interaction

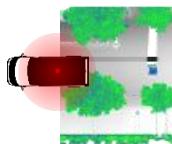
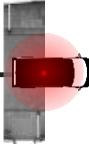
Automation

P.C. Server

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Point Cloud Server: Problems



- Problem:

- Massive data → need

- Sharing
 - Filtering
 - Efficient I/O
 - Compression

- Point cloud != only processing

- We need a service!

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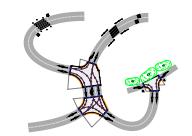
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Point Cloud Server: State of the art

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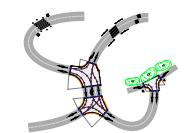
Streets

Interaction

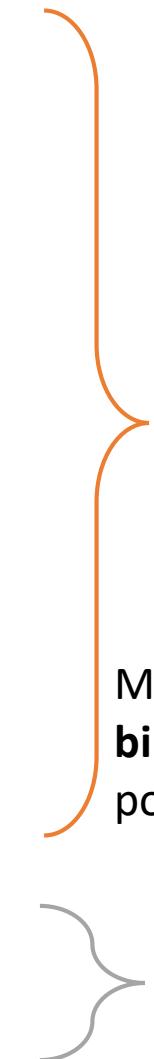
Automation

P.C. Server

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



Otepka et al., 2013

Rieg et al., 2014

van Oosterom et al., 2015

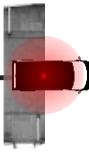
Managing
billions of nD-
points : difficult !

≠

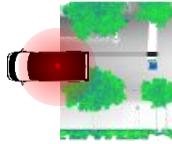
Managing **million**s
of groups of points: e

Grey

Todo : simplify, images



Point Cloud Server: Method



- Idea:

PCS = a ... server !

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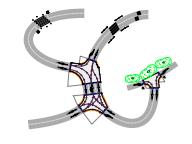
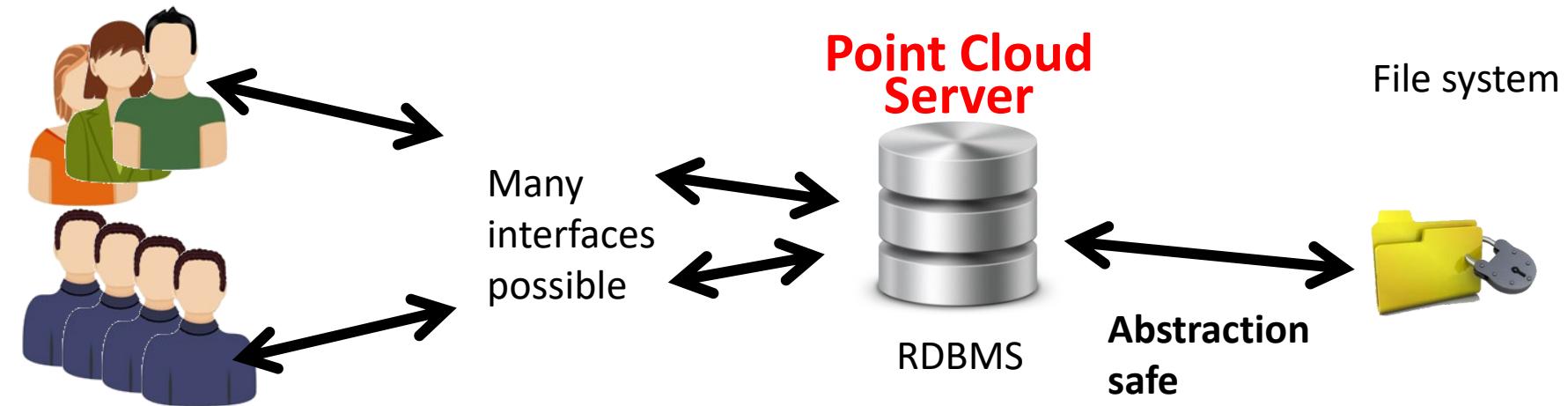
Streets

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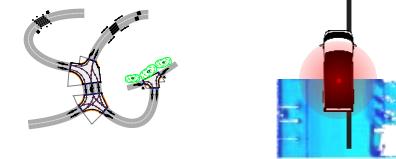
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Point Cloud Server: Method

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• Workflow

LOAD

- server reads
- client sends

EXPORT

- server sends
- client reads
- point streaming
- point cloud files as a service

RDBMS

METADATA

- secure and relational
- extended (trajectory, sources)
- generalisation/vis.

PROCESSING

- in-base easy prototyping
- classic out-of-base workflow

STORE

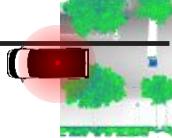
- groups of points
- compressed

FILTER

- indexes
- can use other GIS data

width=6; lane=2

width=8; lane=3



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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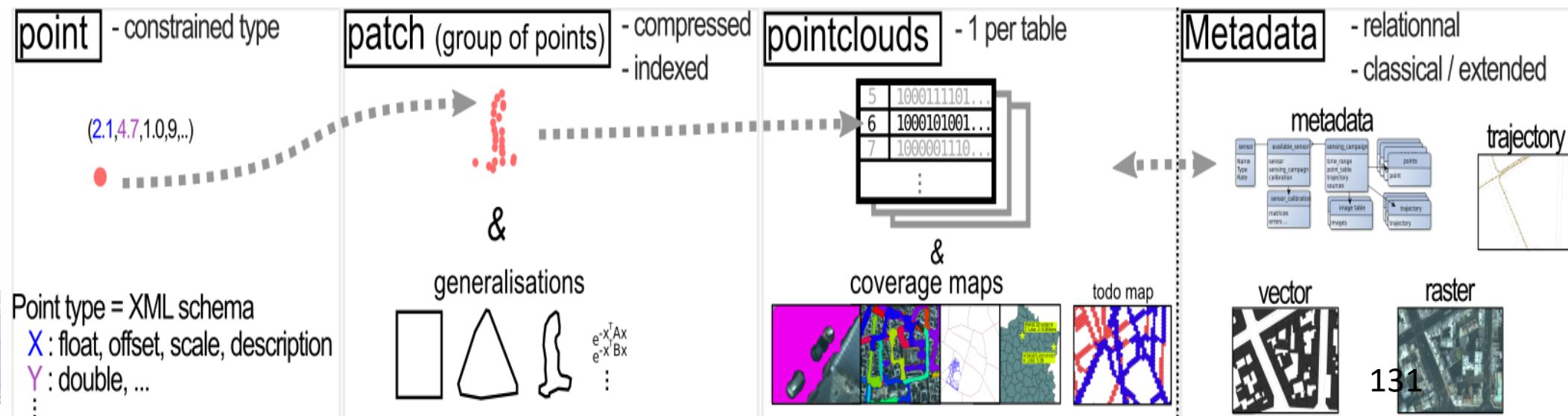
Automation

P.C. Server

Conclusion

- Paris loading speed: 75k pts/s writing : 200k pts/s
 - Not far from actual sensing speed
 - Could be faster ([Vanoosterom2015](#))

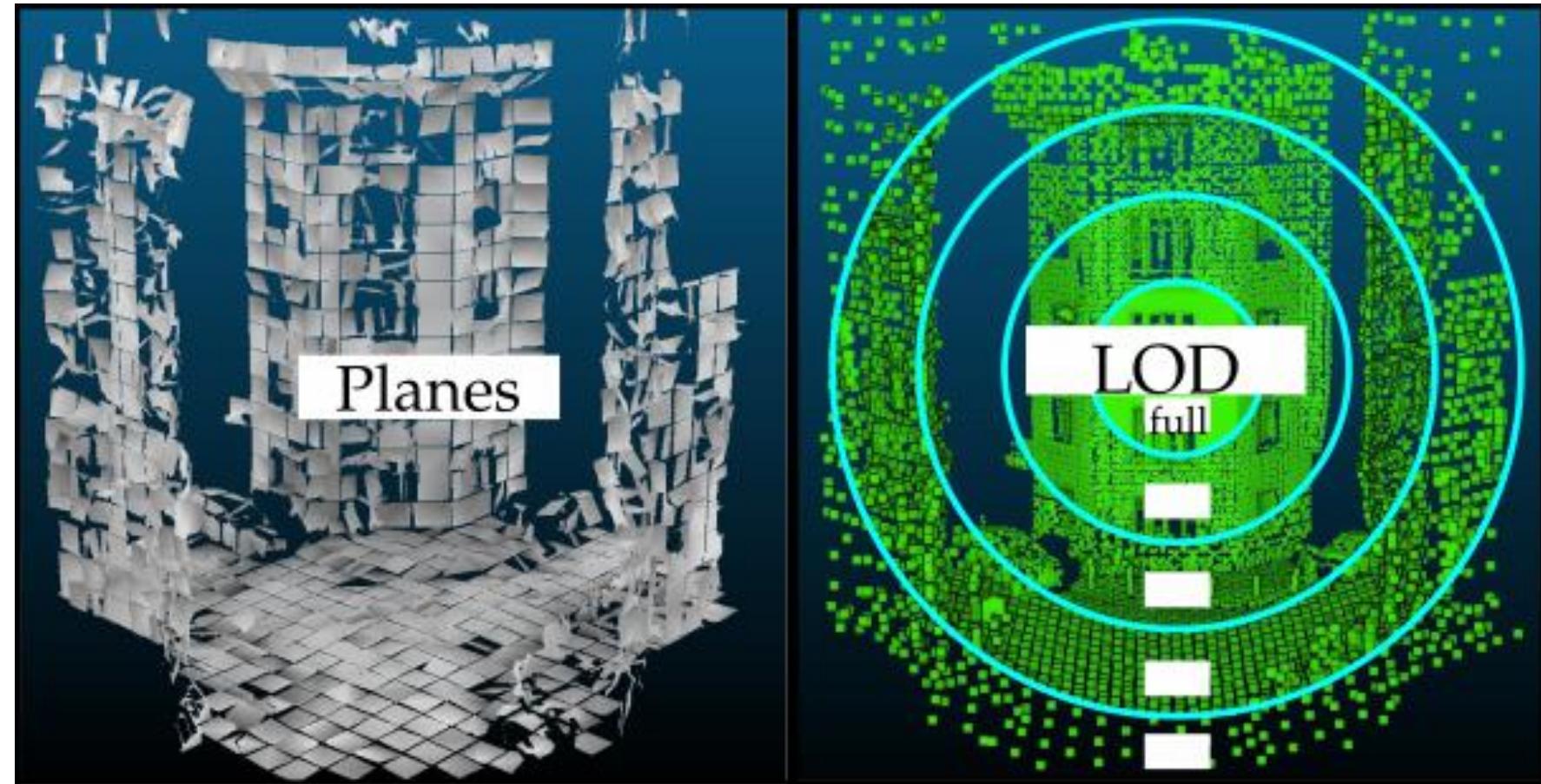
- We load point clouds, but how are they stored?



Point Cloud Server: generalisation



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



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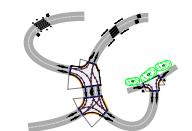
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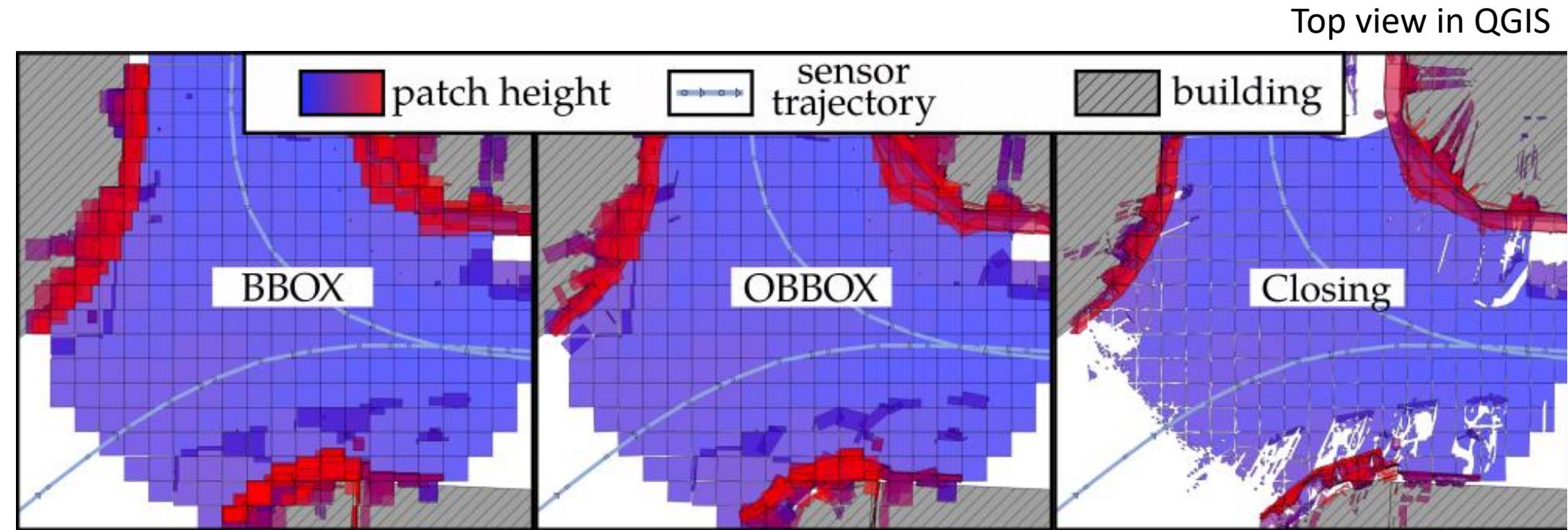


Point Cloud Server: generalisation



- Other generalisation

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



Point Cloud Server: processing



- More generalisation

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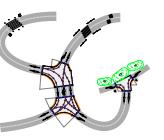
Streets

Interaction

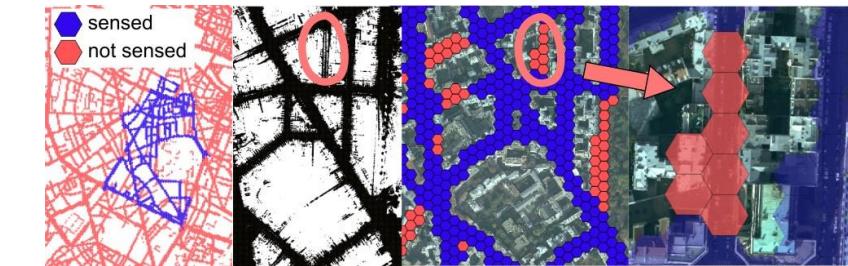
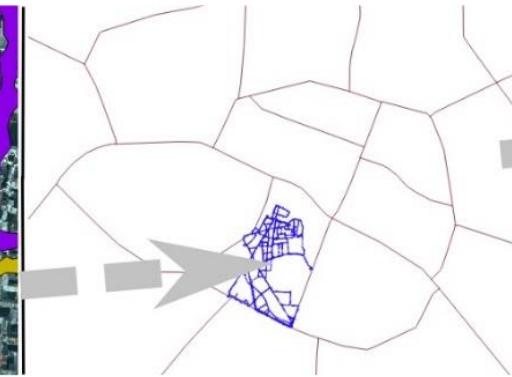
Automation

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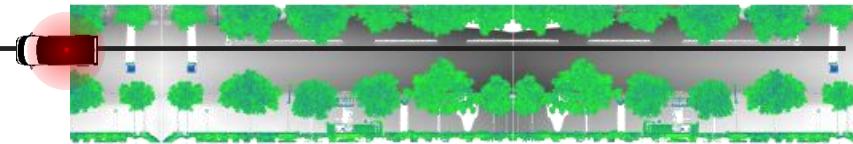
width=4; lane=1



Point Cloud Server: filtering



width=6; lane=2



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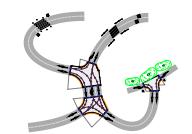
Streets

Interaction

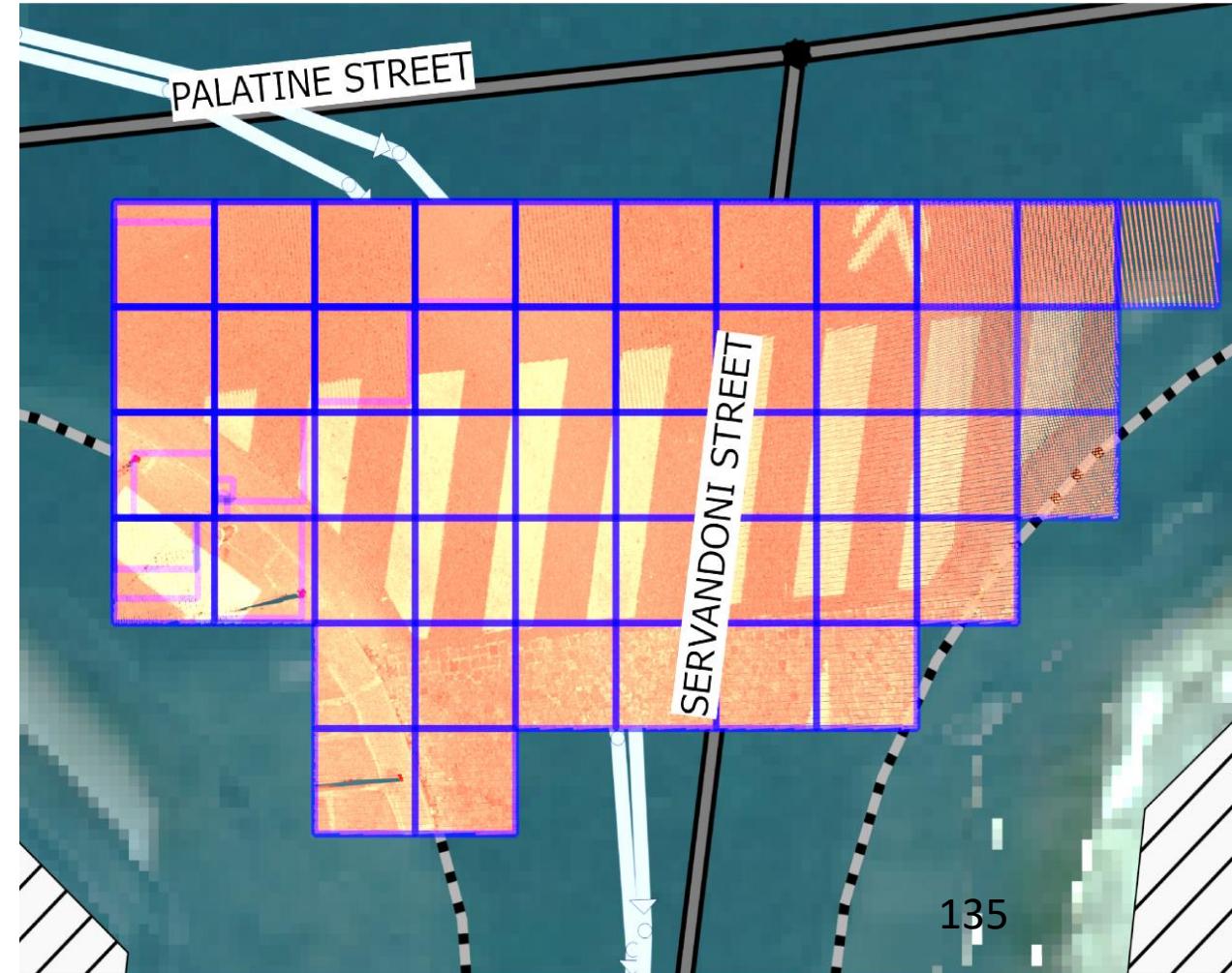
Automation

P.C. Server

Conclusion



- With so much data:
 - Essential to access only a part of it : example
- Patches that are
 - far from buildings
 - close to the intersection of these 2 streets
 - aerial view color ≈ pedestrian crossing
 - close trajectory
 - with high point density



Point Cloud Server: filtering



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

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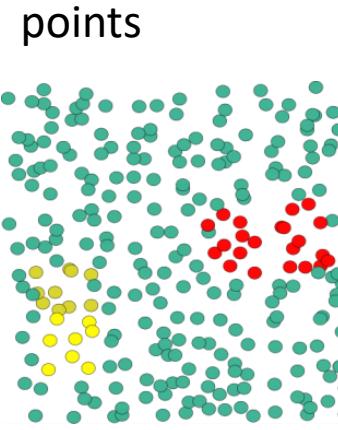
Streets

Interaction

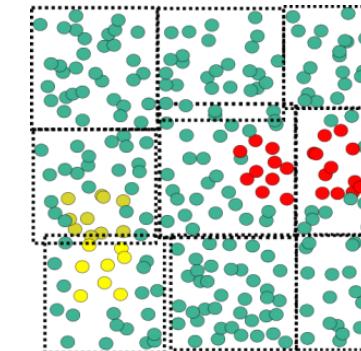
Automation

P.C. Server

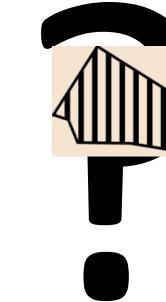
Conclusion



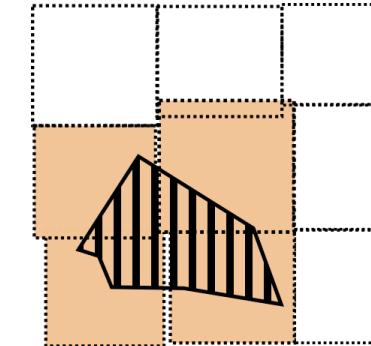
Points in patch



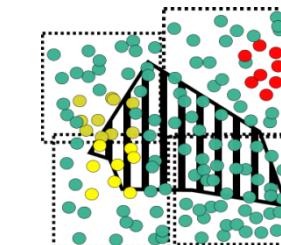
Which points
are inside the
polygon?



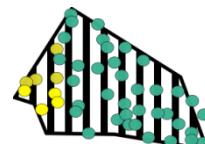
Which **patchs**
are inside the
polygon?



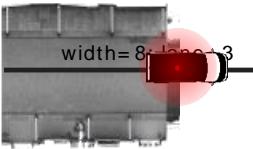
Get points in
these patches



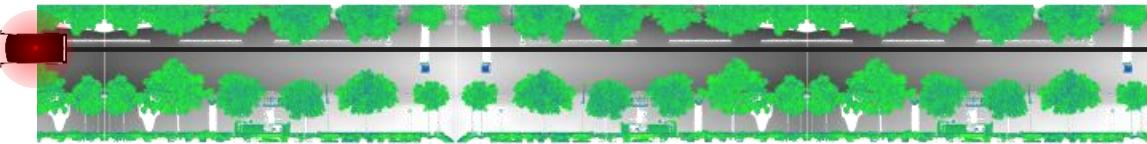
Which
points are
inside the
polygon?



Point Cloud Server: processing



width=6; lane=2



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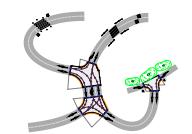
Streets

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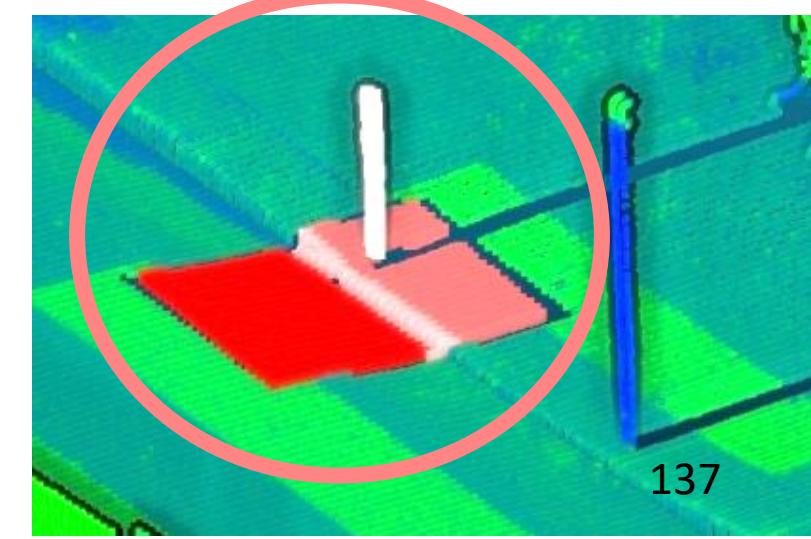
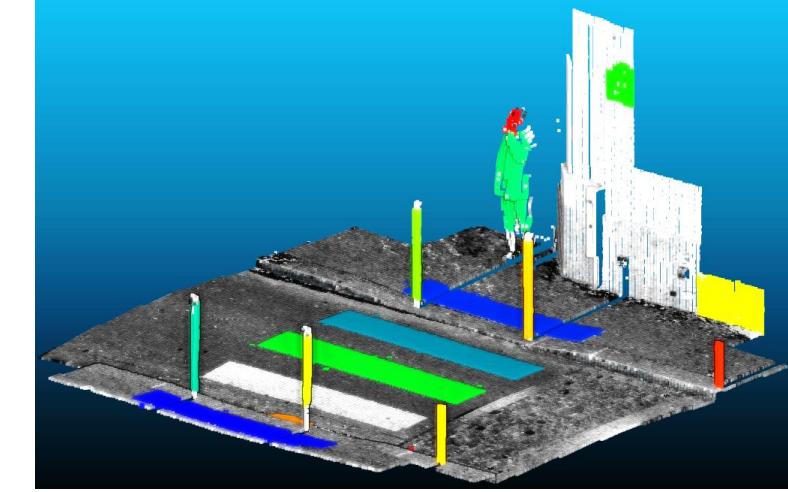
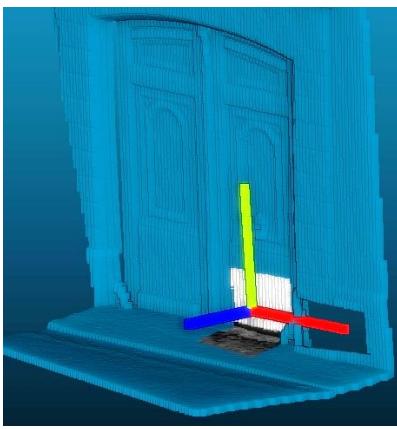
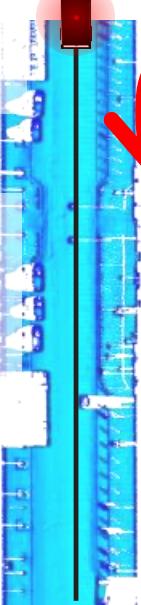


- Postgresql: easy to add in-base processing

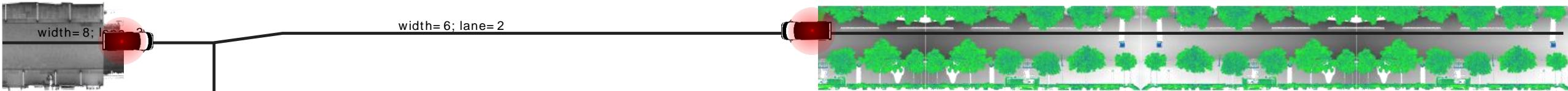
- C/Cpp → for performance
- R/Python → for fast prototyping

- Example :

- Verticality descriptor
- Unsupervised clustering
- Plane & cylinder detection

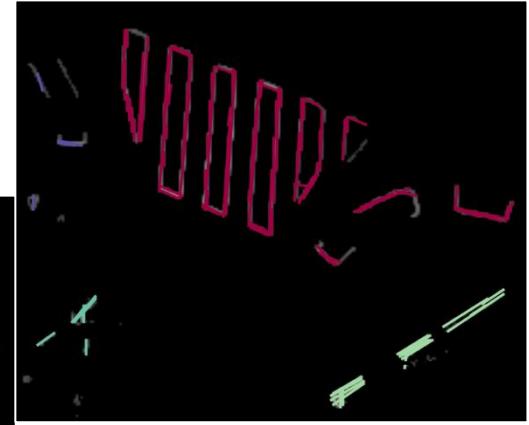
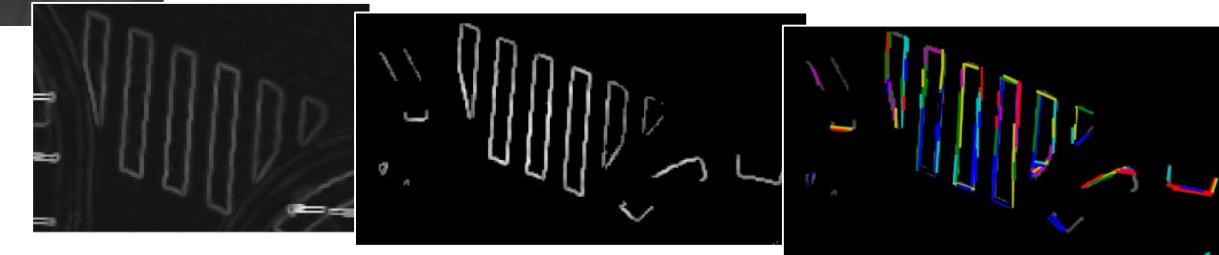
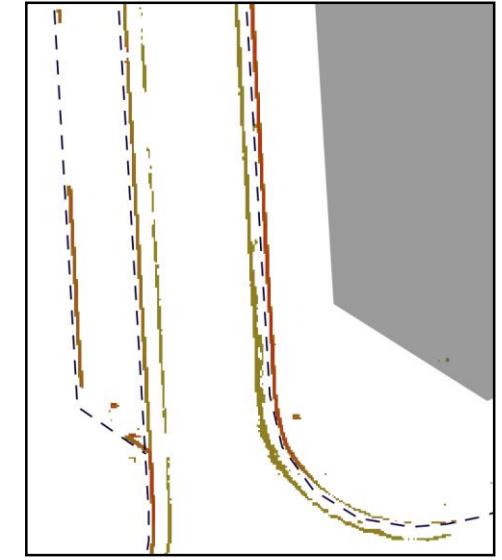
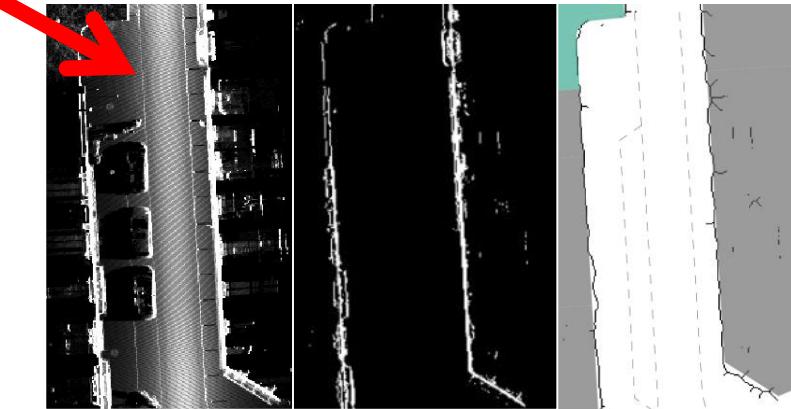
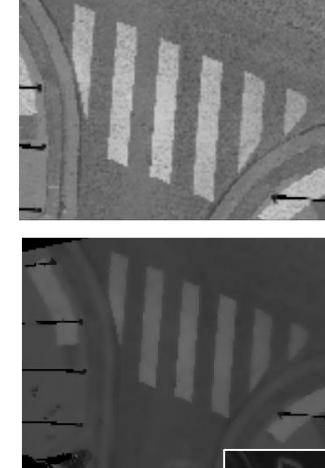


Point Cloud Server: processing



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

width=4; lane=1



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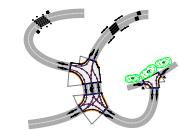
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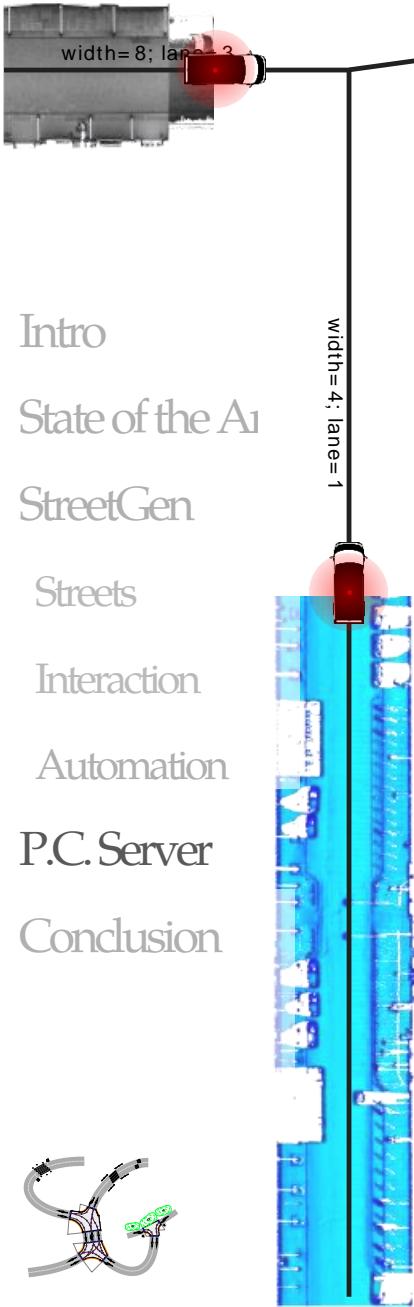
Automation

P.C. Server

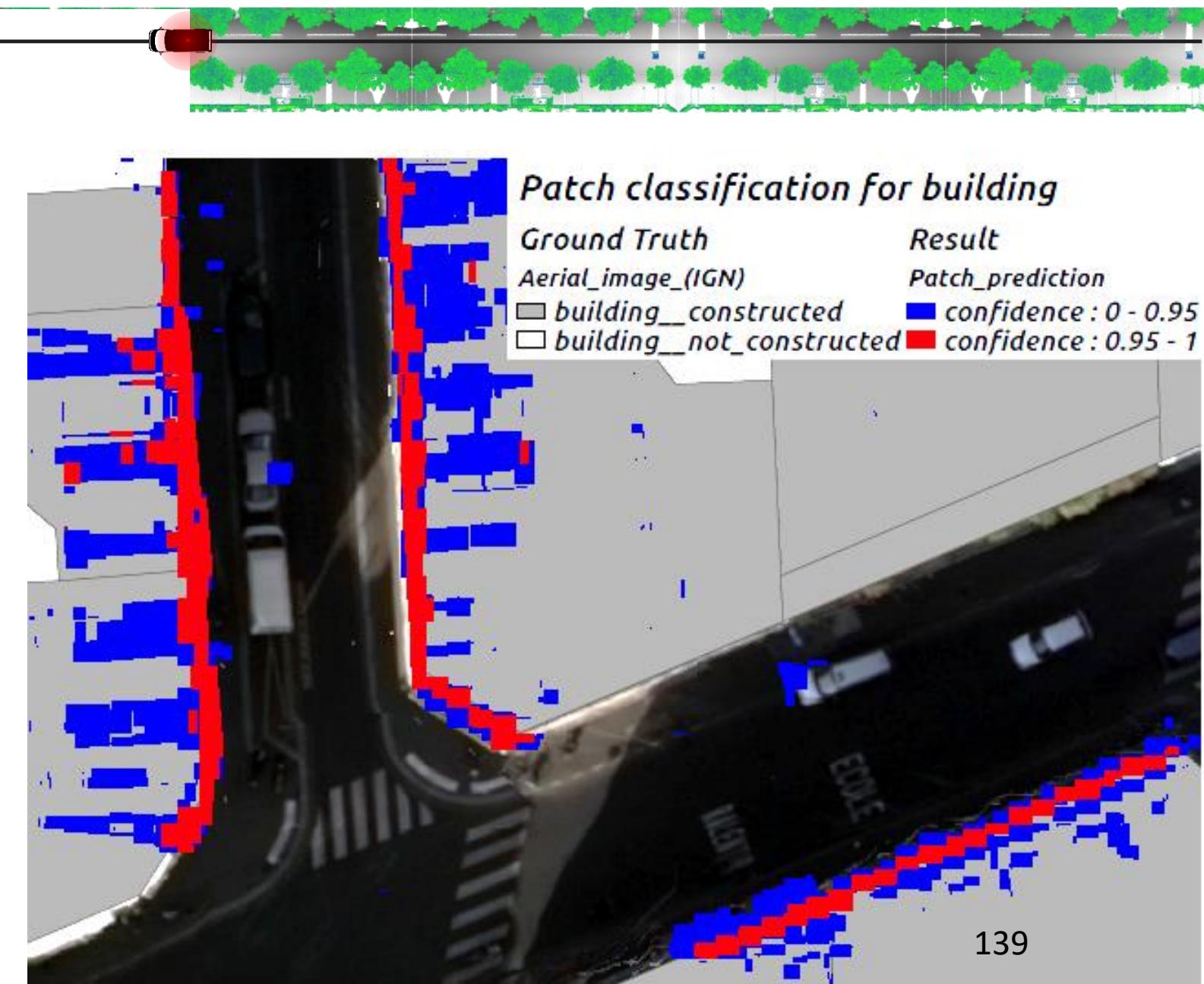
Conclusion



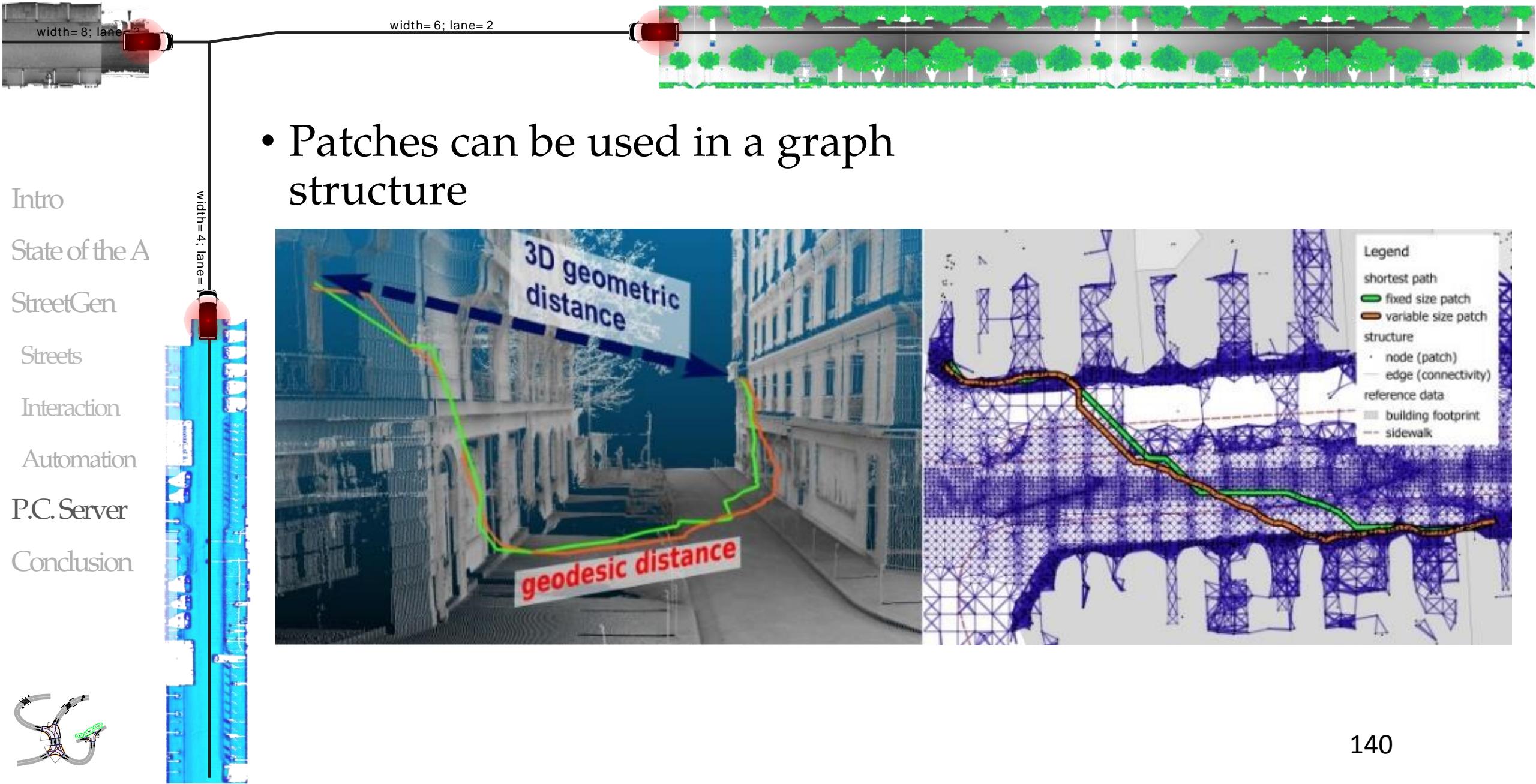
Point Cloud Server: processing



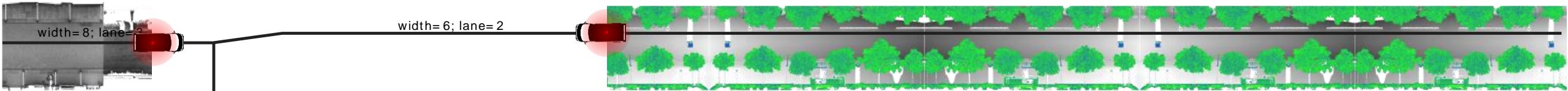
- classification



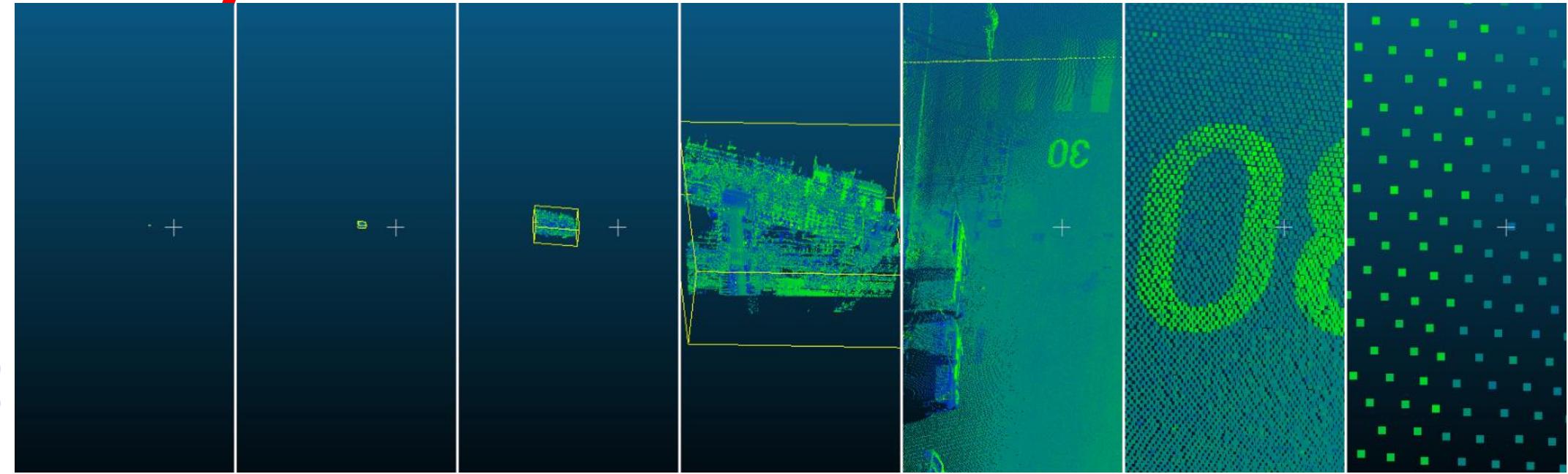
Point Cloud Server: processing



Point Cloud Server: Level Of Detail

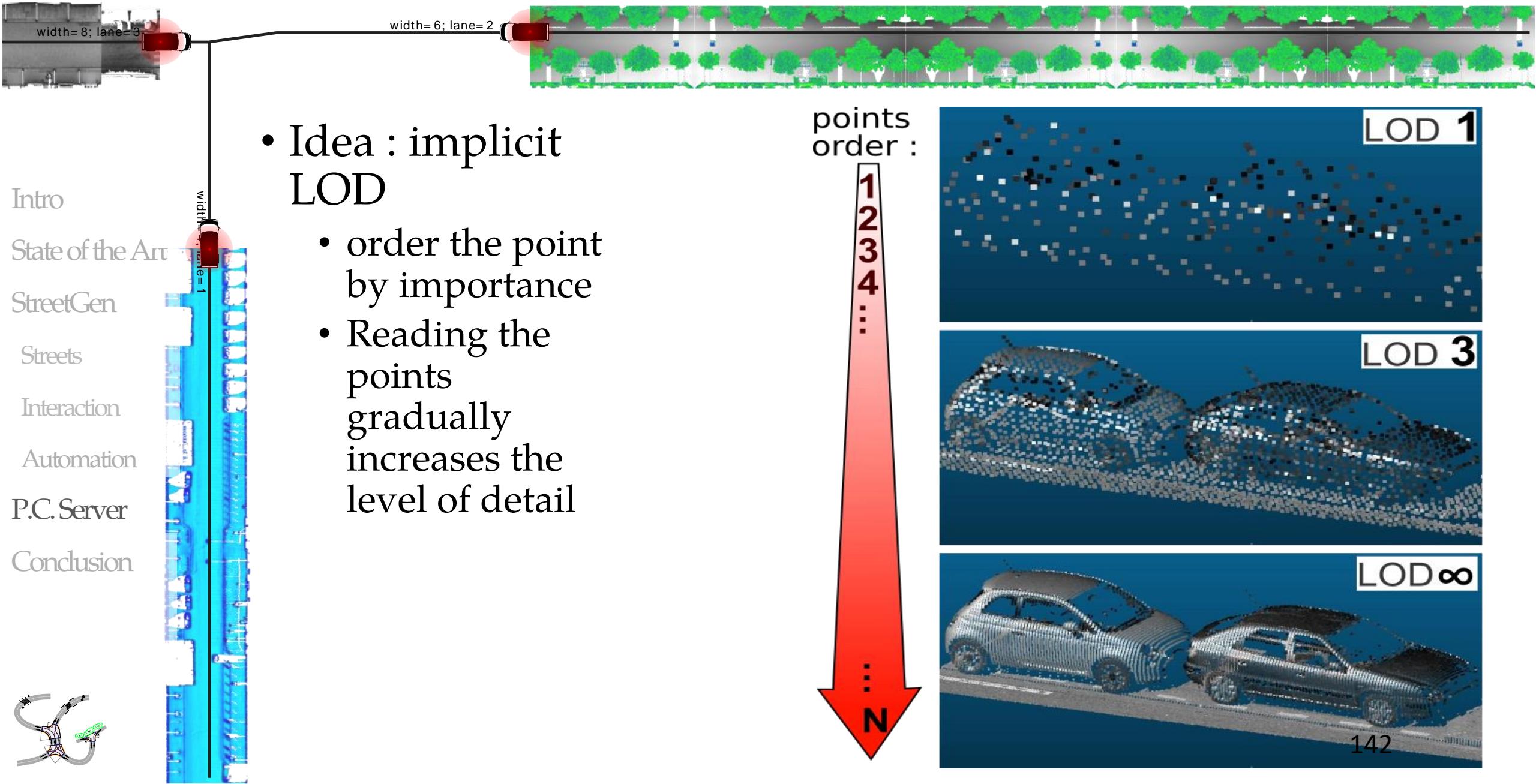


- Level Of Detail (LOD):
 - Sometimes you don't need all the points
12 Millions points, really?



User needs only a given 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

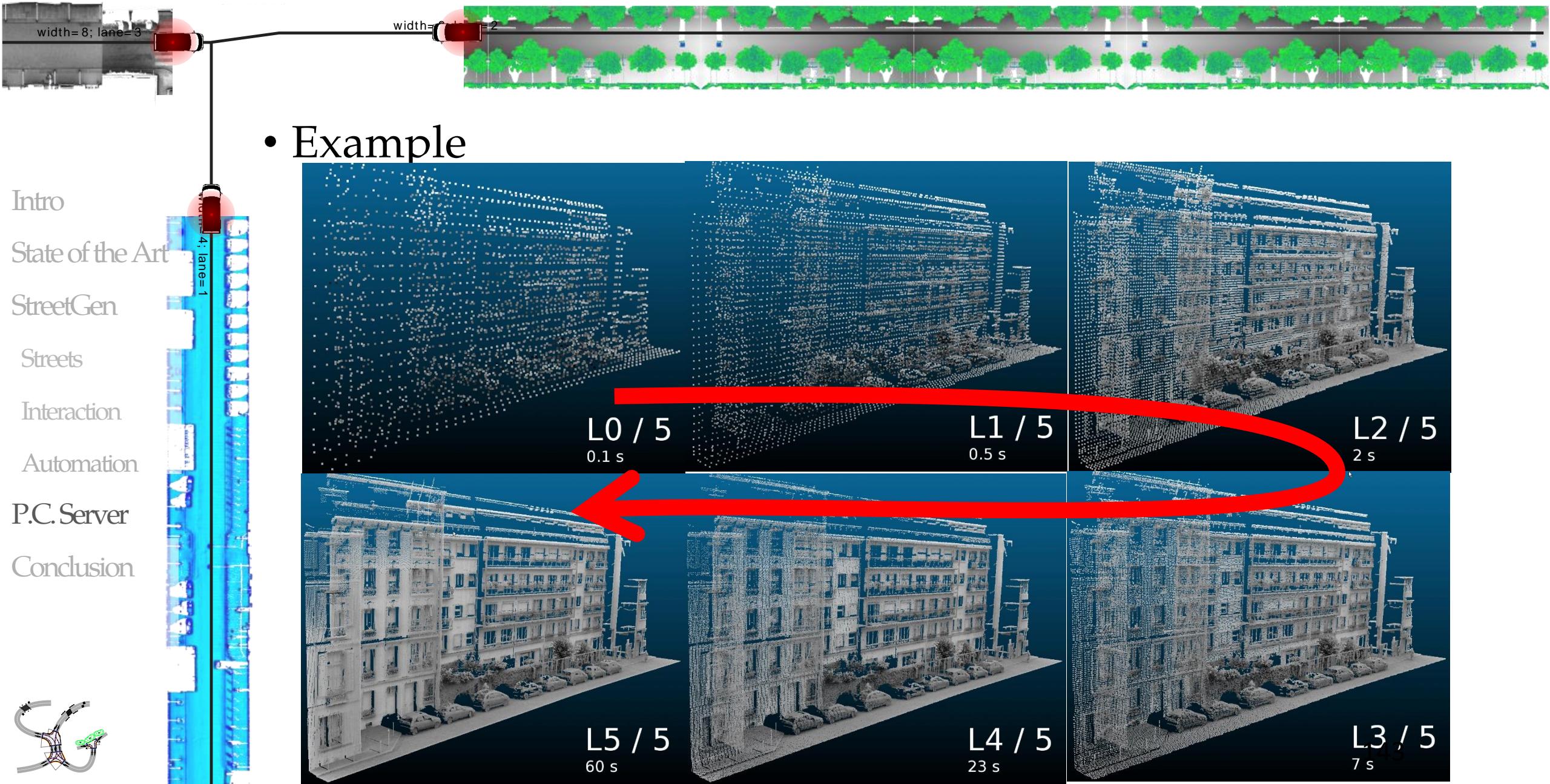
LOD 1

LOD 3

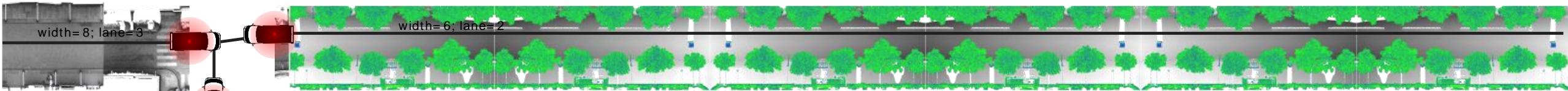
LOD ∞

142

Point Cloud Server: Level Of Detail



Point Cloud Server: Level Of Detail



- LOD enables point streaming

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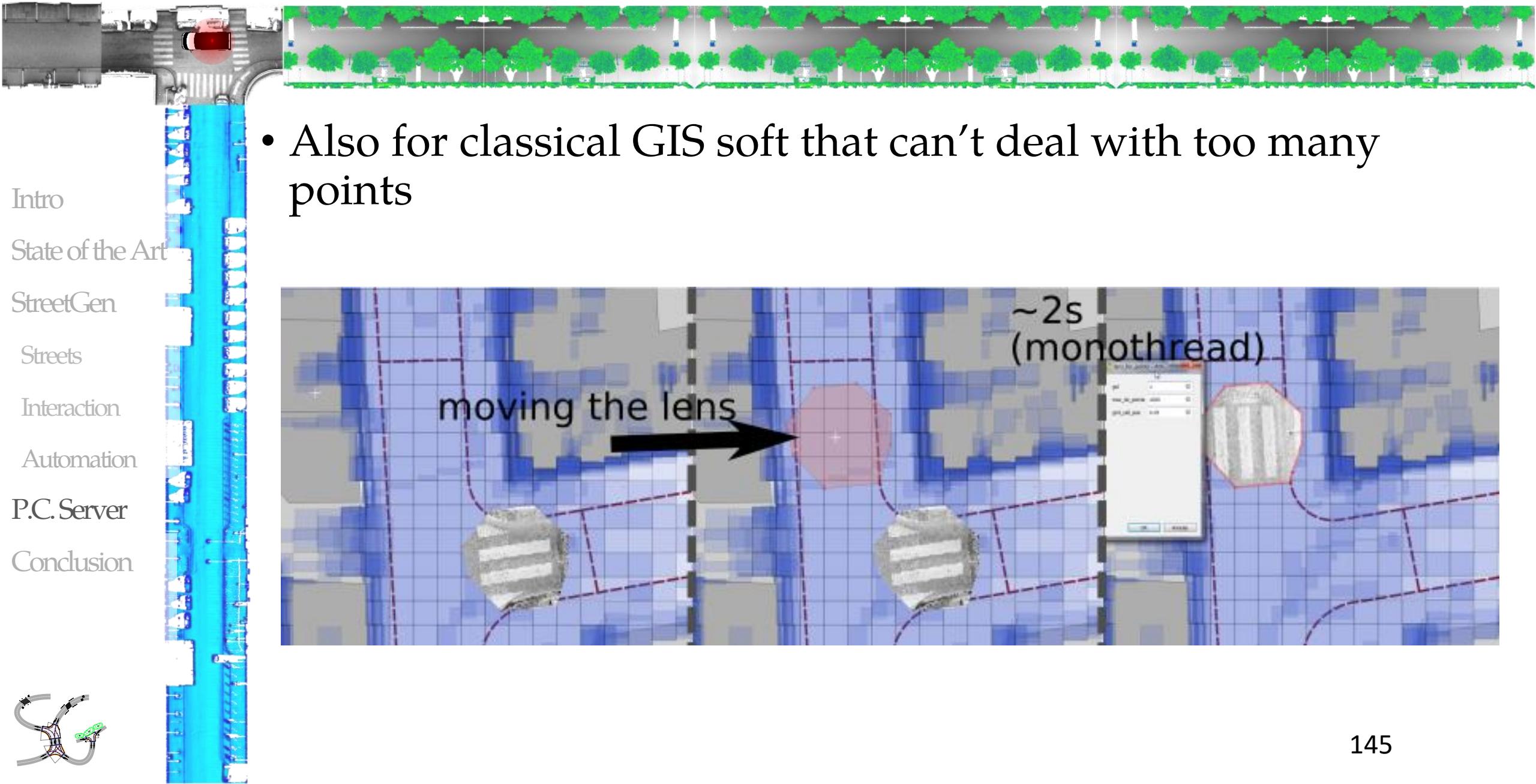
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Point Cloud Server: Level Of Detail



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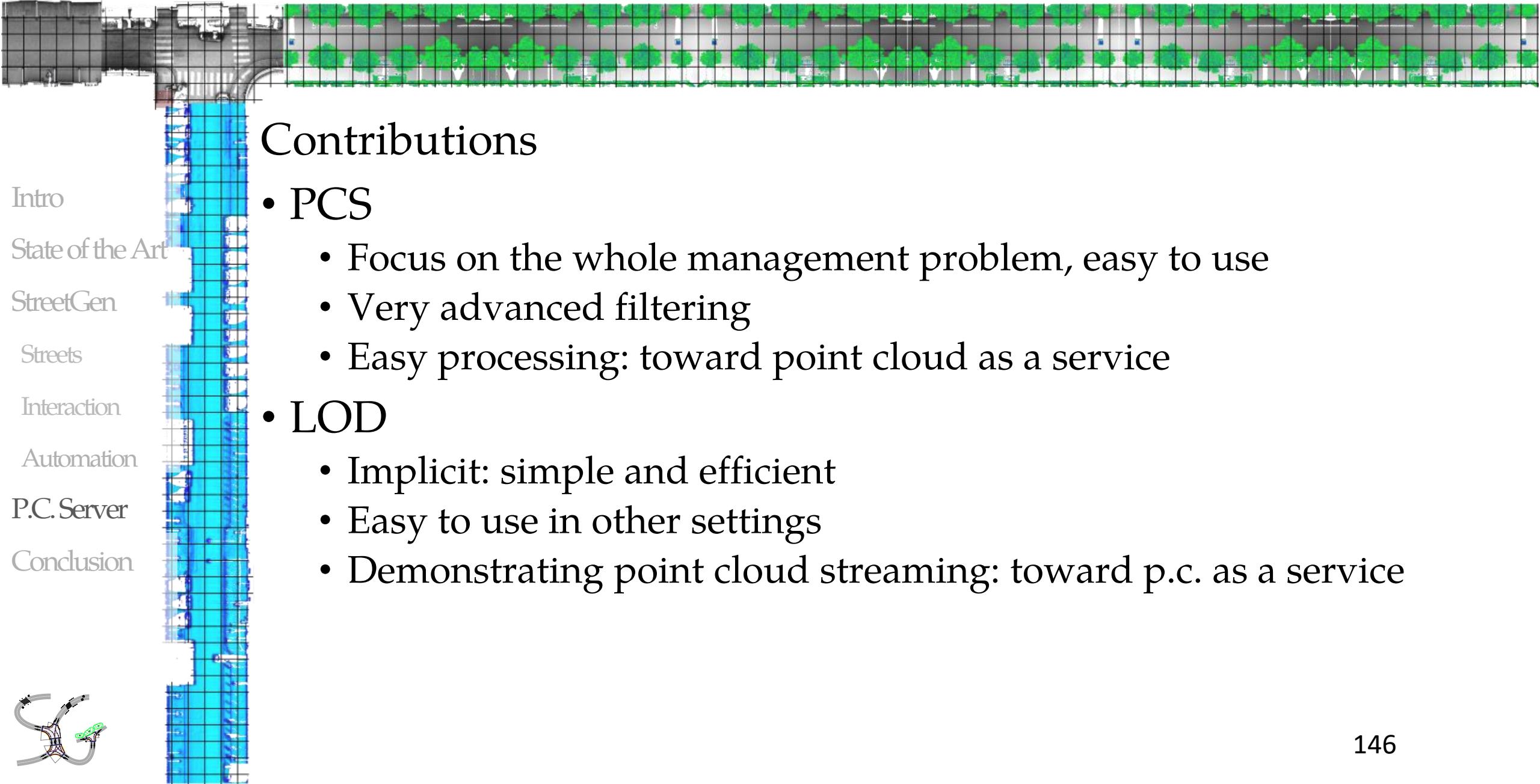
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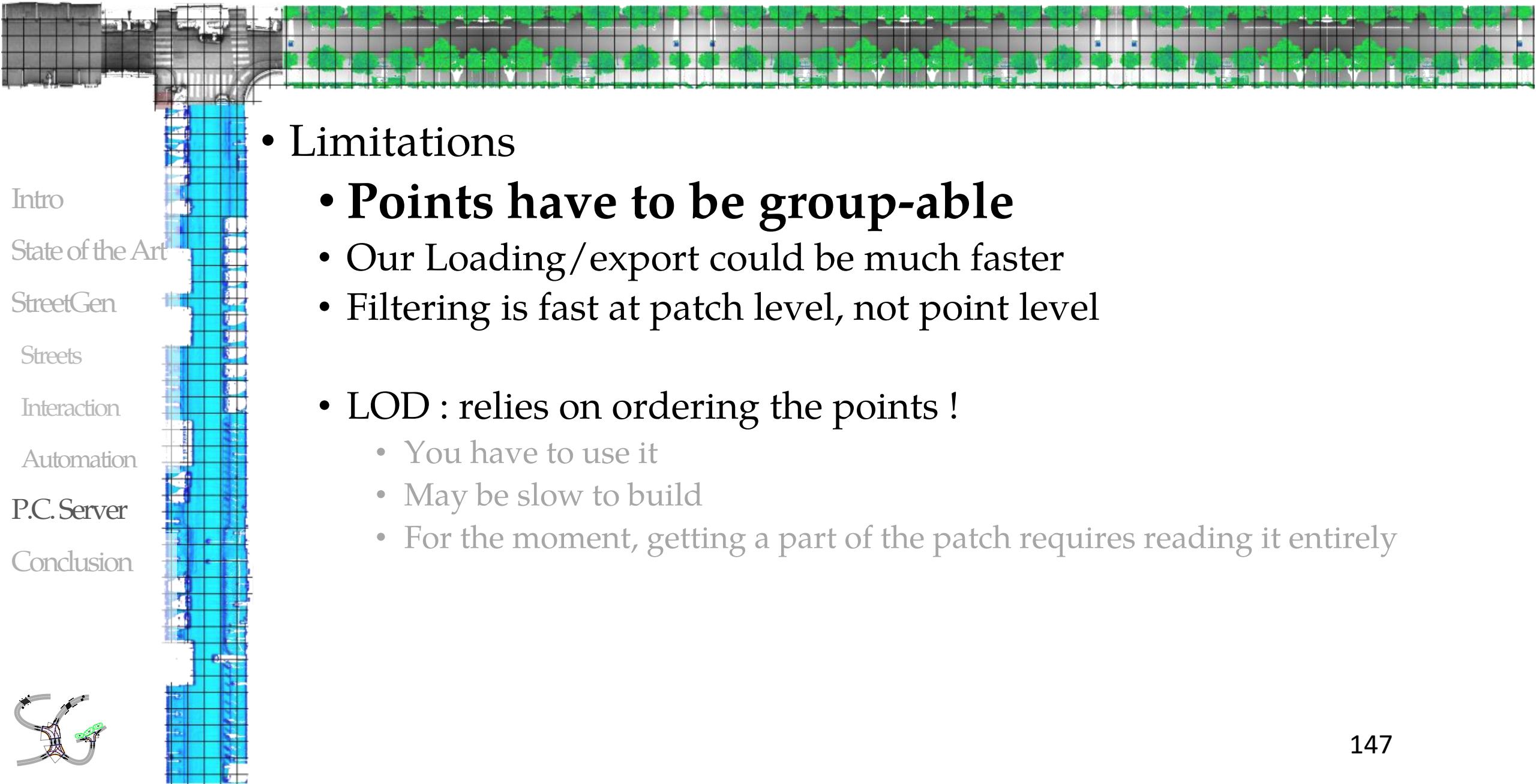
Point Cloud Server: Level Of Detail



Contributions

- PCS
 - Focus on the whole management problem, easy to use
 - Very advanced filtering
 - Easy processing: toward point cloud as a service
- LOD
 - Implicit: simple and efficient
 - Easy to use in other settings
 - Demonstrating point cloud streaming: toward p.c. as a service

Point Cloud Server: Level Of Detail



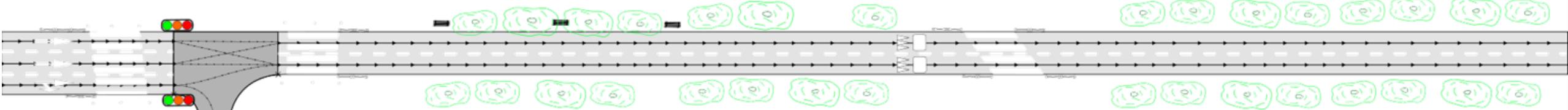
- Limitations

- **Points have to be group-able**

- Our Loading/export could be much faster
 - Filtering is fast at patch level, not point level

- LOD : relies on ordering the points !

- You have to use it
 - May be slow to build
 - For the moment, getting a part of the patch requires reading it entirely



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Conclusion: Summary

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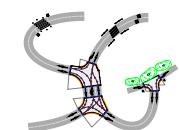
Streets

Interaction

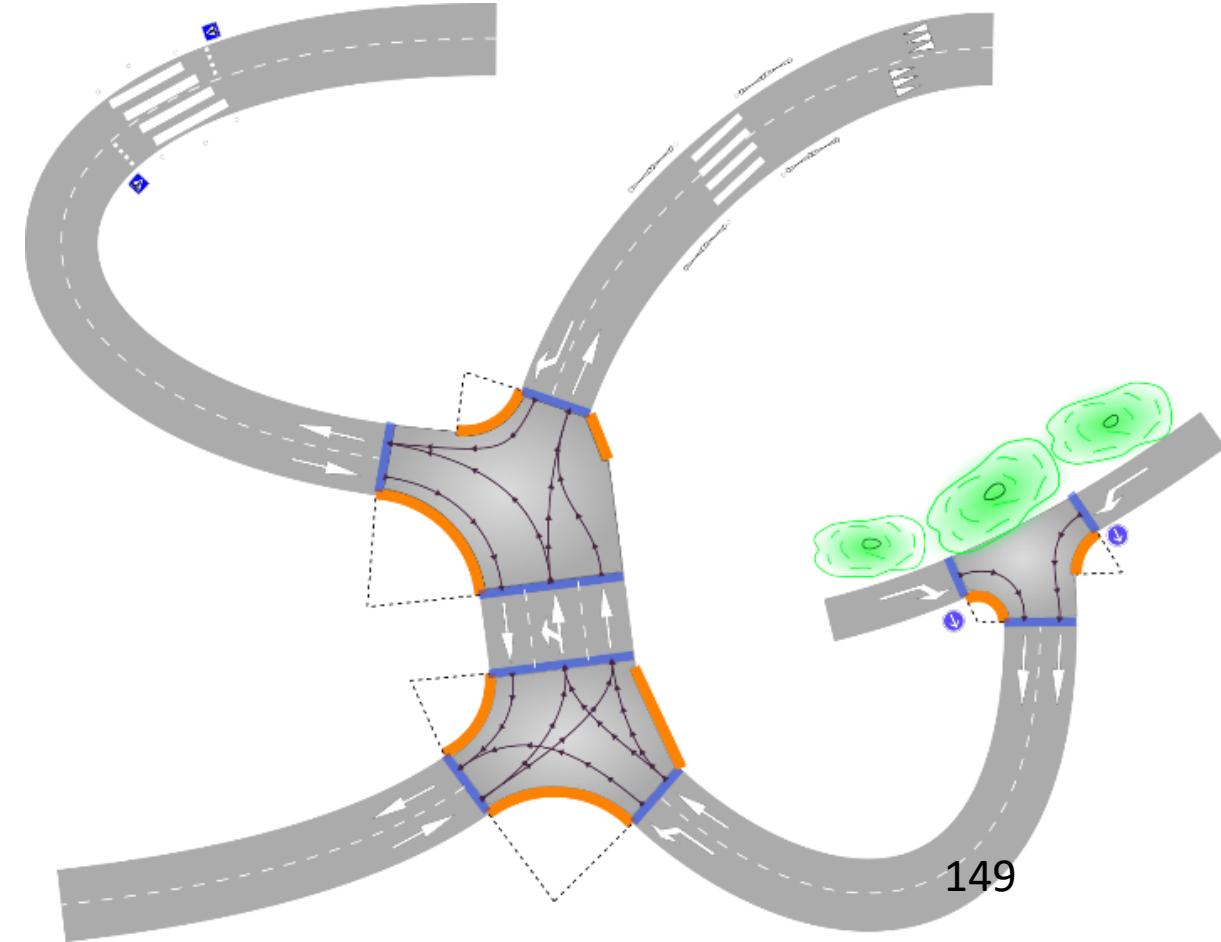
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Conclusion



- 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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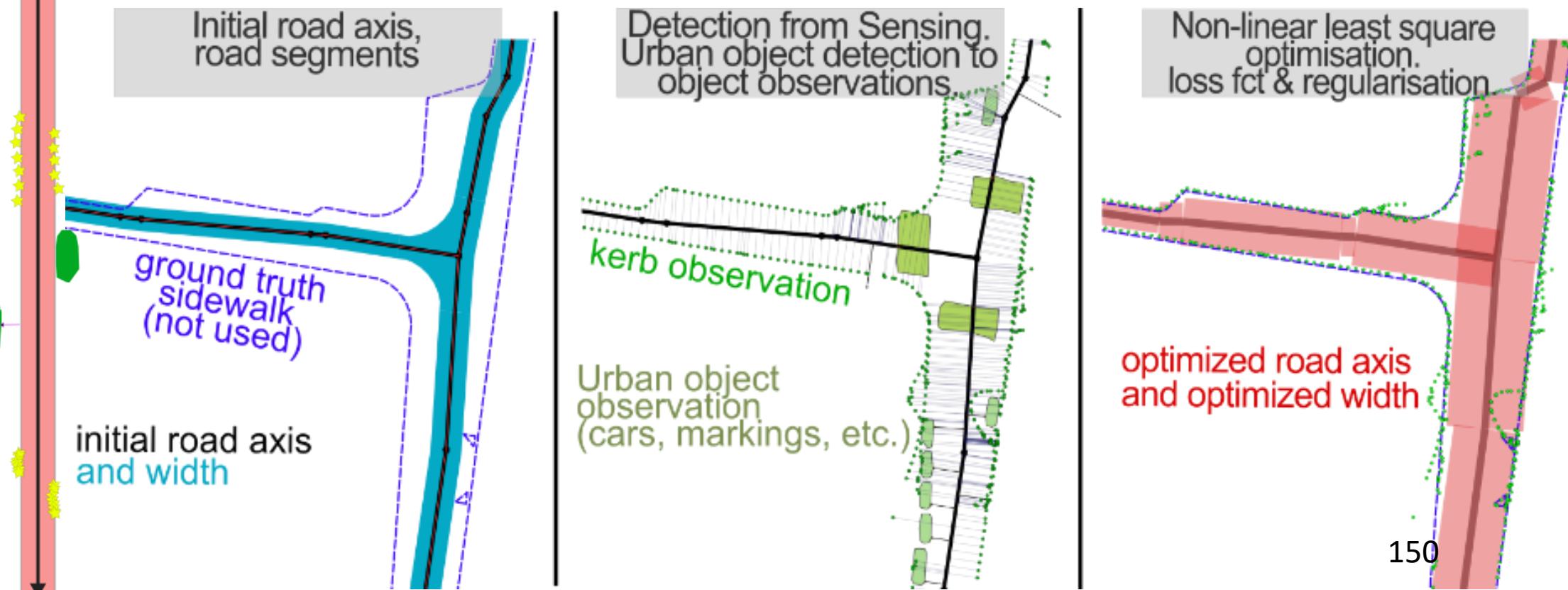
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Conclusion

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



Conclusion: Summary

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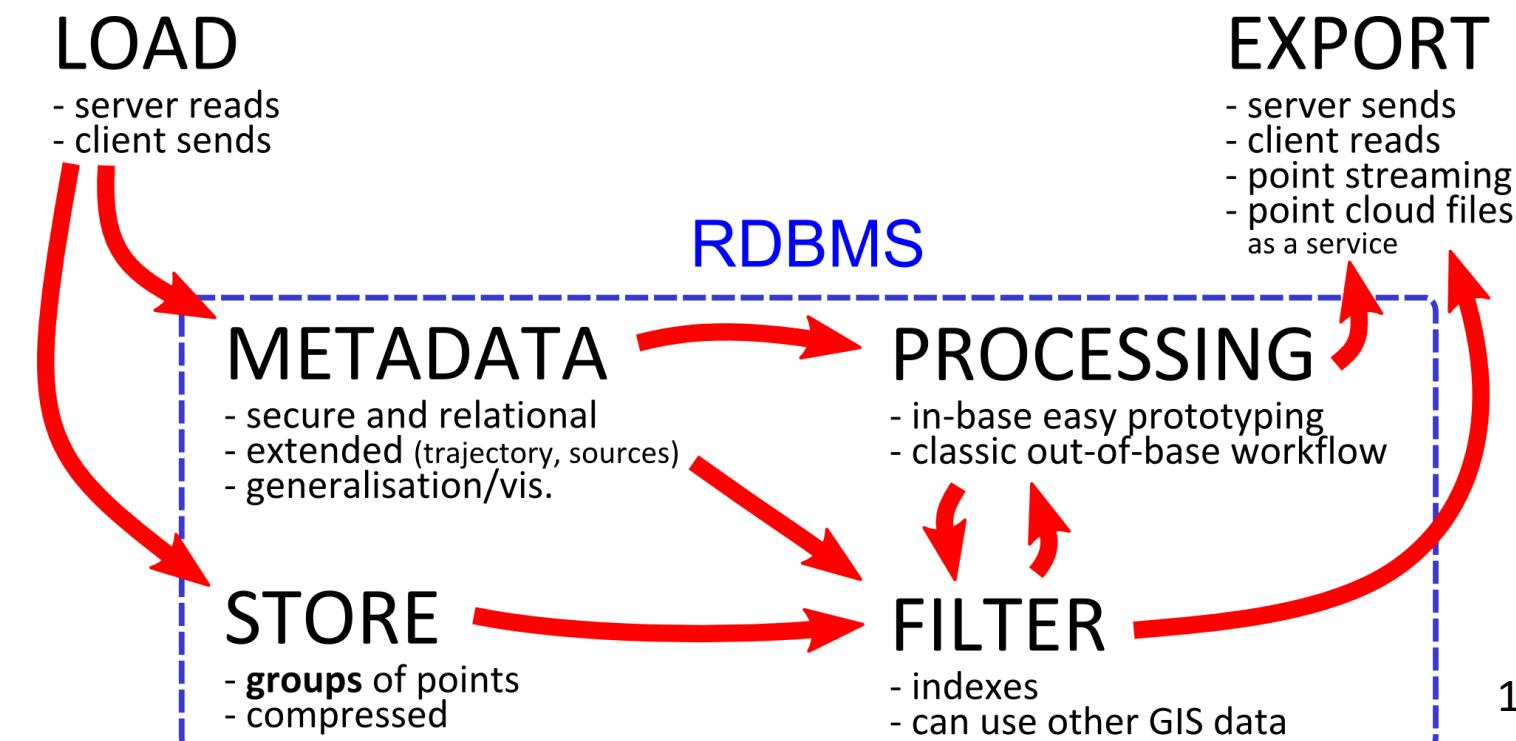
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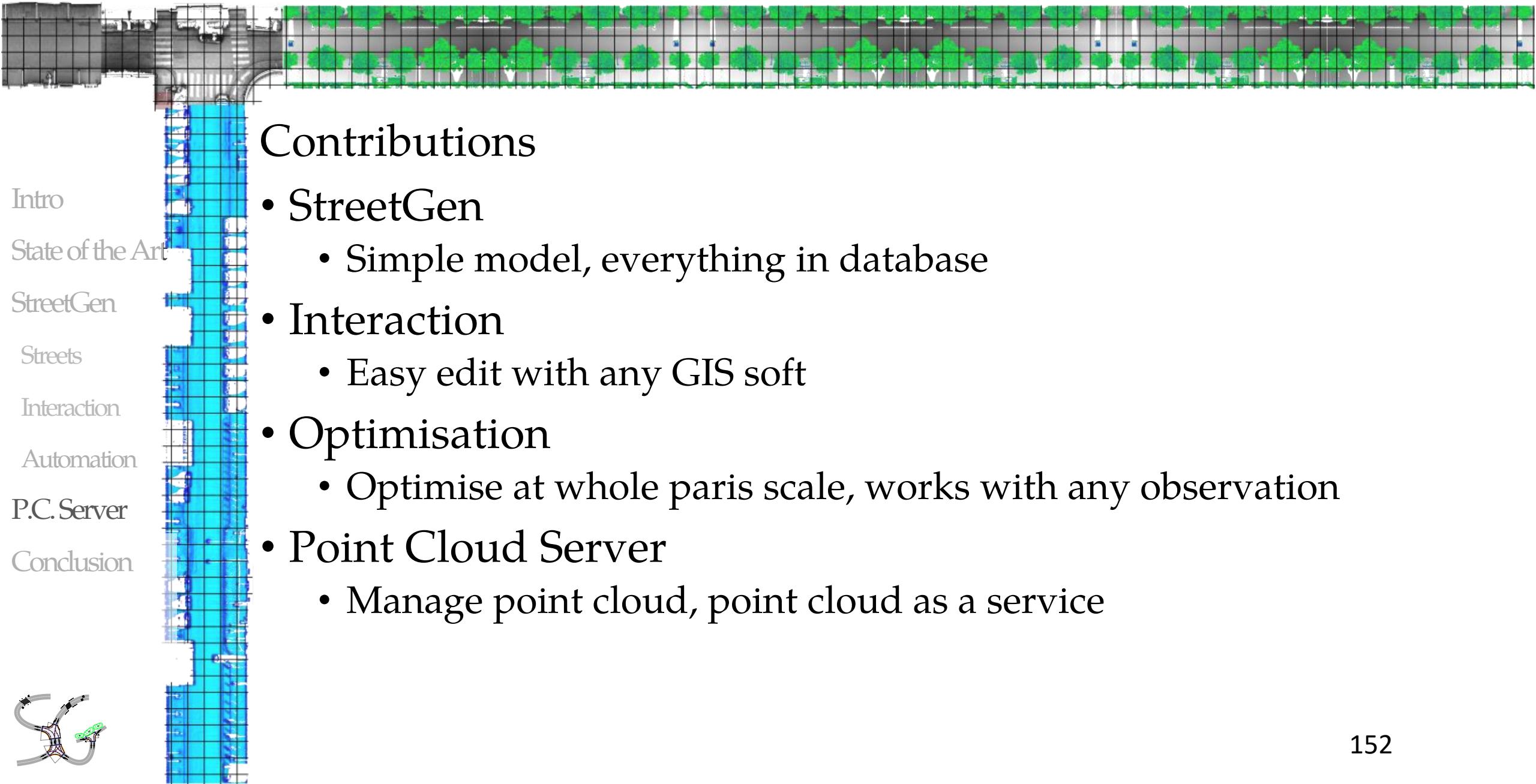
Conclusion



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



Point Cloud Server: Level Of Detail



Contributions

- StreetGen
 - Simple model, everything in database
- Interaction
 - Easy edit with any GIS soft
- Optimisation
 - Optimise at whole paris scale, works with any observation
- Point Cloud Server
 - Manage point cloud, point cloud as a service

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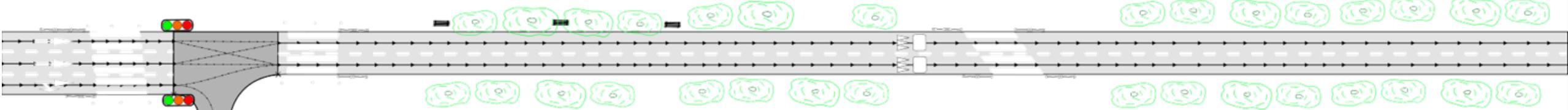
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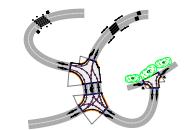
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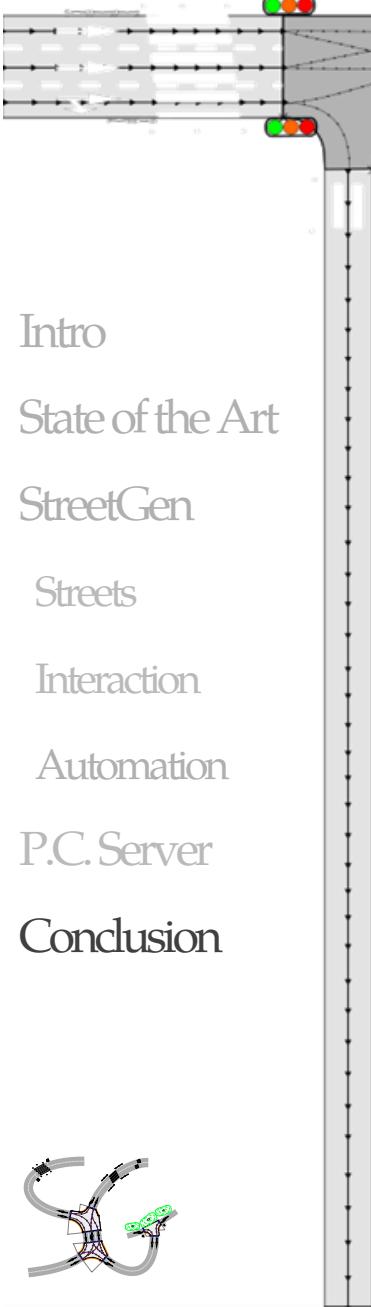
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Conclusion: Limitations

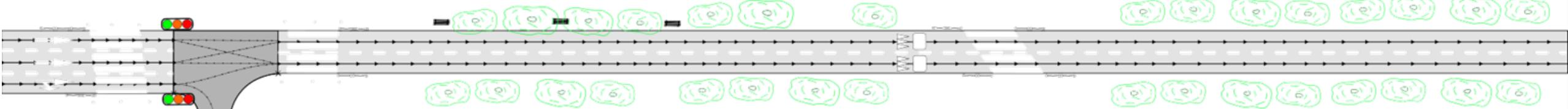


- StreetGen

- Model too simple
- Interaction limited to simple mechanisms
- Optimise only a part of the model

- Point Cloud Server :

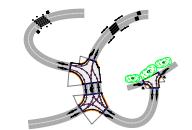
- Must group points into meaningful groups
- Objects are created/edited manually by user
 - Tedious, not much sense



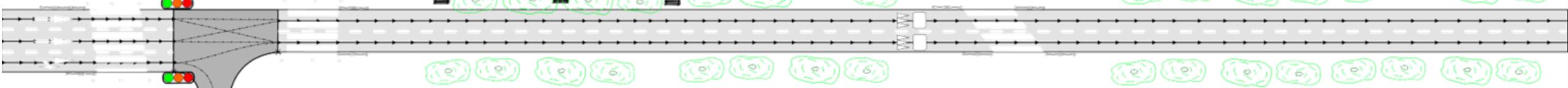
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Conclusion: Perspectives

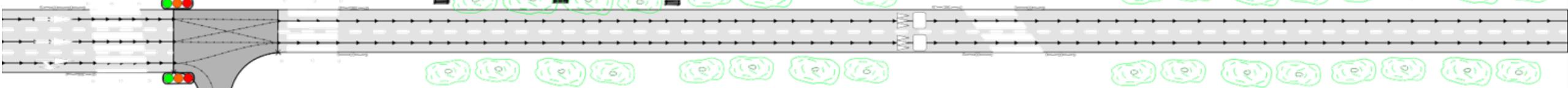


- Only the beginning of inverse procedural street modelling.
 - Object should be created by template/ pattern/ grammar/procedural functions!
 - Dealing with objects and road model simultaneously calls for much stronger modelling and optimisation methods
 - Optimisation should be more powerful (RJ-MCMC)

im

im

Conclusion: Perspectives

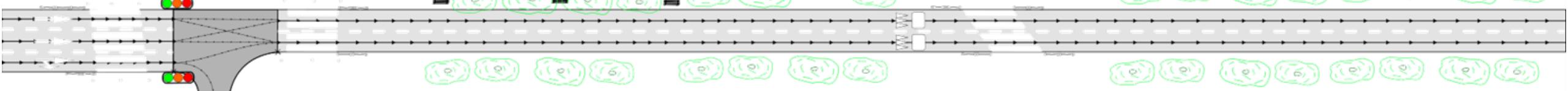


- Major trend in smart vehicle/autonomous cars
 - → maps potentially required by every (Billion) cars
- For the moment: low level information, but
 - All cars will need a shared high level road model

im

im

Conclusion: Perspectives



- Cities are evolving
 - There are several cities in one city:
 - Café terrace: day/night
 - Garbage bin
 - (parking behaviour)
 - Time is essential (simulation/understanding)
 - 4D street modelling ?

im

im

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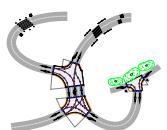
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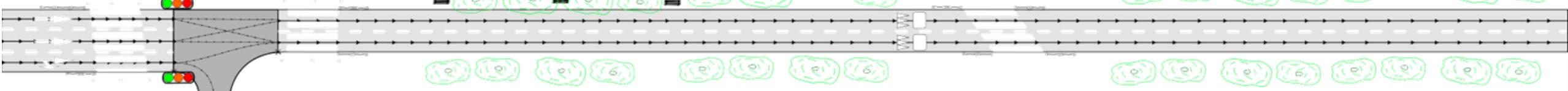
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Conclusion: Perspectives



- To understand city evolutions → study city history
- Historical geodata
 - Hand drawn maps
 - Information needs to be extracted
 - (my current work)



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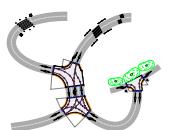
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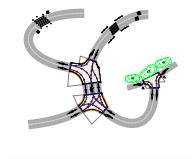
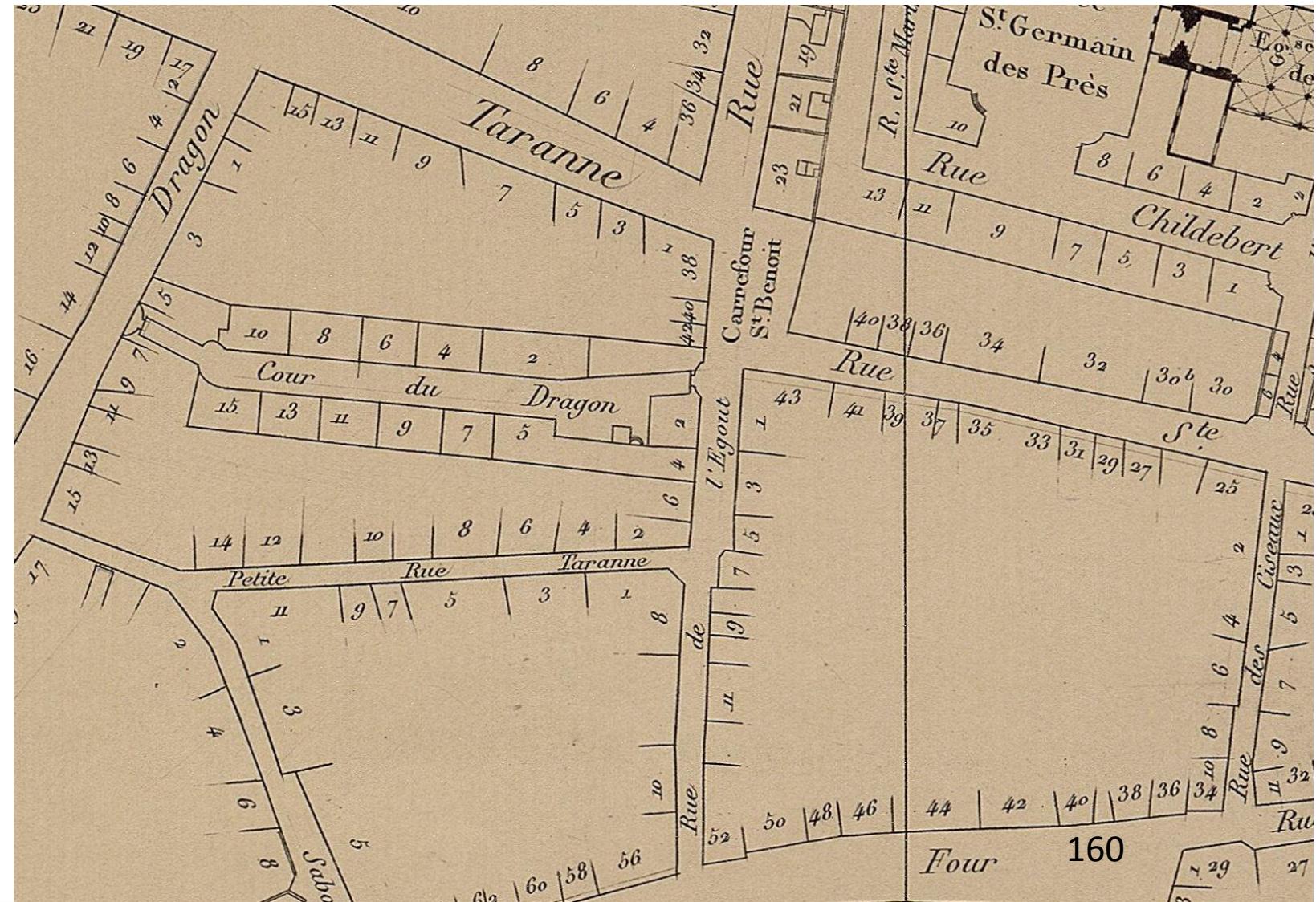
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Conclusion: Perspectives

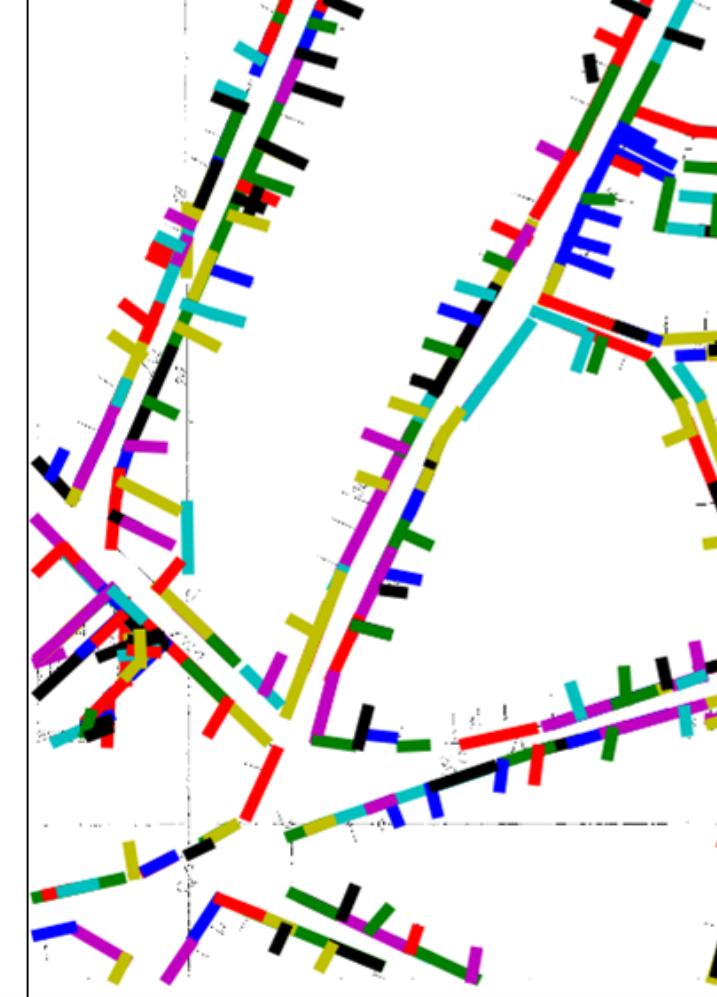
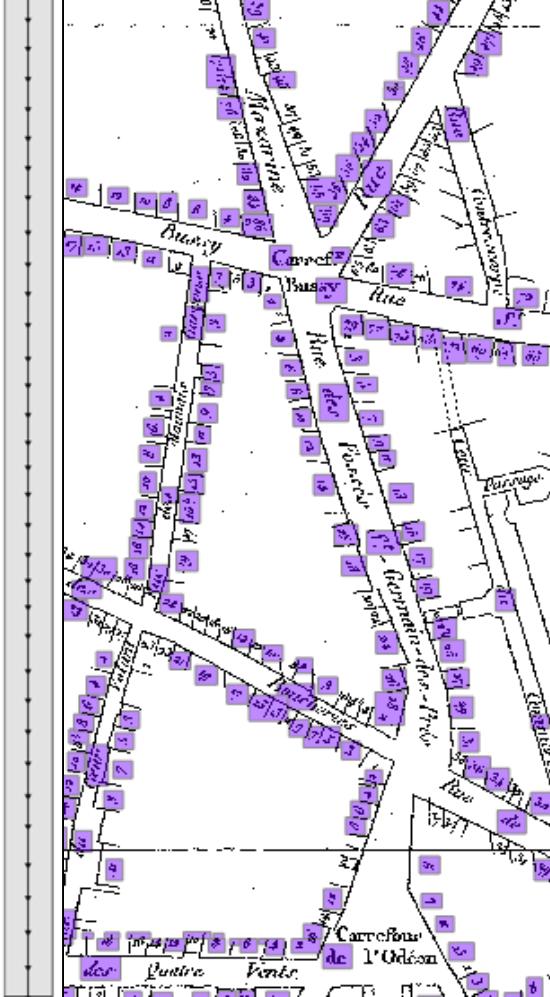
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- Jacoubet,
1810-1836 :
- road model
with
optimisation
& Streetgen
?



Conclusion: Perspectives

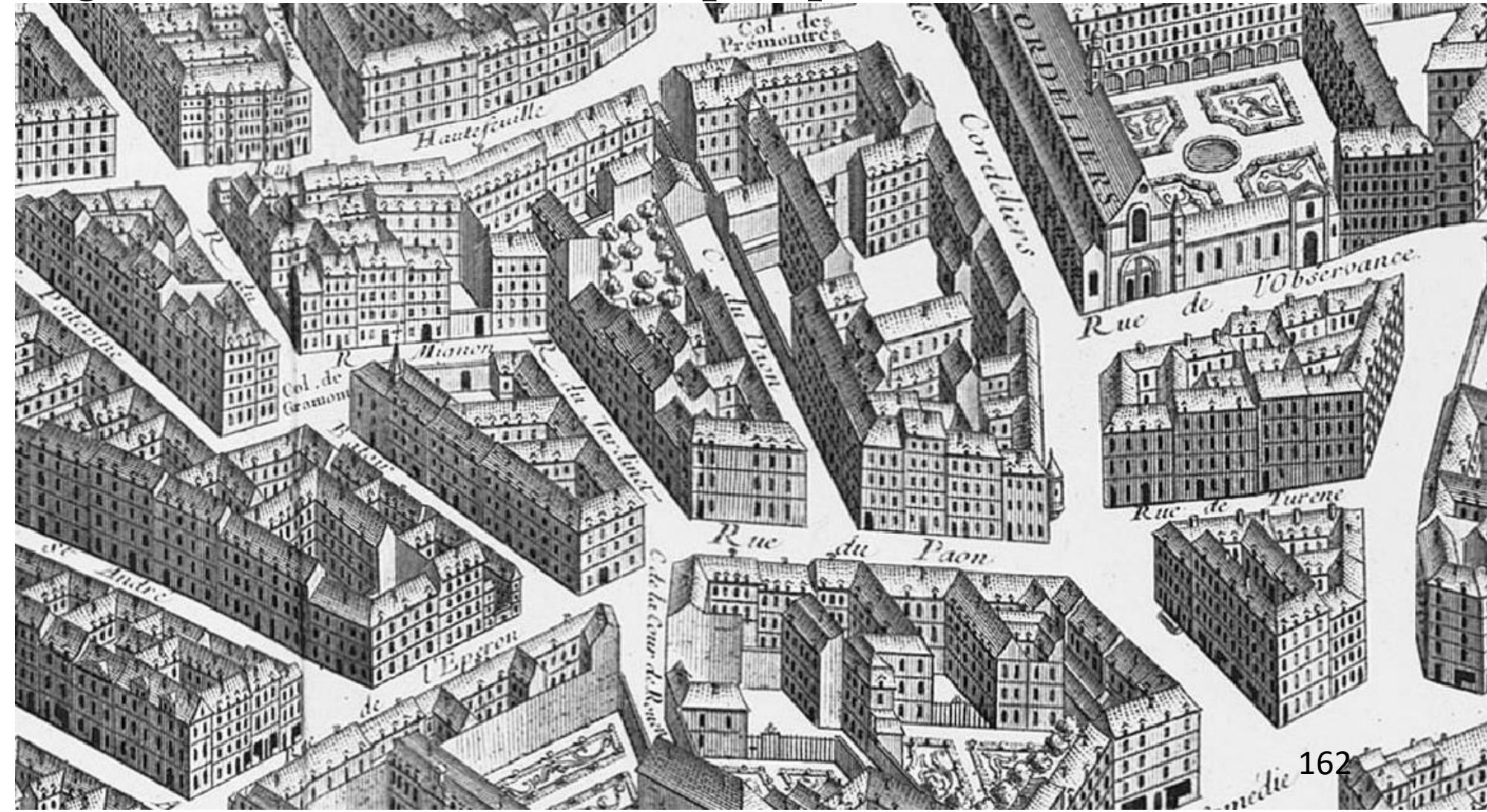
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- Extract building number, buildings limits, street surface (B. Vallet)

Conclusion: Perspectives

- Turgot, 1734-1739 : isometric persp.



QUESTIONS

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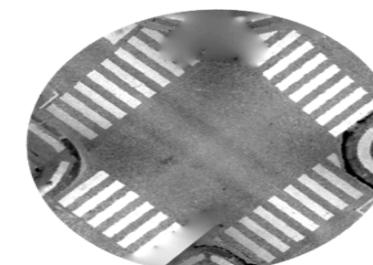
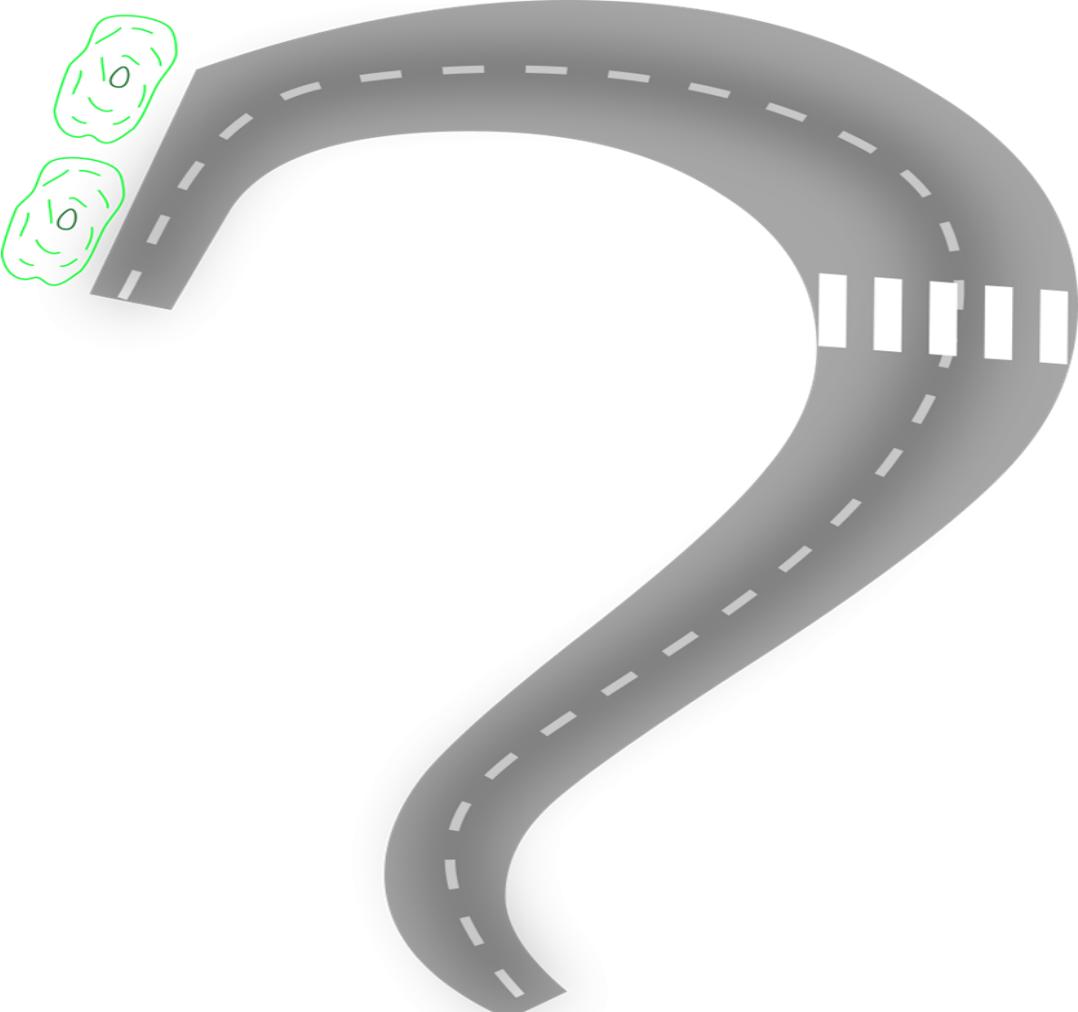
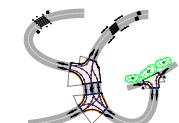
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TODO

- Conclusion need illustrations and splitting slides
- Solve the todo

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notes

- Premiere page: logos en gros

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notes

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Conclusion

- - le besoin de réduire l'information pour pouvoir passer plus de temps à expliquer certains schémas
- - le besoin de fluidifier certaines transitions (notamment la transition nécessaire vu que le Point Cloud Server se retrouve à la fin)

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annexe



State of the art: Existing models

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

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

System / GIS / Simulation / Procedural / Data-driven

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

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



Transportation module

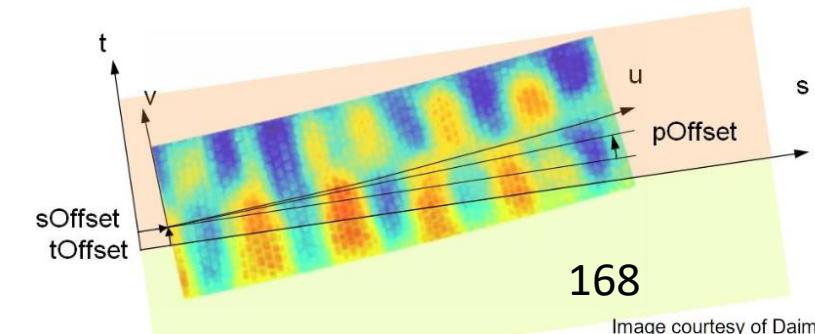
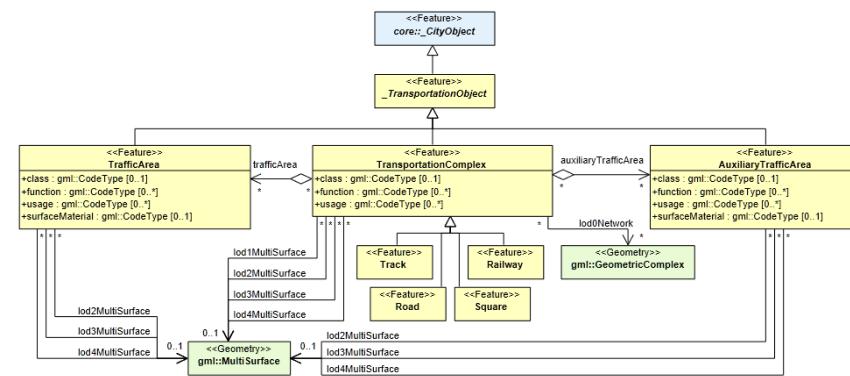
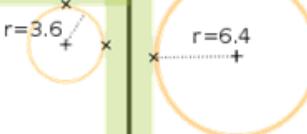


Image courtesy of Daimler AG

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 ...

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Todo bonus: schema XML

Introduction: usages for city model

- Street model ⊂ city model
- Many usages for a city model
 - Urbanism
 - Transport
 - Environment
 - Security
 - Communication
 - ...

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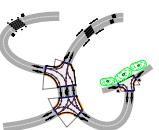
Streets

Interaction

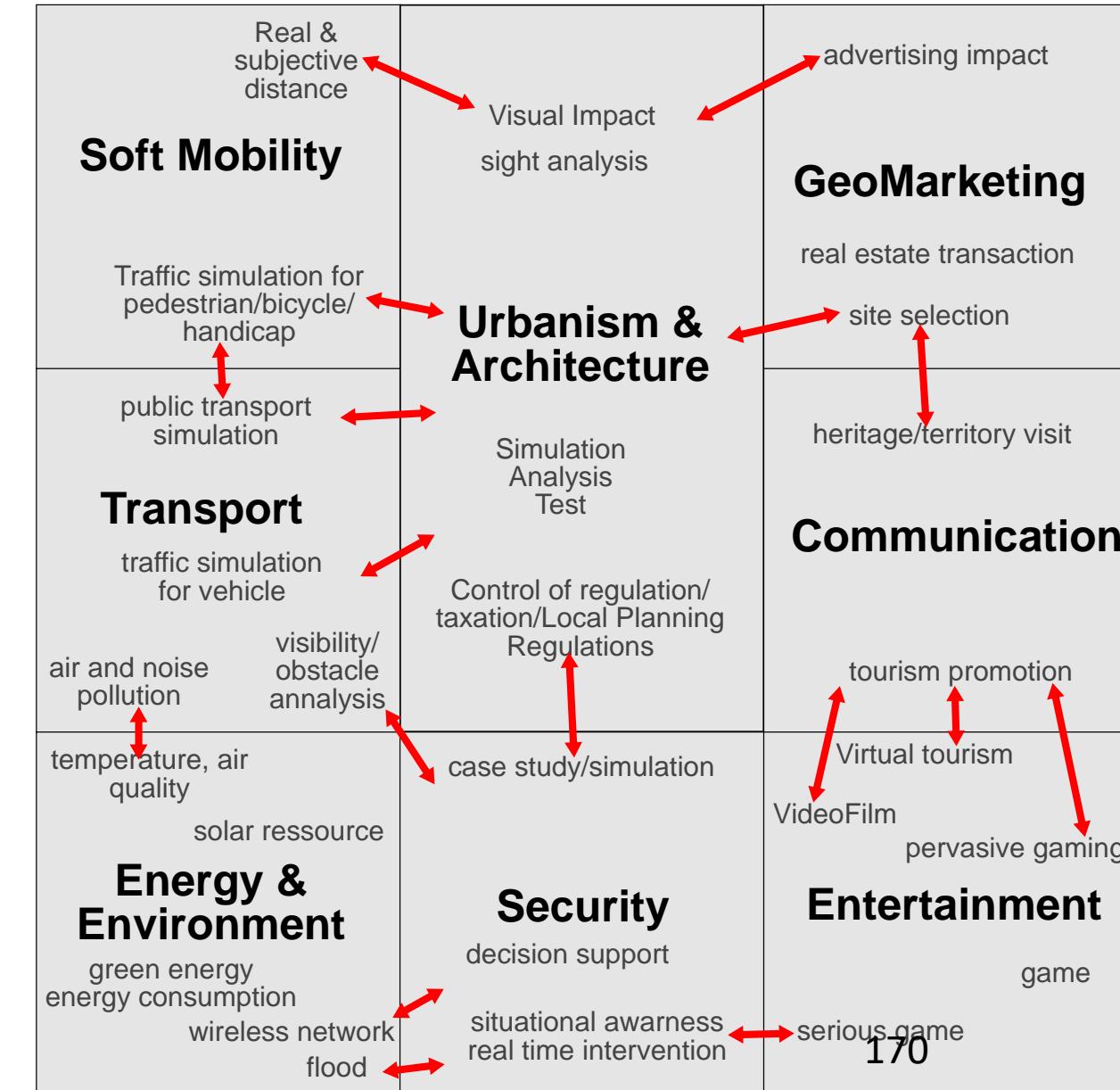
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width=6; lane=2



StreetGen : Kinematic hypothesis

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

$r=3.6$
 $r=6.4$

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

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

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

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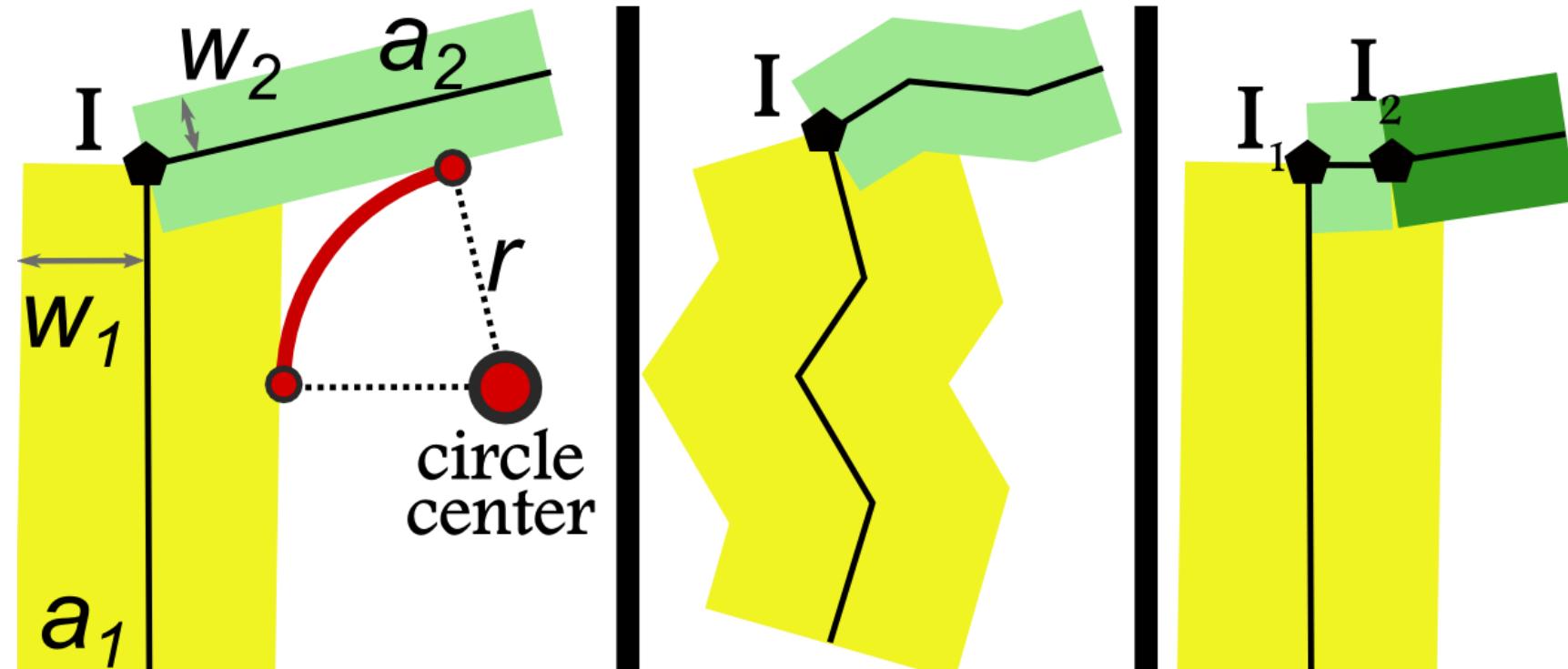
Streets

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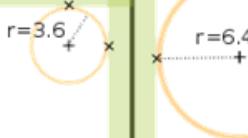
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StreetGen : Kinematic hypothesis

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



- Various radius in Paris

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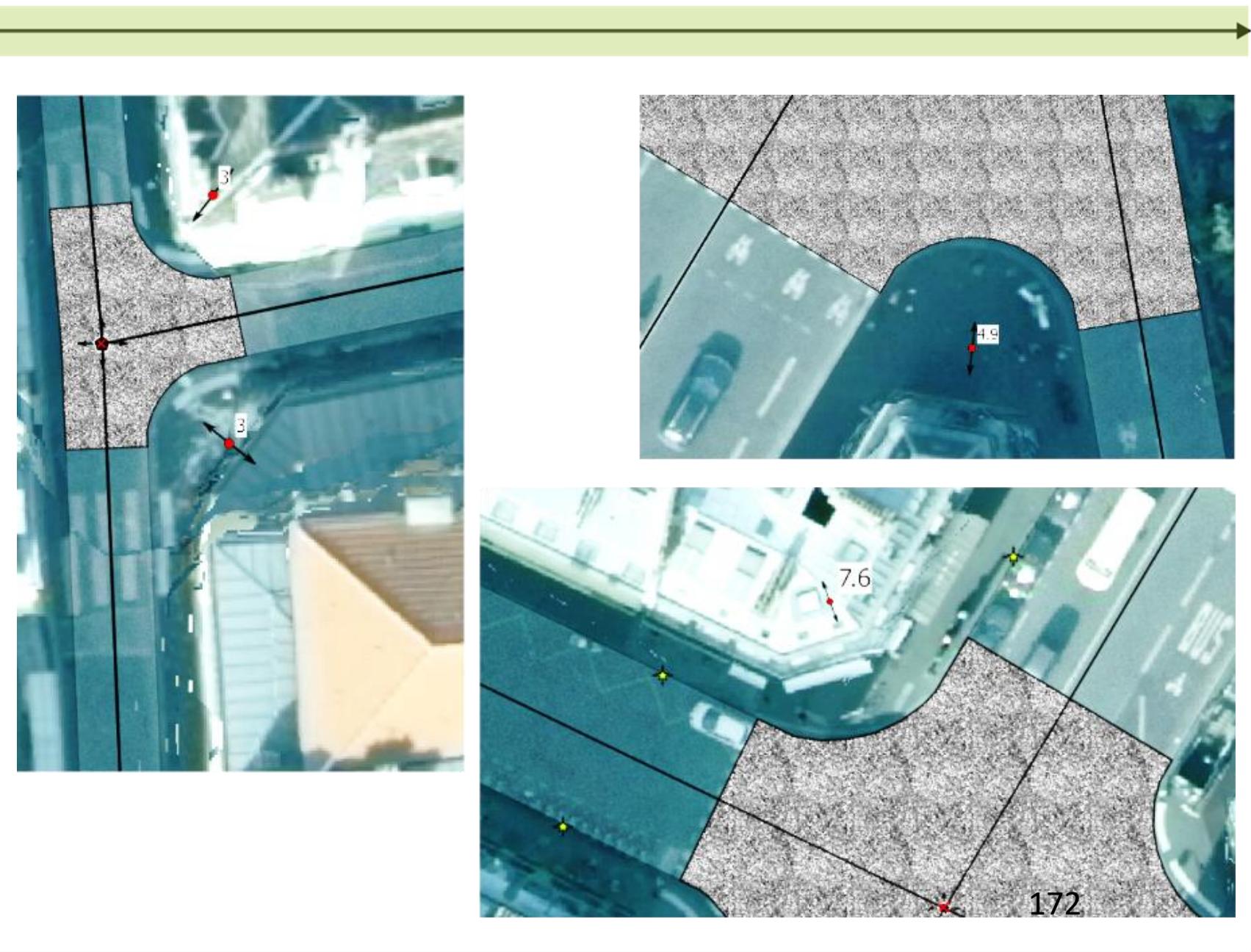
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StreetGen : Kinematic hypothesis

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

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

$r=3.6$

$r=6.4$

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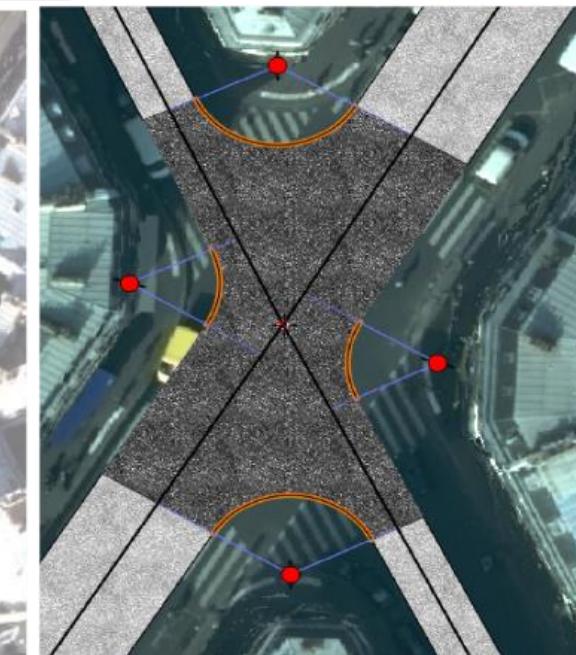
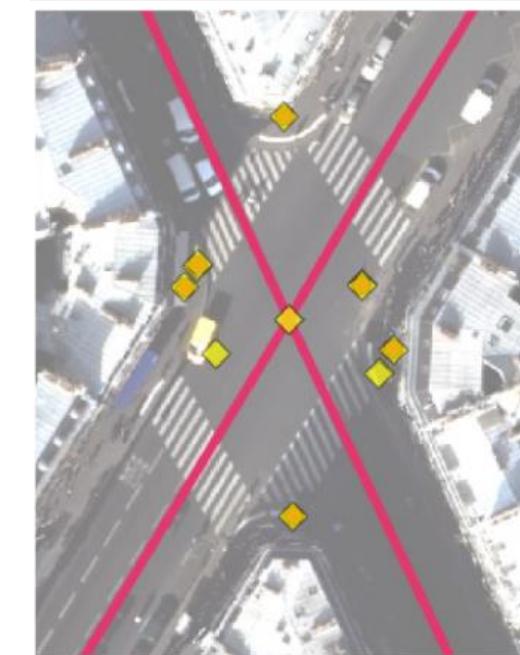
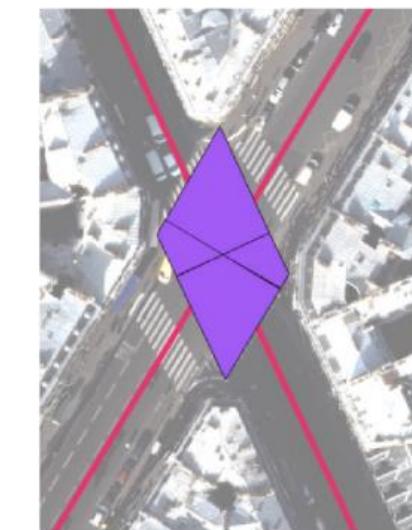
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StreetGen : Road surface

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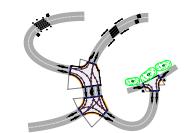
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```

edge id=15; next_l=16
end_node=3 ...
edge id=16; next_l=17
start_node=4 ...
  
```

$r=3.6$

+

x

*

```

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

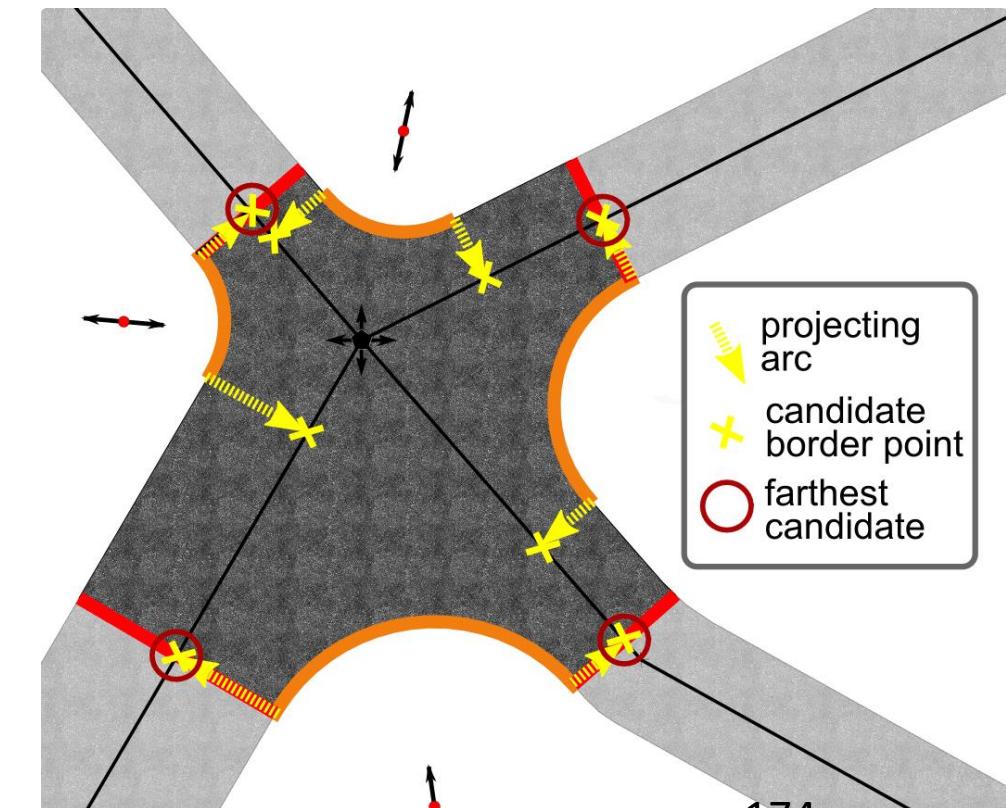
+

x

*

- Find intersection limit :

- Project circle centers
- Farthest per axis



StreetGen : Road surface

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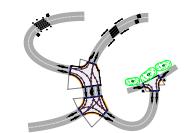
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edge id=15; next_l=16
end_node=3 ...

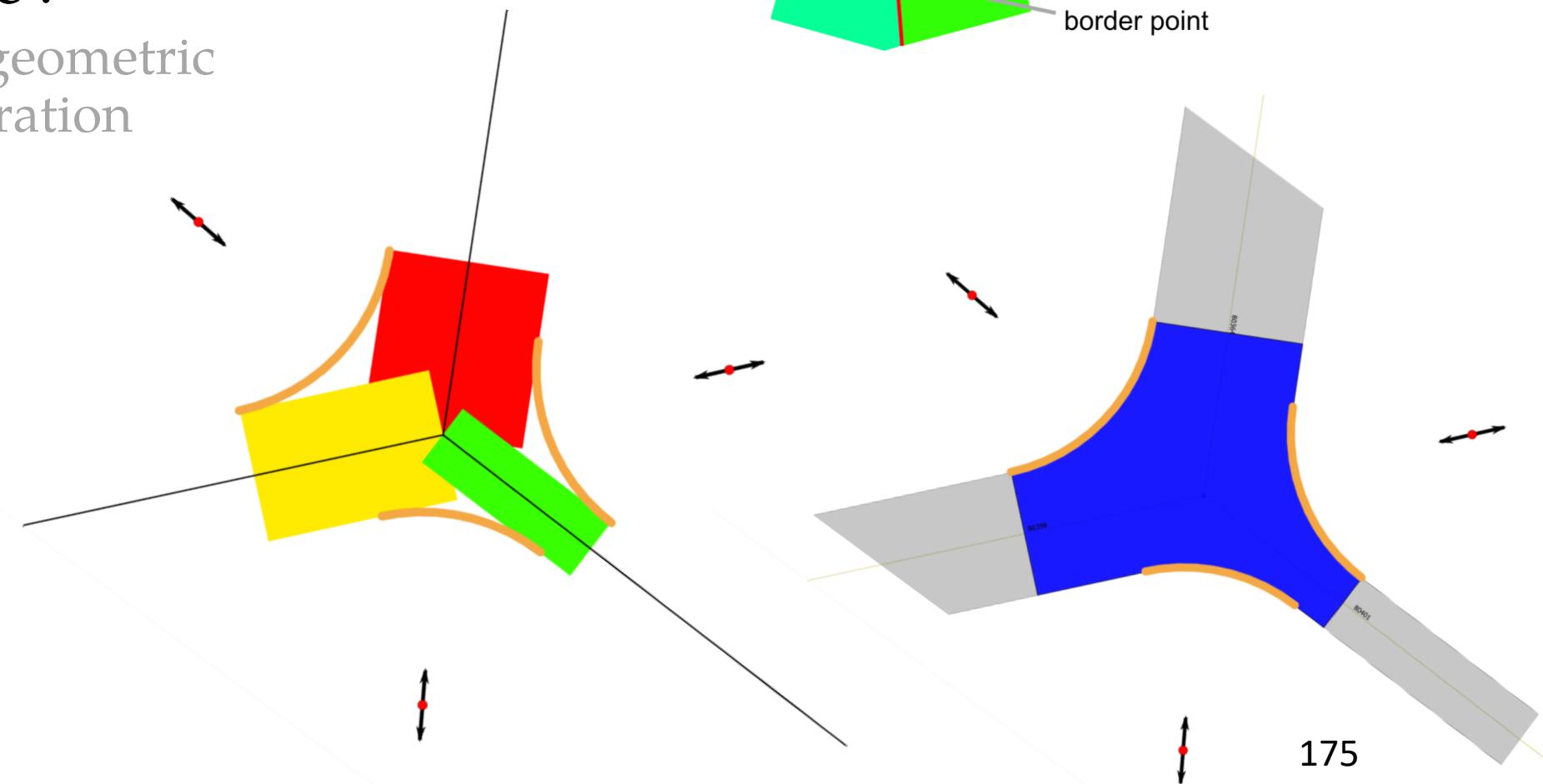
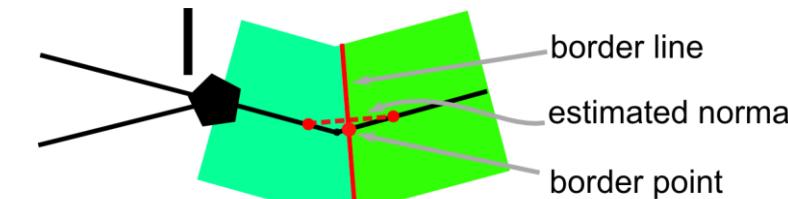
edge id=16; next_l=17
start_node=4 ...

r=3.6 +

r=6.4 +

- Create Intersection surface :

- By geometric operation



StreetGen : Road surface

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

- Special intersection:
- Variable buffer
- No other parameter for road width reduction control

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

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

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StreetGen

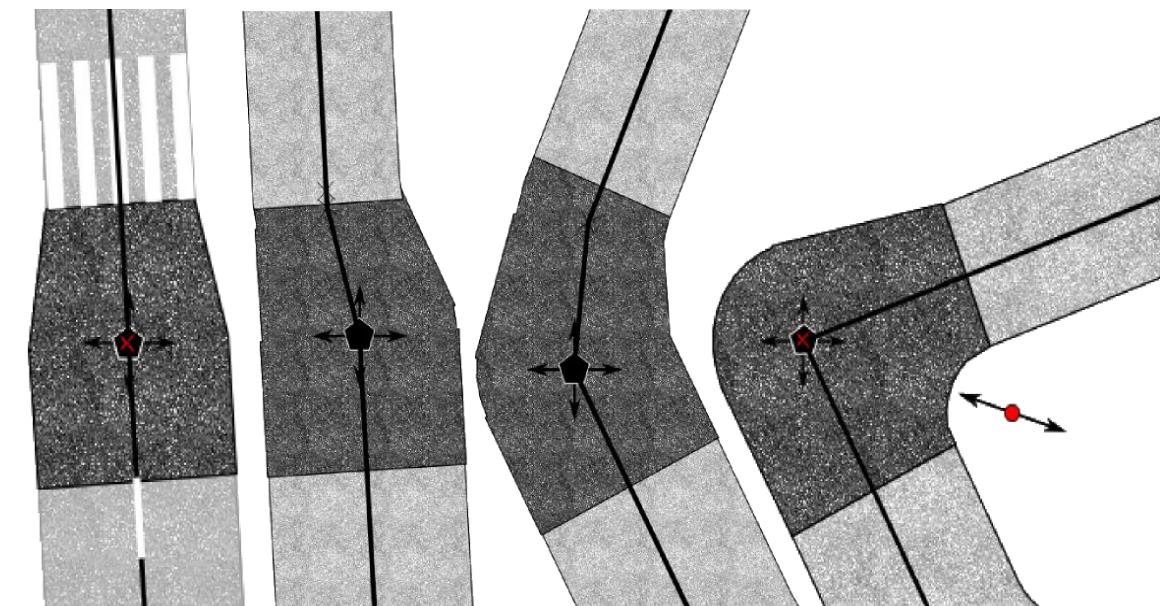
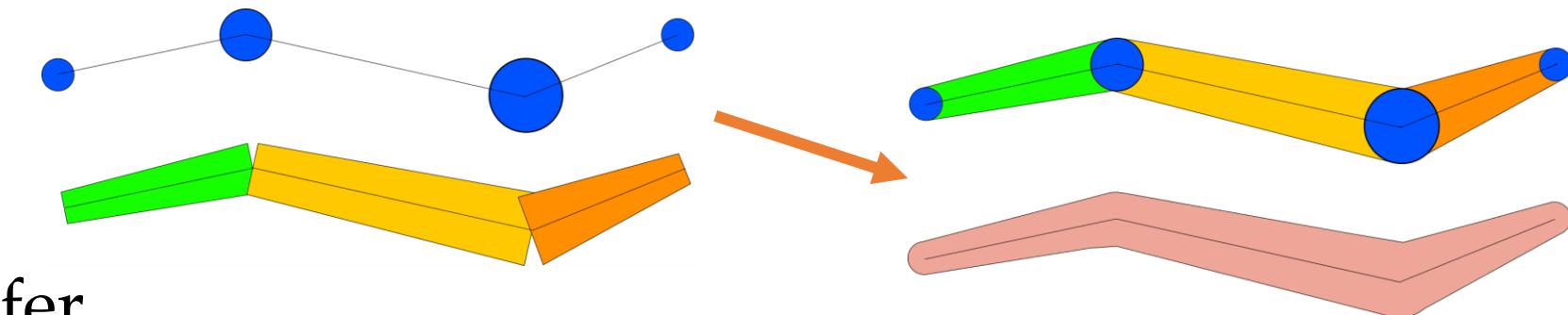
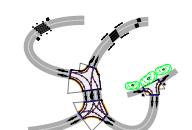
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StreetGen : street objects

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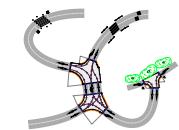
Streets

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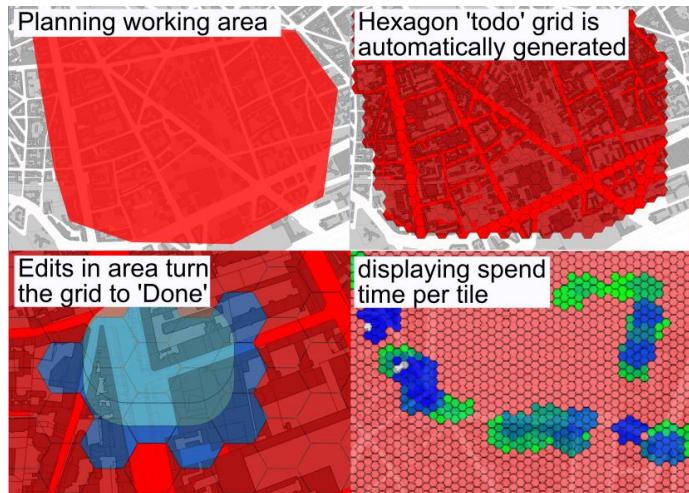
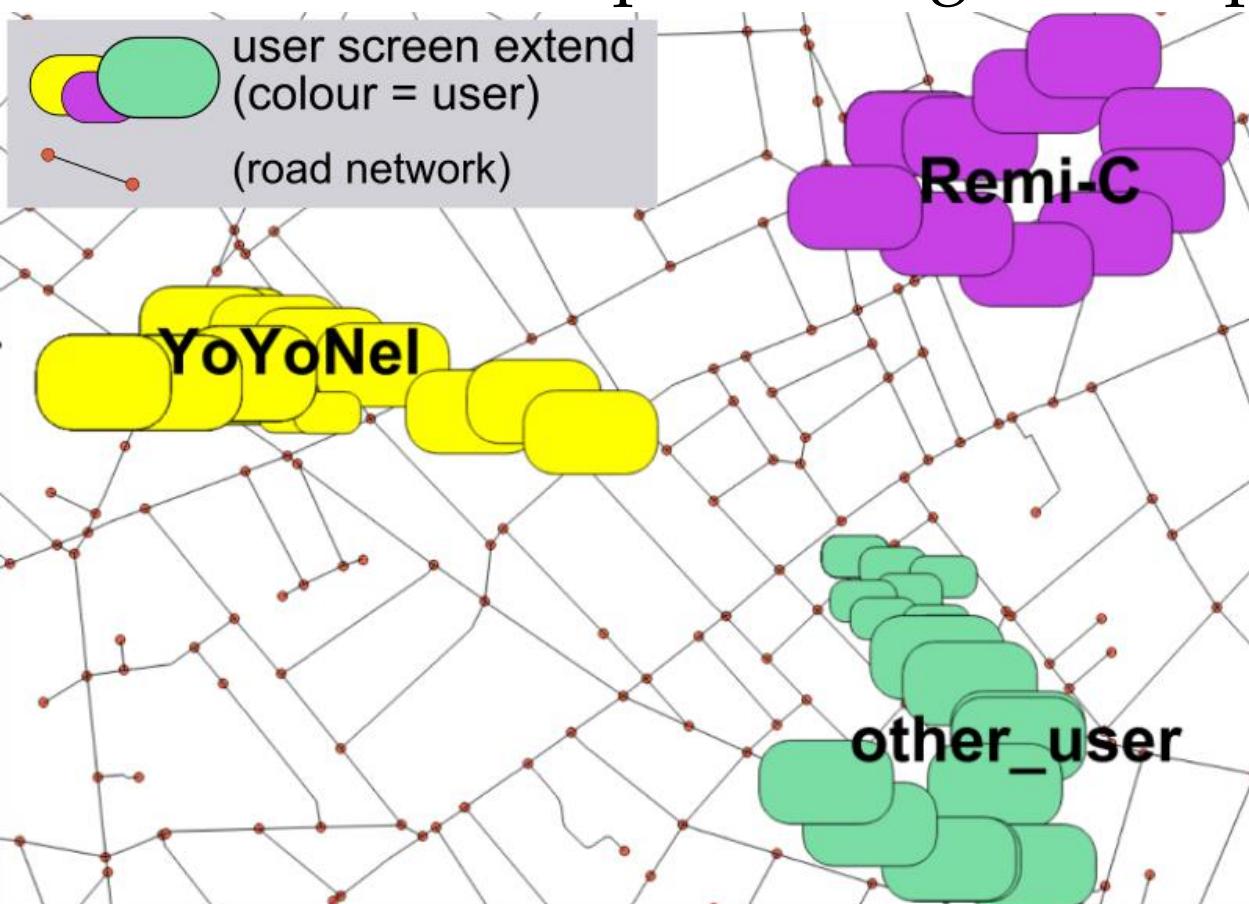
Automation

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Conclusion



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



StreetGen : Kinematic hypothesis

edge id=15; next l=16
end_node=3 ...

r=3.6 + x

edge id=16; next l=17
start_node=4 ...

r=6.4 + x

- Real example of interactive map tracking usefulness

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StreetGen

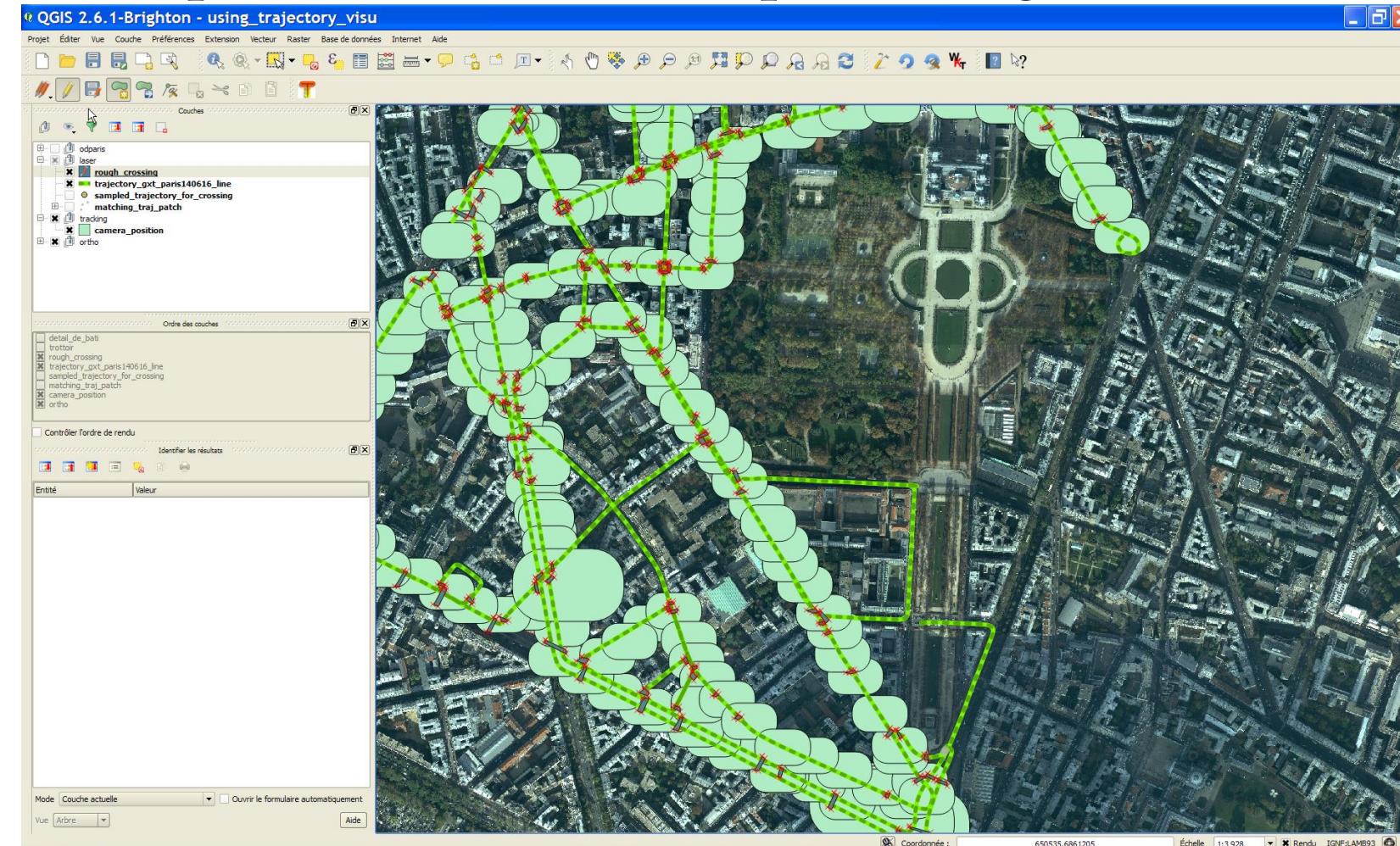
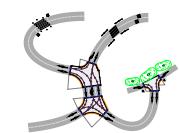
Streets

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Inverse Procedural modelling: forces

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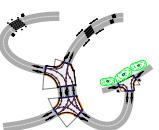
Streets

Interaction

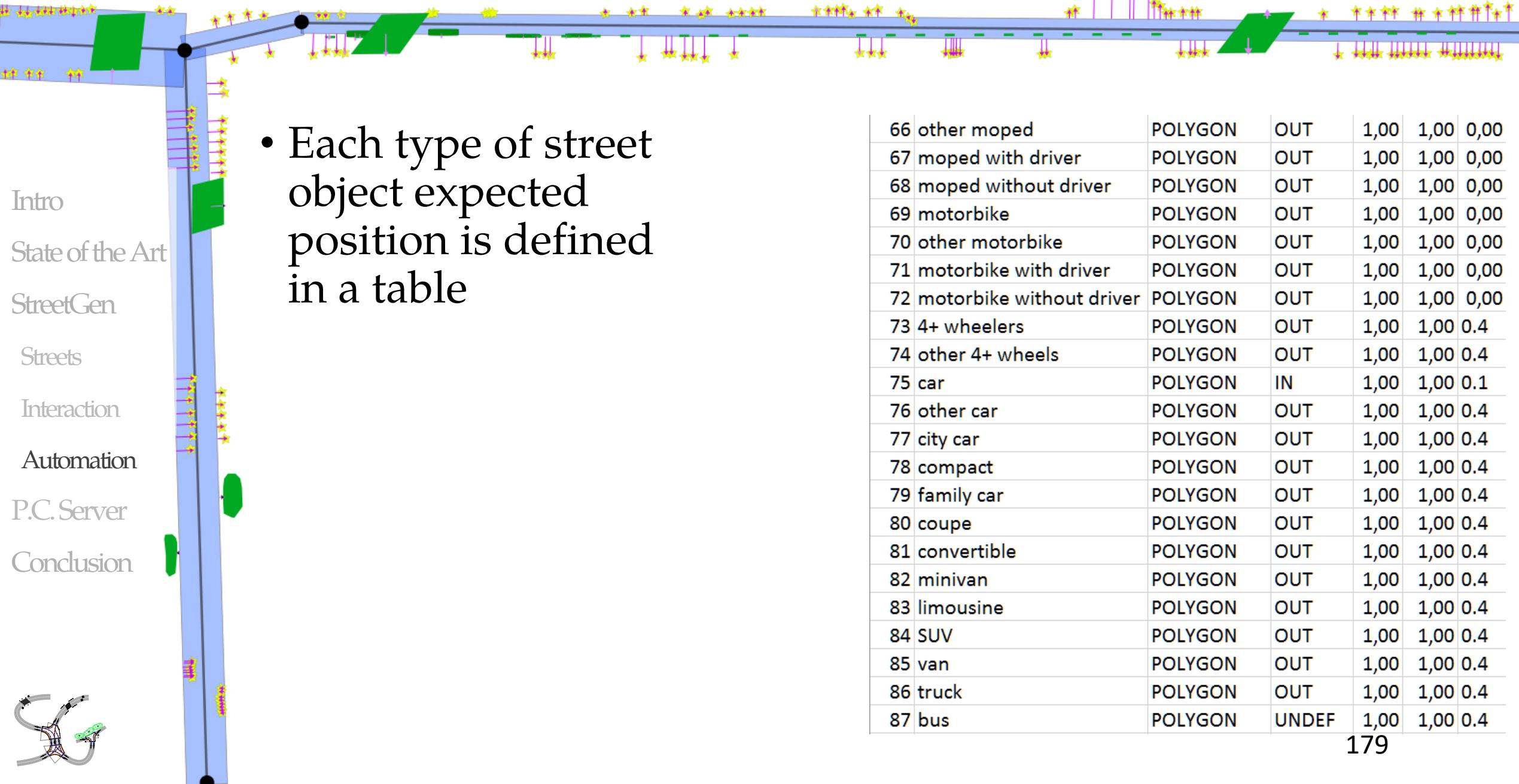
Automation

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Conclusion



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



66 other moped	POLYGON	OUT	1,00	1,00	0,00
67 moped with driver	POLYGON	OUT	1,00	1,00	0,00
68 moped without driver	POLYGON	OUT	1,00	1,00	0,00
69 motorbike	POLYGON	OUT	1,00	1,00	0,00
70 other motorbike	POLYGON	OUT	1,00	1,00	0,00
71 motorbike with driver	POLYGON	OUT	1,00	1,00	0,00
72 motorbike without driver	POLYGON	OUT	1,00	1,00	0,00
73 4+ wheelers	POLYGON	OUT	1,00	1,00	0,4
74 other 4+ wheels	POLYGON	OUT	1,00	1,00	0,4
75 car	POLYGON	IN	1,00	1,00	0,1
76 other car	POLYGON	OUT	1,00	1,00	0,4
77 city car	POLYGON	OUT	1,00	1,00	0,4
78 compact	POLYGON	OUT	1,00	1,00	0,4
79 family car	POLYGON	OUT	1,00	1,00	0,4
80 coupe	POLYGON	OUT	1,00	1,00	0,4
81 convertible	POLYGON	OUT	1,00	1,00	0,4
82 minivan	POLYGON	OUT	1,00	1,00	0,4
83 limousine	POLYGON	OUT	1,00	1,00	0,4
84 SUV	POLYGON	OUT	1,00	1,00	0,4
85 van	POLYGON	OUT	1,00	1,00	0,4
86 truck	POLYGON	OUT	1,00	1,00	0,4
87 bus	POLYGON	UNDEF	1,00	1,00	0,4

Inverse Procedural modelling: forces

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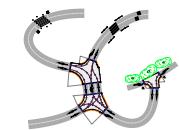
Streets

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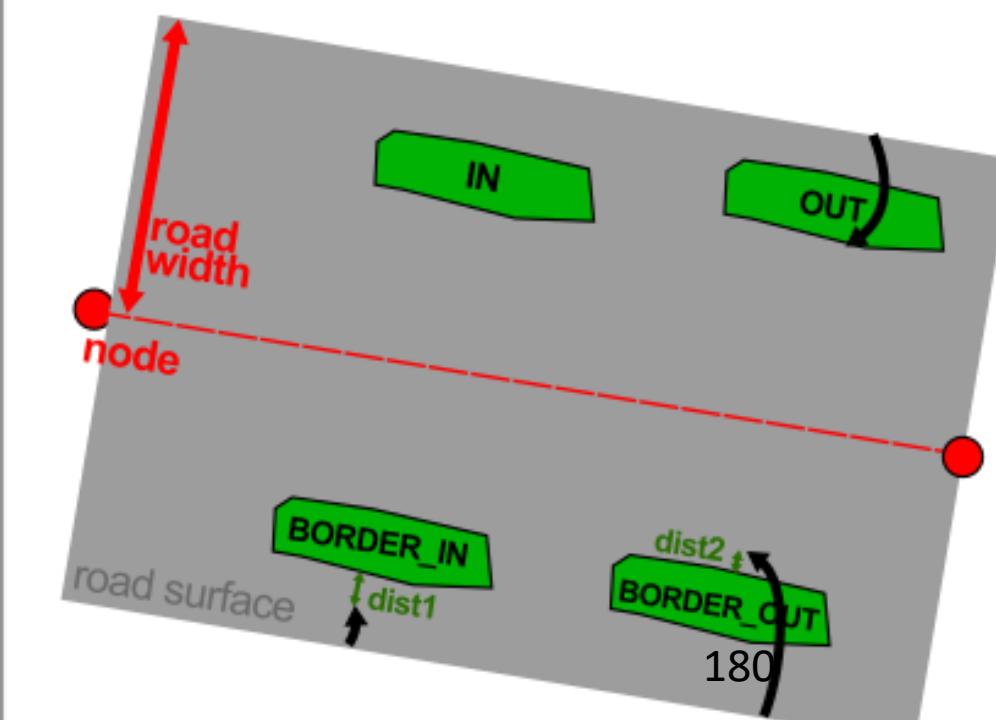
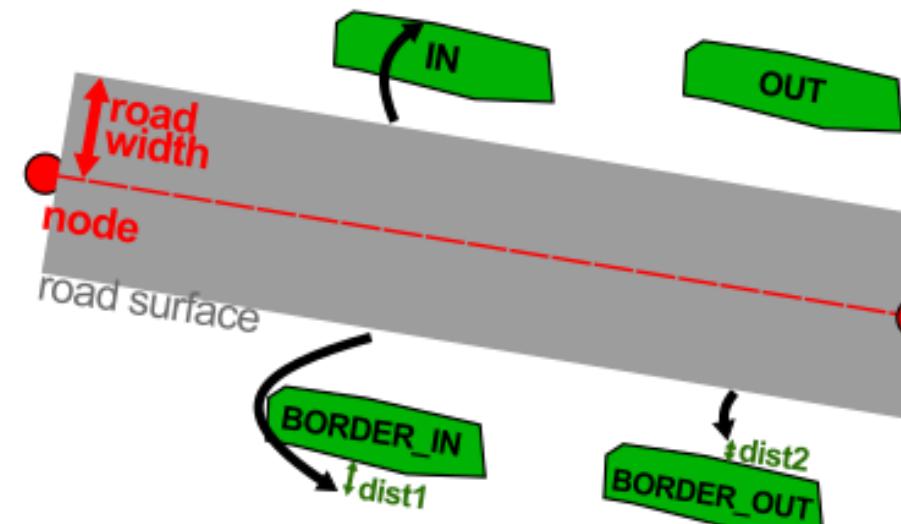
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Conclusion



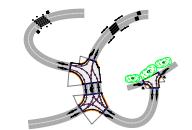
- Observations generate forces on road axis/width
- Each street object type has an expected position:
 - IN/OUT + BORDER_IN/BORDER_OUT + dist

parameters observation ↗ induced behaviour



Inverse Procedural modelling : matching

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- Observations generate force on road axis/width,
- But first :
- Observation ←matching→ road axis:
- Closest road surface



Inverse Procedural modelling: matching

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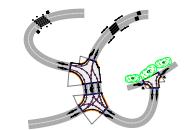
Streets

Interaction

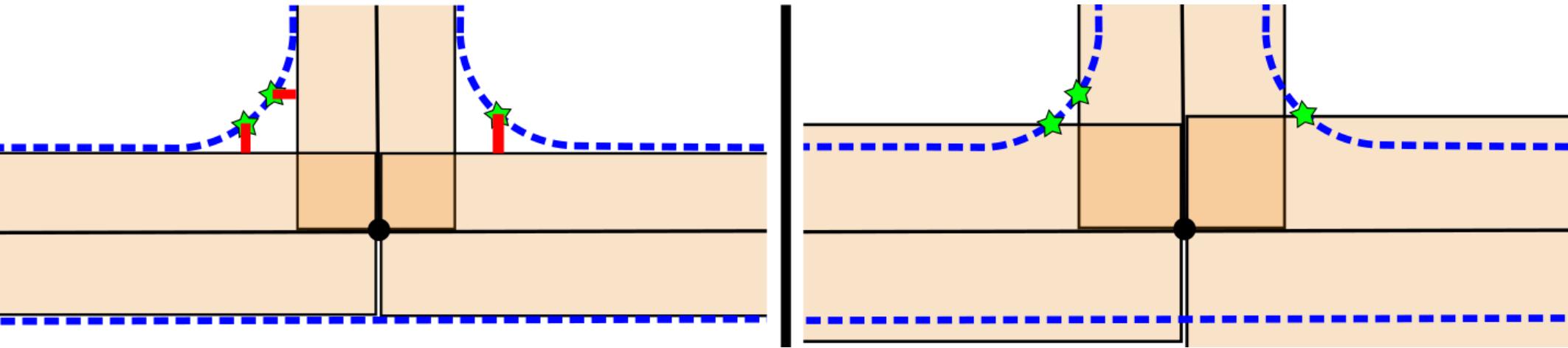
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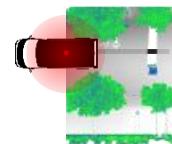
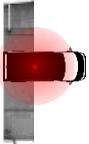
Conclusion



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



Point Cloud Server: Method



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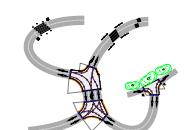
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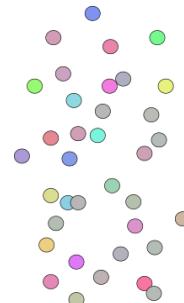
Conclusion



- Main idea about storage

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

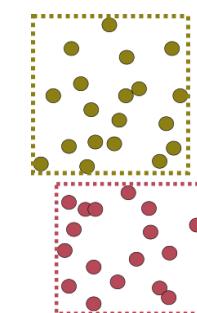
1 row = 1 point
Analogy : Pixels



Billions
points



1 row = N points
Analogy : Image

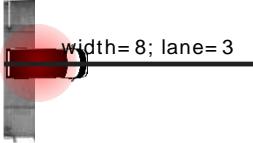


Million
groups

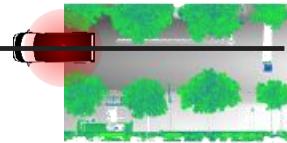


Usage : do we really need
to get points 1 by 1?





width=6; lane=2



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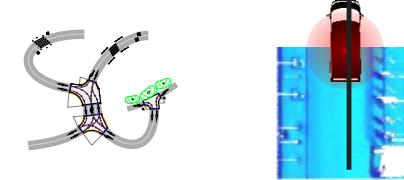
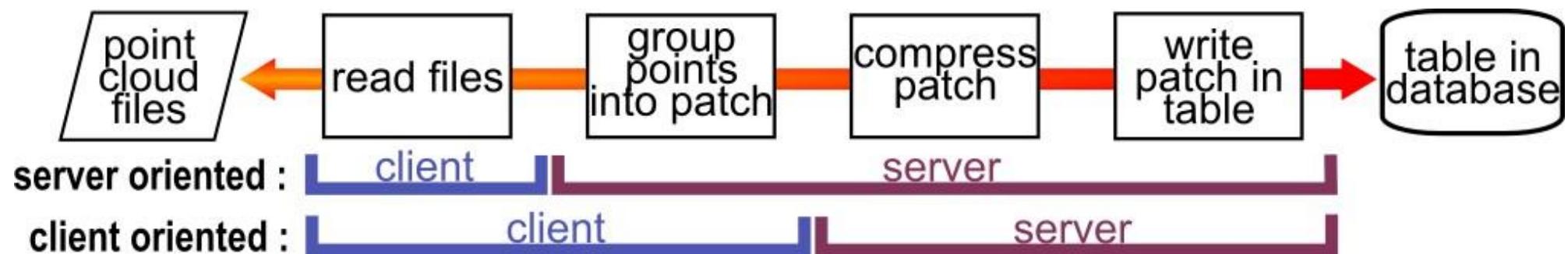
Interaction

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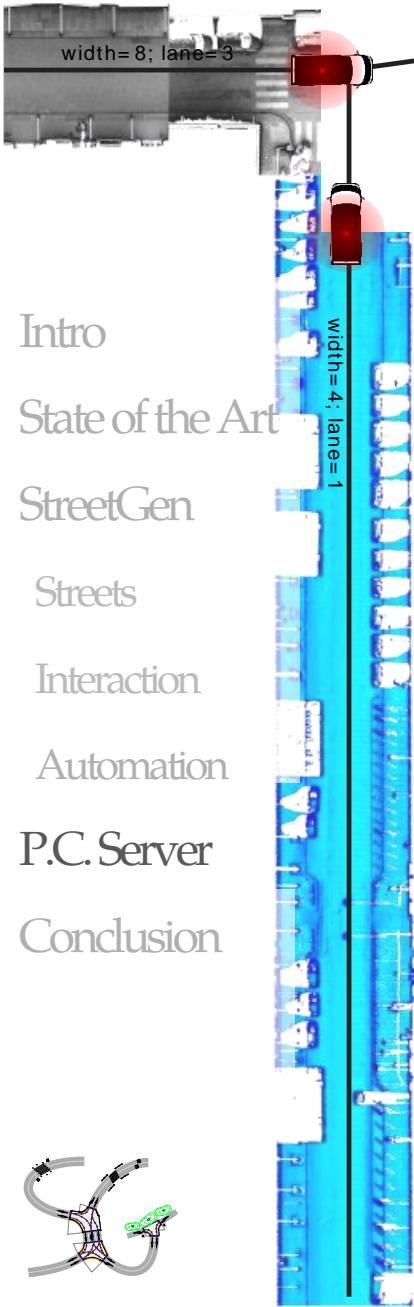
P.C. Server

Conclusion

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



Point Cloud Server: Level Of Detail



- For visualisation, LOD depends on distance to camera

