

# Inverse procedural Street Modelling: from interactive to automatic reconstruction

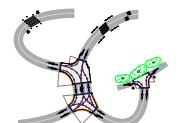
Phd Defense : Rémi Cura, 2016/09/12



Jury:

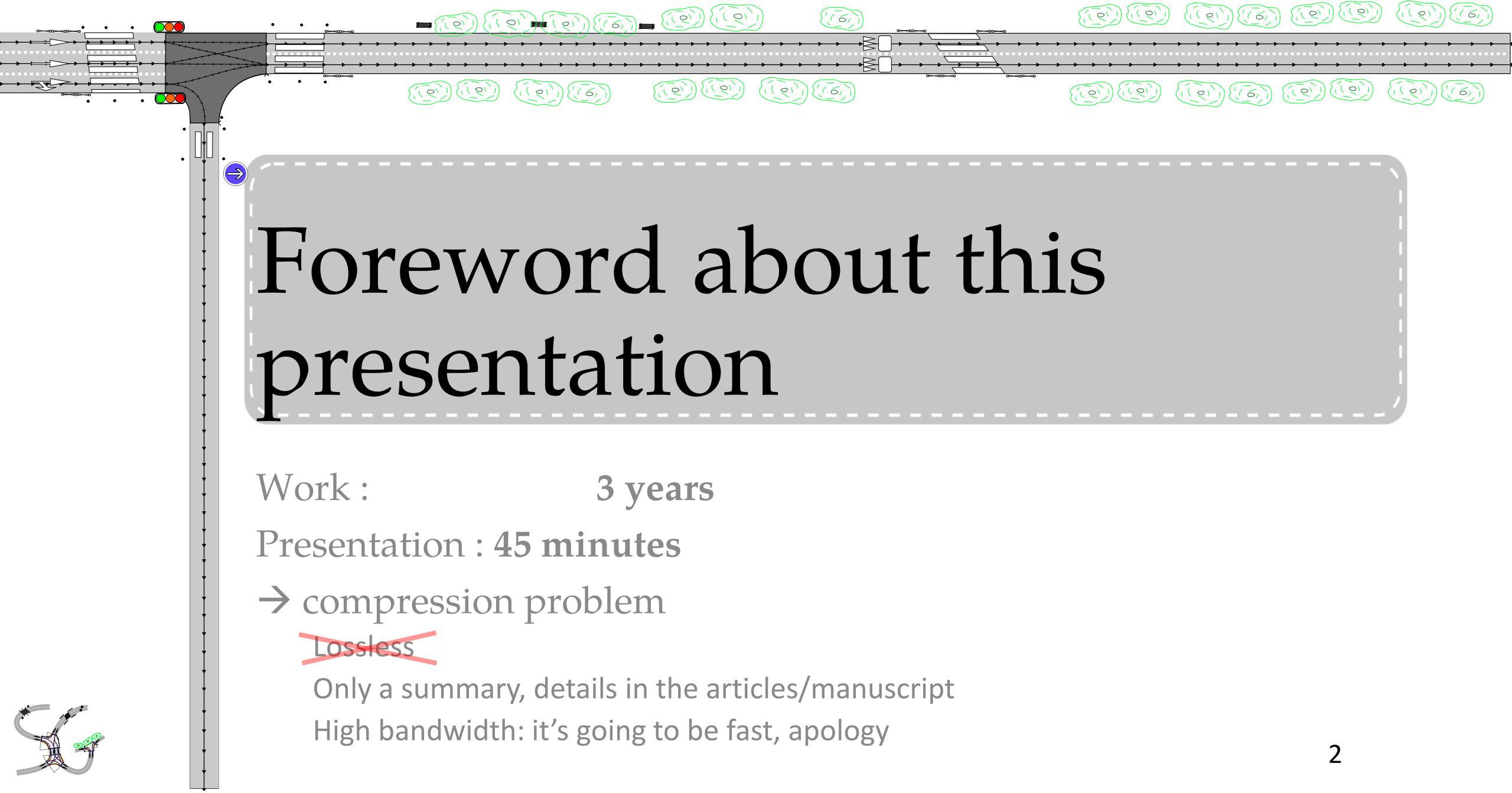
Pr. Christian Heipke (IPI) **R**  
Pr. Peter Van Oosterom (TUDelft) **R**  
Dr. Florent Lafarge (INRIA) **E**  
Pr. Gilles Gesquière (LIRIS) **E**

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



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

UNIVERSITÉ —  
— PARIS-EST  
IGN   
COGIT MATHÉMATIQUES ET SCIENCES DE L'INFORMATION  
INFORMATIQUE, GEODESIE, TÉLÉTOPOGRAPHIE



# Foreword about this presentation

Work : **3 years**

Presentation : **45 minutes**

→ compression problem

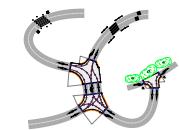
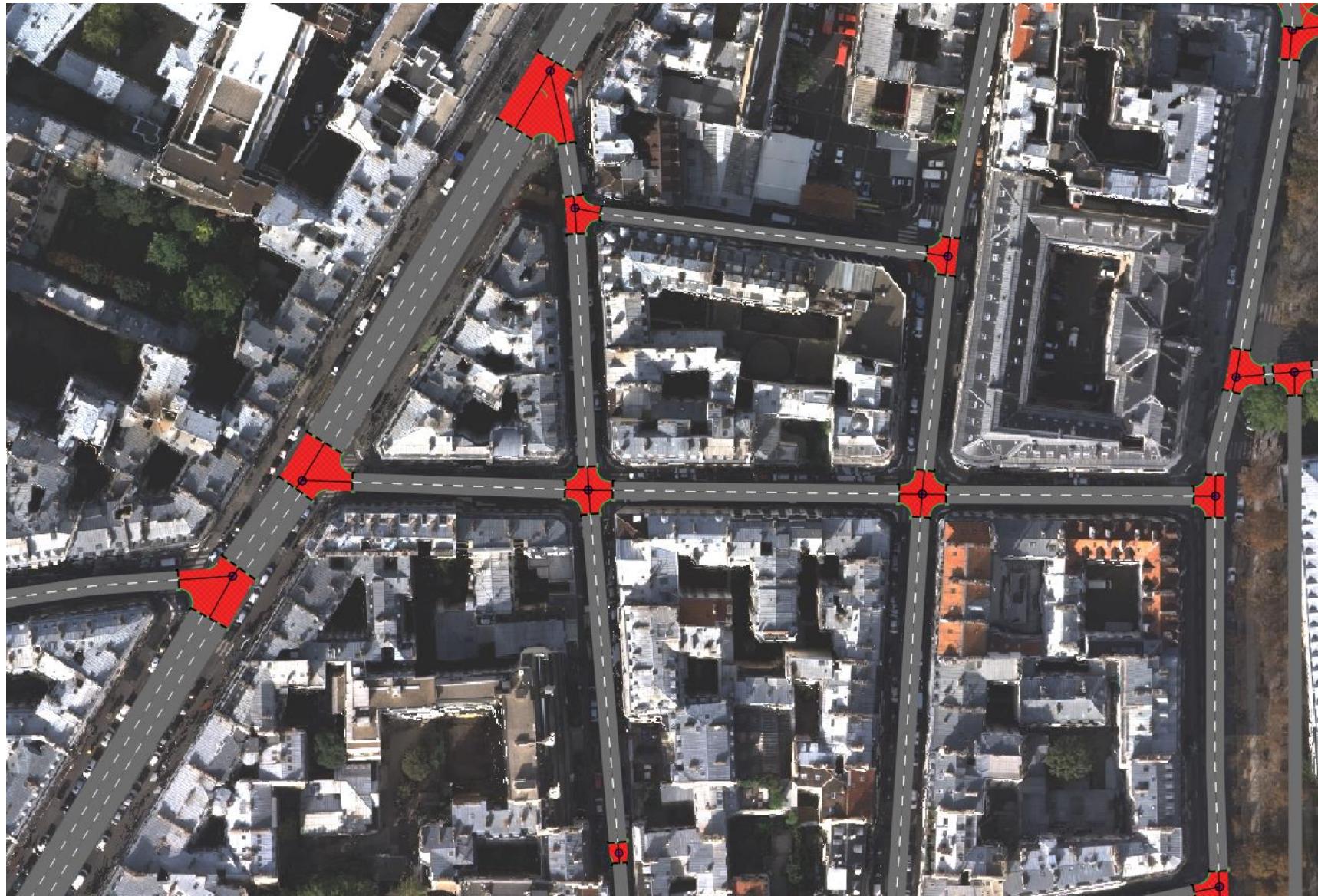
~~Lossless~~

Only a summary, details in the articles/manuscript

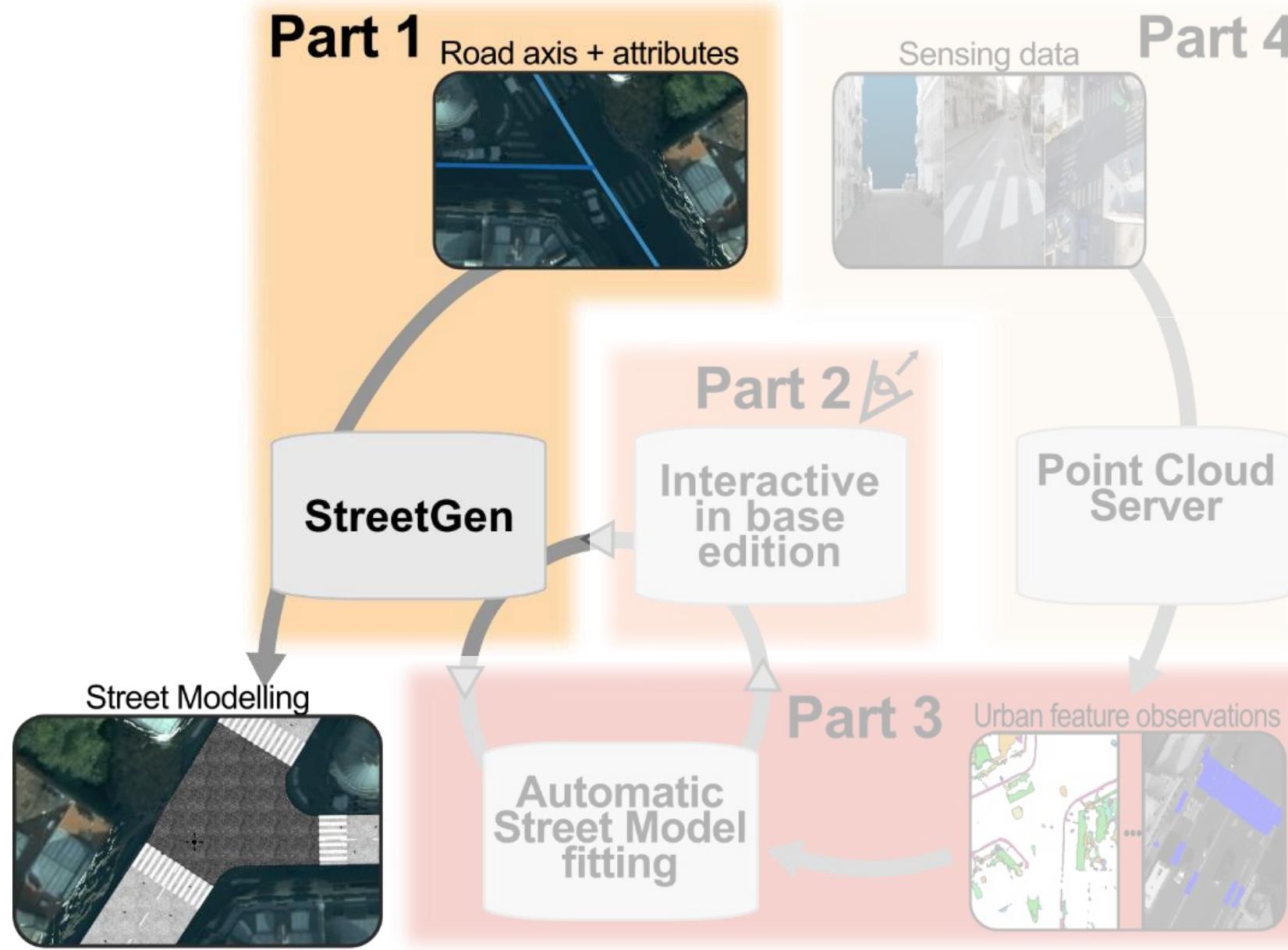
High bandwidth: it's going to be fast, apology

# Abstract

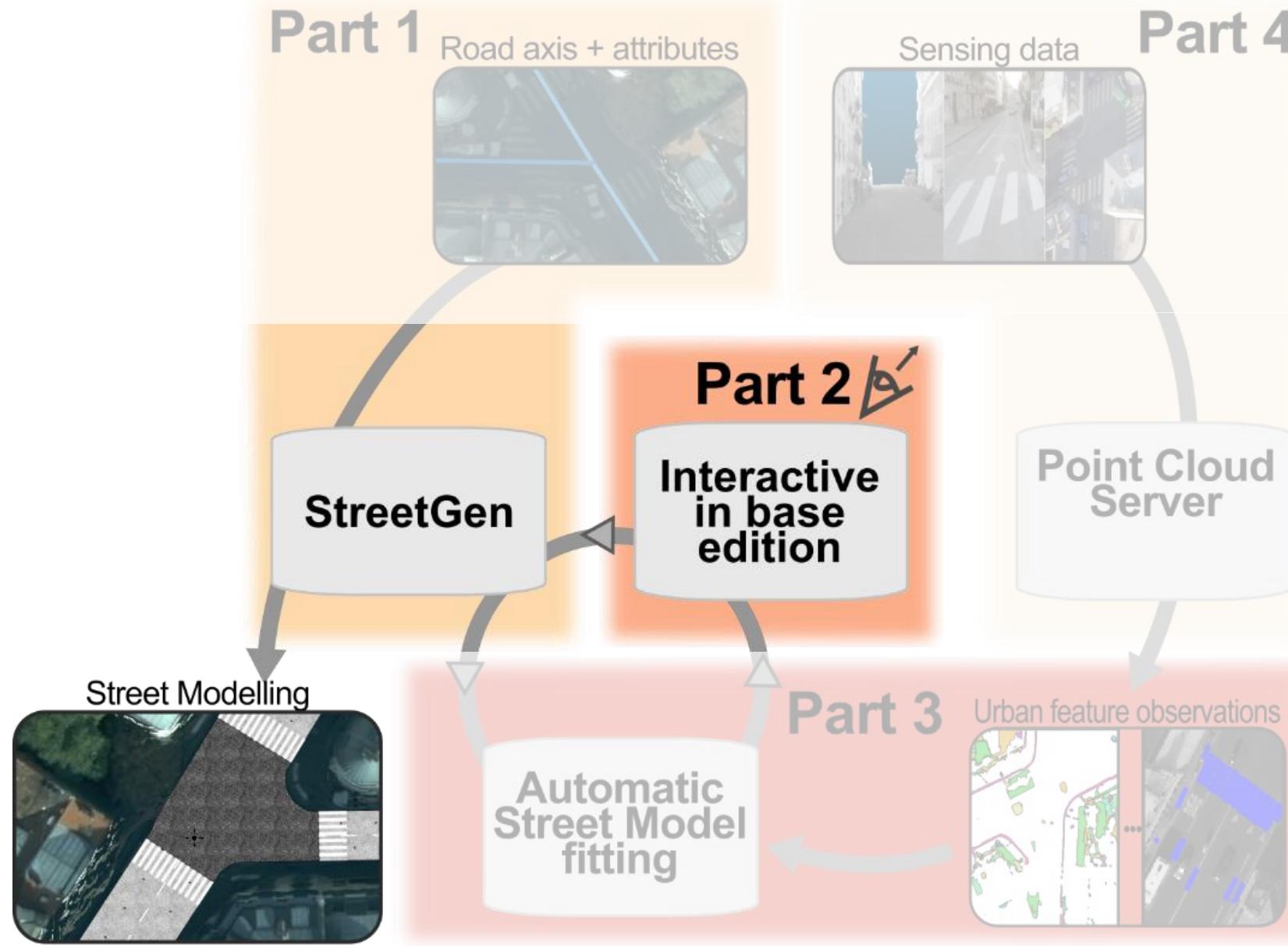
- Procedural street modelling:
- Model streets!



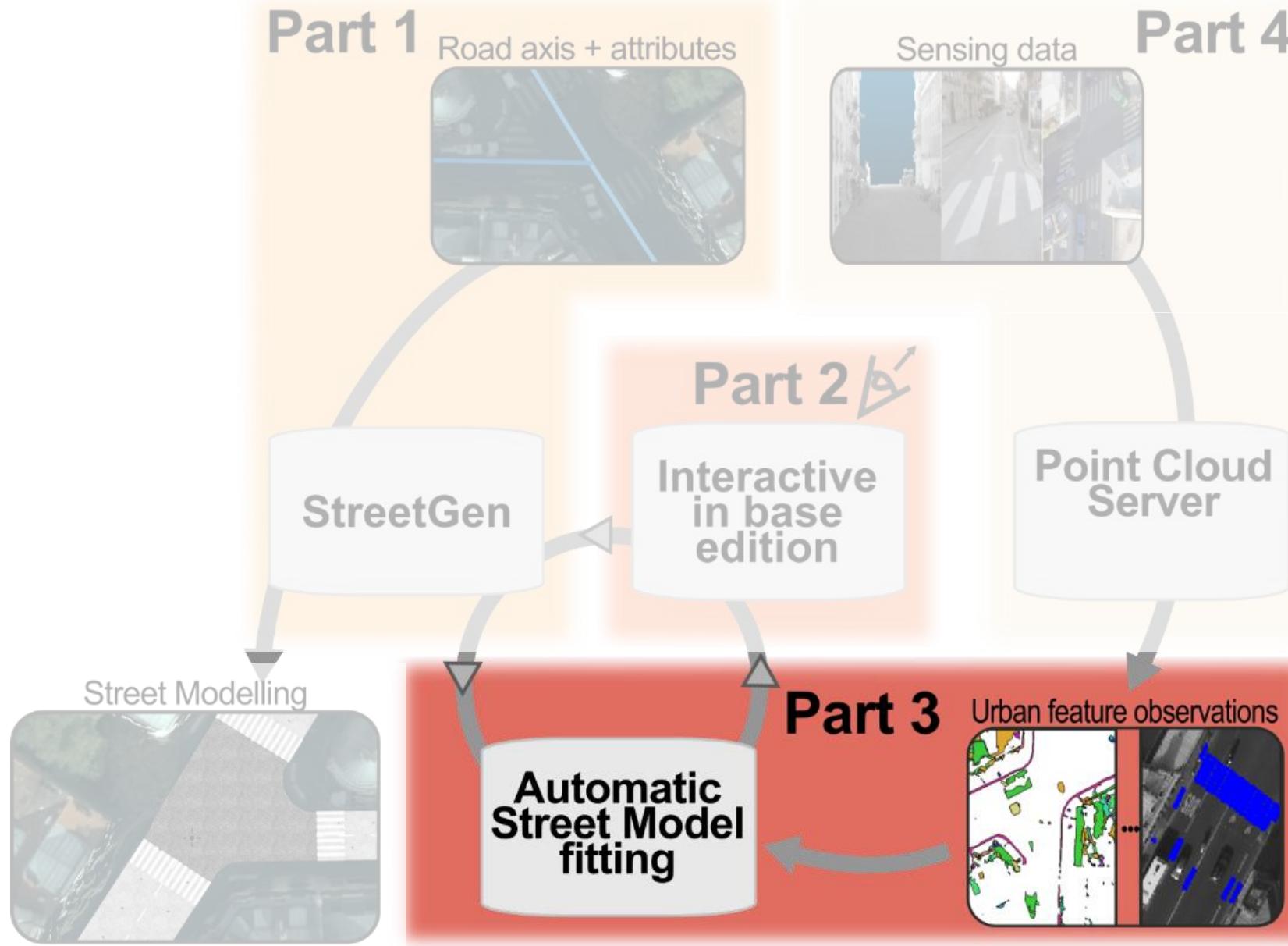
# Abstract



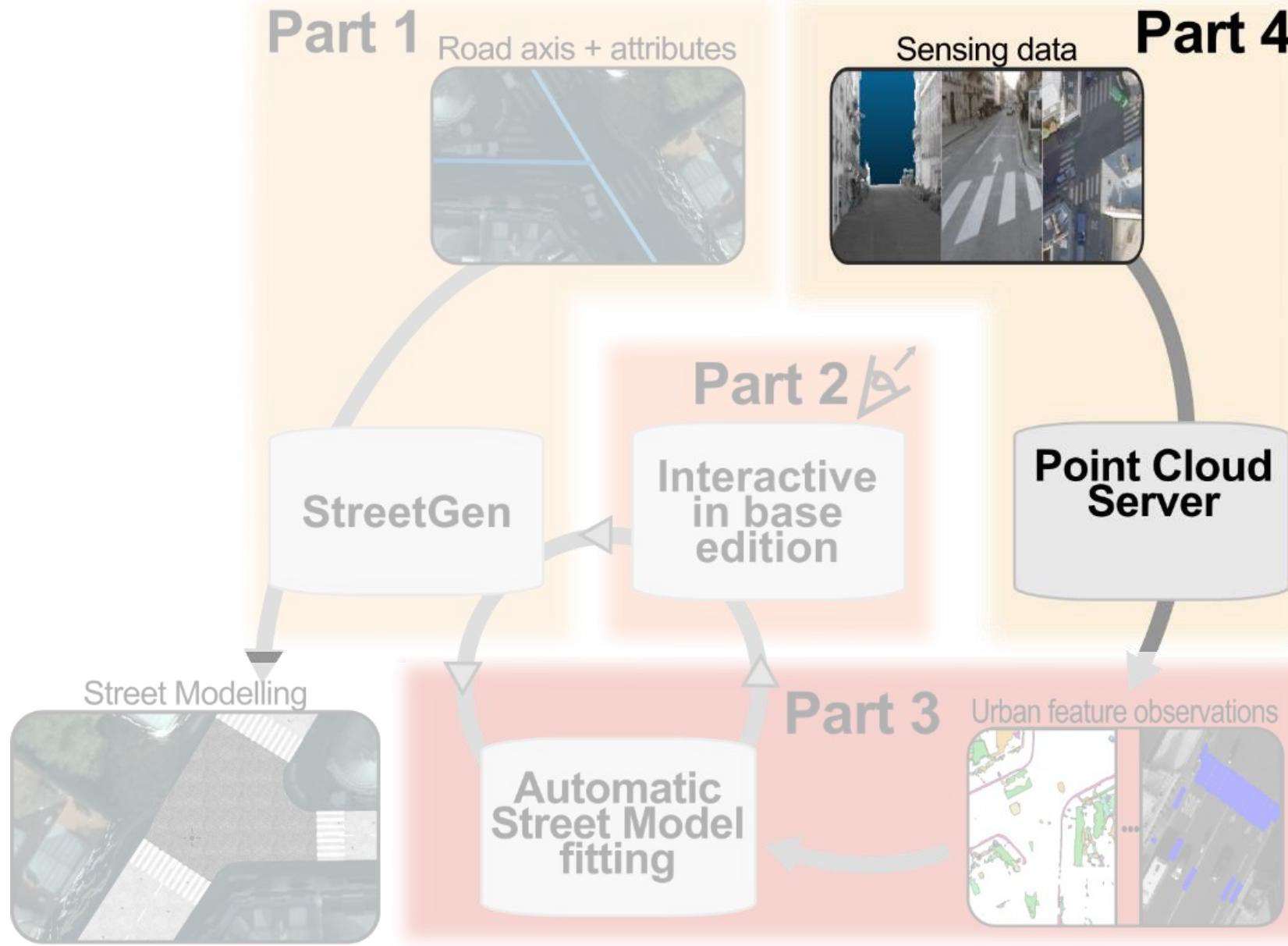
# Abstract



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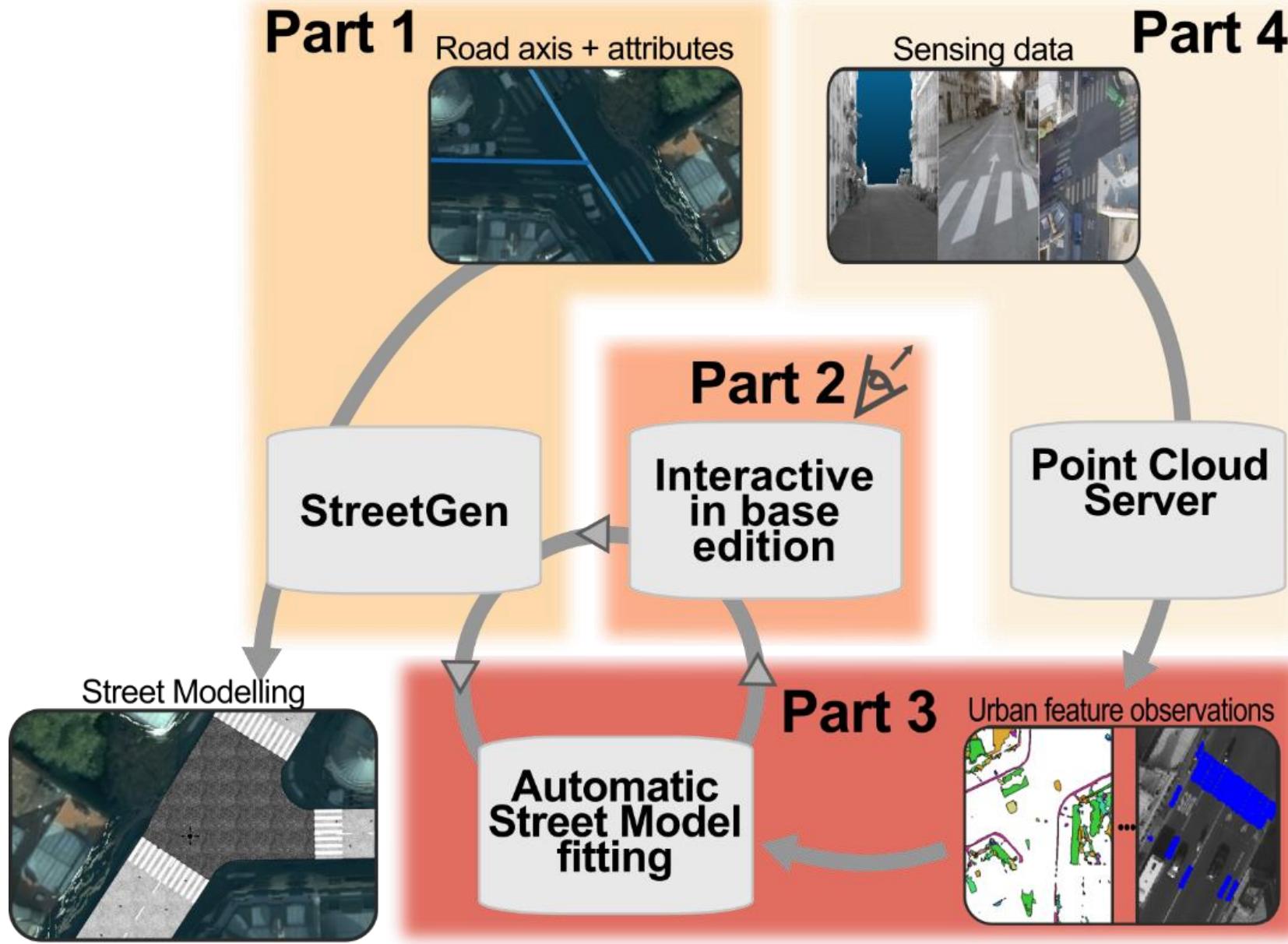


# Abstract



# Abstract

All parts +  
Intro  
State of the art  
conclusion



width= 8; lane= 3

width= 6; lane= 2

Intro

State of the Art

StreetGen

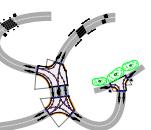
Streets

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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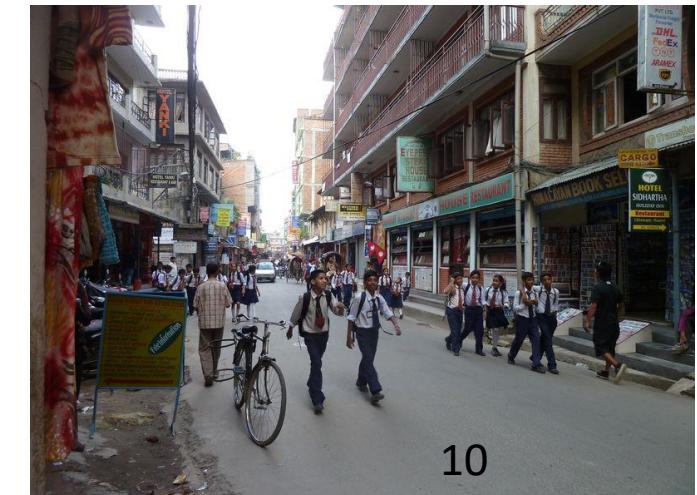
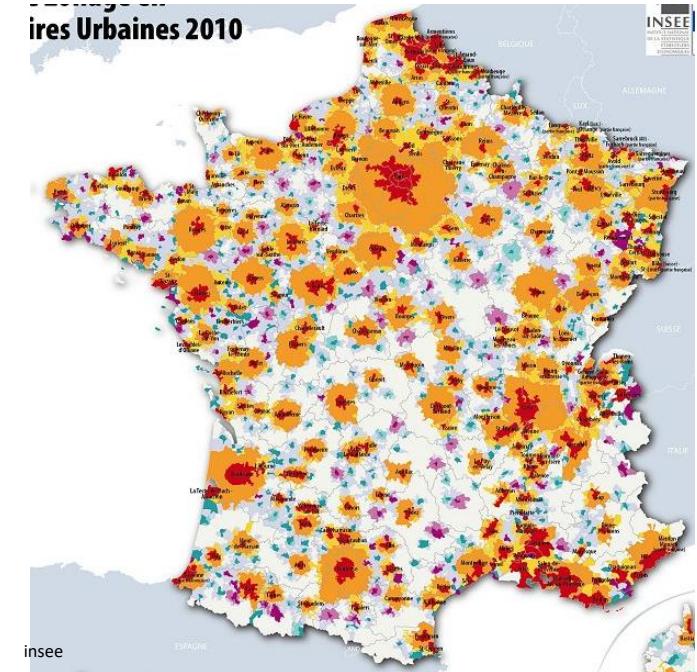
Interaction

Automation

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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



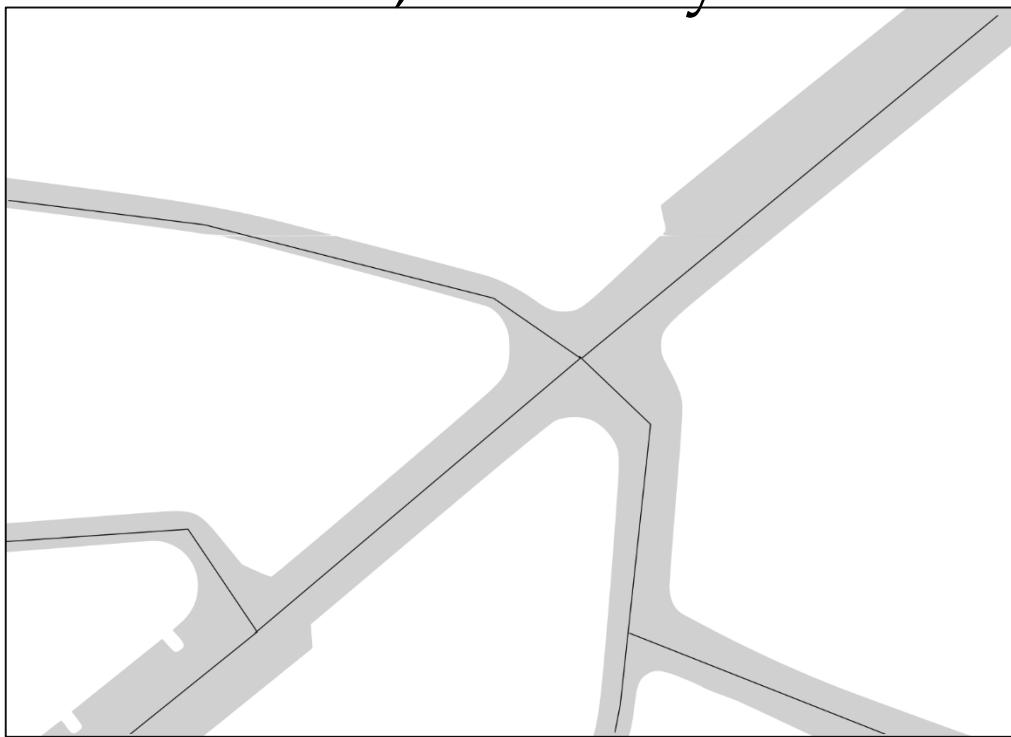
# Introduction: Streets are important

width= 8; lane= 3

width= 6; lane= 2

- Road axis, roadway

width = 4; lane = 1

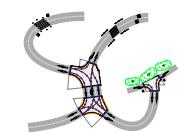


vs

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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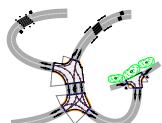
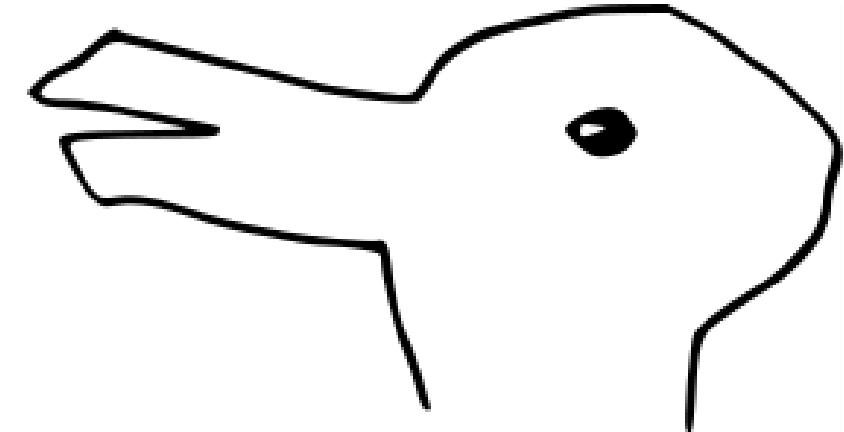
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width= 8; lane= 3

width= 6; lane= 2

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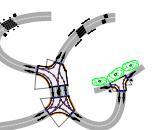
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# Introduction

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



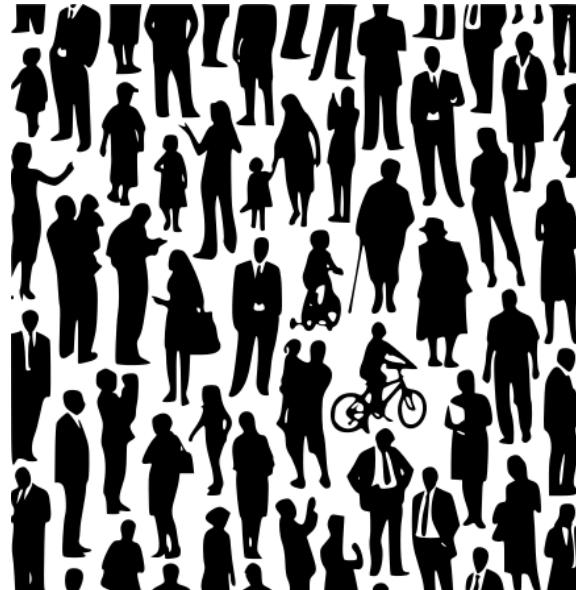
# Introduction: usages for street model

width= 8; lane= 3

width= 6; lane= 2

## Visualisation / analysis / simulation

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



Thales TVNG

Intro

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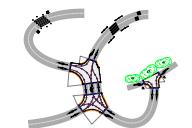
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# Introduction: usages for street model

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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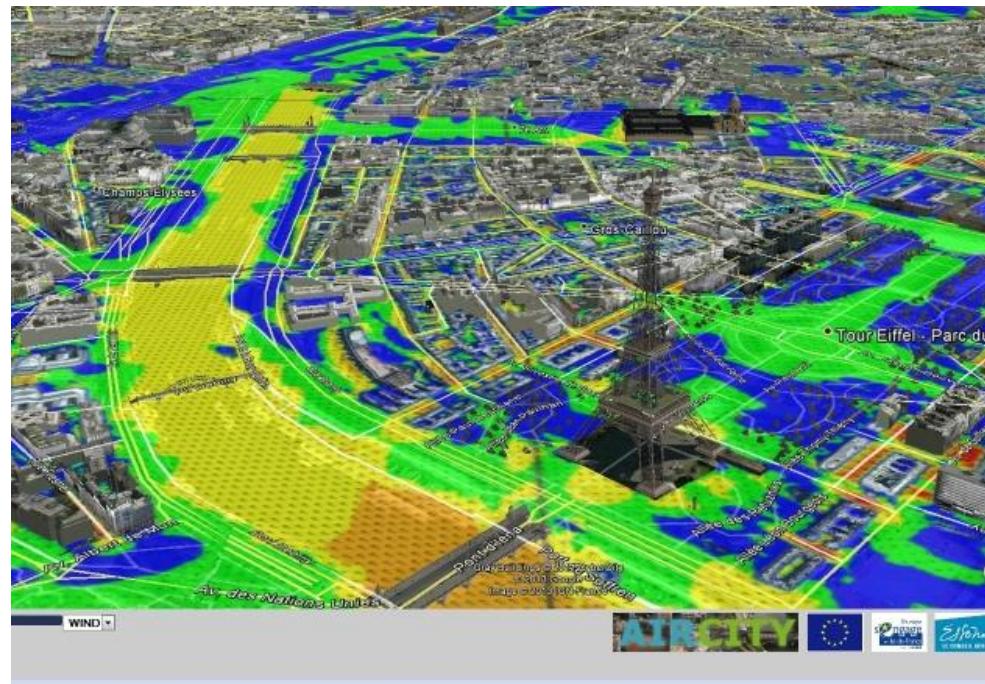
Streets

Interaction

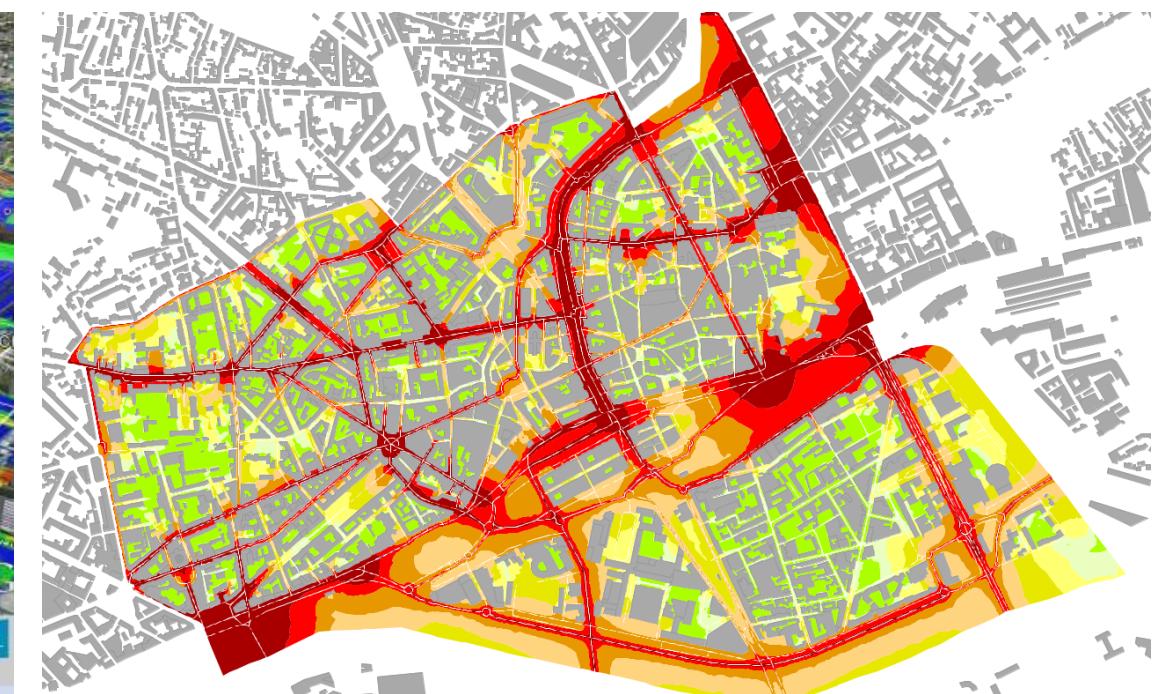
Automation

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Conclusion



Air city: pollution



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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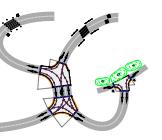
P.C. Server

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 ...



Intro

State of the Art

StreetGen

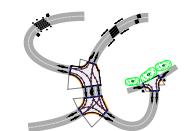
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# State of the art: modelling street is hard

edge\_id= 15; next\_l= 16  
end\_node= 3 ...

edge\_id= 16; next\_l= 17  
start\_node= 4 ...

- 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 ...

edge\_id= 16; next\_l= 17  
start\_node= 4 ...

- complex / traffic / organisation/ sensing

edge\_id= 17; next\_l= 16  
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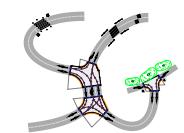
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# State of the art: modelling street is hard

edge\_id= 15; next\_l= 16  
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- complex / traffic / organisation/ sensing

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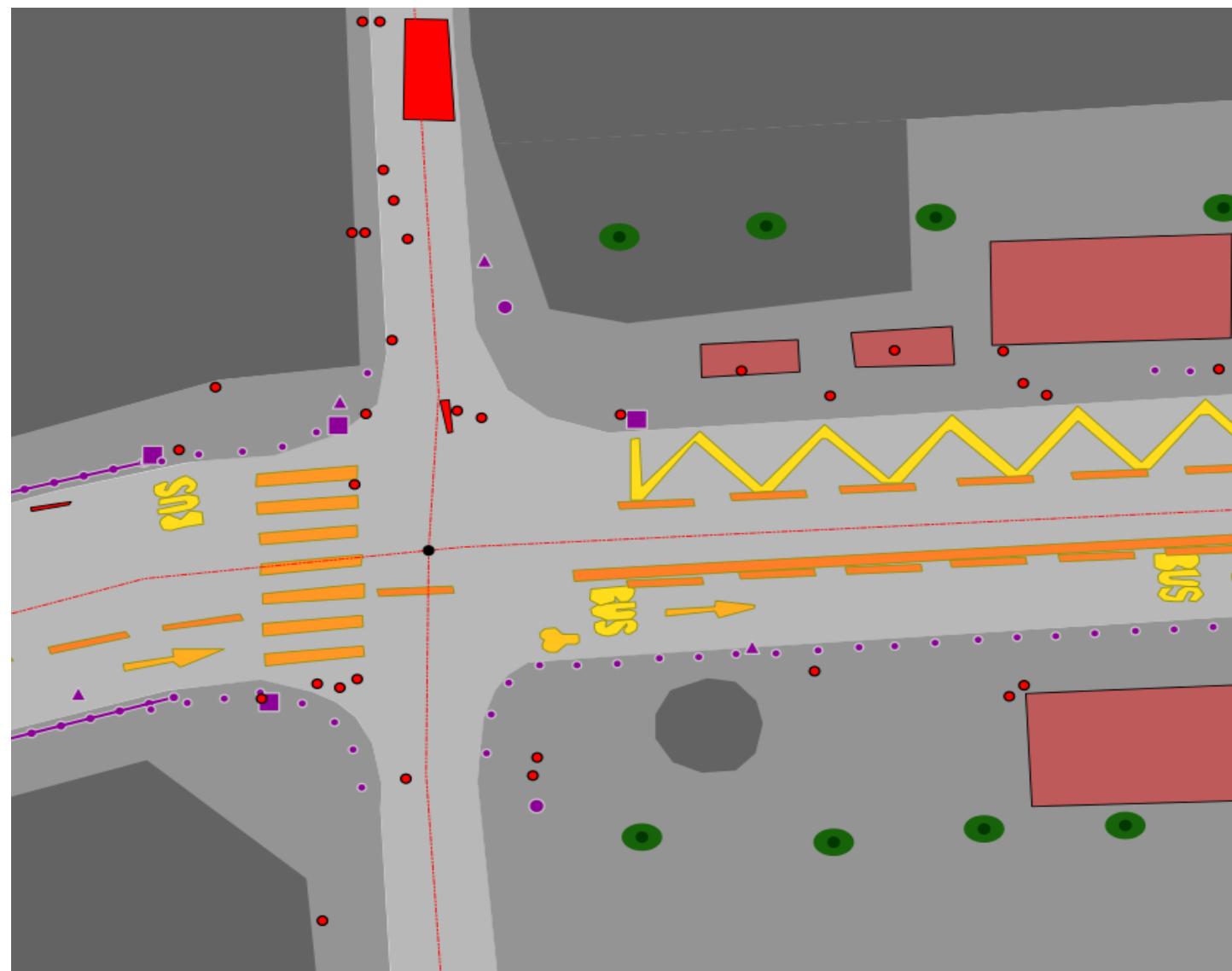
Interaction

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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

edge\_id= 15; next\_l= 16  
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- complex / traffic / organisation/ sensing

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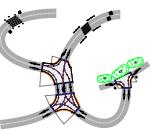
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# State of the art: modelling street is hard

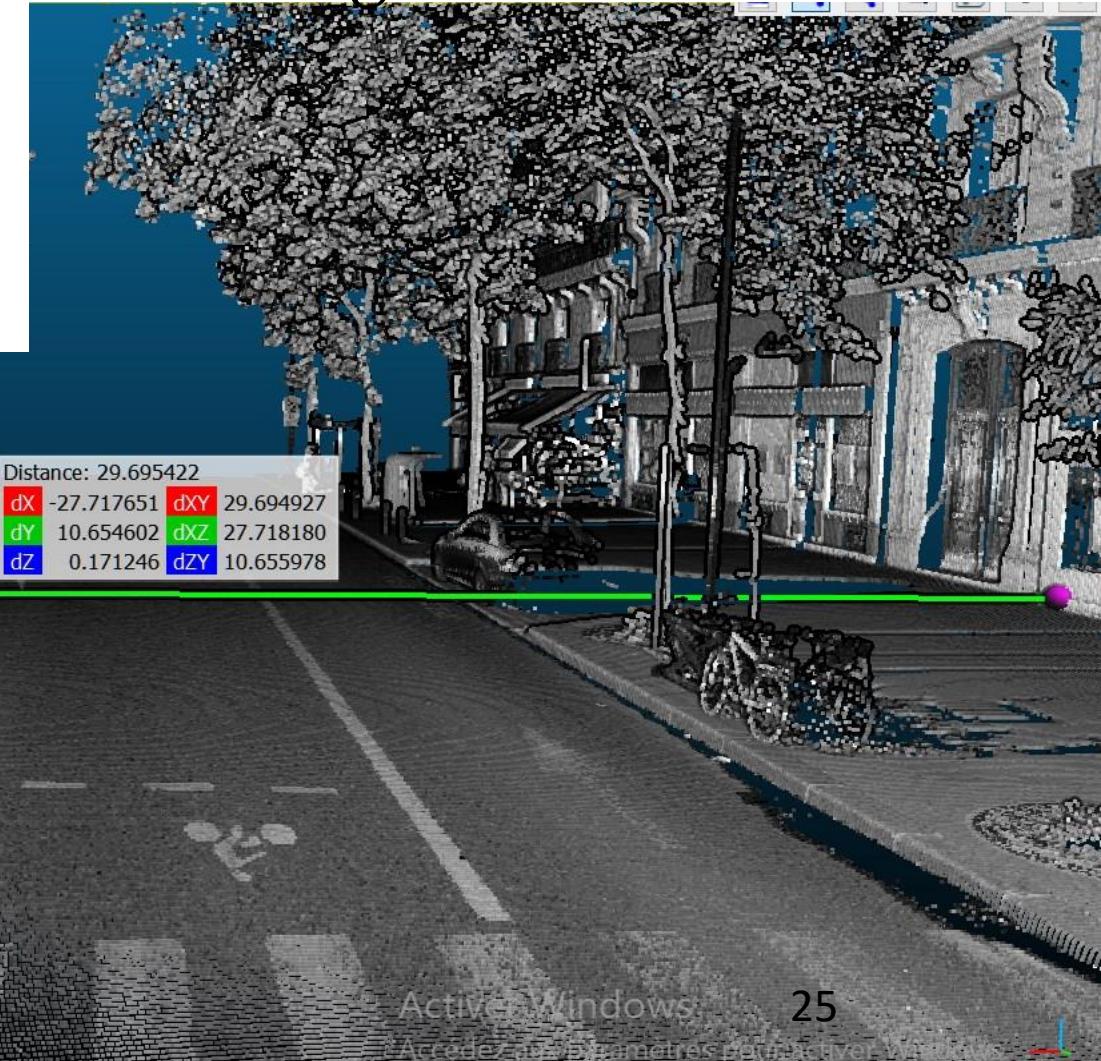
edge\_id=15; next\_l=16  
end\_node=3 ...

- complex / traffic / organisation/ sensing

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

edge\_id=16; next\_l=17  
start\_node=4 ...

edge\_id=17; next\_l=16  
start\_node=4 ...



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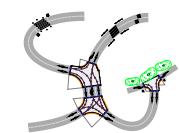
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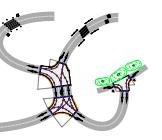
P.C. Server

Conclusion

# State of the art

Modelling street, why is it hard?

## Existing methods



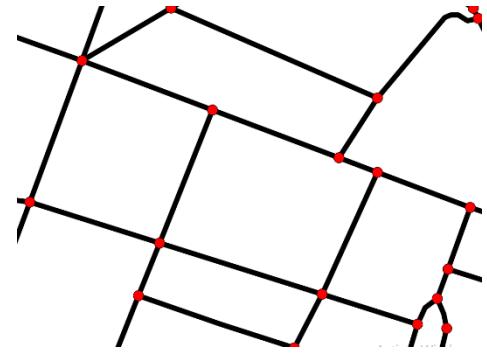
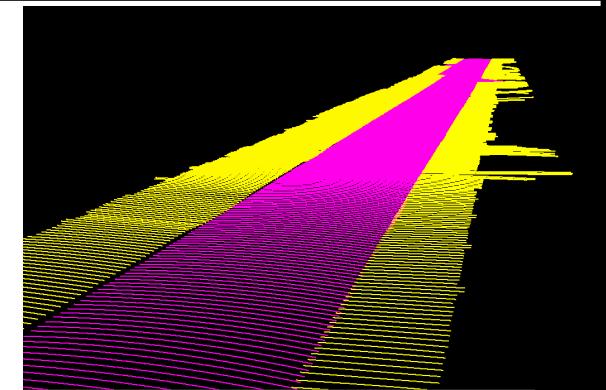
# State of the art: Existing models

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 ...



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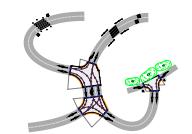
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**data-  
driven**

**model-  
driven**

**for traffic  
simulation**

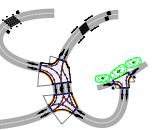
**procedural**

**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

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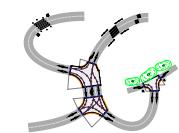
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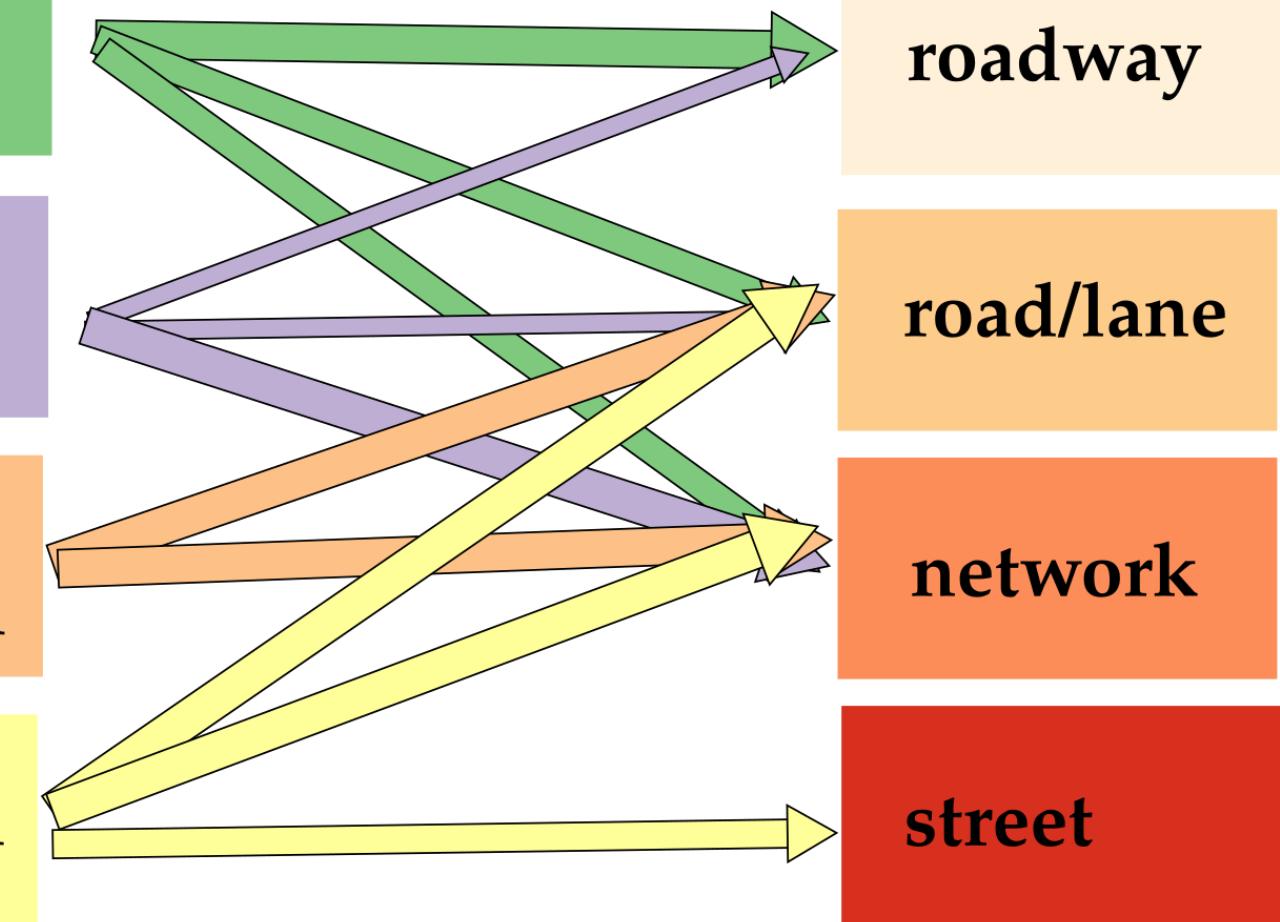


**data-driven**

**model-driven**

**for traffic simulation**

**procedural**



# State of the art: Existing models

edge\_id=15; next\_l=16  
end\_node=3 ...

edge\_id=16; next\_l=17  
start\_node=4 ...

Data-driven / Model driven / traffic simulation / Procedural

- Data-driven modelling
  - From lidar

Boyko2011



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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  
end\_node=3 ...

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start\_node=4 ...

Data-driven / Model driven / traffic simulation / Procedural

- Data-driven modelling
  - From aerial images

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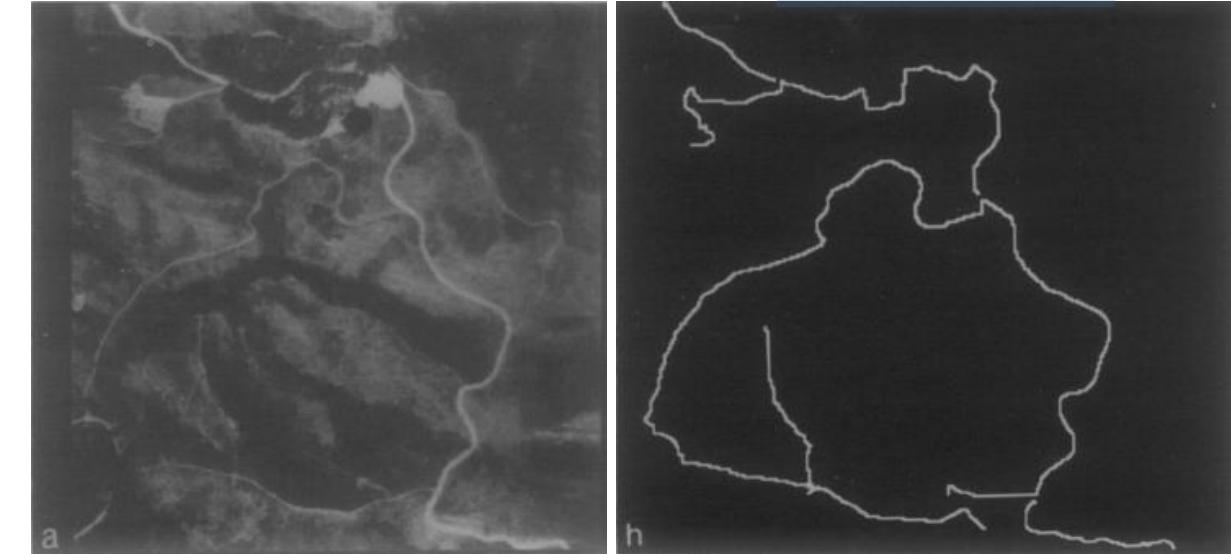
Interaction

Automation

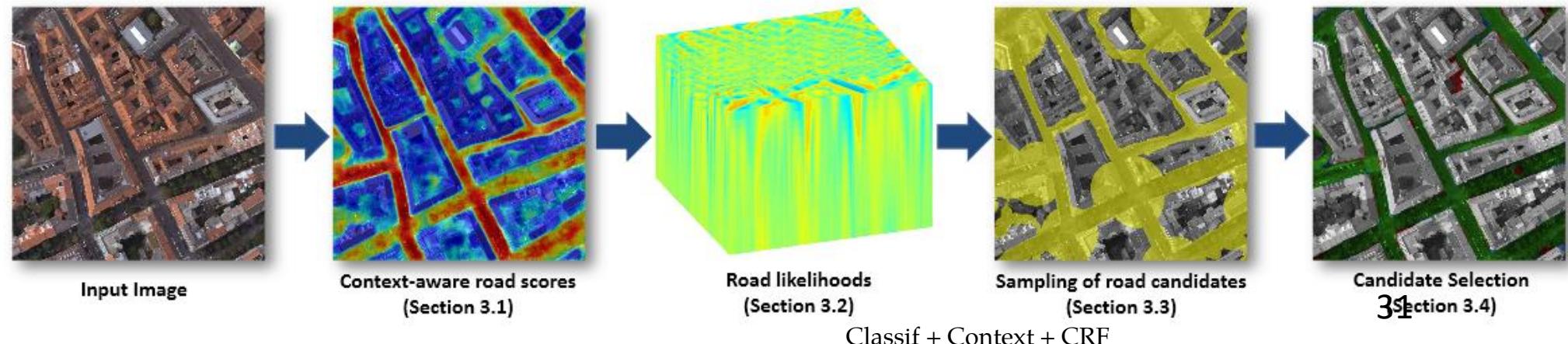
P.C. Server

Conclusion

Fischler1981



Montoya-Zegarra2014



# State of the art: Existing models

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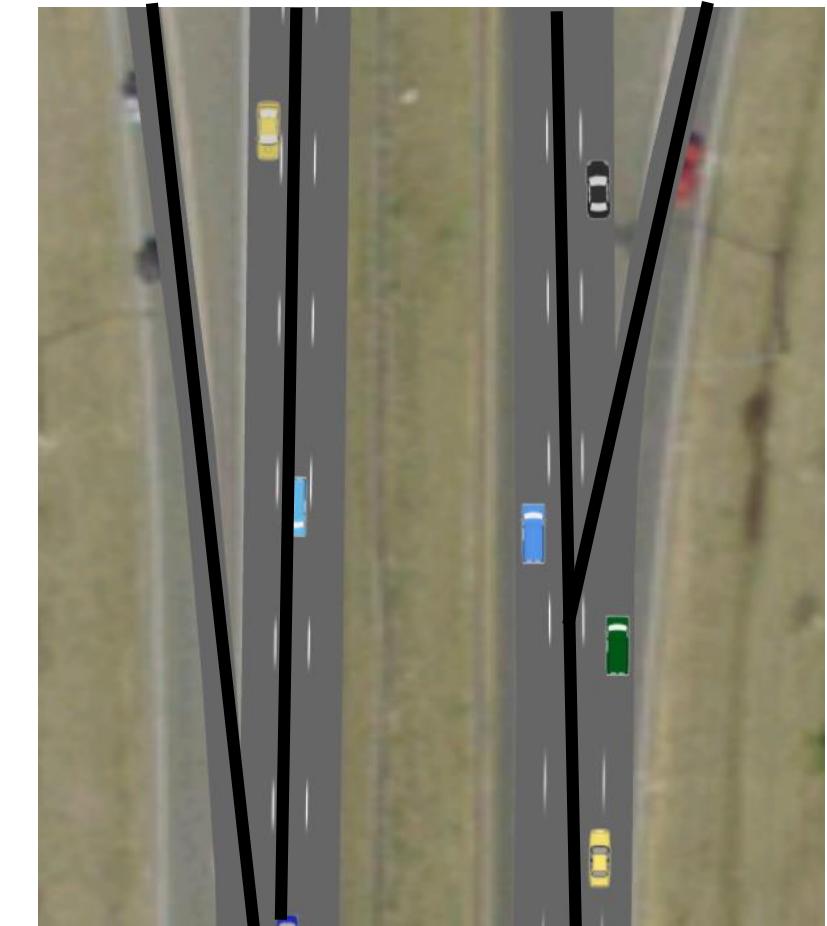
Data-driven / Model-driven / Traffic simulation / Procedural

- Model-driven modelling

Kuntzsch2015



Wilkie2012



Turning radius, network of lane, simulation

# State of the art: Existing models

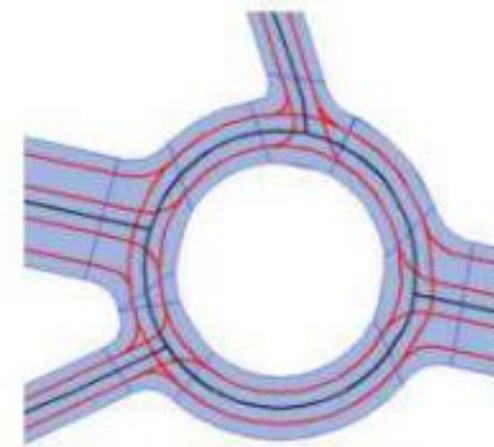
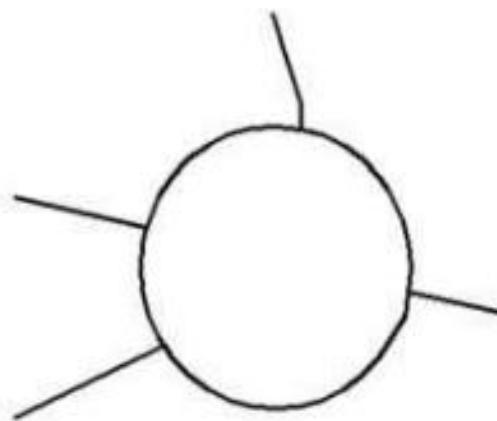
edge\_id=15; next\_l=16  
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Data-driven / Model-driven / Traffic simulation / Procedural

- Simulation-based modelling

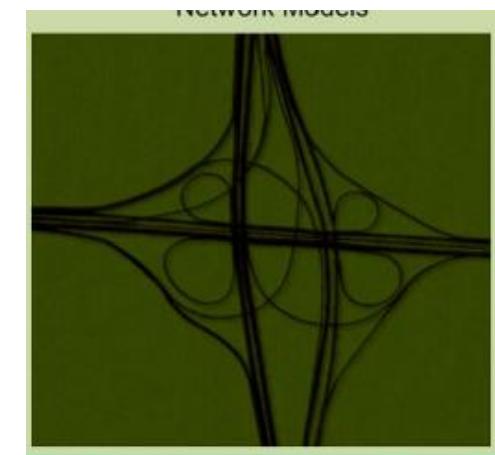
Network from data, guessing lane, intersection by continuity, 3D generation



Despine2011

Wang2015

Segment of road parametrisation, intersection...



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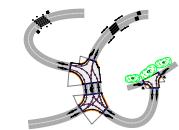
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# State of the art: Existing models

edge\_id=15; next\_l=16  
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Data-driven / Model-driven / Traffic simulation / Procedural

- Procedural modelling

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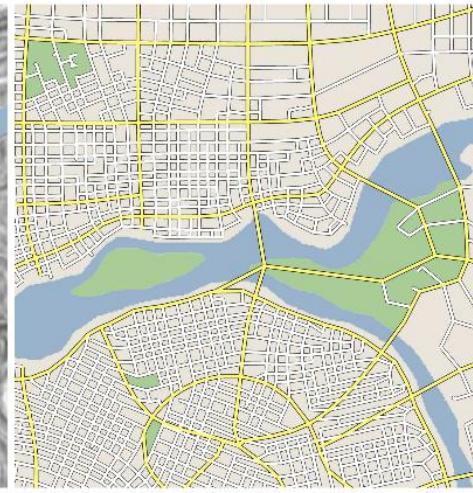
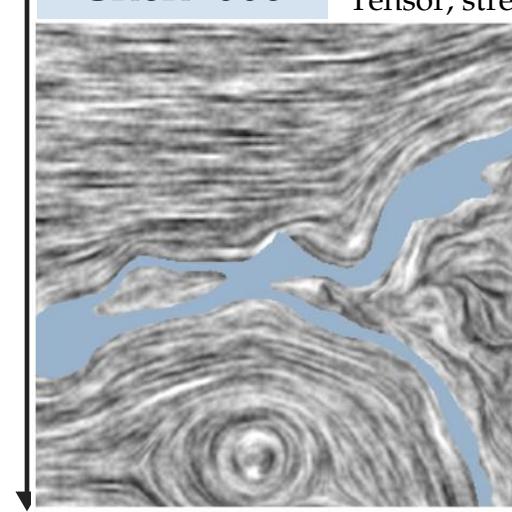
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Chen2008

Tensor, stream line, grammar

Gallin2011



Terrain, graph : shortest path and merging,  
procedural generation

# State of the art: Existing models

edge\_id=15; next\_l=16  
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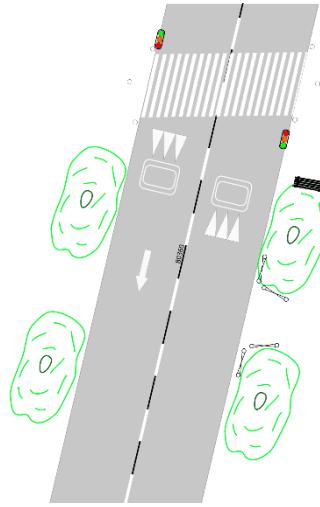
edge\_id=17; next\_l=16  
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**data-driven**

**model-driven**

**for traffic simulation**

**procedural**



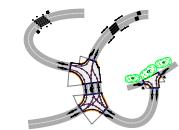
Our work

**roadway**

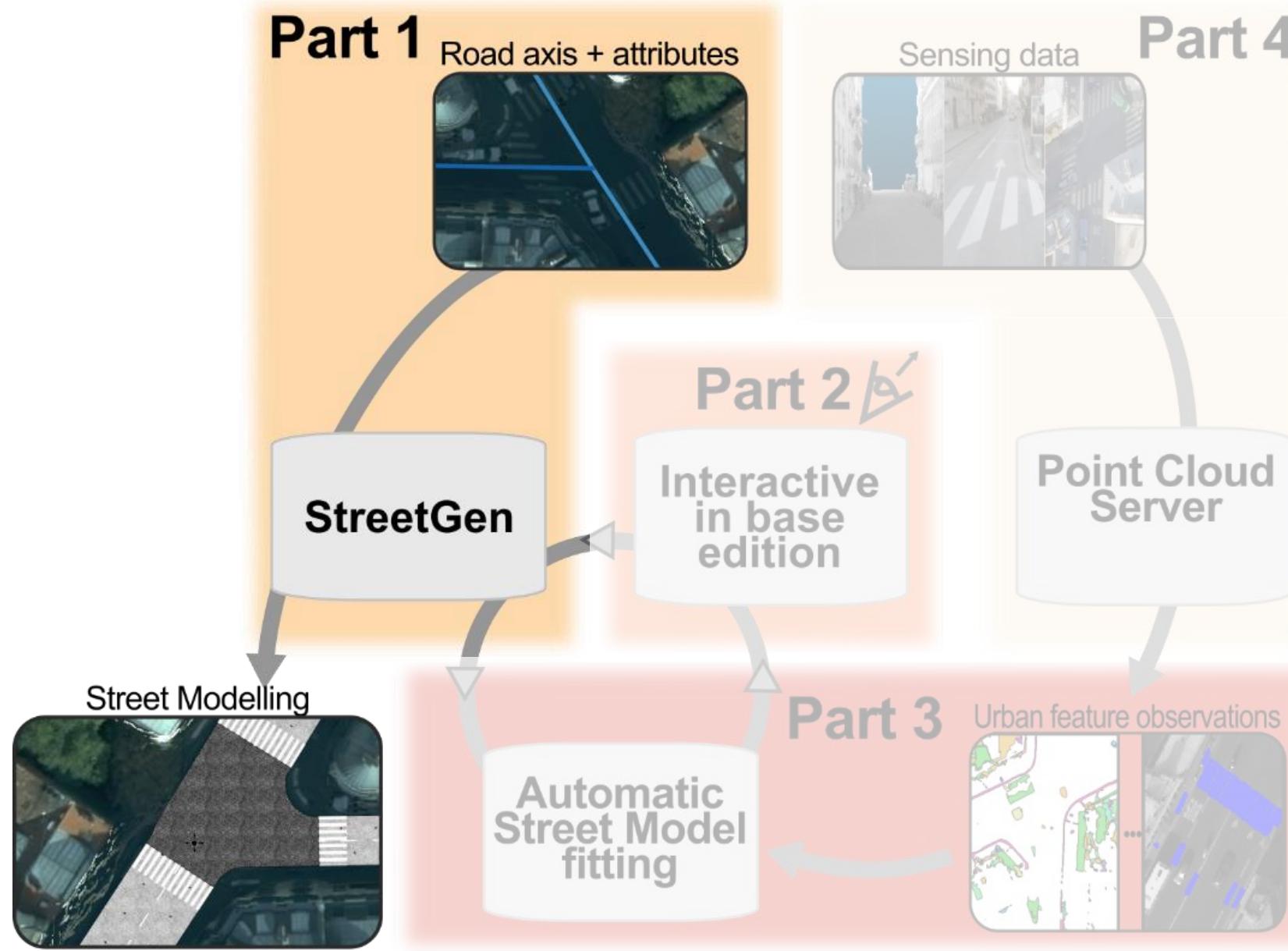
**road/lane**

**network**

**street**



# Abstract



edge\_id= 15; next\_l= 16  
end\_node= 3 ...

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# StreetGen : generate streets

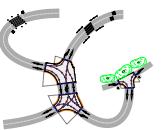
## Design Principle

Kinematic hypothesis

Road surface

Traffic support

Street objects



# 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 ...

Intro

State of the Art

StreetGen

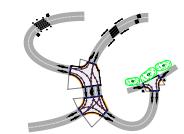
Streets

Interaction

Automation

P.C. Server

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 width/varying width

Intro

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StreetGen

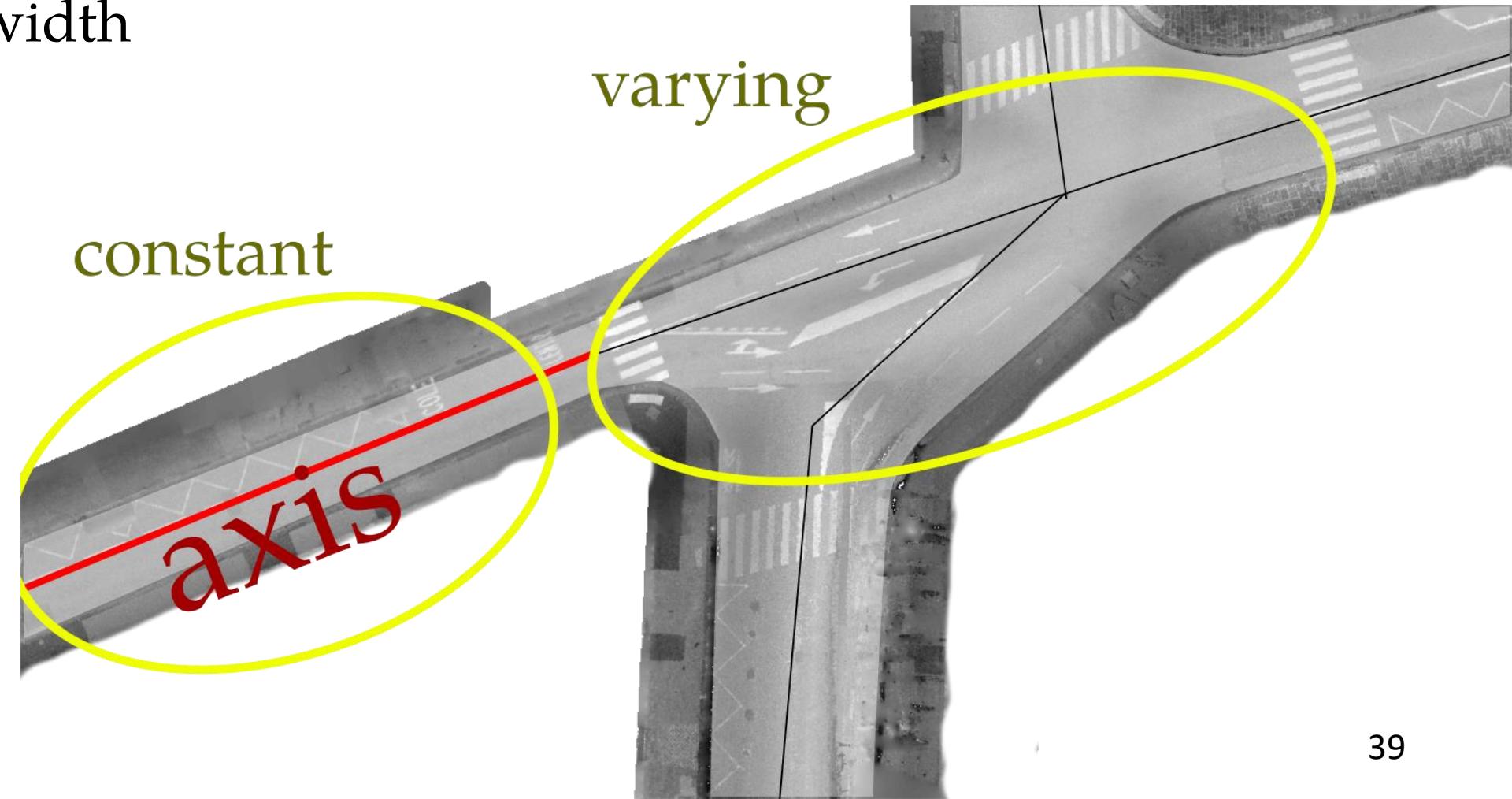
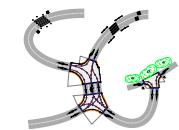
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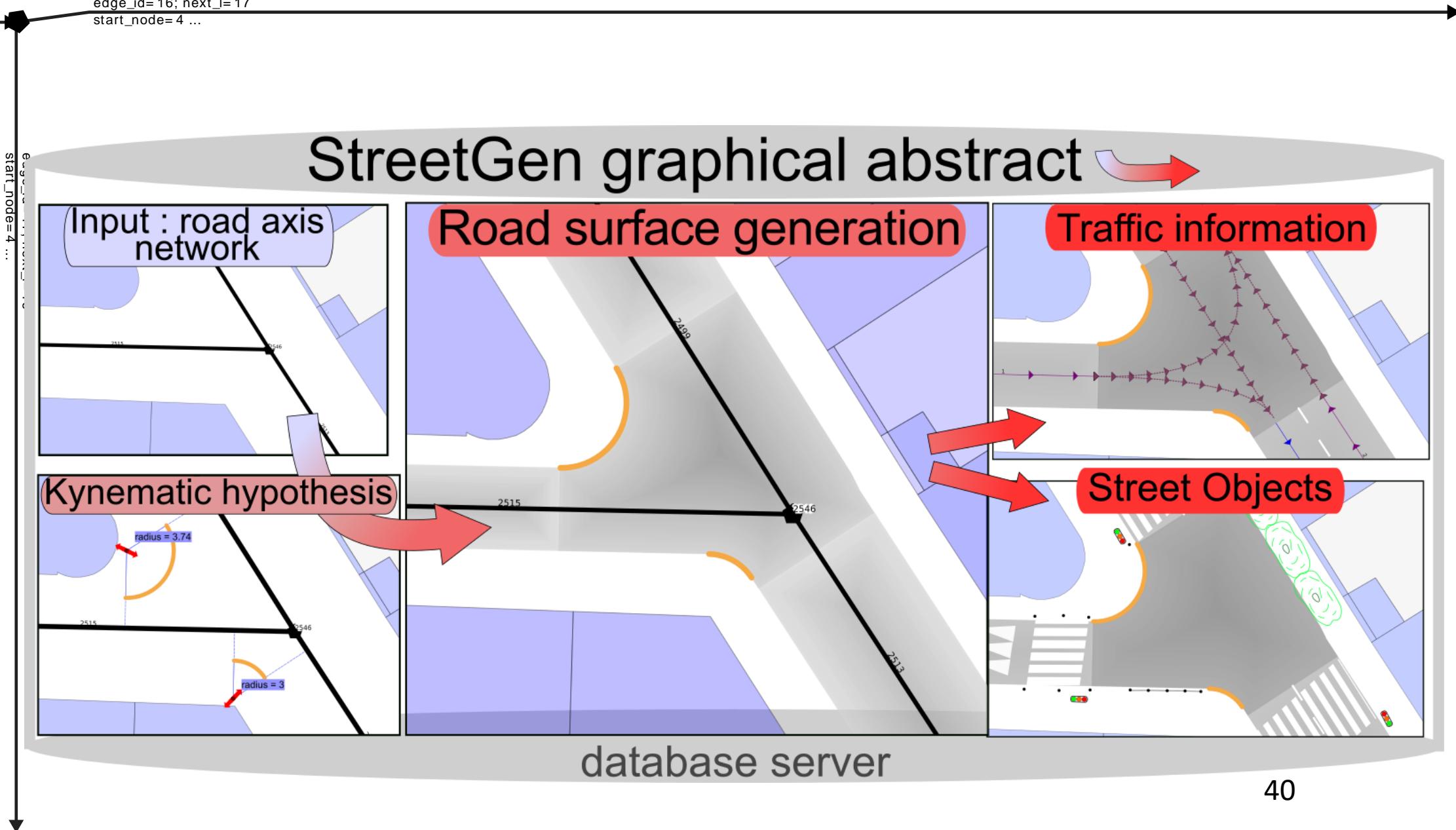
P.C. Server

Conclusion



# StreetGen : graphical abstract

edge\_id= 15; next\_l= 16  
start\_node= 4 ...  
end\_node= 3 ...



# StreetGen : Model

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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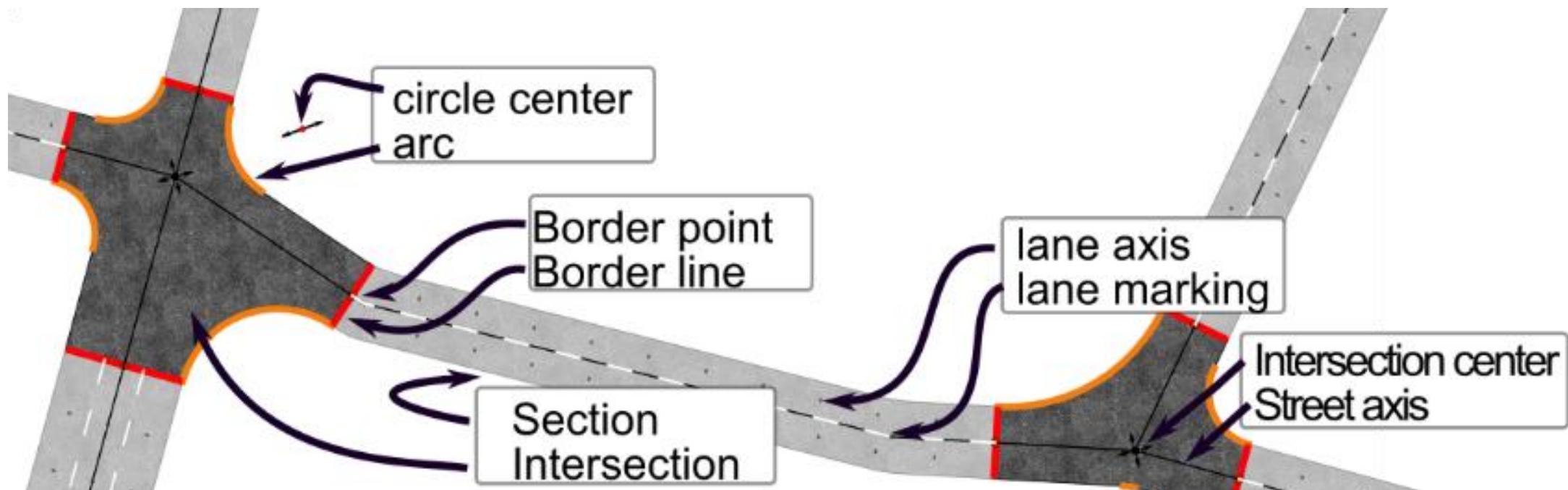
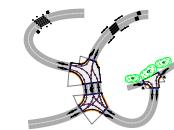
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# StreetGen : Model

edge id=15; next\_l=16  
end\_node=3 ...



edge id=16; next\_l=17  
start\_node=4 ...

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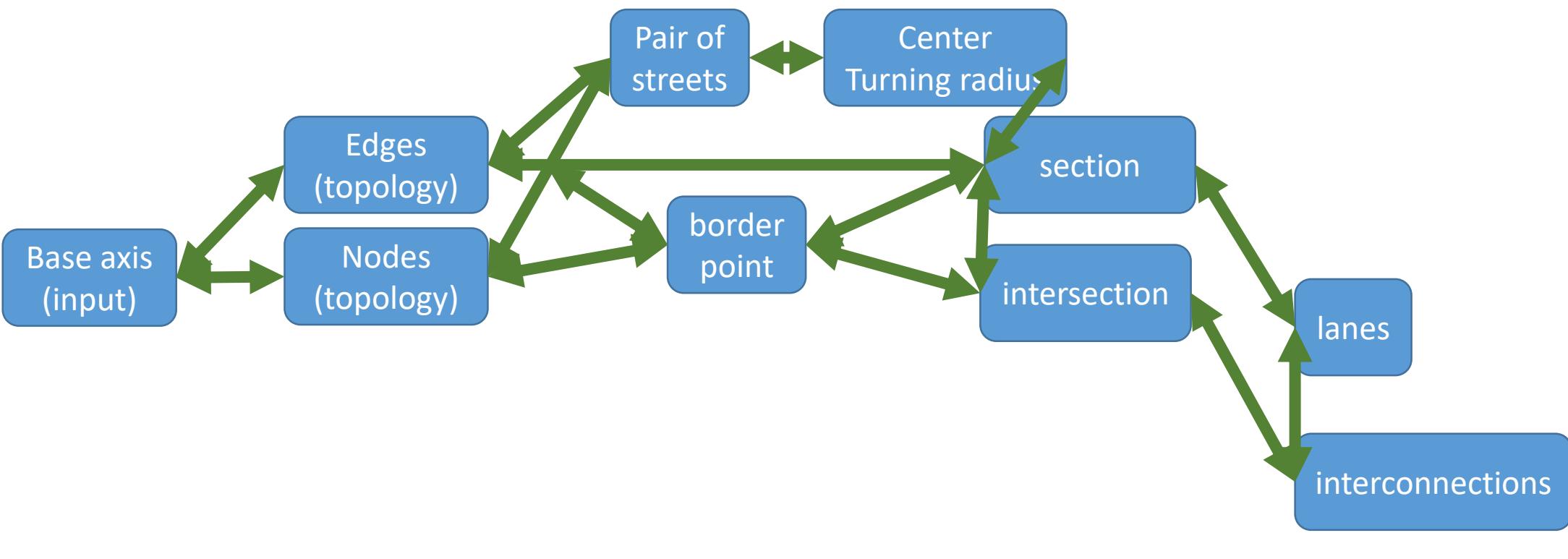
Automation

P.C. Server

Conclusion

- StreetGen model

- (Simplified)
- Everything connected: fully structured model
- No information loss



# StreetGen : design principle

edge\_id= 15; next\_l= 16  
end\_node= 3 ...

edge\_id= 16; next\_l= 17  
start\_node= 4 ...

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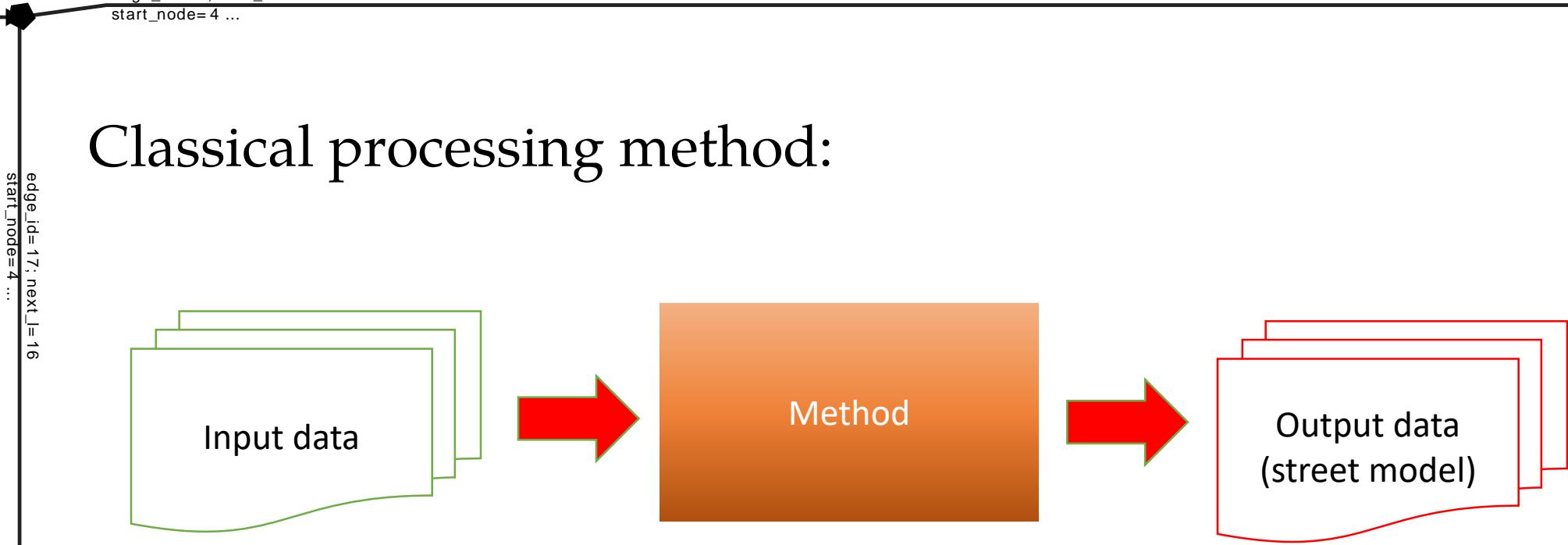
Interaction

Automation

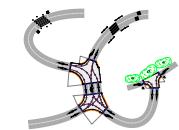
P.C. Server

Conclusion

Classical processing method:



Change? → redo everything  
Several users → 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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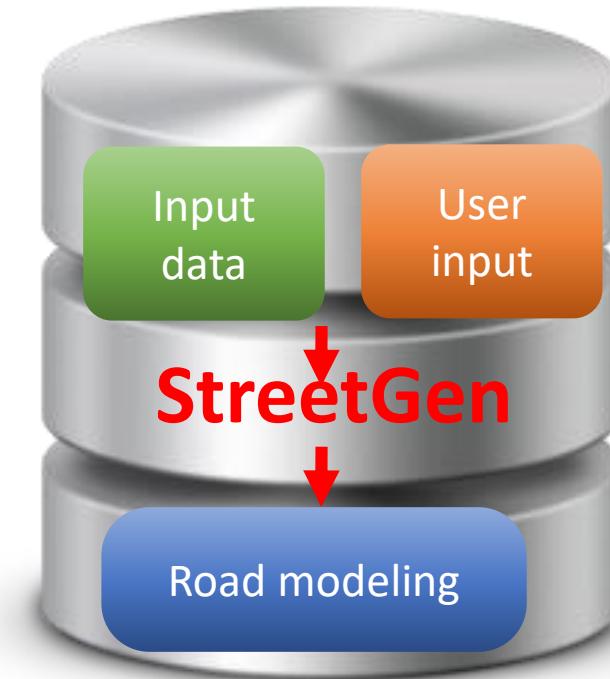
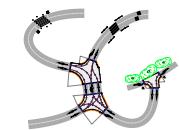
Streets

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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 ...

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

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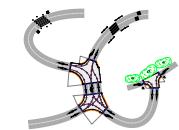
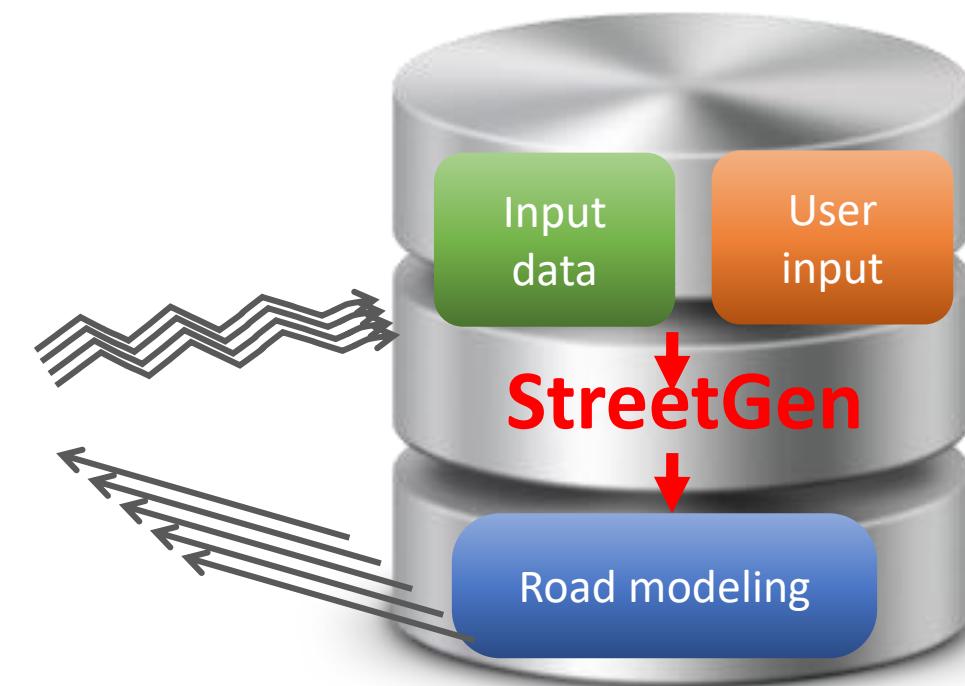
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edge\_id= 15; next\_l= 16  
end\_node= 3 ...

edge\_id= 16; next\_l= 17  
start\_node= 4 ...

edge\_id= 17; next\_l= 16  
start\_node= 4 ...

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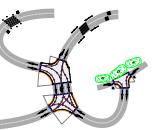
Automation

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Conclusion

# 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 ...



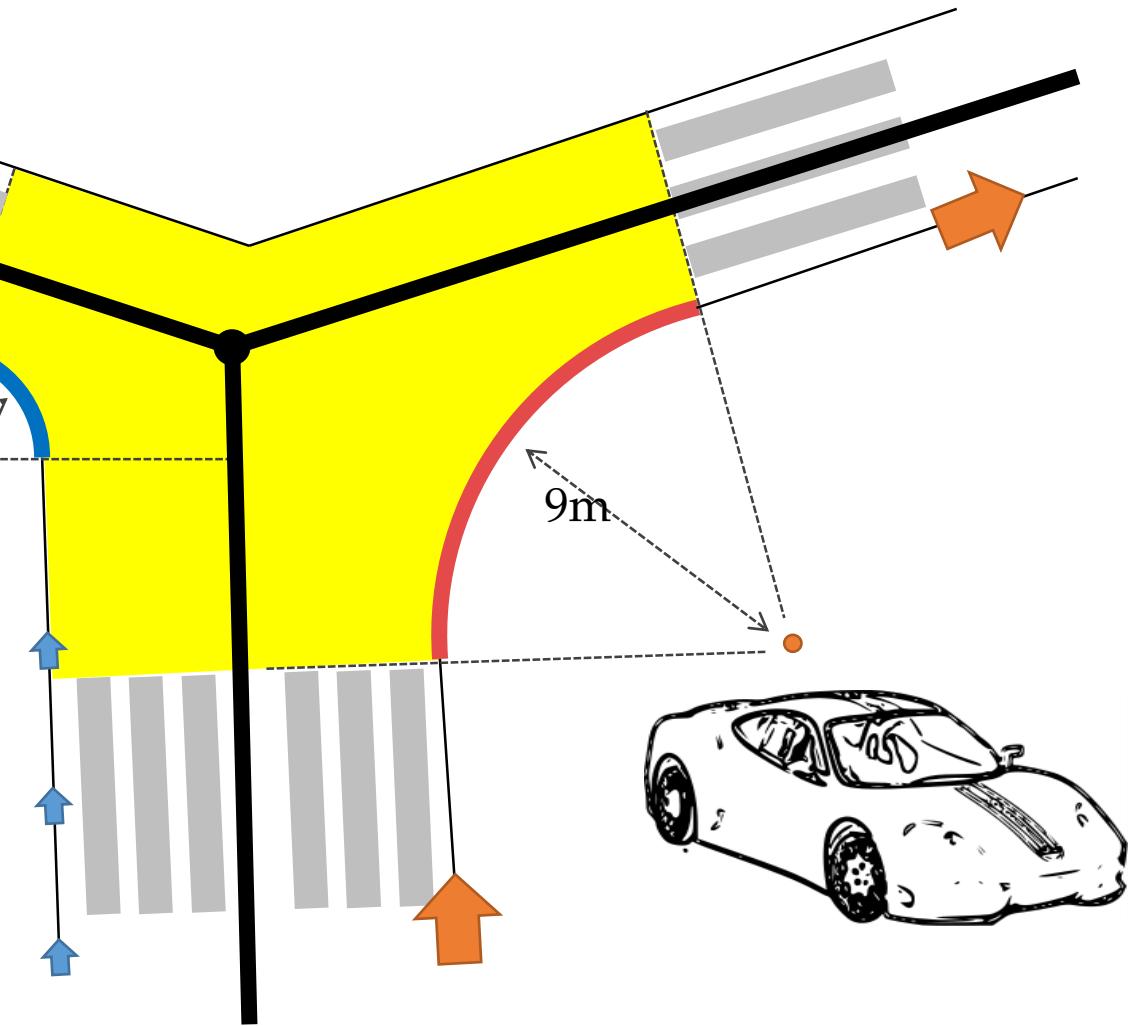
- Kinematic hypothesis

**width**

Road type  
 ↓  
 speed  
 ↓  
 radius



3m



Intro

State of the Art

StreetGen

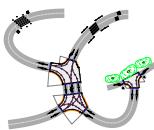
Streets

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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

r=6.4  
+  
x

edge\_id=17; next\_l=16  
start\_node=4 ...

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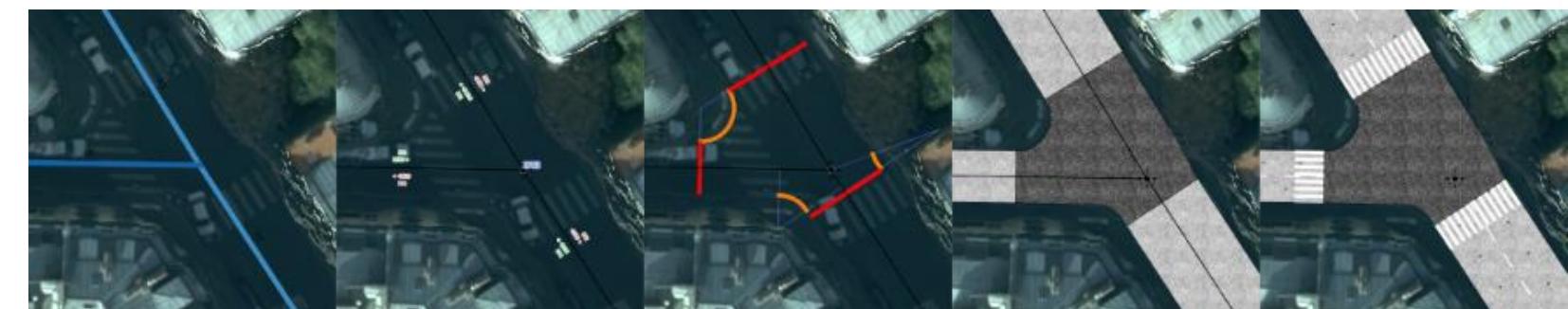
Automation

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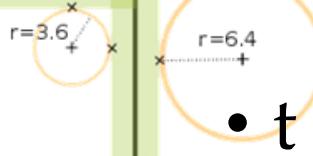
# StreetGen : generate streets

Design Principle  
Kinematic hypothesis  
**Road surface**  
Traffic support  
Street objects



# 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 ...

Intro

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StreetGen

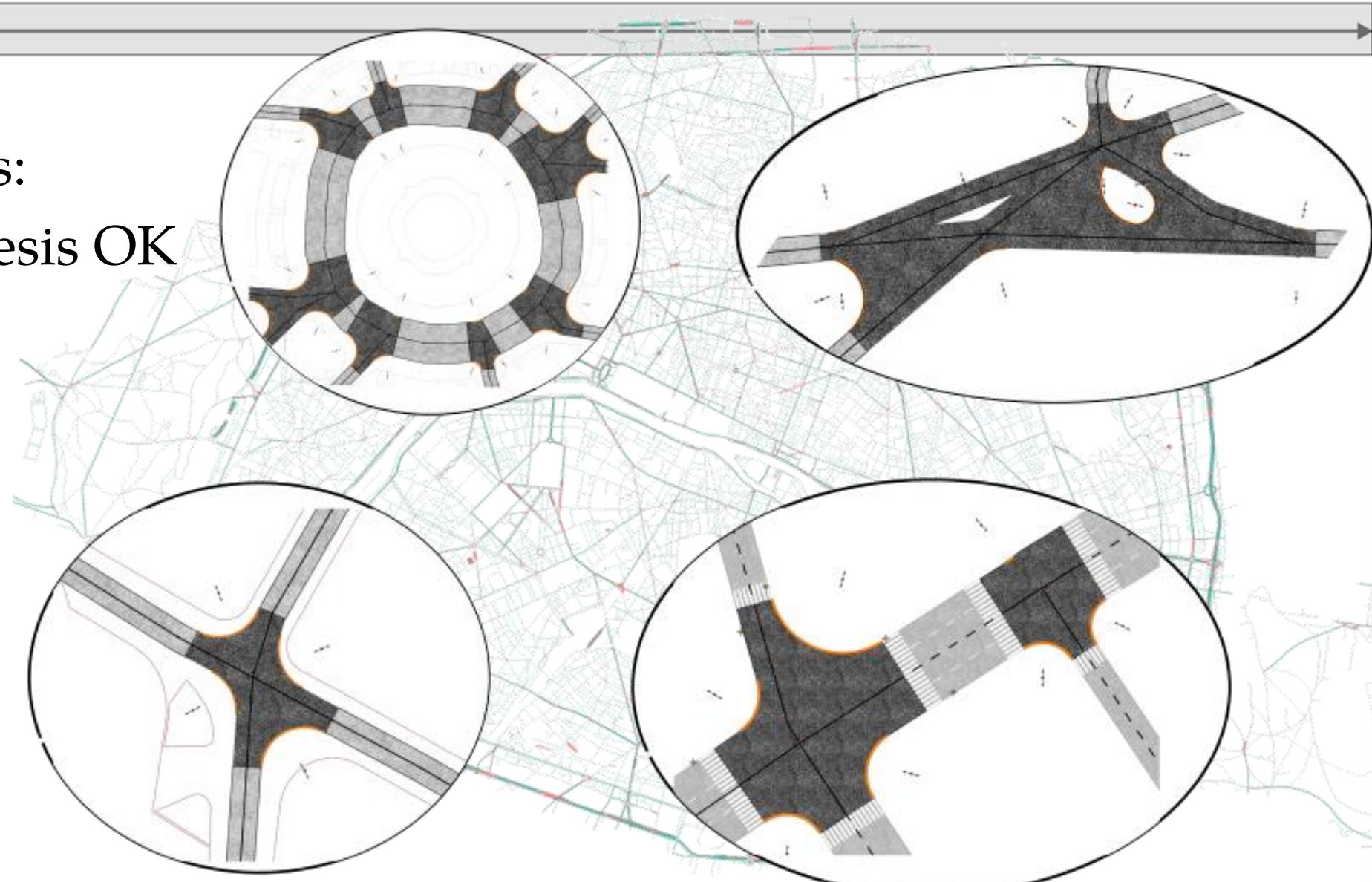
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edge id=15; next\_l=16  
end\_node=3 ...

edge id=16; next\_l=17  
start\_node=4 ...

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# StreetGen : generate streets

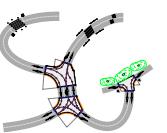
Design Principle

Kinematic hypothesis

Road surface

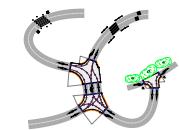
**Traffic support**

Street objects

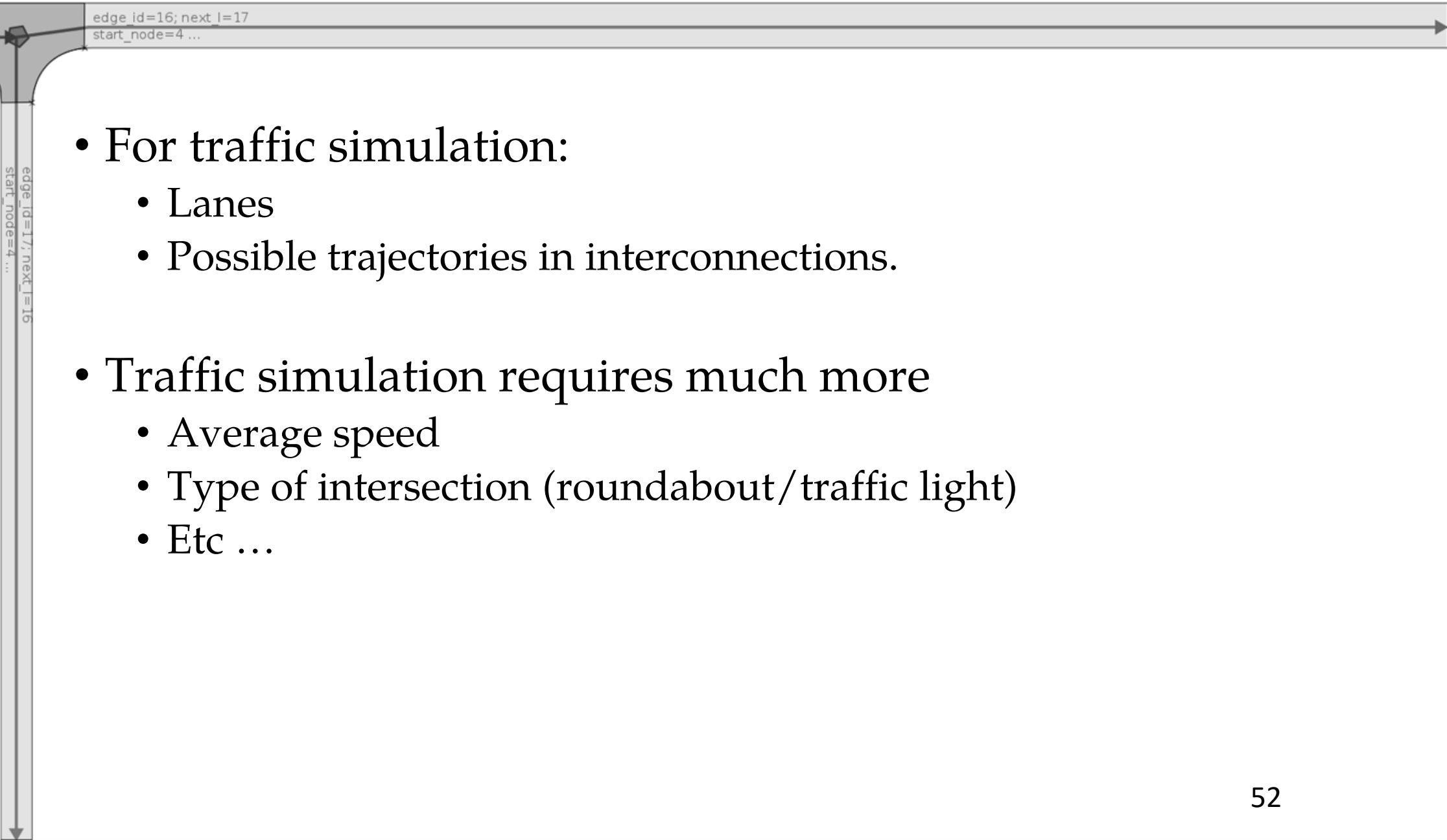


# StreetGen : Traffic Support

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Automation  
P.C. Server  
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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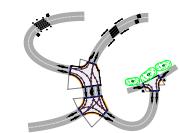
Streets

Interaction

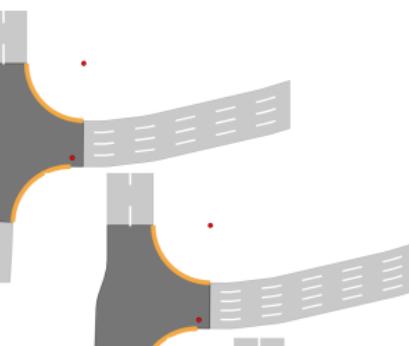
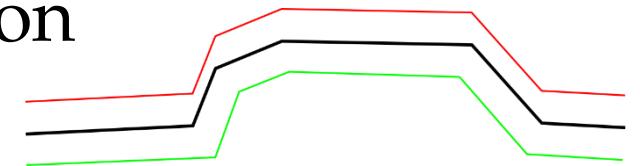
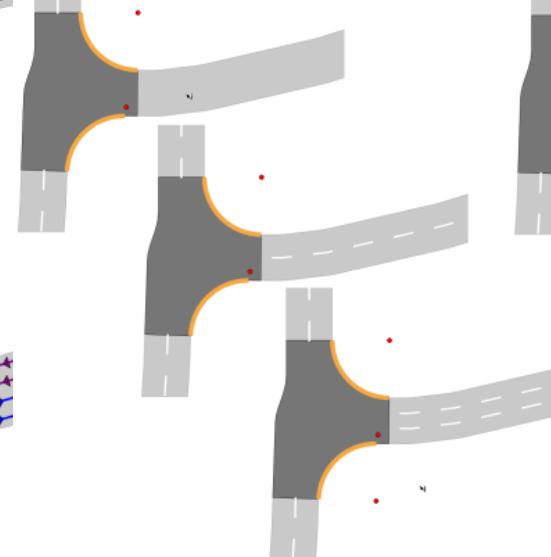
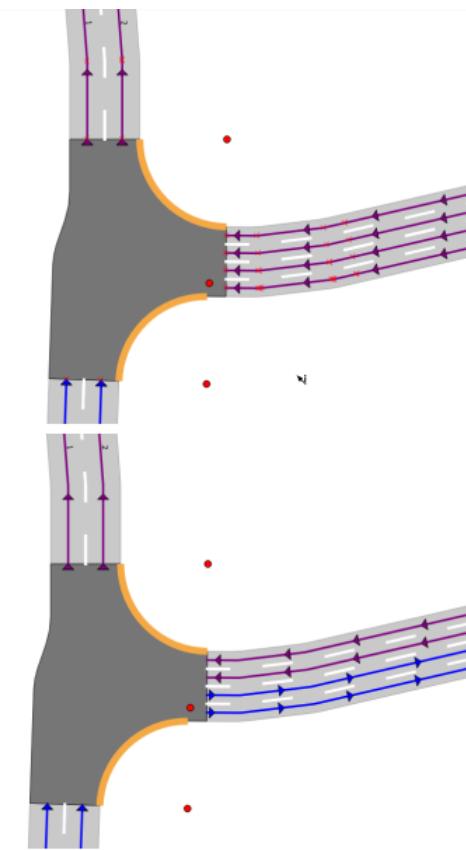
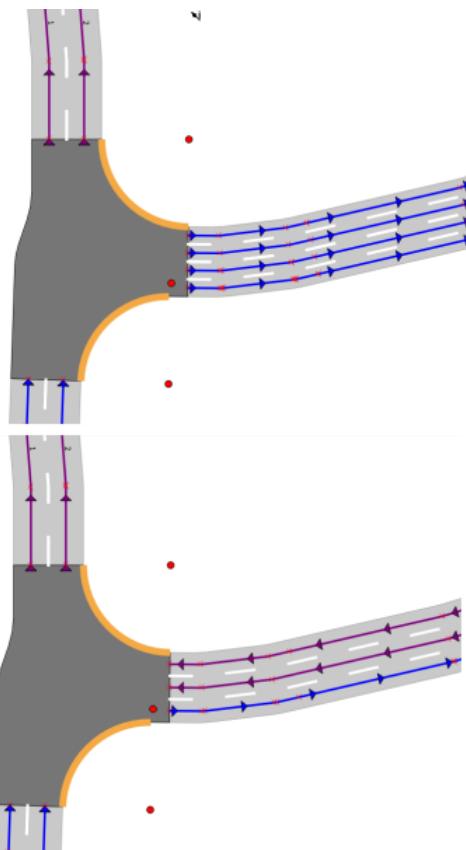
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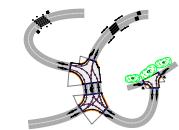


- Lane based on road axis : but not translation

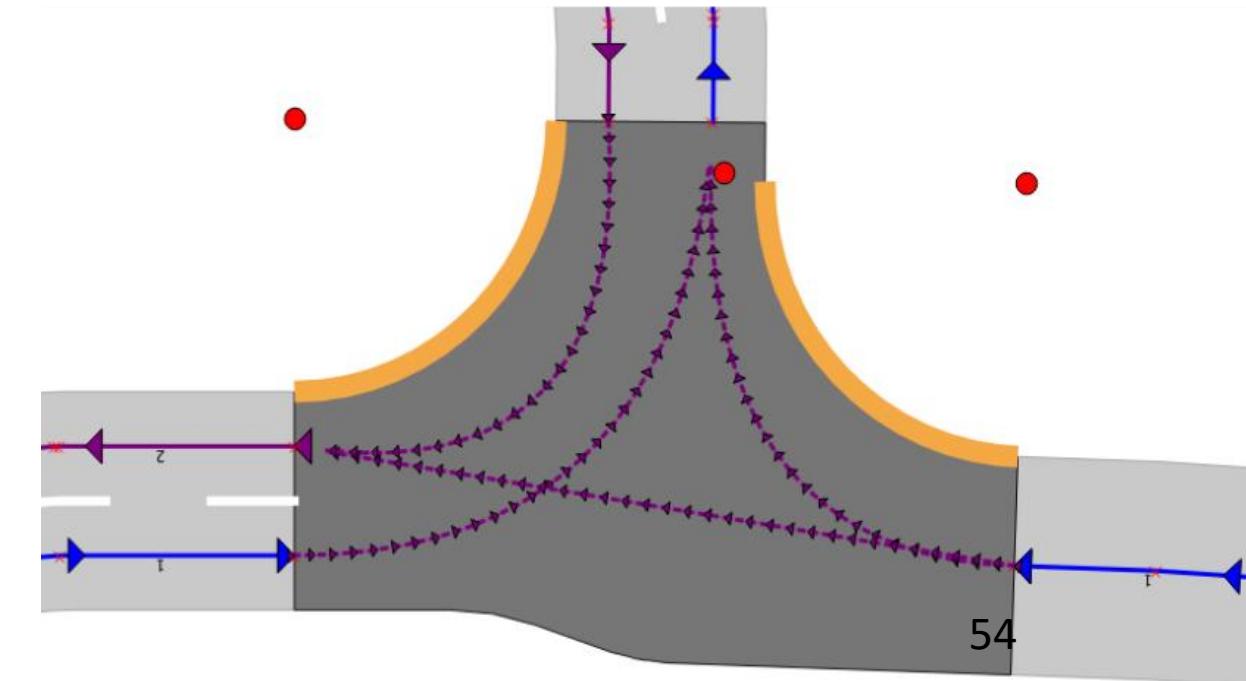
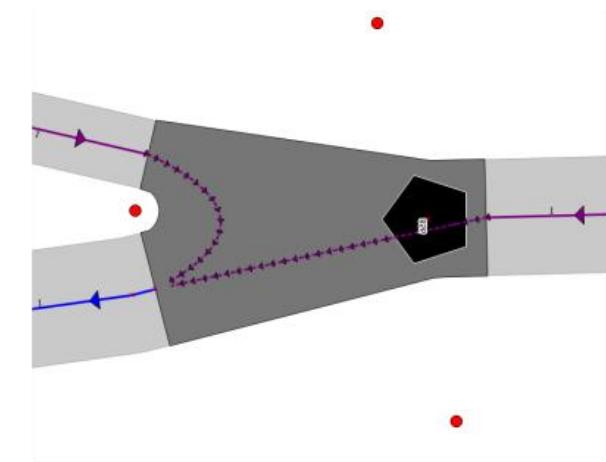
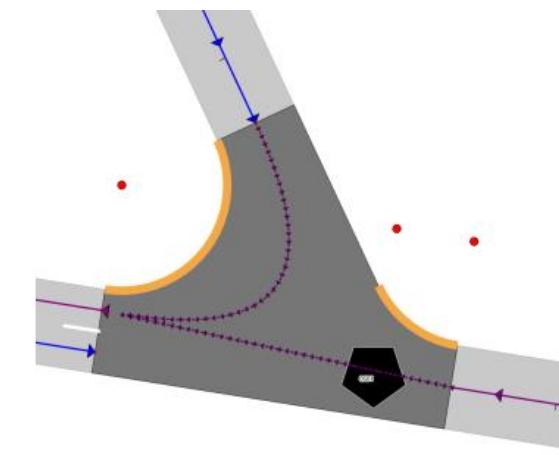


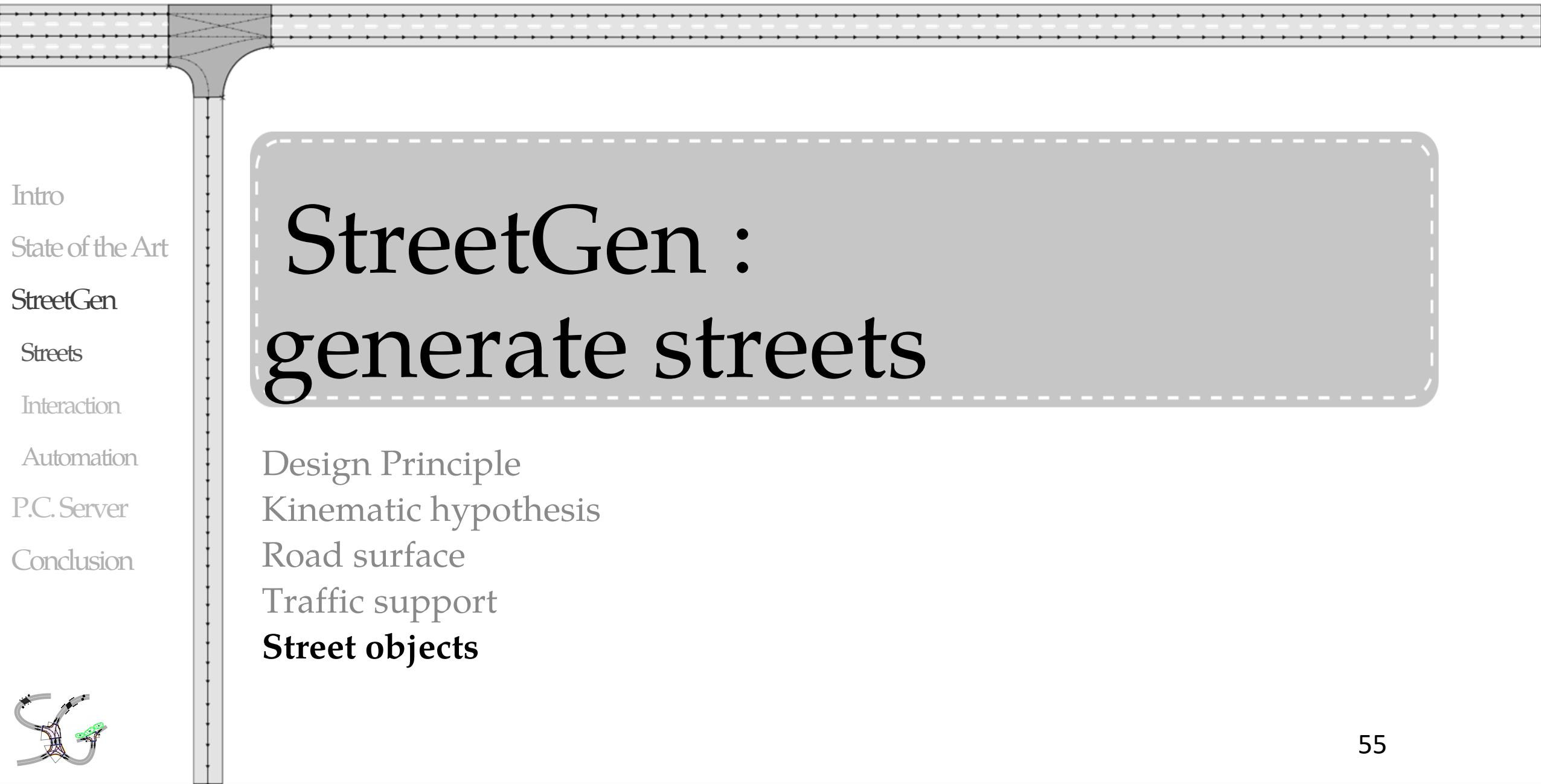
# StreetGen : Traffic Support

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Conclusion



- 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

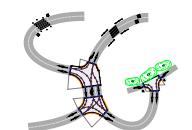




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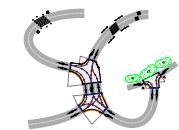
# StreetGen : generate streets

Design Principle  
Kinematic hypothesis  
Road surface  
Traffic support  
**Street objects**

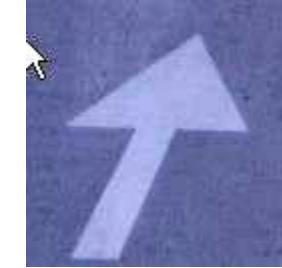


# StreetGen : street objects

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Conclusion



- Streets objects : incredibly varied
  - 13k references on [www.ArchiExpo](http://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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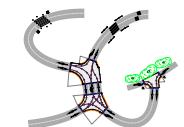
Streets

Interaction

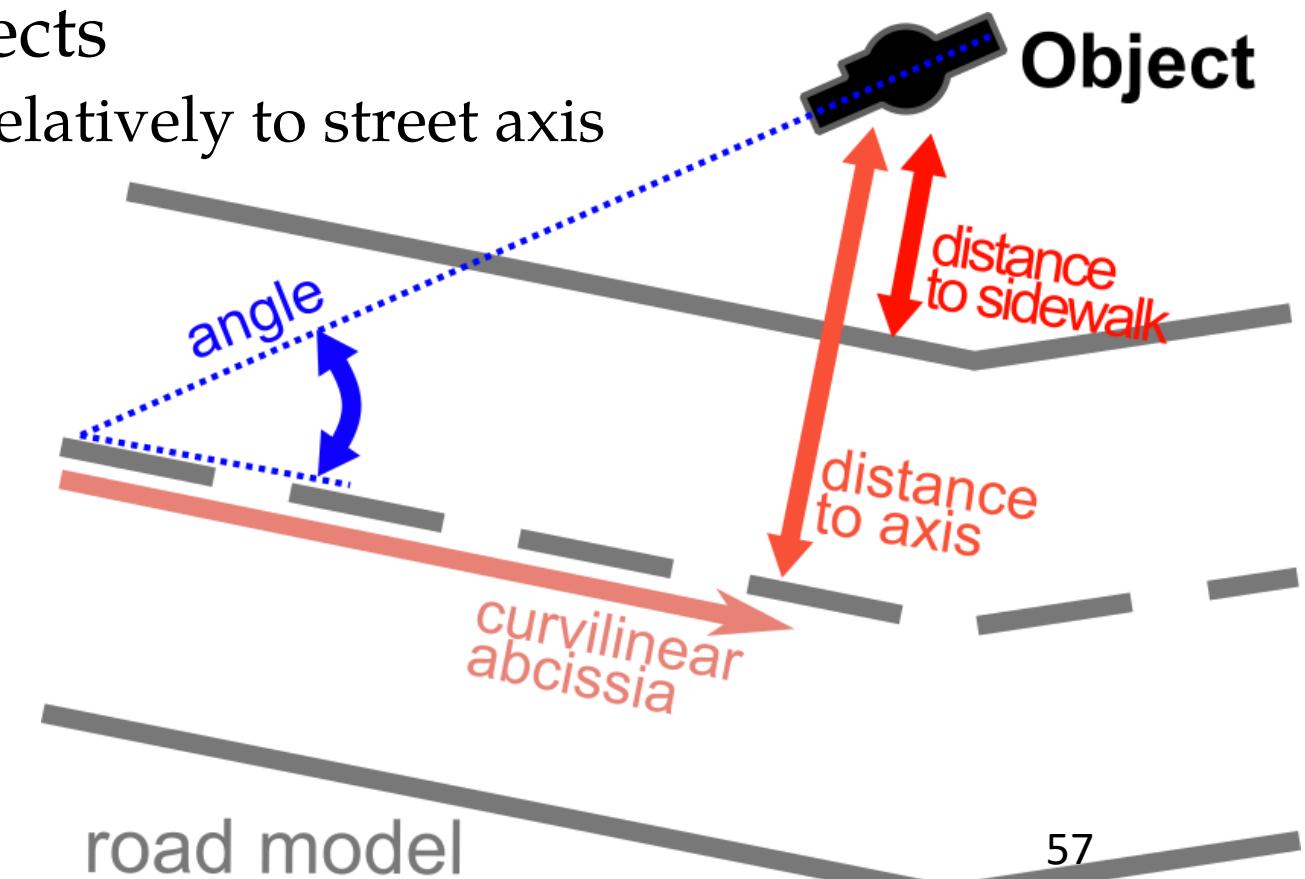
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Conclusion



- 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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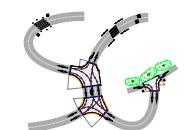
Streets

Interaction

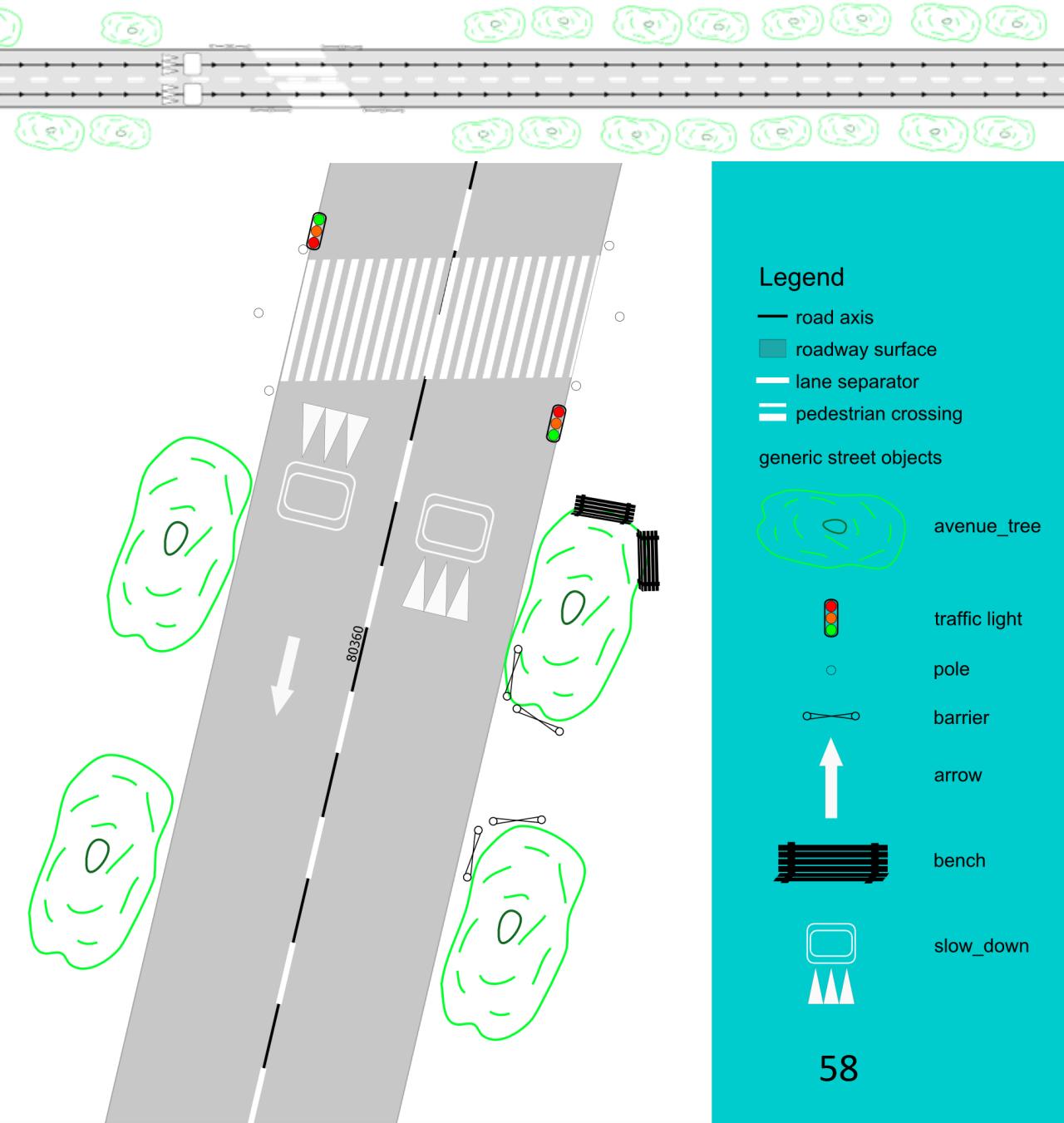
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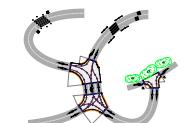


- Objects are **points** with semantic
- DBMS can support any relation (hierarchy, semantic...)

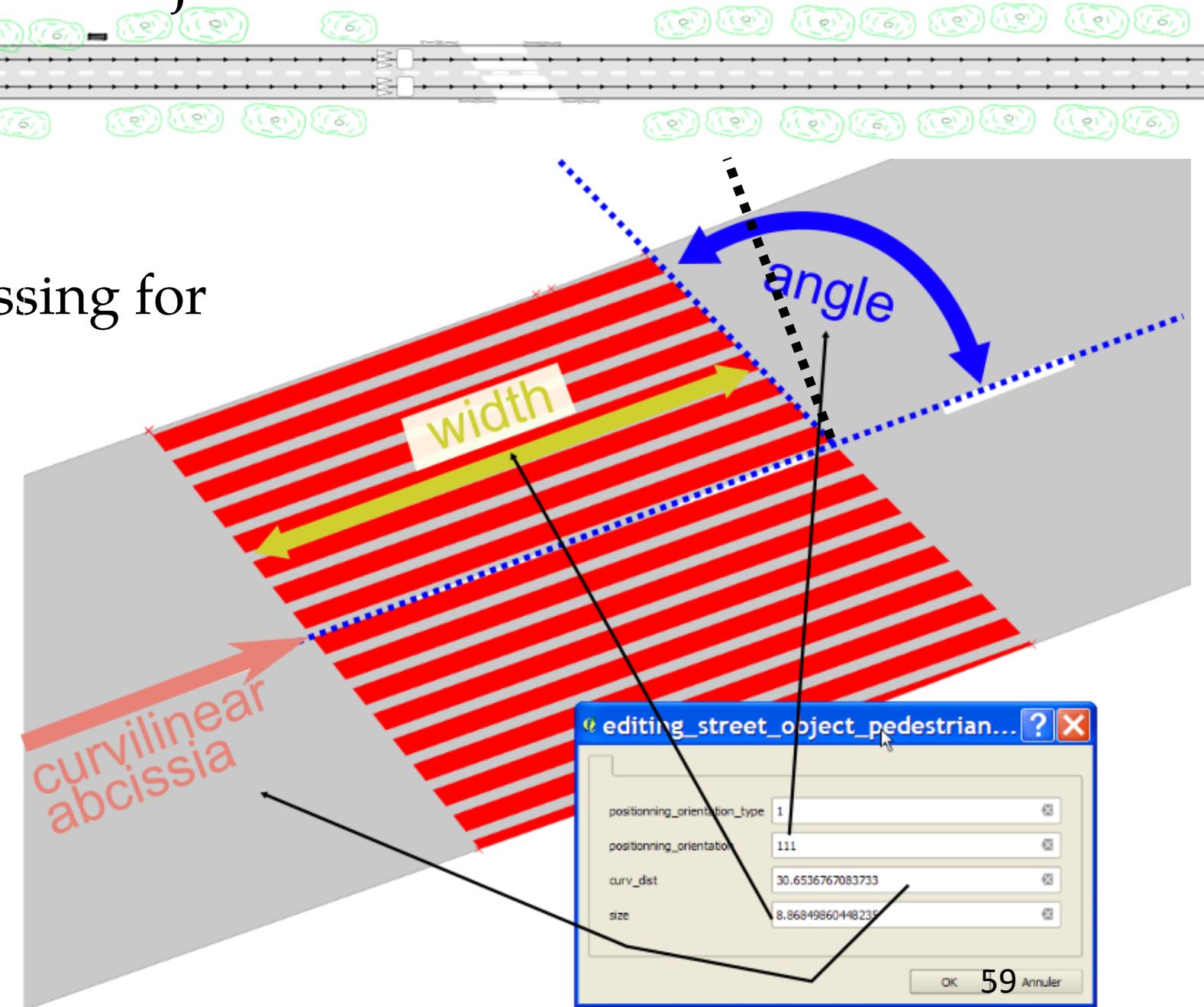


# StreetGen : street objects

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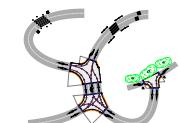
- Also surface
- Pedestrian crossing for instance



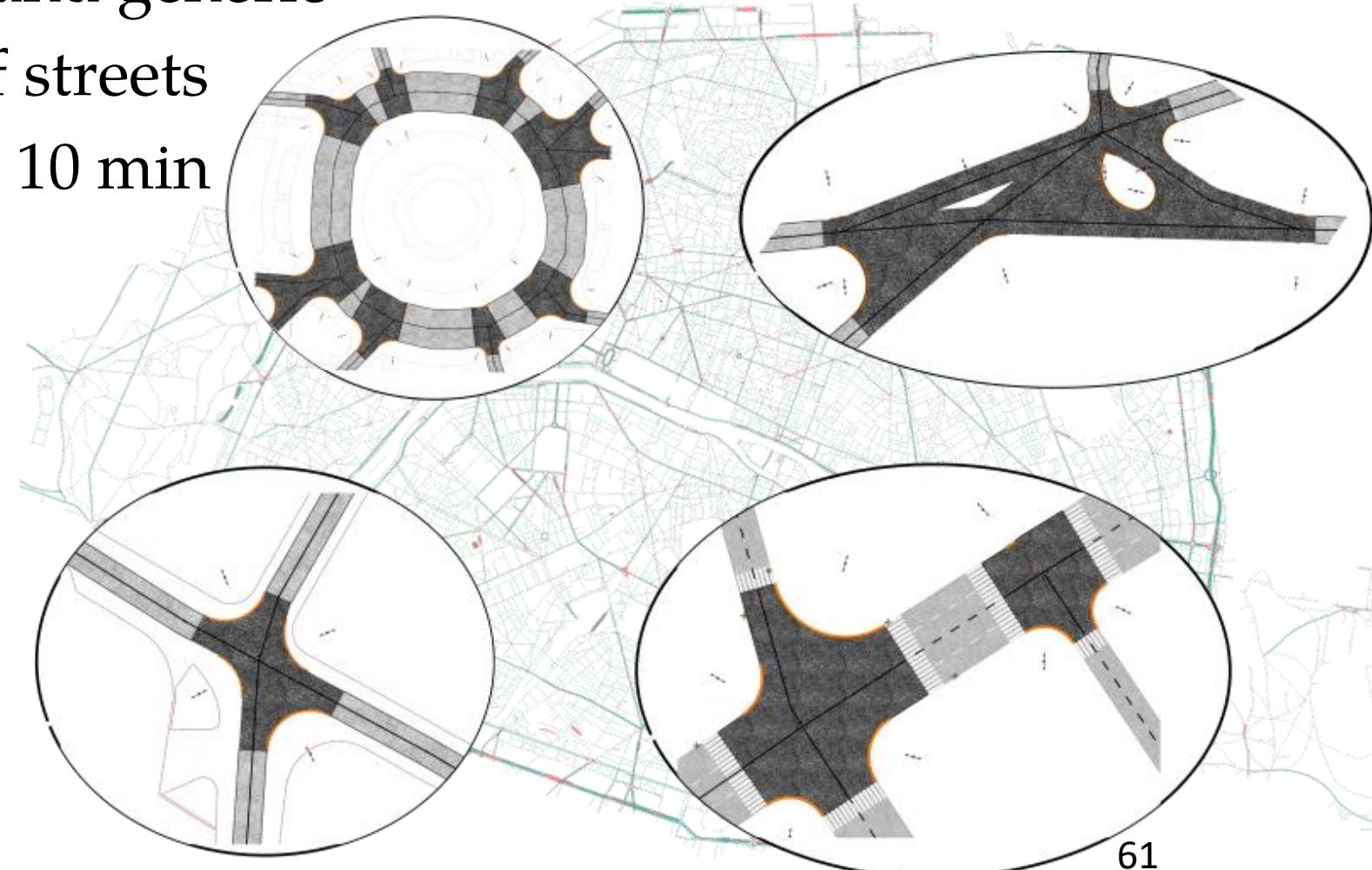


# StreetGen : street objects

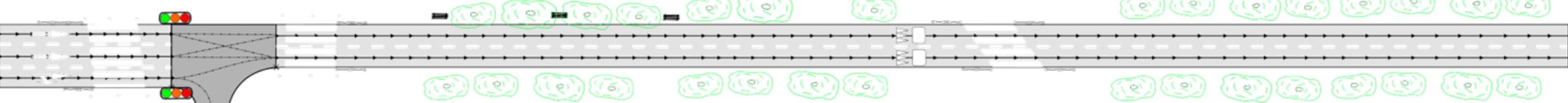
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- Model simple and generic
- OK for most of streets
- Whole Paris in 10 min  
(2' //)



# StreetGen : street objects



- Tested for 3D visualisation
  - Thales NeoDBGS

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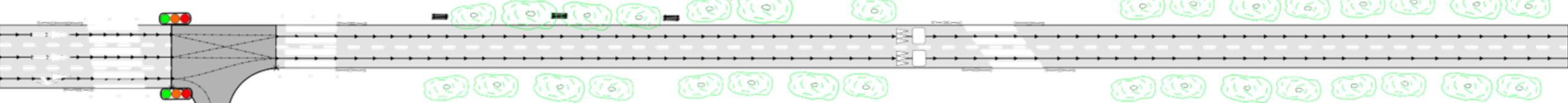
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# StreetGen : street objects



- Tested for traffic simulation (SimuVia)

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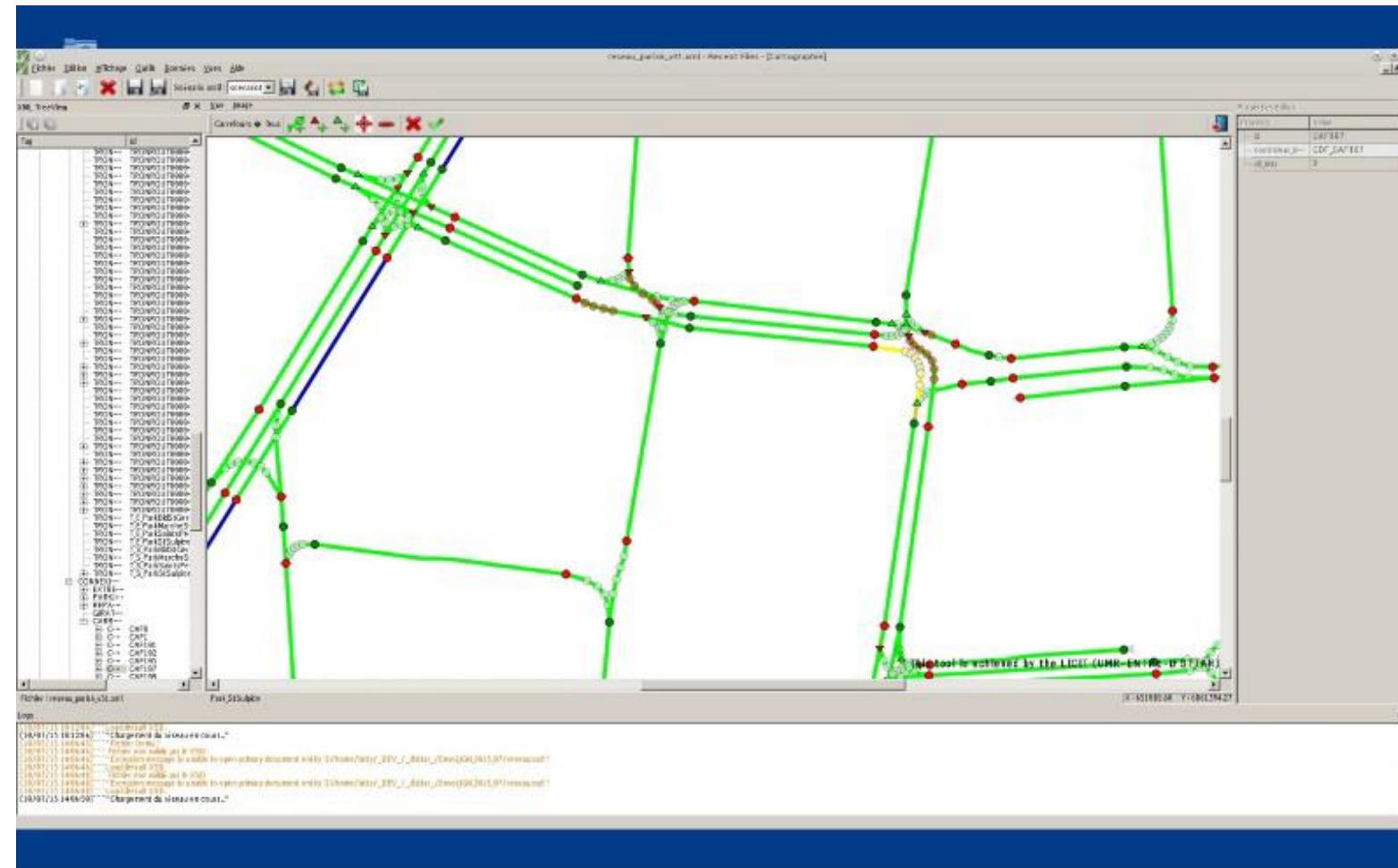
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# StreetGen : street objects

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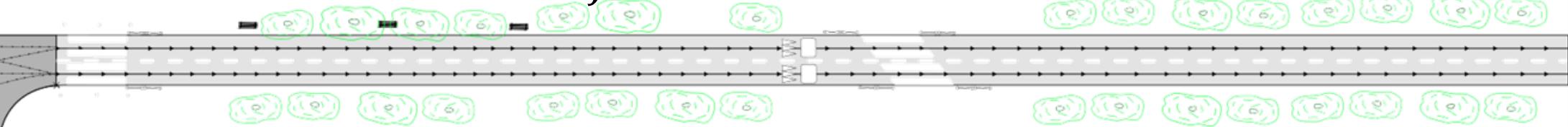
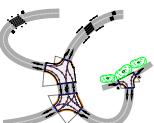
Streets

Interaction

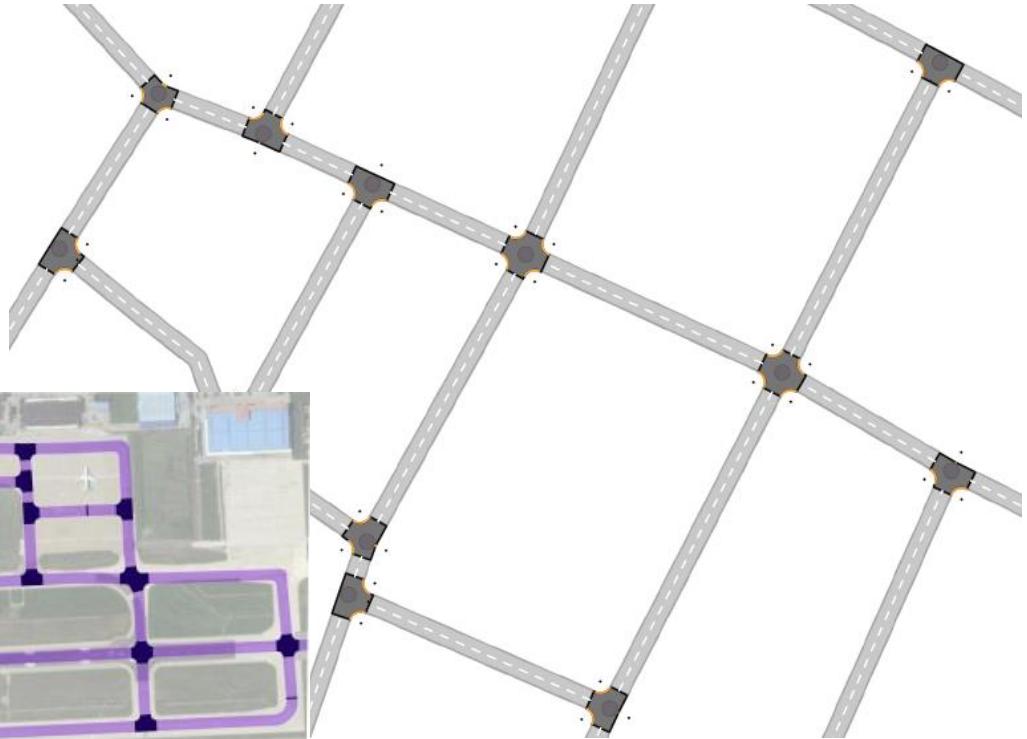
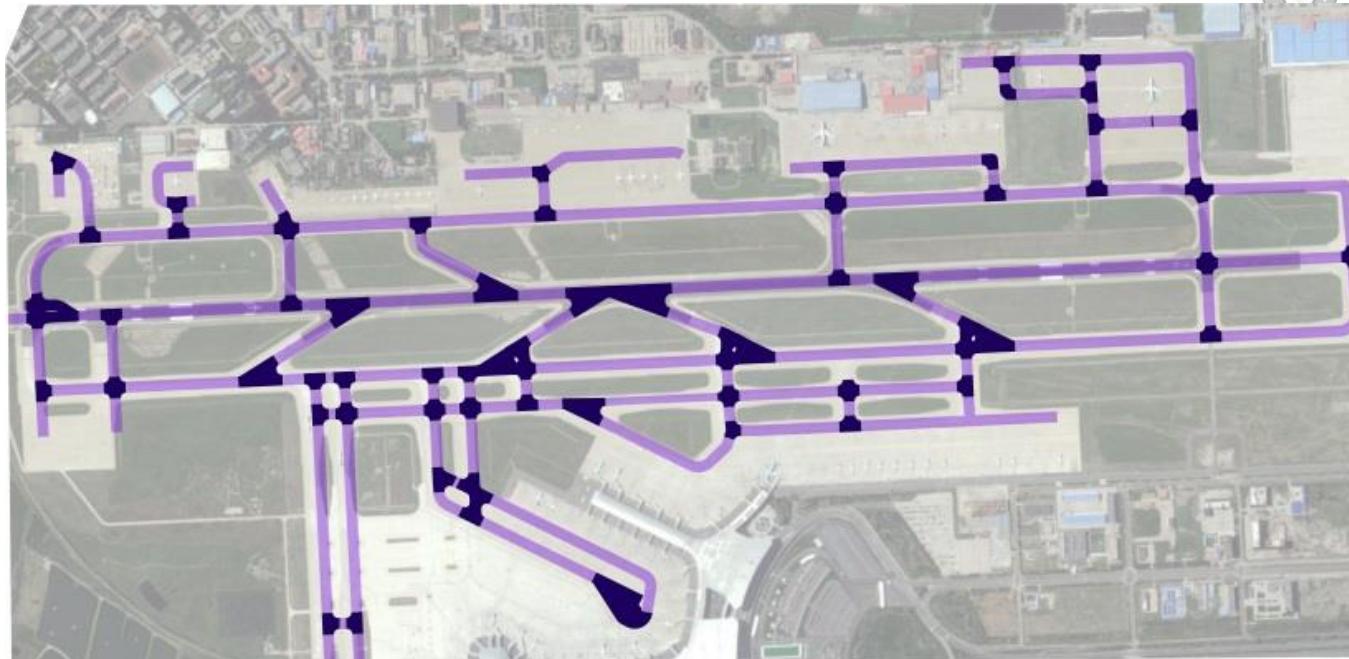
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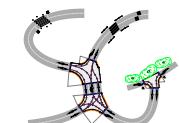


- Tested to model other cities (West Africa)
- Tested to model airport runway



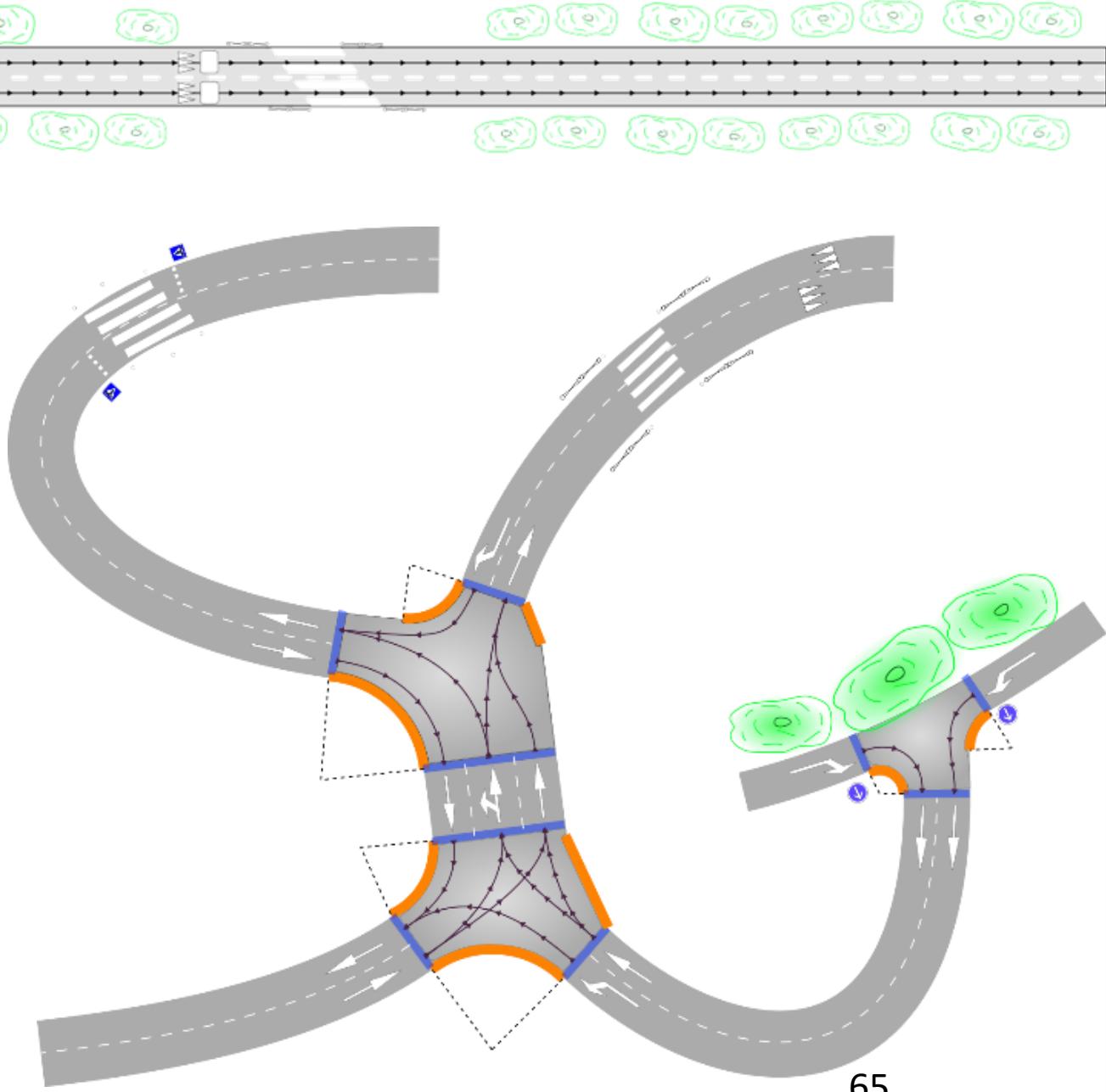
# StreetGen : street objects

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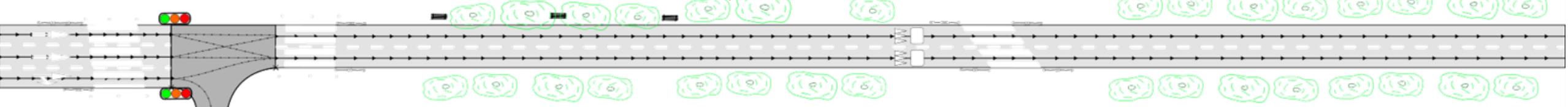
## Contributions

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



# StreetGen : street objects

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- 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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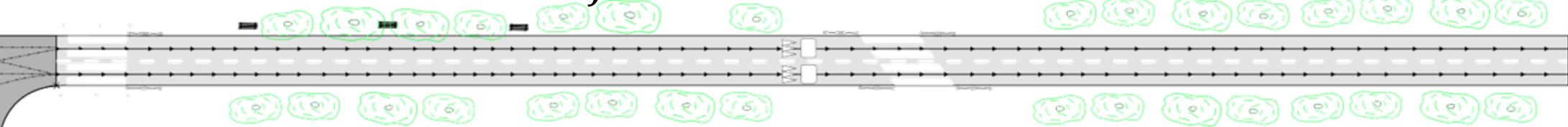
Streets

Interaction

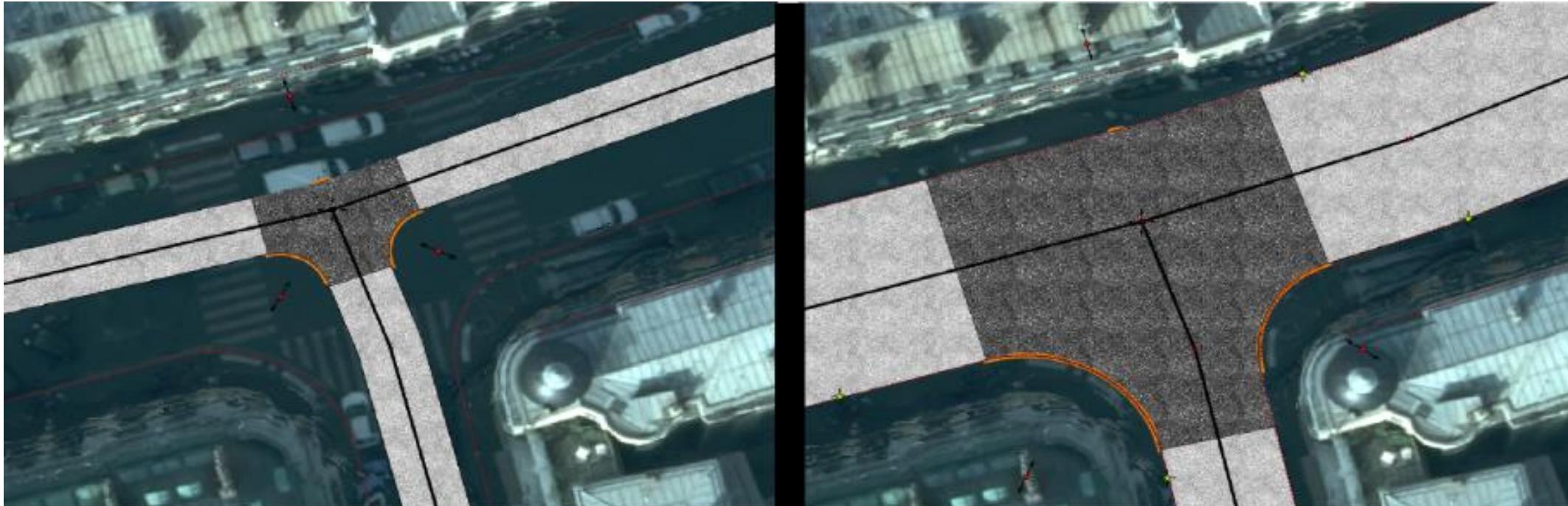
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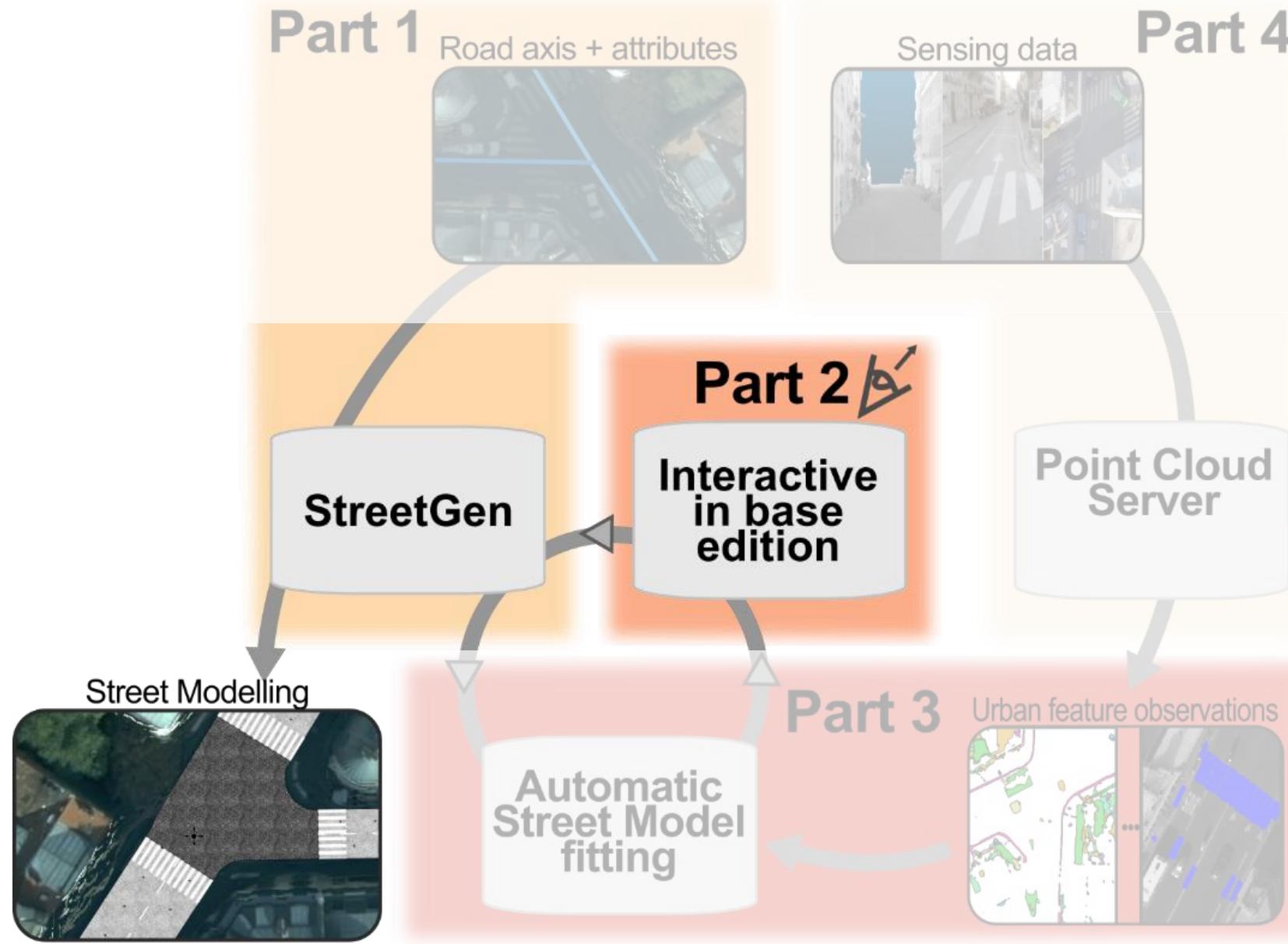
Conclusion

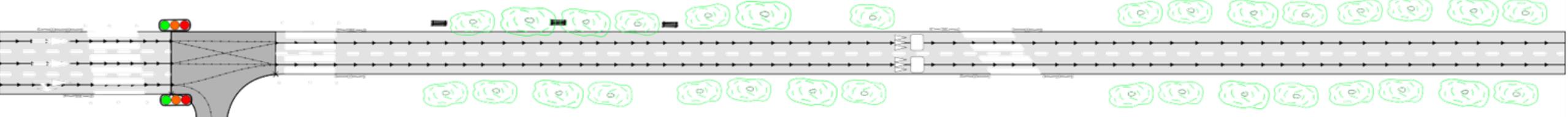


- Input data: not precise
  - For better results, need editing



# Abstract



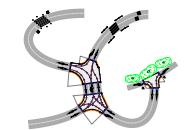


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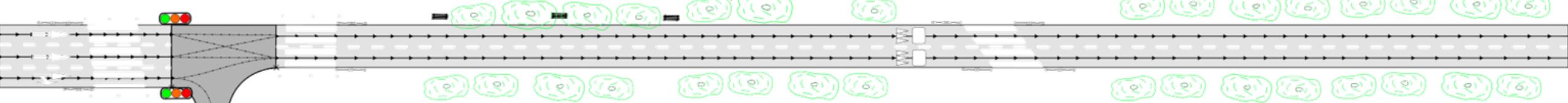
# StreetGen : editing streets (in-base)

## In-base interaction Principle

- Edit road model
- Edit traffic
- Edit objects



# StreetGen : street objects



- How to edit street model easily?

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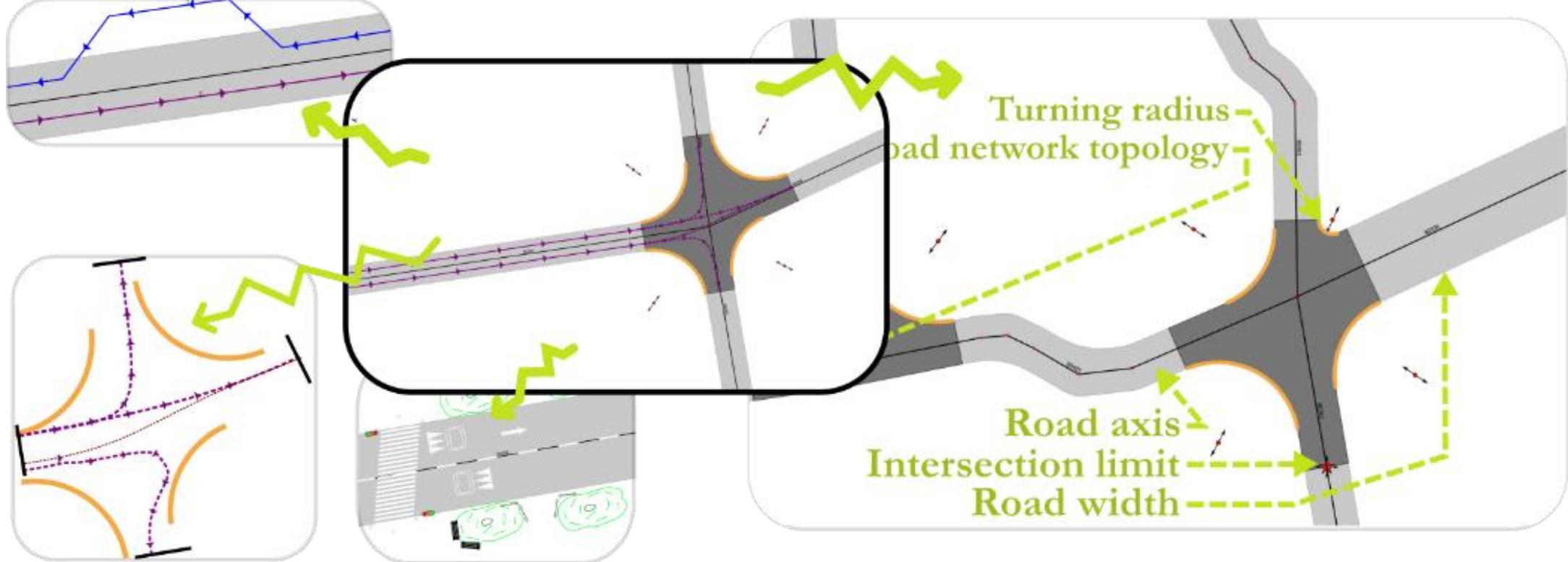
Streets

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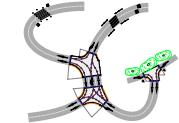
P.C. Server

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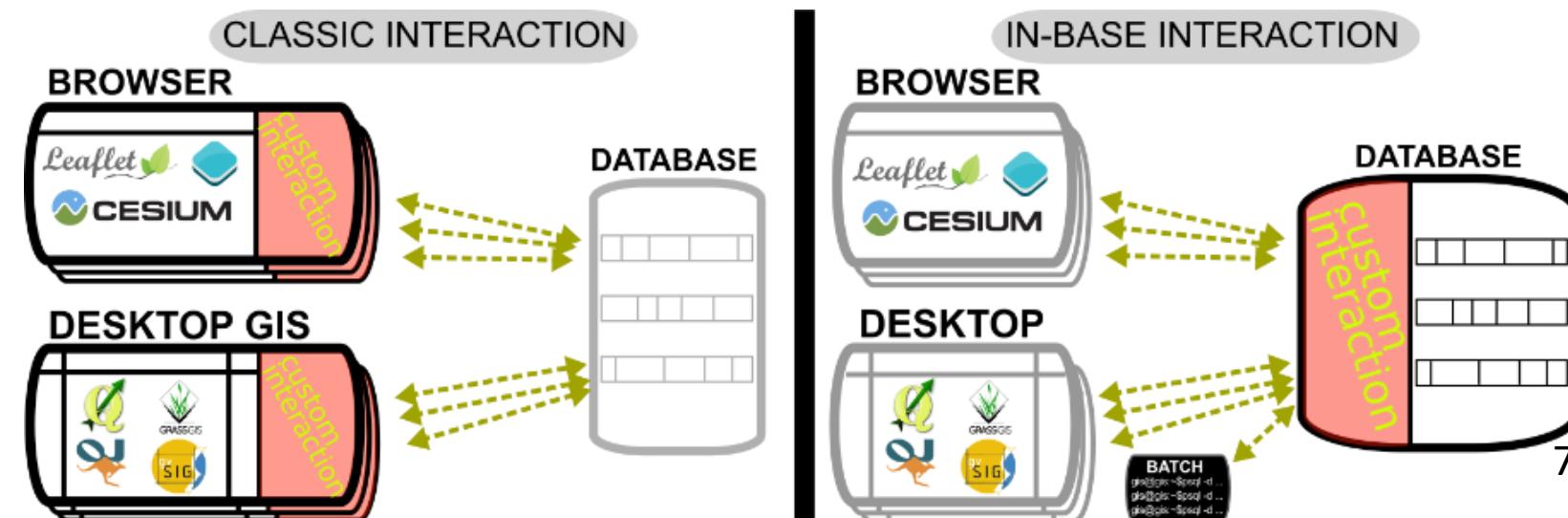


# StreetGen : street objects

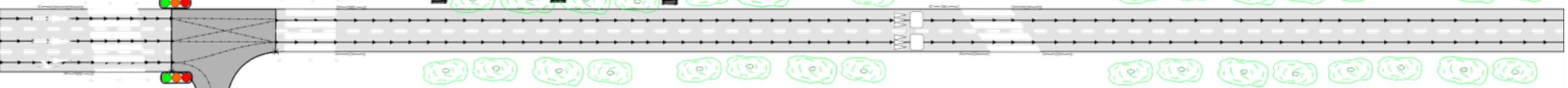
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- Fact : Graphical User Interface (GUI) → hard
- Many GUI for many tools (web/desktop/...)
  - Need to create plugins/interfaces/...
- Use existing tools !
  - GIS tools can already edit vector and attributes
  - specific interactions are in base



# StreetGen : street objects



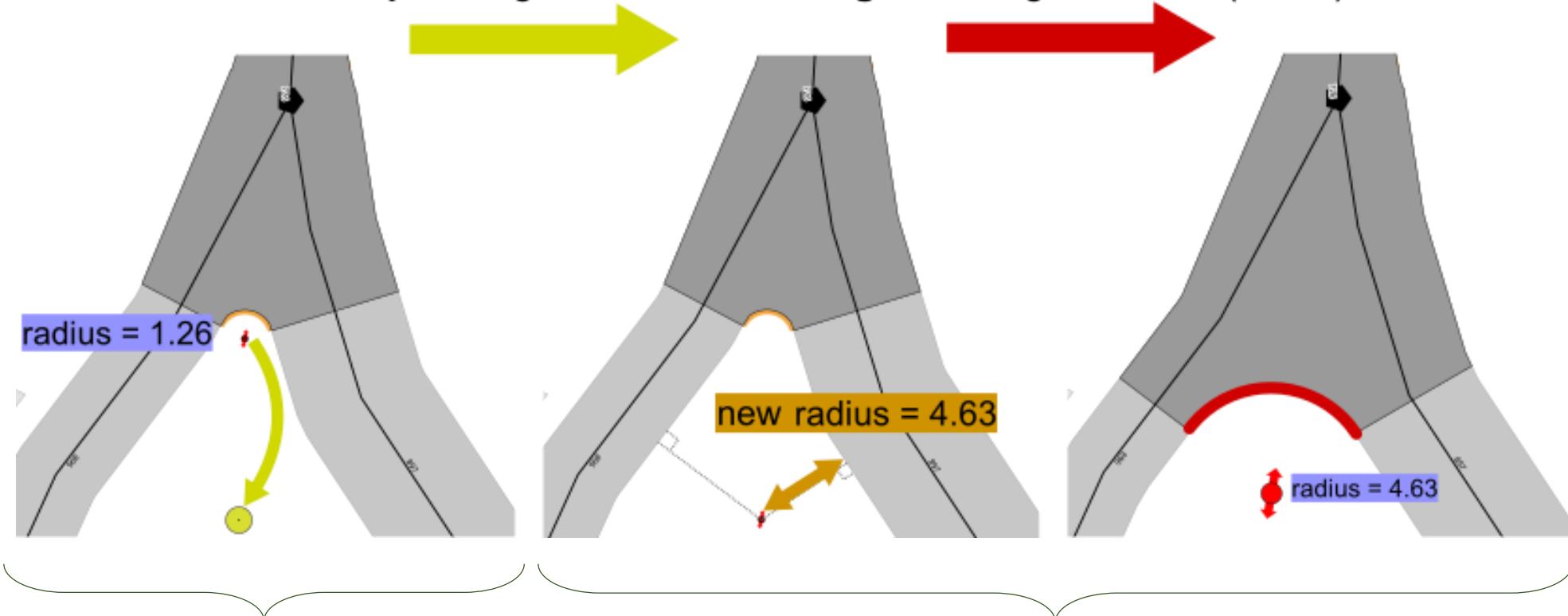
- example:

## User

User edited proxy view:  
**interpret** to get new radius

## Automated

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



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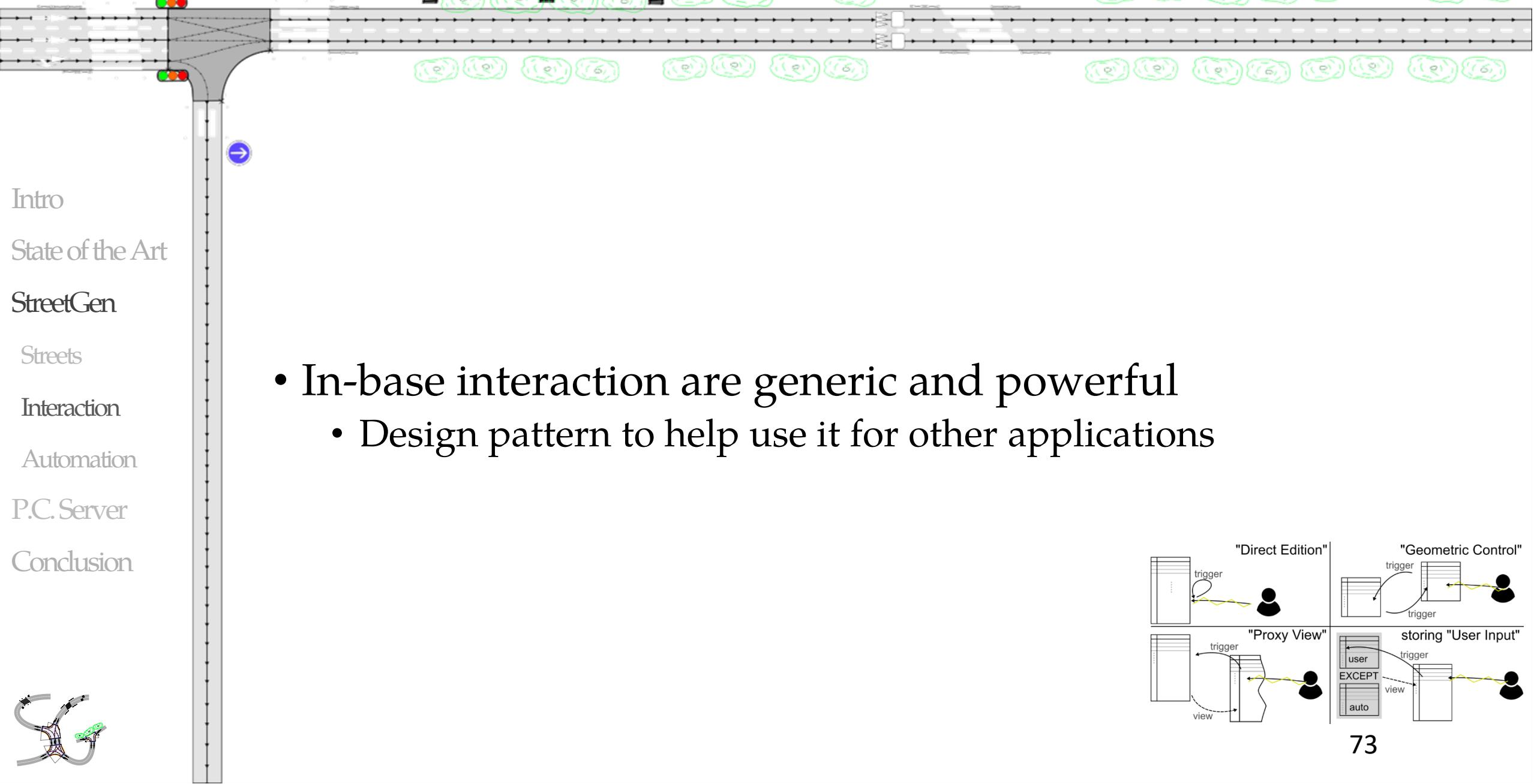
Interaction

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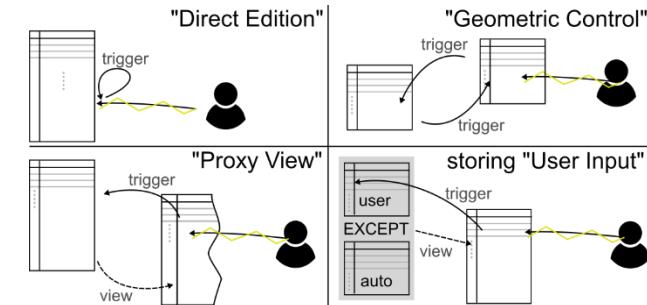
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Conclusion

# StreetGen : street objects



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



# StreetGen : street objects

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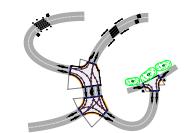
Streets

Interaction

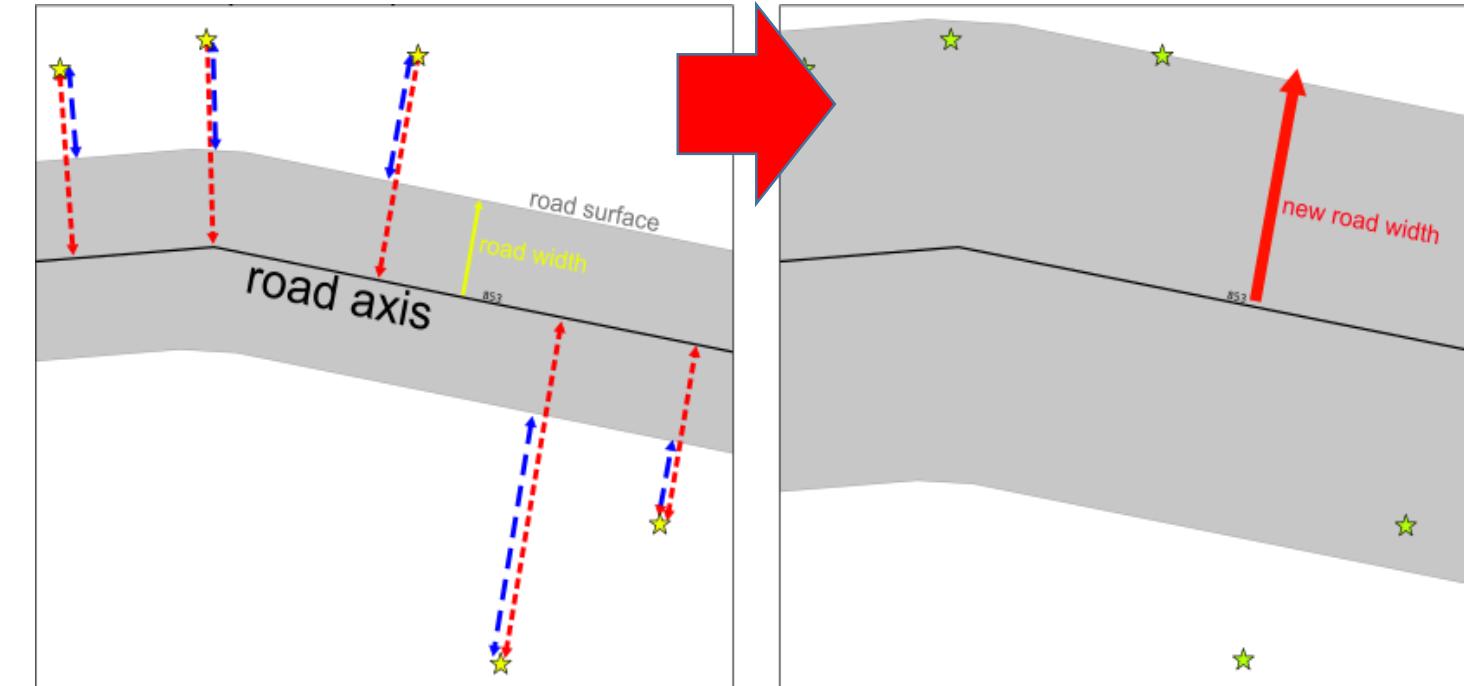
Automation

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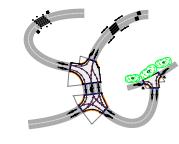


- All StreetGen street model parameters can be edited concurrently
  - Road axis/ width/topology
  - Radius
  - Lane
  - Interconnection
  - objects

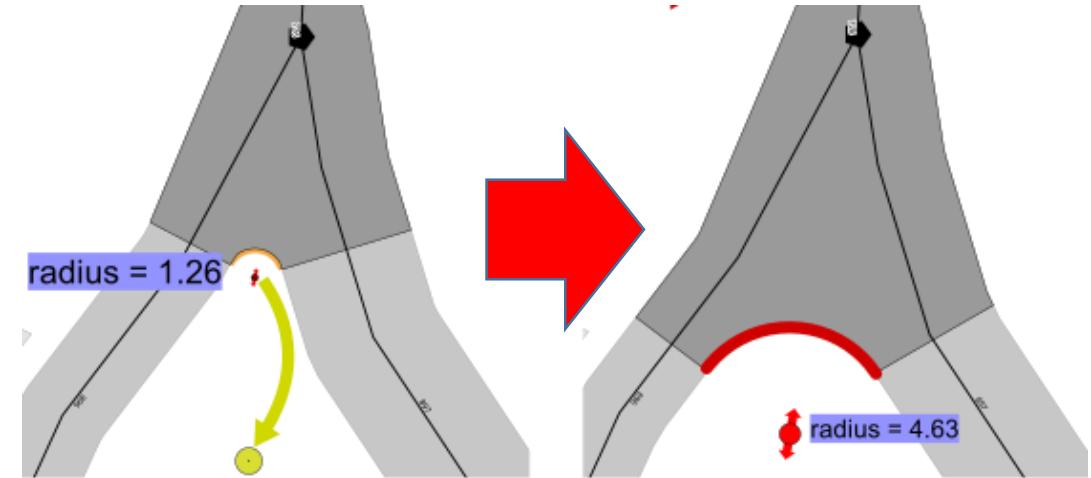


# StreetGen : street objects

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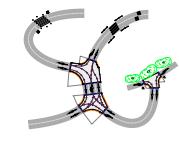


- All StreetGen street model can be edited concurrently
  - Road axis/ width/topology
  - Radius
  - Lane
  - Interconnection
  - objects

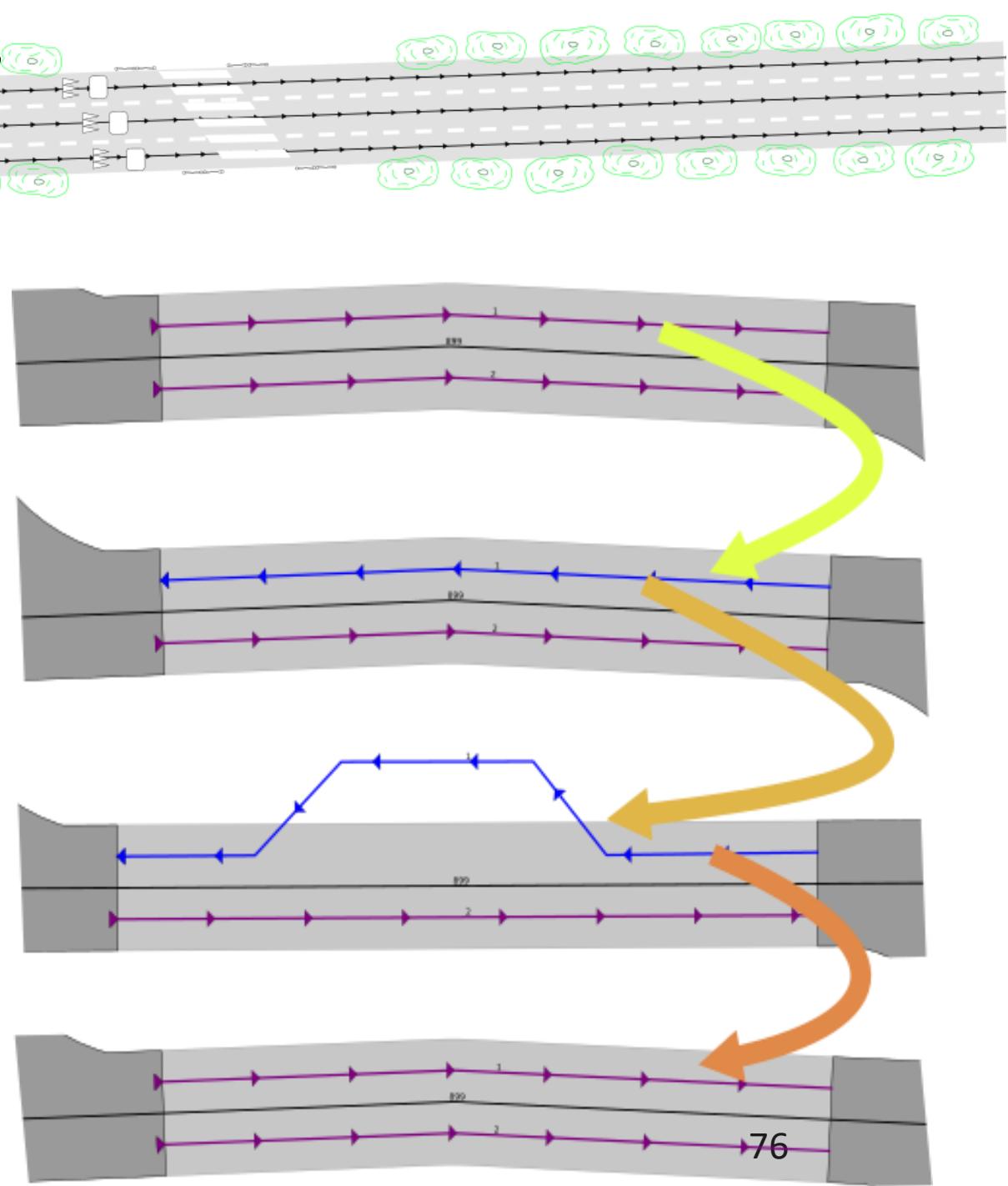


# StreetGen : street objects

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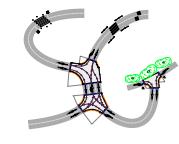


- All StreetGen street model can be edited concurrently
  - Road axis/ width/topology
  - Radius
  - Lane
  - Interconnection
  - objects

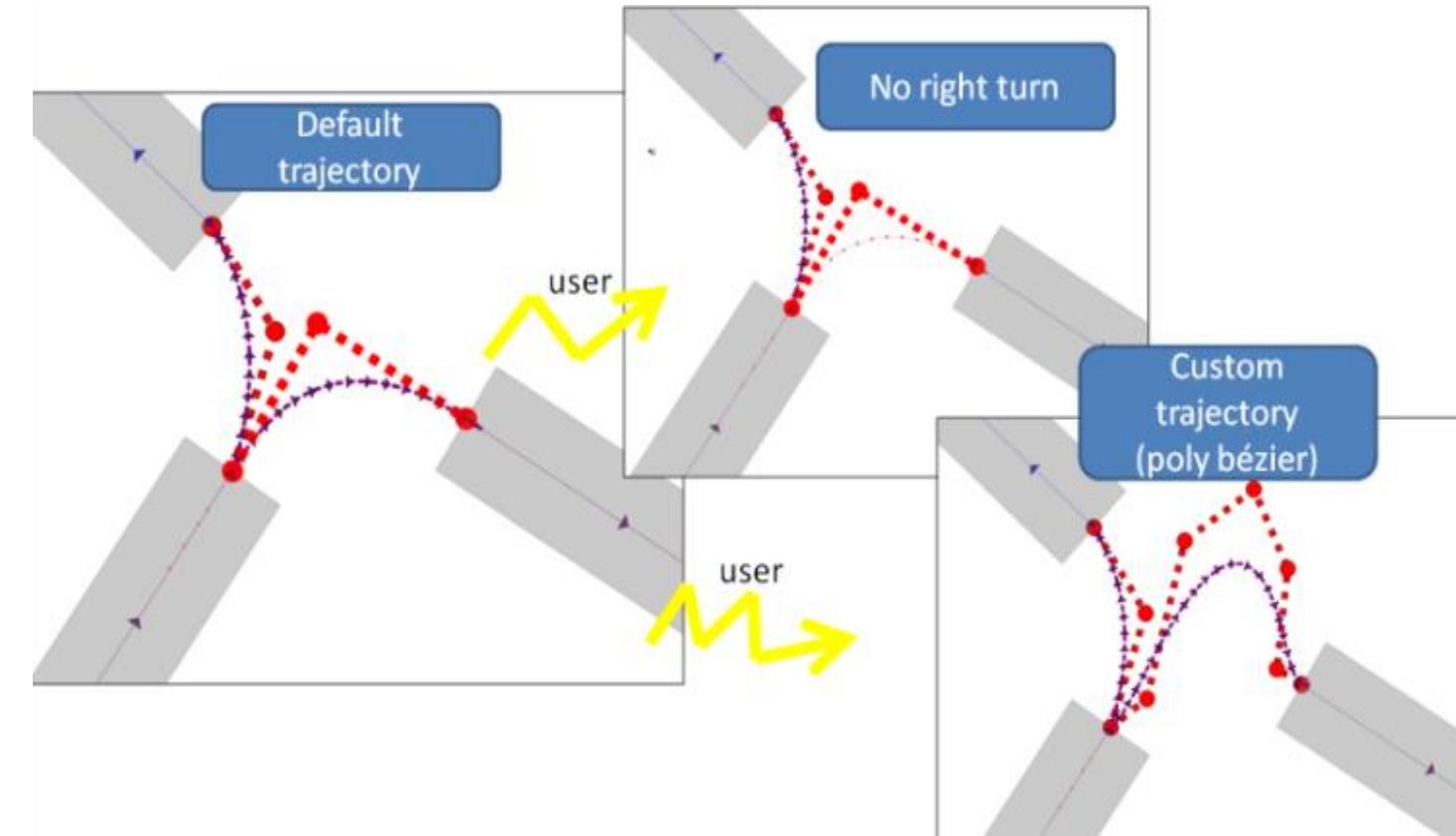


# StreetGen : street objects

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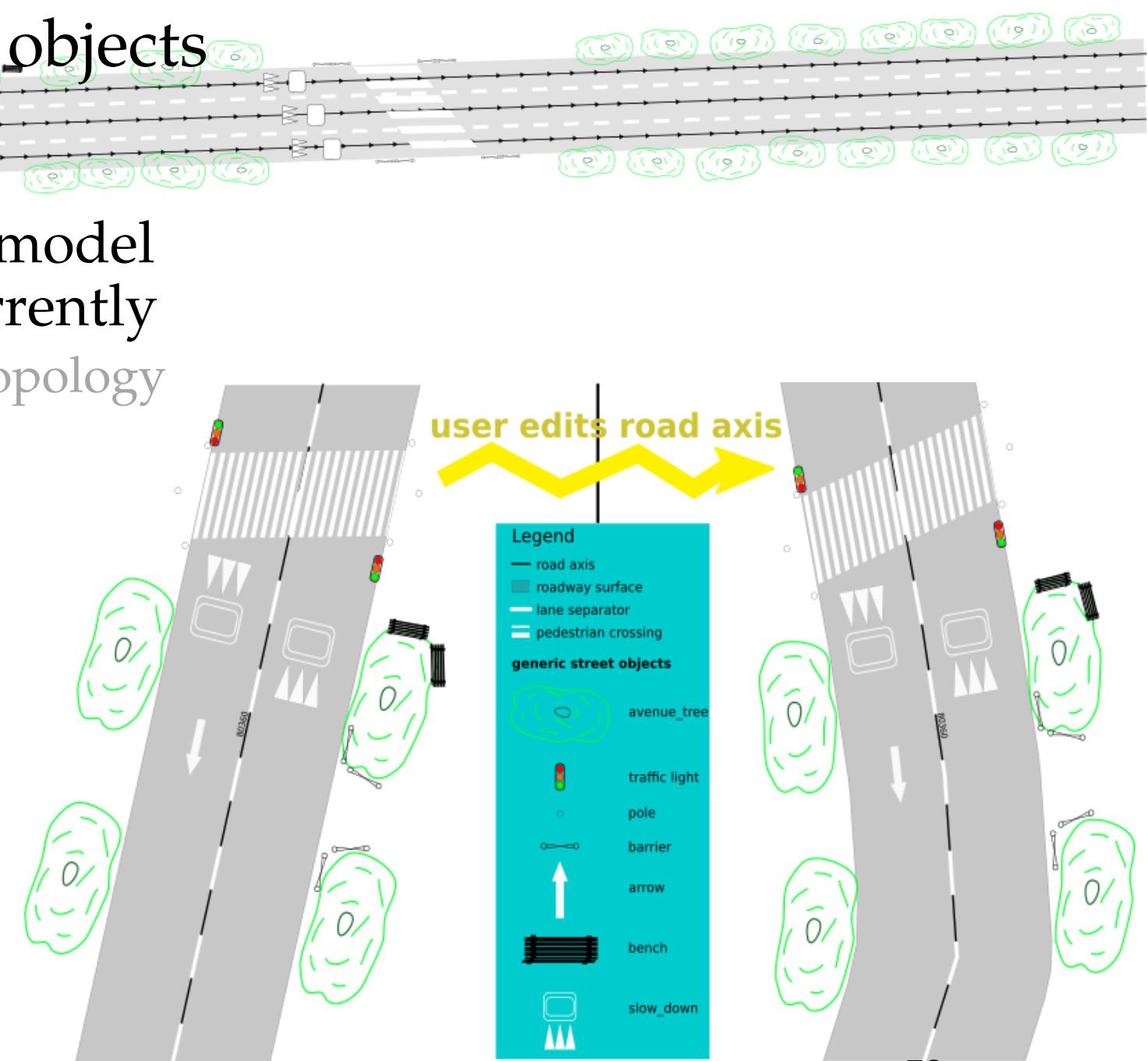


- All StreetGen street model can be edited concurrently
  - Road axis/ width/topology
  - Radius
  - Lane
  - Interconnection
  - objects



# 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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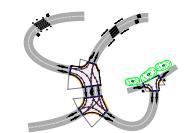
Streets

Interaction

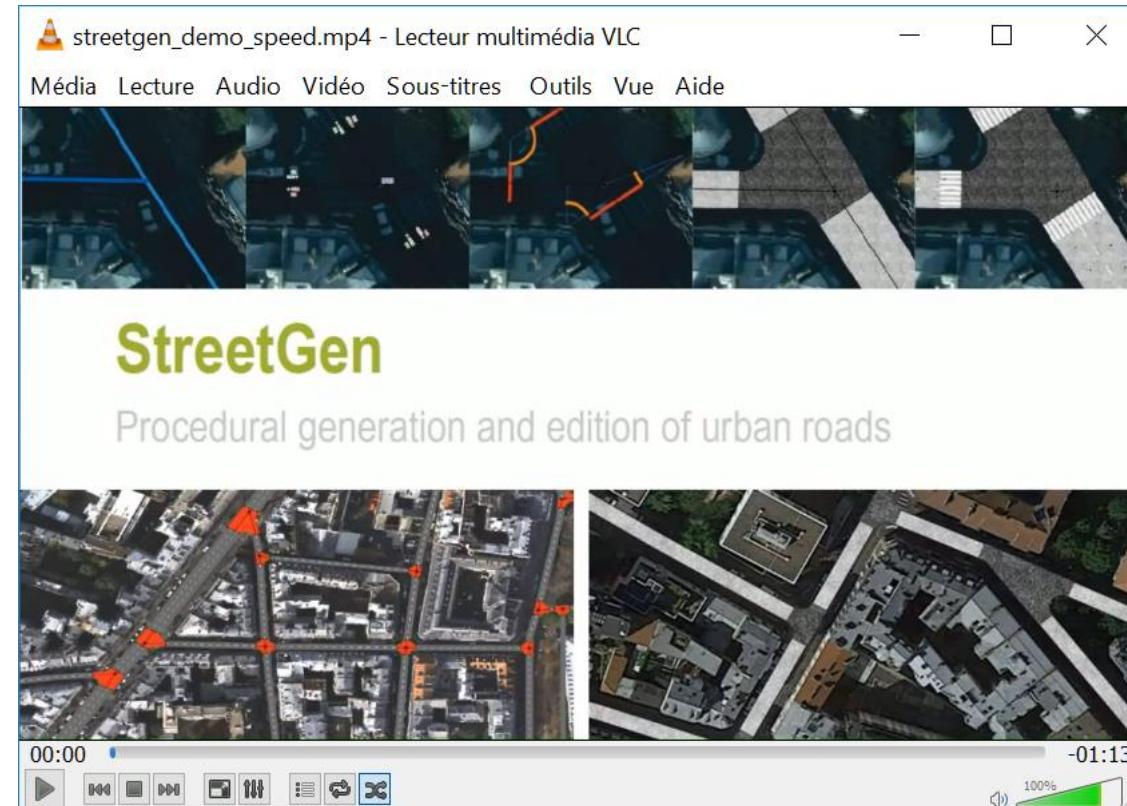
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- Results:
  - Interactions are fast enough to be interactive



Video  
<https://youtu.be/fQZoEfUcNHA>

# StreetGen : street objects

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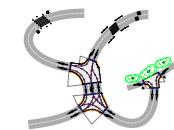
Streets

Interaction

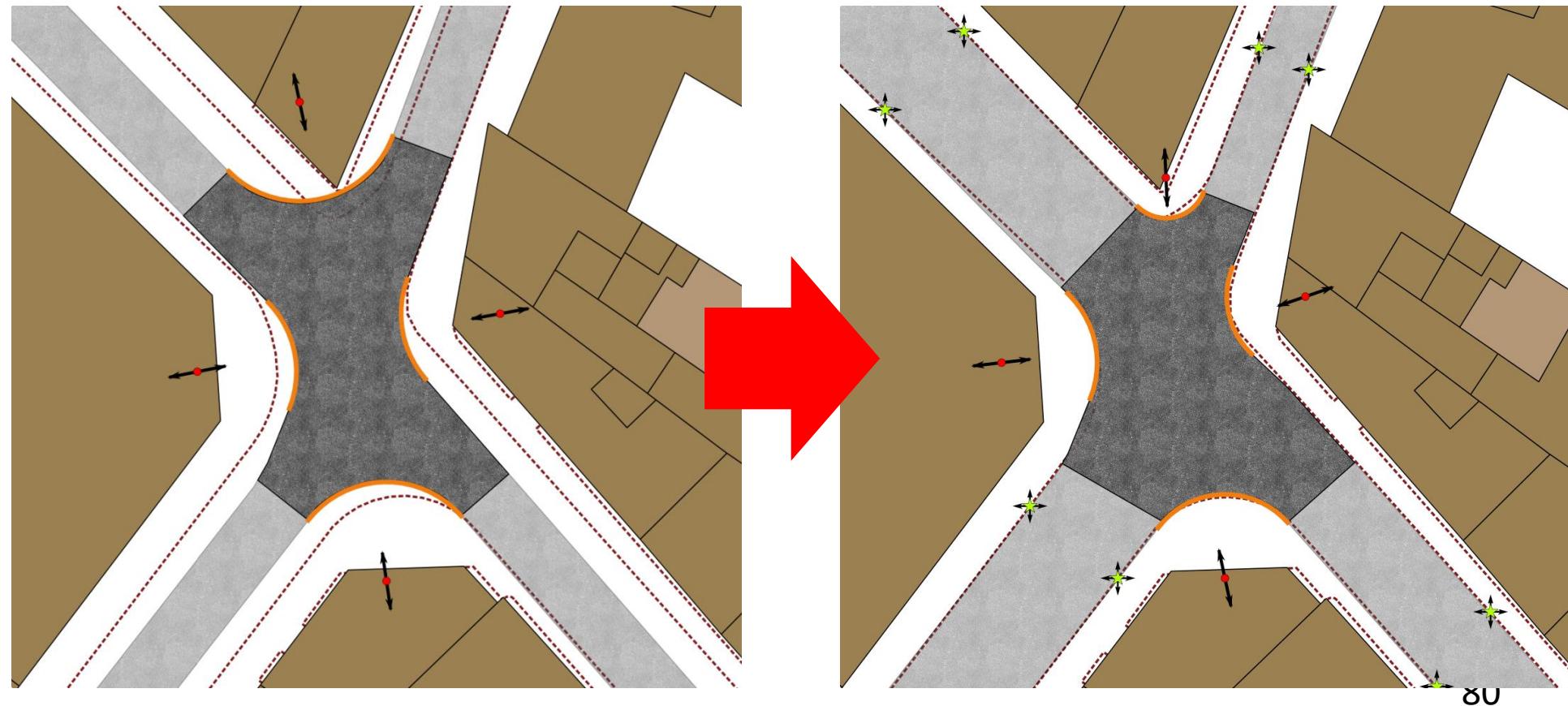
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- Results:



# StreetGen : street objects

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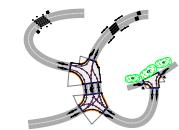
Streets

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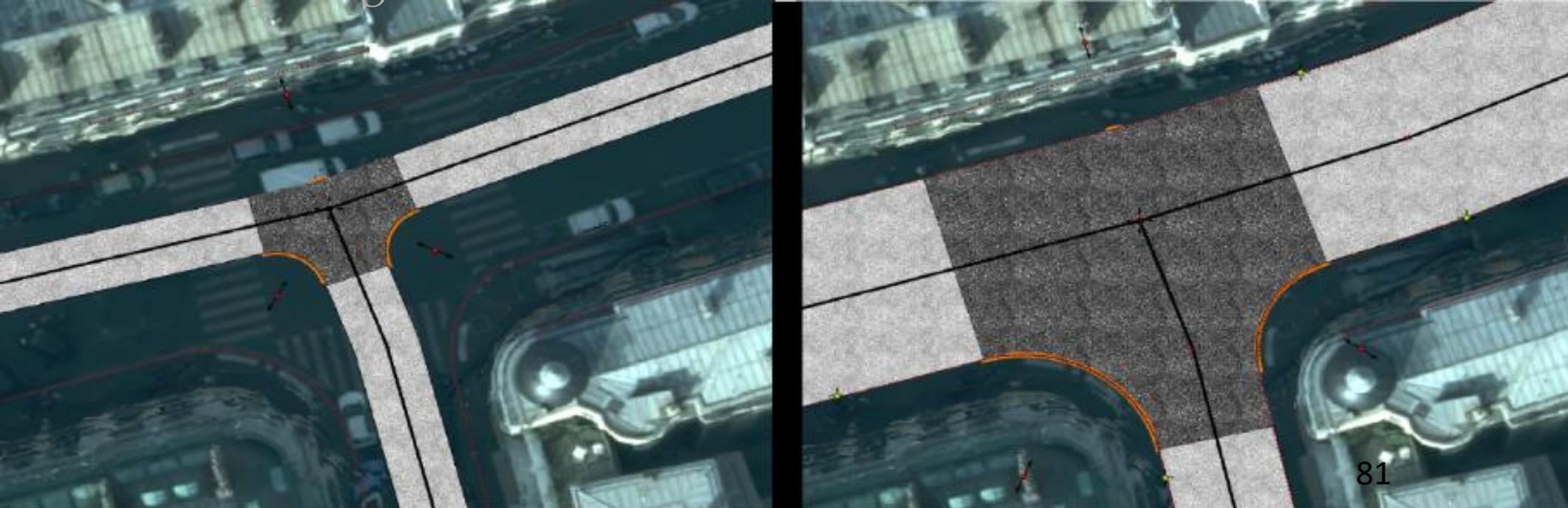
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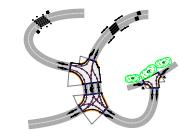
- Contributions

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



# StreetGen : street objects

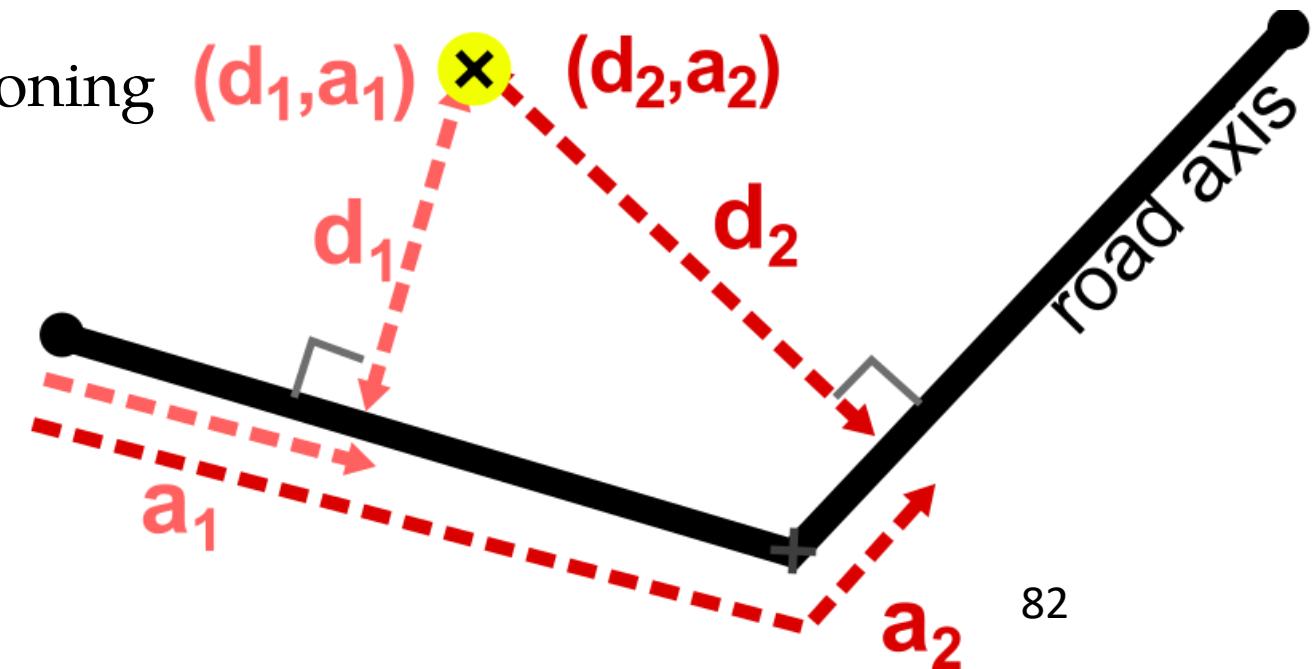
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- Several Limitations

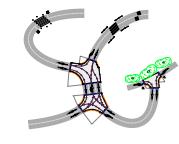
- limited to straightforward interaction  
(guessing user action is easy)
- Old school : Hard to develop/test/maintain
- one transaction → should be short

- Objects: relative positioning  
may be ambiguous

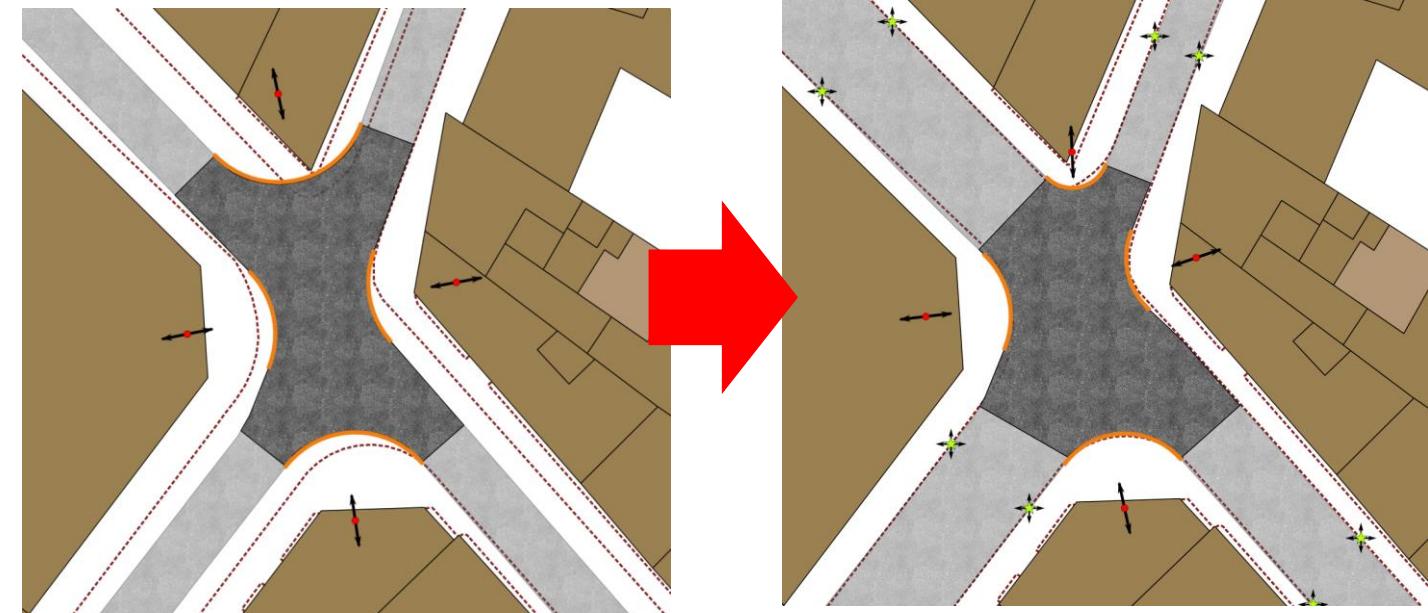


# StreetGen : street objects

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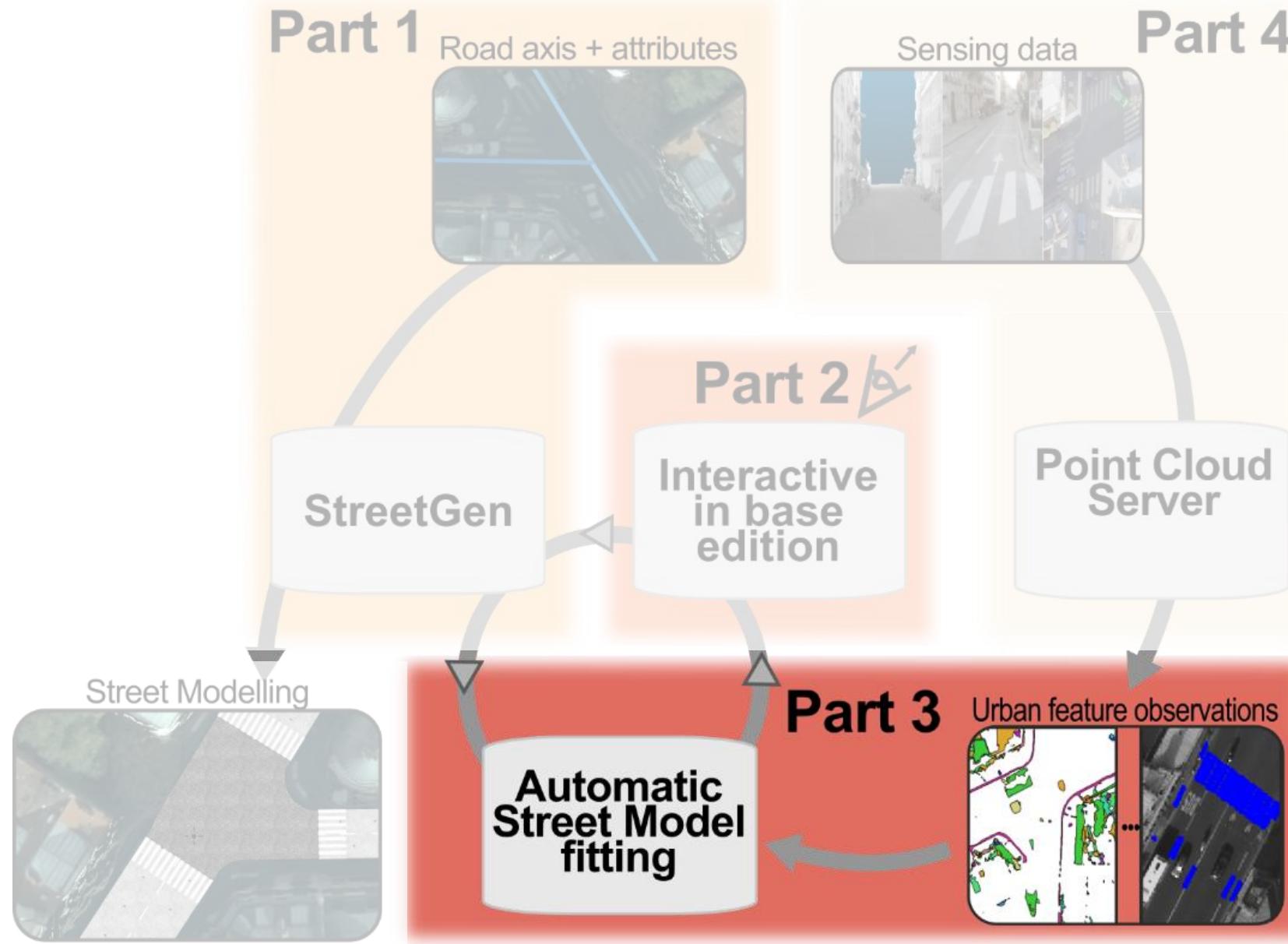


- Manual fitting : we can come close to real streets
  - Tedious
  - Lengthy !



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

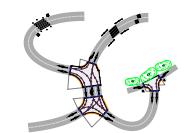
# Automating street modelling

**Inverse procedural modelling concept**

Street objects observations

Fitting principle

Results



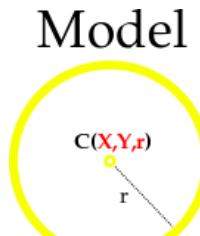
# StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

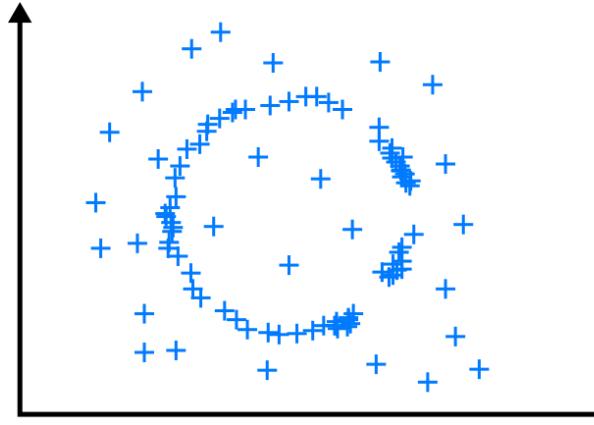
## Inverse Problem:

width= 4; lane= 1



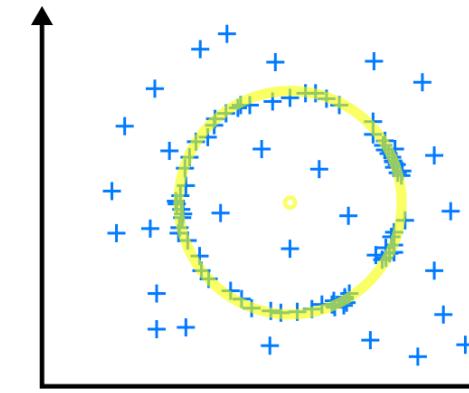
+

observations



fit  
→

Model = C(3.2,2.1,1.5)



## Procedural model

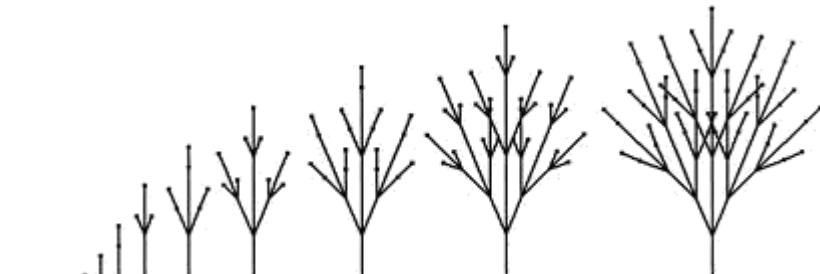
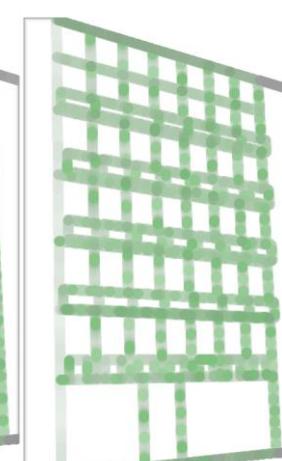
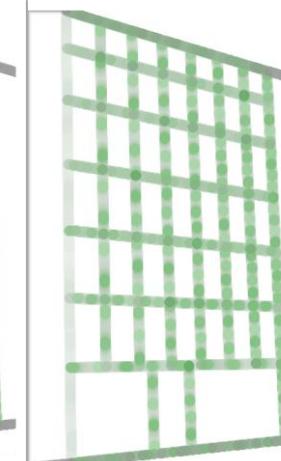
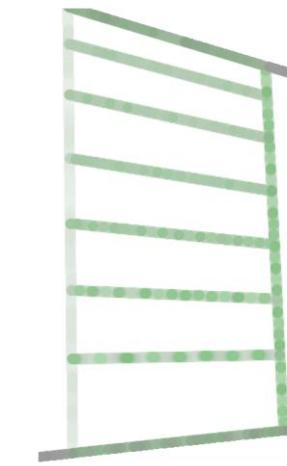


Image : Three-dimensional modelling and visualisation of vegetation for landscape simulation



Thales: Building maker



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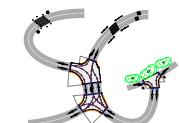
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# StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

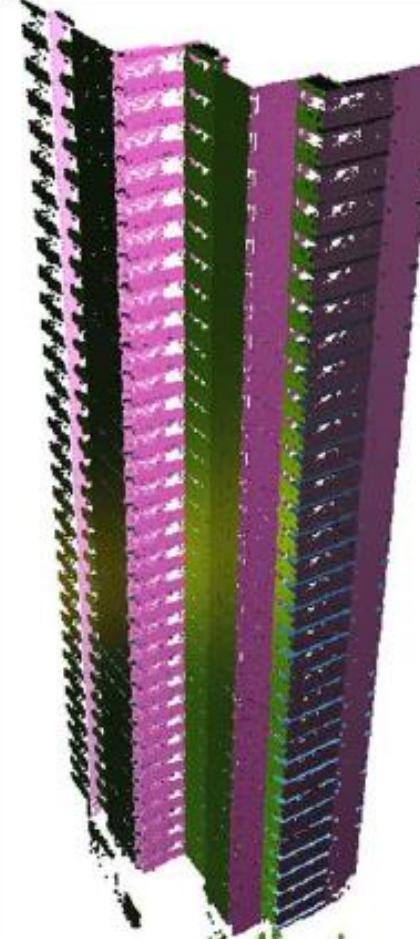
Fit a generic  
procedural model to a  
specific situation

Specific situation?  
→ We need data!



Talton2011

observations



Wan2012



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# StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

- In this work:

Procedural model = StreetGen for road

Observations = any street object **observations (found automatically from sensing data)** from other works

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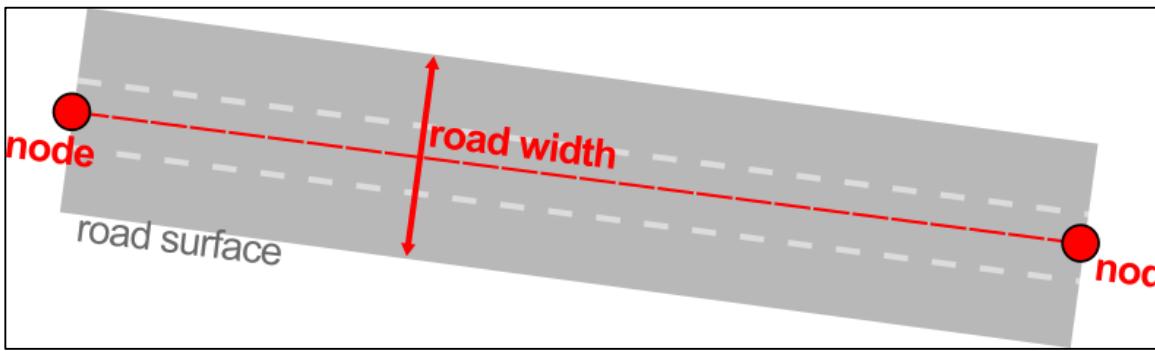
width= 4; lane= 1



# Inverse Procedural modelling: method

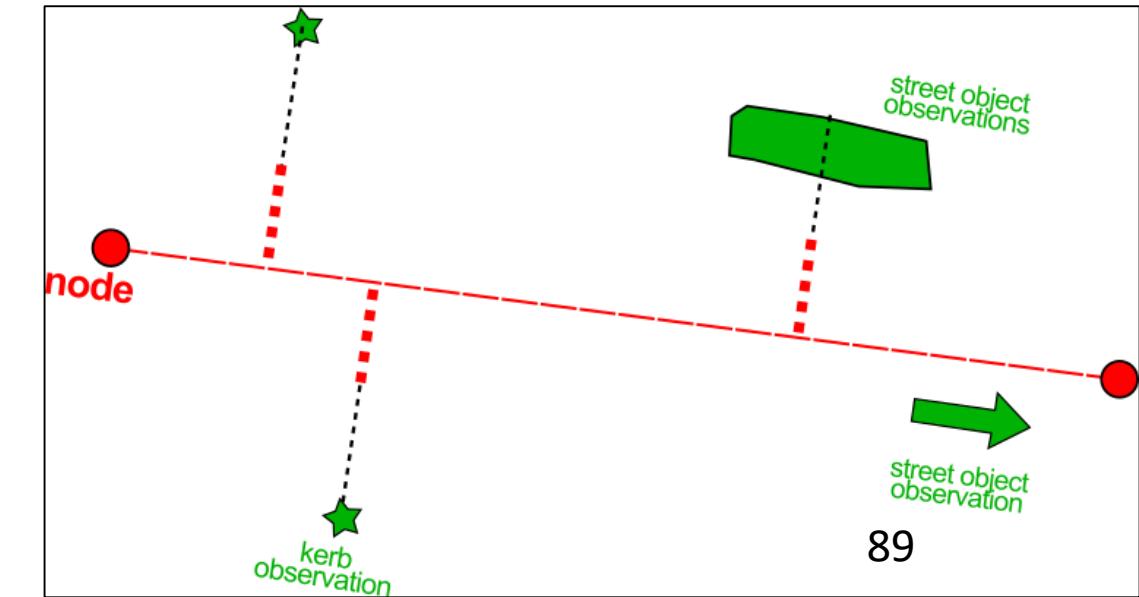
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- Initial road model (< StreetGen>) + observations



observations

- Observations =  
any street object detection



# Inverse Procedural modelling: method

- Initial road model + observations → fitted road model

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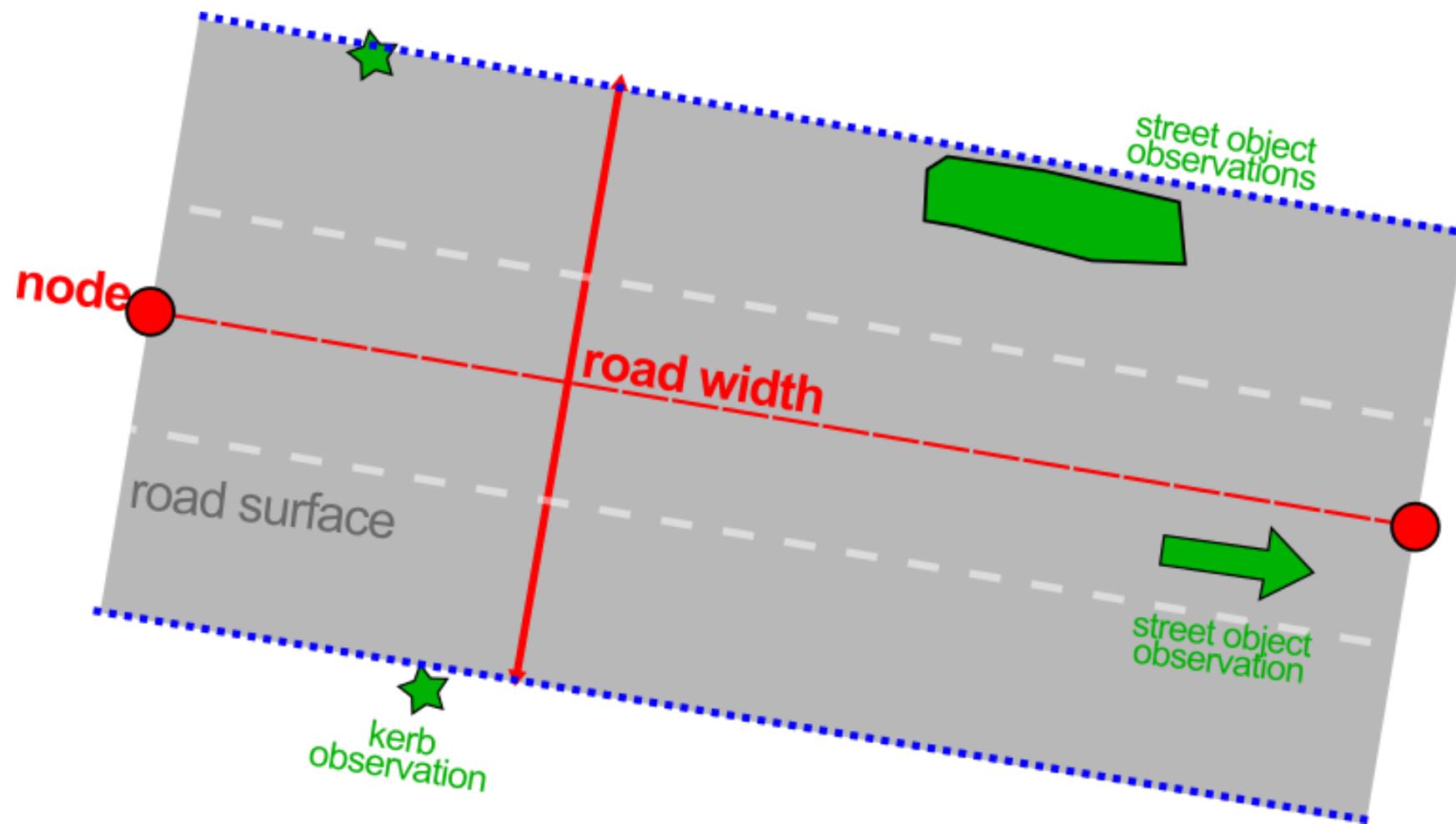
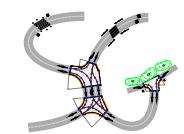
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width= 8; lane= 3

width= 6; lane= 2

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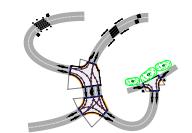
# Automating street modelling

Inverse procedural modelling concept

## **Street objects observations**

Fitting principle

Results



# StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

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

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width= 4; lane= 1

# StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

- What type of data for streets?

- Precise
- Good coverage
- Frequent

- Aerial image?

- Good coverage
- Low 3D precision

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width= 4; lane= 1



# 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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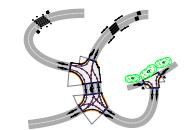
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width= 4; lane= 1



# StreetGen : Inverse procedural modelling

width= 8; lane= 3

width= 6; lane= 2

Lidar: 3D point clouds

- precise 3D



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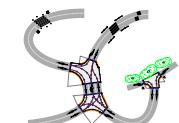
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# StreetGen : Inverse procedural modelling

width= 8; lane= 3

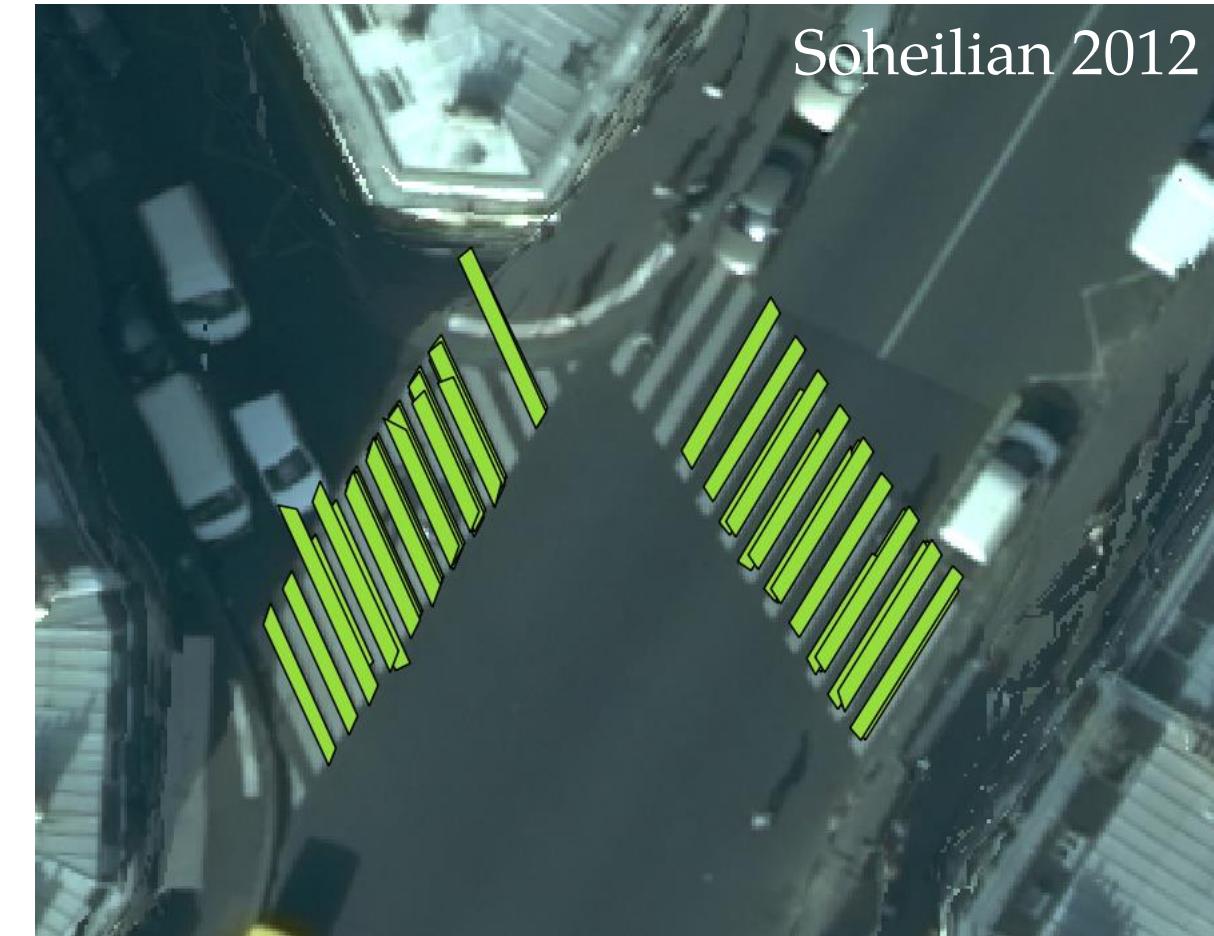
width= 6; lane= 2

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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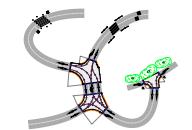
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Interaction

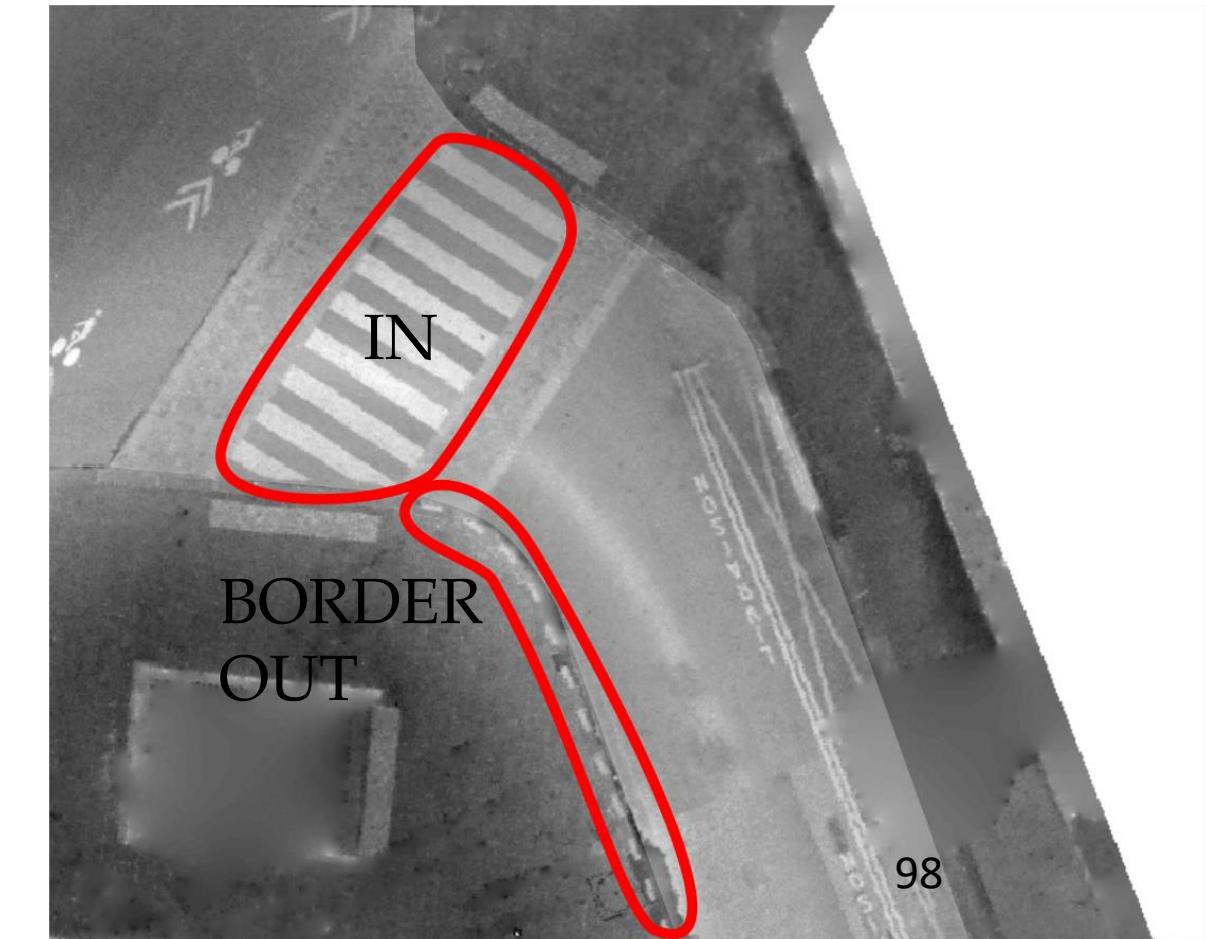
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- Each street object type has an expected position:
  - IN/OUT + BORDER\_IN/BORDER\_OUT (dist)

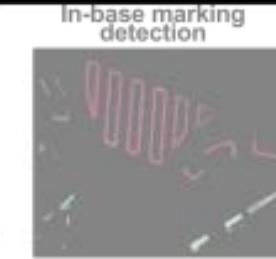
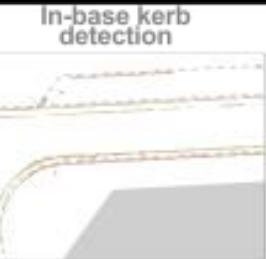
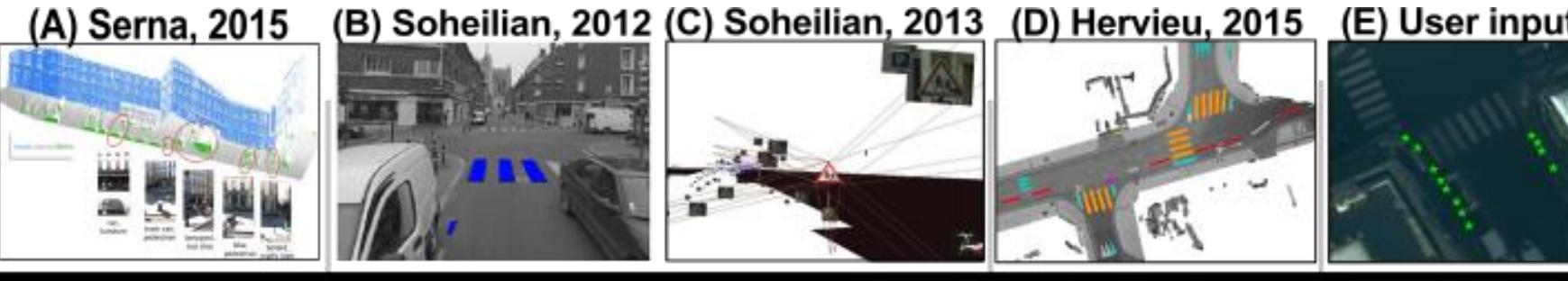


# Inverse Procedural modelling: observations

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- Observations = clues about the roadway
- We rely on other's work:

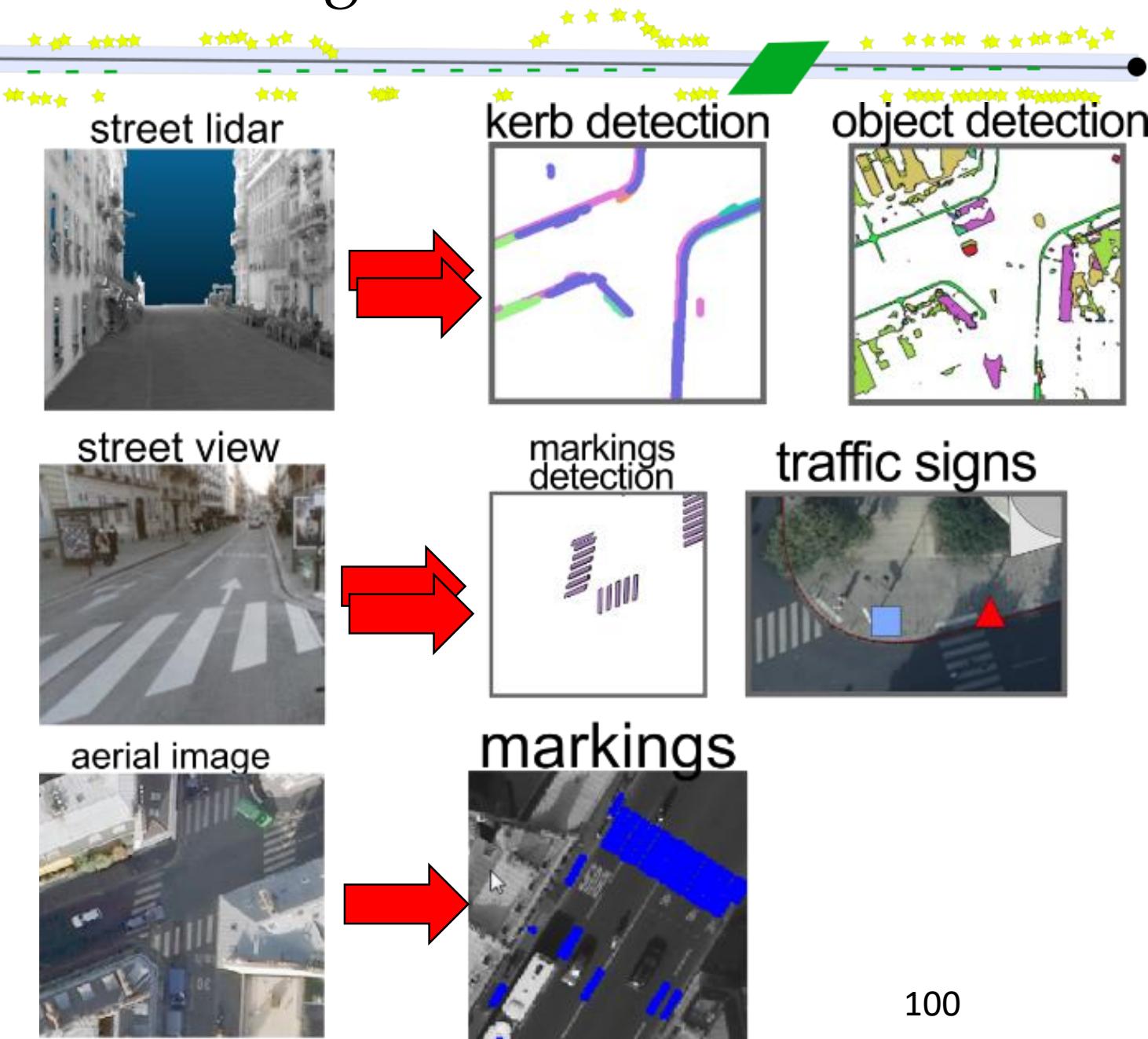
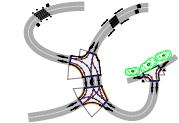
(We can use any street object detection)

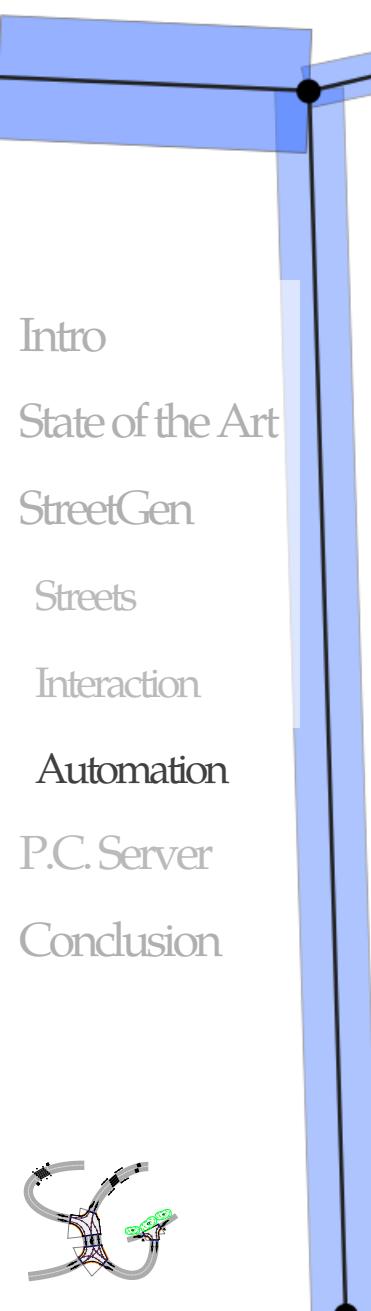


# Inverse Procedural modelling: observations

- Observations = clues about the roadway

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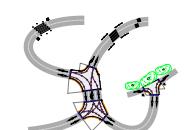
# Automating street modelling

Inverse procedural modelling concept

Street objects observations

**Fitting principle**

Results



# Inverse Procedural modelling: forces

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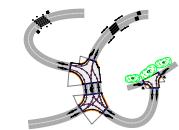
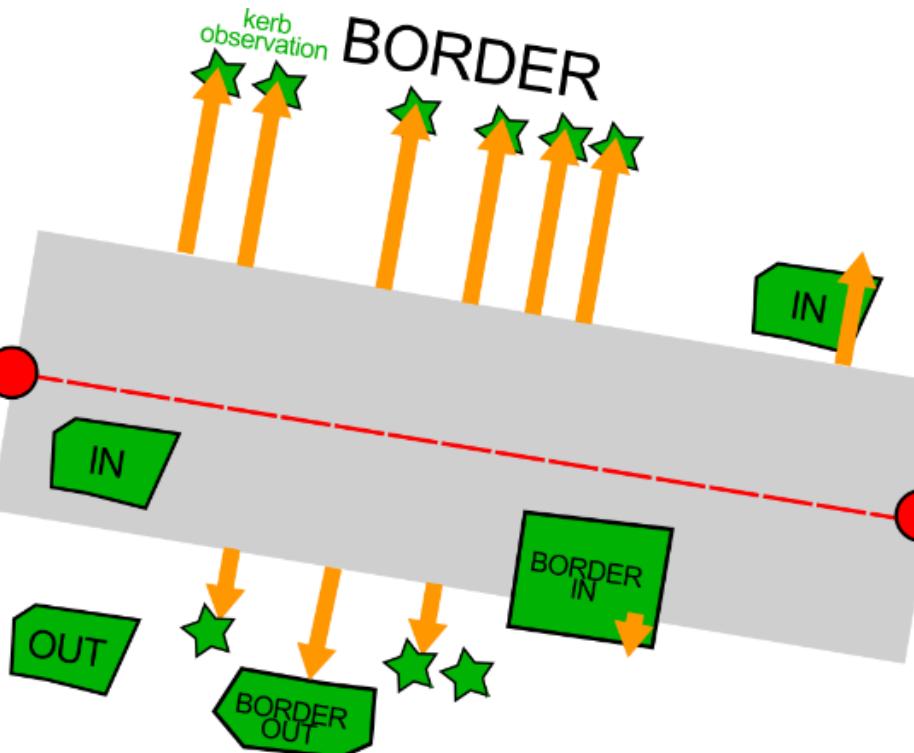
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- Mechanical analogy:
- Each observation push/pull road model



# Inverse Procedural modelling: forces

- Maybe residuals errors. (observations are un-precise)

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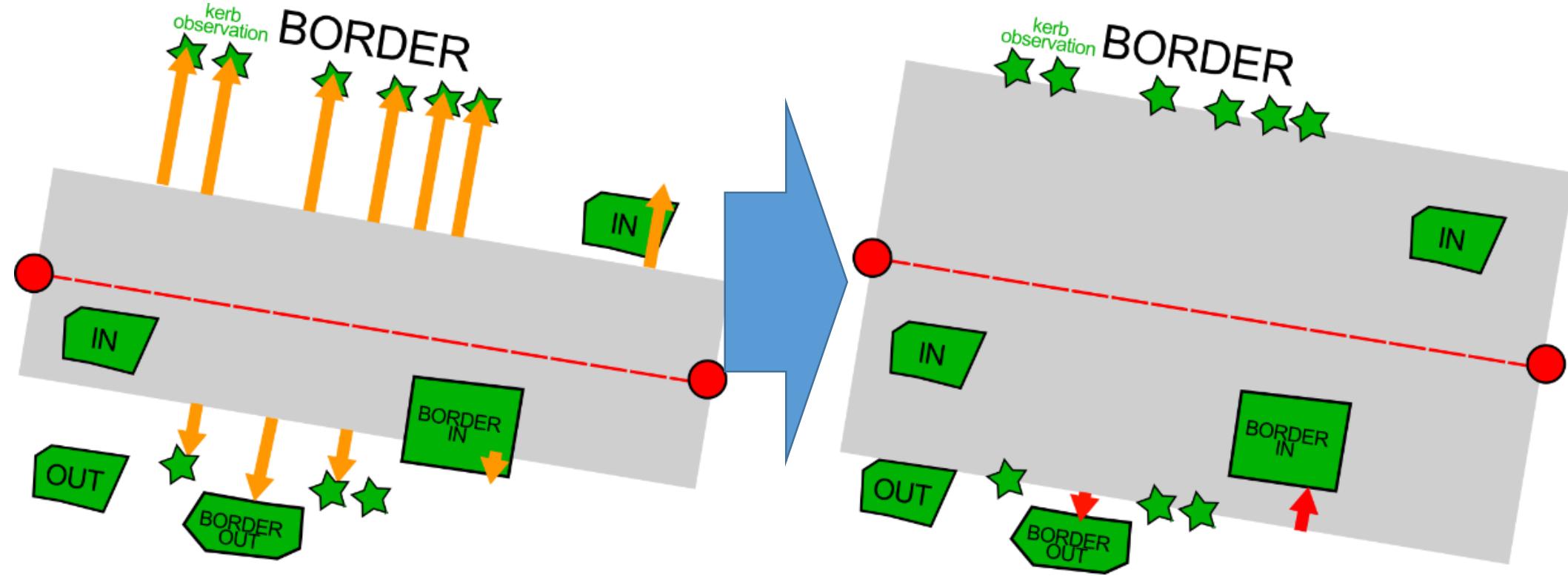
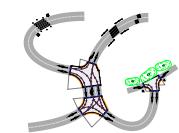
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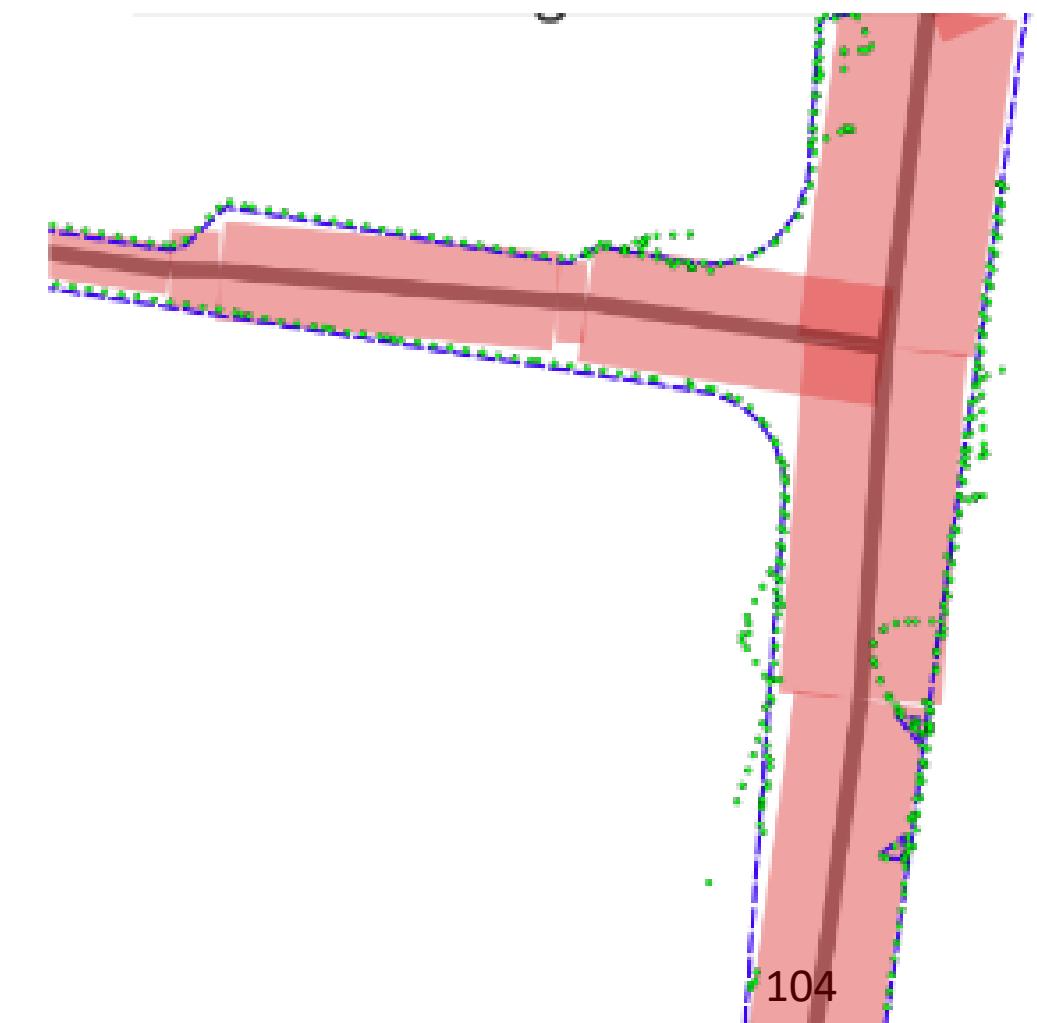
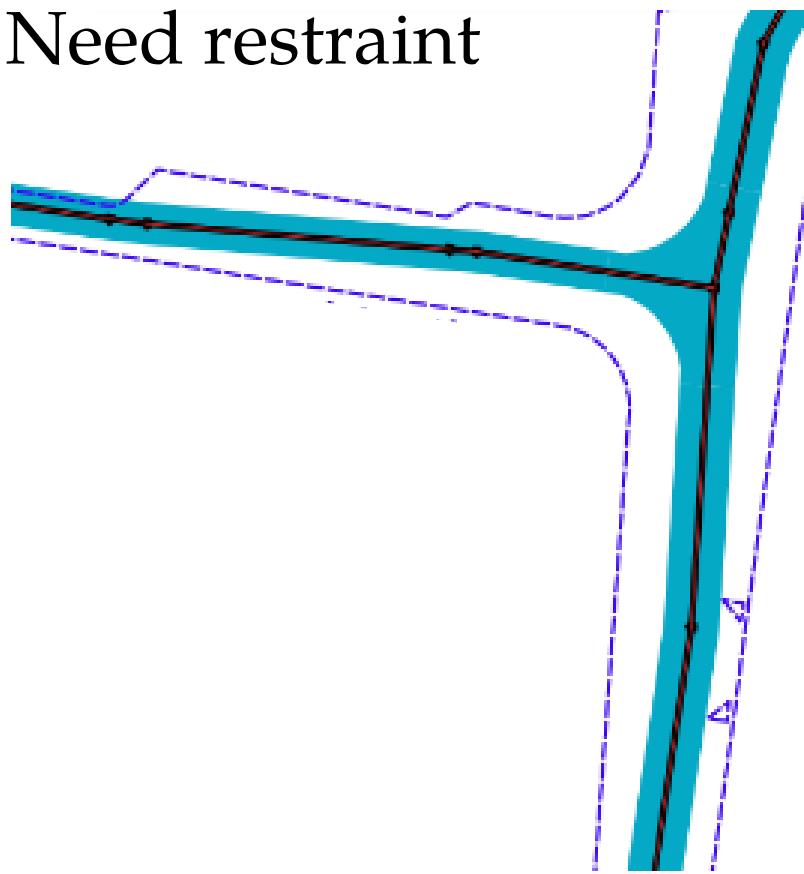
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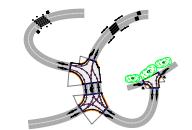


# Inverse Procedural modelling: method

- Real data :
- Some bad observations
- Need restraint



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# Inverse Procedural modelling: forces

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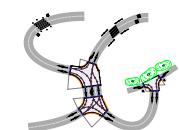
Streets

Interaction

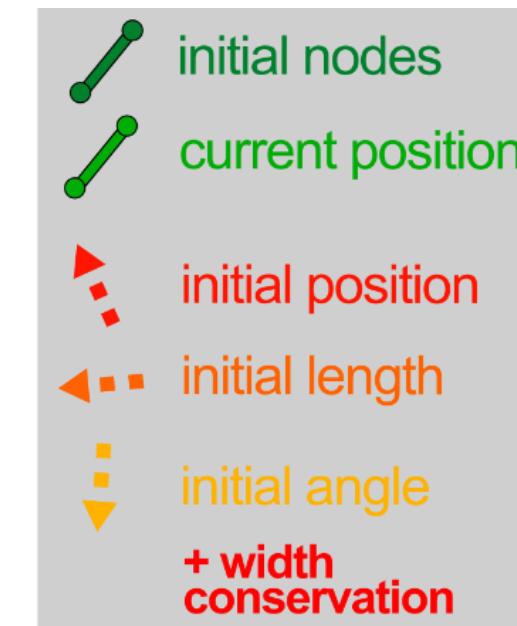
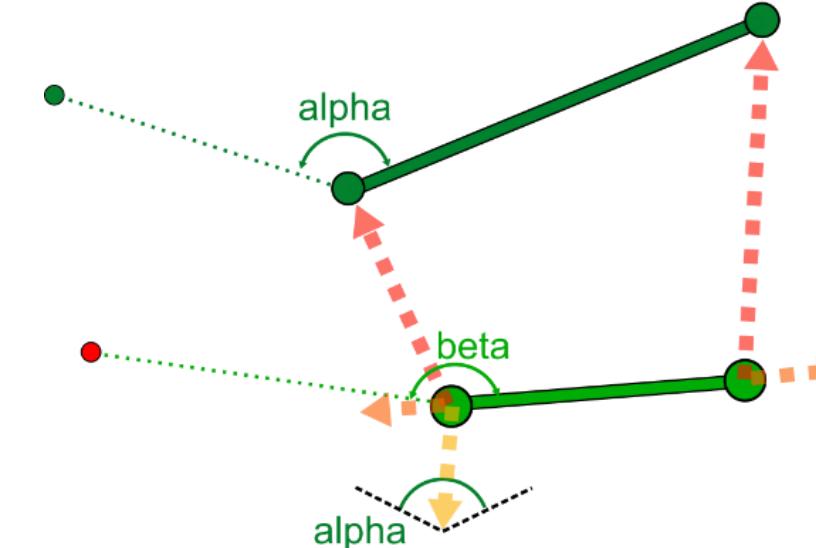
Automation

P.C. Server

Conclusion



- Resisting changes :
  - Conservative forces
  - Express confidence in initial road model



# Inverse Procedural modelling: experiment

Intro

State of the Art

StreetGen

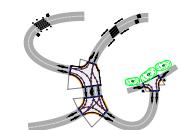
Streets

Interaction

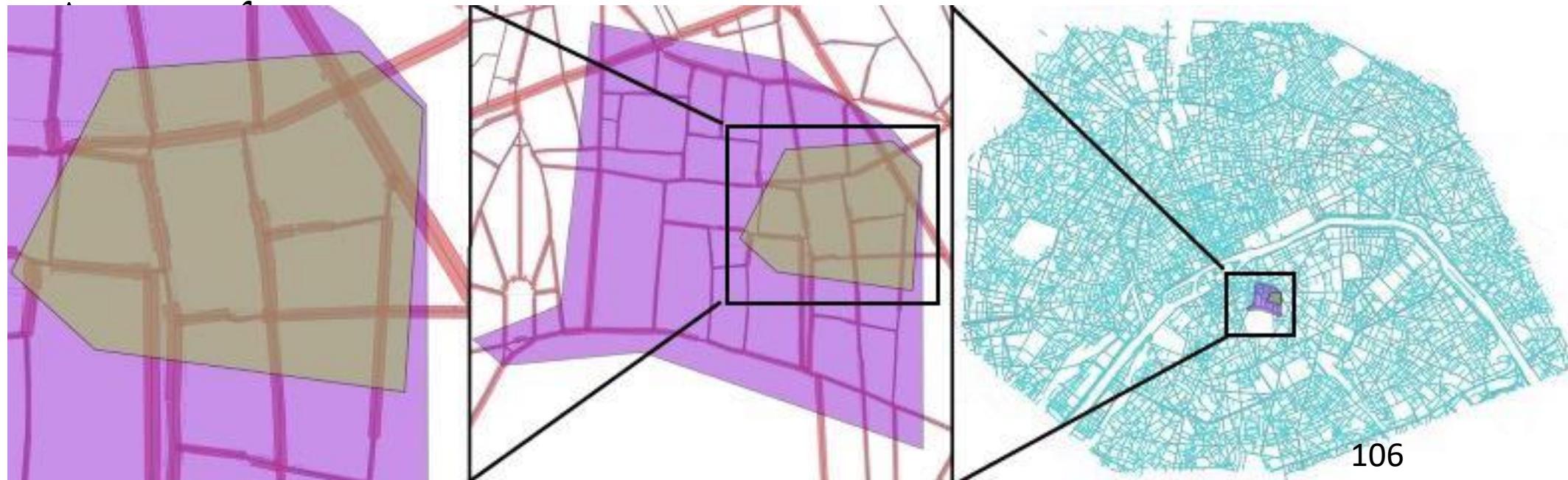
Automation

P.C. Server

Conclusion



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

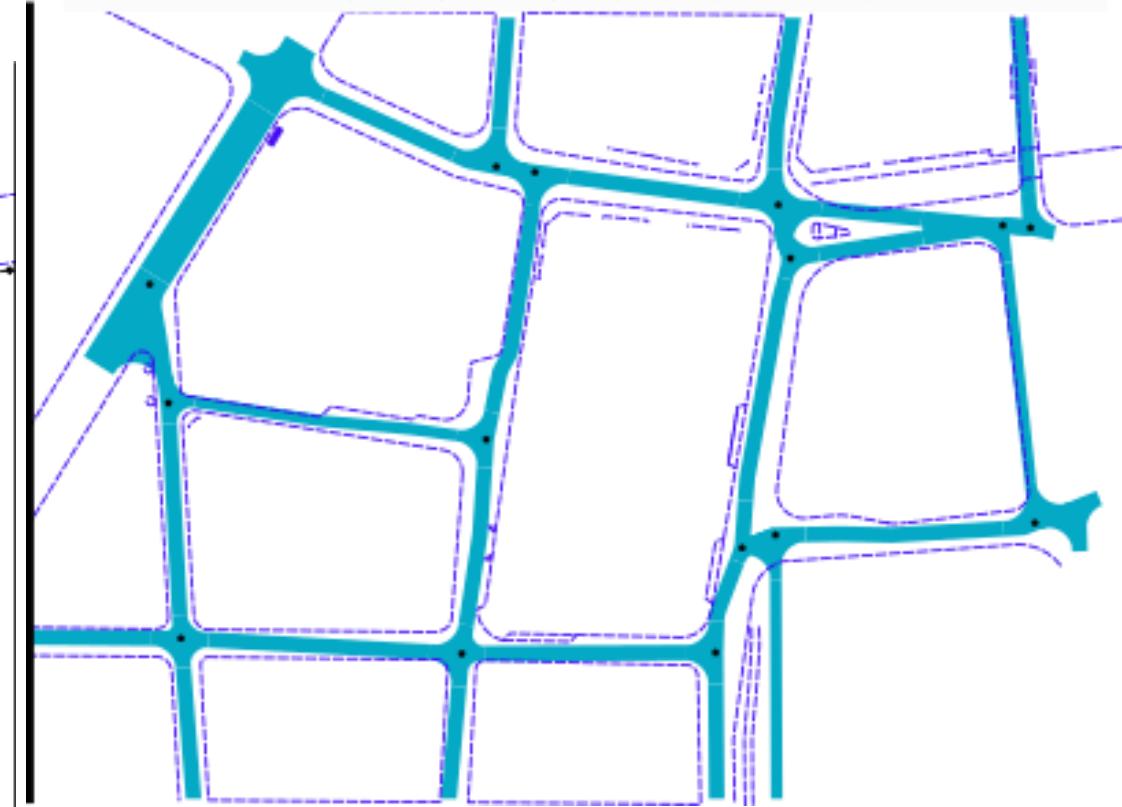


# Inverse Procedural modelling : small area

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

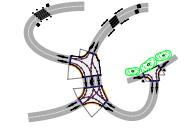


Initial axis and width



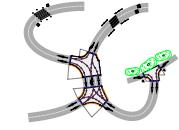
# Inverse Procedural modelling : small area

Intro  
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Interaction  
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Conclusion



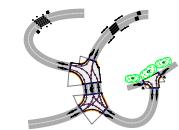
# Inverse Procedural modelling : small area

Intro  
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Automation  
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Conclusion



# Inverse Procedural modelling : small area

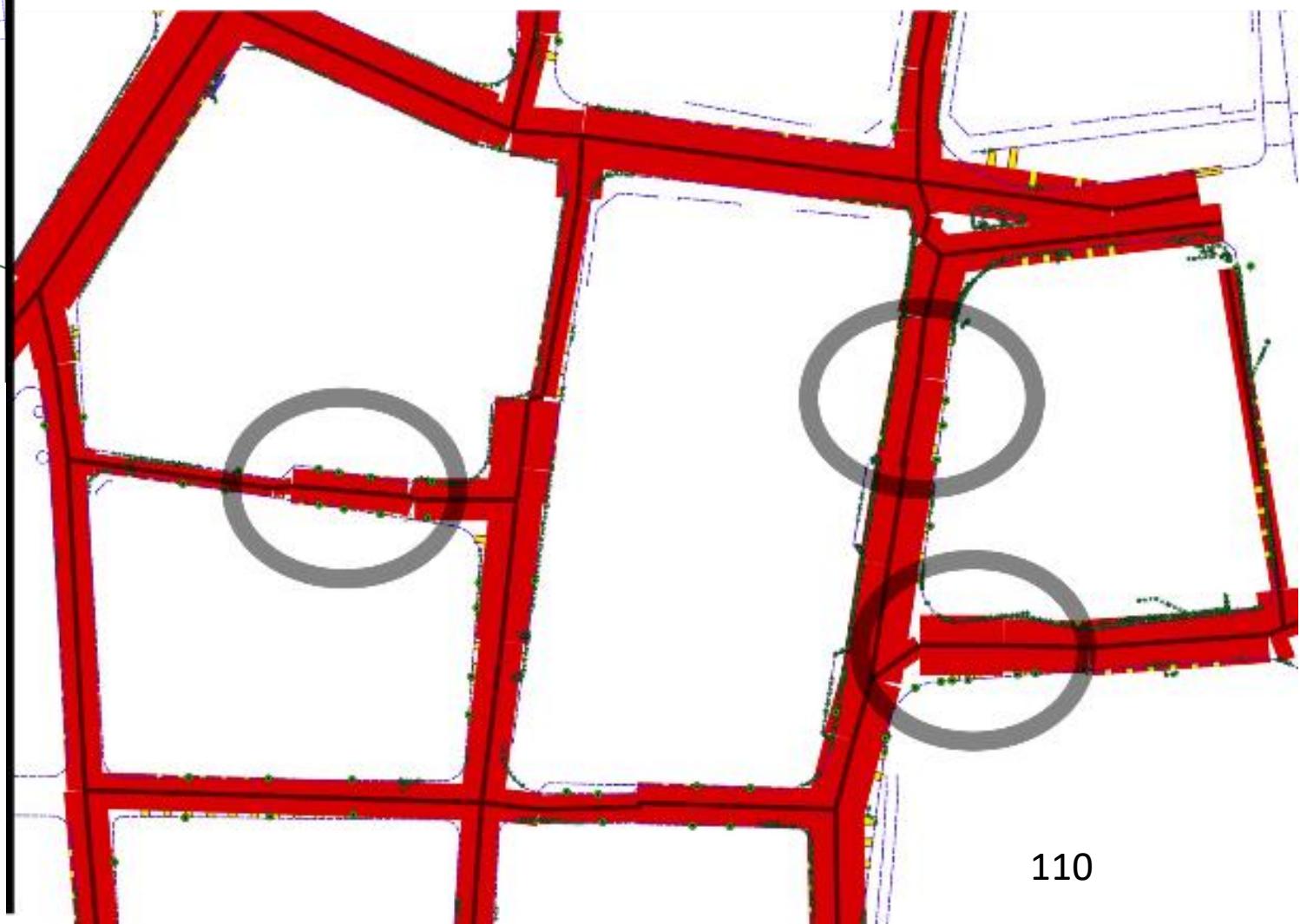
Intro  
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Conclusion



User defines sidewalk points



## Using Kerb and user input



# Inverse Procedural modelling : small area

Intro

State of the Art

StreetGen

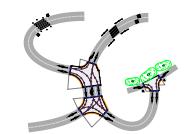
Streets

Interaction

Automation

P.C. Server

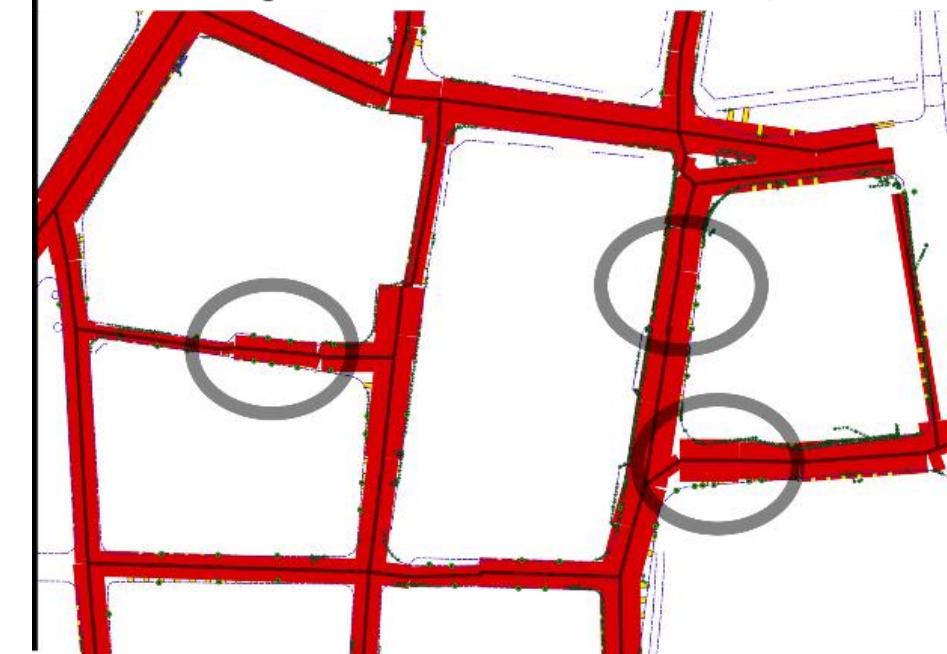
Conclusion



- Using Only kerb observations:
  - 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

Intro

State of the Art

StreetGen

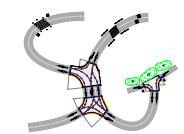
Streets

Interaction

Automation

P.C. Server

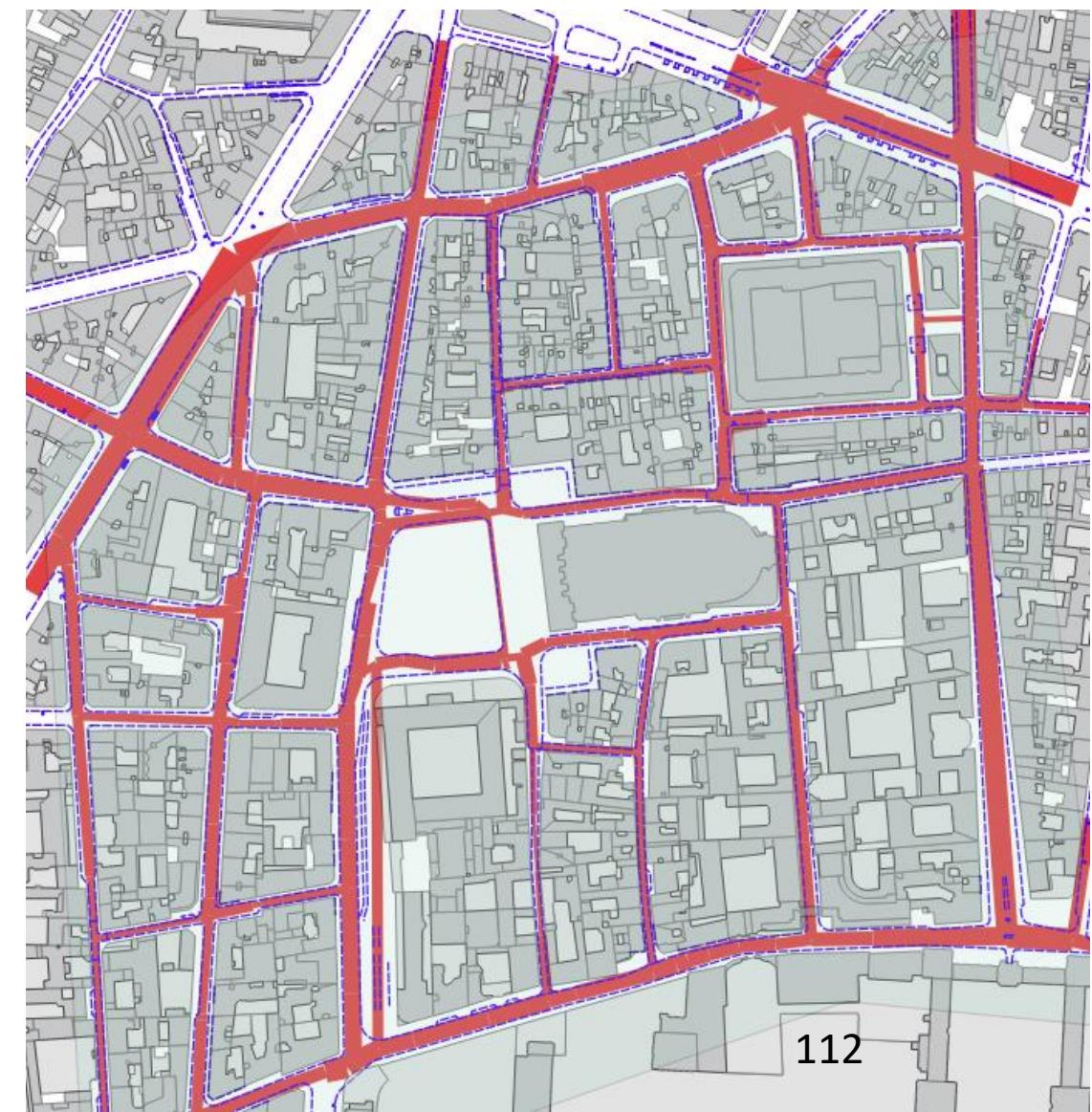
Conclusion



- Whole sensing area:

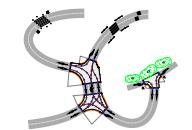
Results:

Looks ok, but,



# Inverse Procedural modelling : sensing area

Intro  
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P.C. Server  
Conclusion



- 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

Intro

State of the Art

StreetGen

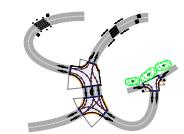
Streets

Interaction

Automation

P.C. Server

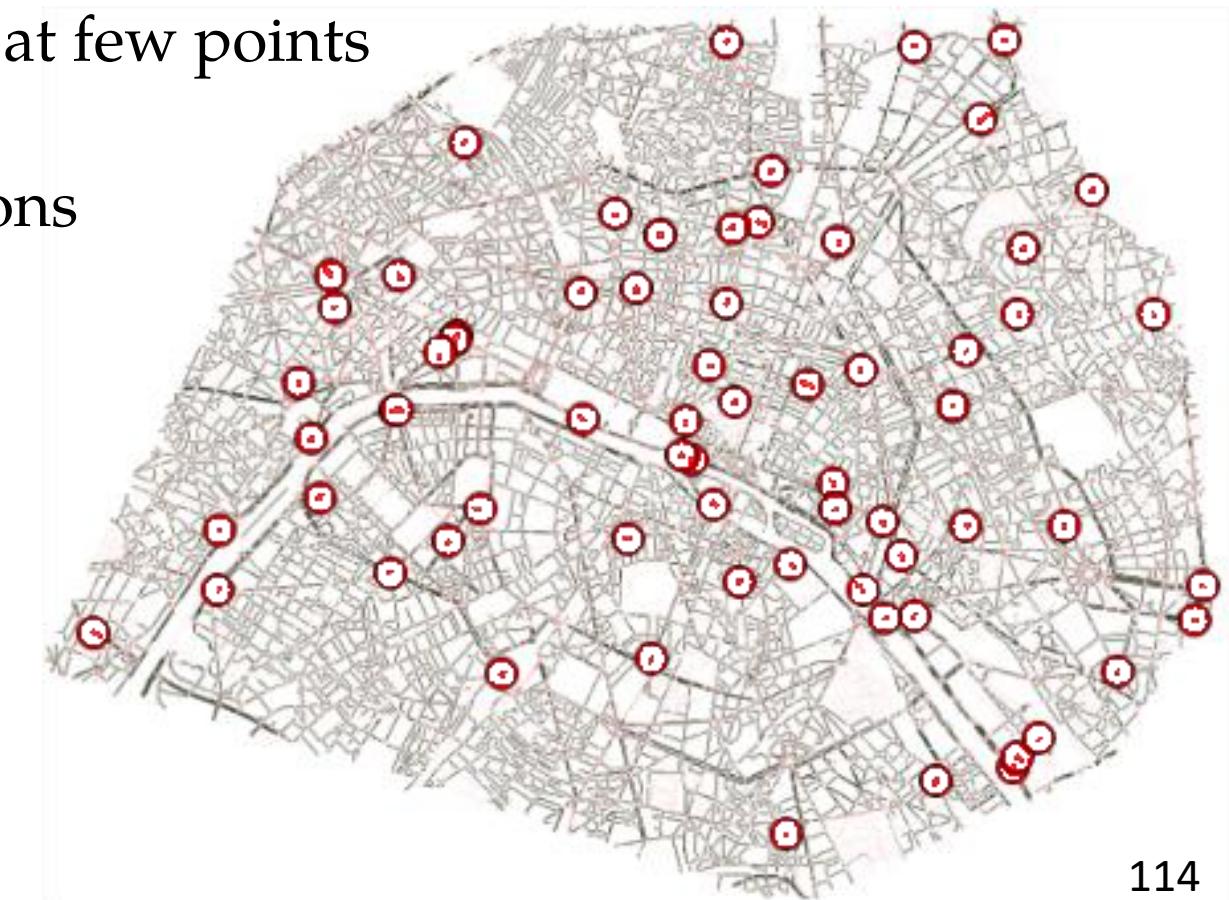
Conclusion



- 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

Intro

State of the Art

StreetGen

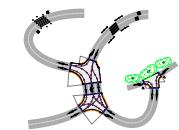
Streets

Interaction

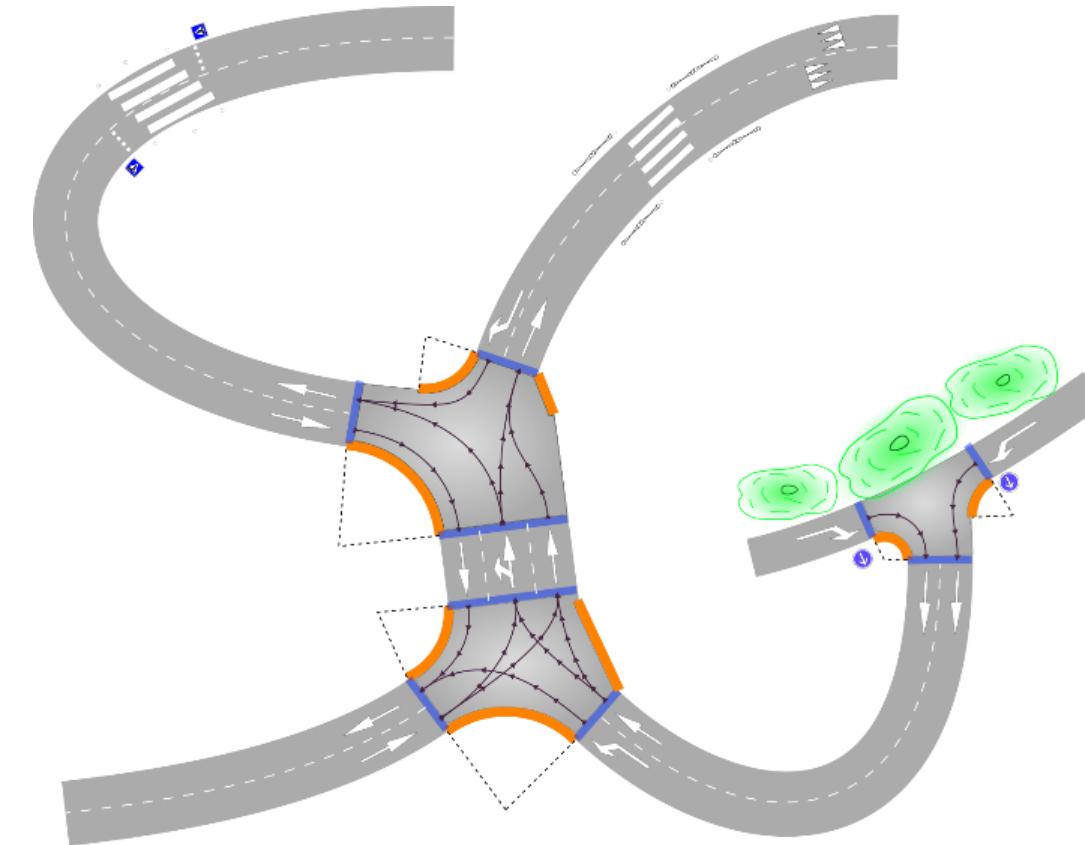
Automation

P.C. Server

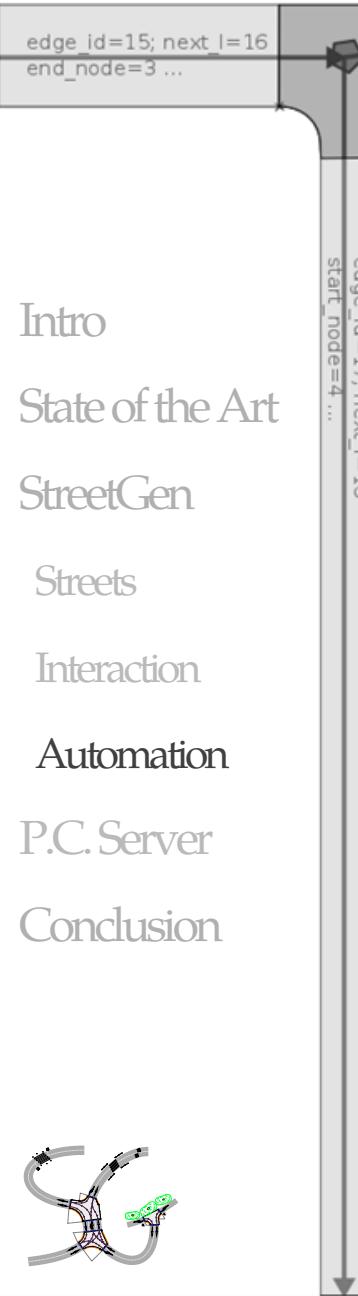
Conclusion



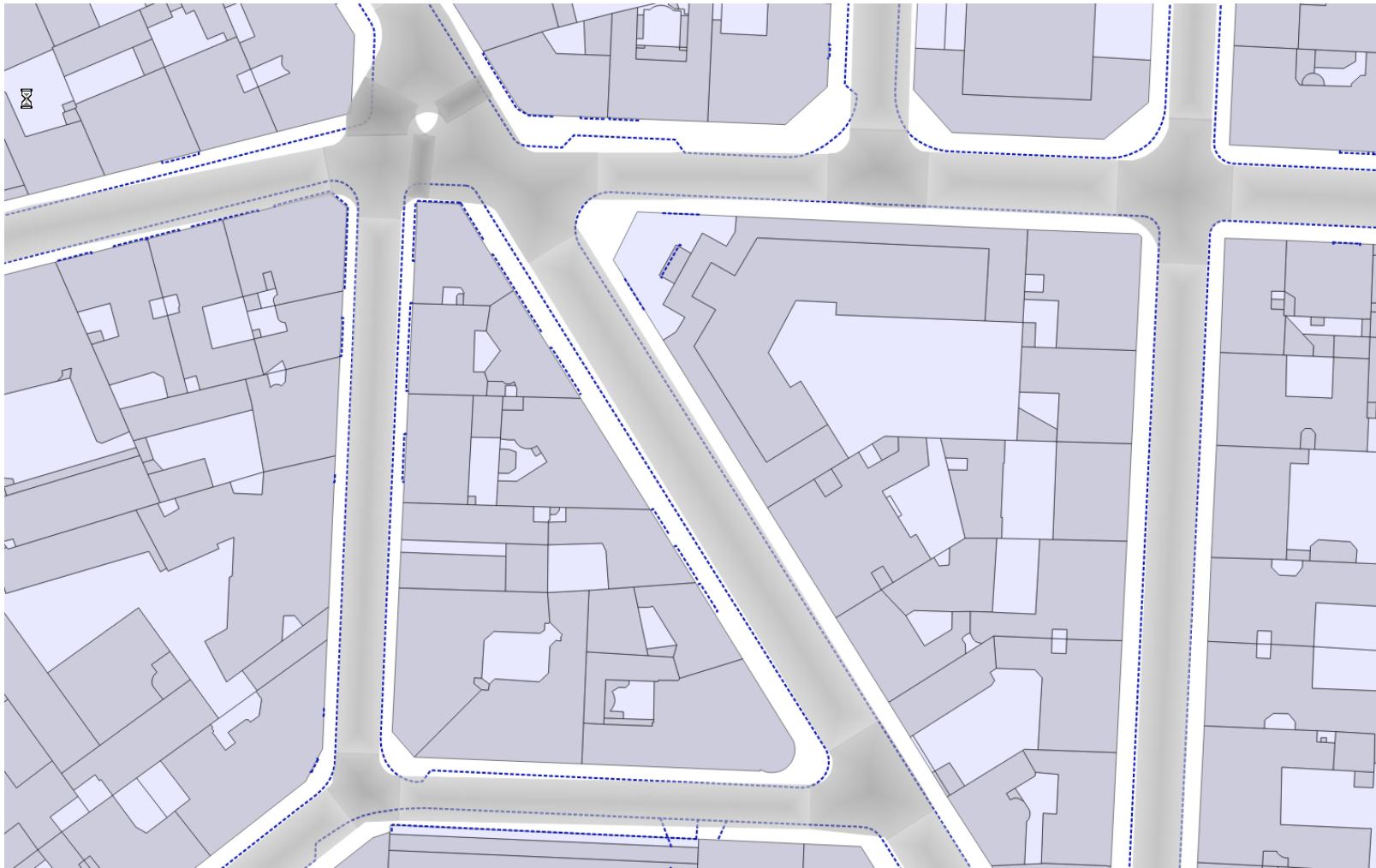
- Once simple road model is optimised,  
we can generate streets with StreetGen



# Inverse Procedural modelling: Streetgen on optim

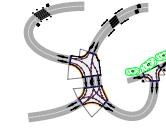


- Streetgen after optimisation

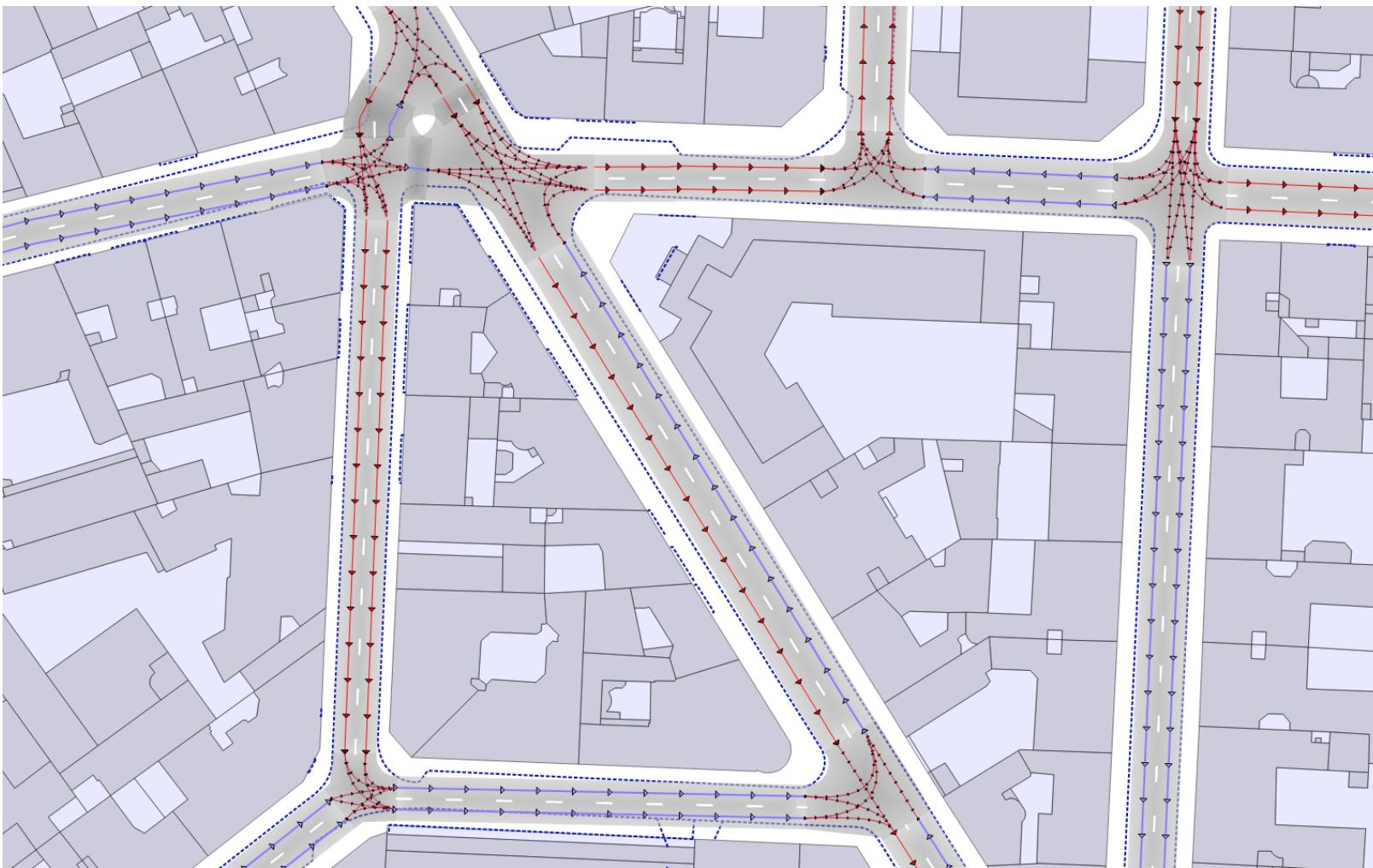


# Inverse Procedural modelling: Streetgen on optim

Intro  
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Conclusion



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



# Inverse Procedural modelling: error sources

Intro

State of the Art

StreetGen

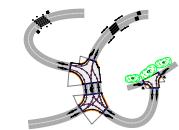
Streets

Interaction

Automation

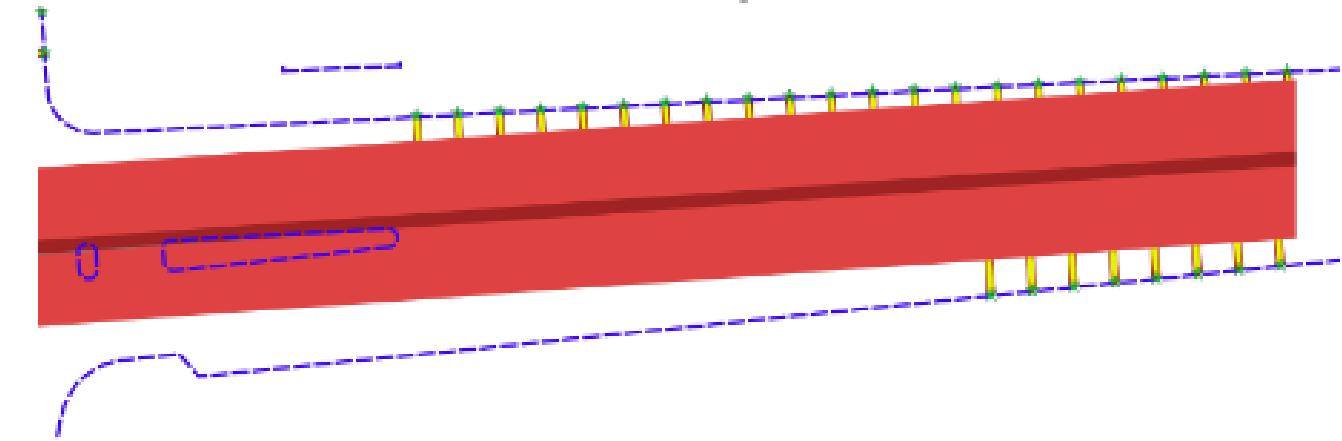
P.C. Server

Conclusion

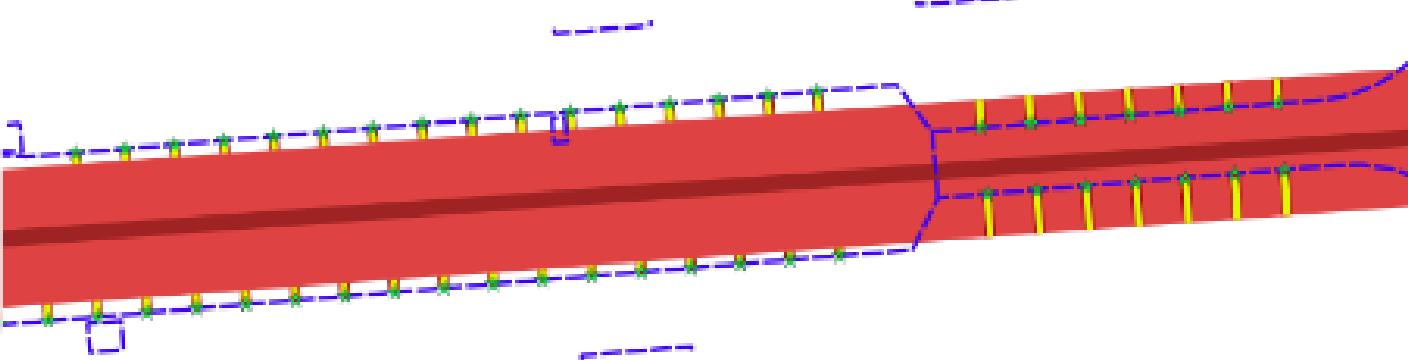


- Residual errors sources

Road model too simple

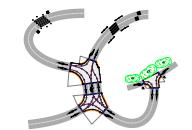


Over constrained (not enough split)



# Inverse Procedural modelling: Limitations

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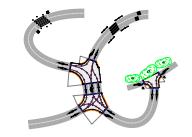


## Contributions:

- 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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Conclusion

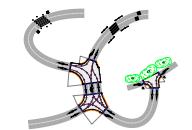


- **Limitations**

- 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)

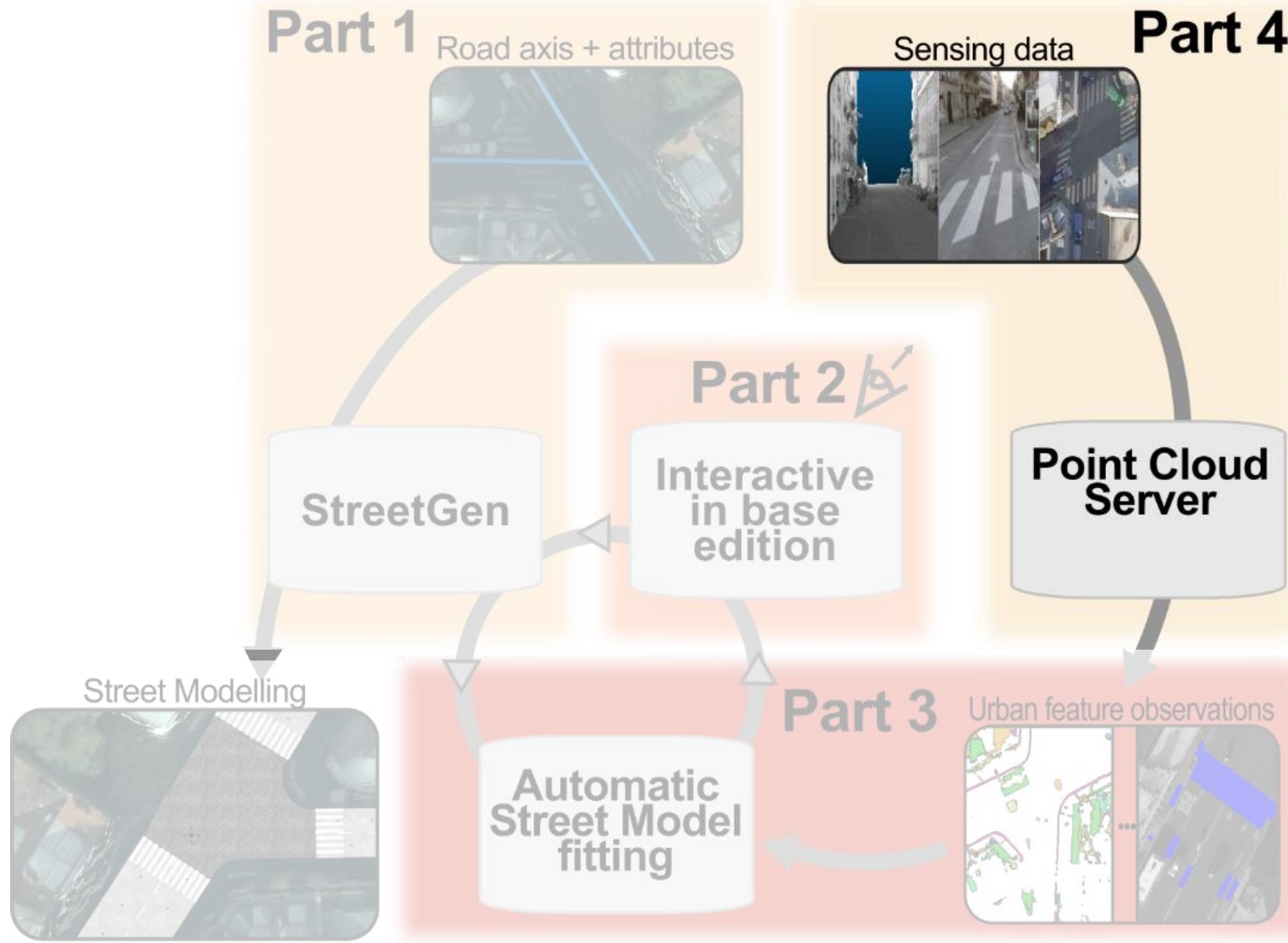
# Inverse Procedural modelling: Limitations

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Conclusion



- Need many observations
  - For the entirety of Paris
  - >2000km of sidewalk
  - >1 million objects (without markings)
- Many different objects: many different methods for observations detection extracted from raw data: point cloud
- How to deal with massive point cloud (Paris scale) and help design observation detection methods?

# Abstract



width= 8; lane= 3

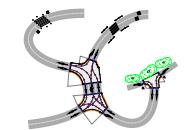
width= 6; lane= 2

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Conclusion

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

State of the Art

StreetGen

Streets

Interaction

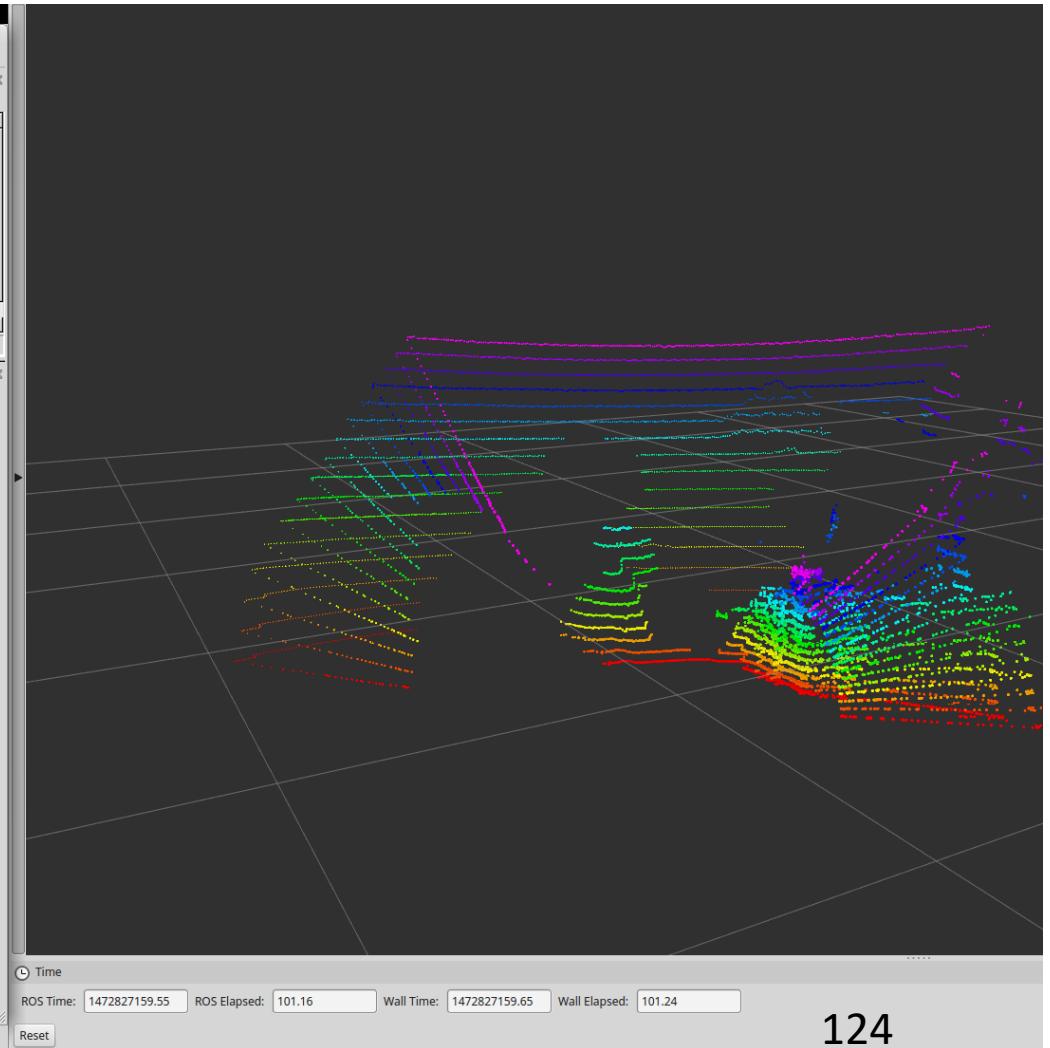
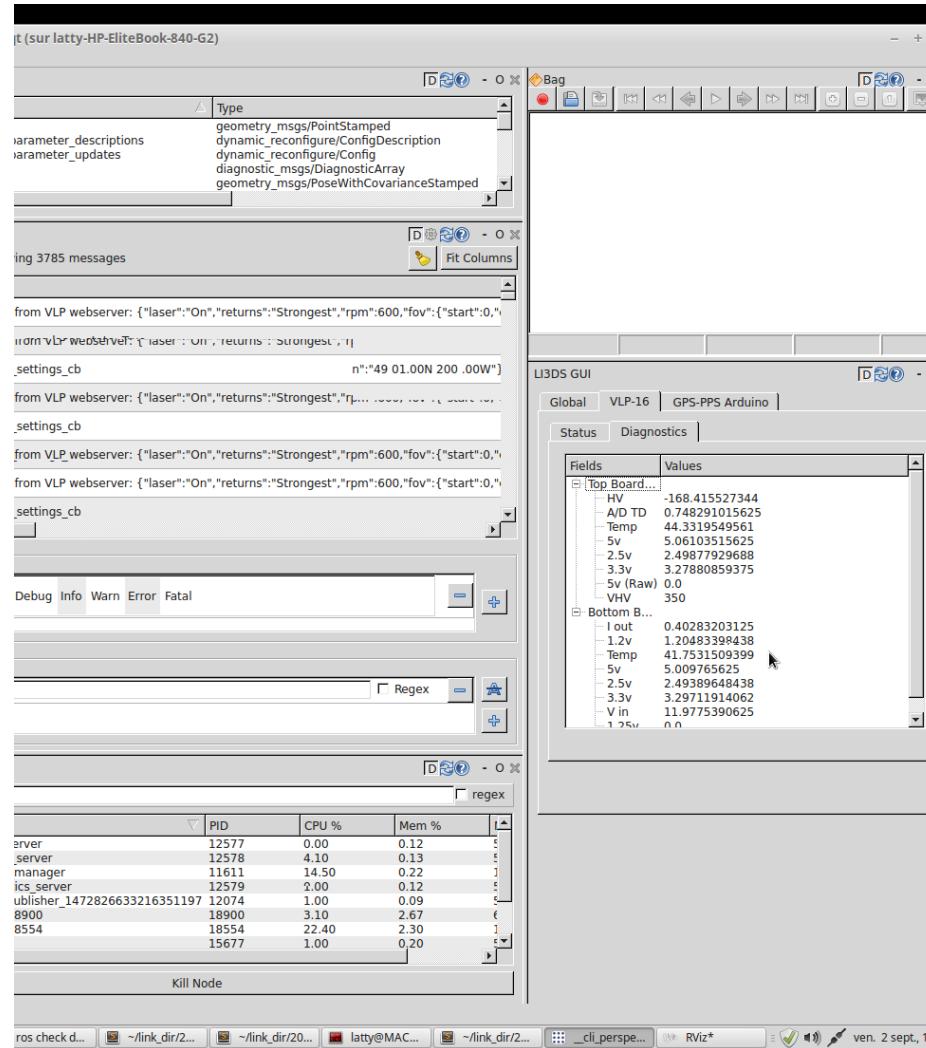
Automation

P.C. Server

Conclusion



width= 4; lane= 1



width= 8; lane= 3

width= 6; lane= 2

Intro

State of the Art

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Streets

Interaction

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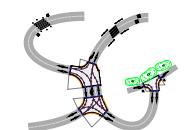
Conclusion

width= 4; lane= 1

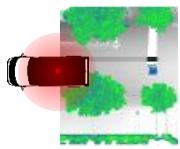
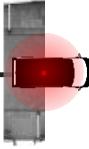
# Data for observations: Point Cloud Server

Short introduction to Lidar

**Point Cloud Server**



# Point Cloud Server



Intro

State of the A

StreetGen

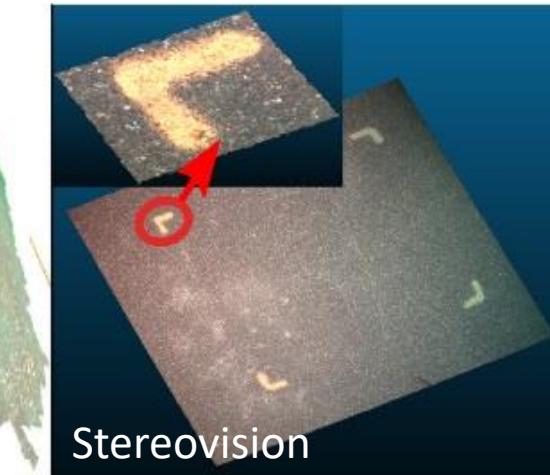
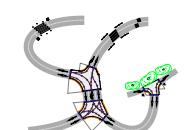
Streets

Interaction

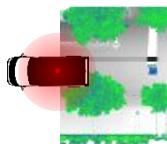
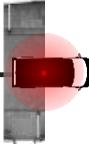
Automation

P.C. Server

Conclusion



# Point Cloud Server: Problems



- Problem:
  - Massive data → need
    - Sharing
    - Filtering
    - Efficient I/O
    - Compression
  - Point cloud != only processing
    - We need a service!

Intro

State of the A

StreetGen

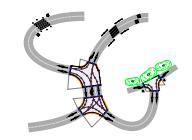
Streets

Interaction

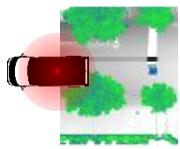
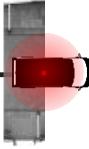
Automation

P.C. Server

Conclusion



# Point Cloud Server: State of the art



Intro

State of the A

StreetGen

Streets

Interaction

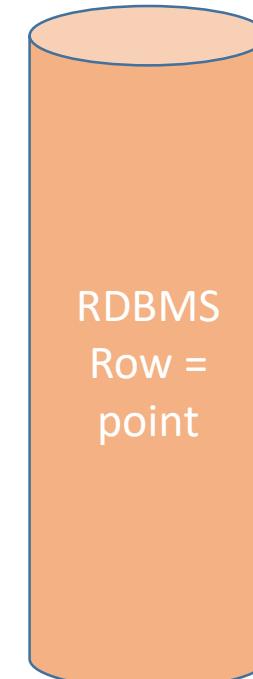
Automation

P.C. Server

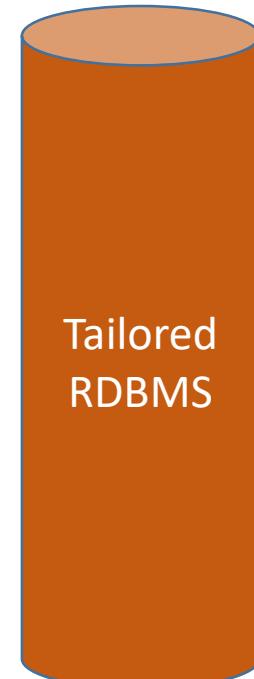
Conclusion



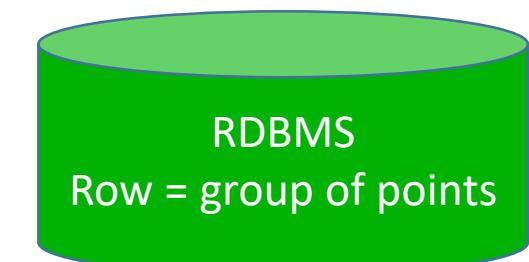
Otepka2013



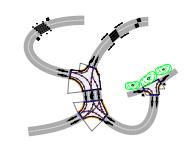
Rieg2014 VanOosterom2015

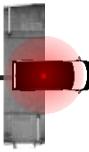


Managing  
**billions** of nD-  
points : difficult !

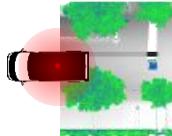


Managing **millions** of  
groups of points: easy!





# Point Cloud Server: Method



- Idea:

PCS = a ... server !

Intro

State of the A

StreetGen

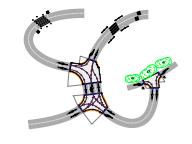
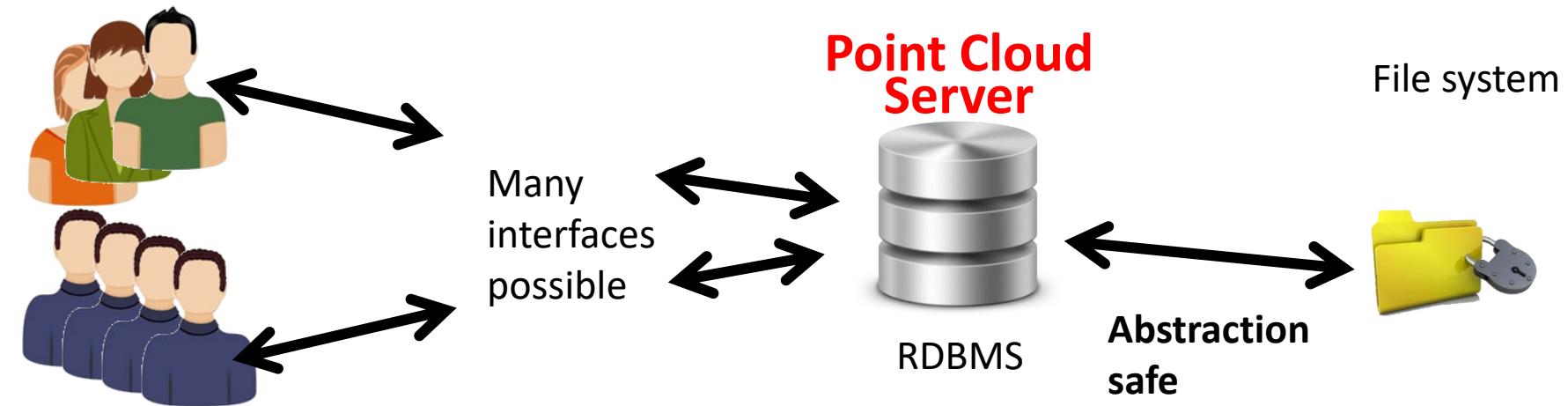
Streets

Interaction

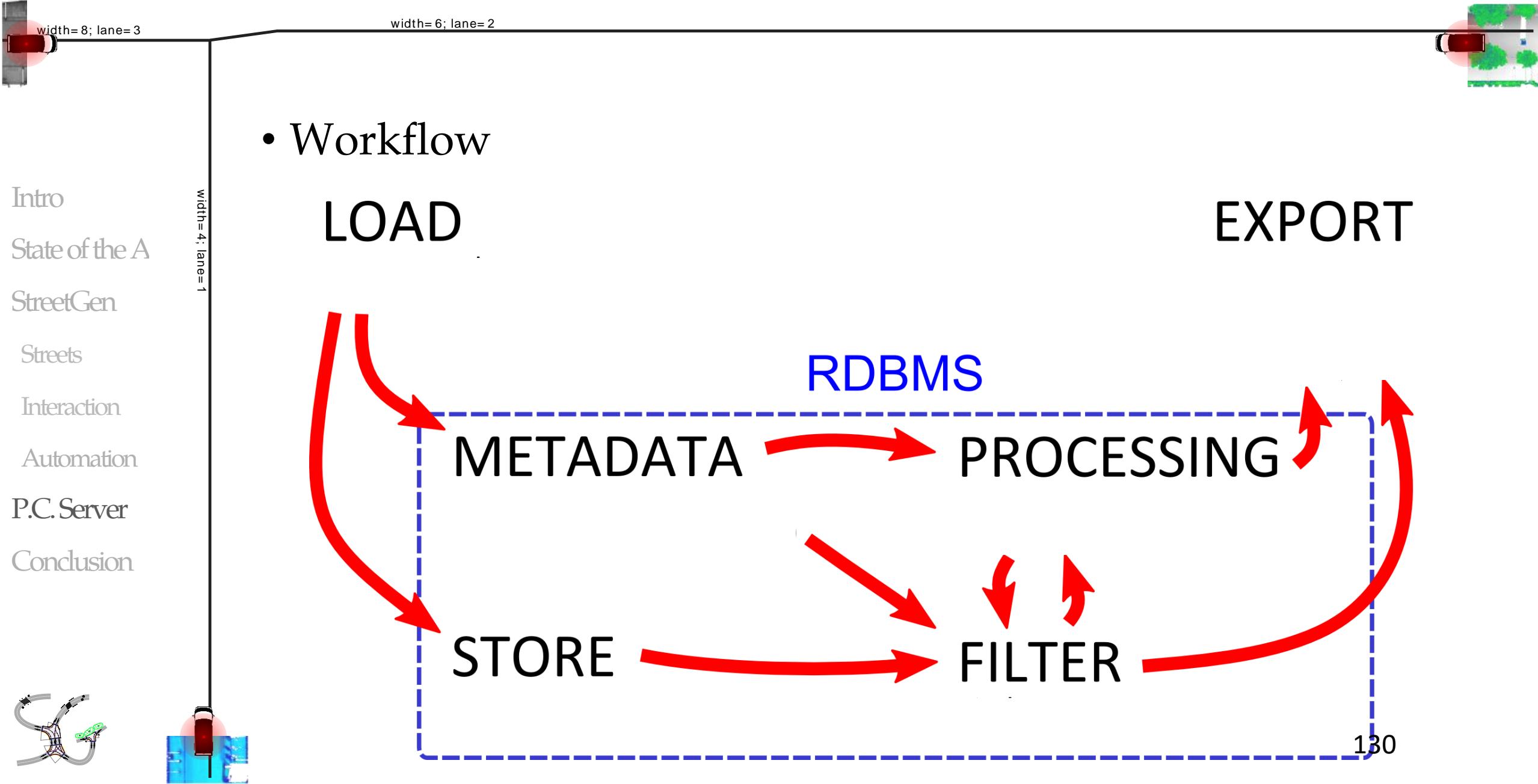
Automation

P.C. Server

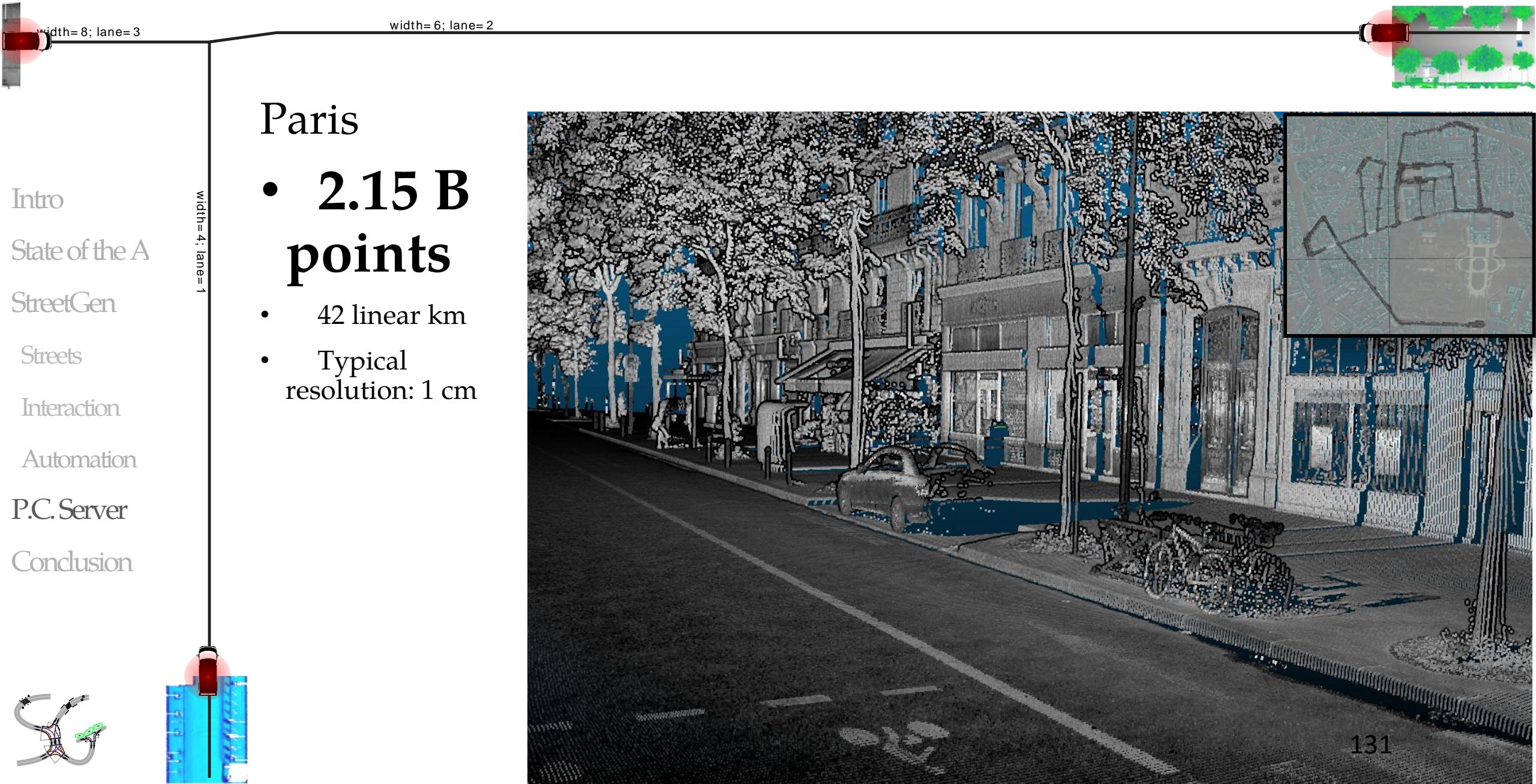
Conclusion



# Point Cloud Server: Method



# Point Cloud Server: Loading/Exporting



# Point Cloud Server: Loading/Exporting



Intro

State of the A

StreetGen

Streets

Interaction

Automation

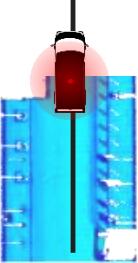
P.C. Server

Conclusion

- Paris

- loading speed: 75k pts/s
  - writing : 200k pts/s

- Not far from actual sensing speed
  - Could be faster ([Vanoosterom2015](#))



# Point Cloud Server: Loading/Exporting



Intro

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StreetGen

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Interaction

Automation

P.C. Server

Conclusion

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

**point** - constrained type

(**2.1**,**4.7**,**1.0**,**9**,..)



Point type = XML schema

X : float, offset, scale, description  
Y : double, ...

**patch (group of points)** - compressed  
- indexed



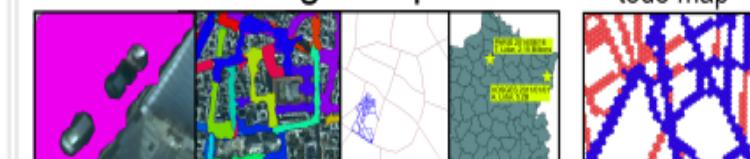
&  
generalisations



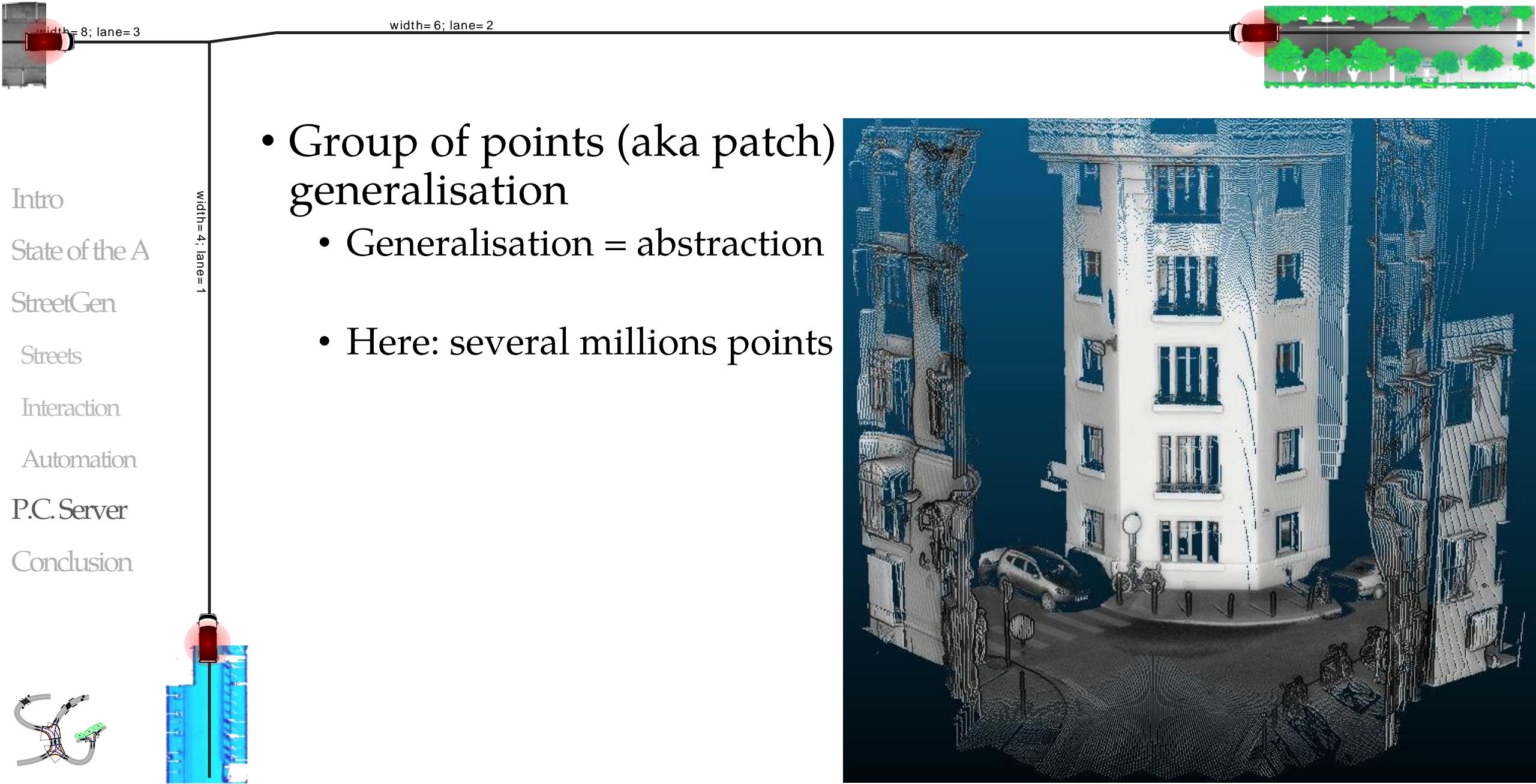
**pointclouds** - 1 per table

5	1000111101...
6	1000101001...
7	1000001110...
	⋮

&  
coverage maps



# Point Cloud Server: generalisation



Intro

State of the A

StreetGen

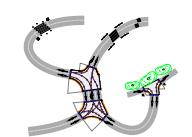
Streets

Interaction

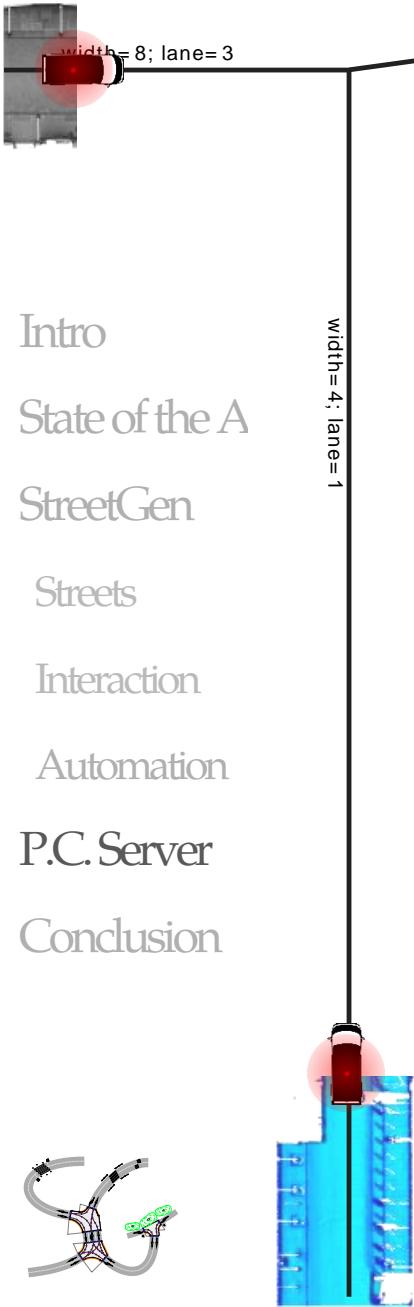
Automation

P.C. Server

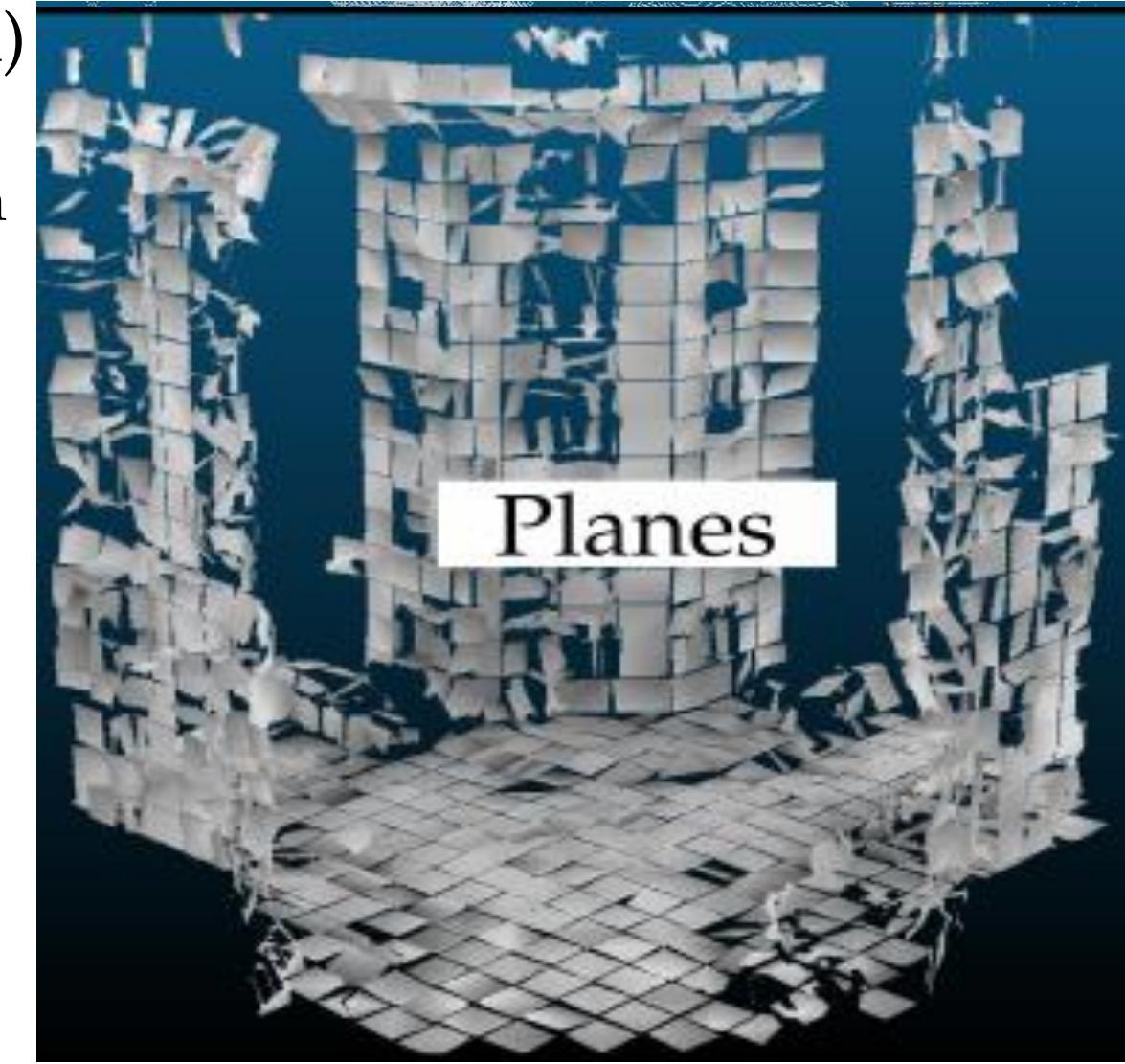
Conclusion



# Point Cloud Server: generalisation



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



Intro

State of the A

StreetGen

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P.C. Server

Conclusion

# Point Cloud Server: generalisation



- Other generalisations
  - Essential : abstracting the data = more abstract usage
  - Generalisation tailored to an usage

Intro

State of the A

StreetGen

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Interaction

Automation

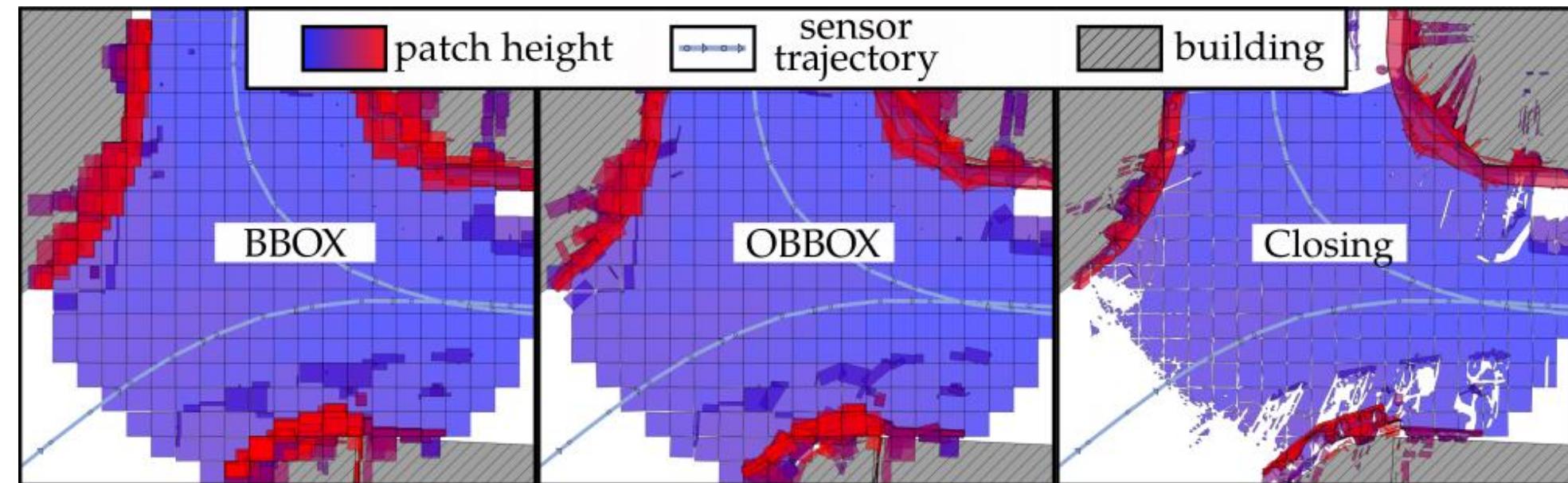
P.C. Server

Conclusion

width=4; lane=1



Top view in QGIS



# Point Cloud Server: processing



- More generalisation
- Coverage map: where are the point clouds?



Intro

State of the A

StreetGen

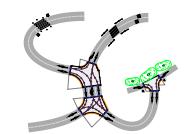
Streets

Interaction

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Conclusion



# Point Cloud Server: filtering

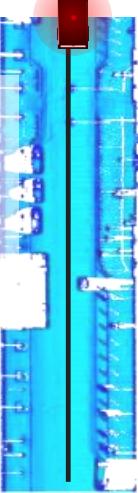


width=6; lane=2



- 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
  - with high point density
  - ...

width=4; lane=1



Intro

State of the A

StreetGen

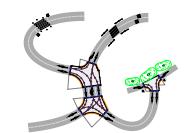
Streets

Interaction

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Conclusion



# Point Cloud Server: filtering



width=8; lane=3

width=6; lane=2



- In 100ms: 1k patches for few millions points over a 2 billions point cloud

Intro

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StreetGen

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Conclusion

width=4; lane=1



# Point Cloud Server: filtering



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

Intro

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StreetGen

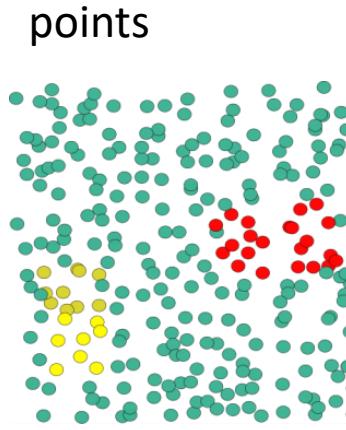
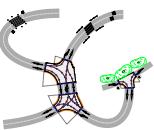
Streets

Interaction

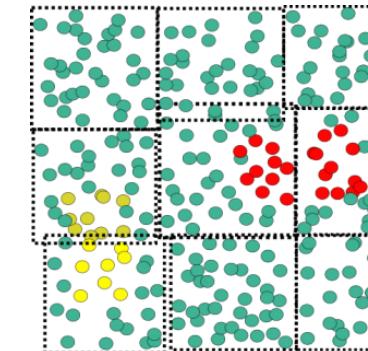
Automation

P.C. Server

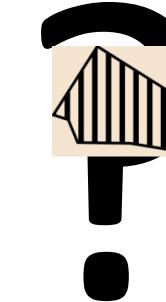
Conclusion



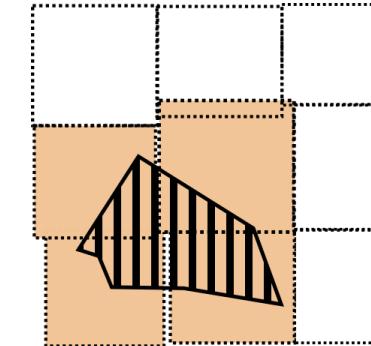
Points in patch



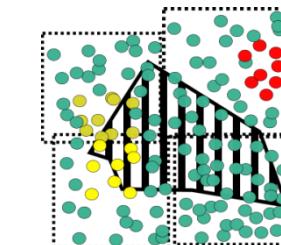
Which points  
are inside the  
polygon?



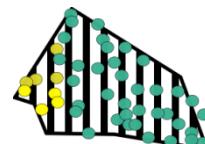
Which **patchs**  
are inside the  
polygon?



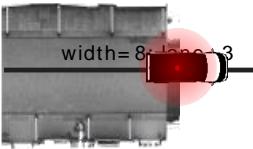
Get points in  
these patches



Which  
points are  
inside the  
polygon?

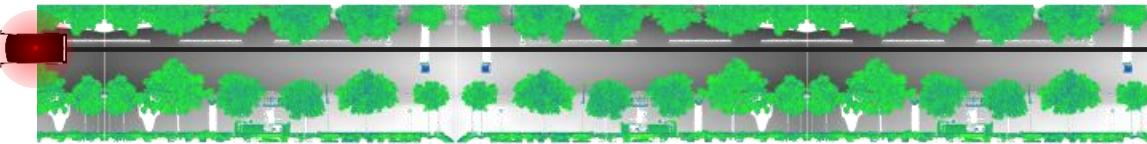


# Point Cloud Server: processing



width= 8; lane= 3

width= 6; lane= 2



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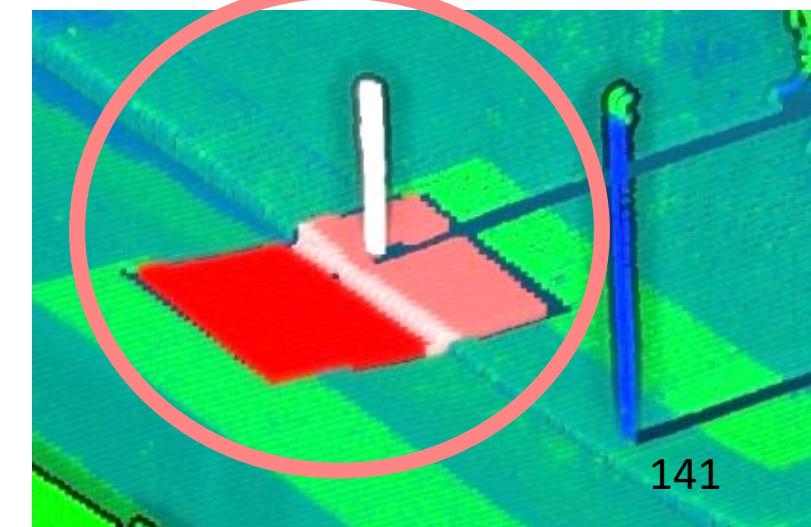
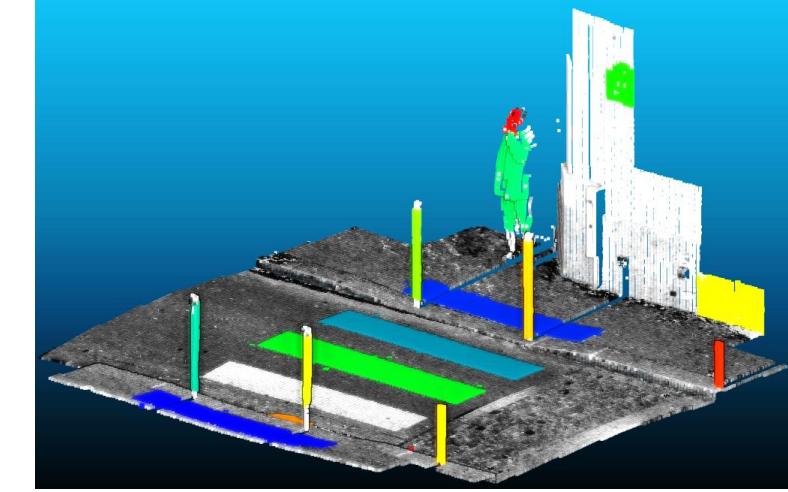
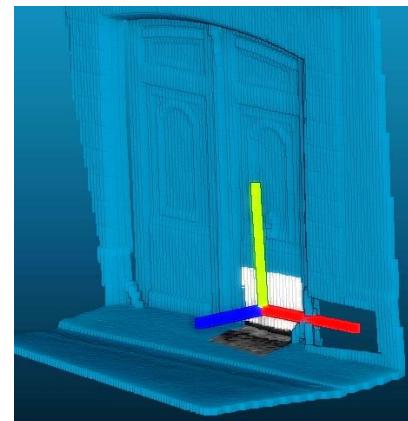
width= 4; lane= 1

- Postgresql: easy to add in-base processing

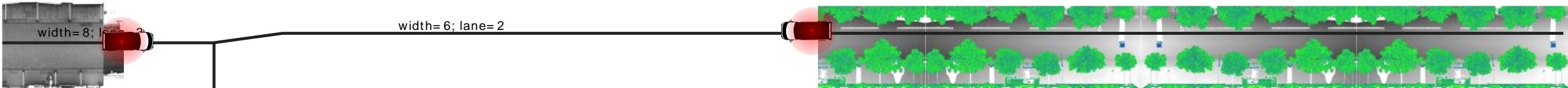
- C/C++ → for performance
- R/Python → for fast prototyping

- Example :

- Verticality descriptor
- Unsupervised clustering
- Plane & cylinder detection



# Point Cloud Server: processing



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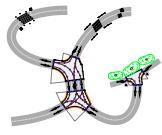
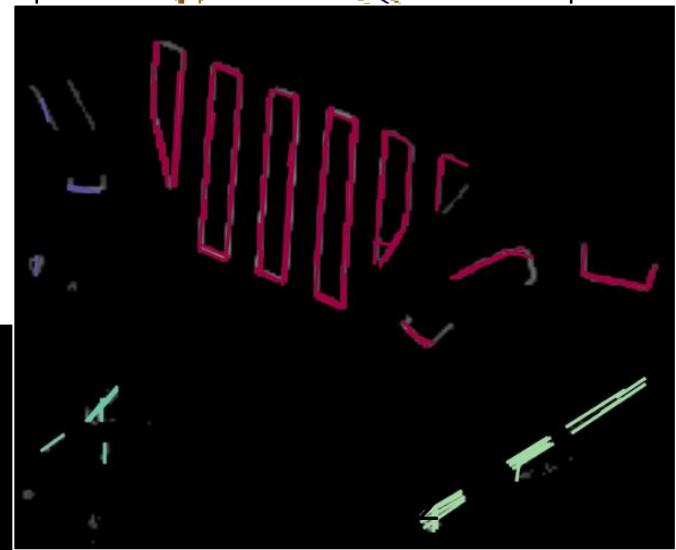
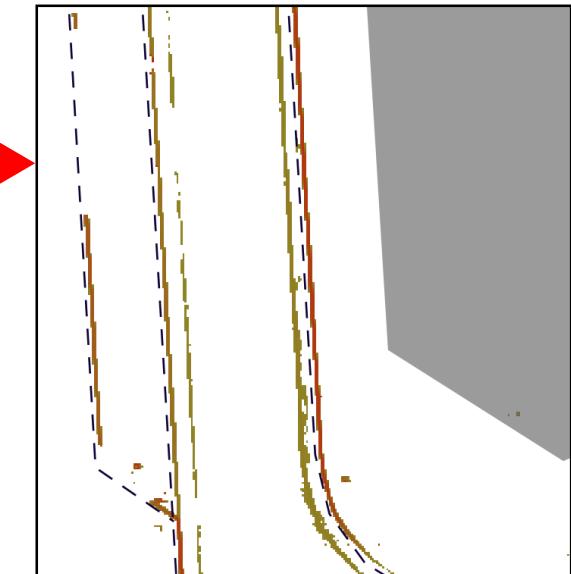
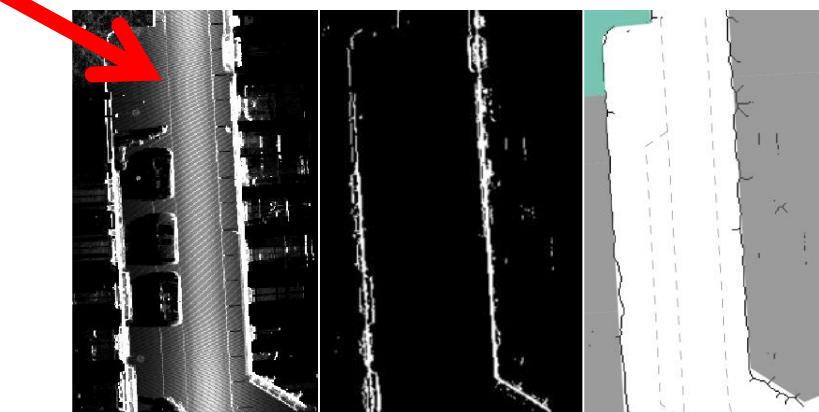
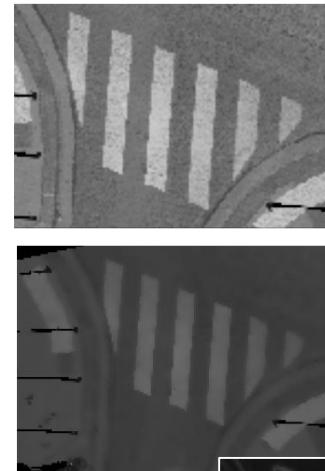
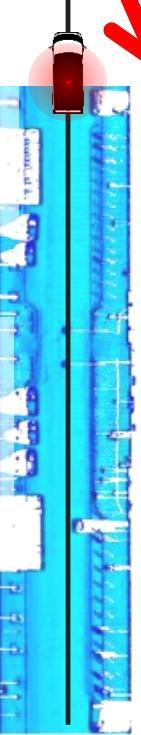
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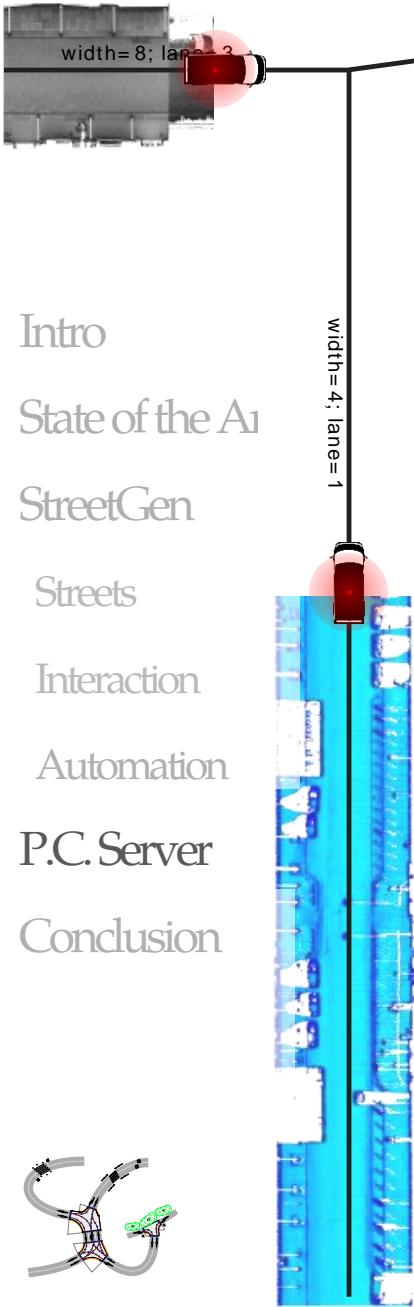
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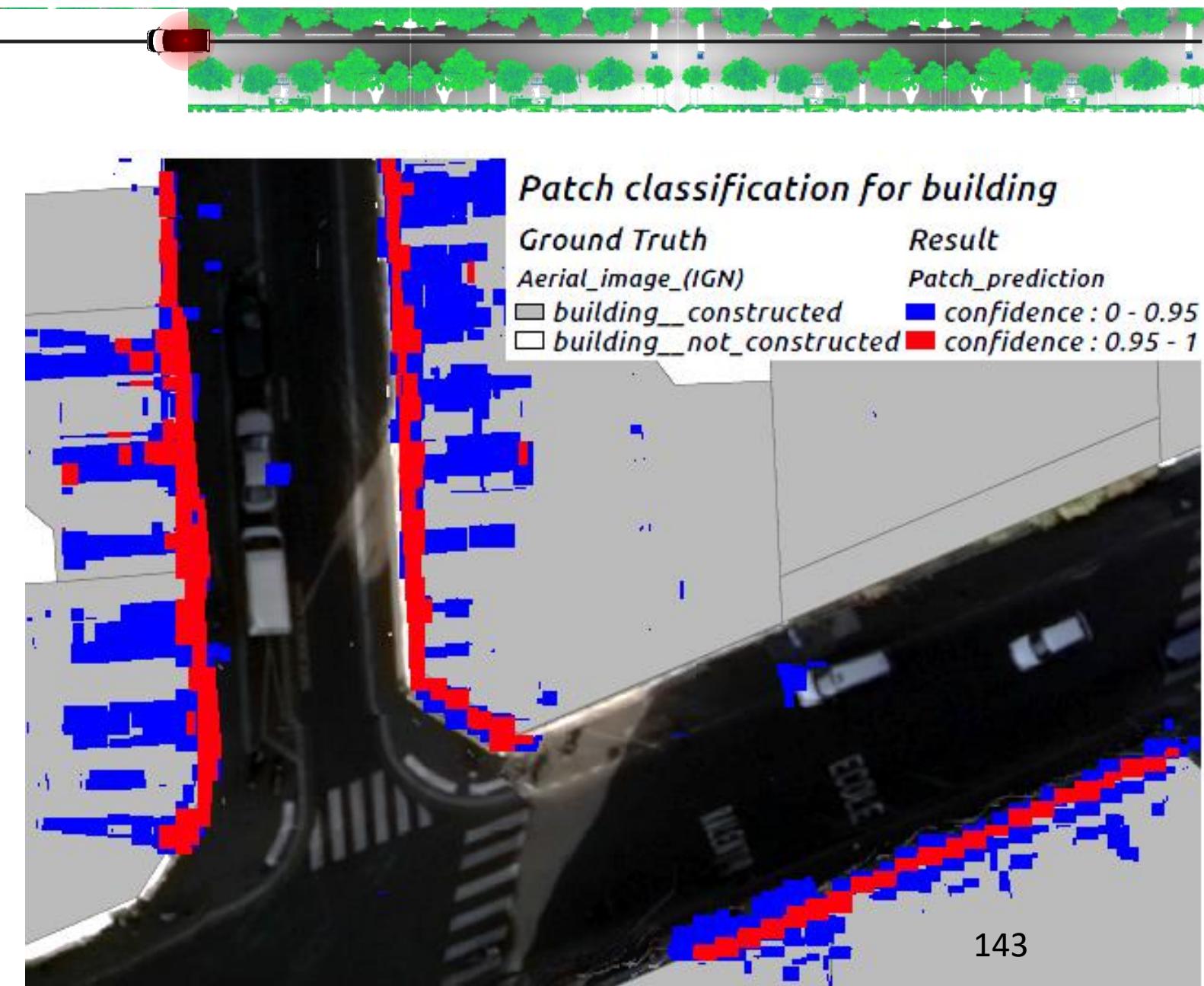
- Converting patch to raster
  - Cornerstone detection
  - Marking detection
  - Façade detection



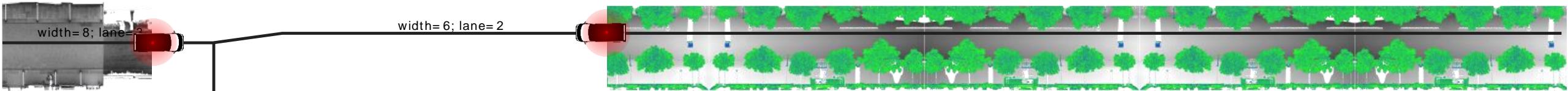
# Point Cloud Server: processing



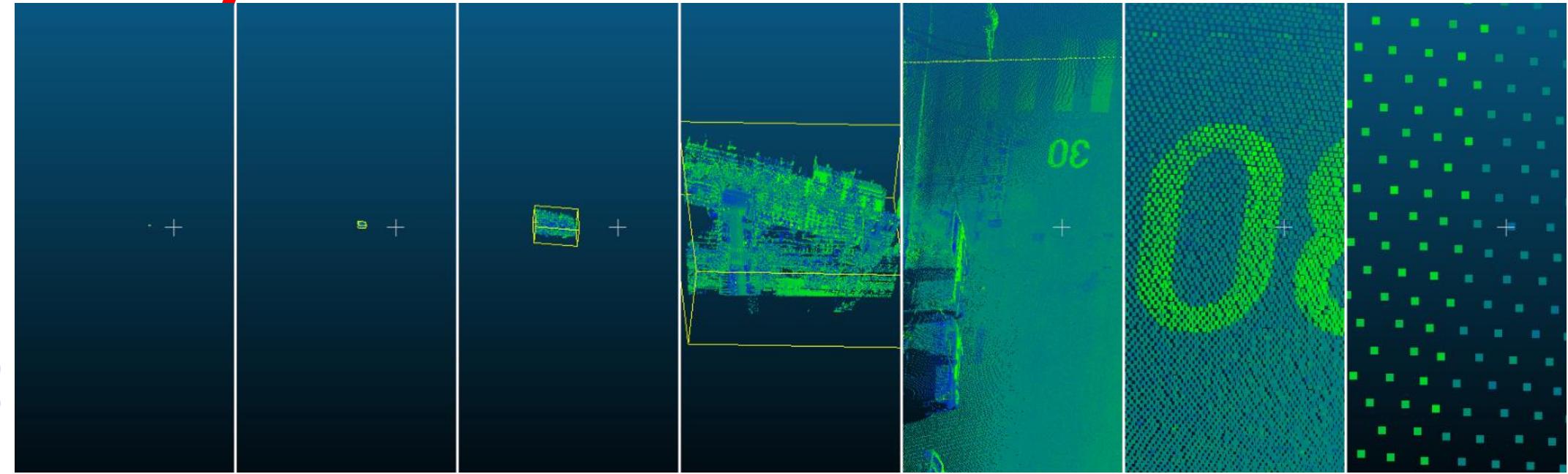
- classification



# Point Cloud Server: Level Of Detail

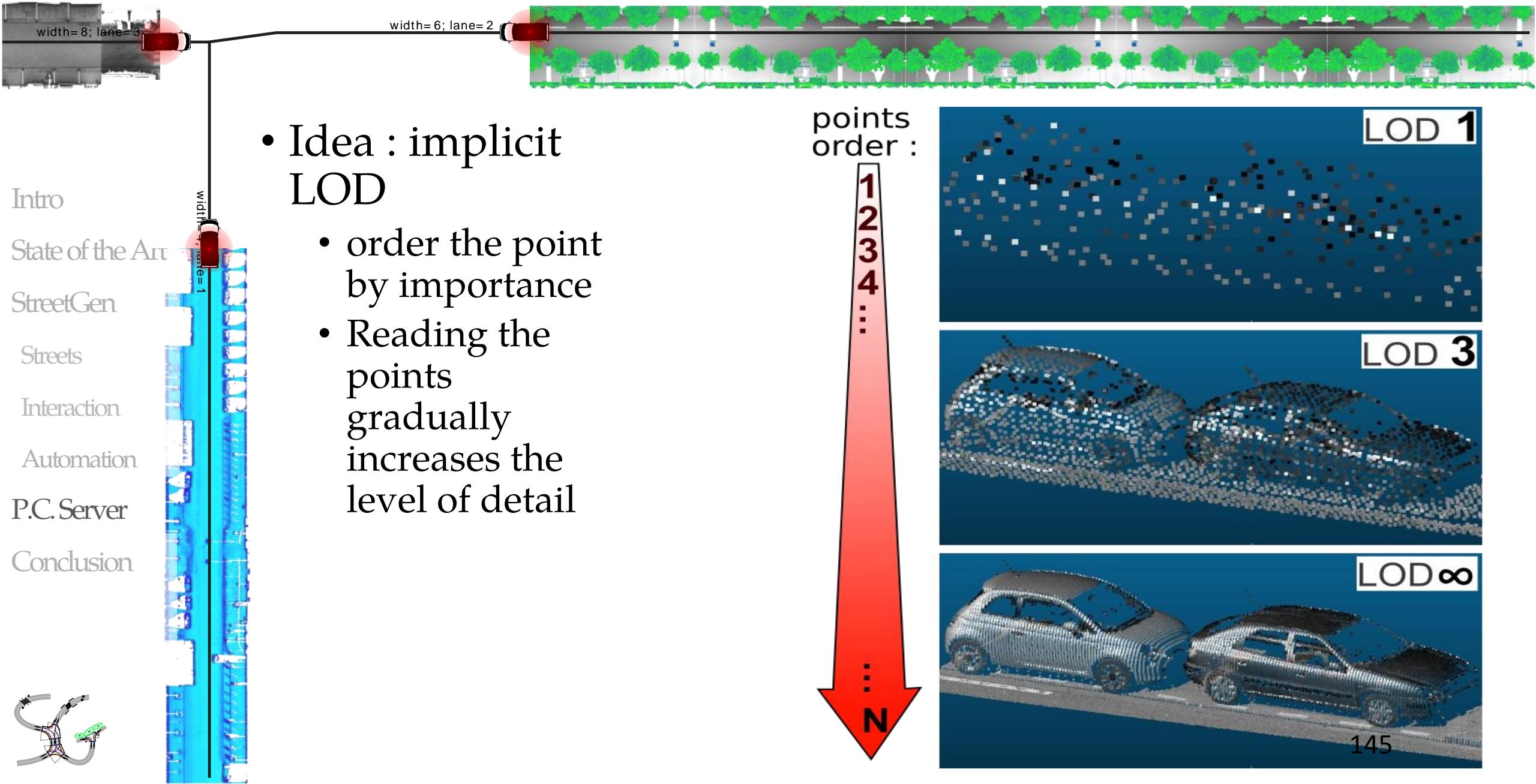


- Level Of Detail (LOD):
  - Sometimes you don't need all the points  
12 Millions points, really?



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

points order :

1  
2  
3  
4  
⋮  
N

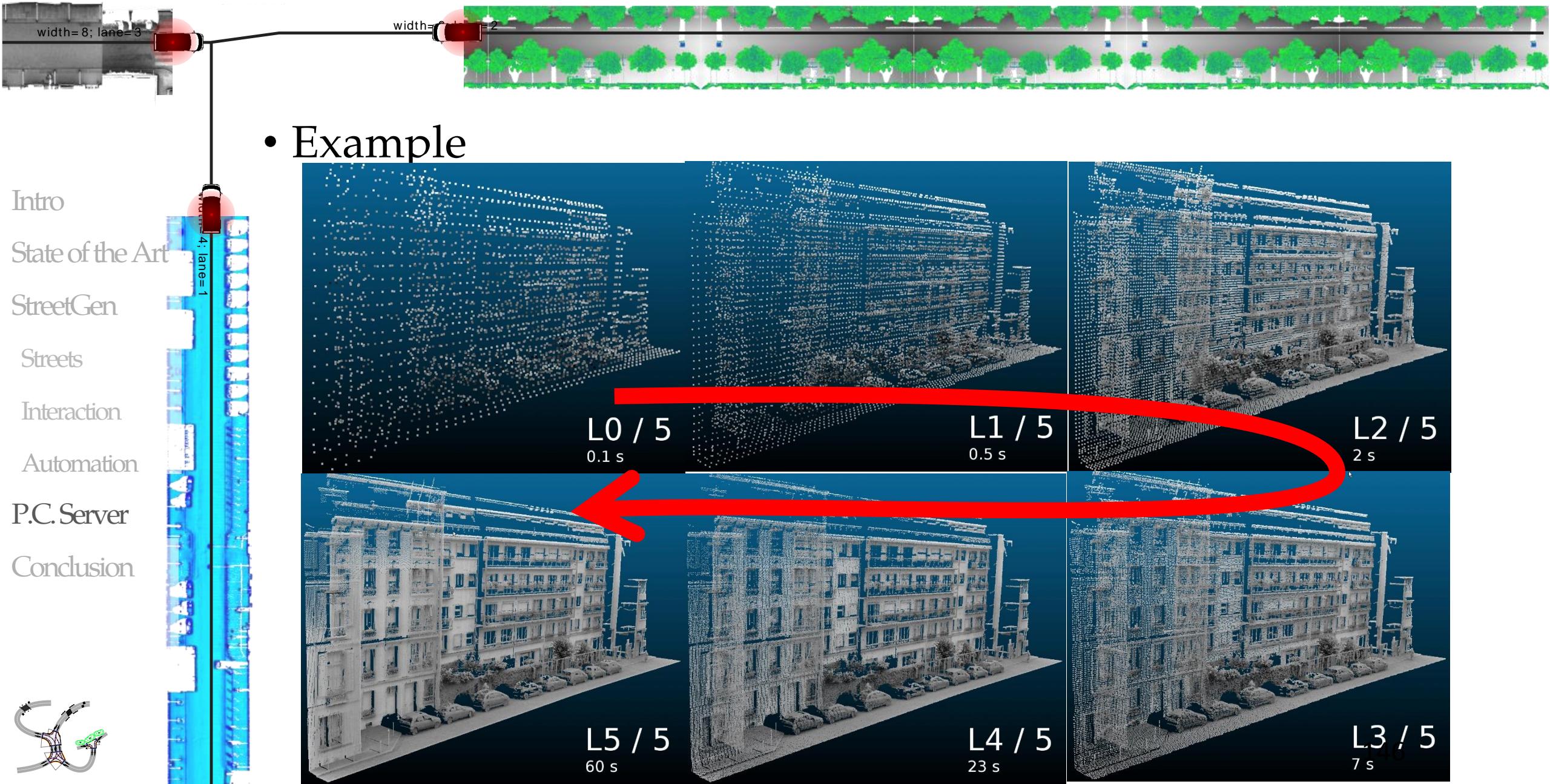
LOD 1

LOD 3

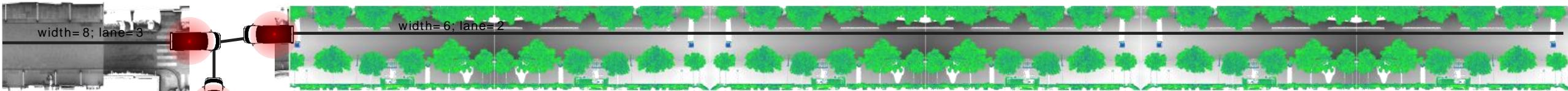
LOD  $\infty$

145

# Point Cloud Server: Level Of Detail



# Point Cloud Server: Level Of Detail

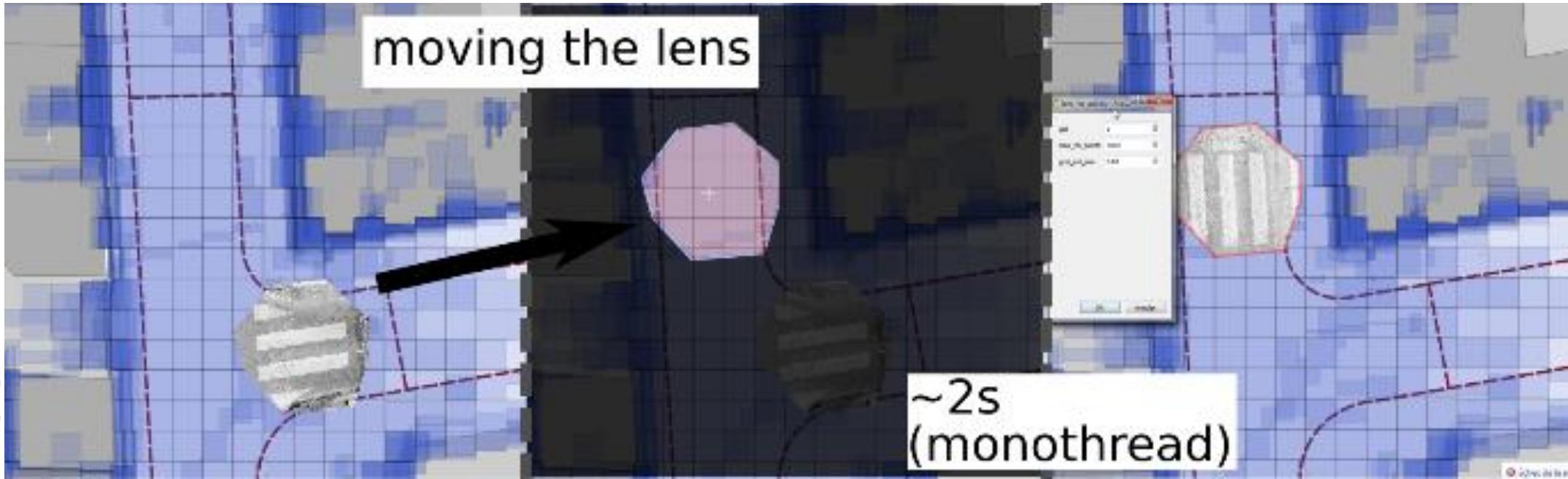


- LOD enables points streaming



# Point Cloud Server: Level Of Detail

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



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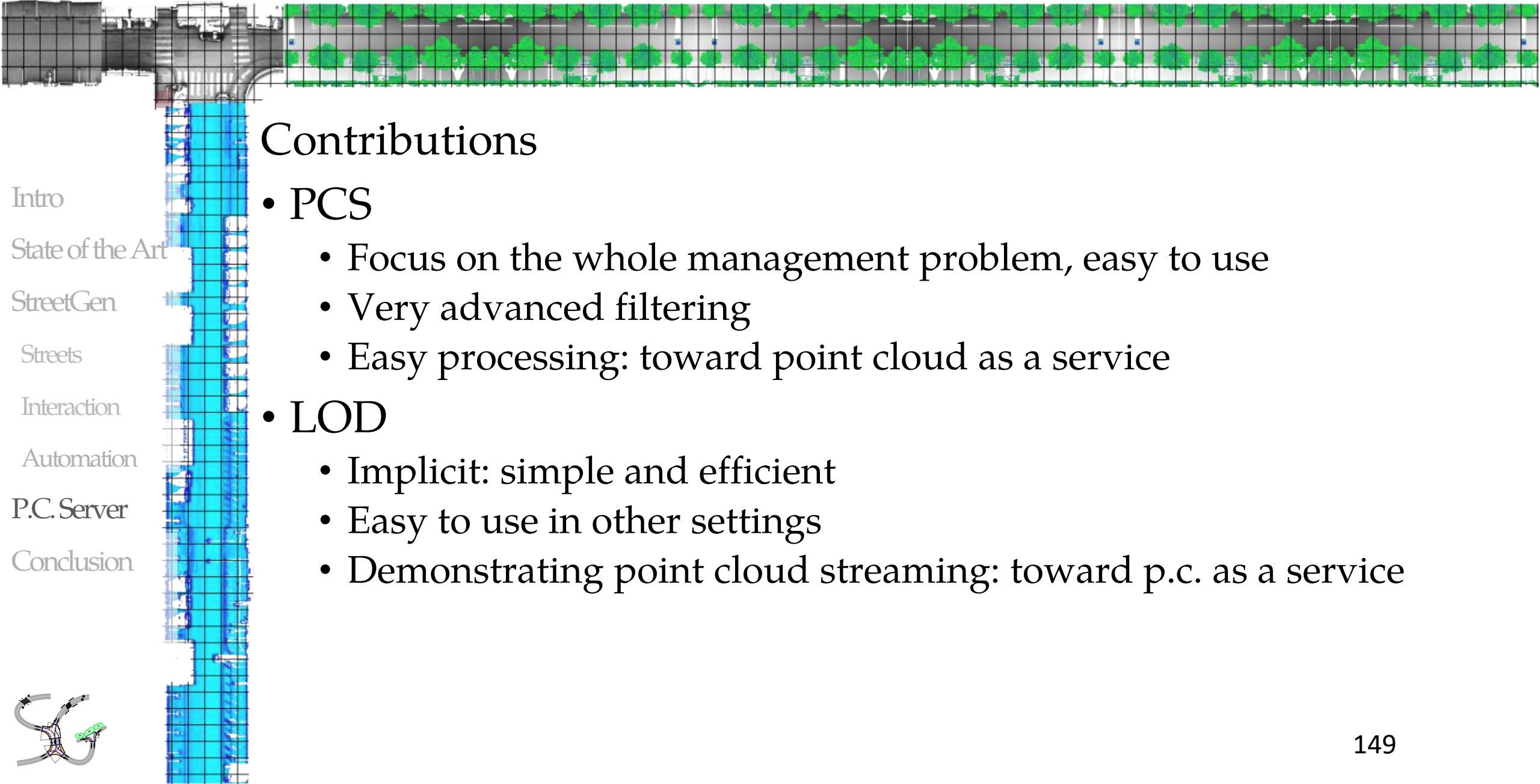
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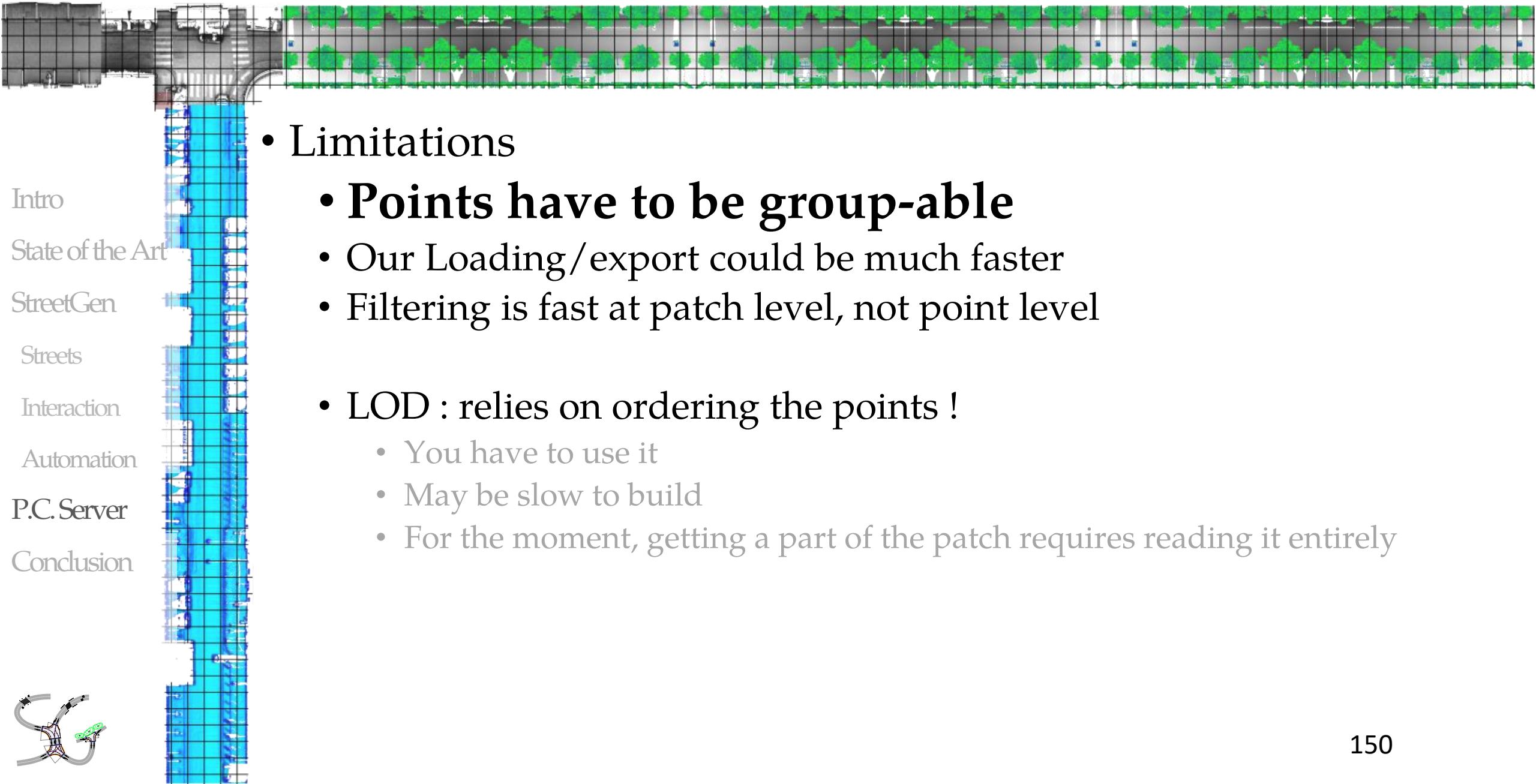
# Point Cloud Server: Level Of Detail



## 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



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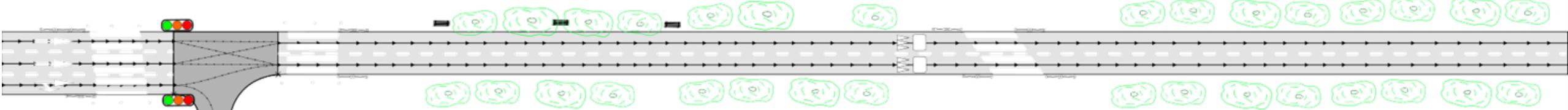
- Limitations

- **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**

Limitations

Perspectives



# Conclusion: Summary

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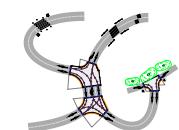
Streets

Interaction

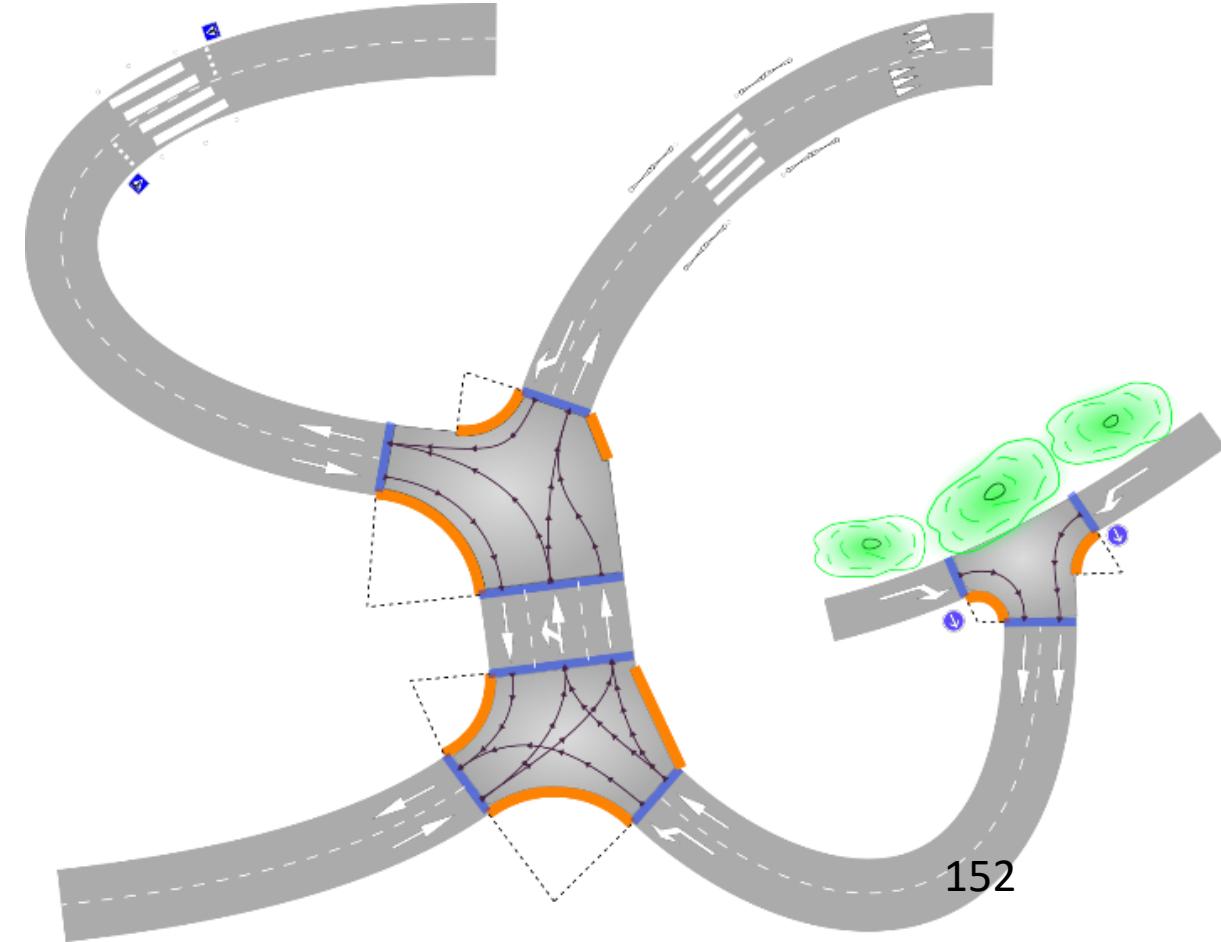
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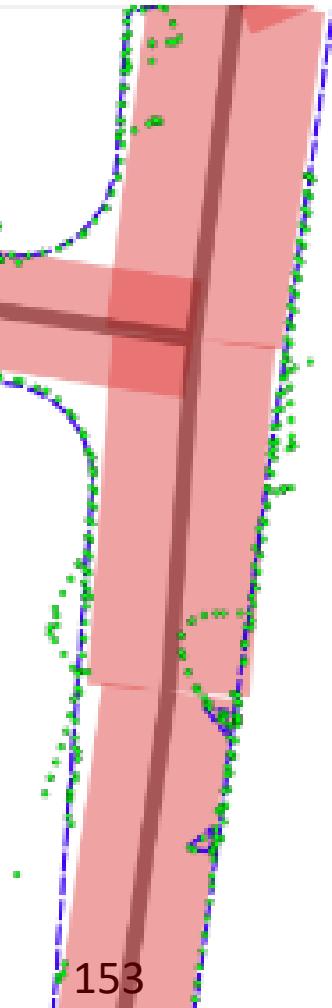
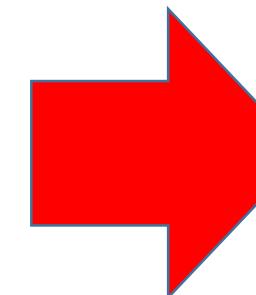
- From low information: generate best guess street model at Paris scale and edit it (multi-user, using many GIS software): StreetGen



# Conclusion: Summary

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

initial road axis  
and width



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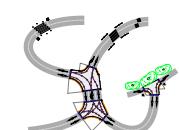
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# Conclusion: Summary

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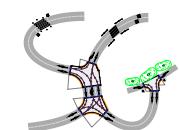
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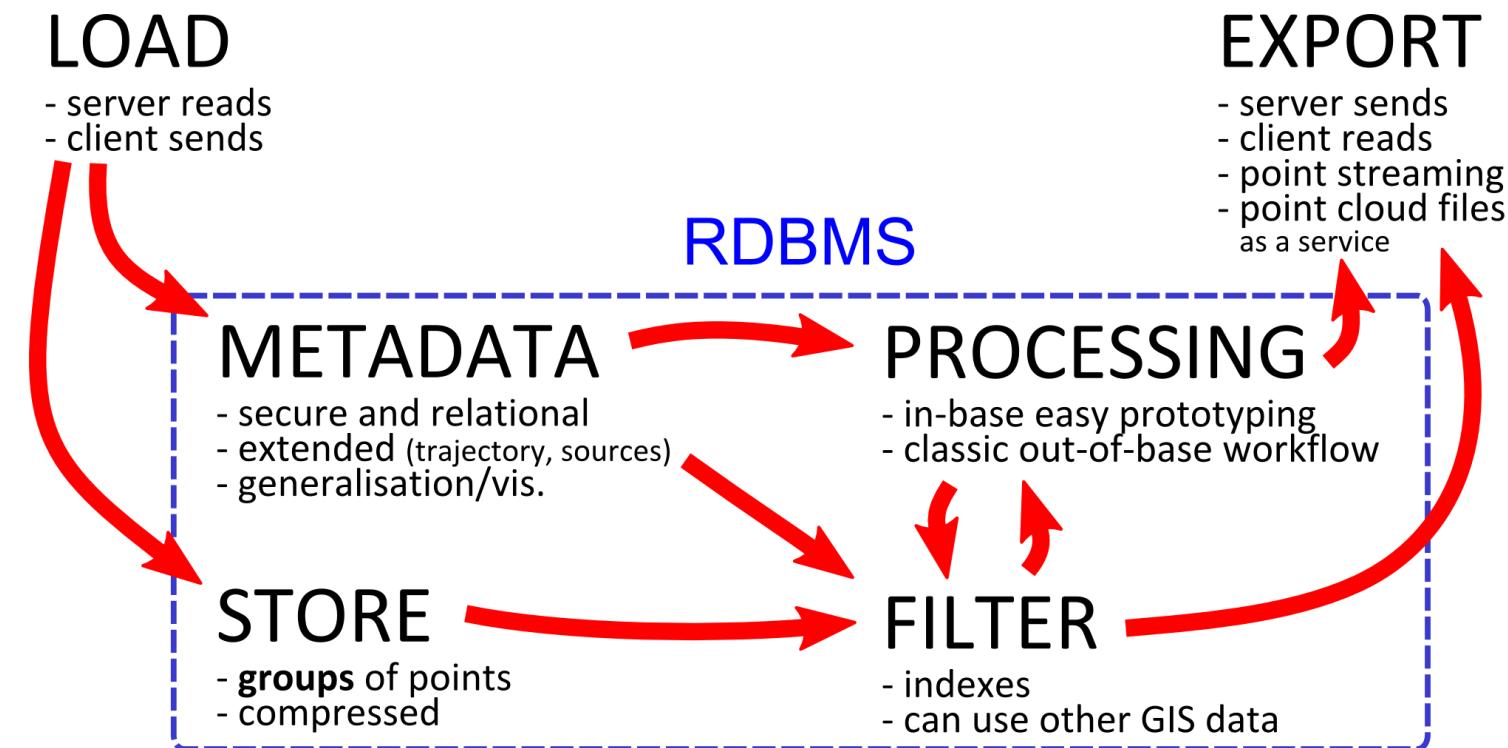
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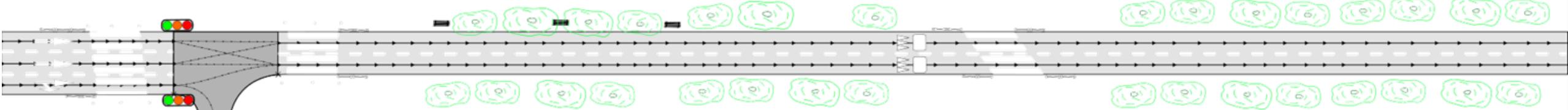
- Manage a massive amount of 3D points (from mobile mapping). Act as a service for usage/processing/visu:  
**Point Cloud Server**



# General contributions

## Contributions

- StreetGen
  - Simple model, everything in database
- Interaction
  - Easy editing 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



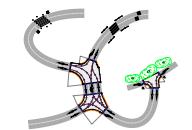
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# Conclusion

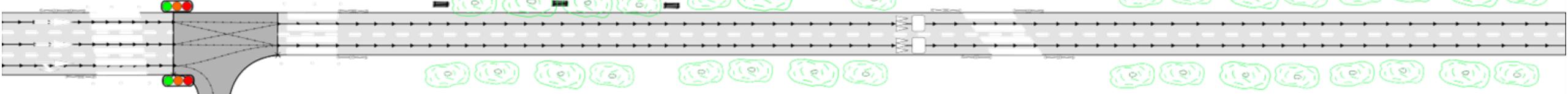
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# Conclusion: Limitations

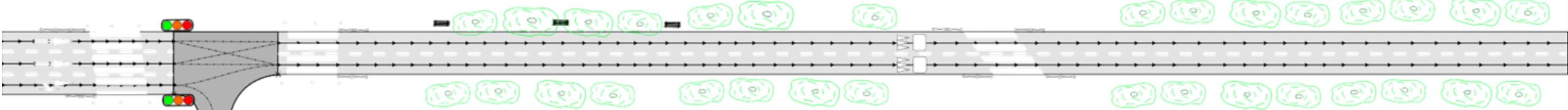


- StreetGen

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

- Point Cloud Server :

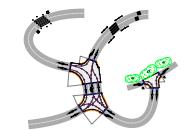
- Must group points into meaningful groups
- Objects are created/edited manually by user
  - Tedious, not much sense



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# Conclusion: Perspectives

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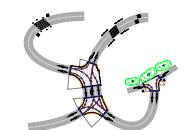
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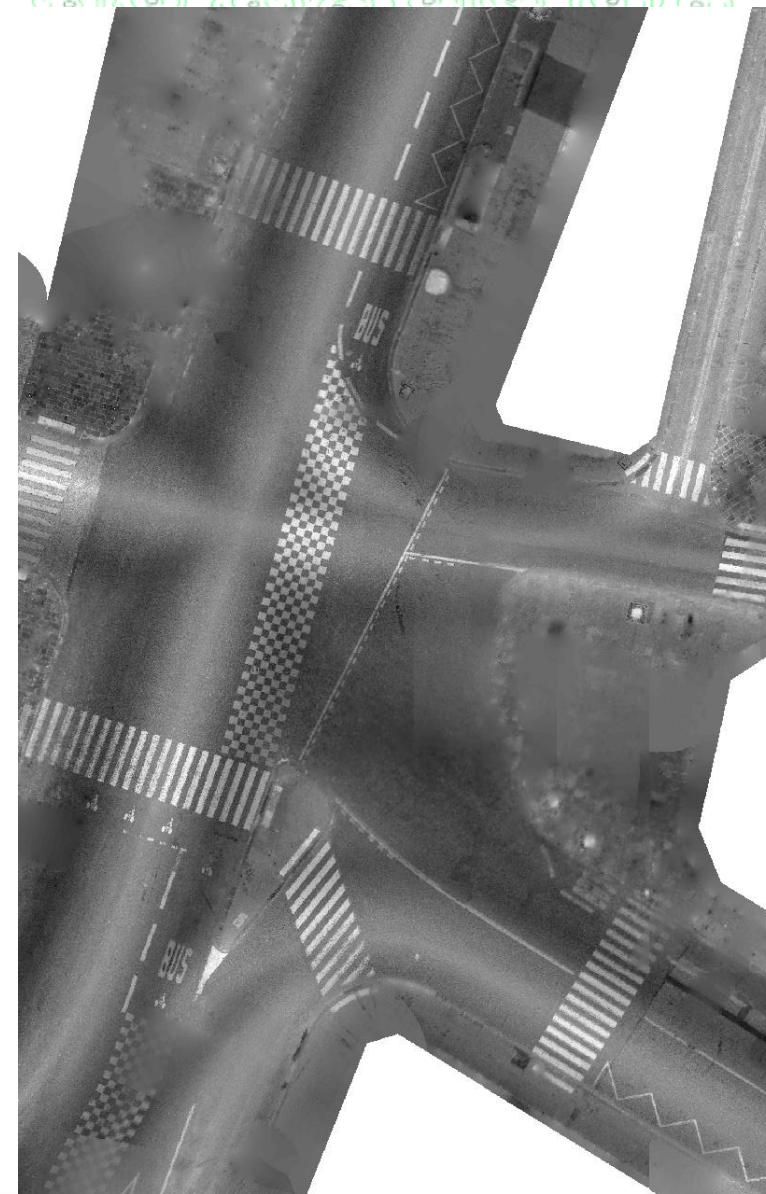
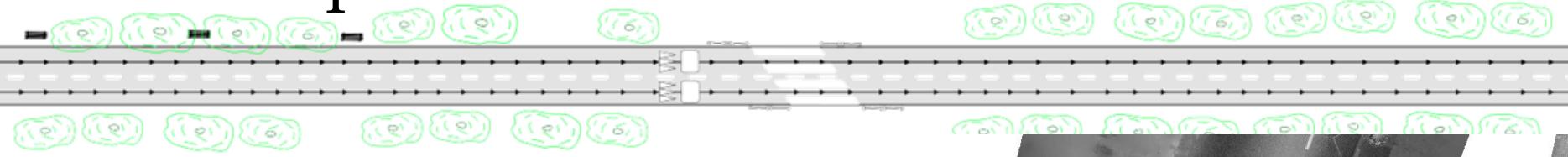
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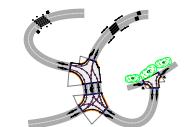


- Only the beginning of inverse procedural street modelling.
  - Object should be created by template/ pattern/ grammar/ procedural functions!
  - Dealing with objects and road model simultaneously calls for much stronger modelling and optimisation methods
  - Optimisation should be more powerful (RJ-MCMC)

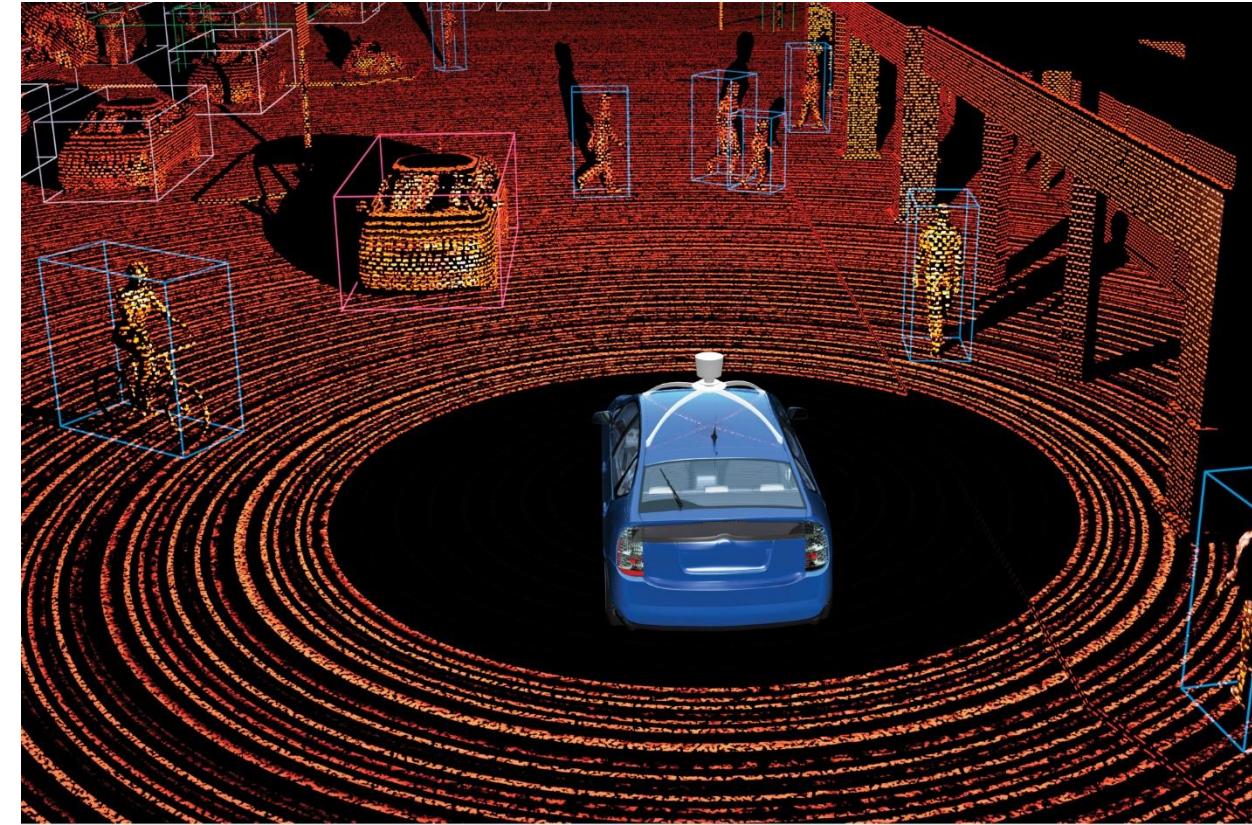
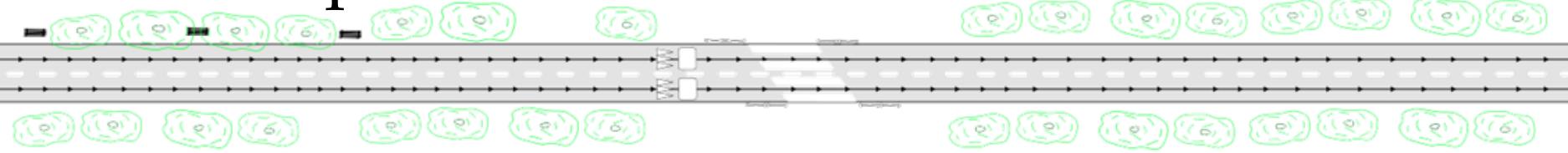


# Conclusion: Perspectives

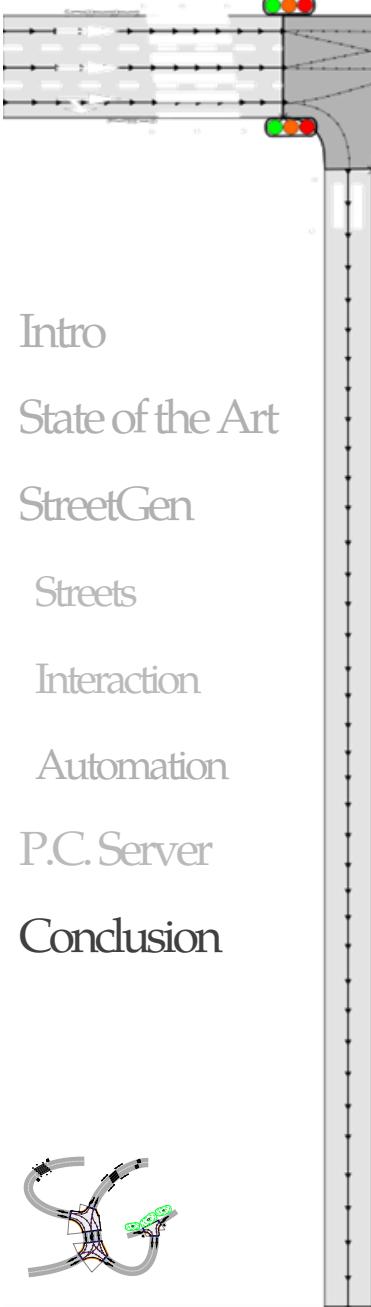
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- Major trend in smart vehicle/autonomous cars
  - → maps potentially required by every (Billion) cars
- For the moment: low level information, but
  - All cars will need a shared high level road model

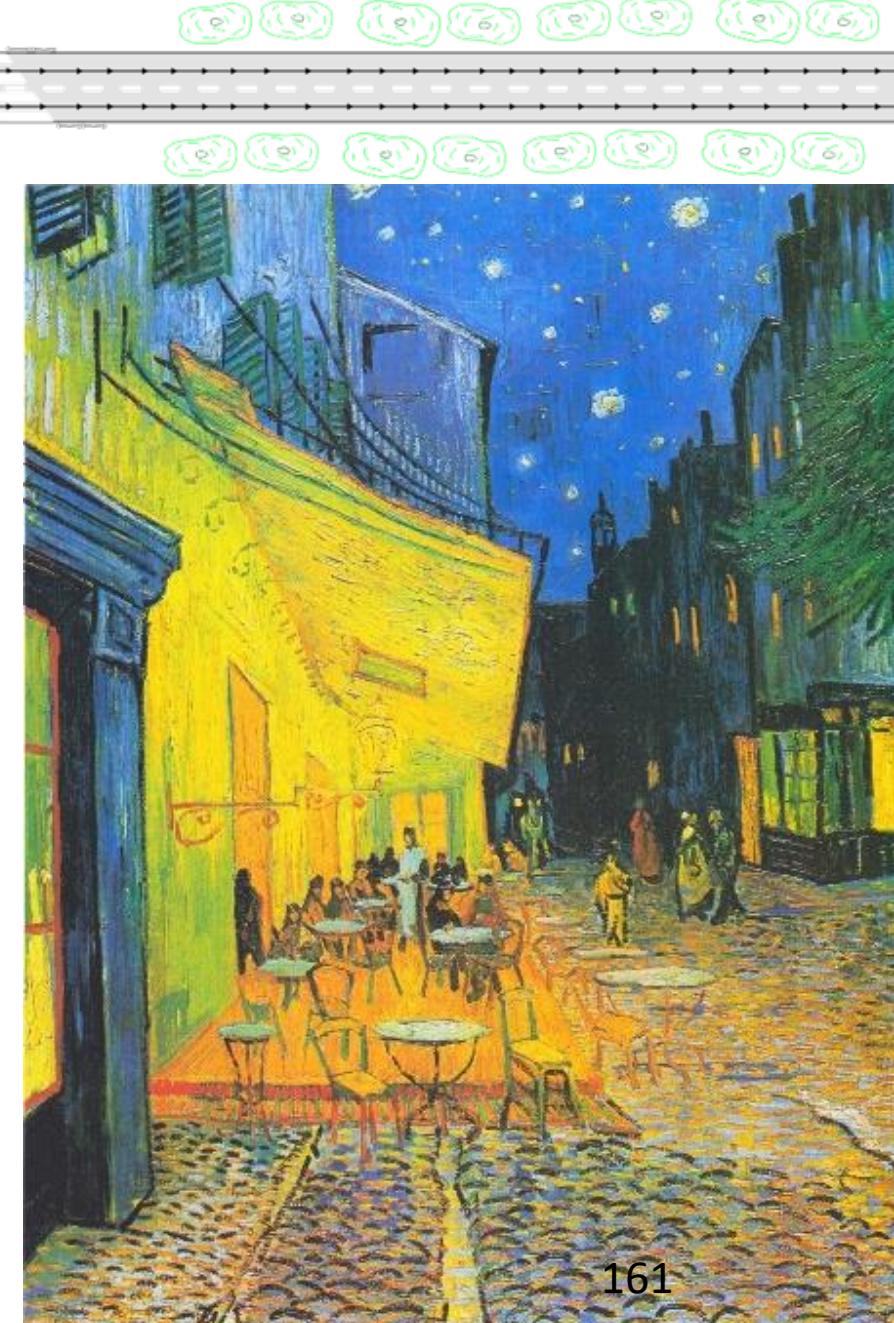


# Conclusion: Perspectives



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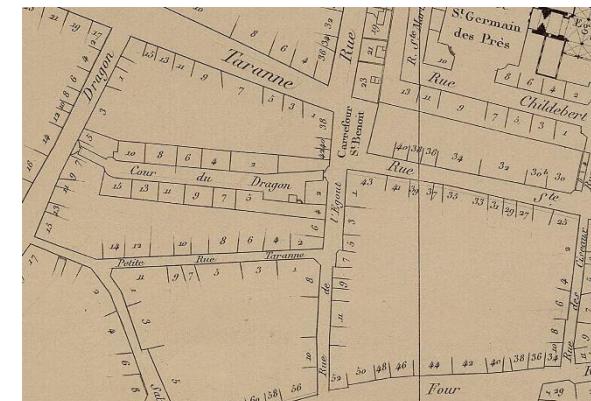
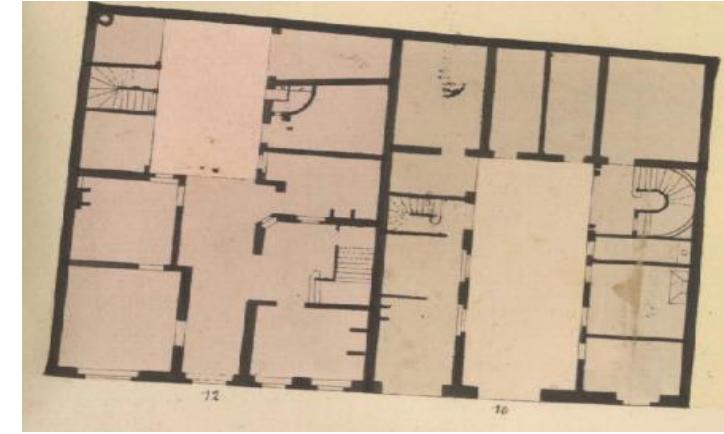
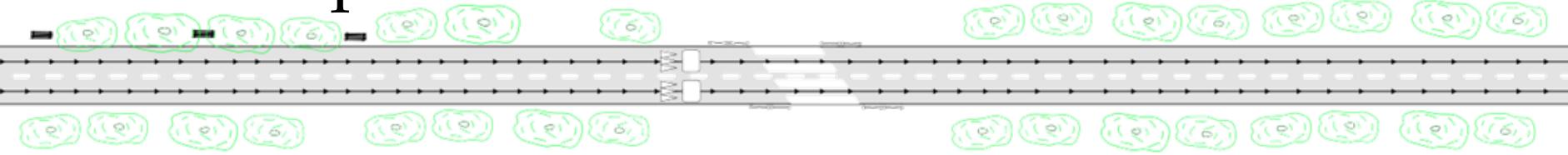
- Cities are evolving
  - There are several cities in one city:
    - Café terrace: day/night
    - Garbage bin
    - (parking behaviour)
  - Time is essential  
(simulation/understanding)
  - 4D street modelling ?





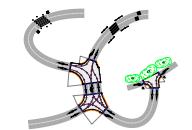
# Conclusion: Perspectives

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

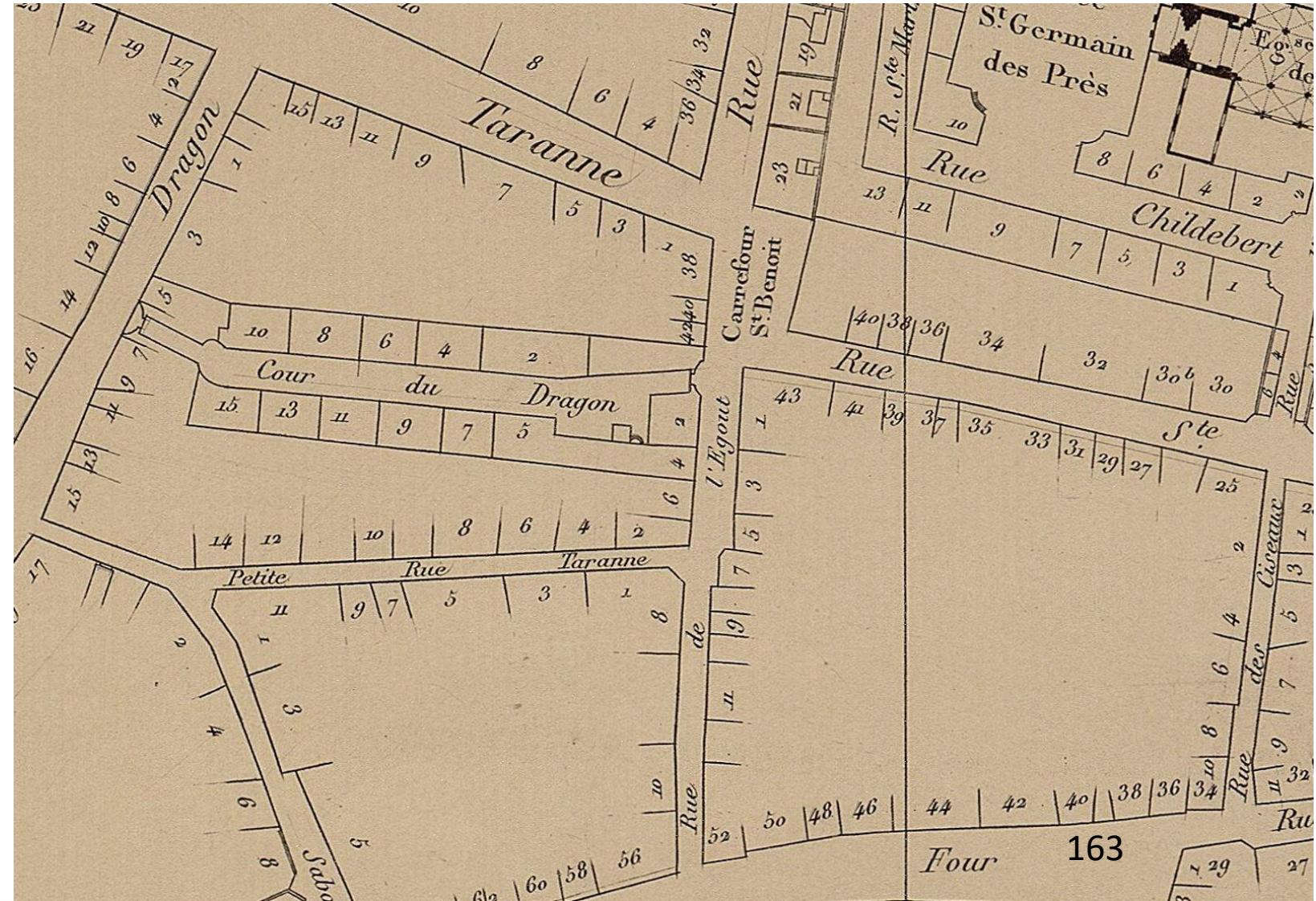
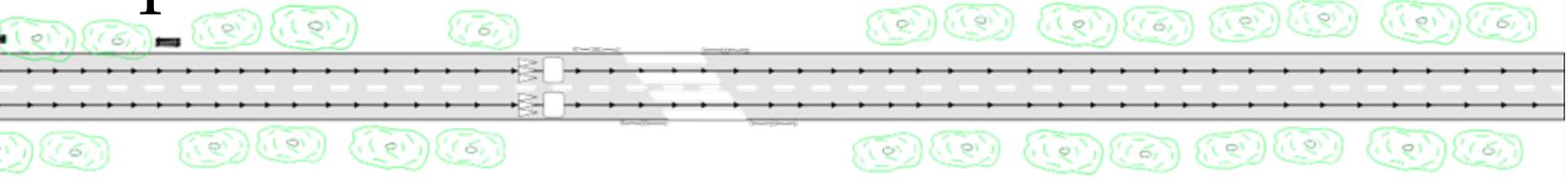


# Conclusion: Perspectives

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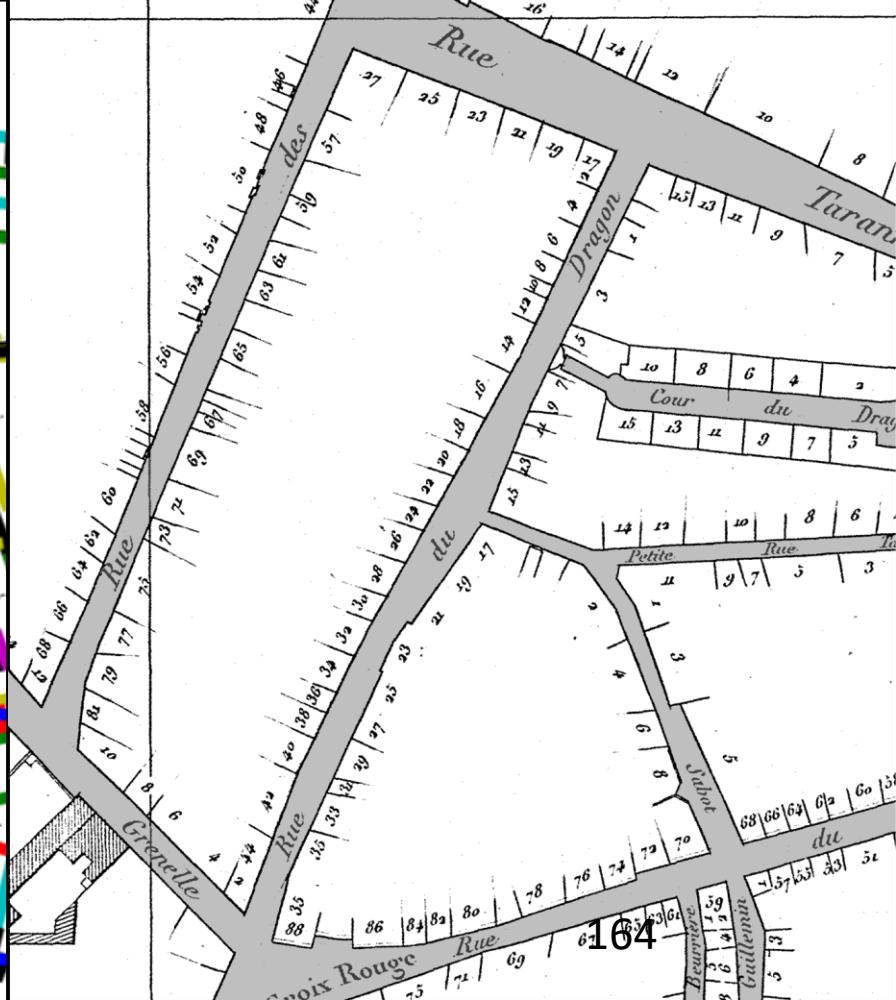
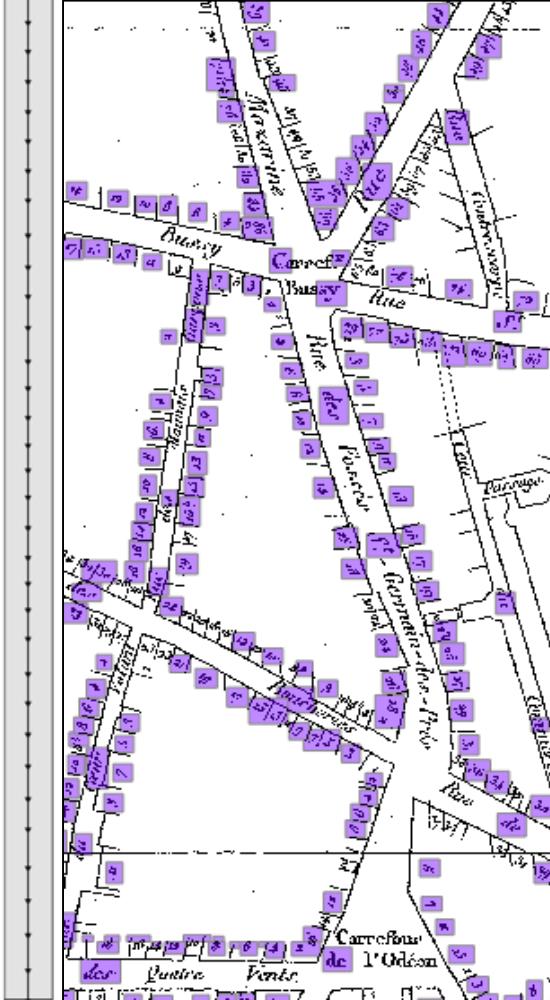


- Jacoubet,  
1810-1836 :
- road model  
with  
optimisation  
& Streetgen  
?



# Conclusion: Perspectives

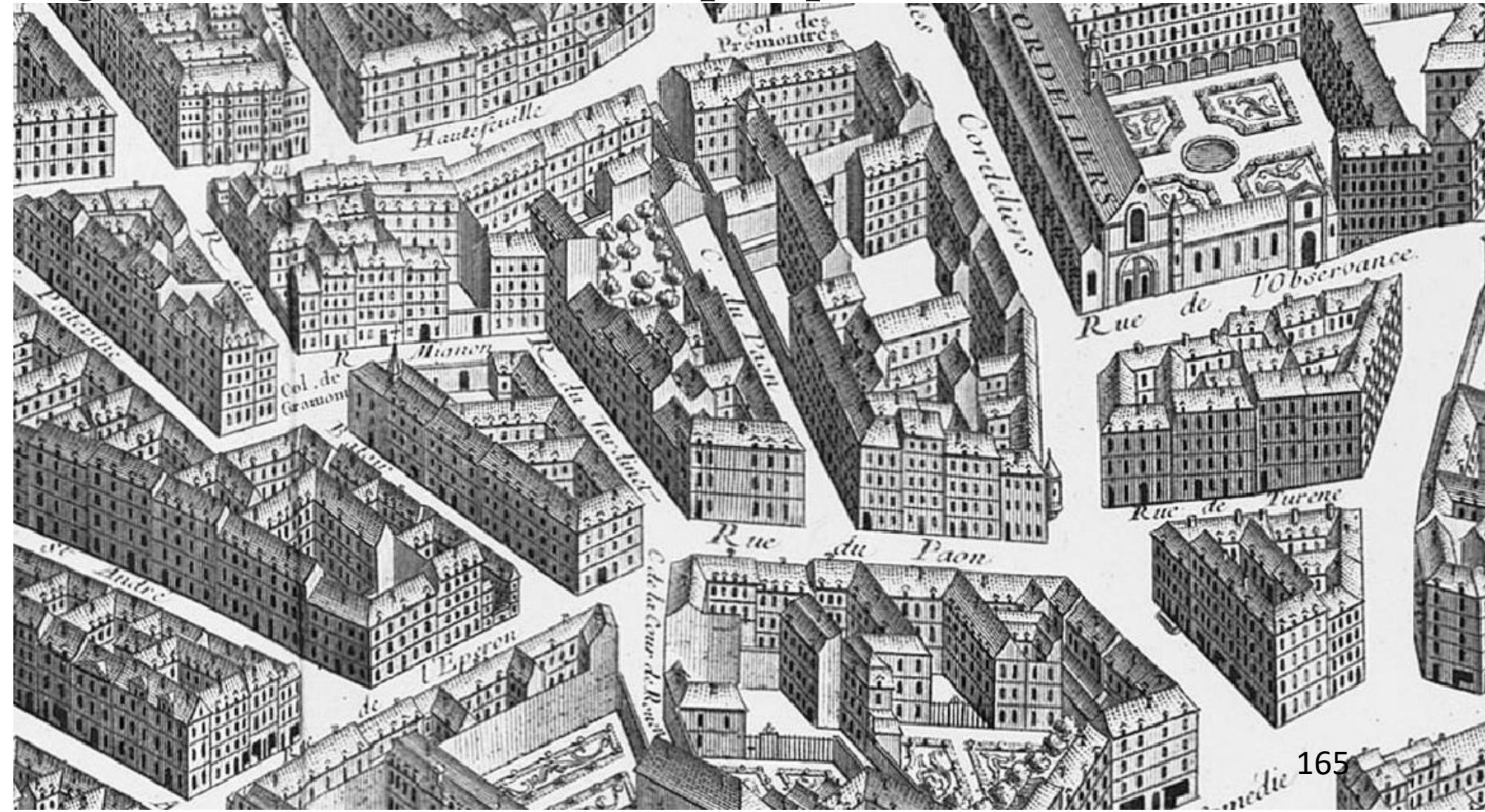
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- Extract building number, buildings limits, street surface (B. Vallet)

# Conclusion: Perspectives

- Turgot, 1734-1739 : isometric persp.



# QUESTIONS

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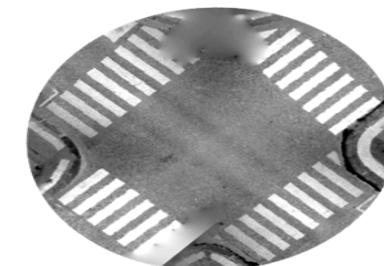
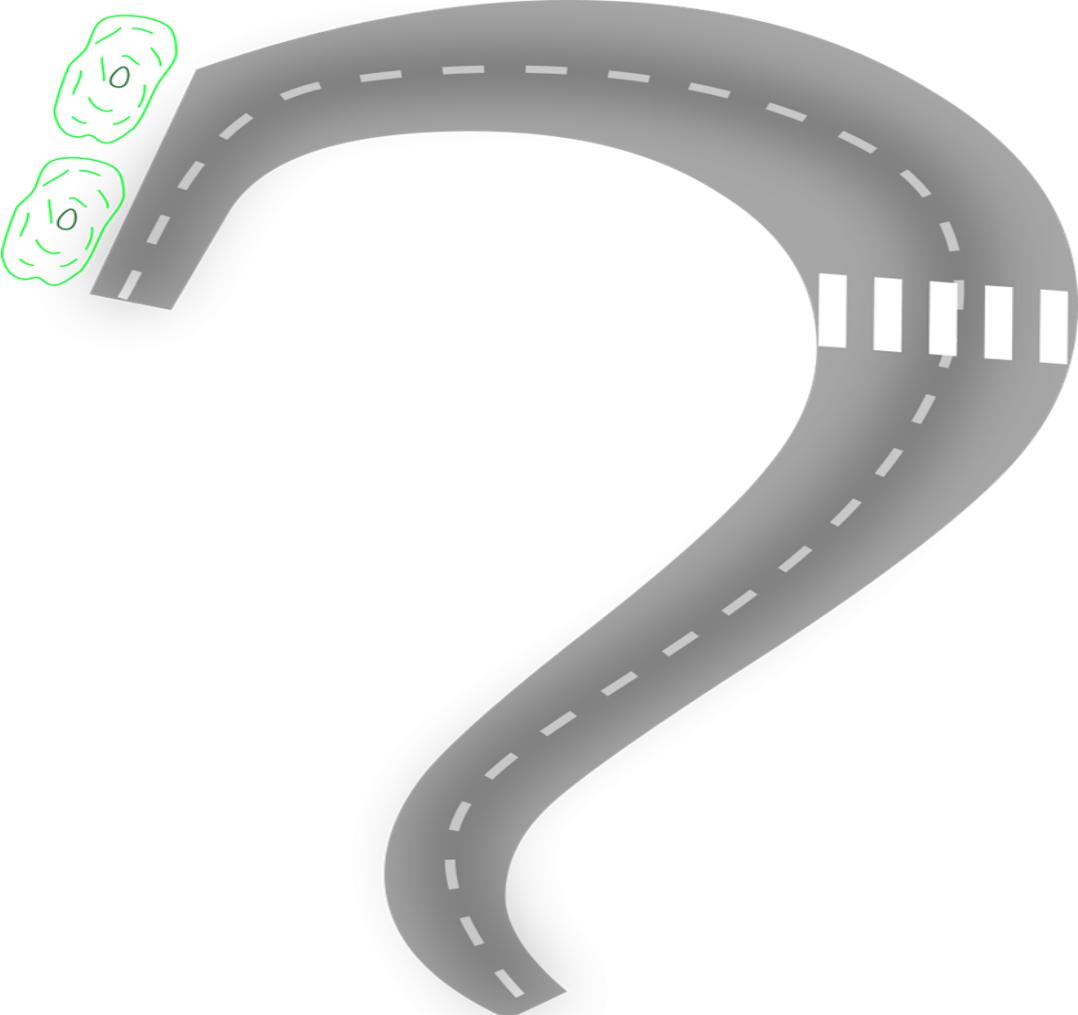
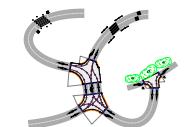
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# appendix

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



Transportation module

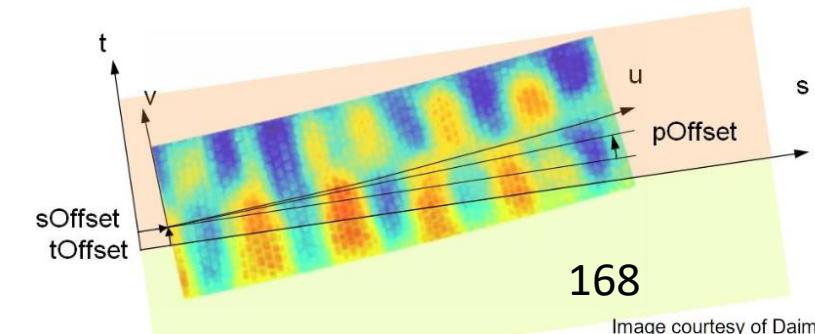
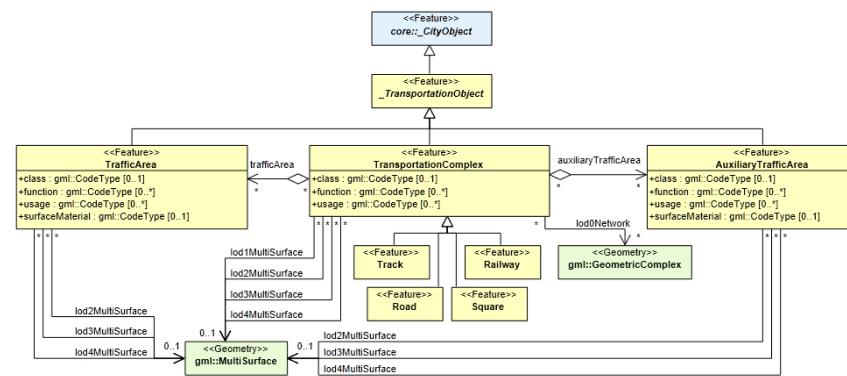
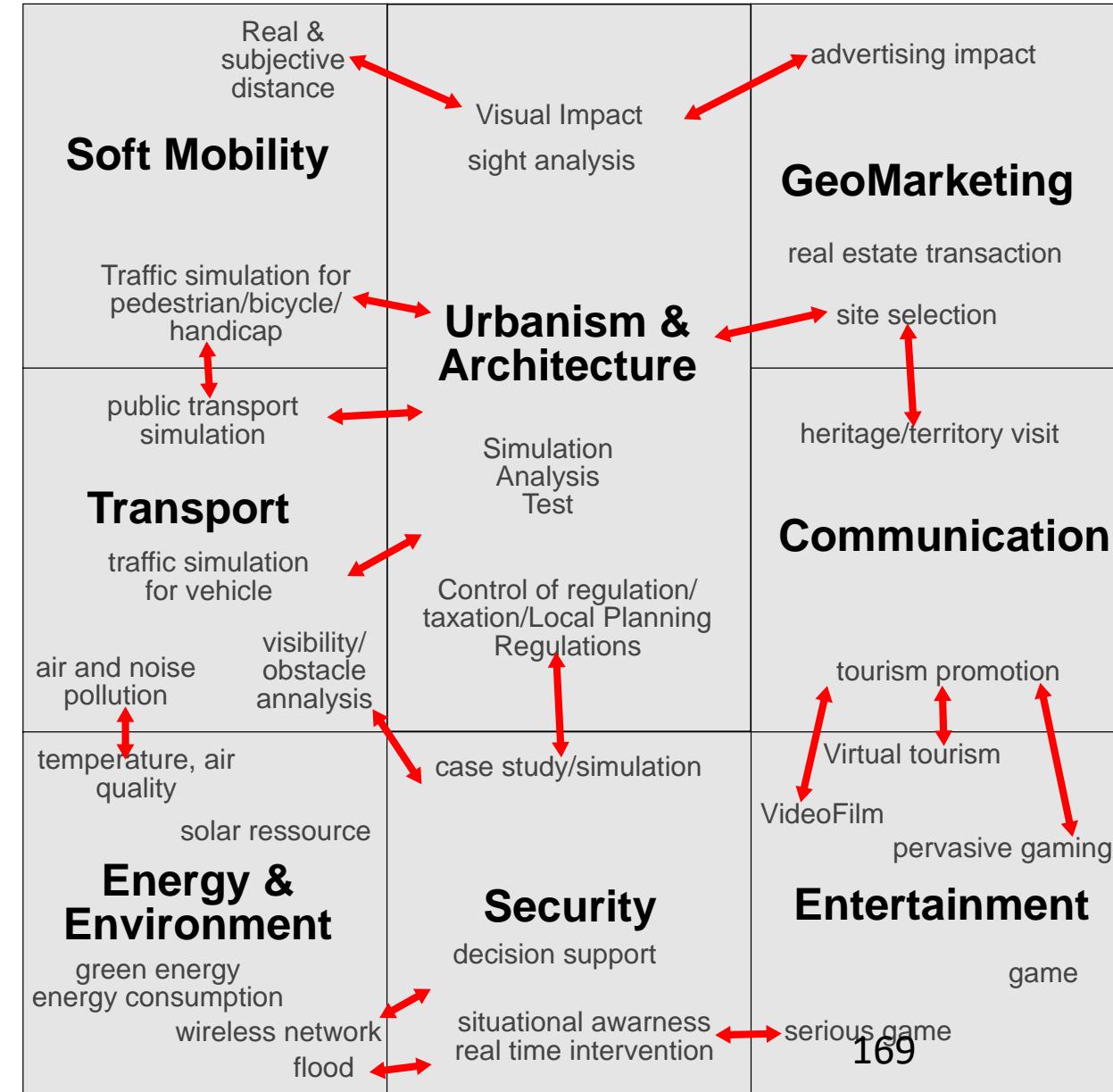
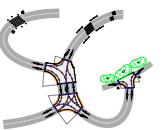


Image courtesy of Daimler AG

# Introduction: usages for city model

- width=8; lane=3
- width=6; lane=2
- Street model ⊂ city model
- Many usages for a city model
  - Urbanism
  - Transport
  - Environment
  - Security
  - Communication
  - ...

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# 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 ...

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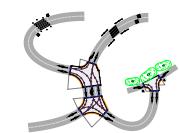
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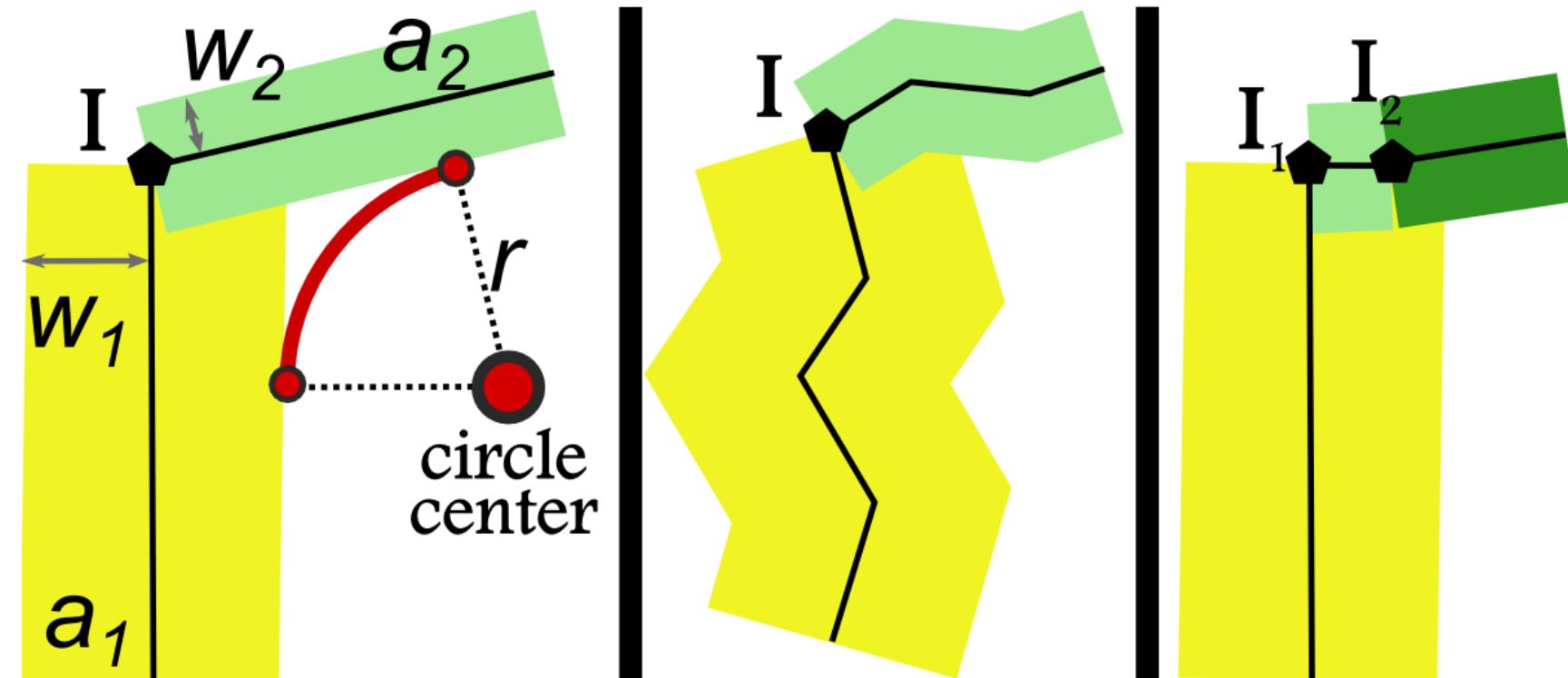
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- We have road axis, road width
  - How to compute circle center and arcs?
  - ~~analytical computing (vector, angle) ?~~



# StreetGen : Kinematic hypothesis

edge id=15; next\_l=16  
end\_node=3 ...



- Various radius in Paris

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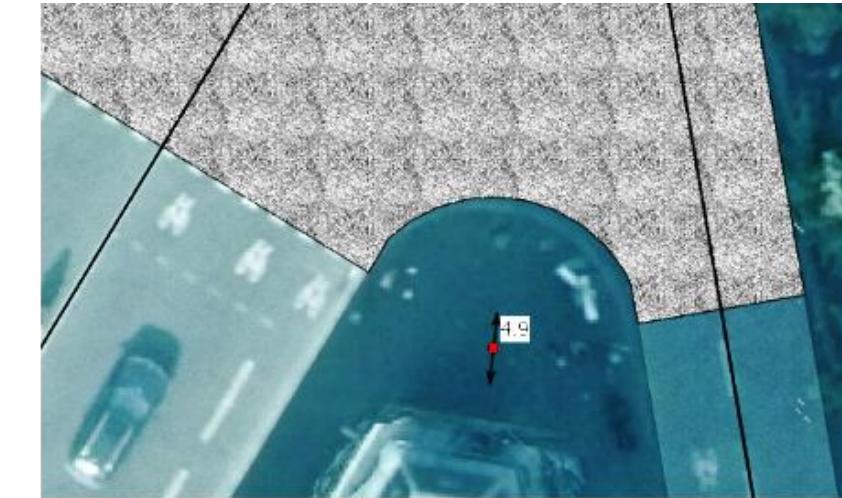
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# StreetGen : Kinematic hypothesis

edge id=15; next\_l=16  
end\_node=3 ...

r=3.6  
+  
x

edge id=16; next\_l=17  
start\_node=4 ...

r=6.4  
+  
x

• t

edge id=17; next\_l=16  
start\_node=4 ...

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State of the Art

StreetGen

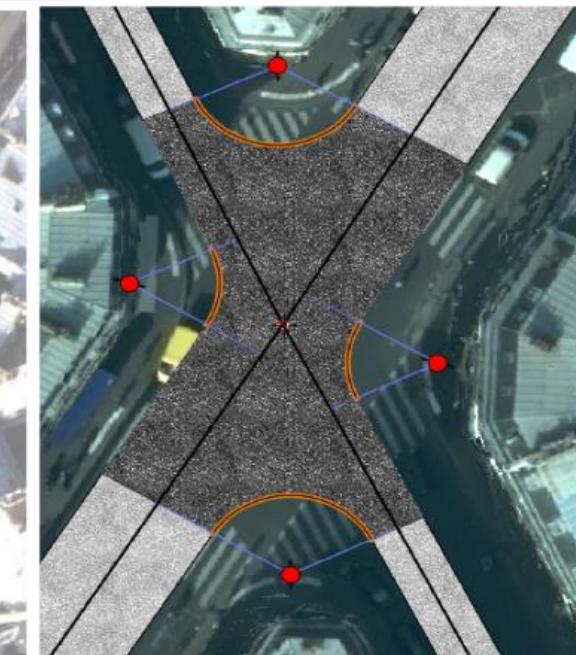
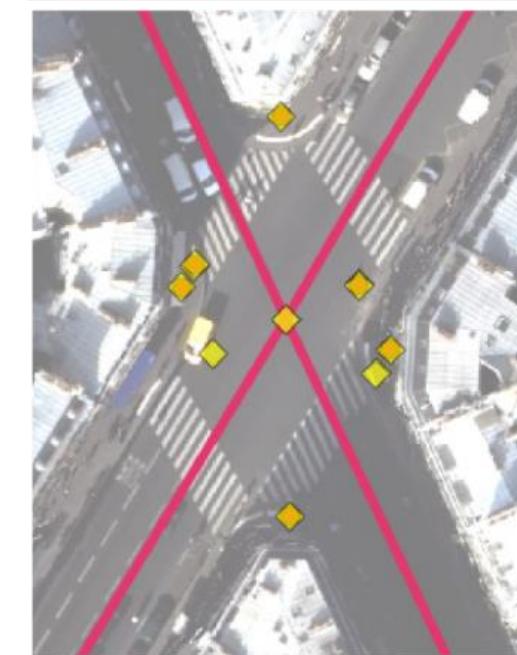
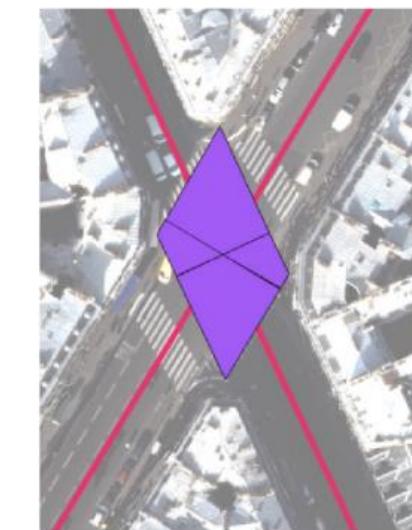
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# StreetGen : Road surface

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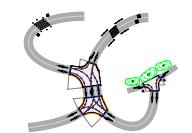
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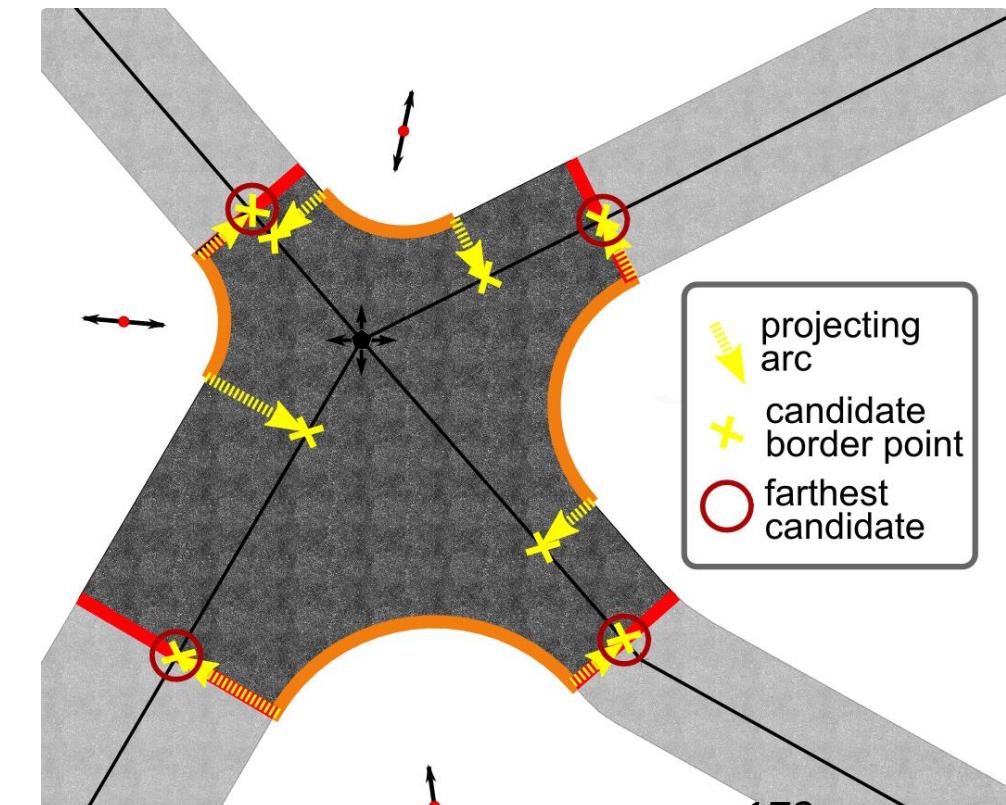
```

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

$r=3.6$

$r=6.4$

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



# StreetGen : Road surface

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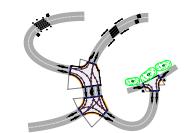
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edge id=15; next\_l=16  
end\_node=3 ...

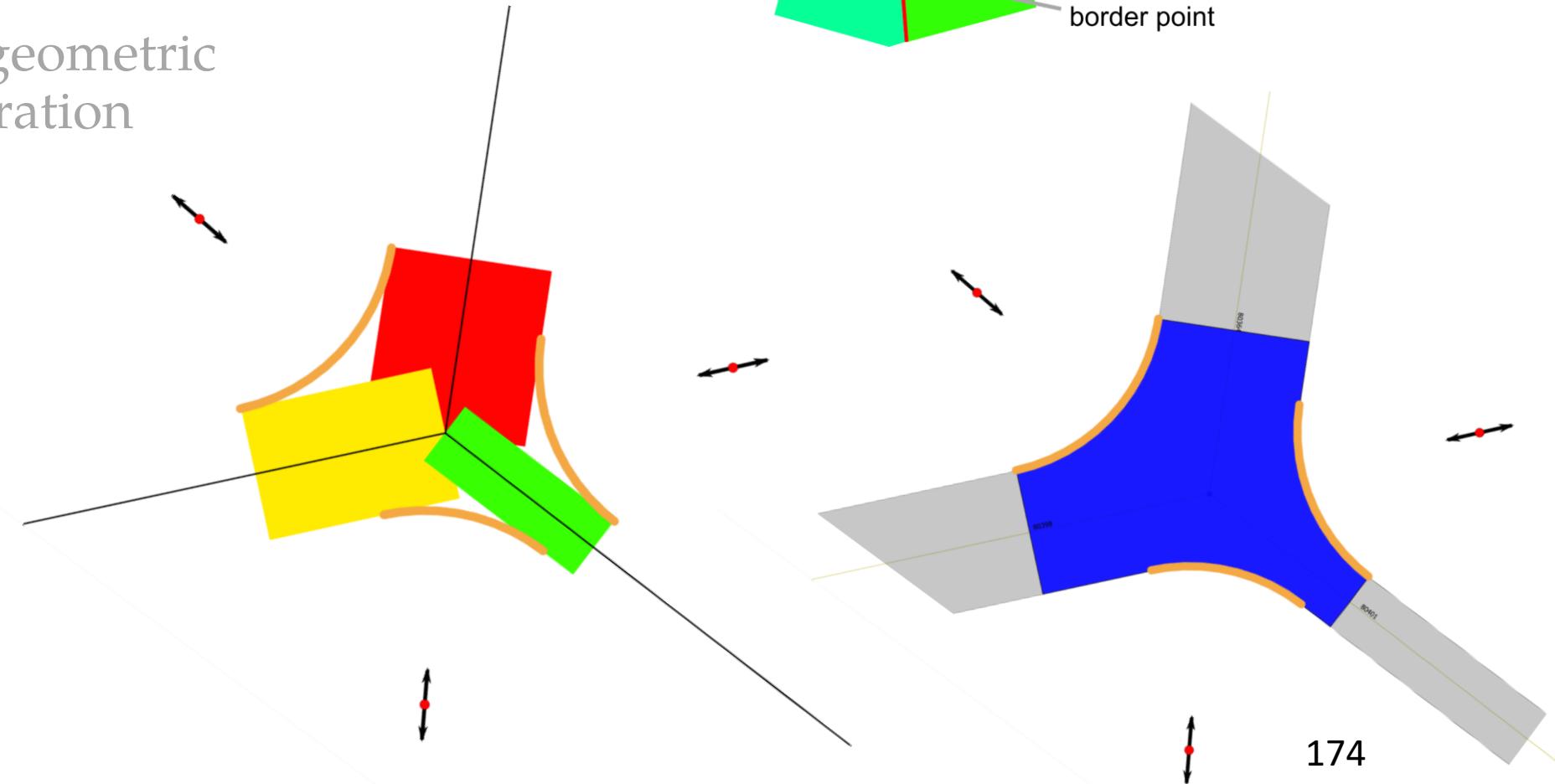
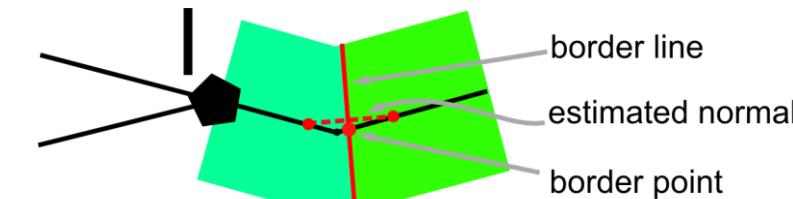
edge id=16; next\_l=17  
start\_node=4 ...

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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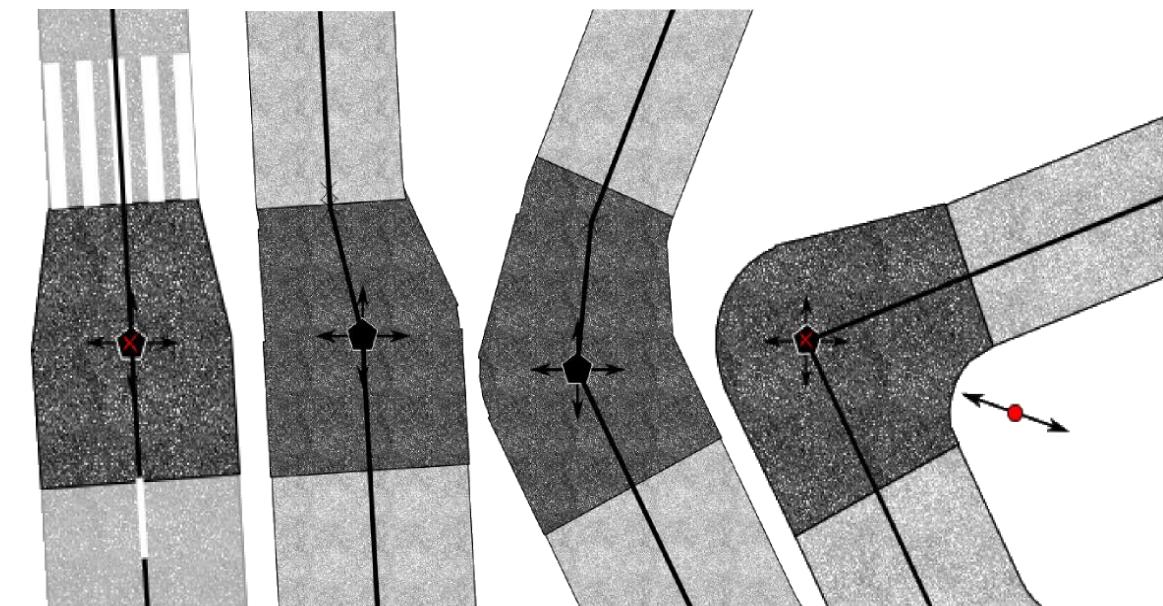
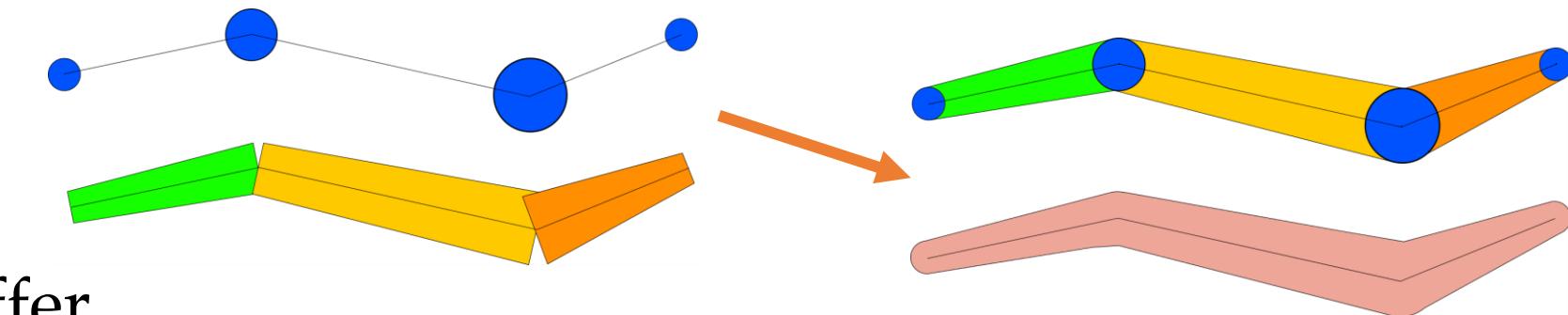
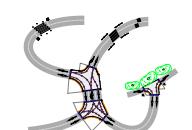
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# StreetGen : street objects

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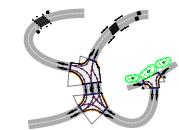
Streets

Interaction

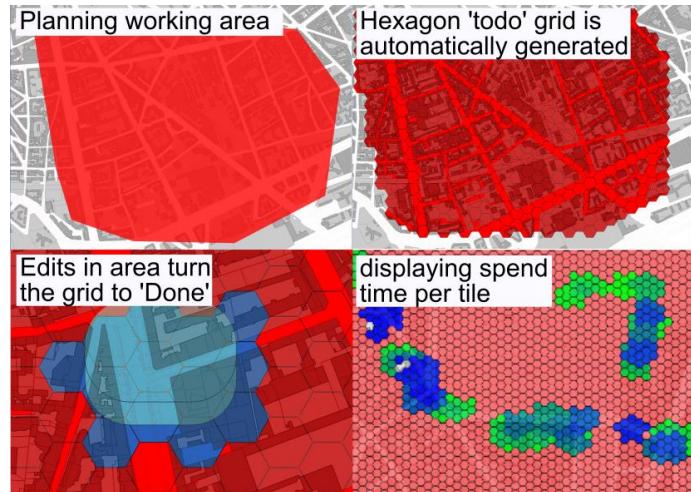
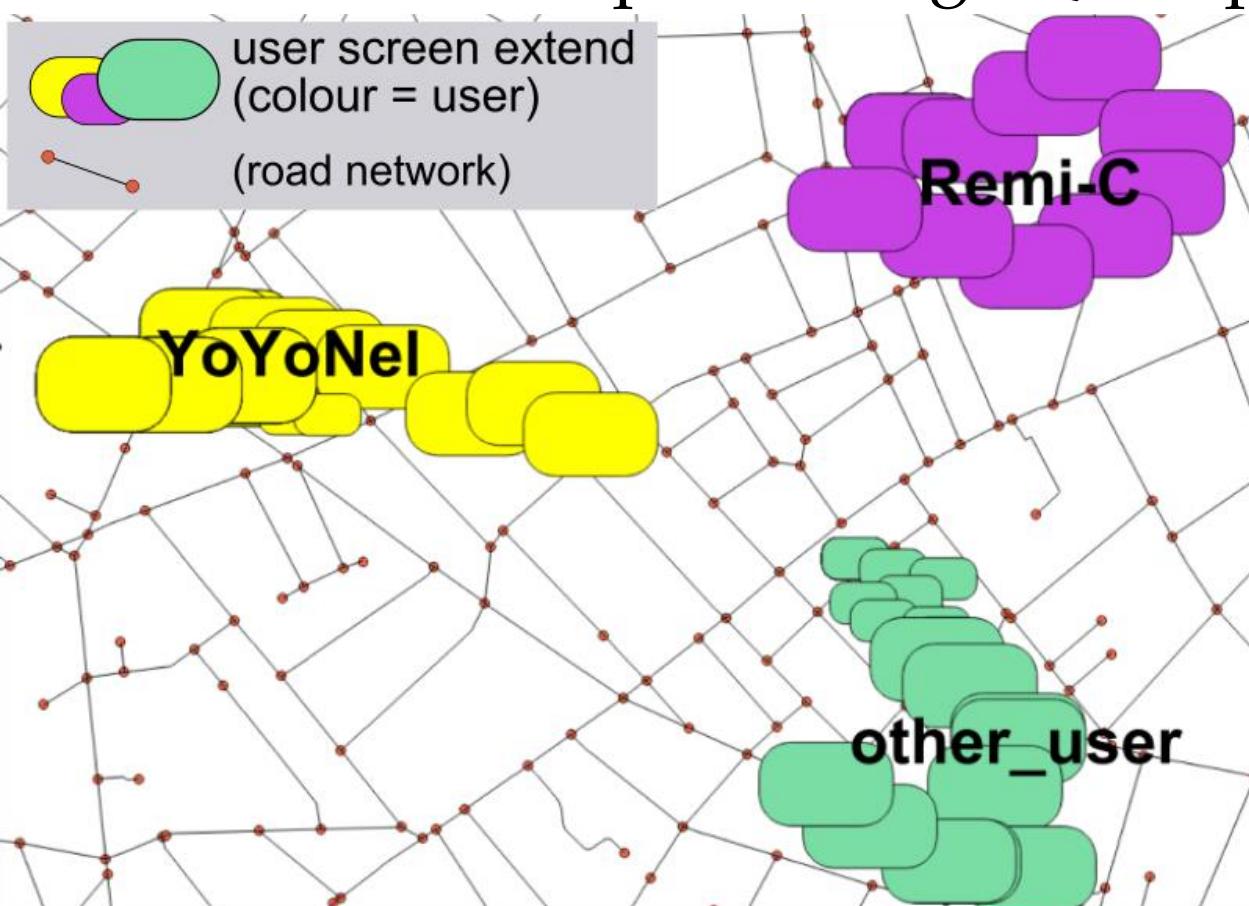
Automation

P.C. Server

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

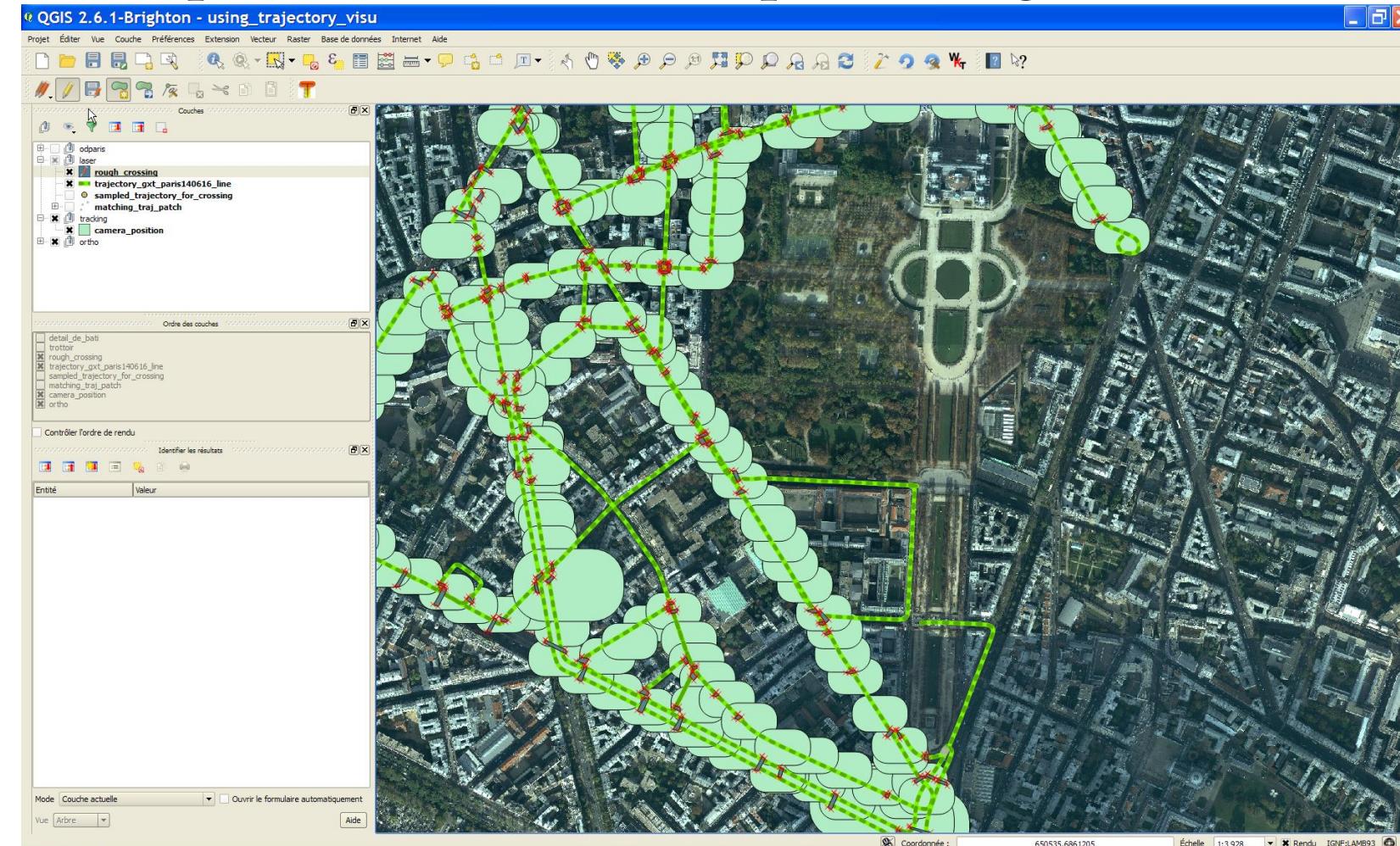
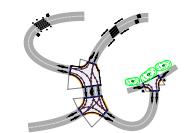
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# Inverse Procedural modelling: forces

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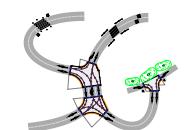
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Conclusion



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

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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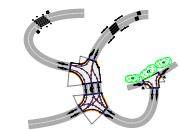
Streets

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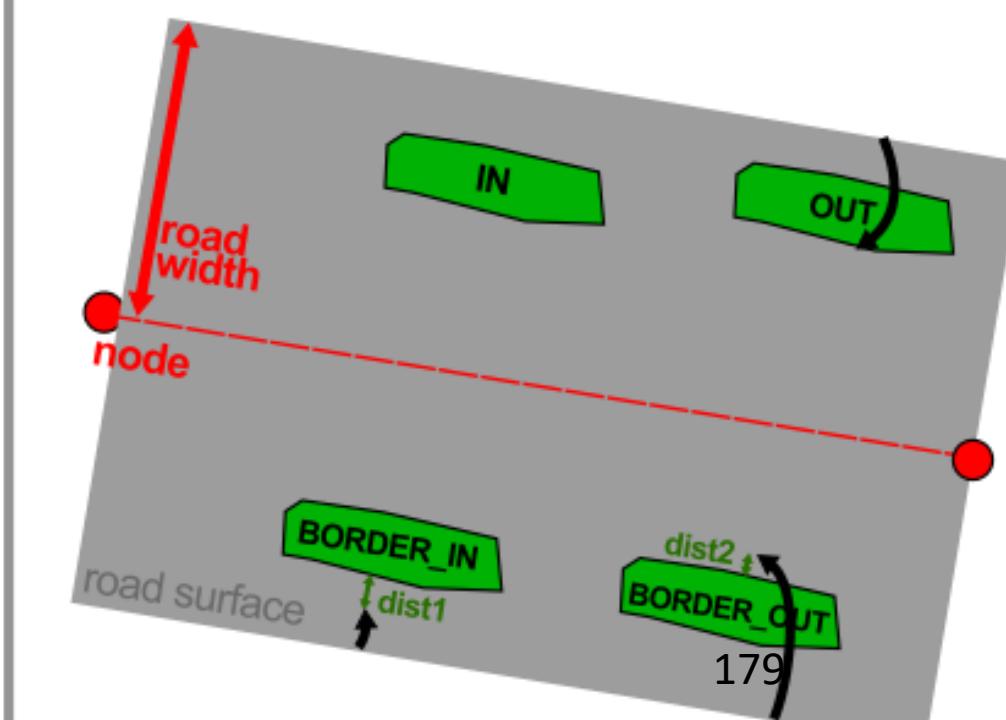
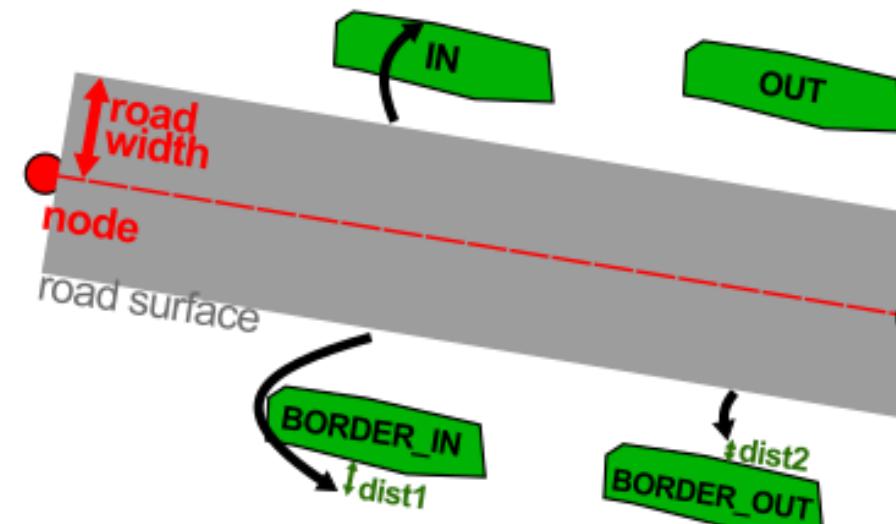
P.C. Server

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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State of the Art

StreetGen

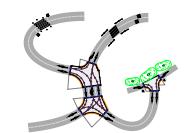
Streets

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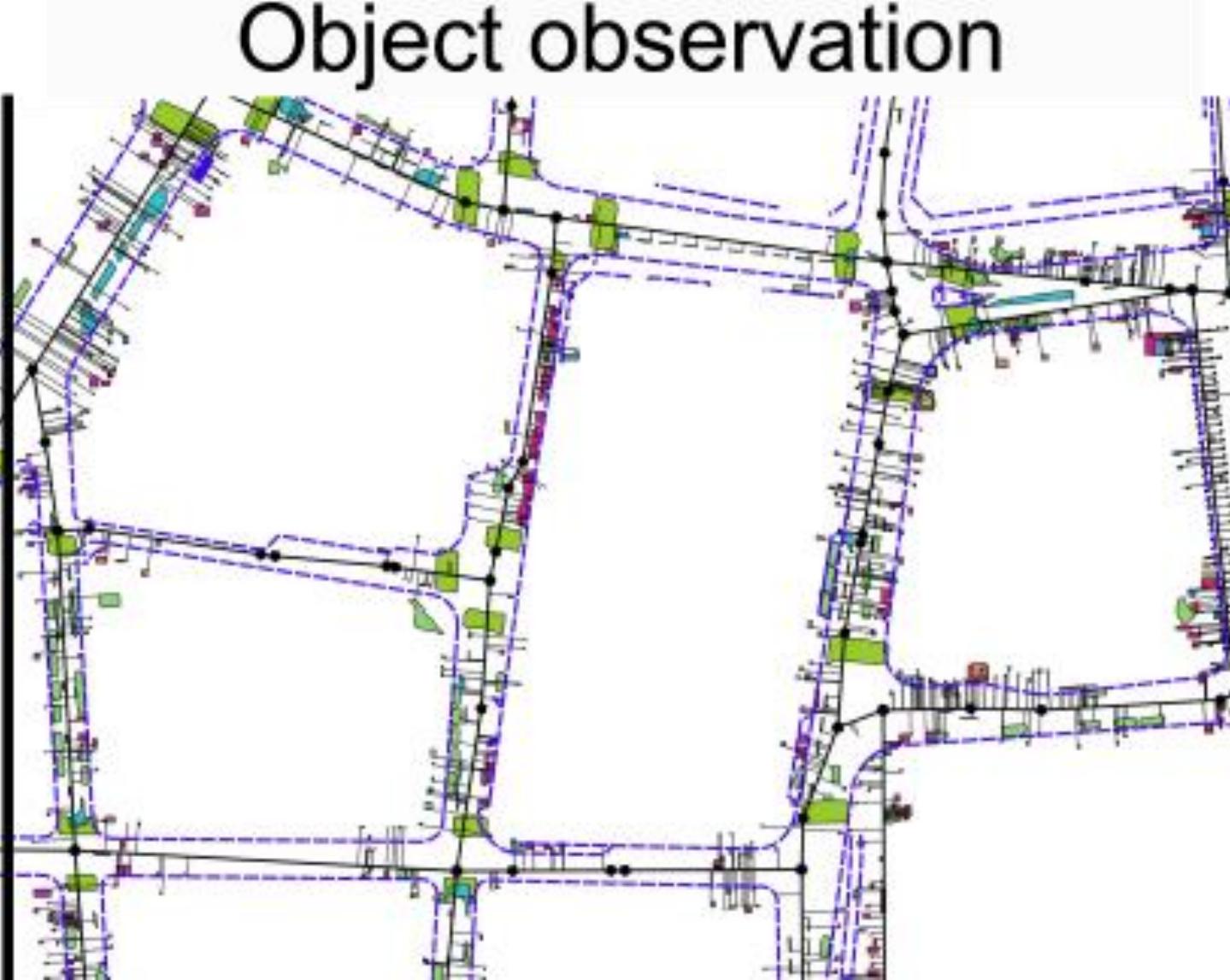
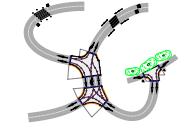


- Observations generate force on road axis/width,
- But first :
- Observation ←matching→ road axis:
- Closest road surface



# Inverse Procedural modelling : small area

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# Inverse Procedural modelling: matching

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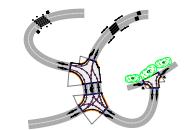
Streets

Interaction

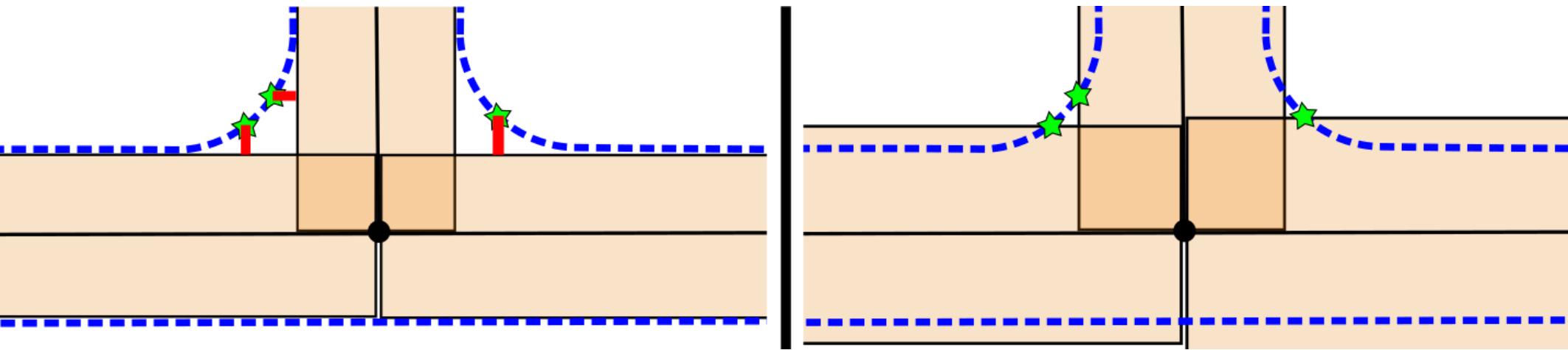
Automation

P.C. Server

Conclusion



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



# Point Cloud Server: Method

Intro

State of the A

StreetGen

Streets

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Automation

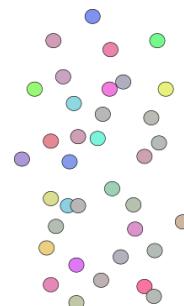
P.C. Server

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 (.... )

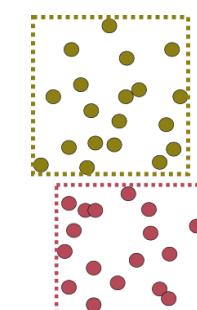
1 row = 1 point  
Analogy : Pixels



Billions  
points



1 row = N points  
Analogy : Image

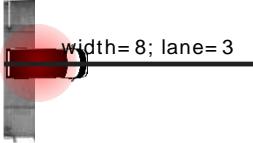


Million  
groups



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





# Point Cloud Server: Loading/Exporting

Intro

State of the A

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Automation

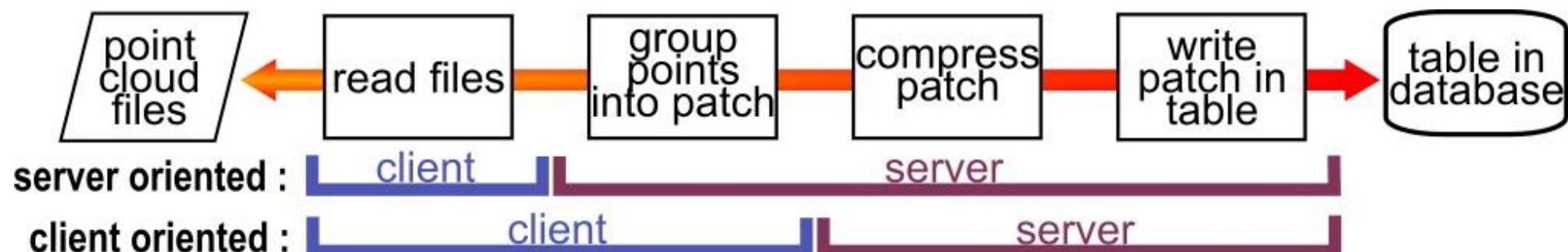
P.C. Server

Conclusion



width=6; lane=2

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



# Point Cloud Server: processing



- Patches can be used in a graph structure

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State of the A

StreetGen

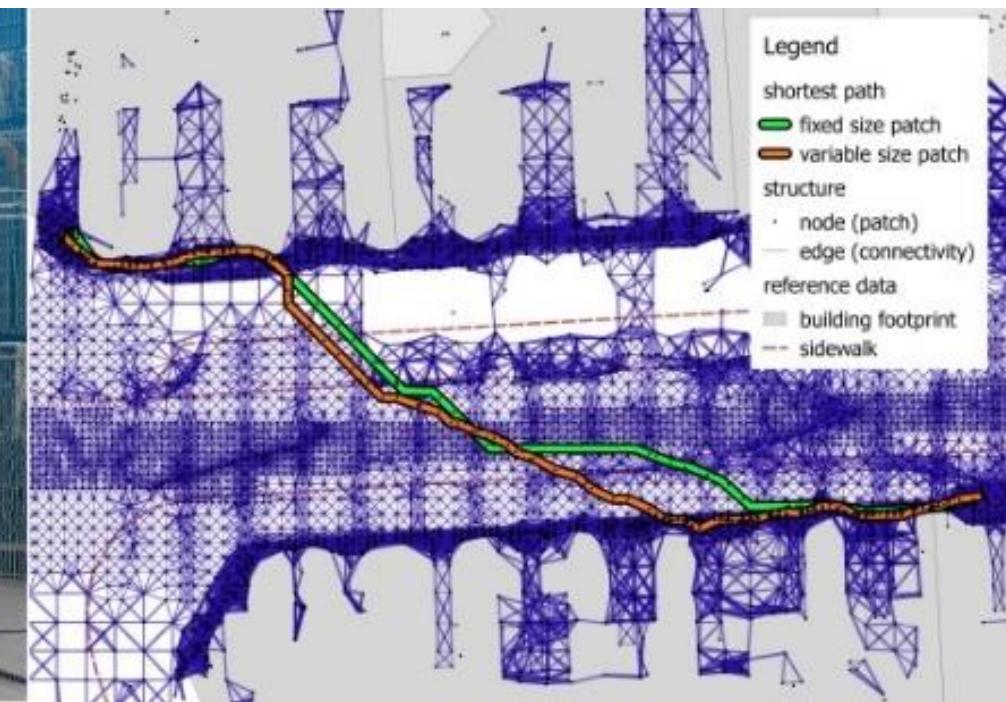
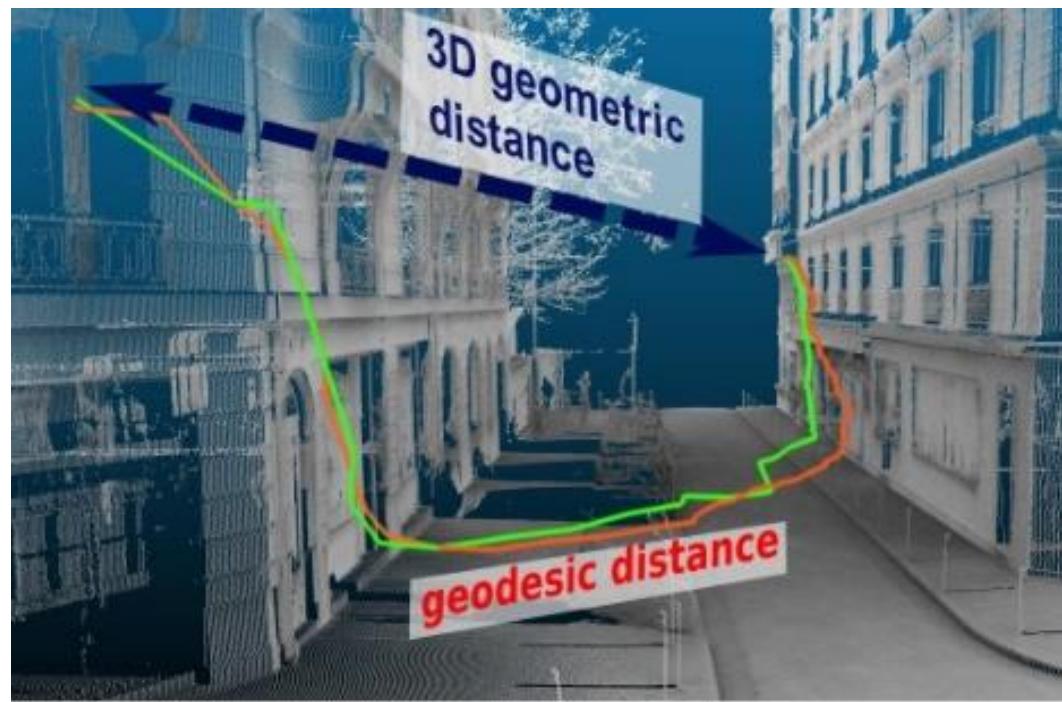
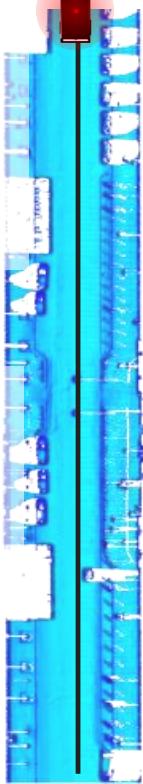
Streets

Interaction

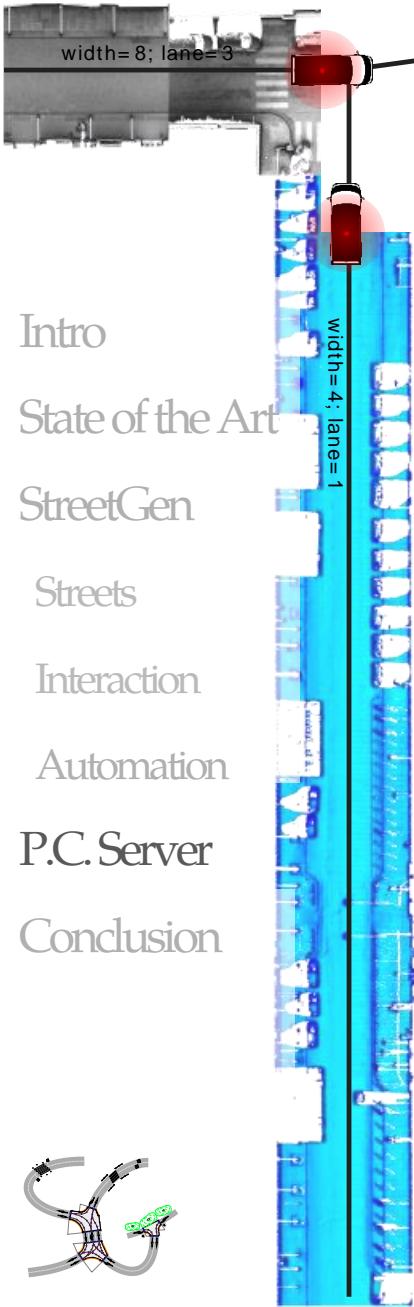
Automation

P.C. Server

Conclusion



# Point Cloud Server: Level Of Detail



- For visualisation, LOD depends on distance to camera



Level 5 to 0  
(from center)  
186