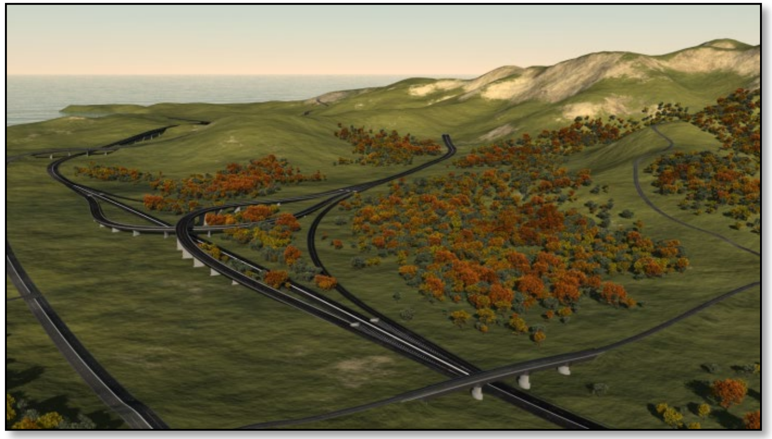
Génération de mondes virtuels
Paysages routiers



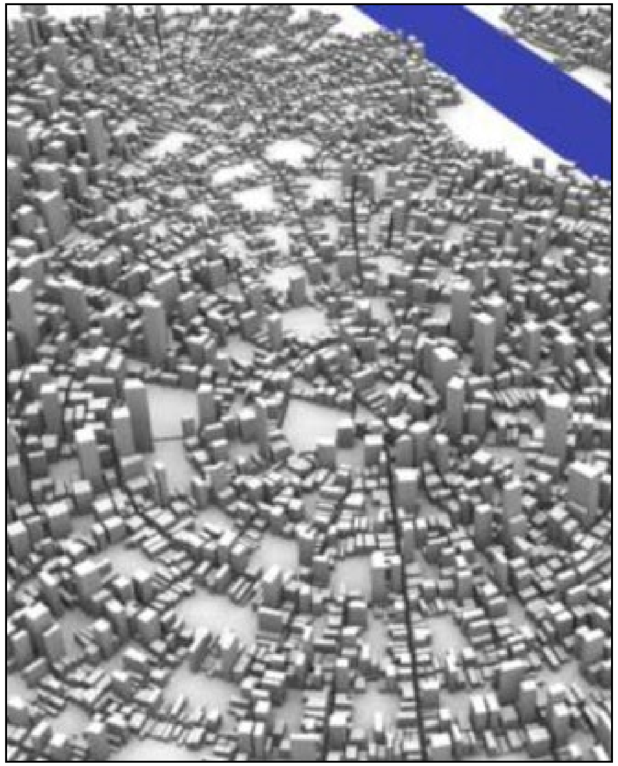
Adrien Peytavie

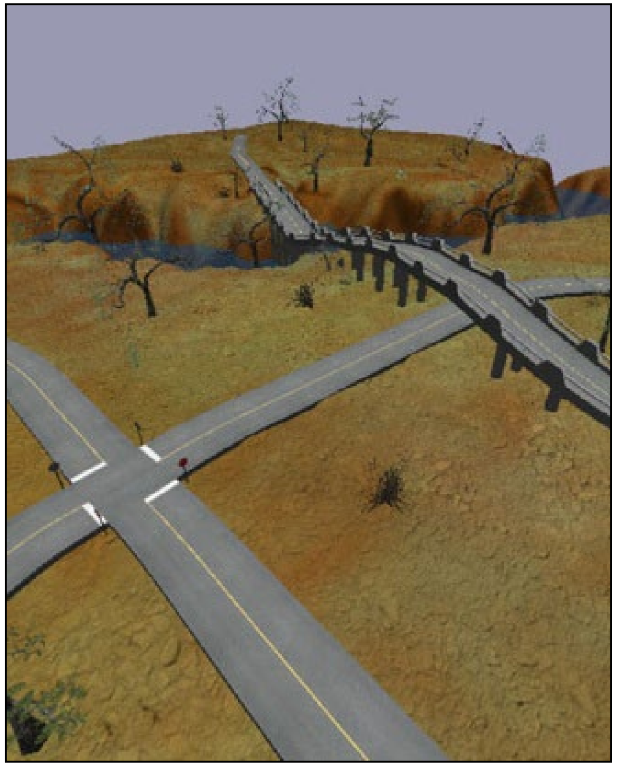
LIRIS - Laboratoire d'InfoRmatique en Image et Systèmes d'information
IUT Lyon 1 – Université Claude Bernard Lyon 1

Webinar 3D et Geospatial, 5 mai 2022

Motivation

Related Works - Roadscapes





Generation of complex street network

Rules of growth [PM01] Tensor fields [CEW08]

Example based method [ABVA08]

Interactive editing of roads

Vector editing [BN08]

Clothoïds arcs [MS09]

Automatic technique for generating country roads

Generating Roadscapes

1 - Road

2 - Networks

3 - Village

Road generation

Generate one road

1. Defining a cost function depending of the landscape
   Control the path trajectory

2. Find an anisotropic shortest path
   Approximate the continuous problem into a discrete problem

3. Modify terrain and procedural geometry generation
   Excavation and embankment operations

1/ Cost function - Surface roads

Problem

Roads follow or avoid the characteristics of the terrain

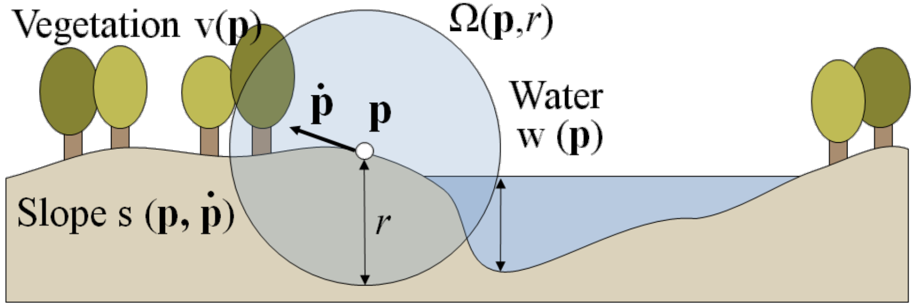
Cost function enable to control the trajectories

$$c(\mathbf{p},\dot{\mathbf{p}},\ddot{\mathbf{p}}) = \sum_{i=0}^{i=n-1} \mu_i \circ \kappa_i(\mathbf{p},\dot{\mathbf{p}},\ddot{\mathbf{p}})$$

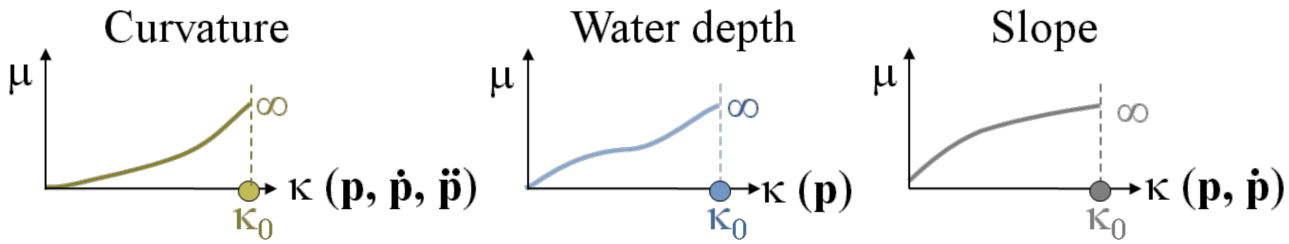
Transfert function

Characteristic function

Characteristic function for road surface



Weighting function

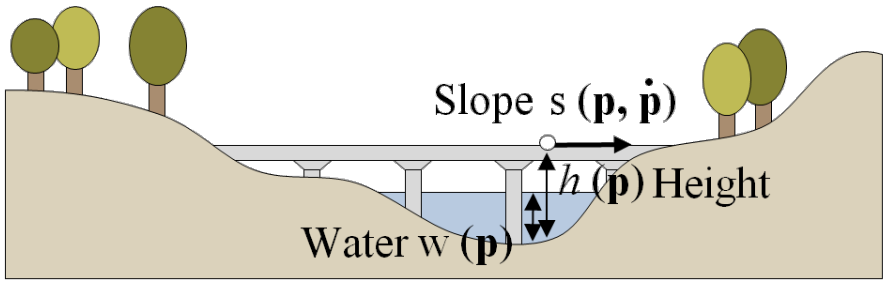


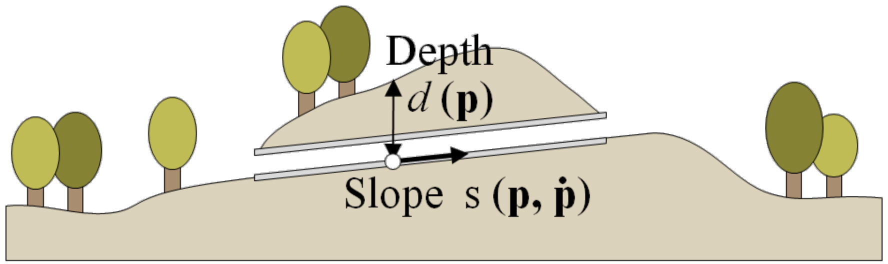
Bridges and Tunnels

Problem
Take into account the characteristics of the terrain

Bridge parameter
Bridge height $h(\mathbf{p})$
Slope $s(\mathbf{p},\dot{\mathbf{p}})$, water $w(\mathbf{p})$
Curvature $c_o(\mathbf{p},\dot{\mathbf{p}},\ddot{\mathbf{p}})$

Tunnel parameter
Tunnel depth $d(\mathbf{p})$
Slope $s(\mathbf{p},\dot{\mathbf{p}})$
Curvature $c_o(\mathbf{p},\dot{\mathbf{p}},\ddot{\mathbf{p}})$





2/ Anisotropic shortest path problem

Problem

Find the path $\boldsymbol{\rho}$ between 2 points $\mathbf{a}$ and $\mathbf{b}$ minimizing the cost along the path

Minimize the line integral of a weighted cost function

$$C(\rho) = \int_0^T c(\mathbf{p}(t), \dot{\mathbf{p}}(t), \ddot{\mathbf{p}}(t))\,\mathrm{d}t$$

Position

Velocity

Acceleration

Path $\boldsymbol{\rho}^*$ that minimizes the functional

$$C(\rho^*) = \min_{\rho \in \mathcal{P}} C(\rho)$$

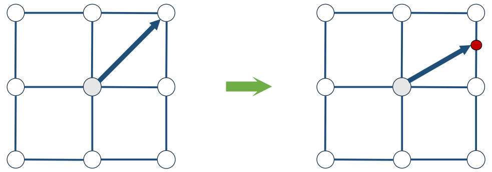
Shortest path methods

Isotropic cost depends on position $c(\mathbf{p})$ [MP91, Tsi95, AMS00, PBT98]

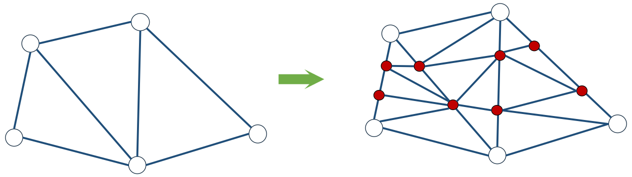
Anisotropic cost depends on position, velocity and acceleration

$$c(\mathbf{p}, \dot{\mathbf{p}}, \ddot{\mathbf{p}})$$

Regular grid + Displacement of node position [JV04]



Polygonal mesh + Inserting Steiner points [AMS05]



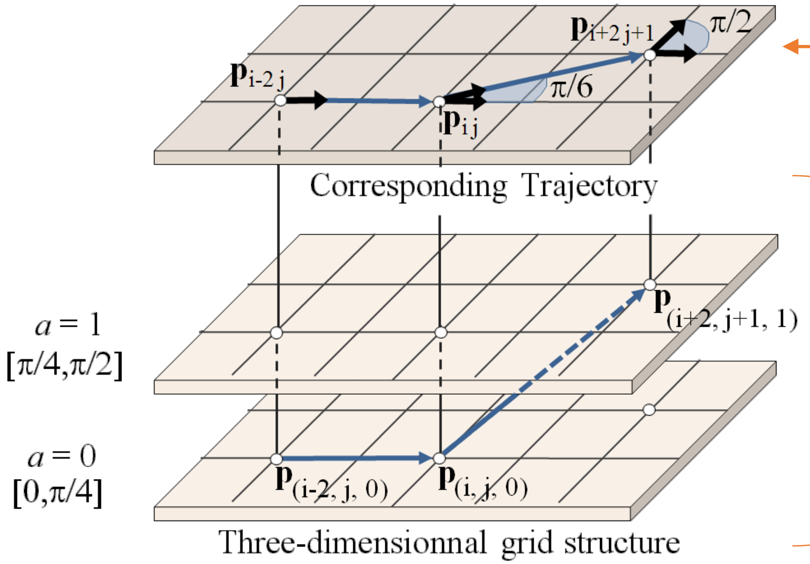
Shortest path 3D

Input data

Continuous complex terrain [PGMG 09]
Layer characteristics (bedrock, sand, water, Forest)

Method

Reduce the continuous problem into a discrete problem
Using a 3D discrete grid
Creation of the graph connecting each nodes (mask)



Projection onto a plane

3D representation of data overlapping grids

Each grid maps to an angle interval

Shortest path 3D

A* shortest path algorithm

1. While Q is not empty, select $\mathbf{p}_{ij}$ with minimal value.
2. If $\mathbf{p}_{ij} = \mathbf{b}$, stop the alorithm.
3. For all $\mathbf{q} \in \mathcal{M}_k(\mathbf{p}_{ij})$, evaluate the cost $c(\mathbf{p}_{ij},\mathbf{q}) + h(\mathbf{q})$.

If $c(\mathbf{p}_{ij},\mathbf{q}) + h(\mathbf{q}) < c(\mathbf{q})$ then predecessor of $\mathbf{q}$ is $\mathbf{p}_{ij}$.

Heuristic $h(\mathbf{p}) < c(\mathbf{p}\ ,\ \mathbf{q}) + h(\mathbf{q})$, $h(\mathbf{p}) = \|\ \mathbf{b}\text{-}\mathbf{p}\ \|$ **Line integral** $c(\mathbf{p}_k, \mathbf{p}_{k+1}) = \int_{t_k}^{t_{k+1}} c(\mathbf{p}(t), \dot{\mathbf{p}}(t), \ddot{\mathbf{p}}(t))\, \mathrm{d}t$

Problem

Graph complexity : nb nodes $O(\mathrm{a}\ \mathrm{n}^2)$ and nb arcs $O(\mathrm{a}\ \mathrm{n}^2\ \mathrm{k}^2)$

Ex: $500^2 \times 16 = 4\mathrm{M}$ nodes, $500^2 \times 16 \times 48 = 192\mathrm{M}$ arcs

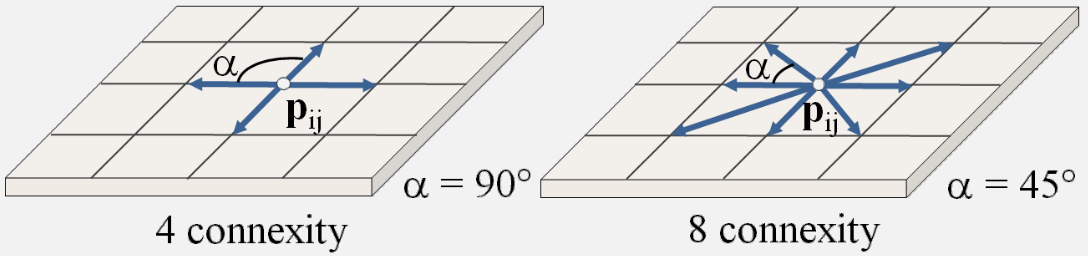
Resolution

Using masks and acceleration by stochastic sampling

Masks

Problem

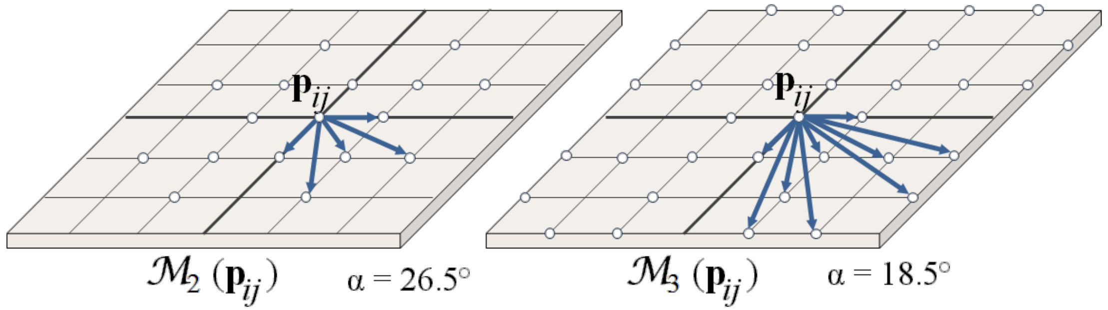
Angle resolution is either 90° or 45° when considering the 1-neighborhood



Segment mask

Use of masks with a larger neighborhood

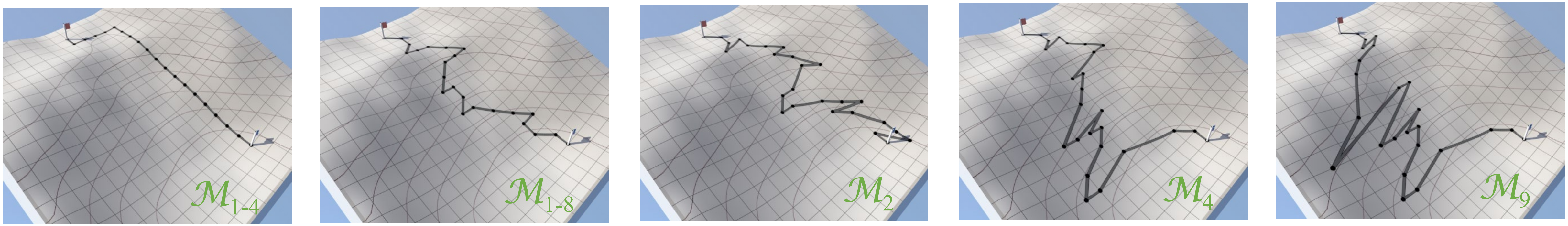
Store the connectivity between points with generic masks



Masks

Influence of mask size

Increase the angle resolution α but also the number of arcs n_k



k	α	Cost	n_k	Time
1	45,0	122 978	8	0,34
2	26,5	91 187	16	0,83
3	18,5	89 408	32	1,49

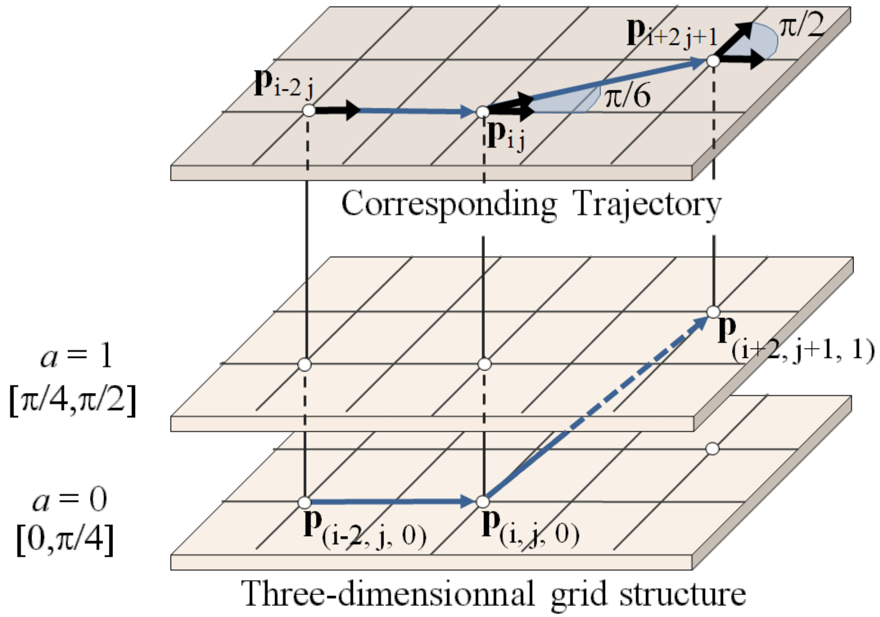
k	α	Cost	n_k	Time
4	14,0	89 228	48	3,29
5	11, 3	89 096	80	6,40
9	6,3	88 876	224	22,59

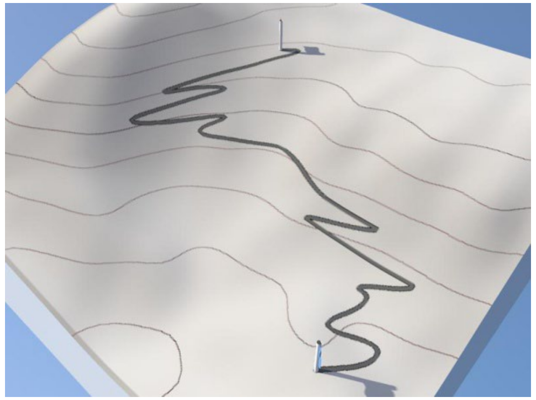
Curvature

Problem

Control the curvature

Discretization of the space in 3D (m intervals)





Model	Cost	Time
Without	64 693	0,1
With	60 676	1,9

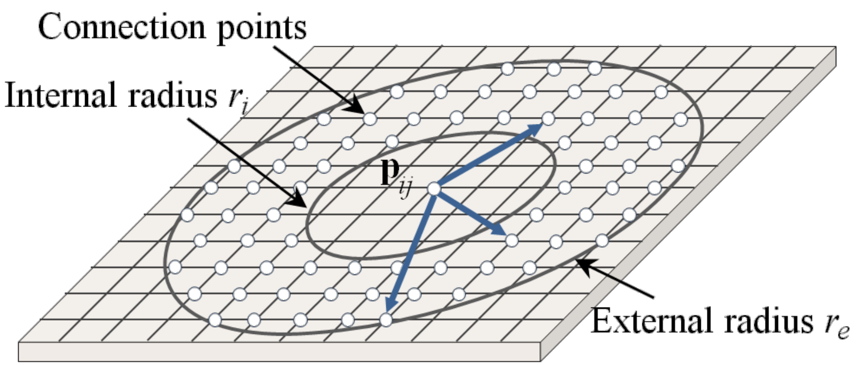
Bridges and Tunnels

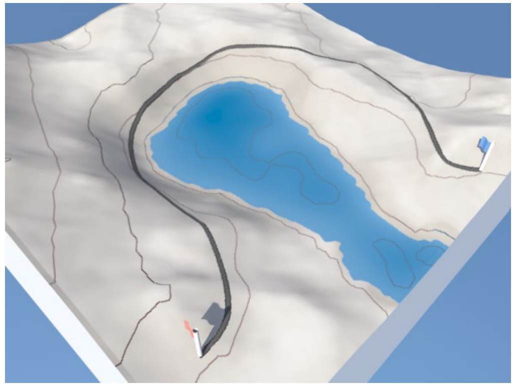
Problem

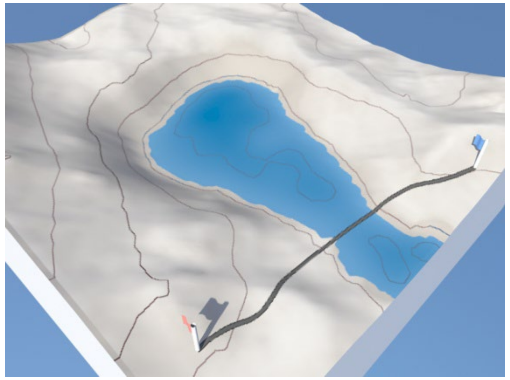
Create bridge and tunnel with this method

Large segment mask

$$\mathcal{T}(\mathbf{p}_{ij}) = \{\mathbf{q} \neq \mathbf{p}_{ij} \| r_i \leq \|\mathbf{p}_{ij} - \mathbf{q}\| \leq r_e\}$$







Technique	Cost	Time
Only road	65 778	0,8
Road + Bridge	45 974	47,8

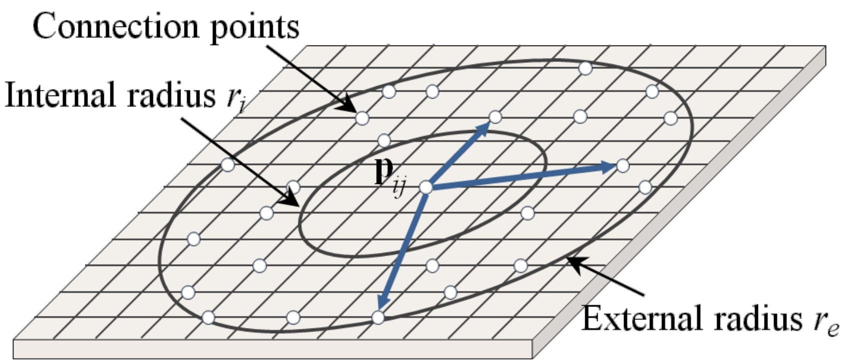
Stochastic sampling

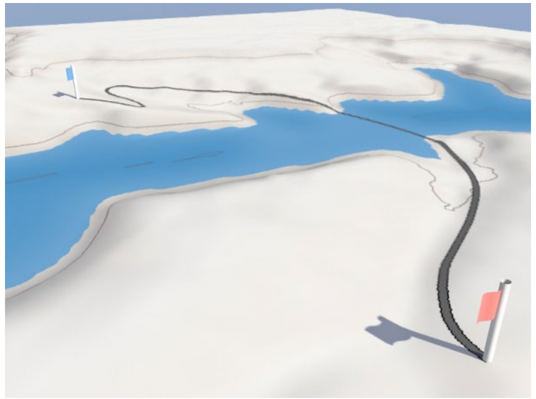
Problem

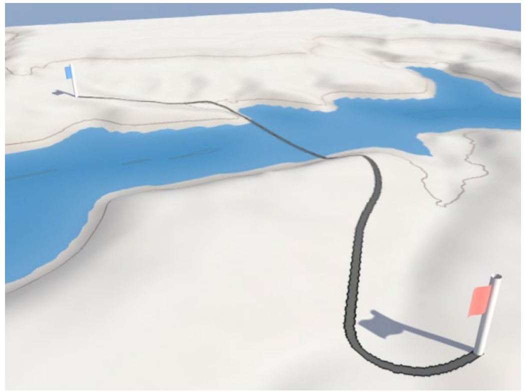
Number of arcs too important

Complexity of the algorithm in O (*a n* ln *n*)

Stochastic sampling on the set of arcs







Technique	Cost	Time
Bridge	89 210	149,0
Stochastic bridge	91 222	5,8

3/ Procedural generation of road mesh

Problem

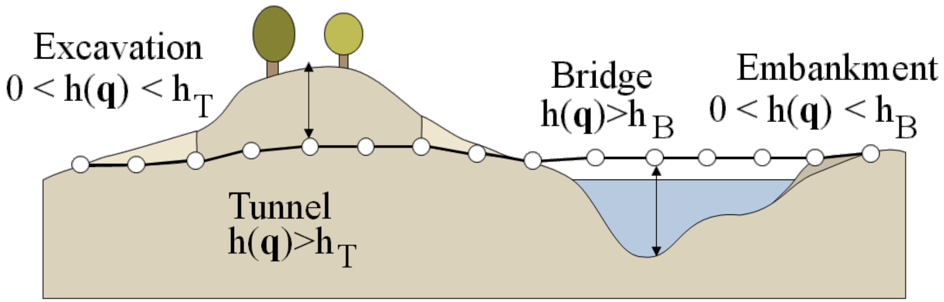
The mesh of the road should adapt to the mesh of the terrain seamlessly

Algorithm

1- Segmentation of the curve (road, tunnel, bridge)
2- Excavation and embankment operations on terrain
3- Generation of procedural models

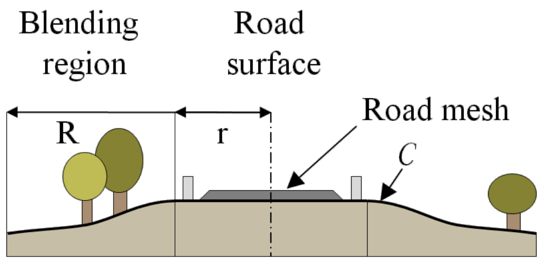
Segmentation of the curve

Analysis area of bridges and tunnels

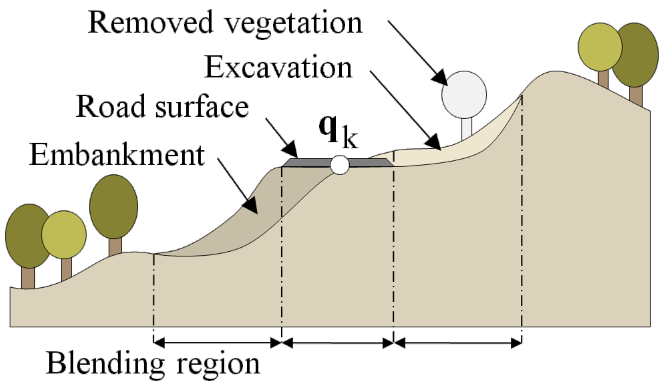


Road generation

Excavation and embankment operations on terrain



Generic road model



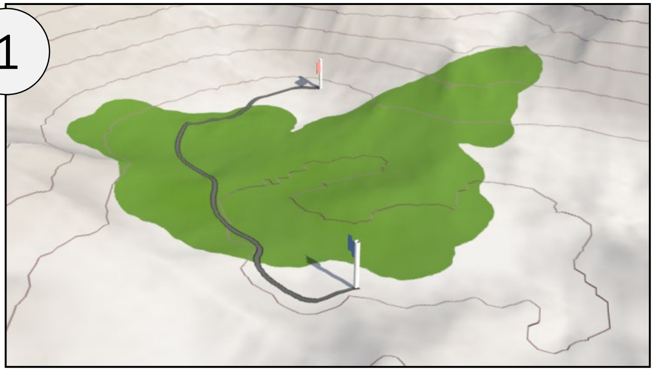
Landscaping + generated road

Creating procedural models with architectural plan

Model of Millau Viaduct

Results

Control



Example 1
Low weight vegetation

Slope : Average
Vegetation : Low

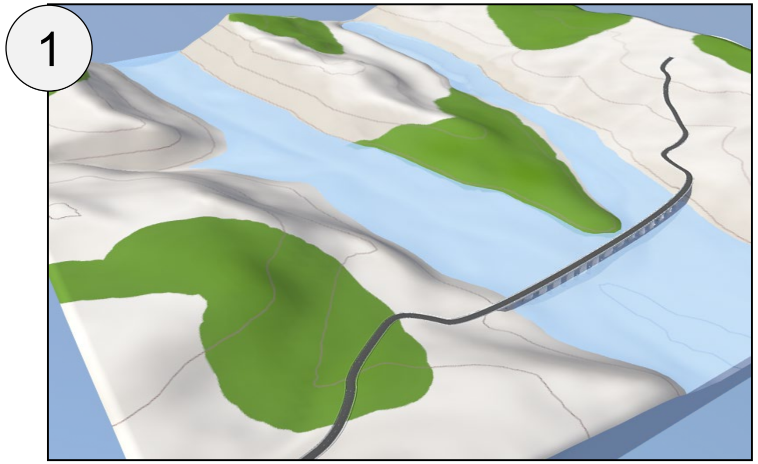
Example 2
Average weight vegetation

Slope : Average
Vegetation : Average

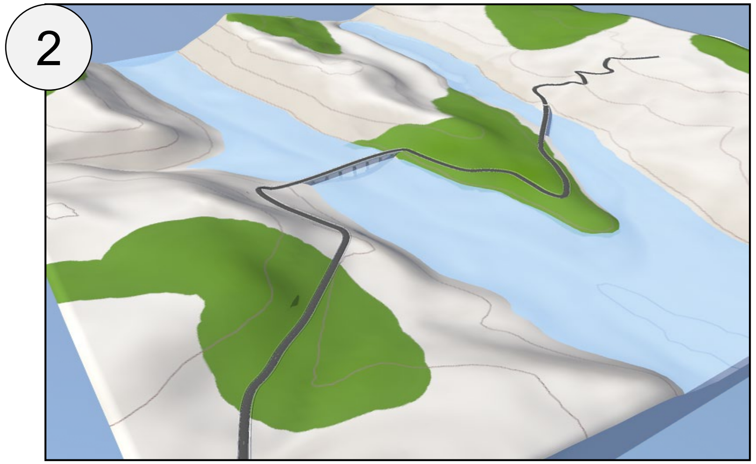
Example 3
Heavy weight vegetation

Slope : Average
Vegetation : High

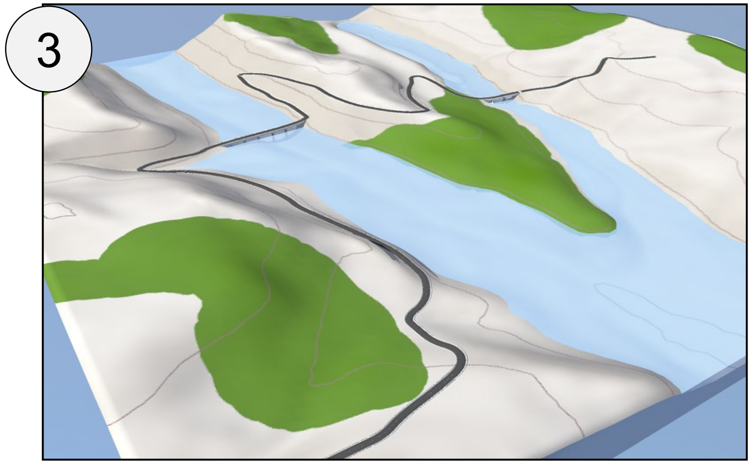
Control



Slope : **Average**
Water : **Low**
Vegetation : **Low**



Slope : **Average**
Water : **High**
Vegetation : **Low**

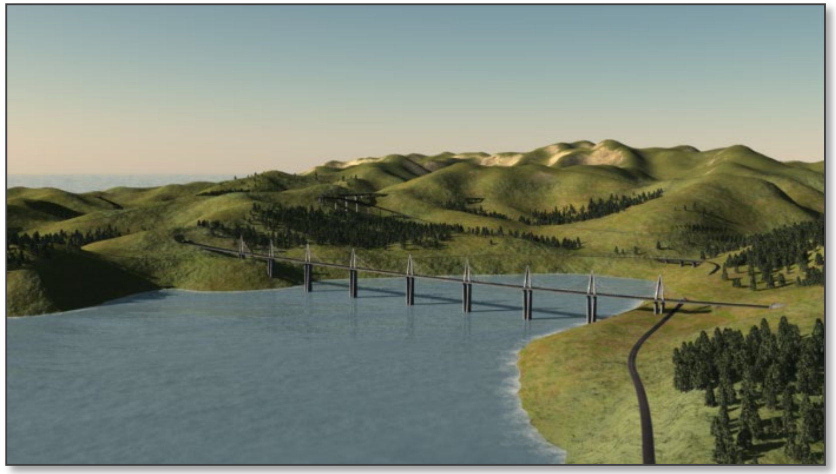


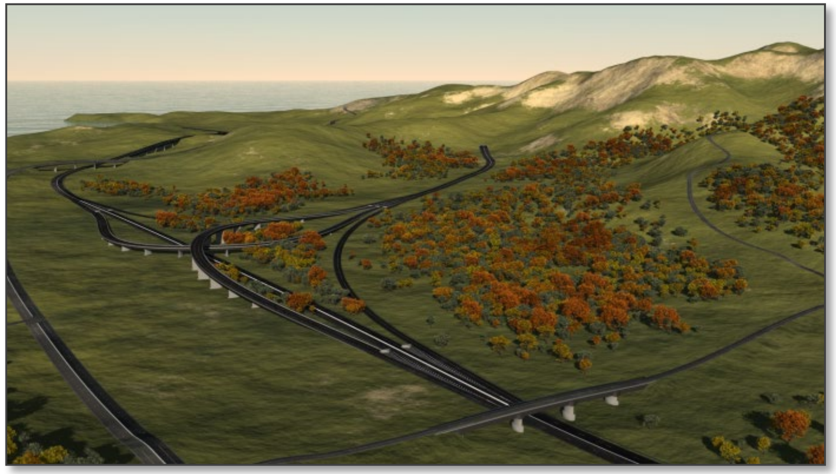
Slope : **Low**
Water : **High**
Vegetation : **High**

Road network generation

Generate hierarchical road network

1. **Procedural framework for creating a hierarchical road network**
   Connecting a set of cities, towns and villages
2. **Constrained road generation framework**
   Cost functions (terrains, cities and previously created roads)
3. **Proximity graph generation algorithm with a non Euclidean metric**
   Control the number of roads

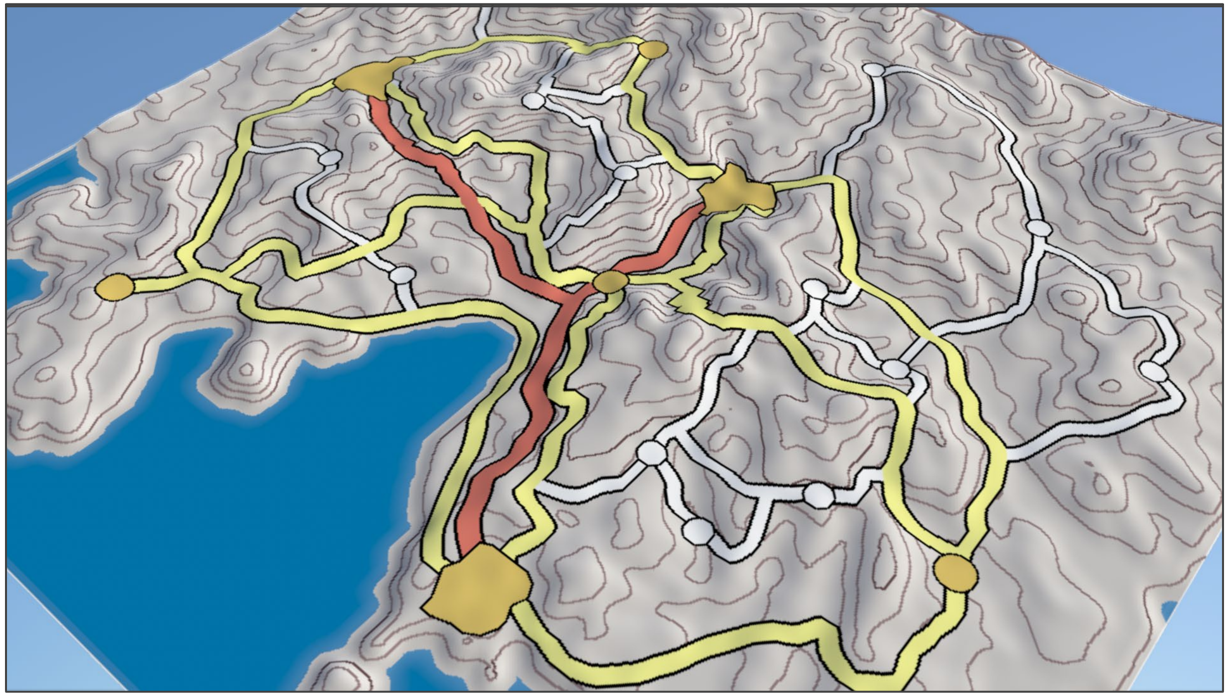


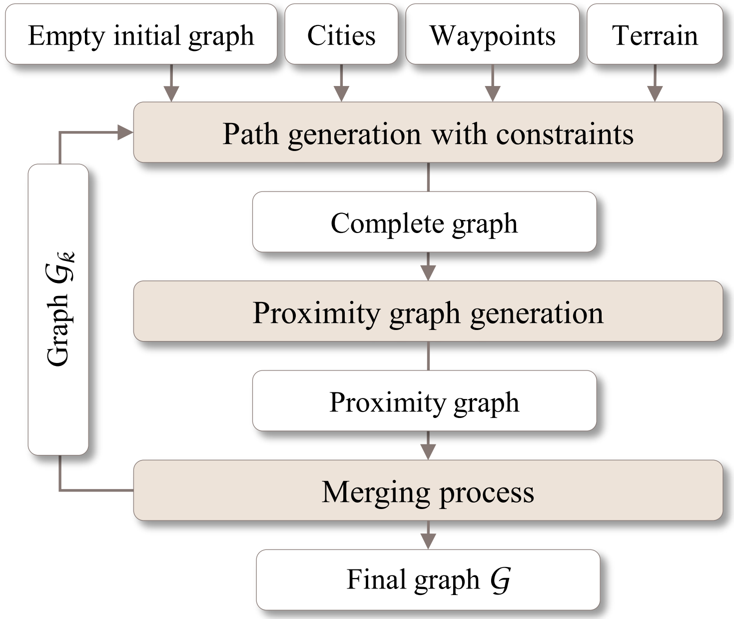


1/ Road Network generation

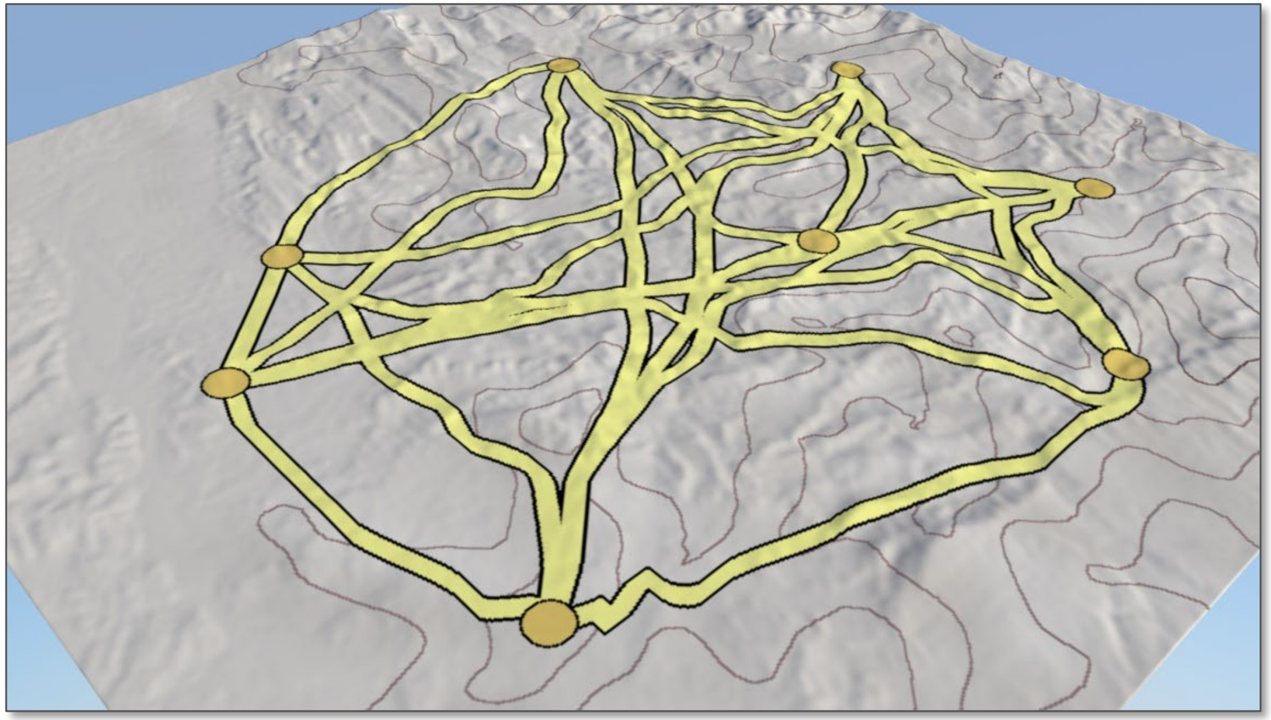
Problem

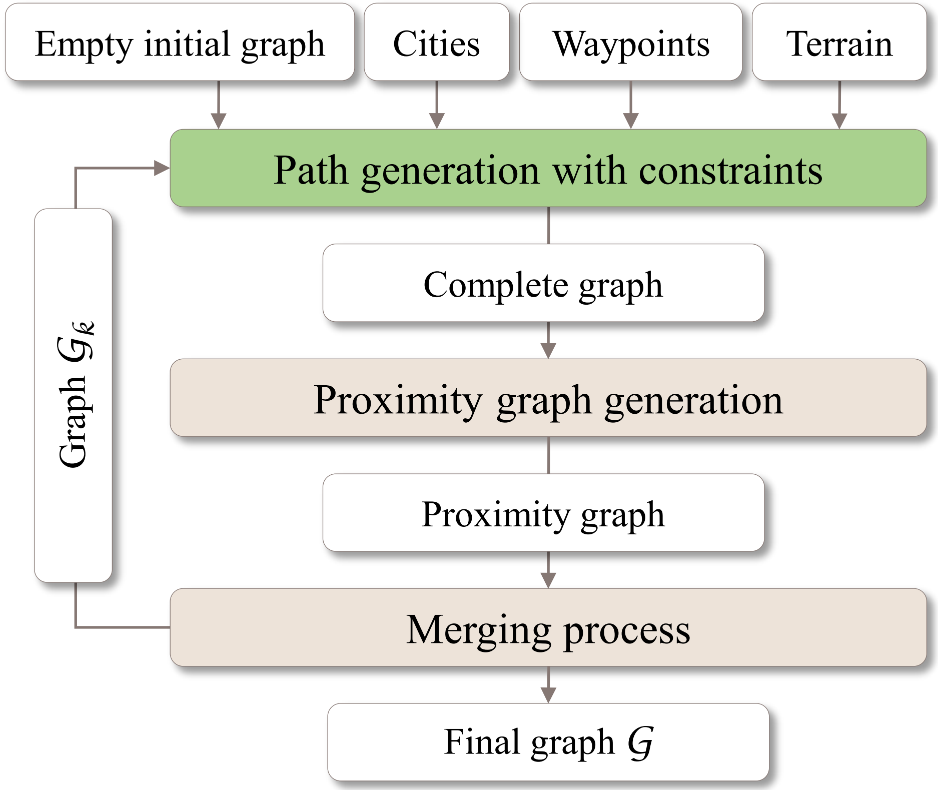
Generating a hierarchical road network





Paths generation





Road Network generation

Problem

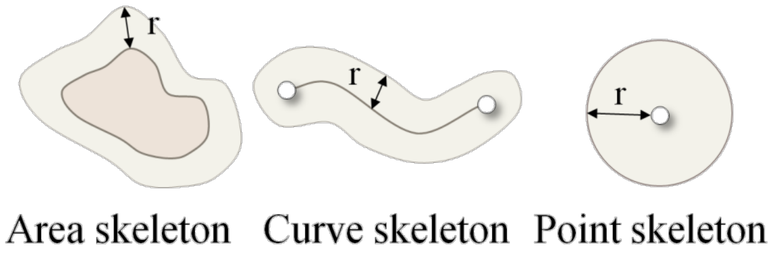
Control the road path generation algorithm

Constraint with cost function $\mathbf{c}(\mathbf{p}, \dot{\mathbf{p}}, \ddot{\mathbf{p}})$ [GPMG10]

$$c(\mathbf{p},\dot{\mathbf{p}},\ddot{\mathbf{p}}) = v(\mathbf{p}) + w(\mathbf{p}) + s(\mathbf{p},\dot{\mathbf{p}}) + g(\mathbf{p},\dot{\mathbf{p}},\ddot{\mathbf{p}}) + \boxed{h(\mathbf{p})}$$

Density of vegetation $\mathbf{v}(\mathbf{p})$,
Water height cost $\mathbf{w}(\mathbf{p})$,
Slope in the direction of the road $\mathbf{s}(\mathbf{p}, \dot{\mathbf{p}})$,
Curvature $\mathbf{g}(\mathbf{p}, \dot{\mathbf{p}}, \ddot{\mathbf{p}})$,

Control $\mathbf{h}(\mathbf{p})$ (influence of a set of compactly supported primitives)

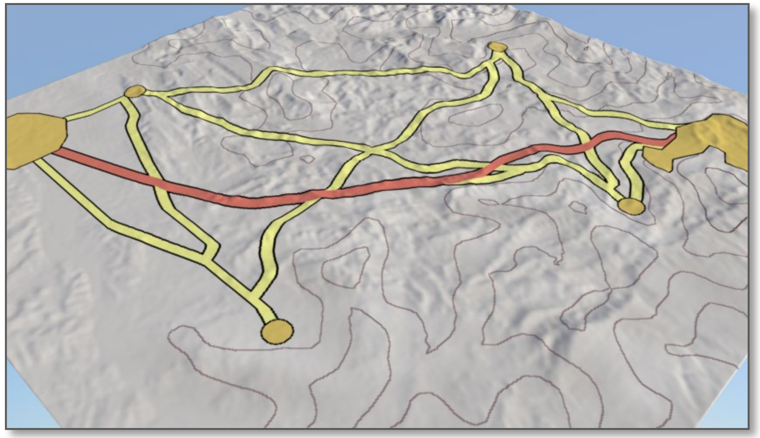


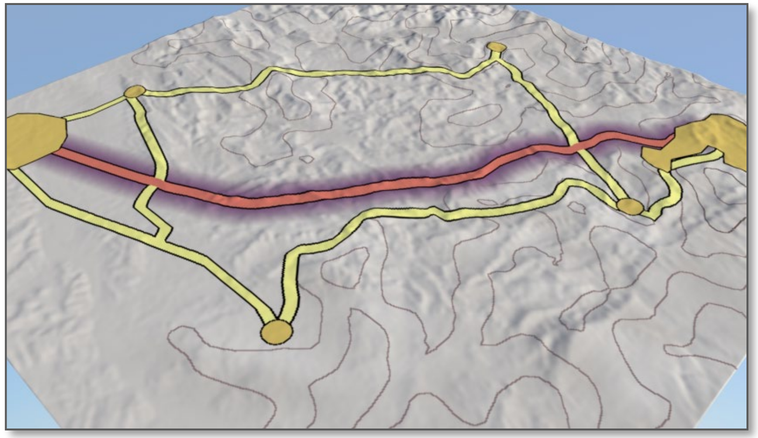
$$h(\mathbf{p}) = \sum_{i=0}^{i=n-1} h_i(\mathbf{p})$$

Road Network generation

Local control

Influence of roads (Highways)





Limiting the generation of the major road network in the neighboring of the highway

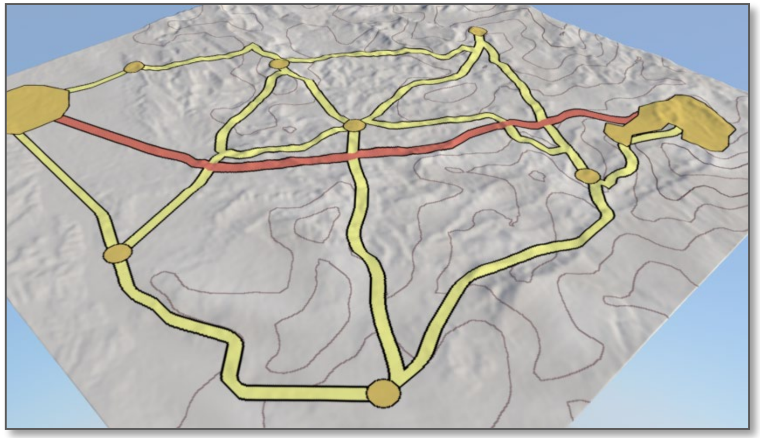
Curve skeleton

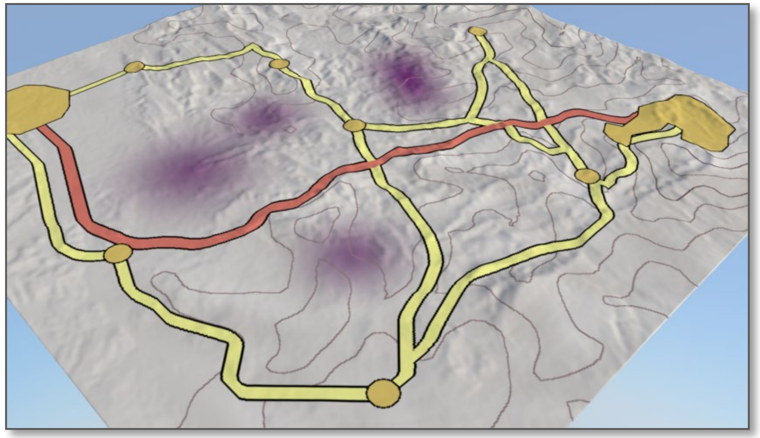
Limit the number of intersections (primary roads and highway roads)

Road Network generation

Local control

Control of a bounded region





Impact of an influence region over the road network generation process

Examples

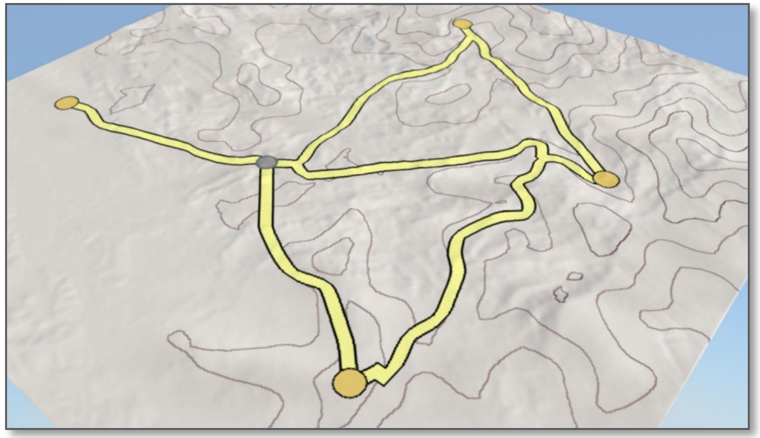
Conform to land use policies

Do not traverse a park

Road Network generation

Waypoints

Control of the road generation process

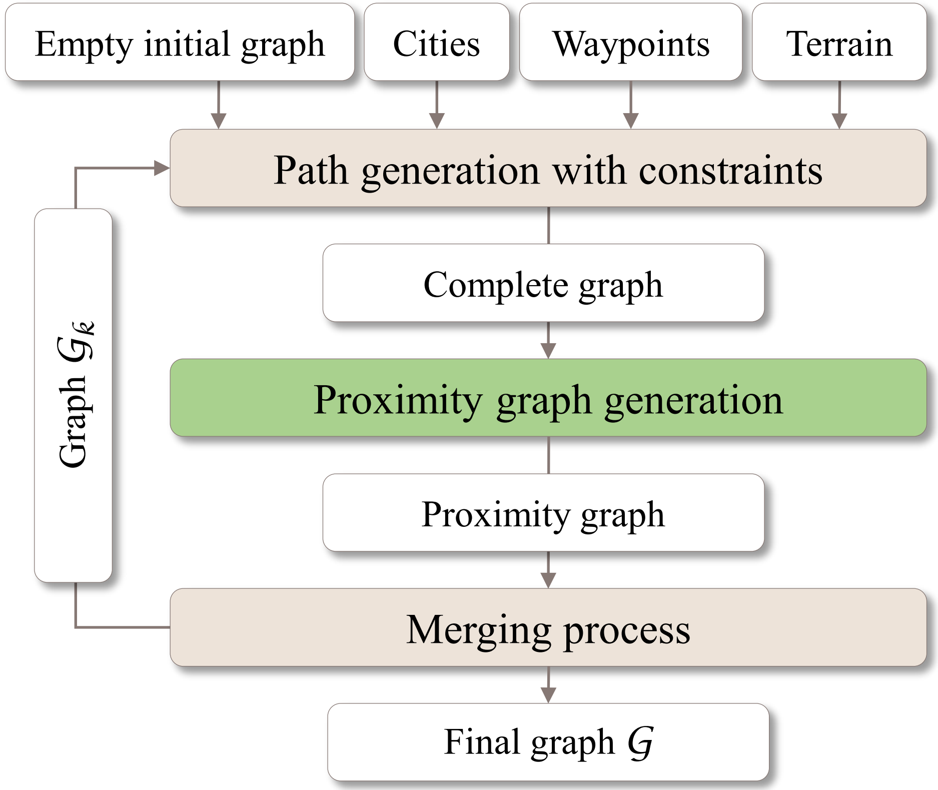


Two different constrained road networks generated with a single persistent waypoint

Persistent waypoints : virtual nodes in the graph

Road specific waypoints : control points attached to a given edge

2/ Proximity graph generation



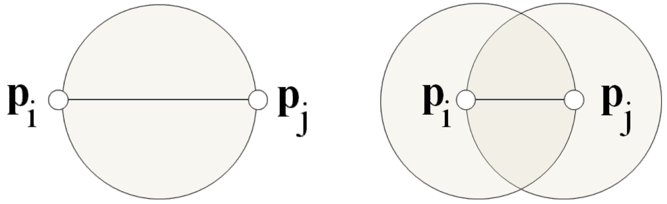
Graph generation algorithm

Goal

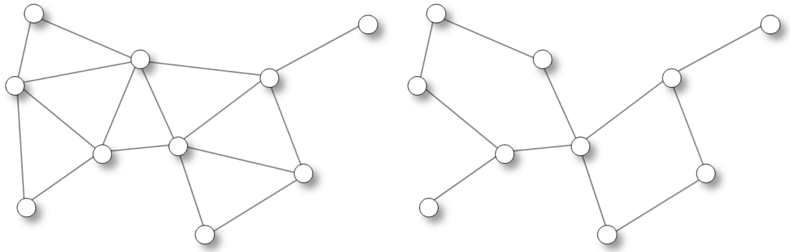
Generation of a geometric skeleton connecting a set of points

Fundamental concepts

Delaunay[Del34],
Gabriel graph[GS69],
Relative neighbor graph[Lan69], ...



Gabriel graph Relative neighbor graph



Gabriel Graph Relative Neighbor Graph

$$\mathcal{B}(\mathbf{a}, r) = \{\mathbf{p} \in \Omega, d(\mathbf{a}, \mathbf{p}) < r\}$$

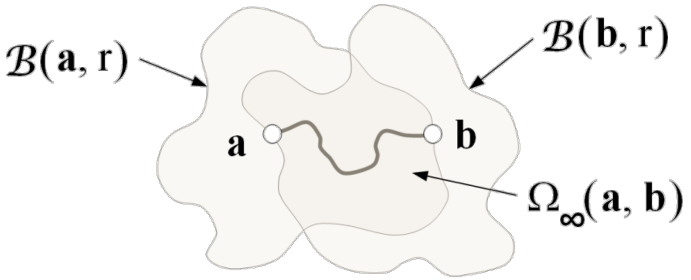
Creating edge if the influence region is empty

Graph generation algorithm

Non Euclidean model

The parameterized neighborhood region of (a, b) as:

$$\Omega_\gamma(\mathbf{a},\mathbf{b}) = \left\{\mathbf{p} \in \Omega,\, d(\mathbf{a},\mathbf{b})^\gamma < d(\mathbf{a},\mathbf{p})^\gamma + d(\mathbf{b},\mathbf{p})^\gamma\right\}$$



Geometric representation

Continuous shortest path between two points **a** and **b** [GPMG10]
Control of the network density with γ parameter

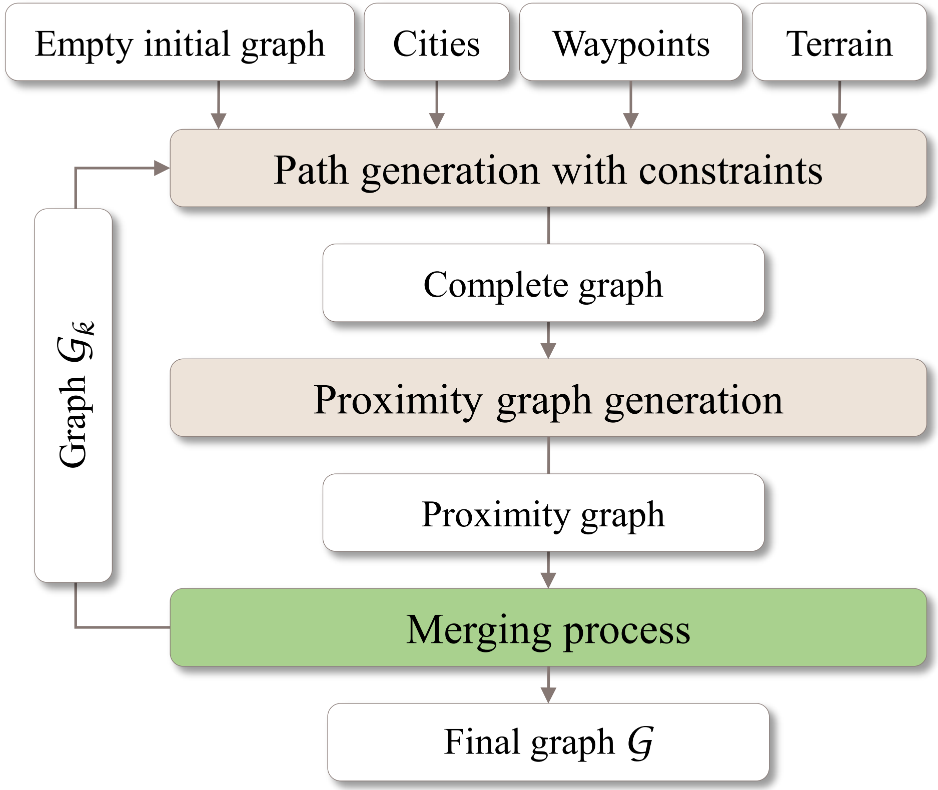
Graph generation algorithm

Different road networks connecting 3 cities, 6 towns and 16 villages

	Highways		Major roads		Minor roads	
γ	n	Length	n	Length	n	Length
1.2	3	194	19	700	70	269
2.0	2	96	11	383	39	371
8.0	2	96	9	290	29	368

The parameter γ control the density and the redundancy of roads

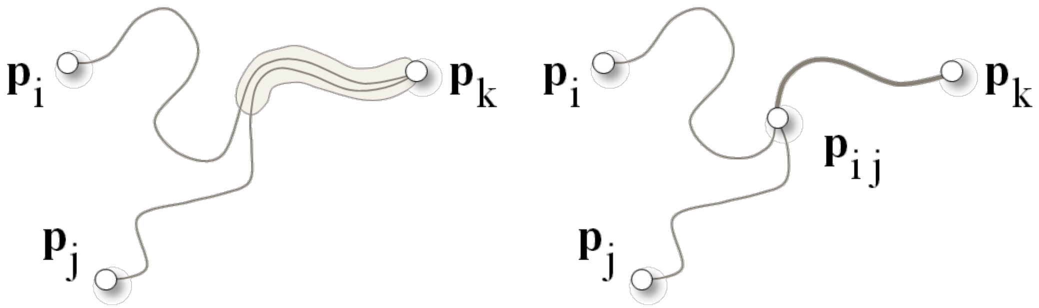
3/ Merging Process



Path Merging

Goal

Simplification of the graph (merging close parts)



Initial geometric graph   Simplified graph

Algorithm

1) Compute for all pairs of arcs the Fréchet distance (non Euclidean metric)
2) Merge all close parts where :

Insert Steiner points in the graph (instantiated as intersections and interchanges)

$$d_{\mathcal{F}}(f,g) = \inf_{\alpha,\beta} \max_{t\in[0,1]} d\Big(f(\alpha(t)), g(\beta(t))\Big)$$

Path Merging

Application

Approximation of the Fréchet distance by its discrete variation

Simplification process showing an initial network and the resulting simplified network

Primary and secondary roads do not merge with toll highways
Primary and secondary roads merge with toll free highways

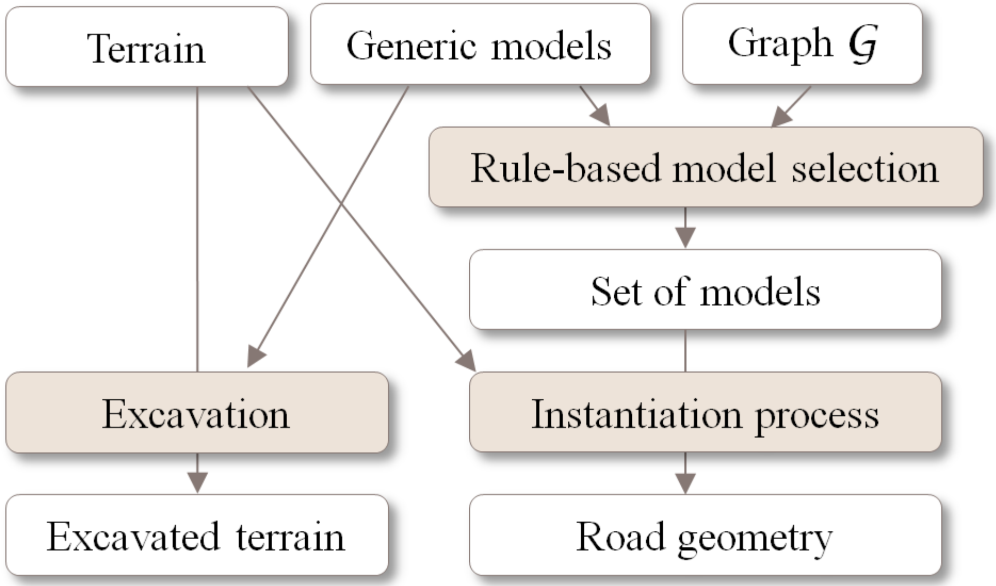
Secondary roads can always merge with primary roads

Geometry instantiation

Problem

Generate the geometry from the graph

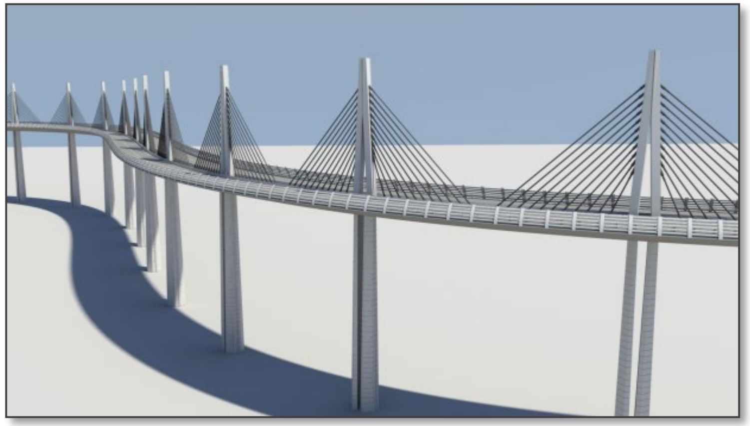
The geometric models should seamlessly match together and with the terrain

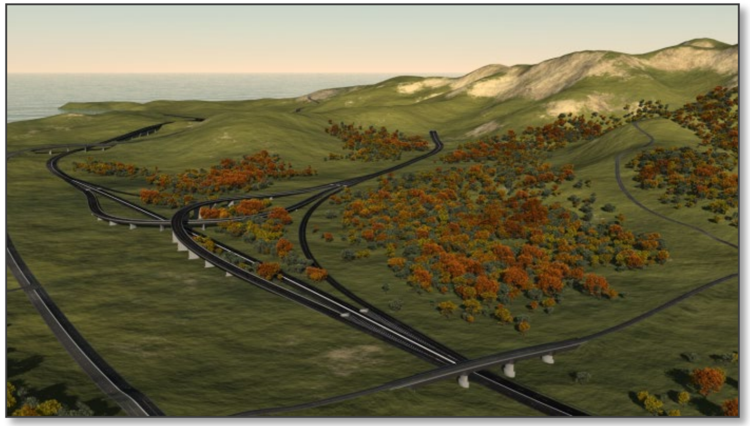


Geometry instantiation

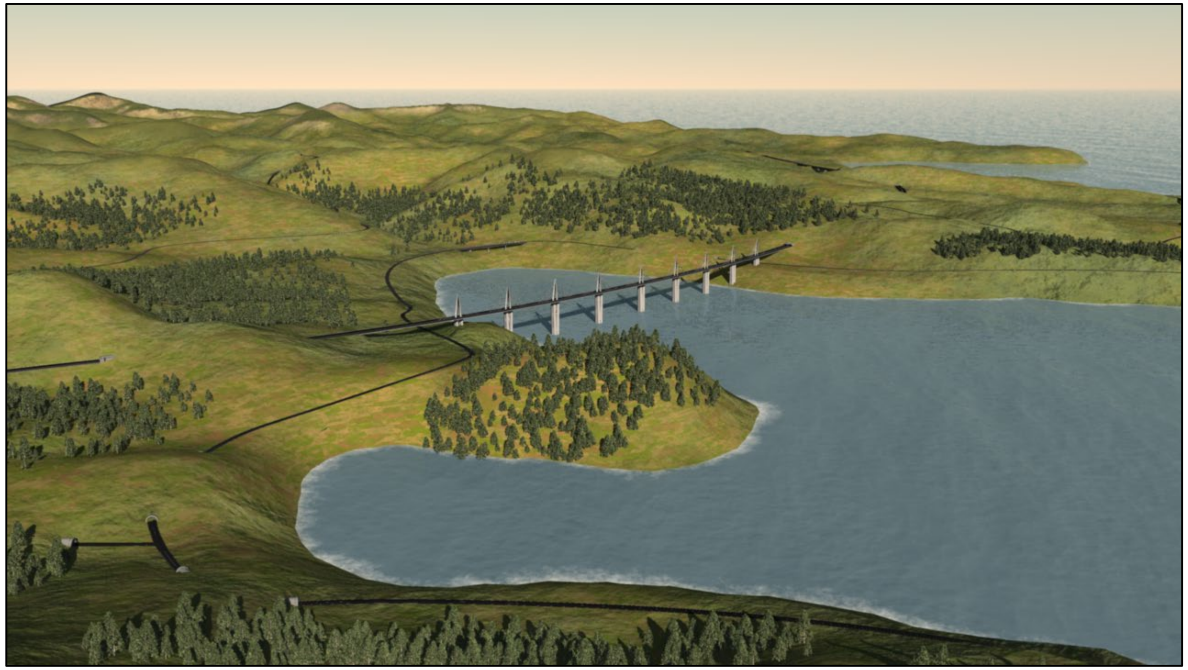
Algorithm for generating the geometry

1. Apply a set of selection rules to define nodes and edge models.
2. Excavations and embankments of the terrain.
3. Generate the geometry of every model according to its attributes.

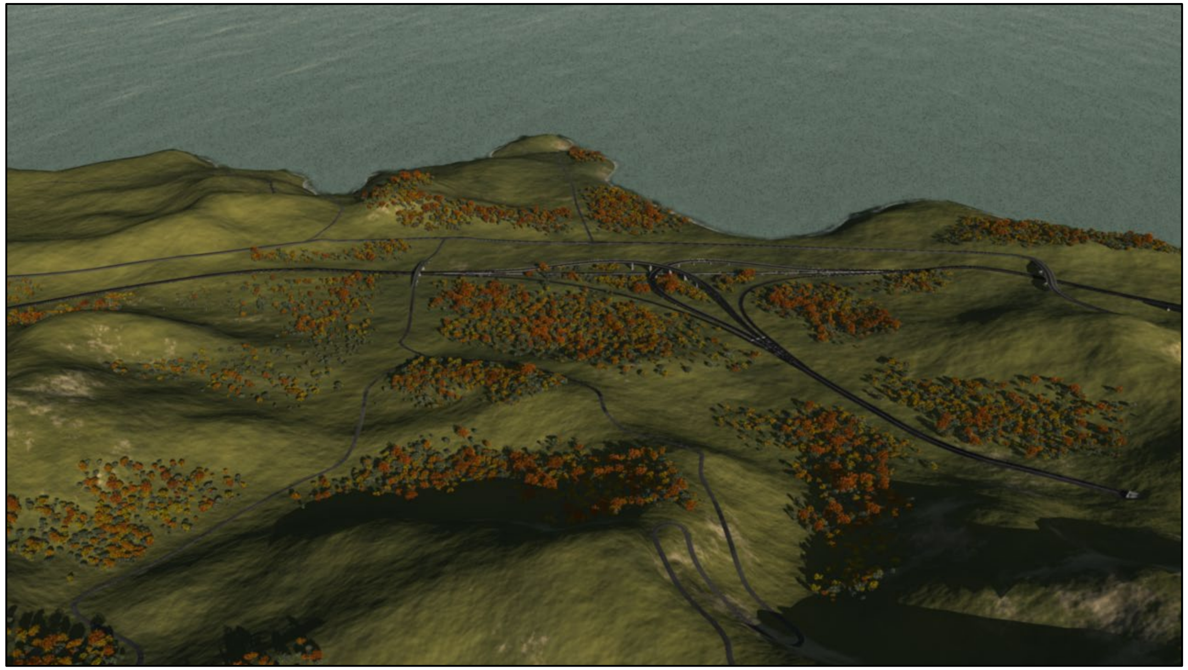


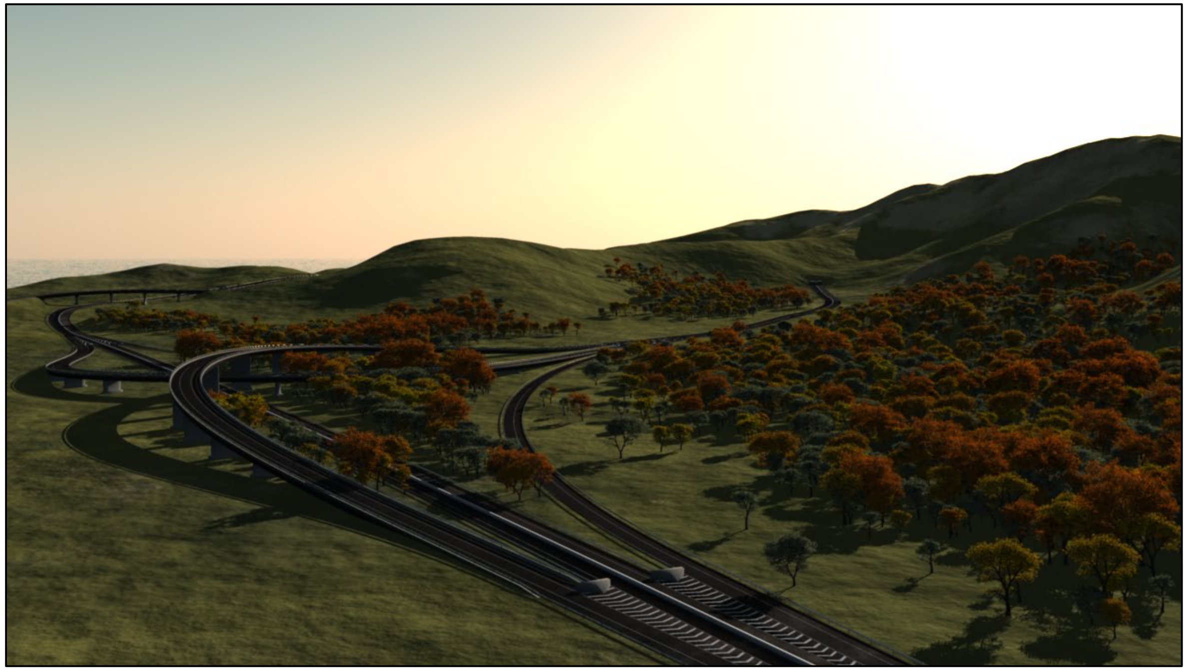


Results



Results





Village generation

Overview

1

Growth of a village skeleton

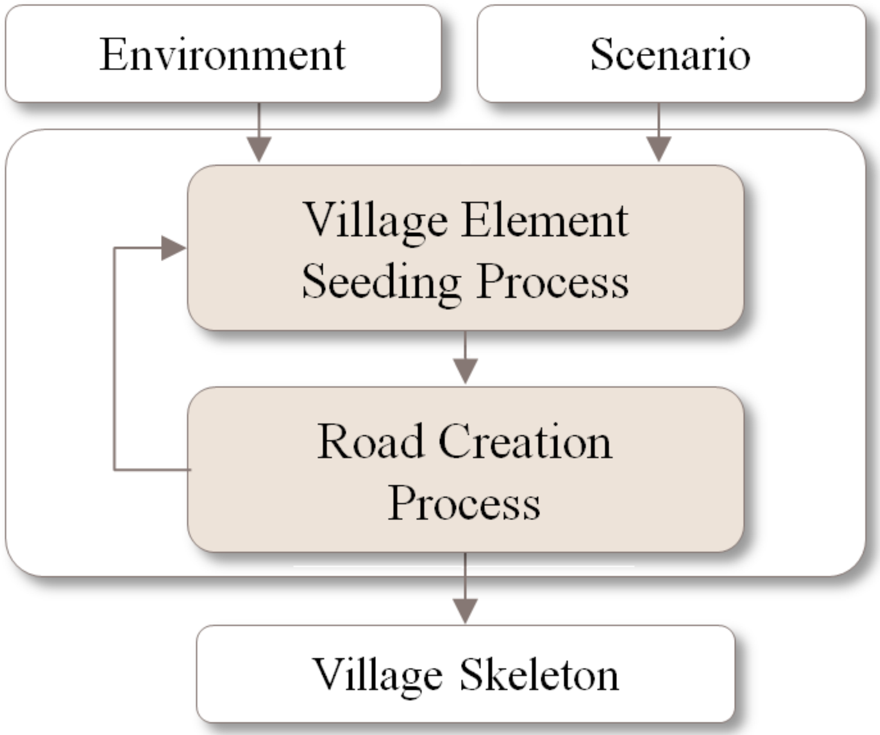
2

Land parcels generation

3

Geometry generation

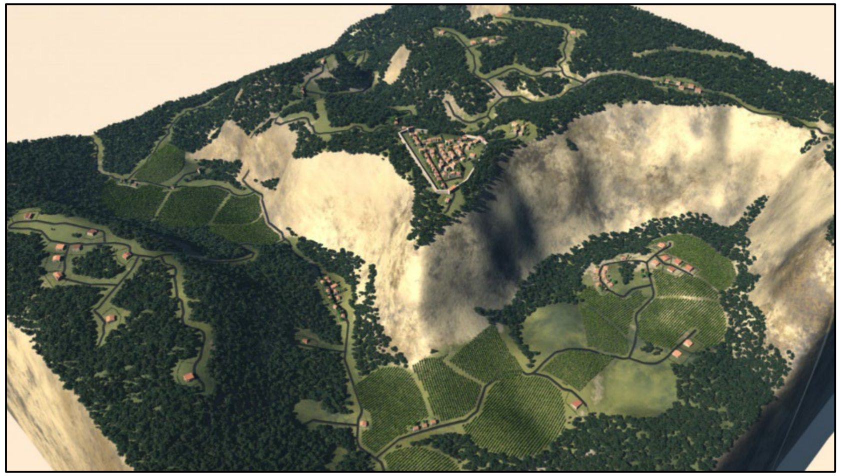
1/ Growth of a village skeleton

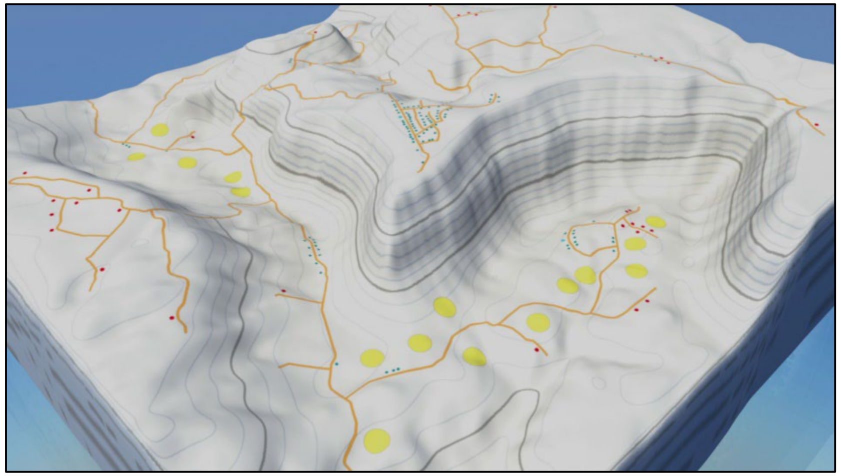


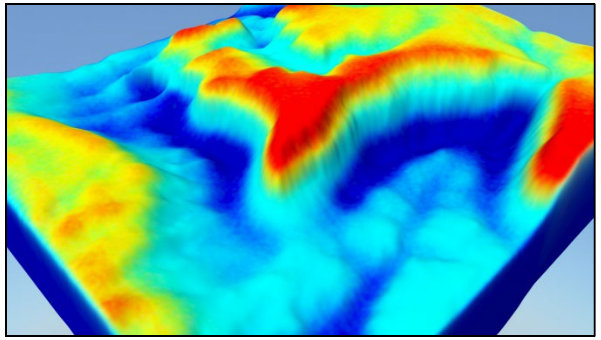
Seeding algorithm

1. Generate randomly a position **p** for building **B**.
2. If construction is possible, we compute a local interest value **I(B)**.
   The parameters depend on village and building types.
3. Aggregation test to decide to keep the position **p** for **B**, with a probability of success depending on I(B).
4. Iterate the process until a good position is found.

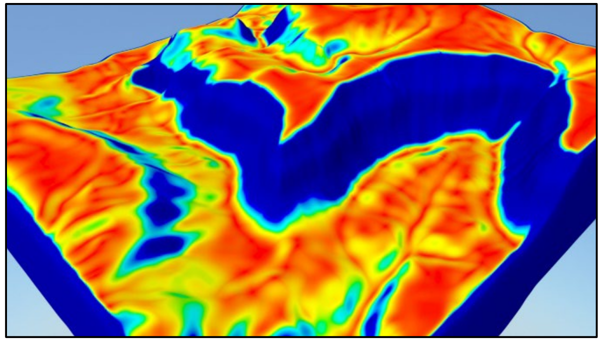
Interest maps



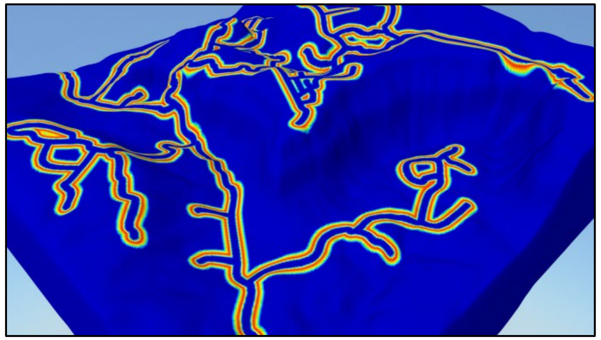




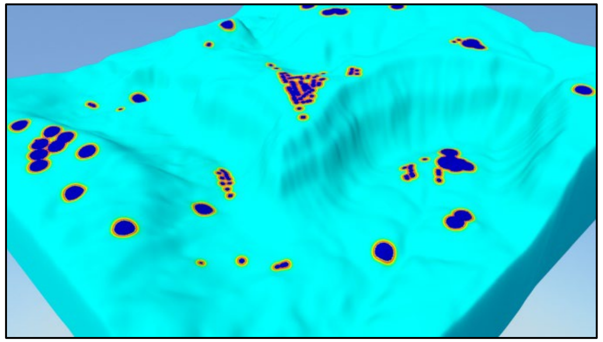
Geographical domination



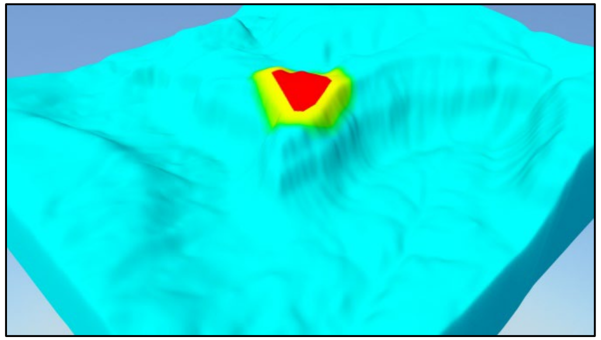
Slope



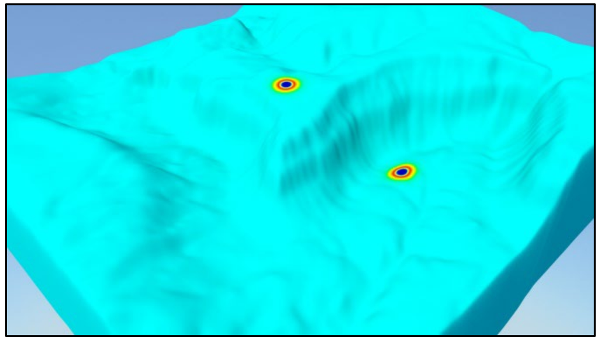
Accessibility



Sociability



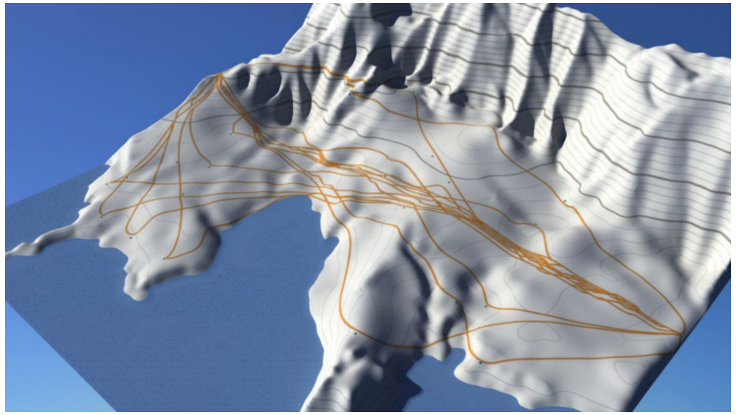
Fortication



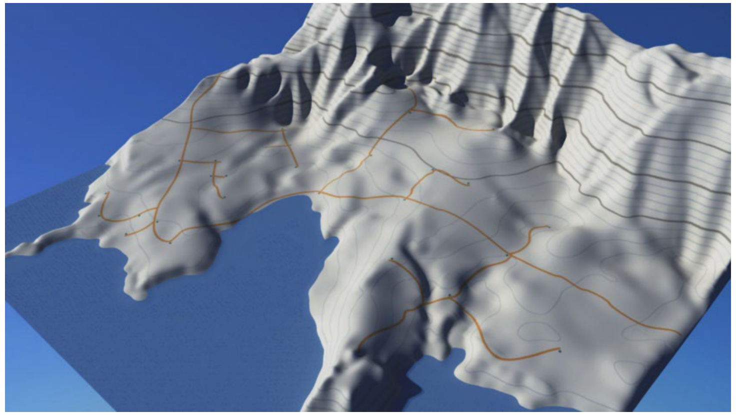
Worship

1/ Growth of a village skeleton

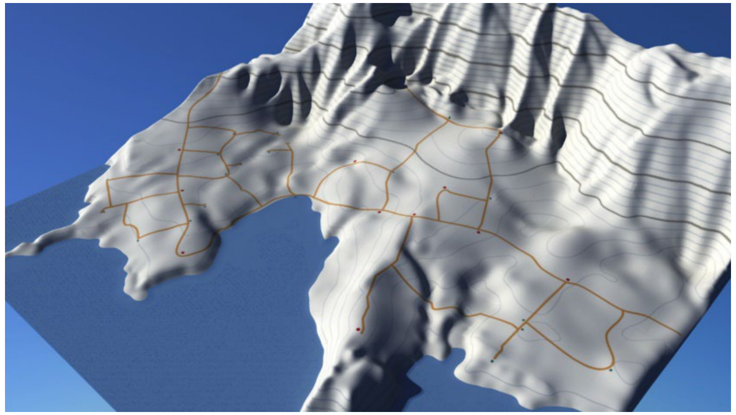
Road creation process (shortest path algorithm**)**



without road re-use

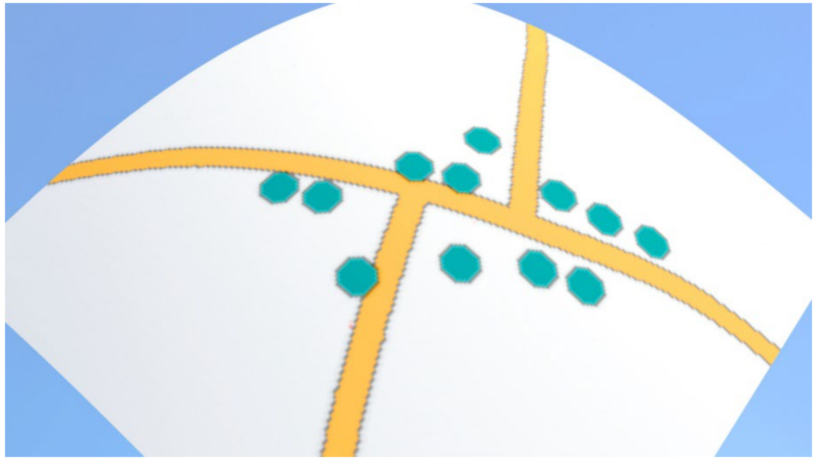


with road re-use



with road cycle generation

2/ Land parcels generation

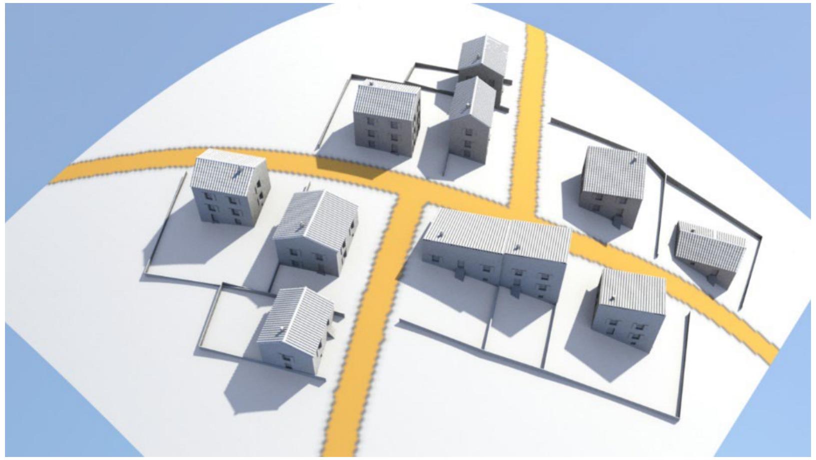

Village skeleton


Road conquest


Corner conquest


Region conquest

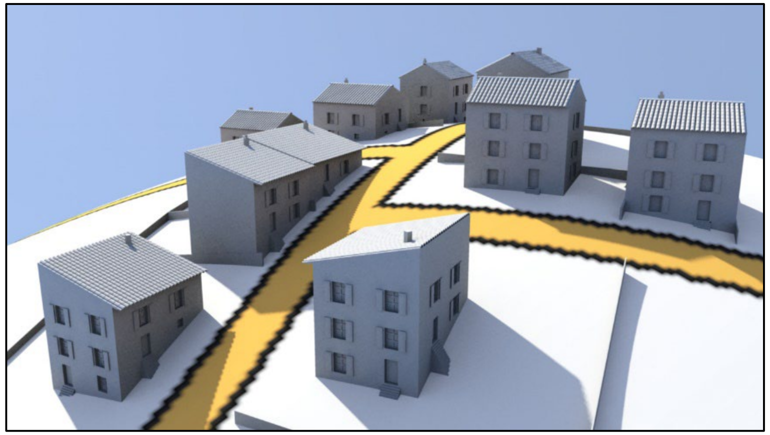

Parcel simplification

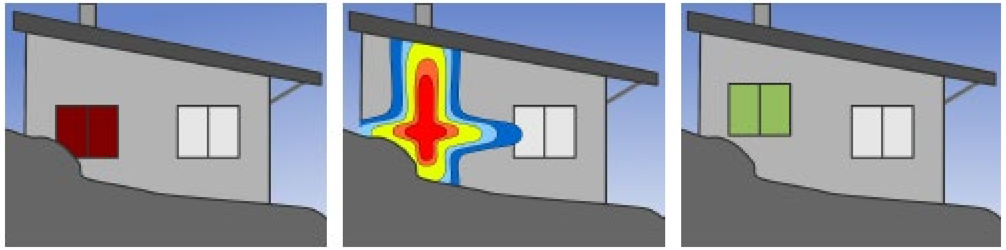

Building generation

3/ Geometry generation

Open Shape Grammar

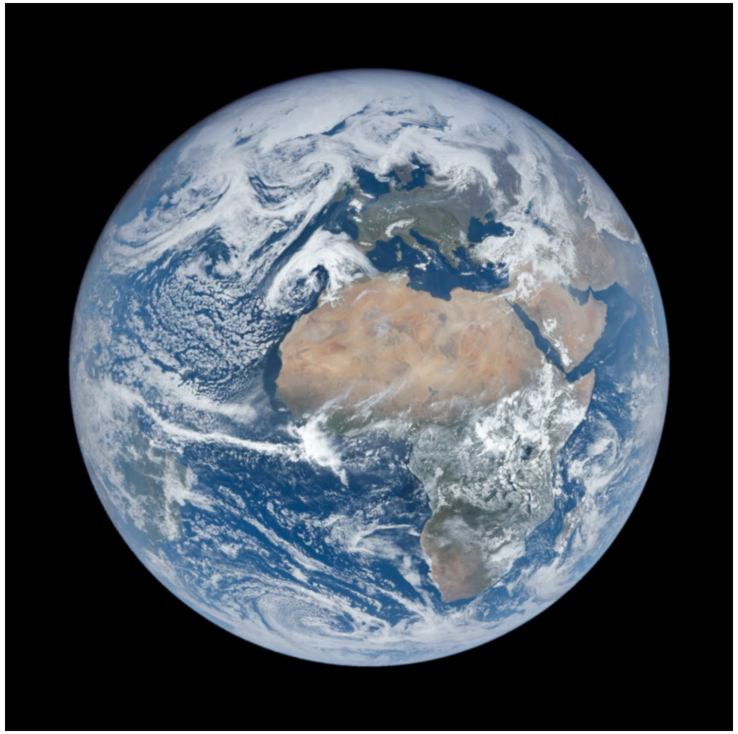
Shape adaptation (door, windows)





Travaux futurs

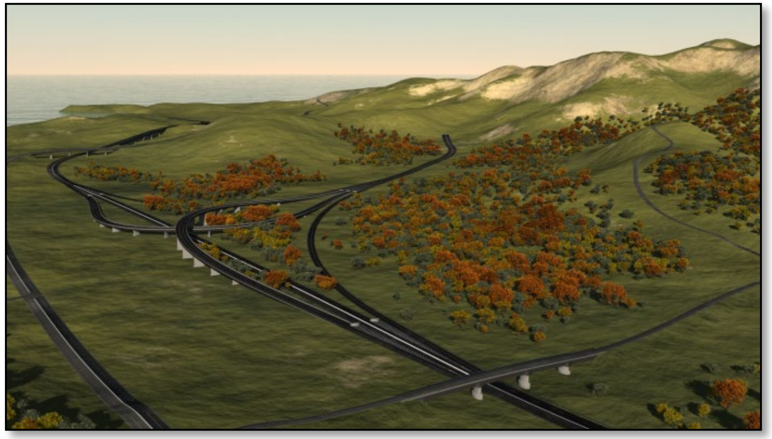
Mixité et cohabitation des moyens de transport



Génération planétaire

Génération de mondes virtuels

Paysages routiers



Adrien Peytavie

LIRIS - Laboratoire d'InfoRmatique en Image et Systèmes d'information
IUT Lyon 1 – Université Claude Bernard Lyon 1

Webinar 3D et Geospatial, 5 mai 2022